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Indoor Positioning and Tracking System Implementation Based on Wireless LAN Infrastructure Network

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Abstract

Wireless Local Area Networks are becoming increasingly popular today especially those based on IEEE 802.11 b/g standard. In this paper, we study the implementation of positioning and tracking system for indoor areas using the existing wireless local area network infrastructure. Such systems make use of location fingerprinting technique rather than time or direction of arrival techniques for determining the position of mobile units. Fingerprinting technique operates by recording and processing the received signal strength information of the wireless clients that measured from multiple access points to provide the location of the user mobile unit. The methodology, positioning system stages (hardware and software) and data collection of the positioning system are presented. Analyzing the experimental results gives 2 meter accuracy, and shows that the accuracy and performance of the positioning system depends mainly on reference points density and number of access points in the infrastructure network.

Keywords:* *Indoor Positioning, Location Fingerprinting, Wireless Localization, Location Based Services, Received Signal Strength, Wireless LAN.

الخلاصـــــــة

الشبكات اللاسلكية المحلية اصبحت اليوم مستخدمة بشكل واسع خصوصا تلك المبنية على المقياس العالمي (*IEEE 802.11 b/g*). هذا البحث يتناول دراسة و بناء نظام تحديد و تعقب المواقع في داخل المباني مستخدما البنية التحتية للشبكات اللاسلكية المحلية الموجودة اصلا في المباني. هذه الانظمة مبنية على استخدام تقنية بصمة الاصبع الموقعية (*Location Fingerprinting*) بدلا من تقنيات وقت وصول الاشارة و اتجاه وصول الاشارة لتحديد موقع الوحدات المتنقلة. تقنية بصمة الاصبع تعمل بواسطة تسجيل و معالجة معلومات قوة الاشارة المستلمة للاجهزة المربوطة بالشبكة اللاسلكية و المقاسة من العديد من اجهزة البث اللاسلكي و المسمات نقاط الوصول (*Access Points*) لتحسب مكان المستخدم للمحطة المتنقلة. النظريات، مراحل النظام لتحديد الموقع (المادية و البرمجية) و كيفية جمع المعلومات تم مناقشتها. تحليل نتائج التجارب اعطت دقة 2 متر و كشفت ان الدقة والكفائة لنظام تحديد المواقع يعتمد بشكل اساسي على عدد النقاط المرجعية (*Reference Points*) و عدد اجهزة البث اللاسلكي نقاط الوصول (*Access Points*) الموجودة في البنية التحتية للشبكة.

1. Introduction

Recently, there is increasing interest in accurate location finding techniques and location-based applications for indoor areas. The Global Positioning System (GPS) and wireless positioning services in Global Systems for Mobile Communications (GSM) also address the issue of location finding. However, these technologies cannot provide accurate indoor positioning, which has its own independent market and unique technical challenges.

Accurate indoor positioning (or indoor geolocation) is an important and emerging technology for commercial, public safety, and military applications. In commercial applications for residential and nursing homes there is an increasing need for indoor positioning systems to track people with special needs, the elderly, and children who are away from visual supervision, to navigate the blind, to locate in-demand portable equipment in hospitals, and to find specific items in warehouses. In public safety and military applications, indoor positioning systems are needed to track inmates in prisons and navigating policemen, fire fighters, and soldiers to complete their missions inside buildings. These incentives have initiated interest in modeling the radio channel for indoor geolocation applications, development of new technologies, and emergence of generating the indoor positioning products. To help the growth of this emerging industry, there is a need to develop indoor positioning systems using available modern technology [1] [2].

Figure 1 illustrates the functional block diagram of a positioning system. The main elements of the system are a number of location sensing devices that measure metrics related to the relative position of a Mobile Unit (MU) with respect to a known Reference Point (RP), a positioning algorithm that processes metrics reported by location sensing elements to estimate the location coordinates of MU, and a display system that illustrates the location of the MU to users. The location metrics may indicate the approximate arrival direction of the signal or the approximate distance between the MU and RP. The Angle of Arrival (AOA) is the common metric used in direction-based systems. The Received Signal Strength (RSS), carrier signal Phase of Arrival (POA), and Time of Arrival (TOA) of the received signal are the metrics used for estimation of distance [2]. As the measurements of metrics become less reliable, the complexity of the position algorithm increases. The display system can simply show the coordinates of the MU, or it may identify the relative location of the MU in the layout of an area.

This display system could be software residing in a private Personal Computer (PC) or a mobile locating unit, locally accessible software in a Local Area Network (LAN), or a universally accessible service on the Web. Obviously, as the horizon of accessibility of the information increases, design of the display system becomes more complex [3][4].

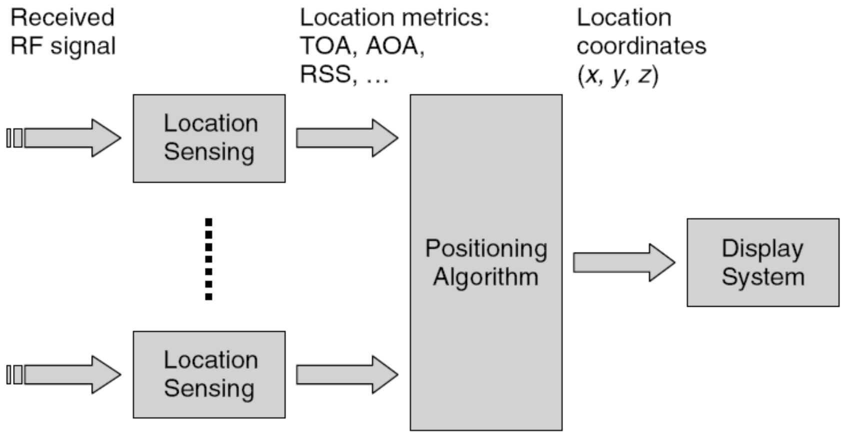


Figure 1: A Functional Block Diagram of Wireless Positioning Systems.

