國立交通大學

資訊科學與工程研究所

碩 士 論 文

在無線區域網路中以訊號交集為基礎之指紋辨識混合定位方法

A Framework Using Fingerprinting for Signal Overlapping-Based Method in WLAN

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中 華 民 國　九 十 七 年 六 月

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摘 要

此篇論文將針對傳統室內定位方式的缺點去改善，並結合兩種傳統以收訊強度為基礎的室內定位不同方式的優點，一方面可以不需要預先大量的測量許多不同位置上的收訊強度，而是利用線上階段的訊號交集範圍的結果來做為訓練資料，另一方面可以隨著時間來增加精準度(降低誤差距離)。更重要的是，將針對訊號波動及障礙物的問題深入探討並設計為提出演算法中的一部份，在此稱作「以訊號交集為基礎之指紋辨識混合定位方法」。最後將經由實際建置觀測無線網路基地台及實作此定位系統來驗證這個方法。在實驗的過程，我們將會討論實際實作在真實環境下遇到的一些問題並比較提出的方法相較於傳統的方法的優缺點。

關鍵字：無線區域網路、室內定位、RSSI 定位、RSSI 三角測量定位、RSSI 指紋辨識定位、RSSI 混合式定位系統

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ABSTRACT

In this paper, we proposed a novel method that contains the advantages of two kinds of RSSI-based localization methods, RSSI Triangulation and RSSI Fingerprinting methods, to improve some disadvantages of traditional RSSI-based localization methods. The advantage of the former is that we could determine the possible region of the wireless device without collecting a large amount of training data and making a great training effort. However, in most case Triangulation method cannot determine the position of the user precisely and usually leads to a larger error distance. As for the latter, RSSI fingerprinting method wastes a lot of time and human resource to collect all possible RSSI in all possible regions. On the contrary, it always gets more precise result. This paper combines the advantage of these two schemes. The proposed scheme doesn't have to pre-collect so much RSSI records and makes use of the results of signal coverage overlapping method as the input of RSSI fingerprinting method in the online phase.

Key Word: Wireless Local Area Network, Receive Signal Strength Indication, RSSI Localization method, RSSI Fingerprinting method, RSSI Triangulation method , Hybrid RSSI Localization System

誌　　謝

首先，我要先感謝我的指導教授在兩年來對我的指導，感謝博士班的學長姐在研究上給了我很多的意見，包含繼偉學長、佳純學姐、子逸學長，以及即將要讀博班的卓政逸工程師，不論實作或是理論上都給了我很大的幫助；還要謝謝碩二的同學們包含家銘、雨芊、秉翰、家維，也在 Meeting 的時候給了我許多寶貴的意見；還有碩一的學弟們像是汎勳、穎昌、釗俊、書倫學弟們。其中我最感謝的，莫過於繼偉，在畢業口試前，陪著我和家銘一起排練，一頁一頁的幫我看陪我聽並思考怎麼表達出我想表達的東西，能不能用清楚的投影片順暢的表達，對於繼偉學長的幫助，我心中真的是不勝感激，有說不出的感謝只能用我最深的敬意向您說一聲：「學長，謝謝您!」

最後，誠如張之藩所說：「要謝的人太多了，不如謝天吧~」

CONTENTS

CHAPTER 1 INTRODUCTION

Localization systems nowadays are widely used in many applications, such as many road guide services, navigation services, and wireless network devices tracking service and so on. Localization systems can be roughly categorized into Indoor Localization System and Outdoor Localization System. Outdoor Localization System mainly consists of GSM Localization System and GPS Localization System [1], while according to the principle the Indoor Localization Systems could be categorized to Angle of Arrival System (AOA System), Time (Difference) of Arrival System (TOA, TDOA System),Receive Signal Strength Indication System(RSSI System). For most part, Outdoor Localization System is used for comparatively wide-range area, such as road guide, navigation or airline navigation, which tolerant error range can be larger (20~100 meter or more). But it's not suitable for indoor environments because the required accuracy of applications is usually higher than the one that we mentioned before. Normally, Wireless Local Area Network (WLAN) is one of the most widely used wireless networks. Since the Angle of Arrival and Time Difference of Arrival methods all need other special hardware which are usually not inexpensive, these methods are somewhat not suitable for normal WLAN localization. Compared to the methods mentioned before, RSSI localization method is relatively better for WLAN environments. We are going to introduce the pros and cons of these method's design principles and the implementation approaches in the following paragraph.

1-1 Issues of Localization

Generally speaking, the requirements of localization can be categorized into four parts. In the first place, accuracy is one of the most important issues of localization. According to the different application of the localization, the requirement of accuracy is also different. Beside, the volume of localization devices should also be adequate, or the huge volume of localization devices will lead to much inconvenience. The localization system should work day and night, in other words, it can work continuously all day long. Furthermore, the refresh rate should also fast enough to meet the needs of the different applications. Last but not the least, the price and easy-to-use are always important issues of localizations.

