Received Signal Strength Fingerprint and Footprint Assisted Indoor Positioning Based on Ambient Wi-Fi Signals

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Abstract —Positioning is a basis for providing location information to mobile users. With the GPS signal strength hindered by the structure, indoor users cannot obtain their positions through their handheld devices. Indoor positioning has recently been conducted based on received signal strength (RSS) fingerprint from indoor wireless access devices. Integrating indoor position information with Smartphone can provide more precise in-building information. In this paper, we propose a novel indoor positioning scheme assisted by a RSS fingerprint and footprint architecture. Smartphone users can get their position based on RSSs from ambient Wi-Fi access points surrounding them. With the assistance of collecting RSSs from ambient Wi-Fi signals, confining RSSs by directions, and filtering burst noises, our propose scheme can overcome the severe signal fluctuation problem in the building. Meanwhile, the proposed RSS fingerprint and footprint matching mechanism can raise the accuracy of location estimation. The experiment results show that our proposed scheme can achieve a certain level of accuracy in the indoor environments and outperform other solutions.

Keywords: Indoor Positioning, Received Signal Strength, Fingerprint, Smartphone

I. INTRODUCTION

Location based service (LBS) can guide people to visit an unfamiliar place. For example, backpackers can easily obtain the local information from LBS while they just arrive at a place totally new for them. LBS can also be applied to commercial promotion. For example, when people take a stroll in a shopping mall, a nearby merchant they approach can send electronic coupons to them to achieve an effective advertising. However, the foremost issue for LBS is how to accurately obtain the users' position. The more accurate user's position can be determined, the more precise information can be provided. The quality of LBS can be therefore raised.

With the assistance from Global Positioning System, people outside buildings can easily get their positions with a certain level of precision. However, there has been far less improvement on the indoor positioning. Most of past works on indoor positioning intuitively use the self-constructed radio emitters likes Wi-Fi access points (APs) or ZigBee sensor nodes as fixed reference points. Then the positions of the targets which were normally nomadic laptop computers would be estimated based on the received signal strengths (RSSs) from these intrinsic points. Nowadays, Wi-Fi signals are perceived almost everywhere. Hence, the proposed positioning scheme is based on the radio strengths from Wi-Fi APs. The accuracy of the estimated position can be raised by referring to ambient signals from not only the intrinsic Wi-Fi APs, which is self-constructed so that the corresponding referred signals are stable and reliable, but also the extrinsic Wi-Fi APs, which is not self-construct so that the corresponding referred signals may not be stable and reliable. Meanwhile, with recent developments in mobile communications technologies, smartphones have become a more indispensable device than a laptop computer for most of people. Intensifying the positioning function on smartphones by adding in the indoor positioning function can facilitate a ubiquitous LBS concept with the extension from outside only to anywhere.

Based on above, we propose a practical design philosophy for indoor positioning. Our proposed positioning scheme is mainly composed of two stages. In the first stage, called an offline stage, the positioning system collects the ambient signal strengths to construct the RSS fingerprint. The ambient signals not only come from the intrinsic APs but also from the extrinsic ones. The former ones would play a more important role than the latter ones since the reliability and stability of the former ones are higher than the ones of the latter ones. Even though the extrinsic APs are not stable, these APs indeed provide additional reference information for positioning. To prevent the surging radio waves from affecting the correctness of the RSS fingerprint, filtering out the abnormal signals is needed. Also, to make a more precise fingerprint as a reference basis for the second stage, RSS fingerprint information is confined to orientation and direction restriction. Meanwhile, the RSS footprint sequences based on the related strengths received from the intrinsic APs at different designated representative points would be labeled. In the second stage, called an online stage, a Wi-Fi enabled smartphone can be positioned based on the collected information in the offline stage. The strengths of ambient signals from any APs around the smartphone would be collected by the phone first. The smartphone then forwards the collected signals to the positioning system. After that, a weighted voting algorithm is used to determine the final position based on the collected ambient signals by comparing the RSS fingerprint and foot print database in the positioning system. The system assigns higher reference weights to the signals from the intrinsic APs compared to the extrinsic ones. Although the signals from the extrinsic APs less contribute to positioning, they still can help raise the accuracy of positioning. This paper aims at how to craft the whole positioning system. Meanwhile, our comprehensive experiments prove the effectiveness of the proposed scheme in an indoor environment.