2. Indoor Positioning Algorithms Using Received Signal Strength Information

The goal of an indoor localization system is to estimate the location of MU by combining measurement metrics from a number of Access-Points (AP) distributed in the area in a process called data fusion. We classify indoor geolocation techniques based on the signal attribute being used for localization into AOA, TOA and RSS based algorithms. Each class is further sub-classified based on their data fusion algorithm into distance based or pattern matching based subclasses. The indoor radio channel have many problems such as suffers from several multipath propagation, heavy shadow fading and low probability for availability of line-of-sight signal propagation path between the transmitter and receiver, therefore both AOA and TOA algorithms may have many difficulties in the indoor environments. Received signal strength (RSS) algorithm development may gives better positioning system without any modifications to wireless LAN network infrastructure. In addition, this technique is relatively simple and more robust in multipath conditions compared to other techniques (AOA & TOA) [2][4].

Received Signal Strength RSS is a signal metric that most off the shelf wireless devices can measure. As an example the MAC layer of IEEE 802.11 WLAN provides RSS information from all active AP's in a quasi periodic beacon signal that can be used as a metric for positioning. In open outdoor environments RSS decays linearly with log distance, thus a MU can uniquely map an observed RSS value to a distance from a transmitter and consequently identify its location by using distances from three or more AP's. Unfortunately instantaneous RSS inside a building varies over time; even at a fixed location; this is caused largely by channel variations due to shadow fading and multipath fading [5][6].

Therefore, statistical approaches using pattern matching algorithms to location estimation have been developed. The descriptions of positioning algorithm that use RSS metric for indoor localization are explained below [7].

Let (x,y) be the MU location to be determined, **O** = [O1(x,y), O2(x,y) … Om(x,y)] is an observed RSS vector from AP1, AP2, …, APm located at (x1,y1), (x2,y2),…, (xm,ym) respectively. Let **Z**(x,y) = [Z1(x,y) Z2(x,y)… Zm(x,y)] be the vector of expected RSS measurements at (x,y). The MU's location can be estimated as $(\hat{x}, \hat{y})$ where **Z**$(\hat{x}, \hat{y})$ provides a good approximation of **O** = [O1(x,y), O2(x,y) … Om(x,y)]. The error function can be defined as:

$$\varepsilon(x, y) = \|O(x, y) - Z(x, y)\|^2 = \sum_{i=1}^{m}(O_i(x, y) - Z_i(x, y))^2 \qquad \ldots(1)$$

The estimated location for $(\hat{x}, \hat{y})$ must minimize (1). In other words:

$$\nabla \varepsilon(x, y) = 0 \qquad \ldots(2)$$

$$(\hat{x}, \hat{y}) = \arg\max(\varepsilon(x, y)) \qquad \ldots(3)$$

Applying (2) to (1) to obtain:

$$\sum_{i=1}^{m}(O_i(x, y) - Z_i(x, y))\frac{\partial Z_i(x, y)}{\partial x} = 0 \qquad \ldots(4)$$

$$\sum_{i=1}^{m}(O_i(x, y) - Z_i(x, y))\frac{\partial Z_i(x, y)}{\partial y} = 0 \qquad \ldots(5)$$

or in a matrix form:

$$\begin{bmatrix} O_1(x, y) - Z_1(x, y) \\ O_2(x, y) - Z_2(x, y) \\ . \\ . \\ O_m(x, y) - Z_m(x, y) \end{bmatrix}^T \begin{bmatrix} \frac{\partial Z_1(x, y)}{\partial x} & \frac{\partial Z_1(x, y)}{\partial y} \\ \frac{\partial Z_2(x, y)}{\partial x} & \frac{\partial Z_2(x, y)}{\partial y} \\ . & . \\ . & . \\ \frac{\partial Z_m(x, y)}{\partial x} & \frac{\partial Z_m(x, y)}{\partial y} \end{bmatrix} = 0 \qquad \ldots(6)$$

Path loss models are often represented by a constant and a logarithmic component:

$$Z_i(x, y) = \beta_0 - \beta_1 \ln[(x - x_i)^2 + (y - y_i)^2] \qquad \ldots(7)$$

where β_0, β_1 are some site specific constant values. Thus:

$$\frac{\partial Z_i(x,y)}{\partial x} = \frac{-2\beta_1(x-x_i)}{(x-x_i)^2+(y-y_i)^2} \qquad \ldots(8)$$

$$\frac{\partial Z_i(x,y)}{\partial y} = \frac{-2\beta_1(y-y_i)}{(x-x_i)^2+(y-y_i)^2} \qquad \ldots(9)$$

Substituting (7) and (8) & (9) in (6) results in a set of nonlinear over-determined equations [7].

To find a numerical solution for the set of nonlinear equations, most RSS based positioning systems create a priori conditional probability distribution of RSS in an environment (***Radio Map***) during an offline training phase called fingerprinting [8][9]. A high resolution grid of reference points at known locations will be selected. At each k-th Reference Point (RP) on the grid a reference fingerprint vector $Z(x_k, y_k) = [Z_{k1} Z_{k2} ... Z_{km}]$ is collected. During the localization period the MU uses a matching algorithm to map an observed RSS fingerprint vector to a physical location. In this algorithm the MU can determine its location without knowing the exact location of the access points. The basic algorithm in this class is called Nearest-Neighbor in Signal Space (NNSS) [10]. In this algorithm MU compares an observed RSS vector with all available fingerprints in the reference radio map and finds a reference point with the smallest Euclidean distance in signal space and reports that as the current location of the device. Suppose that MU observes **O** = [O1(x,y), O2(x,y) … Om(x,y)], the Euclidean distance between this vector and the k-th reference point entry in the radio map $Z(x_k, y_k) = [Z_{k1} Z_{k2} ... Z_{km}]$ is given by:

$$D_k = \left(\sum_{i=1}^{m} (O_i - Z_{ki})^2 \right)^{1/2} \qquad \ldots(10)$$

This technique maps the location of MU to an entry on the radio map. Another variation of this algorithm finds the M closest reference points and estimate the location based on the average of the coordinates of these M points. Since the total RSS value is the sum of signal strengths of each individual path in a multipath environment, therefore RSS based systems take advantage of the existing multipath diversity in the channel.

