Indoor WIFI localization on mobile devices

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***Abstract*—Indoor WIFI localization is challenging especially when deployed over wireless device with limited system resource. Although GPS can give approximate position of the mobile users, it is usually limited indoor due to the degradation of signals by the building structures. While various alternative WIFI localization techniques have been proposed for indoor uses, accurate results are hard to achieve due to the instability nature of wireless signal. In this paper, we discuss the performance of multi-trilateration and fingerprinting localization techniques in the context of mobile applications. The implementation of WIFI localization on mobile allows the users with WIFI-enable devices such as smartphone to locate their position and/or navigate themselves within the building. During our experiments, we noted that the selection criteria that involves selecting available access points to be used as a reference position considerably affect the accuracy of the positioning calculation. The tradeoff between multi-trilateration and fingerprinting in terms of correctness, computational complexity and system resource consumption have been discussed. Additionally, we proposed the suitable configuration for these localization algorithms as a means to achieve more accurate positioning results.**

I. Introduction

In recent years, the rapid development of mobile smartphone technologies made them play an important role in our daily life. The percentage of smartphone users increase drastically each year. The price of smartphone becomes affordable and these devices are now easily accessible among the population. The mobile applications can facilitate and assist daily life activities of mobile users.

In this paper, we are interested in using smartphones for localization and tracking purposes. The localization and tracking techniques can be deployed in various means e.g. surveillance of the elders or patients, guidance for visitors, navigation for the blinds, specific items tracking in warehouses. Although each smartphone is usually integrated with GPS module that provides approximate geographic coordinate using satellite signal. This function is usually limited when deployed within the building as the signal from the satellite can not propagat well through building structures. Hence, additional indoor localization techniques are required in order to provide more precise position within the building.

Indoor geolocation technology has become a novel emerging technology during the decade. The idea of WIFI localization was first introduced by [1] where WIFI access points (APs) were deployed along with WIFI enable mobile devices to locate the approximate position. The difficulties for mobile positioning system have been stated in [2] including radio propagation model and the deployed infrastructure. Hence, efficient localization algorithms vary between different signaling techniques and overall system architectures. Several localization techniques exist where mobile users can approximate their relative position to the reference points using different measuring signal metrics such as the angle of arrival (AOA), the time of arrival (TOA), the carrier phase of arrival (POA) or the received signal strength indicator (RSSI) [3]. In wireless mobile localization however, we're solely interested in using the RSSI as a measuring metric to retrieved the user's location. This paper discusses the tradeoff between two WIFI localization techniques: multi-trilateration and fingerprinting. Although some works have mentioned these techniques, the fact that the experiments were done in different device, different configurations and different infrastructures give the different perspectives of leveraged problems. We discuss the tradeoff between these localization algorithms and analyze the benefits and tradeoff for mobile application context. We propose the selection criteria of the reference points which lead to the better results obtained during the experiments.

The remainder of this paper is organized as follows. In section II, we survey related work in WIFI indoor localization techniques. In section IV, we discuss our research methodology and presents the overview of our system model. Section V presents the results obtained from the testbed and the discussion of the results. Finally, we conclude our research work and its perspective in the last section.

II. Literature reviews

The work for mobile WIFI localization has been first proposed in [1] where user's signal strength and their orientation is used to determine the position through the *triangulation* techniques. Another technique called *multi-trilateration* which converts RSSI to distance estimation is one of the most commonly-known localization approach [3]. These localization techniques usually encounters difficulties in finding the appropriate radio propagation modeling that match the real world experiments. Moreover, signal instability due to noises

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and interferences becomes an important issues to determine an exact user's position. Several work has proposed a radio propagation model but they are site-specific signal modeling which varies upon different building structures [4]. Later, a technique called *fingerprinting* has been proposed. With fingerprinting technique, a unique set of AP-s associated to the position are collected in a database. The size of database grows with the scaling unit of the observed area. Several optimization algorithms can be applied along with the fingerprinting techniques to find the closet match between the list of different AP's RSSI measurement at the position and the existing measurement in the database in order to define the current location. An extension to the fingerprinting technique is presented in [5], [6] where the probabilistic approach for finding the closet match have been proposed to improve the old deterministic approach.