1-2 Outdoor Localization

Global Positioning System (GPS) is originally developed by the United States Department of Defense uses in the military purpose positioning system, mainly by the outer space part, the ground control part and the user acceptor and so on which are composed of three major parts. The first part is outer space part including highly approximately is 20,200 kilometers, 24 satellites (in 2008 had 29), distributes on the inclination angle 55 degree 6 close circular tracks, the satellite distribution enables on the Earth any place, any time at least to be possible simultaneously to observe to 4 above satellite signals. The second part is ground control part, which distributes by the satellite control center in global composed of certain inspection stations. The user receiver has the main performance, the receive satellite broadcast's signal, and carries on processing to the signal, provides to locates the useful information. As a result of the American armed forces against fear precise localization by the enemy use, will be infiltrated in the initial period localization signal the mixed miscellaneous news to reduce the localization the accuracy, will provide for the folk utilization when its miss distance will be most may to 100 meters, also will be the initial period utilization the reason which will limit. Relieved the signal disturbance completely after 2000, the error only then reduced to 15 meters ~20 meters, but the military purpose and the civil precision still had a dropping variance, the folk use's error still reached about military 10 times. Because the precision increases, makes GPS the civil category to expand, in the past the error was big when only suited for the ships, the large-scale delivery vehicle use, after the error further reduced, continually the common saloon car, even individual user, entered the acceptable scope. But the user enters the building overhang, the lane to make or in the building, because the satellite signal is weaken causes GPS to locate is unable to display effectiveness, must therefore seek other aiding methods.

1-3 Indoor Localization

With the rapid growth of telecommunication and multimedia, the requirements of localization and navigation are increasing day by day, especially at some complicated indoor environments such as airport lobby, department store, fast food multiple stores, library, basement parking lots etc, which often needs to trace or locate the moving terminals in the position of the indoor space. Nowadays, the most popular and widely used wireless network is wireless local area network, WLAN or Wi-Fi. For many issues, we need to locate the user’s position. But due to the restrictions of complicated factors such as locate time, locate precision and multiple environments, comparatively well-defined localization techniques nowadays cannot be make good use of it. Consequently, professionals proposed many solutions of indoor localization such as A-GPS [2] localization techniques, Wi-Fi localization (also called WLAN Localization) techniques, and graphical analysis, signal localization, computer vision localization and so forth. These indoor localization technology may induce as a whole is several kinds, namely the GNSS [3] technology (for example pseudo satellite and so on), locates the technology wireless (wireless communication signal, radio frequency wireless label, ultrasonic wave, light track, wireless sensory element localization technology and so on), other localization technology (computer vision, dead-reckoning and so on), as well as GNSS and wireless localization combination localization technology (A-GPS or A-GNSS).

Wi-Fi Localization (WLAN Localization)

WLAN Localization, one kind of brand-new information acquisition platform, may realize the complex wide range localization, the monitor and the tracing duty in the widespread application domain. But network node owns localization is the majority application foundations and the premise. The current quite popular Wi-Fi localization is wireless confined network series IEEE802.11 of standard one kind of localization solution. This system selects the method which the experience test and the signal dissemination model unify, easy to install, needs the very few base depots, can use the same first floor wireless network structure, the system overall accuracy is high. Finland's Ekahau Corporation [4] developed has been able to carry on the indoor localization using Wi-Fi the software. The Wi-Fi cartography's precision probably in 1 meter to 20 meters scopes, overall, it is more precise than the honeycomb network triangulation localization method. But, if locates which Wi-Fi junction point does the reckoning rely on merely in is recent, but is not relies on the synthesis signal strength chart, is very easy in the floor localization to make a mistake. At present, it applies in the small scope indoor localization, the cost is low. But regardless of uses in indoor or the outdoor localization, the Wi-Fi transceiver can only cover radius 90 meter within the regions, moreover very easy to receive other signals the disturbance, thus affects its precision, locator's energy consumption is also high.

Wireless Sensor Network Localization

Wireless Sensor Network (WSN) Localization is increasingly popular. Advances in wireless sensors have made it possible to construct ad hoc networks using cheap wireless sensor nodes. These sensor nodes are composed of a low power process, an acceptable amount of memory, sensor board and network adaptor. Many common applications are emerging. In WSN Localization, wireless sensors could both be transmitter and receiver to locate the position of the users. In these applications, it is necessary to precisely orient these wireless sensor nodes with respect to a global coordinate system so as to report data which is geographically meaningful.