3. Wireless LAN Fingerprinting Positioning Technique

Systems of indoor positioning based on location fingerprinting technique have emerged as a simple approach that can provide location-aware capability for devices equipped with wireless local area network (WLAN) interfaces.

Compared to other techniques such as angle of arrival (AOA) and time of arrival (TOA), the fingerprinting technique is more effective in indoor due to prevalent multipath effect and non line-of-sight environment that cause inaccurate angle and time estimation. Although, in building indoor positioning system based on WLAN infrastructure, the cost of dedicated indoor positioning systems can be avoided [11].

The location fingerprinting is a technique that exploits presumably a unique relationship between Received Signal Strength Indication (RSSI) and an indoor location. The RSSI can be obtained by virtually all IEEE 802.11 b/g WLAN interface cards. Given an indoor area covered with WLAN signals, the indoor positioning systems based on location fingerprinting technique can be deployed in two phases [12]: offline (training) phase and on-line (positioning) phase as shown in figure 2.

First, the ***off-line phase*** is when a site-survey of RSS from multiple Access Points (APs) is performed to collect patterns of RSS. The result of this phase is a database that maps between RSS patterns (which is called location fingerprinting), and locations in that area.

The RSSI database is called a ***Radio Map***. The location fingerprints can be as simple as patterns of averaged RSS or distributions of RSS from a number of APs. In order to generate the database, Reference Points (RPs) must first be carefully selected. Locating a MU at one RP location, the signal strengths (SSs) of all the APs are measured. From such measurements the characteristic feature of that RP (its SS) is determined, and is then recorded in the database. This process is repeated at another RP, and so forth until all RPs are visited [13][14].

In the literature systems that maintain or estimate distributions of RSSI for each location usually have better positioning performance. Therefore, understanding of actual RSSIs distribution could be a key to improve the performance of indoor positioning systems [15][16].

Second, the ***on-line phase*** is when the system can determine objects location by measuring samples of RSS pattern at a particular location and comparing it with location fingerprints in radio map. The MU measures the RSS at a place where it requires its position, the measurements are compared with the data in the database using an appropriate search/matching algorithm. ***Pattern Matching*** or pattern classifications are often used to estimate the objects location by finding the closest match for the RSS pattern.

The most common pattern classification technique is distance based technique such as the Euclidean distance between the samples of RSS pattern and the location fingerprints. The location associated with the fingerprint that has the smallest Euclidean distance is returned as the estimate of the objects location [13][14].

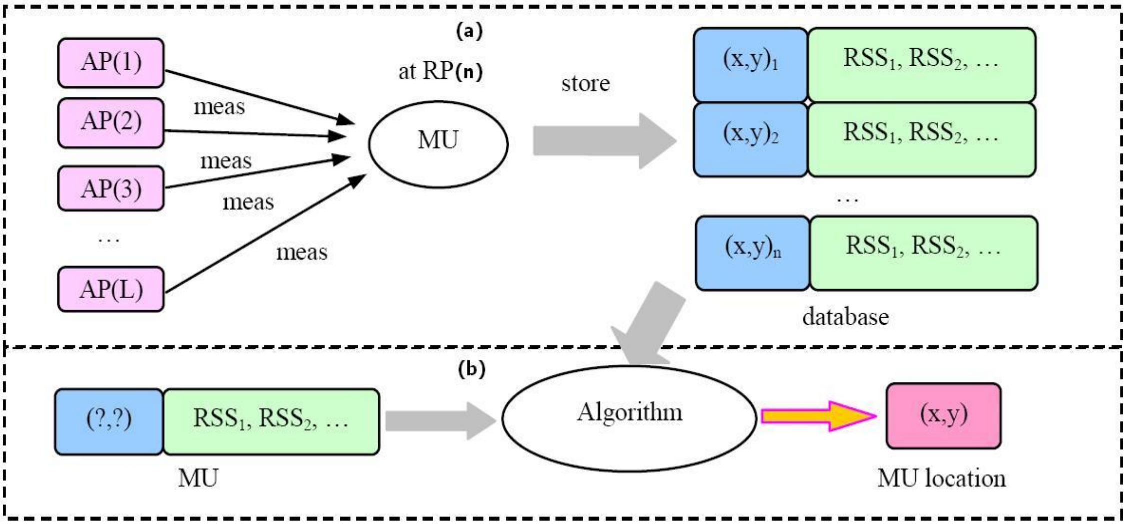


Figure 2: Two Phases of Fingerprinting:

(a) Training Phase (b) Positioning Phase

4. Implementation of Indoor Fingerprinting Positioning System

The basic components of the WLAN are Access Points (AP) and the mobile Units (MU), typically a laptop with a WLAN card, a mobile phone (GSM/CDMA) or Personal Digital Assistants (PDA) with Wi-Fi Capabilities.

To create a wired network infrastructure, Ethernet cables are placed throughout the building and then buildings are connected together using fiber optic cables. With a Wireless LAN, in order to create the network infrastructure, access points are placed in various locations throughout a building and even outdoors. Various mobile clients then communicate with each other by first communicating with these access points.

WLAN standardization centers around the protocol called the IEEE 802.11 (Institute of Electrical and Electronics Engineers) which have different versions (such as 802.11b with 11 Mbps and 802.11g with 54 Mbps). The design construct a network environment based on wireless LAN infrastructure and support the protocol over the 802.11b/g. The design of this system organized by client-server, access points and laptops as client devices. The positioning system tracks the users with IEEE 802.11 supported devices (laptop, mobile phones, PDA with Wi-Fi support) across the coverage area of a WLAN. The main client used here is laptop that communicates with the database positioning server and sends the necessary RSSI at a predetermined frequency, where the server analyses the data received and tries to estimate the location of the client. Figure 3 shows positioning system based on wireless LAN infrastructure network.

