WiFi-Based Indoor Positioning for Multi-Floor Environment

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Abstract—**In recent years, the research of WiFi-based indoor positioning system is prone to attracted with the widely deployed of WLAN and mobile devices. However, there are still some problems unsolved. Most WiFi-based positioning algorithms did not consider multi-floor environment and did not consider building with complex compartments. This paper proposed a WiFi-based indoor positioning system that combined both of the characteristic of trilateration and scene analysis methods. And system can determine which floor the user maybe on. The experiment show the algorithm is workable with acceptable accuracy.**

Keywords- Indoor positioning; WLAN; Radio Propagation Model; Virtual AP; Calibration Factor (CF)

I. INTRODUCTION

GPS is the most popular positioning system nowadays. The accuracy and signal's coverage are met the conditions of most applications. However, if the system wants to be effective, it must be maintained in LoS (Line of Sight) between the positioning satellite and the receiver. Therefore, the user must in the outdoor environment without shelter to locate. In the indoor environment and the basement, GPS signals will weaken rapidly by shielding effect produced by building, partition plates. In most of the indoor time, the GPS positioning scope is limited, because the user can not receive GPS signals in the building. In these constraints, the indoor positioning is more challenge than outdoor positioning. Therefore, it has been one of the most focused research topics in recent years.

Current indoor positioning systems use variety of different wireless transmission technology. For example, WiFi[1][3][9], infrared[11], RFID (Radio Frequency IDentification)[8], GSM/CDMA[4], ultrasound[7], vision[6] and laser [10]. But beside the accuracy, equipments cost also need to focus on. Such as [7][10], they are too expensive and too much setup time to equip those system. Besides, The current mobile devices which have wireless network connectivity growing popularity like notebook computers, PDA, and smart phone. In view of this, the WiFi-based positioning method attracts more consideration.

Most WiFi-base indoor positioning systems estimate the received RF signal and then calculate the possible position of user. The changing of the radio signals attenuation in the indoor environment is an important issue. H. Hashemi published the research of radio signals in the indoor environment of fading channel model in 1993[5]. That paper provides a comprehensive analysis of the changing of radio signal in the indoor environments encountered in walls or partition plates. And the radio signals transmission change in the three-dimensional. The pioneering research of WiFi-based indoor positioning system was published in 2000[9]. It proposed the two different positioning with WiFi signal. Empirical method is to use mobile devices to collect samples in the desired space. Recording coordinate and the received APs' signal strength indication (RSSI) and BSSID of sampling points in four directions to create the radio map database. In the positioning phase, received signal strength and BSSID will be compared with the database to determine the current position. Another method is to calculate the possible position via radio propagation model. The method put the number of measured reference points into the radio propagation attenuation model [13] to get predictive relationship between signal strength and distance. The experiment compared two methods; the empirical method has higher accurate result which can reach 2-3 meters of error distance. Relatively, radio propagation model is easier to set up. Furthermore, Nearest Neighbors in Signal Space (NNSS) algorithm is proposed in [9] for computing the distance of signal space between the observed and recorded measurements. Chen and Luo [14] use the radio propagation model with the obstacles attenuation factor (OAF) in order to reduce the errors affected from building walls when to convert the detected signal strength into the distance. The result shows that localization errors have a significant improvement.

WiFi-based positioning system, in currently, is divided mainly into the RF trilateration based and the RF fingerprint based methods. The RF trilateration utilizes at least three APs to calculate distance and estimate user's location. But the higher positioning accuracy becomes more difficulty because of affected by multipath in the building. Besides, the need of AP's coordination is another problem. In most case, it is hard to get the detailed position of APs' installation. Fingerprint samples the signal data within the system off-line and put them into the radio map. The accuracy of the method is dependent on the density of sampling: the denser sampling, the higher accuracy.

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Conventional WiFi position service did not consider multi-floor problem. Nowadays, there are several tens of APs will be install in a building for providing WiFi service, and not all AP will be detected in the area of the building. If we want to adopt these APs' information for providing indoor positioning service, several problems arise. In this paper, we combine the characteristics of RF trilateration and RF fingerprint method to solve the positioning problem for multi-floor environment. The proposed method determines the floor where the user maybe on first and then determine the position where the user maybe at. The experiment show the strategy is workable with acceptable accuracy. It also spends lower construction procedures and enhances usability and accuracy of the positioning system.