The rest of this paper is organized as follows. Section II illustrates some related works about positioning scheme. Section III describes the system architecture and the proposed scheme. Section IV, we practically evaluate the performance of the proposed system and conduct a performance comparison with other positioning schemes. A brief conclusion is presented in Section V.

II. RELATED WORK

Recently there has been a shift in attention from a focus on outdoor positing to a concentration on indoor positioning. Using the received signal strengths surrounding the user is the most intuitive way. The authors in [1] utilized the received-signal-strength index (RSSI) of radio signals radiating from fixed reference nodes and reference tags placed at known positions to locate the user. The signals come from the self-established radio radiators only. However, taking other ambient signals as reference may be beneficial to promote the positioning precision. Other reference information may be used to identify the user position, such as a vision based mechanism using prior knowledge about the layout of the indoor environment [2]. However, the positioning system needs to use a large space to store the sequences of images and image sequence matching could result in more time consumption compared to character sequence matching.

Among many RSS based indoor positioning techniques, the most common wireless signal is Wi-Fi since the IEEE 802.11 APs are pervasively deployed as a wireless local area network (WLAN) nowadays. Before the Wi-Fi technique becomes popular, the radio-frequency (RF) based RADAR system in [3] has been proposed according to empirical measurements by recording and processing signal strength information at multiple base stations to determine user location. Meanwhile, some hybrid indoor location estimation methods were proposed, such as using the two-dimensional marker to complement the Wi-Fi strength based one [4] or heterogeneous different wireless technologies involving the cellular GSM, DVB, FM and WLAN [5]. However, a wireless access point with a higher radio coverage, such as GSM, FM base stations, less contribute to indoor positioning which requires a fine scale.

The placement of access points can affect the precision of location estimation. A new defined SNR ratio regarding the location discriminant information as the signal and the degree of unstable measurements as the noise is referred to deploy APs for reducing position errors [6]. However, APs are normally displaced unintentionally. Different influence weights are assigned to different access points with unequal contributions for location estimation [7]. A main challenge for utilizing the strengths of received Wi-Fi signal for estimation in an indoor environment is the severe multipath effect and signal fluctuation. A machine learning based fingerprinting system was proposed to overcome the impact of the temporal variation caused by the multipath effect [8][9].

As the mobile wireless technique has been revolutionized, the personal device for ubiquitous communication to Internet is advanced from a laptop PC to a handheld smartphone. Smartphone users become a main RSS fingerprint collector and help the positioning server build up a radio map first. Then mobile users can track their positions with measured RSS from the surrounding access points by referring the pre-established fingerprint database in the server [10]. Moreover, the inherent gyrometer in the smartphone can determine the orientation and direction of the phone. RSS fingerprint information filtered by the orientation information can facilitate to eliminate the noisy location estimation so that the accuracy of the location estimation can be raised [11].

III. SYSTEM ARCHITECTURE AND PROPOSED SCHEME

This section illustrates the conceptual processing flow and some main application modules in the proposed indoor positioning system. The system mainly contains the two stages shown in Fig. 1, including the offline and online stages. In the offline stage, Wi-Fi enabled smartphones are used to collect the received signal strengths at all designated locations. Then the RSS fingerprint information is established after removing the burst noises among all RSSs per location and confining the RSSs by the direction of the smartphone. Besides, the RSS footprint sequences at all designated locations are also built based on the related strengths received from the intrinsic APs. The RSS fingerprint information and footprint sequences are both stored in the system for being referred in the second stage. In the online stage, when a new user would be located, the mobile user would use the smartphone to scan the surrounding signals and send all RSSs back to the system. The positioning system would remove unlikely RSSs by the noise filter and the smarphone direction and then use the RSS footprint sequences to narrow down the comparison computation of the current RSS and all historical RSSs in the fingerprint database. These two phases mainly include five processes shown as follows.