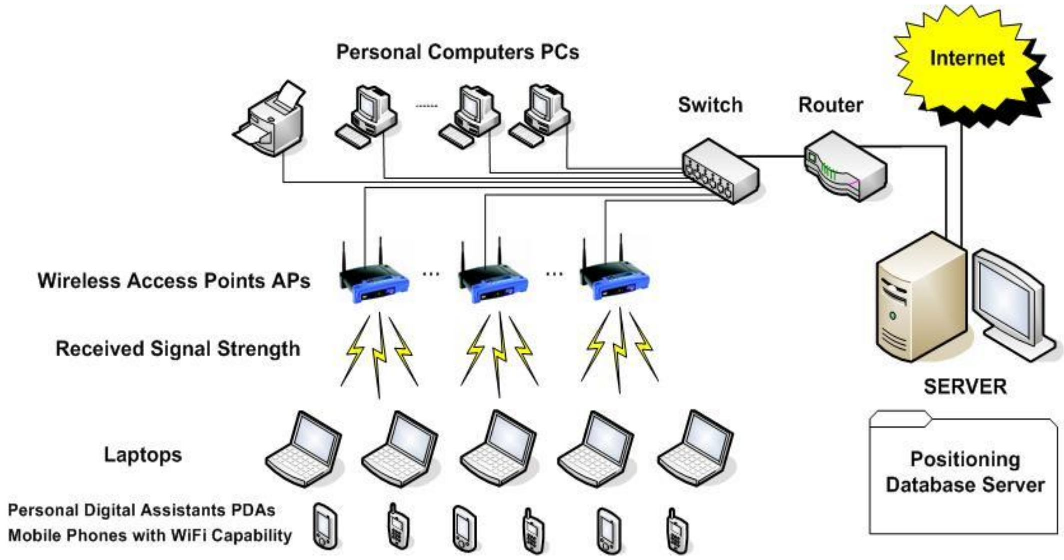


Figure 3: Positioning System Based on Wireless LAN Infrastructure Network.

A. Indoor Positioning Client Software

A DELL inspiron 1525 laptop computer equipped with a Dell 1395 WLAN built-in card with a client manager software developed were primarily used to collect samples of RSS from access points (APs) in the building.

The client manager software provides link quality and AP monitoring capabilities. This client software monitors IEEE 802.11g radio frequency channels which operate in the 2.4 GHz band. Note that this radio spectrum is shared by other equipment in the 2.4 GHz ISM band (Industrial, Scientific, and Medical Band) such as Bluetooth. The information available to the user from the client manager software includes the AP's name, AP's medium access control (MAC) address, received signal strength RSS (dBm) and channel number. In our proposed indoor positioning system, the client software in different laptops collects samples of RSS from access points and sends these samples messages to indoor positioning database server.

B. Indoor Positioning Server Software

The indoor positioning system server software includes two key functions as follows:

- ***Sampling Function (Off-Line Phase):*** Recording and saving the location fingerprinting database of different sample points in the building. In our work, Microsoft Windows 2003 Server installed on hardware model type HP Proliant ML370 server is used to store location fingerprinting data, and we could define the scanning frequency and maximum reading count for every sample point. Samples of RSS from access points are received from indoor positioning client software

- ***Tracking Function (On-Line Phase):*** Showing the real-time location of user or equipment in which indoor positioning client software is installed. The fingerprinting tracking technique with pattern matching method is used to forecast and calculate the user location as shown in figure 4.

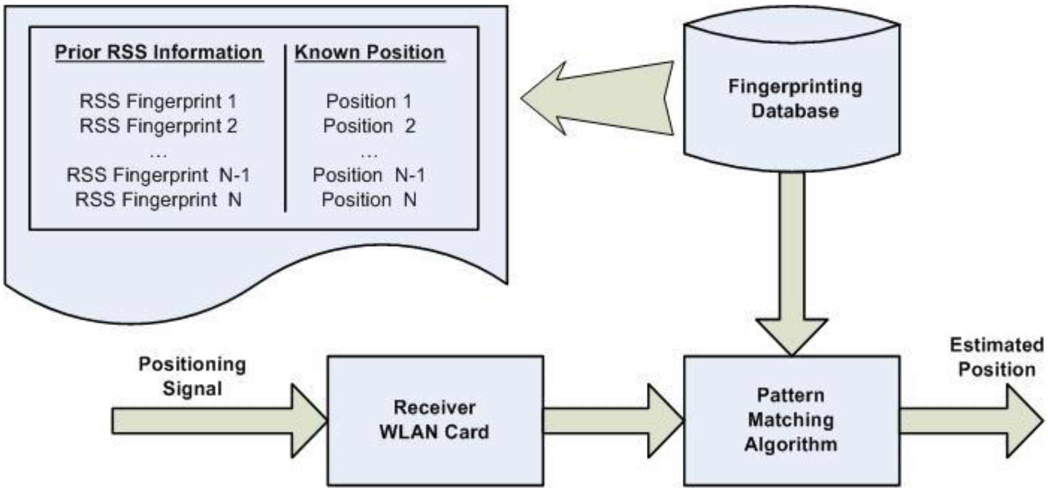


Figure 4: Fingerprinting Technique with Pattern Matching Algorithm

C. Fingerprinting Experimental Model

The experiments that are tested in the building have its wireless infrastructure network available. Figure 5 shows the layout of the building. The building has dimension of 60 m by 40 m, an area of about 240 sq. m, and includes about 34 rooms.

The wireless network in the building has five access points to cover all the area of the building. The five wall-mounted access points provide overlapping coverage in the portion of the building area where the experiments were carried out to obtain many readings from different APs in order to develop reference points (RP) of fingerprinting radio map. The APs used from Linksys products, Linksys wap54g wireless APs operates in 2.4 GHz ISM frequency band.