Wireless Sensor Network Localization presents a new problem in system design. In the first place, the low cost of the wireless sensors nodes facilitates massive scale and comparatively high parallel performance. On the contrary, each wireless sensor node is likely to have limited resources, such as reliability, power source, and only local communication with the modest number of neighboring nodes.

The goal of WSN Localization System is to determine the physical positions of a group of wireless sensor nodes. And the position of these wireless sensors nodes could be global coordinate through the global position system. Because the low price of sensors, users can equip with the sensor to locate the position of the users. Compared to the wireless local area network, WSN Localization Systems can also be deployed over an area that something need to be monitored in. For instance, a large amount of wireless sensor nodes could be deployed in a battlefield to detect the enemy instead of landmarks.

For outdoor localization methods, such as GSM Localization or GPS Localization methods, they are all not suitable for indoor environments. As the paragraphs mentioned above, the satellite signal is weaken for GPS Localization systems to locate indoor devices. Therefore, we must seek other aiding methods.

There are many different indoor environments, for example, WLAN (Wi-Fi, including 802.11a, 802.11b, 802.11g and 802.11n), WSN (Ad Hoc Sensor Network) and so forth. According to the concept of indoor localization could be categorized into Angle of Arrival, Time (Difference) of Arrival, Received Signal Strength Indication. The RSS based positioning system employs the signal intensity to build the distribution map, and compares the signal intensity of transmitters with receivers to determine the location of the users. Because the previous mentioned indoor localization methods in WLAN based on the RSSI still have some disadvantages. For one thing, RSSI fingerprinting method wastes too much time on training phase. In others words, it is inefficient to pre-collect enough RSSI records to match the most possible region from every divide units of the indoor environment. It needs a great amount of human resource to measure RSSI in different indoor environments. Nonetheless, RSSI Triangulation method normally could only determine an overlap region of three or more monitor anchor nodes rather than a specific point. Consequently, in average the error distance of RSSI Triangulation method is larger than RSSI Fingerprinting method. On the contrary, RSSI Triangulation method wastes no time on training phase.

CHAPTER 2 RELATED WORK

There are a number of research papers about indoor localization. We could group these indoor localization systems into three general categories: (1) Angle of Arrival Systems (Angle of Arrival System) [5], (2) Time of Arrival Systems (TOA System)[6], (3)Time Difference of Arrival Systems (TDOA Systems), (4) Receive Signal Strength Indexing Systems (RSSI Systems) [7][8], RSSI systems could be subdivided into two parts, the one is Triangulation method and the other one is RSSI Fingerprinting method [9]. We will introduce these different methods and their problems such as limitations or disadvantages.

2-1. Angle of Arrival System (AOA System)

In the first place, the Angle of Arrival System is using a special kind of directional antenna to locate wireless devices. And this kind of antennas contains a multiple element array in which the exact location of each wireless devices .The basic assumption is that all of the nodes in the network have Omni directional antenna. Every wireless devices of Angle of Arrival System is small but capable of receiving separate signals. Angle of Arrival is defined as the angle between the propagation direction of an incident radio frequency signal and some reference direction that is called orientation. Orientation also represents a fixed direction that the Angle of Arrival is measured is represented in degrees in a clockwise direction from the North. When the orientation is 0^o or point to the North, the Angle of Arrival is absolute degree, otherwise, relative degree as the Figure 1 shown. The point P and point Q are given points with coordinates (x_1, y_1), (x_2, y_2) respectively. And the unknown point A's coordinate (x, y) could be calculated by the time difference with the directional antenna to calculate. In other words, Angle of Arrival System also needs to use time difference of arrival concept to determine the distance of A to given points.