III. Localization Techniques

In this section, we give an overview of two localization techniques of interest: multi-trilateration and fingerprinting. Given the unknown coordinate $X = (x_r, y_r)$. We're interested in comparing the performance between these two techniques as well as discussing about the appropriate setting parameters that should adapt to our framework.

1) Ranging Techniques: Before going into details of various localization techniques, the basic knowledge of ranging techniques is required since it will later be used to retrieve the approximate distance during multi-trilateration process. Ranging techniques allow users to estimate physical distance between the position $X = (x_r, y_r)$ and any reference point $X_i = \{(x_i, y_i) | i \in \mathbf{N}\}$. The physical distance can be estimated based on different signal measurement metrics such as signal propagation time, angle of arrival or signal strengths [3]. However, due to the limitation of a mobile device hardware, we only focus on the ranging technique which is based on received signal strength indicator (RSSI) detection.

Knowing that signals decay with the distance traveled and by knowing the transmitted power level at the reference AP X_i, the users can compute their distance from X to X_i. By measuring the received signal power at the unknown location, the users can evaluate how far they are from the transmitter by considering the attenuation factor or pathless level. Generally, the indoor signal propagation model can be expressed as:

$$P(X)[dBm] = P(X_i)[dBm] - 10\alpha \log(r_i) - L_w[dBm] \quad (1)$$

where $P(X)$ is the measured RSSI at the unknown position X, $P(X_i)$ is the transmitted power from the i^{th}reference AP at the position X_i. α indicates the pathloss attenuation factor and $L_w[dBm]$ indicates the wall attenuation factor which varies between different building infrastructures. In general n and $L_w[dBm]$ depend on the building layout and construction material and need to be derived empirically [1], [4].

In this work, as most of the experiments were done along the corridor which is mostly an open space. We simplified our propagation model by neglecting the effect of wall attenuation. Our radio propagation model is defined with $L_w[dBm] = 0$ and $\alpha = 2$ which follows the free space path loss propagation model.

2) Multi-Trilateration: Multi-Trilateration technique consists of calculating the position based on approximate distance between at least $n \geq 3$ reference AP positions. Given:

- $X = (x_r, y_r)$ as a coordinate of an *unknown location*,
- $X_i = (x_i, y_i)$ as coordinate of *reference point* i,
- r_i the distance from X to a reference point X_i,

we can use the geometry of circle in equation 2 to determine the relative position of X compared to n reference APs with $i \in [1, n]$:

$$(x_i - x_r)^2 + (y_i - y_r)^2 = r_i^2 \quad (2)$$

By rearranging terms given linear equations, we can write the matrix as:

$$AX = b \quad (3)$$

where

$$A = 2 \cdot \begin{bmatrix} x_n - x_1 & y_n - y_1 \\ \vdots & \\ x_n - x_{n-1} & y_n - y_{n-1} \end{bmatrix} \quad (4)$$

and

$$b = \begin{bmatrix} (r_1^2 - r_n^2) - (x_1^2 - x_n^2) - (y_1^2 - y_n^2) \\ \vdots \\ (r_{n-1}^2 - r_n^2) - (x_{n-1}^2 - x_n^2) - (y_{n-1}^2 - y_n^2) \end{bmatrix} \quad (5)$$

This solution can be resolved using minimum mean square error techniques. The square of the Euclidean norm given the solution as a form:

$$\begin{aligned} ||AX - b||_2^2 &= (AX - b)^T (AX - b) \\ &= X^T A^T AX - 2X^T A^T b + b^T b \end{aligned} \quad (6)$$

By derivation with respect to X, we obtain:

$$2A^T AX - 2A^T b = 0 \iff A^T AX = A^T b \quad (7)$$

Hence, X can be derived by providing the coordinate and the distance to n reference AP positions.