These APs have different MAC addresses and operate in multi-rate direct sequence spread spectrum technology. It supports raw data rate of 6, 11, 22, 36, 48, 54 Mbps. The power level of these access points are 100 mWatt, where the range of the network depends on the power level and the data rate at which it is operating. Therefore, all APs configured to operate on data rate 54 Mbps with 100 mWatt transmission power.

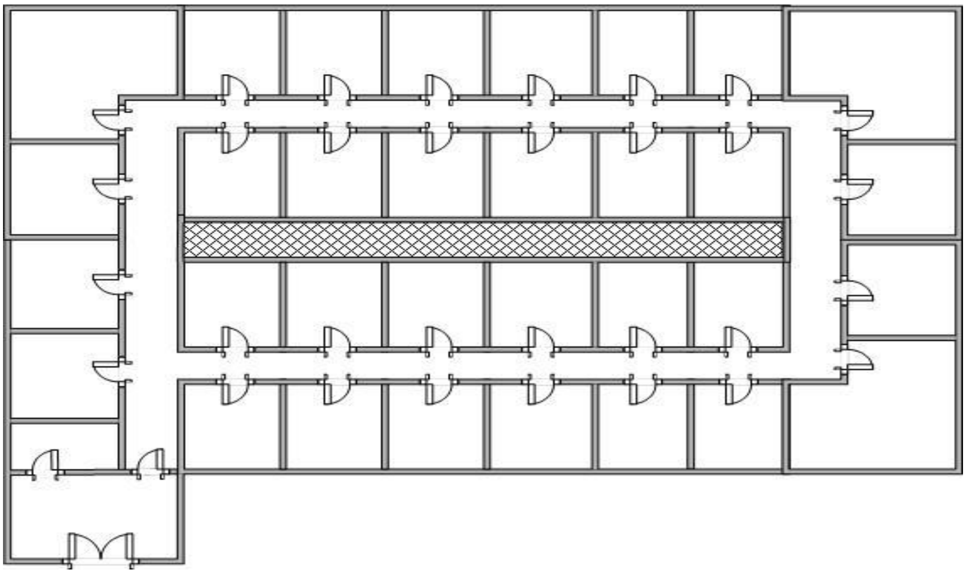


Figure 5: The layout of the building where the experiments are carried out

D. Data Collection and Database Development

A key step in our research methodology is the data collection phase. The information about the radio signal as a function of the user's location are first recorded. As discussed in Section 3, the radio signal information are used to construct and validate models for signal propagation during off-line analysis as well as to determine the location of a user in real time.

The information available by wireless LAN cards may be the *signal strength* (SS) or *the signal-to-noise ratio* (SNR). Signal strength is reported in units of dBm and SNR is expressed in dB. A signal strength of *s* Watts is equivalent to *10*log10(s/0.001)* dBm. A signal strength of *s* Watts and a noise power of *n* Watts yields an SNR of *10*log10(s/n)* dB. For example, signal strength of 1 Watt is equivalent to 30 dBm. Furthermore, if the noise power is 0.1 Watt, the SNR would be 10 dB.

Experiments were carried out in order to test the feasibility and reliability of wireless positioning based on the WLAN infrastructure. While conducting the experiments, during off-line phase, groups of data were recorded in database files.

The data records include all the necessary information to get fingerprinting database of the building, such as the *time* information *(t)*, *MAC* address of access point, *Signal Strength (SS)* information, *Noise*, *Signal-To-Noise Ratio (SNR)*, transmitter channel of access point *(f)*, *Basic Service Set Identifier* (*BSSID)* of access points.

The radio signal, as a ranging signal, should be 'stable' and 'consistent' at a fixed point. In order to test this, a stationary measurement experiment was conducted. The measurements were collected from access points during the 8 hours working day (8 a.m – 4 p.m). The readings of RSS are taken at equal intervals, such as every 15 minutes, or 30 minutes or every one hour. If we take 15 minutes interval time, then we have 60/15 = 4 intervals per hour, multiply this by 8 hours working day, yields 4*8 = 32 readings for each access point at a specific position (x,y). Then take the average of these readings and this will represent the RSS from one access point on the signal map. To complete calculation for each reference point (RP) in the radio map, the readings for each reference point position (x,y) should take from all access points which are five access points here, as will be explained in figure 6.

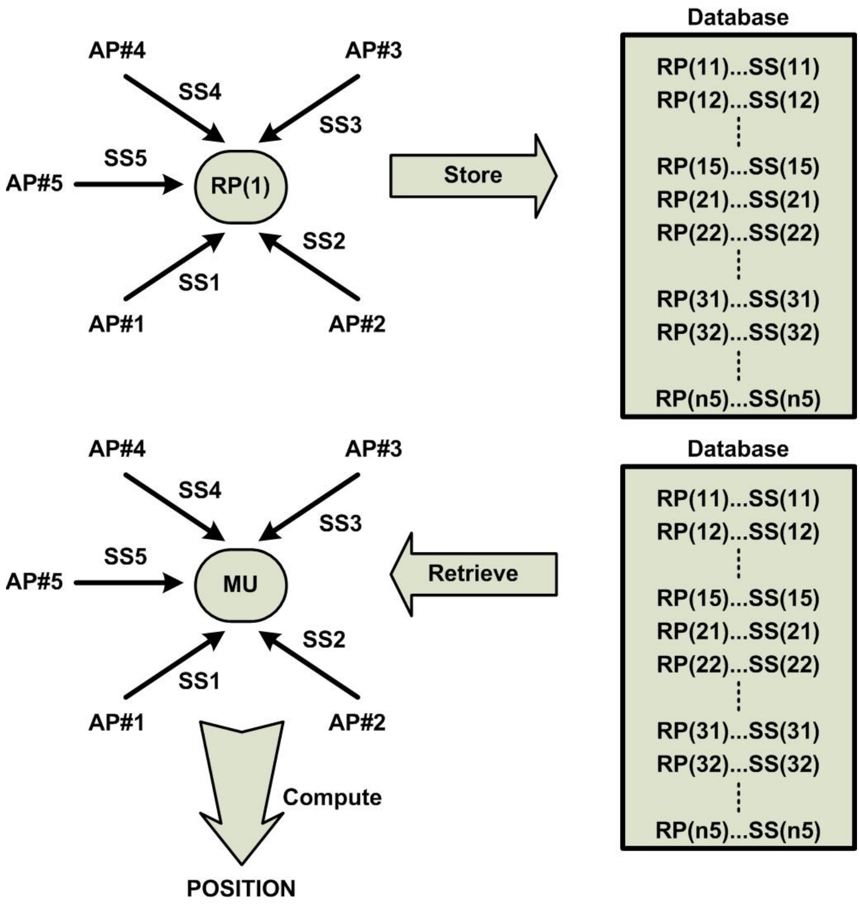


Figure 6: Fingerprinting Database Generation Using Reference Points and Received Signal Strength