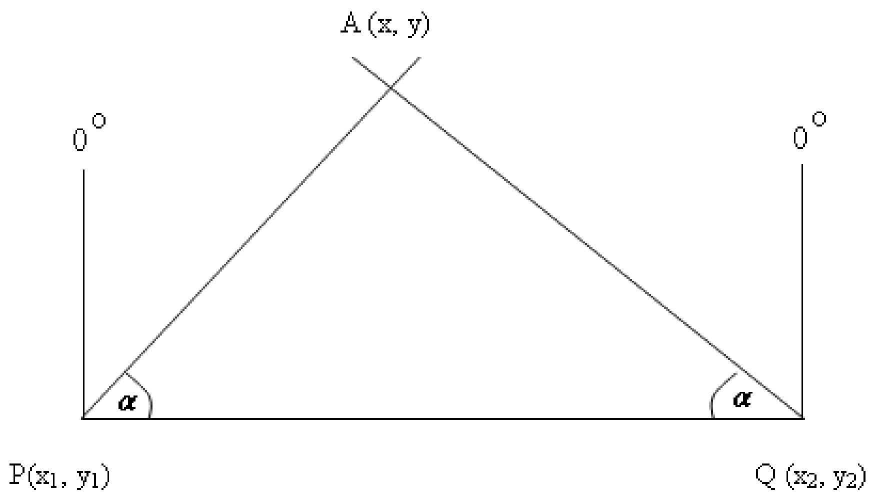


Figure 1: Orientation of Angle of Arrival

One common approach to obtain Angle of Arrival measurements is to use an antenna array on each sensor node. Obviously, only one single directional antenna gives only the bearing not the distance between transmitter and receiver. That is to say, several directional antennas could locate well apart are require in Angle of Arrival positioning. We assume that the beacons have no information about their orientations and the unknowns can detect the Angle of Arrival information between neighbor nodes by using one of the above methods. It is possible to calculate the line-of-sight path from transmitter to receiver. Similarly, we can place another wireless device with directional antenna in different place configuration to repeat the same procedure. The intersection point of two line-of-sight paths represents the location of transmitting wireless devices. Angle of Arrival provides localization services especially suitable for wireless devices that are arranged linearly or areas of sparse wireless devices density. For instance, the straight high way in wide field is very suitable for Angle of

Arrival System.

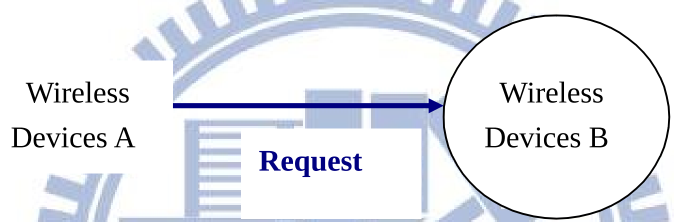
The Disadvantages of Angle of Arrival System

Originally, Angle of Arrival System is used in the localization of the large-scale region, so the default environment between the transmitter and receiver is line-of-sight. It is especially suitable for Angle of Arrival System for the receivers are arranged in a line. But in normal indoor environments, there are many obstacles such as pillars or walls. Angle of Arrival System's accuracy is highly influenced by the obstructions so that Angle of Arrival is not suitable for such environments. The localization concept is based on the angle of received RF signals. Once the signal is affected by multipath effect or other RF signal noise, the accuracy is also decreased. In addition, normal wireless local area network devices such as laptops or access points are not equipped with such special directional antenna. In other words, if the purpose of the system is to locate the positions of wireless devices under wireless local area network, the Angle of Arrival System is also not proper to use.

2-2. Time (Difference) of Arrival System (TOA, TDOA System)

Time of Arrival System locates the moving terminals by measuring the wireless signals sent by these moving terminals. The transmitter of TOA system will send two kinds of signals simultaneously to the receivers. One is ultrasonic waves and the other is the radio frequency signals. The speed of the ultrasonic signal is 331+0.6 t, and the measurement unit of the t is centigrade. The Time of Arrival System require the moving terminals send wireless signals with time stamp to ensure the propagation time from the moving terminal to the receiver. Time of Arrival System makes use of the propagation time between the transmitter and receiver times the speed of the signals to evaluate the distance between them.

In traditional Time of Arrival methods could be categorized into two kinds of methods. The first one is One Way Ranging and the other one is Two Way Ranging. In the first kind of method, measuring distance is to use the difference of Time of Flight (TOF) of signals from two asynchronous transceivers. Once the wireless terminals have synchronized their clock to a common clock, these wireless terminals could adapt the second method to measure location. Figure 2 represents the scenario of using Two Way Ranging to measure distance in Time of Arrival System. And the distance between two wireless devices can be depicted as the equations below:



$$T_{OFA} = \frac{1}{2}[(T_1 - T_0) - T_{REPLY}]$$

$$D_{AB} = T_{OFA} * C$$

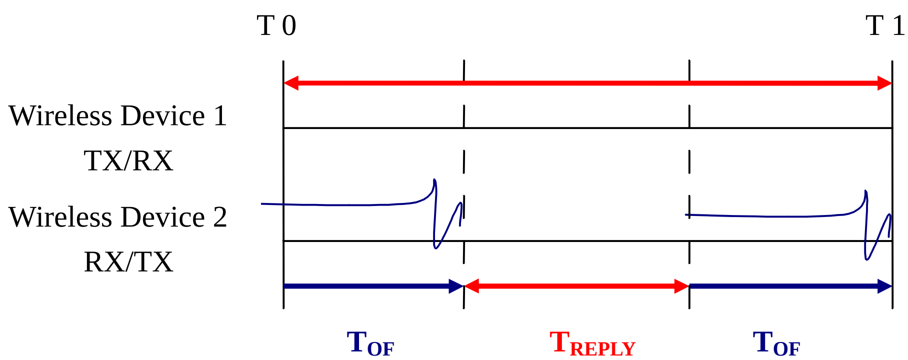


Figure 2: Two Way Ranging of TOA System

In Two Way Ranging of TOA System, the packet switching between two wireless devices is using Time Multiplexed of Half-duplex. This kind of procedure mainly depends on the mechanism that merges localization and communication to calculate the distance. Requestor usually sends a packet containing time information to responder. After synchronizing time clock with responder, the requester could determine the time of flight by sending a packet to show the completion of synchronization. But these two kinds of methods are easily restricted by the specification of every communication protocols, so the ranges that can be measured by TOA and accuracy are also restricted.

Time Difference of Arrival System (TDOA System)

Time Difference of Arrival System is to calculating the time difference between some anchor wireless devices to evaluate the distance based on the Time of Arrival method. In traditional, Time Difference of Arrival makes use of One Way Ranging techniques of Time of Arrival. Under this kind of construction, every isochronous anchor wireless devices implement the measuring distance method of Time of Arrival. Afterwards, we could base on a common reference time of every anchor wireless devices to compute the time difference one another to get the location as Figure 3 shown.

In this method, anchor node needs to re-synchronize the clock by an outer common clock or by broadcasting beacon frame periodically to every terminal wireless device. This beacon frame could be sent from coordinator or a known position terminal and every terminal also knows the distance from the coordinator or a known position to itself. No matter Time of Arrival System or Time Difference of Arrival system, they all needs precisely synchronization clock in their systems, in other words, once the clock is not meet the precision requirement these system will not work well.

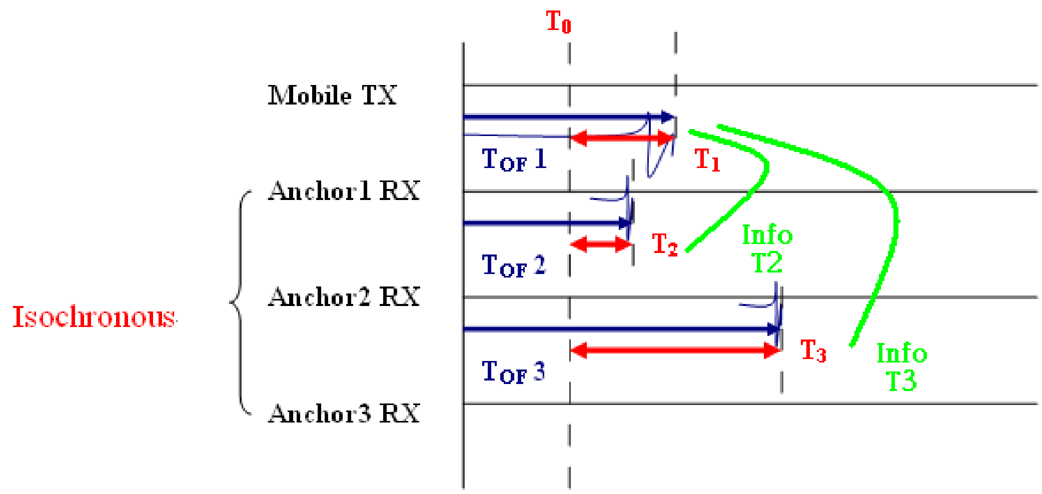


Figure.3 TOA Estimation T1, T2, T3

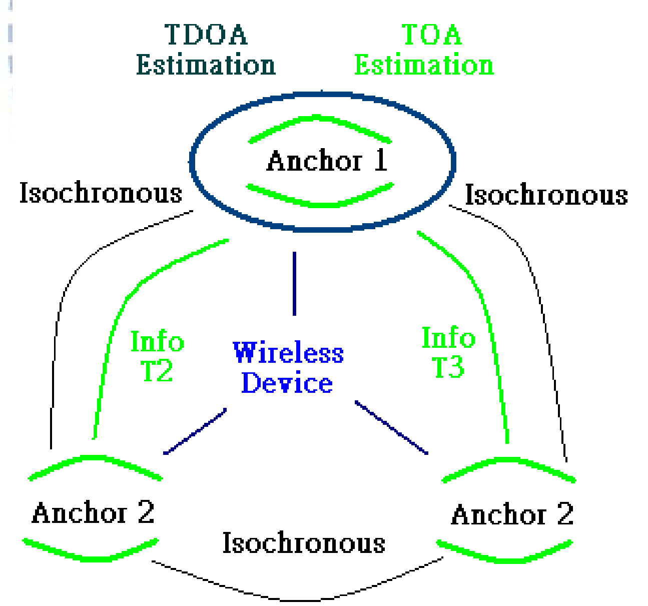


Figure.4 The Working Concept of TDOA

The Disadvantages of Time (Difference) of Arrival System

The accuracy measurements of Time (Difference) of Arrival System are signal-to-noise ratio, frequency stability of the clock, propagation error of radio frequency wave, the speed of response signal by the data source and so forth.