The remaining sections of this paper are as follows: in the second section describes the system design, data collection, determine the floor and plane positioning. Experiments are conducted to determine the floor in the third section. Conclusion is presented in the last section.

II. System Design

The positioning algorithm is divided into three phases: data collection phase, system calibration phase, and positioning phase. Data collection phase included to build the radio map in the desired space and to record the RSSI, BSSID, coordinates, directions and place of sampling points. System calibration phase corrects the factor to enhance the system accuracy. Positioning phase determine the floor first and then the exact position later.

A. Data Collection Phase

In RF trilateration method for WiFi-based positioning system, APs' information should be collected beforehand. However, in some building, it is hard to obtain the exact coordination of APs due to different administrative competences of building structure, networking, and mobile services. Instead, several sampling point are chosen to collect the APs' information like RF fingerprint method. Each sampling point's information, denoted by S_{jk}, includes the RSSI, BSSID along with the sample place and floor number.

A sampling point scans at most p data of AP. Nowadays, WiFi APs were densely deployed in a building, and it is easy to obtain around a dozen of AP's information at a sample. They only valued are those APs with stronger RSSI.

$$S_{jk} = \{(b_{ijk}, ss_{ijk}) \mid 1 \le i \le p\} \tag{1}$$

Suffix k means it is on kth floor and j means it is the jth sample on k^{th} floor. b_{ijk} is the i^{th} AP's BSSID and ss_{ijk} is the i^{th} RSSI of j^{th} sample in order of RSSI on the k^{th} floor, respectively.

B. Floor Estimation

A three-dimension coordinate system is used to record the locations of sampling points and denoted by $L(x, y, k)$, where x and y are in meters, k denotes which floor and defined in eq. (1). In our previous test, mobile device could receive same AP's signal even same signal strength at different floor. In the conventional position algorithm, such as proposed in [12], it may result in error in above case when apply the algorithm in a multi-floor environment. Therefore, determining the floor where user is currently on before estimating the exact position is necessary. Fig. 1 illustrates the first 4 floor plain-view drawing of the experimental building where is totally 8 floors. All of the dots are the sampling point. The asterisk is measurement point. The decision equation is defined as follows:

$$D = \min_k \left\{ \frac{1}{N_k} \left\{ \sum_{j=1}^{N_k} \left| u - S_{jk} \right|^2 \right\}^{\frac{1}{2}} \right\}, \tag{2}$$

where u is the measured APs' information of a user for estimation and is a set as follows:

$$u = \{(b_i, ss_i) \mid 1 \le i \le p\} \tag{3}$$

N_k is the number of sample points in k^{th} floor. S'_{jk} is the subset of S_{jk} and defined as follows: if exist b_i belong to u and also belong to S_{jk}, then $S'_{jk} = S_{jk}$. If exist b_i belong to u but not belong to S_{jk}, then $S'_{jk} = \{\phi\}$. Besides, a minimum available received signal, T_{min}, is used to instead of the mismatch AP when calculating the signal distance between u and S'_{jk}. For example, if $u = \{ (b_a, ss_{u,a}) (b_b, ss_{u,b}) (b_c, ss_{u,c}) \}$ and a sample point, assume to be S without lose of generality, $S = \{(b_a, ss_{s,a}), (b_b, ss_{s,b}), (b_d, ss_{s,d})\}$, then $|u - S|$ is defined as

$$\sqrt{(ss_{u,a} - ss_{s,a})^2 + (ss_{u,b} - ss_{s,b})^2 + (ss_{u,c} - T_{\min})^2} \tag{4}$$