The accuracy depends on how many reference points (RP) measurements on the fingerprinting radio map of the building such as for each 1 meter, each 2 meters or for each room in the building. The database in the positioning server will contain the following important information's at each RP measurement (**x, y, RSS, MAC address of AP)**.

Also the mapping of the access points in the floor map is positioned. Then the RF fingerprinting technique will use the database generated during the off-line phase to calculate or find the position of the mobile unit MU by using *Nearest Neighbor in Signal Space (NNSS)* pattern matching method.

This is done by taking the stronger signal strength from nearest access points to find the most correct position that best matches the signal strength information of the MU device by comparing it with the grid database of the signal map stored in the positioning database server to determine the device's position within a few meters.

5. Experiments and Results

The IEEE 802.11b/g standard for WLAN uses radio frequencies in the license-free band at only two ISM bands, 2.4 GHz for indoor/outdoor applications and 5.7 GHz for outdoor applications only which is not suitable for indoor because it is very sensitive to reflected and absorbed walls and it can effects human body more than 2.4 GHz.

In the 2.4GHz band, Bluetooth devices, cordless phones, microwave ovens and other devices can be a source of interference.

Multi-path fading is another common phenomenon in RF wave propagation. A transmitted signal can reach the receiver through different paths, each having its own amplitude and phase. These different components combine and produce a distorted version of the transmitted signal. Moreover, changes in the environmental conditions, such as temperature or humidity, affect the RSS.

All these problems should take into account when designing an indoor positioning system. The fingerprintting technique is the best to be used, because most of these effects are really present.

Since fingerprinting positioning technique depends mainly on received signal strength, therefore it should study the RSS behavior in the test building at different environments.

The indoor positioning system discussed in section 4 was implemented and checked in an existing wireless LAN network on the test building as shown in figure 7, where it shows the distribution of the five wall mounted APs in the building layout, while the small shadows circles represents where the RPs will be taken in each room of the building.

The RPs may be selected equally spaced according to a regular grid or selected irregularly depending on accuracy demands and the building structure.