A common drawback of time-based localization scheme such as Time of Arrival Systems, Time Difference of Arrival and Angle of Arrival System all need expensive hardware of special purpose equipped with the user or network infrastructure. Even if only the insignificantly small time error, which will result in a serious faulty result. Under the indoor environments, when the diffraction or reflection makes over the phases of the signal therefore indication deviation from line of sight. That is to say, the influence of multipath effect has a great impact to the accuracy of Time-based of Arrival System. In addition, the influence of multichannel effect on the Time of Arrival System is decided by the phases and amplitude of the reflection wave. In general, owing to the variation of environmental factors, the transient time will vary.

2-3 Received Signal Strength Indication System (RSSI System)

Received Signal Strength Indication is a measurement of the power present in a received radio signal. RSSI [8] is generic radio receiver technology metric, which is usually invisible to the user of device containing the receiver, but is directly known to users of wireless networking of IEEE 802.11 protocol family. RSSI normally uses a byte (0~255) to represent signal distribution from the weakest to the strongest, and RSSI's range could be arbitrary defined by different manufactories. Since the RSSI can aware of a lot of information about the quality of signal, including the relative distance between transmitter and receiver, the propagation model of the radio frequency signal, the situations that affected by other wireless signals and so forth.

a. RSSI Triangulation Method

Compared to the outdoor topology search, indoor topology search needs to locate the wireless devices by using more accurate methods. In order to collect information of the wireless local area network, we develop the indoor topology search system which is used to monitor the wireless network and track the connections between wireless devices. If we want to locate a wireless device, we at least need to place three monitor nodes to calculate the position of the wireless devices. In wireless localization fields, there are two kinds of popular localization methods by receive signal strength. One is triangulation method and another is wireless fingerprinting. In indoor localization system, we deployed three monitor access points (MAP) in a floor which can collect Receive Signal Strength Indication (RSSI). We could translate the received strength to geometric relative distance. In addition, we calculate the coordinate of the wireless devices by many localization methods in the scale of the map. These methods are going to be introduced in the following paragraphs.

Base on the received RSSI from our three or more monitor access points to determine all the wireless devices under specific floor. In the following paragraph, we will use formal form to define the problem with mathematical solution so-called RSSI Triangulation Method to solve the problem.

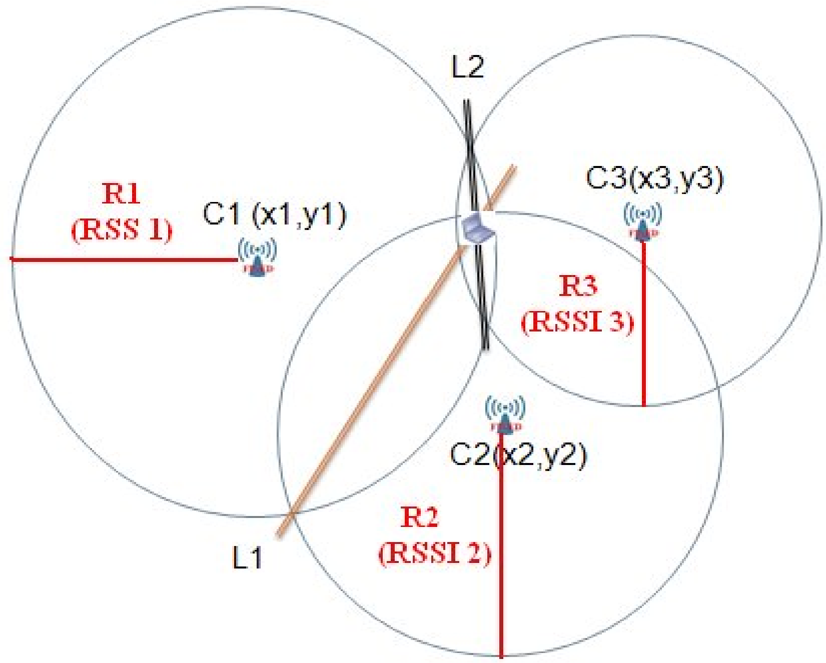


Figure5. The Scenario of RSSI Triangulation Problem

Triangulation Problem Formulation

- ☐ *Input: Coordinate of Monitor Access Points (MAP)*

  (x1, y1) (x2, y2) (x3, y3)

  Receive Signal Strength Index of 3 MAPs

  RSSI1, RSSI2, RSSI3

  Corresponding to distance from goal to 3 MAPs

  R1, R2, R3

- ☐ *Output: Coordinate of Wireless Devices (x , y)*

In the first place, we need to limit the distance between two center points of two circle is between R1+R2 and |R1-R2|, or two circles will have no intersection are even no intersection point.