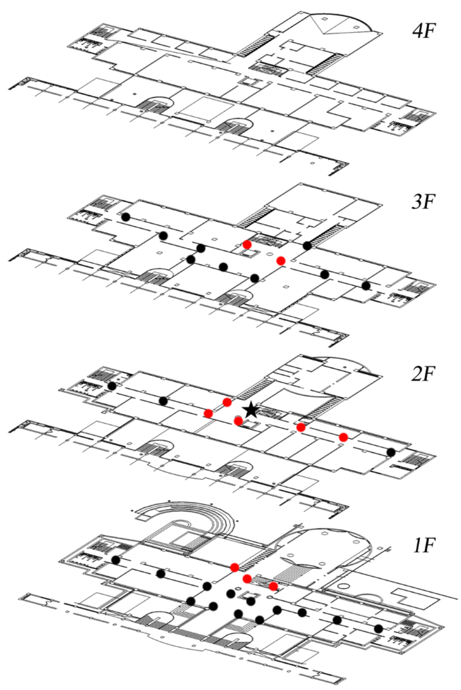

Figure 1. Floor estimation schematic diagram, the asterisk denotes location of u, black and red spots on behalf of S, and red only spots represent S'.

C. Virtual AP

Having the user's floor, the exact position is determined using a concept of Virtual APs. According to the research of the radio propagation model with the obstacle affect factor (OAF)[14]:

$$P(d) = P(d_0) - 10\log(\frac{d}{d_0})^n - OAF\ , \qquad (5)$$

where $P(d)$ represents the signal strength at d meters. $P(d_0)$ is the signal strength at the reference distance d_0. And n is path loss coefficient factor of model. *OAF* is all the obstacles affects include walls, partitioning plates. But how to calculate the value of *OAF* is a significant problem in set up the signal propagation model for the building which uses the WiFi-based indoor positioning system. User can detect a very huge variation of RSSI from an AP if the user turns a corner or gets into a room causing the radio be shaded by walls. A predefined OAF cannot fulfill the demand. This problem causes the majority of position estimation error.

We also find two interesting problems that cause error when applying RF propagation model in positioning: the first is that not all APs emit same power. Via actual measurement, for illustration, we detected -32dBm and -36 dBm for AUSU WL-330gE 802.11g AP and D-Link DIR-300 Wireless AP from 1 meter distance, respectively. The second is that not all mobile devices have same resolution in detecting radio signal. In general, general purpose smartphone and laptop report RSSI in one dBm scale and different devices report different RSSI values very frequent on the condition of same place and same time. In the proposed system, the change of $P(d_0)$, n from any situation and the value of *OAF* are all integrated into *CF* (Calibration Factor). So the propagation model for in-door WiFi-based positioning system becomes

$$P(d) = P_{ref} - 10\log(\frac{d}{d_0})^n - CF \qquad (6)$$

In system calibration phase, it can adjust *CF* to enhance the accuracy. In our test, the average of *CF* is about 27(dBm) and system can get the better accuracy. P_{ref} is a referenced power level instead of $P(d_0)$, and is assumed to be -32dBm in this study.

The motivation of our study is that if the position of sampling point and the position of measurement point are close in distance, they have highly probability suffering same attenuation from APs. Therefore, we use the sampling point to reversed deduce the position of APs which called virtual APs, and then use the coordinates of virtual APs to calculate the user's position. Therefore, system doesn't need to know any position of AP.

Considering a case as shown in Fig. 2, there are three mobile users and one AP. The mobile user 3 whom stands on k_1 floor will detect AP that set-up in k_2 floor with attenuated signal strength. The AP can be though as an AP where locates far from the current position. We still image that there is an AP deployed at the position calculated from sampling points and call it virtual AP. Whether AP is realistic or not, all of AP is regarded as virtual AP in the system.

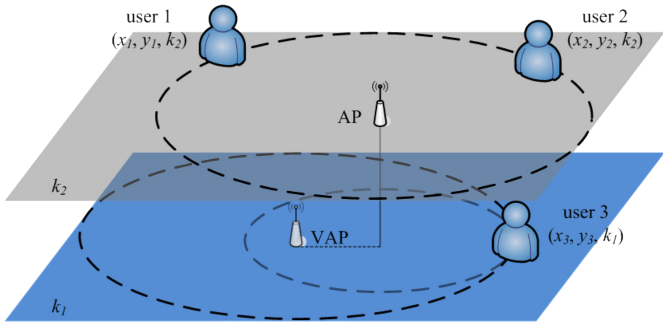

Figure 2. Virtual AP illustration.