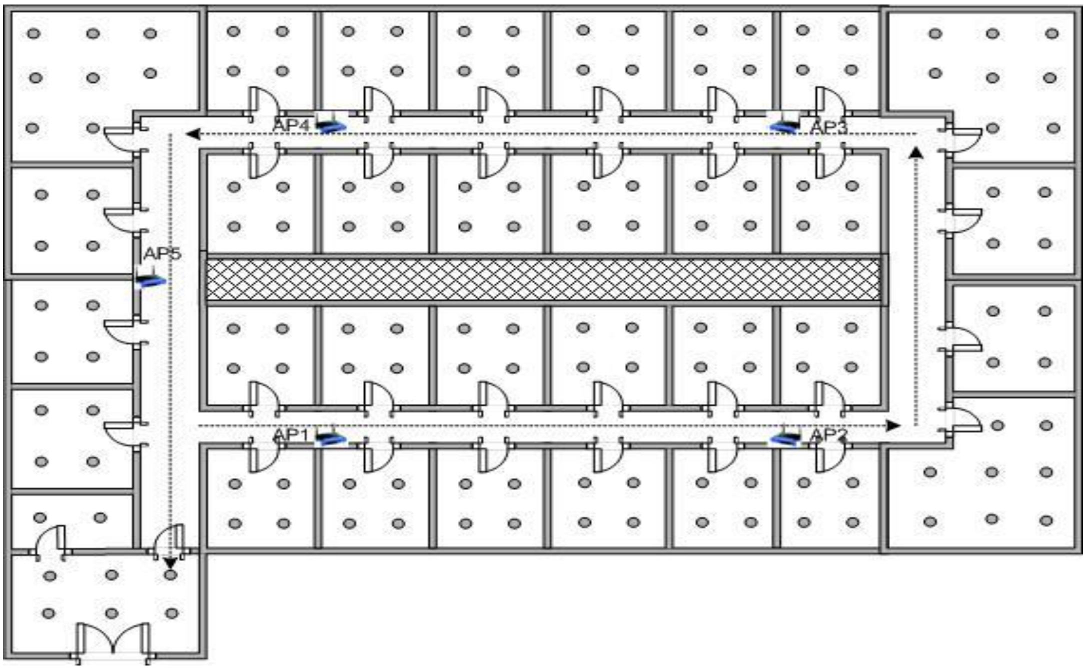


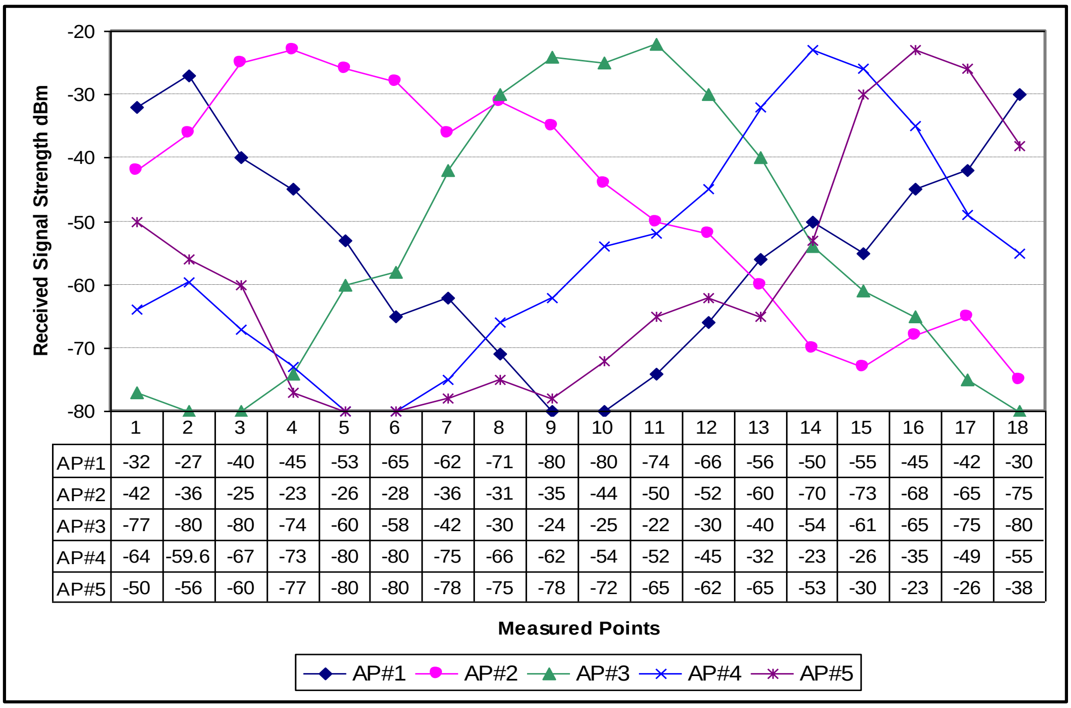
Figure 7: Distribution of Access Points and Reference Points on the Building Layout

Figure 8 shows the RSS that measured from each of the five APs which varies as the user walks along the outer hallway of the building in a counter-clockwise direction (Figure 7) summarized by 18 test locations.

The walk begins and terminates from the right corner close to AP#1 to end of the hallway after AP#5. There is a definite trend in the RSS recorded at the five APs as the user walks around the loop. Its clear from the measurements that the signal received from AP is the strongest when the user is close to it and weakest when the user is far away.

For example, it is seen that RSS at the position near AP#1 may approach -27 dBm. As the distance between the measuring position and AP1 increases, the signal is attenuated. However, the signal is attenuated at different rates in different directions to reach the low sensitivity receiving below -80 dBm where the RSS is greatly attenuated because there are many walls absorbing the signal wave.

This strong trend is an indication that using RSS to infer location is a promising approach. The sharp drop at about -80 dBm can be explained by noting that the receiver sensitivity for the WLAN card we used was -82 dBm.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
AP#1	-32	-27	-40	-45	-53	-65	-62	-71	-80	-80	-74	-66	-56	-50	-55	-45	-42	-30
AP#2	-42	-36	-25	-23	-26	-28	-36	-31	-35	-44	-50	-52	-60	-70	-73	-68	-65	-75
AP#3	-77	-80	-80	-74	-60	-58	-42	-30	-24	-25	-22	-30	-40	-54	-61	-65	-75	-80
AP#4	-64	-59.6	-67	-73	-80	-80	-75	-66	-62	-54	-52	-45	-32	-23	-26	-35	-49	-55
AP#5	-50	-56	-60	-77	-80	-80	-78	-75	-78	-72	-65	-62	-65	-53	-30	-23	-26	-38

Figure 8: RSS Measured from Five APs When The User Walks Along Hallway of The Building

Another experiments performed to test the behavior of APs with different average signal strength at the same location. During this experiment, we sampled the signal strength from each AP at a specific location at the rate of one sample per second.

Figure 9 shows the relation between the average RSS from some access points (AP#1 & AP#2) and the percentage of samples we receive from it during a period of 5 minutes.

As shown, the gathered signal from different APs exhibits different characteristics. Since many factors affect signal propagation such as number of people moving in environment, doors opening and closing, and other changes in the environment as discussed above, these can explain such temporal changes shown in the figure.

The number of samples collected from an AP is a monotonically increasing function of the average RSS of AP. Assuming a constant noise level, the higher the signal strength, the higher the signal to noise ratio and the more probable it becomes that the 802.11b/g WLAN card will identify the existence of a packet.

There are some cases in which the signal can be greatly attenuated even when the measuring position is quite near to the AP. The weaker samples reflect this phenomenon.

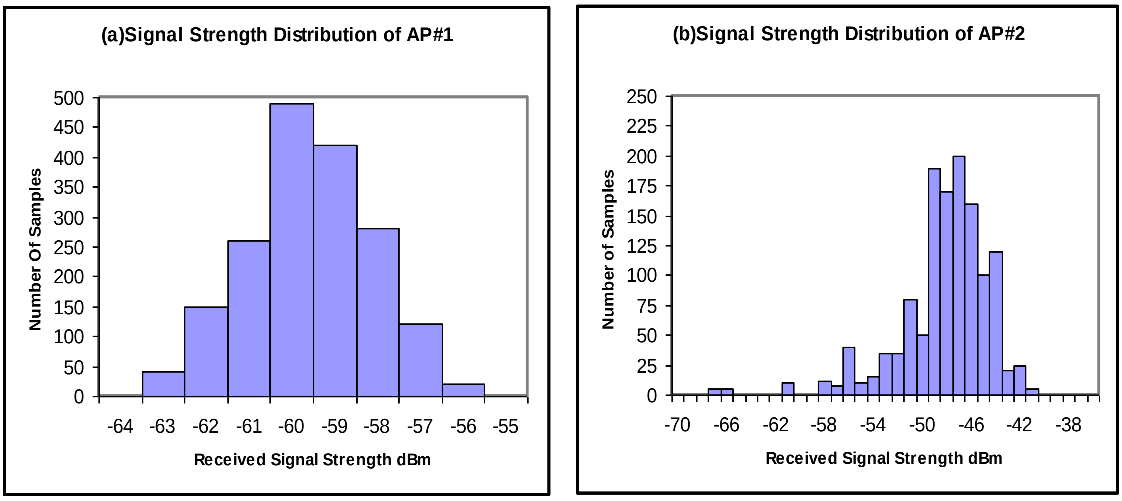


Figure 9: Signal Strength Distributions Measurement of Some Access Points in the Building

The very well distribution of APs in the building layout gives good signal strength for data communication, where the WLAN card sensitivity reads low signals up to -82 dBm but data communication occurs only when the signal strength more than -70 dBm.