- ☐ Limitation : |R2-R1|<= C1C2 <= R1+R2

  [Two Circles have 2 intersections]

☐ Equation of three Circles:

C1: $(x - x1)^2 + (y - y1)^2 = r1^2$

C2: $(x - x2)^2 + (y - y2)^2 = r2^2$

☐ The Intersection Line Function

L1: Intersection Line of C1, C2

L1: $2(x2-x1).x + 2(y2-y1).y = (x2^2-x1^2) + (y2^2-y1^2)+(r1^2-r2^2)$

In the same way, L2 can also be described.

☐ Limitation : |R2-R1|<= C1C2 <= R1+R2

[Two Circles have 2 intersections]

☐ Equation of three Circles:

C2: $(x - x2)^2 + (y - y2)^2 = r2^2$

C3: $(x - x3)^2 + (y - y3)^2 = r3^2$

☐ The Intersection Line Function

L2: Intersection Line of C1, C2

L2: $2(x3-x2).x + 2(y3-y2).y = (x3^2-x2^2) + (y3^2-y2^2) + (r3^2-r2^2)$

☐ The Equation of Circles

C1: $(x - x1)^2 + (y - y1)^2 = r1^2$

$\Rightarrow (x^2-2.x.x1+x1^2) + (y^2-2.y.y1+y1^2) = r1^2$ -(1)

C2: $(x - x2)^2 + (y - y2)^2 = r2^2$

$\Rightarrow (x^2-2.x.x2+x2^2) + (y^2-2.y.y2+y2^2) = r2^2$ -(2)

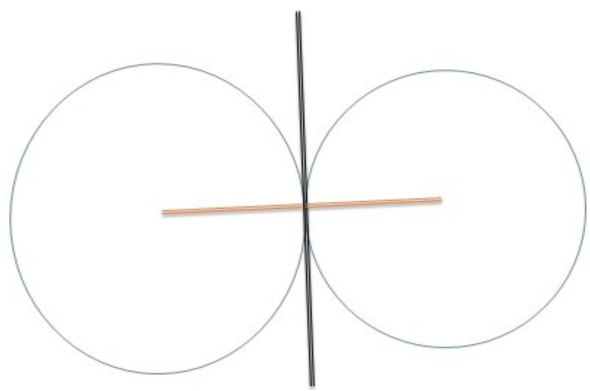
(1) - (2)

$2(x2-x1).x+2(y2-y1).y=(x2^2-x1^2) + (y2^2-y1^2) + (r1^2-r2^2)$

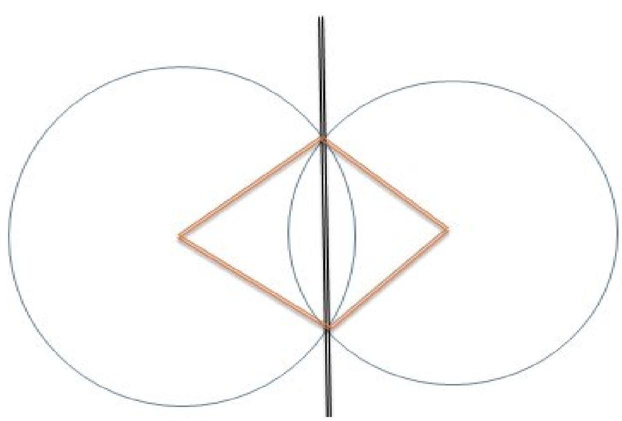
☐ The Intersection Line has different meaning of 3 different cases

Case 1 : No intersection

Case 2 : Common Internal Tangent



Case 3 : Two Intersections



☐ Use Chroma Formula to solve the intersection (x , y)

$$x = \frac{\triangle x}{\triangle} \qquad y = \frac{\triangle y}{\triangle}$$

$$\triangle = 4 \begin{vmatrix} x2-x1 & y2-y1 \\ x3-x2 & y3-y2 \end{vmatrix}$$

$$\triangle X = 2 \begin{vmatrix} (x2^2-x1^2)+(y2^2-y1^2)+(r2^2-r1^2) & y2-y1 \\ (x3^2-x2^2)+(y3^2-y2^2)+(r3^2-r2^2) & y3-y2 \end{vmatrix}$$

$$\triangle Y = 2 \begin{vmatrix} x2-x1 & (x2^2-x1^2)+(y2^2-y1^2)+(r2^2-r1^2) \\ x3-x2 & (x3^2-x2^2)+(y3^2-y2^2)+(r3^2-r2^2) \end{vmatrix}$$