There are three scenarios: the first is vertical relationship as Fig. 2, the location of AP mapped to the k1 floor. The second scenario is horizontal relationship like the walls. The last scenario mixes both of two. In any scenario, the system will not calculate the location of AP, only deduce coordinate of virtual APs.

D. Plane Positioning

In plane positioning, it has two processes. System calculates the coordinate of virtual AP first and determines mobile user location via virtual AP second. For convenience, the location of virtual AP and mobile user are called target point temporarily.

To calculate the target point by trilateration, we proposed a weighted screening (WS) method to determine the location of intersection from three circles. The circles defined from signal strength of three reference points are denoted by c_1, c_2 and c_3, respectively. The intersection points of two circles will no more than two. If there are two intersections, system will select one which closes to third circle. If there is no intersection, it will use section formula by RSSI ratio to determine a point that is on the shortest line of two circles. Then, system average three points from three circles and get the target point. One of possible cases when applying WS is shown in Fig. 3.

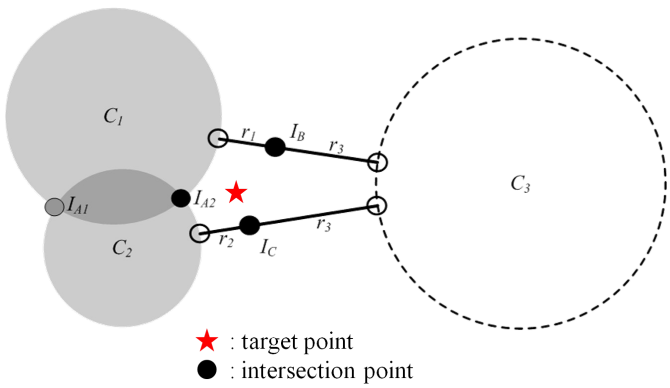

Figure 3. One of the cases of WS method for determining target point

In other words, system using WS trilateration method with three sampling points to calculate location of virtual AP. Then system executes WS method once again with three different virtual APs to get location of mobile user. Moreover, the three sampling points used to calculate virtual AP are decided by the smallest of $|u - S|$ in previous. So that three virtual APs imply to need three APs in plane positioning process. System chose the top 3 strongest RSSI of AP mobile user scanned.

E. Calibration Phase

Calibration is for calculating calibration factor (CF) which performs before positioning phase and after data collection phase. Having sampling radio map, some calibration points are chosen for system calibration, the calibration process is same as plane positioning; besides the coordinates of calibration points are known.

III. EXPERIMENT

In this section, we have tested the accuracy of the floor estimate and plane positioning. The experiments are tested in the electronic building, CYCU. It is an 8-floor building with about 60 × 25 m^2 plane area for each floor and with 51 detectable APs. And there are deployed 57 sampling points within this building. The distance is 5 meters from each other points. The mobile device is HTC Desire smartphone and has Android 2.2 O/S. The scan interval is once per second and total scan time is 60 seconds for each sampling point. Due to the WiFi signal's wave length is about 12.5 cm and is susceptible to attenuation by human body [2], and will affect the detected signal from AP. The experiment in data collection phase collects data in all four directions and averages them. Other parameters are as follows: P_{ref} is set to be -32dBm; n is set to be 2.7. *CF* is automatically calculated by system after calibration phase and in this test is 27dBm.

A. Floor Estimation

The estimated point, u, is chosen at three random positions on 1st, 2nd and 5th floor, and named A, B, and C, respectively. Fig. 4 through 6 show the experimental results for each floor. The test results show the floor estimation has highly accuracy.

In figure 5, the signal data on the 5th to 8th floor in test points B3 has a horizontal line. That is because the scanned AP in the test points doesn't contain any AP that be detected by the sampling point in the 5th to 8th floor. The phenomena is also shown in figure 4 except the sampling point at $k = 6$.

The curve in figure 6 is not fully consistent with a quadratic curve in each fixed j^{th} of S_{jk} is because the structure of building is complex and the AP on the other floor may be unreachable. In general, we can find the smallest value which mobile user on.