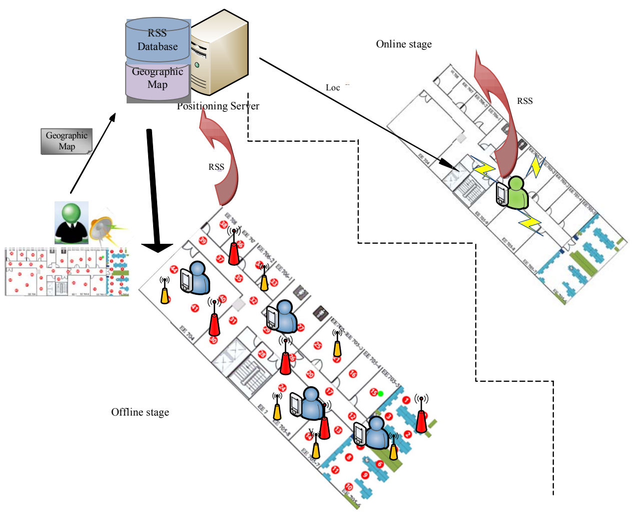

Figure 1. The Conceptual Flow of the Proposed Indoor Positioning System

A. Gathering RSS Fingerprint Information

To construct the RSS fingerprint data in the environment, a Wi-Fi enabled smartphone is used to gather the RSS information at some designated locations. The more the collected RSS information at each location, the more accuracy the fingerprint data can guarantee. If there are n designated locations and m raw RSS data to be collected at each location, the complexity of the total raw RSS data is O(mn).

B. Generating RSS Fingerprint Data

Refining the collected RSS data can achieve a higher precision for positioning. Two sub-processes for generating RSS fingerprint data are included below.

1. Confining the RSS by the direction of RSS Smartphone Collector:

While collecting the RSS data, we also use the gyrometer on the smartphone to obtain the Azimuth, Pitch and Roll defined below. The corresponding operation is shown in Fig. 2.

- Azimuth(γ): angle between the magnetic north direction and the y-axis, around the z-axis (0 to 359). 0=North, 90=East, 180=South, 270=West
- Pitch(θ): rotation around x-axis (-180 to 180), with positive values when the z-axis moves toward the y-axis.
- Roll($\emptyset$): rotation around y-axis (-90 to 90), with positive values when the x-axis moves toward the z-axis.

$$\text{Orientation}=\begin{cases} \text{N}, & \text{if } 315 < \gamma \le 45 \\ \text{E}, & \text{if } 45 < \gamma \le 135 \\ \text{S}, & \text{if } 135 < \gamma \le 225 \\ \text{W}, & \text{if } 225 < \gamma \le 315 \end{cases}$$

$$\text{Rotation}=\begin{cases} \text{horizontal}, \text{if } -22.5 \le \theta < 22.5 \\ \text{rotate } 45\,, \text{ if } -67.5 \le \theta < -22.5 \\ \text{vertical}, \text{if } -112.5 \le \theta < -67.5 \end{cases}$$

Roll=No restrict

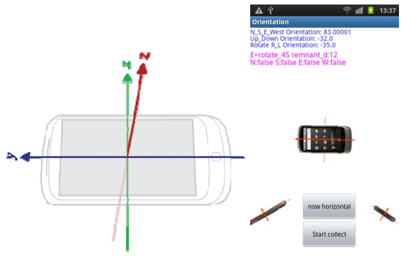

Figure 2. Confining the RSS by the Direction of RSS Smartphone Collector

2. Filtering out Burst Noises:

All collected RSSs at each designated location would be sorted in a descending order. To filter out the abnormal RSSs, we only consider the middle n values in the ordered RSS set by removing the extreme conditions (comparatively high or low RSSs). The less n is, the more stable the considered RSSs are. Filtering can make the collected RSS data concentrated in a normal condition without subsuming abnormal noisy RSSs. Then we take the average of all normal RSSs as the fingerprint RSS value for the location.

C. Generating RSS Footprint Data

Extrinsic APs may be randomly or casually placed at any place so that the signals from them may be interfered or oscillating due to a low placement whereas the placement of the intrinsic APs is well planned by the implementers so that the signals from them are stable. Hence, RSS footprint data are generated based on the signal strengths from the intrinsic APs since such kind of APs are more trustworthy than the extrinsic APs. A RSS footprint sequence at each designated location would be generated in the system by ranking the related RSSs from the intrinsic APs first. When locating some user, the smartphone user needs to send his or her RSS footprint sequence to the system. By comparing the user's RSS footprint sequence and the established RSS footprint ones in the system, we can narrow down the comparative computation to position the user for speeding up the positioning process. An example about generating footprint sequences at the designated locations and user location is shown in Fig. 3.