3) Fingerprinting: To estimate the user location based on the received signal strength RSSI, there exist another technique called *fingerprinting*. Fingerprinting requires offline calibration phase to build a radio map primitively. The building of the radio map involves collecting a number of RSS from each AP at every possible location in indoor environment. Since it is infeasible to collect RSSI at every possible location, the floor layout can be divided into grids. Within each grid, a signal vector of AP's associated BSSID is collected. These samples contain the values of RSSI and BSSID (mac address of AP).

During the localization phase, the users measure the RSSI sample at the unknown location X. The sample contain all RSSI of all neighboring APs in vicinity. This sample will be compared to all previously recorded samples in the database.

The comparison can be compared by computing the minimum distance between signal vector via deterministic algorithms or probabilistic algorithm as discussed in [1], [5].

In this work, the minimum distance from the collection is done by calculating the minimum euclidean distance between these signal samples. Given the set of RSSI sample vector from m APs at the position X as $S = \{s_j | j \in [1, m]\}$. By comparing this sample with all other recorded samples $S_i = \{s_{ij} | j \in [1, m]\}$ in the database, we determine $X = (x_r, y_r)$ by choosing X that gives the minimum distance as follows:

$$d_{min} = \min_{i \in N} \sqrt{\sum_{j=1}^{m} ((s_j - s_{ij})^2} \tag{8}$$

We note that smaller grids provide more accurate results in localization but trigger large size of database and high computational cost. This fingerprinting technique does not required ranging calculation. This is beneficial since the error from the ranging calculation can be avoided.

IV. Research Methodology

A. Hardware Description

The WIFI localization application is developed with android 2.3 API (Gingerbread). The experiment was performed on Sony Xperia Sola smartphone with Wi-Fi 802.11 b/g/n module.

B. Framework

The experiments in the rest of the paper was performed at Chaing Mai university campus where the layout of the building is presented in figure 1. Each grid presents approximately the sampling area of 2x2 meters. We limited our work to only one floor. The reason for choosing the university campus as a testing environment is because the building is already well equipped with large number of access points. We considered in this study 9 main access points as the reference points for multi-trilateration calculation. The position of these access points is illustrated in the figure 1 with star symbols.

C. Experimental Testbed

Once a user uploads the floorplan map to the application. The application scales the appropriate grid size. Two localization technique as previously described in section II were performed. The localization process consists of two phases: *data calibration phase* where reference data information is required to be added into the database and the *localization phase* where the application deployed the reference information to calculate the user's relative position to the reference.

1) Data Calibration phase: This phase involves collecting signal strength information within the building. The characteristic of data required differs for each localization techniques:

- Multi-trilateration technique requires the knowledge of all the 9 reference APs' positions and their transmitted power.
- Fingerprinting requires building the database of the received signal samples within each grid. To do so, the list of RSSI samples from neighboring AP within each grid is collected. The choice of grid's size affects the accuracy of positioning. Smaller grid size gives a more accurate results in finding the exact position however increases database size and the computational complexity.