B. Plane Positioning

In the plane positioning test, u is chosen on 5th floor. There are 7 times tests in this test and all of *CF* is set to be 27. It's not only used WS method, but also traditional matrix method and the NNSS-AVG which proposed in[9]. Table I shows the difference among them. The result shows the error mean of traditional matrix method with virtual AP is 2.913 meters; NNSS-AVG is 1.775 meters. The proposed WS method with

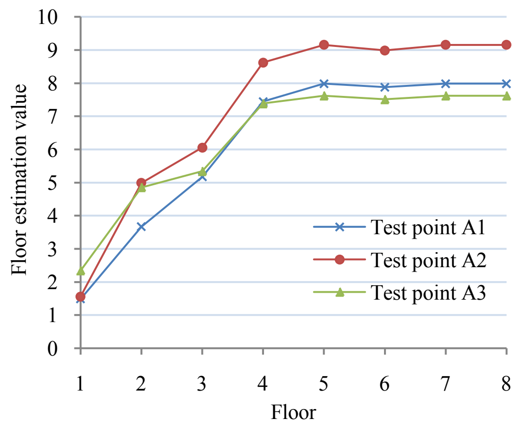

Figure 4. The experiment result on the 1st floor. A1, A2, and A3 are random chosen locations

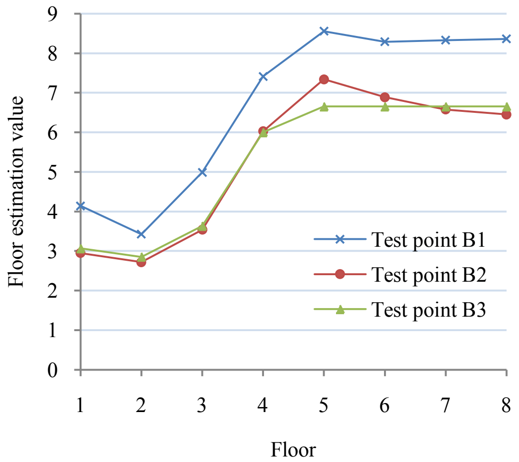

Figure 5. The experiment result on the 2nd floor. B1, B2, and B3 are random chosen locations

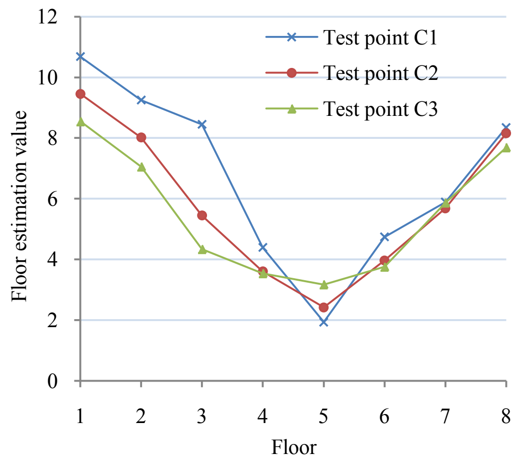

Figure 6. The experiment result on the 5th floor. C1, C2, and C3 are random chosen locations

virtual AP has good accuracy with error mean about 1.616 meters.

Because system used trilateration to calculate target point, so the density of sampling point doesn't need very high. And system doesn't to know real AP locations.

TABLE I. ERROR ESTIMATION OF PLANE POSITIONING

Method	μ (m)	σ^2 (m^2)	*25th*	*50th*	*75th*
Matrix	2.913	2.875	1.525	2.914	4.084
Weighted Screening (WS)	1.616	1.165	0.889	1.213	2.63
NNSS-AVG	1.775	1.25	0.943	1.374	2.757

IV. CONCLUSION

This paper presents a WiFi-based indoor positioning system including the twofold method: floor positioning and plane positioning. The plane positioning combines the characteristics of trilateration and fingerprint method for increase accuracy and reduces the signal collection time. We proposed two new concepts for indoor positioning. The first one is virtual AP and the Second is that we use CF to model the influence of varying $P(d_0)$, n, and OAF to infer an new radio propagation model from measurement/sampling point to virtual AP. The system can be setup fast without cooperation with administrative competences of building structure or networking. It also doesn't need to know AP's location. We also consider the factor of the multi-floor building. Experimental results show the floor positioning is with highly accuracy that is 100% in our experiments. In the plane positioning, the proposed method show its outperformance than NNSS-AVG and the advantageous get larger when sampling points becomes sparse.

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