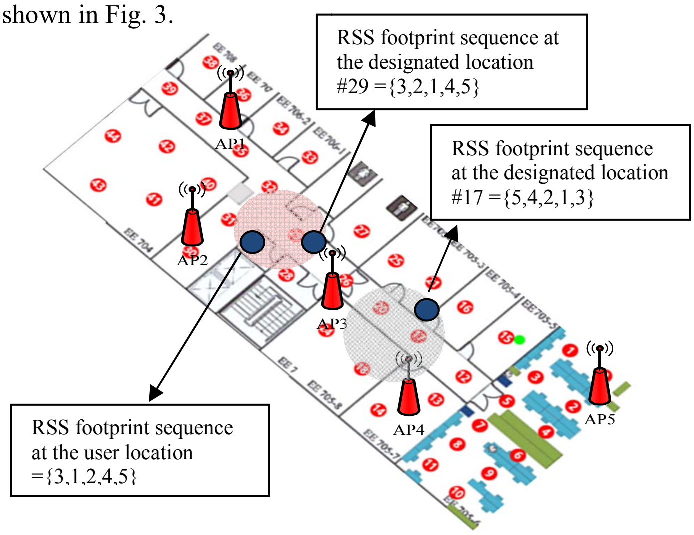

Figure 3. Generating RSS Footprint Sequences

D. Removing the Unlikely Locations While Positioning

When positioning a Wi-Fi enabled smartphone user, the user would send the raw ambient RSSs to the system. The system would process the raw data by the previous three processes and get the RSS fingerprint and footprint data for the current user location. In this process, the system would remove the unlikely locations according to the list of APs which provide the fingerprint RSS data upon the current user location. That means the effective AP list for the current location can eliminate the unlikely location candidates to reduce the comparative computation cost in the huge fingerprint database. Meanwhile, the system would only take those locations having a certain level of footprint similarity into consideration. The footprint similarity (FS) of the footprint data between the designated location k and the current user location is calculated as below

$$FS_k = \sqrt{\sum_{i=1}^{i=n}\left(FP_k^i - FP_{curr}^i\right)^2} ,$$

if there are n designated locations

If the FS for some designated location reaches the predefined threshold, this location would be listed in the location candidate list for further processing.

E. Locating the Final Position

Based on the location candidate set, we use a weighted interpolation scheme to determine the possible location. The positioning system gives a higher weight to the RSS fingerprint data derived from the intrinsic APs for RSS similarity calculation since the intrinsic APs are more reliable than the extrinsic APs. Then the system would interpolate the location regarding the similarity score as a weight. Finally, the positioned location would be pinned on the geographic map shown on the user's smartphone.

IV. EVALUATION RESULTS

This section discusses the experiment results that were conducted to evaluate the proposed system. We will first describe the experimental environments. Preliminary experiments are explained localization result of proposed method. The performance of the proposed system is compared with the traditional RSS fingerprint based positioning system.

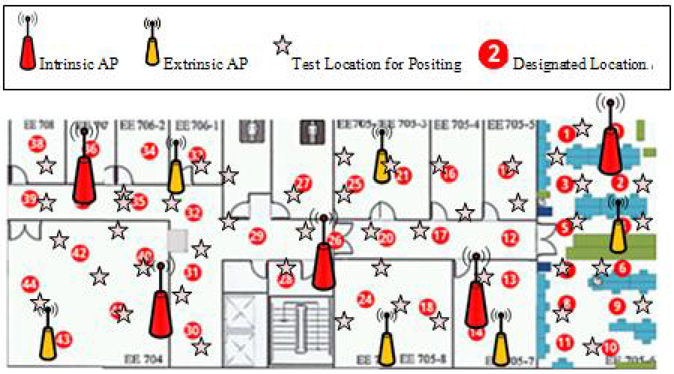

Figure 4. Experiment Environment

A. *Experiment Setup*

To evaluate the proposed system in a real environment, we implemented a positioning application on the Samsung galaxy i9000, which is an Android Smartphone equipped with both a gyrometer. To evaluate the performance of the proposed technique, we have collected realistic RSS data in a WLAN environment shown in Fig. 4. The dimension of the environment is 36m × 15m. Five intrinsic Wi-Fi APs (D-Link Dir635) were placed and five to twenty five extrinsic Wi-Fi APs can be detected around the environment. In the offline stage, we collect the RSS fingerprint data at twelve directions and footprint data at forty four designated locations. Around 30 seconds were taken to collect data at each location. We have implemented one positioning application (shown in Fig. 5) connecting our positioning server to evaluate the system performance.

Figure 5. Snapshot of Implemented Positioning Application on a Smartphone

B. *Evaluation Results*

First, we are interested in how the RSS data collecting time affects the final positioning accuracy. As Fig. 6 shows, different curves mean the different positioning accuracies on different collecting time in seconds. The error distance in meter means the tolerated distance errors when locating one user. We can find the more collecting time and error distances can increase the positioning accuracy. The result can suggest system implementers to make a tradeoff between the collecting time and the positioning accuracy.