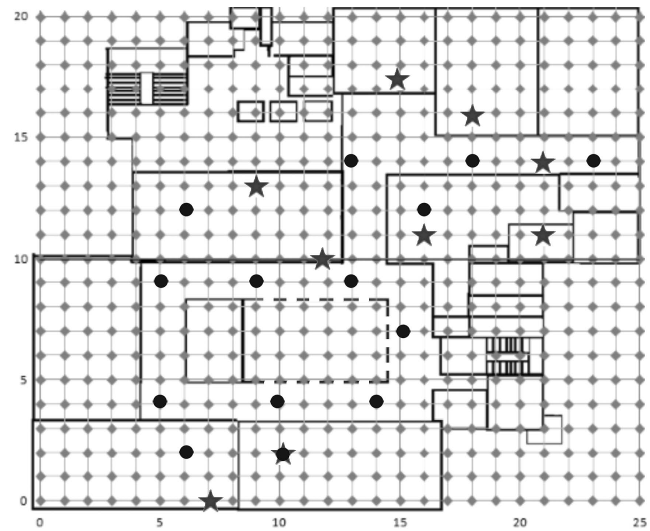


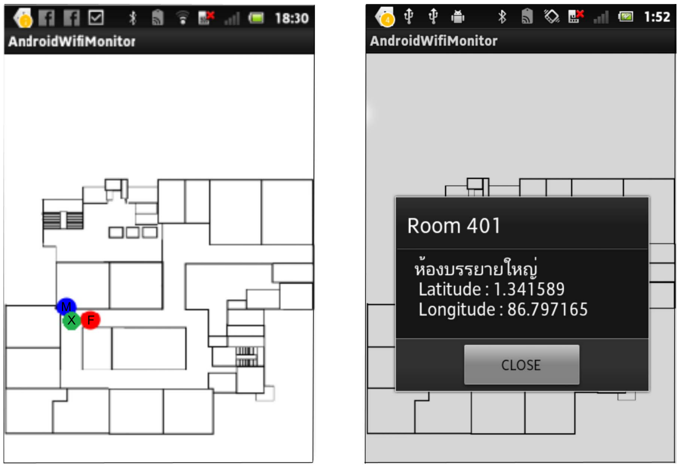
Fig. 1. The layout of the floorplan where we performed the experiments. The star symbol represented the positions of access points that are selected as the reference APs. The circle symbol represents the positions where the localization techniques were performed. The scale of this building floor is 1:2 unit/meters

The collected data is stored in the database and will be used in the second following localization phase.

2) Localization phase: During the localization phase, the WIFI localization application computes their relative position to the previously defined reference position. Figure 2.a shows the screenshot of the application. This screenshot demonstrates the results obtained from two localization techniques compared to the exact location. The results from the multi-trilateration and fingerprinting is represented as the character M and F respectively where the exact position is represented with the character X. The application that we developed also provide navigation system that provides details about each area of the floor and how to get to the place as shown in figure 2.b. In the next section, we compare and discuss the efficiency between multi-trilateration and fingerprinting techniques and propose an adjustment of the setting parameters to achieve a better performance.

V. Experiment results and evaluation

The experiments were performed at various positions as presented with circle symbols in the floor plan illustrated in the figure 1. During the experiment, we have encountered important issues with signal instability. The signals' oscillation made it difficult to compute the exact location. Our experiment has shown that the more the signal is attenuated, the more it becomes unstable and usually results in the wrong localization. We discuss several interesting remarks as follow:



(a) (b)

Fig. 2. The screenshot of the WIFI localization application on smartphone that show the current position of the user within the floorplan (a) and the detail of each area of inside the building as well as the navigation option (b)

A. The number of reference APs

Although several works on positioning and localization have stated that higher number of reference points gives the more accurate prediction of the unknown position with multi-trilateration techniques [3] (e.g. the higher number of satellites gives a more accurate GPS positioning). This is not always true in our context. A large number of reference points (i.e. APs) does not always perform well when it comes to the measurement in low density access points or wireless devices with limited transmission power. The results of accuracy presented as an average euclidean distance error between the calculation obtained from the experiments and the exact position is shown in the table I and table II. The results took an average from 50 experiments.

Table I shows the average distance error of every positions as defined in figure 1. The distance errors indicate the accuracy of the position determination for different number of referenced APs. We remark that the number of n affects the performance of positioning process. As the number of n grows, for example $n = 5$ or 6, it is more probable that the low quality signal will be chosen and leads to the inaccuracy of ranging calculation. To improve this performance evaluation, we propose to select only n neighboring APs with highest RSSI. The results for the position approximation is best when n takes the value of 3 or 4. Multi-trilateration yields the better results in position approximation than when the number n of reference APs take the value $n \leq 4$.

Next, we observe a specific case where at least one access point has a line-of-sight propagation to the mobile receiver. We take the measurements among selected positions that verify this property. The accuracy of the position determination for this specific case is shown in table II, we notice that the results is much more accurate than those previously obtained. We remark that when the received signal is sufficiently strong, positioning process can be done with lower error probability. We can assume that new ranging technique is required when wireless signal propagates through different objects (e.g. wall propagation).