From these measurements it can be seen that the r*eceived signal strength (RSS)* is quite stable and consistent over time, with RSS in the range of -63dBm to -56dBm (with a mean of -59.5 dBm) for AP#1 and -67 to -41 (with mean -54 dBm) for AP#2. All of these results are acceptable, because some environment elements such as the movement of people, computer noise, user's orientation (i.e., the direction he/she is facing), and the influence of other radio signals that will change RSS by amounts of the order of 5 to 10dBm.

During the daytime (or working time) period the RSS has a significant fluctuation. On the other hand, at night the experimental situation is ideal where all network was shut down, with very little signal fluctuation because there is no body in the office building except some users at some days, i.e. in most cases outside working time there is no wireless signals and no transmission at all because all devices are shut down.

After checking the distribution and the stability behavior of the RSS in the indoor environments using RF signal of wireless LAN, it is possible now to test the fingerprinting indoor positioning system by checking the positioning system accuracy and the factors that affects the system performance.

To test the accuracy of the indoor fingerprinting positioning system, the fingerprinting points are compared with the location of the real position. The test results have been verified by measuring Distance Errors.

The Distance Error is defined as the spatial distance between the original point to which the data belongs and nearest RP which is reported by the fingerprinting database. Distance Error is used for measuring the precision.

Average Distance Error can be calculated by taking many testing measurements and recording the minimum and maximum Distance Error. Figure 10 shows position error using different RPs densities.

From these experiment tests it is clear that the accuracy of user MU will increase by increasing number of RPs that measured during off-line phase.

For the positioning system on the test building discussed, a 2 meter accuracy can achieved when using about 200 RPs measured from 5 APs and more accuracy may be reached if we use more RPs.

We also varied the number of APs in the test area to study how APs affect system performance. As shown in Figure 11, it is obvious that system accuracy is greatly affected by the number of APs when using 200 RPs. In the scenario in which there are only two APs, the accuracy of the positioning system is rather low.

In general, to achieve an acceptable accuracy, it is better to add more APs in the area. Practically, the results indicate that for each RP position in the area covered by the WLAN signal, there should be at least three APs to get correct RP position measurements for fingerprinting database.

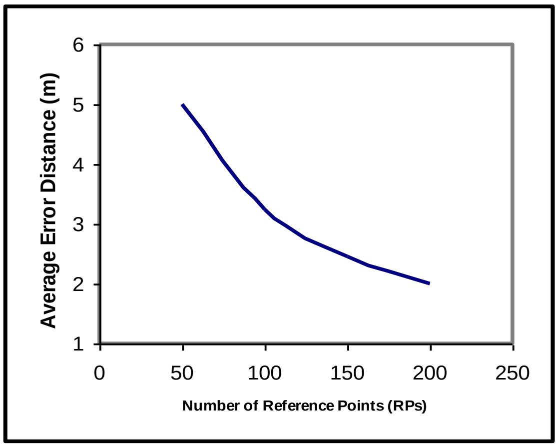
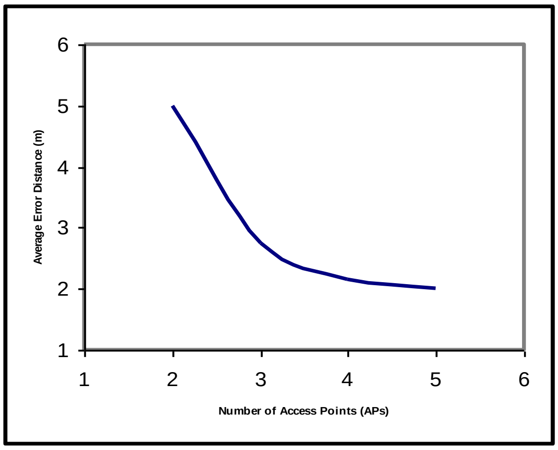


Figure 10: Effects of Reference Points Density



11: Effects of Access Points Number

6. Conclusions

The indoor positioning and tracking system use location fingerprinting technique as a simple approach that can provide location-aware capability for devices equipped with WLAN interfaces.

Compared to other techniques such as angle of arrival (AOA) and time of arrival (TOA), the fingerprinting technique is more effective in indoor due to prevalent multipath effect and non line-of-sight environment that cause inaccurate angle and time estimation.

Although, building indoor positioning system based on WLAN infrastructure, the cost of dedicated indoor positioning systems can be avoided. The fingerprinting positioning technique exploits presumably a unique relationship between Received Signal Strength Indication (RSSI) and an indoor location.

This technique can be deployed in two phases: training phase (offline) in which database of radio map are measured, and positioning phase (on-line) to determine the position of the MU by using pattern matching method called Nearest Neighbor in Signal Space.

The system was implemented and checked on test layout building that has its wireless local area network infrastructure, where the stages for building the system are explained carefully. The hardware requirements and software implementation for user client MU and fingerprinting database server with data collection phase are presented.

From the test results it can be seen that the RSS is quite stable and consistent over time to use in an indoor positioning system based on IEEE 802.11 b/g wireless LAN. Analyzing the experimental results shows that the accuracy and performance of the positioning system depends on the RP density and number of APs in the infrastructure network.

For the testing layout of the test building a 2 meter accuracy reached when using about 200 RPs with 5 APs in the tested layout and more accuracy may be reached if we use more RPs, taking into account it requires at least three APs for each RP to building an indoor positioning system.

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