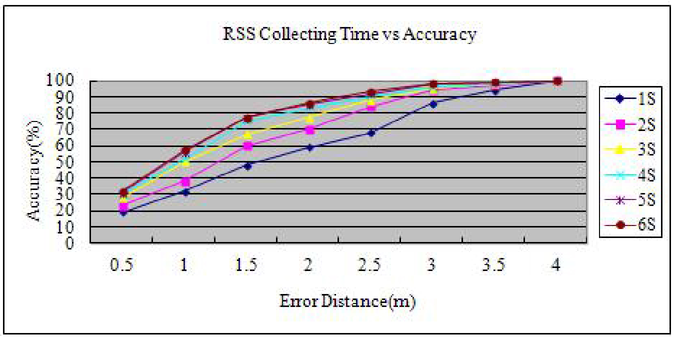

Figure 6. Positioning Accuracy on Different RSS Collecting Time and Error Distances

Besides, we try to compare the accuracy among different positioning schemes. RADAR [3] is the first positioning solution based on the surrounding RSSs. We add the burst noise filtering function into the native RADAR by referring to the [8][9] to find how burst noise removing can help raise the positioning accuracy. We compare these two RADAR based schemes to our proposed one in term of the positioning accuracies on different error distances. As shown in Fig. 7, with the assistance of collecting ambient RSSs, confining RSSs by directions, filtering burst noises, and constructing RSS fingerprint and footprint database, our scheme can outperform others.

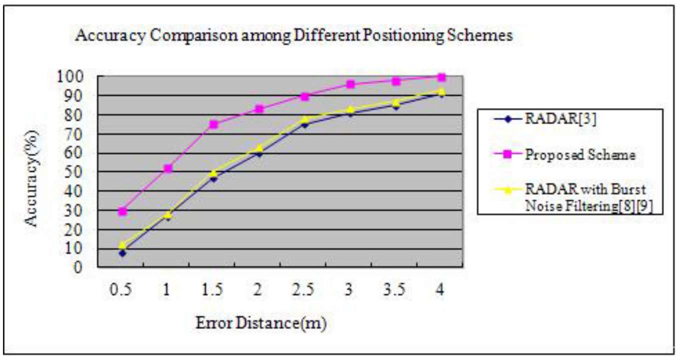

Figure 7. Different Positioning Scheme on Different Error Distances

Furthermore, to understand if ambient signals which not only come from the intrinsic APs but also extrinsic APs can really raise the positioning accuracy compared to using the signals from intrinsic APs only, we conduct the accuracy evaluation about these two scenarios. As shown in Fig. 8, we can find the accuracy gap between them is very obvious when the tolerated error distances range from 1m to 2.2m. Beyond 2.5m, the accuracies for them are very close because the error distance is large enough for indoor positioning. However, using ambient signals still can show its benefit for positioning.

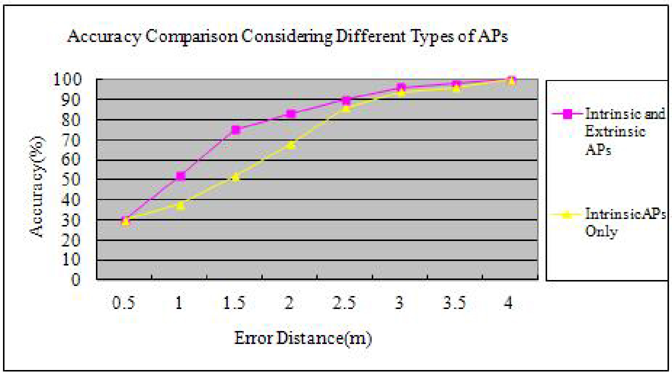

Figure 8. Accuracy Comparison Considering Different Types of APs

V. CONCLUSION

In this paper, we practically illustrate a skeleton about how to design and implement an efficient indoor positioning system. Compared to other solutions, our proposed scheme uses the RSSs not only from intrinsic APs which are constructed by the system implementer but also from extrinsic APs which are constructed by others for positioning. Even though the extrinsic APs may be unstable, our experiment shows these APs indeed provide additional reference information for positioning. Meanwhile, the pre-established RSS fingerprint and footprint database can raise the positioning accuracy and efficiency

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