TABLE I
THE ACCURACY OF THE POSITION DETERMINATION FOR DIFFERENT NUMBER OF REFERENCE APS

Number of reference APs (n)	Approximate error (m)
3	5.690
4	6.156
5	7.485
6	13.001

TABLE II
THE AVERAGED DISTANCE ERROR FOR DIFFERENT NUMBER OF REFERENCE APS IN A SPECIFIC CASE WHERE AT LEAST ONE ACCESS POINT HAS A LINE-OF-SIGHT PROPAGATION TO THE MOBILE RECEIVER

Number of reference APs (n)	Approximate error (m)
3	4.236
4	2.816
5	5.856
6	6.641

B. Trilateration vs. Fingerprinting

Comparing between the fingerprinting and the multi-trilateration technique, we obtained better performance from fingerprinting compared to multi-trilateration technique. When fingerprinting samples are collected for each unit of the floor-plan, for 50 experiments, the average error distance obtained from fingerprinting positioning technique is 2.764 meters. Fingerprinting positioning technique gives more accurate results. Figure 3 shows that the frequency distribution of approximate errors that occurs during the localization using fingerprints provides higher rate of success when compared to the average distant error obtained during multi-trilateration positioning process when $n = 3$.

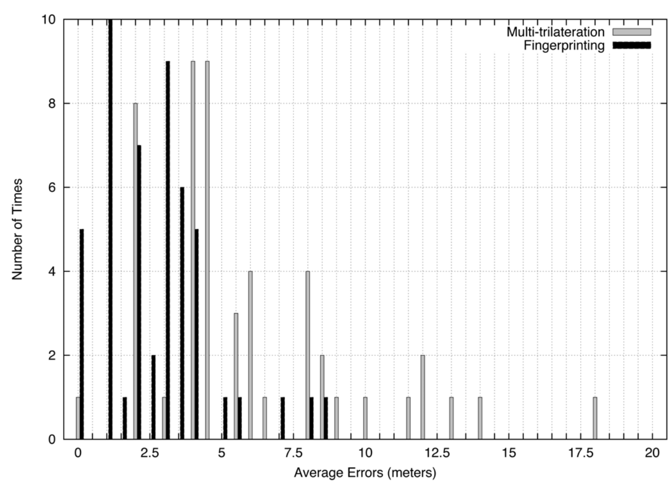


Fig. 3. Frequency distribution of estimated error during the localization

Although the performance of fingerprinting technique outperforms the performance of multi-trilateration, fingerprinting technique requires higher computational resources. Developped under android platform, the computational time to fetch the sampling from the database and to select these best matches between the signal sample vectors with fingerprinting technique require approximately 2-3 seconds for 30-40 samplings. This latency is too high and is not suitable to the real world usage. Hence, the current fingerprinting technique is not suitable to be used with mobile device especially within large area where the database can grow extensively. Moreover, the calibration of a large amount of data before each usage becomes inconvenient. The efficient recovery process when each reference AP is down is also required in this context. The failure or disruption of AP's signal can introduce the errors during the calculation. The The re-calibration is required at each state change of network topology.

Although the Multi-trilateration technique gives a more light-weight solution to the problem, the accuracy of this technique is quiet difficult to achieve with mobile device with WIFI transmission. A more efficient algorithm is required to make the system more robust and accurate.

VI. Conclusion

As signals decay with distance, the RSSI from access points that is situated far away or that is subjected to wall attenuation is usually measured with high level of noise and fading. This problem leads to inaccurate estimation of exact position during localization. In this paper, we discussed the appropriate localization techniques for mobile devices. The experiment showed that the APs should be carefully selected as reference points during the calculation. We remarked that by eliminating some reference AP with lower signal, better performance can be achieved with multi-trilateration process.

The performance between multi-trilateration and fingerprinting localization techniques when process over a mobile device is compared in this paper. Although fingerprinting yields better accuracy compared to multi-trilateration technique, offline calibration of large database and high computational cost is required and leads to high latency and limited system resources in this context. We note that without any further development of the existing algorithm, the performance of these techniques are quite limited when implemented on a smartphone. Our future work includes finding a way to optimize these algorithms to achieve better performance at lower computational cost.

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