Note :
1. $\triangle = 0$ ⇔ no solution
2. $\triangle\ != 0$ ⇔ one unique solution

b. RSSI Fingerprinting Method

A bunch of radio frequency signals to receiver should be pre-record into data base as the feature of specific region. Just like a person record his fingerprint in the data base. RSSI Fingerprinting Method consists of two phases, training phase and online phase. The training phase is also called offline phase, and it often wastes a lot of time and human resource. Because APs that satisfy the 802.11b/802.11g standards will periodically send a special broadcasting packet called beacon to retrieve the signal strength and store into data base. Generally speaking, there are many methods to match the most possible position according to the pre-collected data, such as neural network, Fuzzy system [10], Subspace technology [11], Hidden Markov Model [12] and so on. On the contrary, it can eliminate the obstacles or other indoor RF-based signal effects, such as attenuation, multipath effect, and so on.

The most well-known system that is based on the RSSI Fingerprinting Method is the RADAR System [9]. The RADAR operates by recording and processing signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest. It combines empirical measurements with signal propagation modeling to determine user location and thereby enable location-aware services and applications.

CHAPTER 3: LOCALIZATION ALGORITHM

The current wireless local area network localization scheme mainly based on the RSSI, we propose a scheme that could combine the advantage of two kinds of traditional RSSI based methods, triangulation method and RSSI fingerprinting method. If we only care about the accuracy of localization, the RSSI fingerprinting method is more accurate and much more fault-tolerant than RSSI-based triangulation method in average for the time being. Nevertheless, RSSI fingerprinting method wastes too much time to collect all possible RSSI data at the indoor environment in offline training phase. On the contrary, the advantage of triangulation method is exactly no demand for offline training, we only need to do preliminary work once. So it's high time to design a new scheme to merge the advantage of these two methods; we called it Hybrid Overlapping-based Algorithm (HOF Algorithm).

Hybrid Overlapping-based Algorithm (HOF Algorithm) is based on the signal coverage overlapping to determine the possible area of the wireless devices, and take the three (or more) monitor access point's RSSI record as the fingerprint value of these possible areas. On the other hand, because we have known the type of wireless devices, we could categorize the wireless devices into two kinds. The first kind is access point and the second kind of wireless devices is moving station, such as notebook, PDA, smart phone and so on. We could simultaneously make use of static analysis for access points and dynamic analysis for moving stations. Static analysis means the wireless access points normally will not move due to the limitation of power supply and network resources. Therefore, even if the fluctuation of RSSI we still could collect the range of the fluctuation corresponding to some region of the environment.

3-1. Preliminary

Because the most significant advantage of RSSI-based triangulation method is that the method has no need to waste any time in training phase. The method only needs to determine a RSSI to geometric distance table. Ideally, if there are no obstacles between the transmitter and receiver, that is to say, no obstacles between the monitor access point and the moving station. But in real environments, the signal strength will be affected by many effects, such as signal refraction, signal diffraction, signal reflection, multipath effect and so forth. In the first place, an indoor noise model which is called Floor Attenuation Factor [8] (FAF) is adopted to eliminate the influence of signal multipath effect, signal attenuation and so on. The equation shows the result of Floor Attenuation Factor.

$$P(d)\,[dBm] = P(d_0)[dBm] - 10\,n\log\left\{\frac{d}{d_0}\right\} - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW >= C \end{cases}$$

- P(d) : the signal strength at distance d
- n : the rate at which the path loss increase with distance
- d_0 : the distance of the reference point
- C : the maximum number of obstructions (walls) up to which the attenuation factor makes a difference
- nW : the walls between Transmitter to Receiver

This model provides a flexible solution to solve the influence of indoor obstacles. Although it cannot solve the entire phenomenon that the unstable signal produced, yet it still gives a quantitative method to eliminate the problem. But in real environment, the factor that may have an impact on the RSSI is much more complicated than the model mentioned before. For example, the signal attenuation of the angle between the transmitter and the receiver cannot be precisely calculated by this model. And the signal attenuation phenomenon by these effects cannot also be measured. By the way, let’s see the two cases in the following paragraphs.

Case 1: Influence of Multiple Floors

Sometimes moving station may in the position that may cause monitor access points to calculate a error position, such as determining at a fault floor. For another case, once the station is near the window, its signal may be received by different floors. It will cause a problem, which floor it located?

Owing to these special cases, a solution to will be proposed to solve such problem. In the first place, we concentrate on the moving station is near the window as the Figure.6 shown.

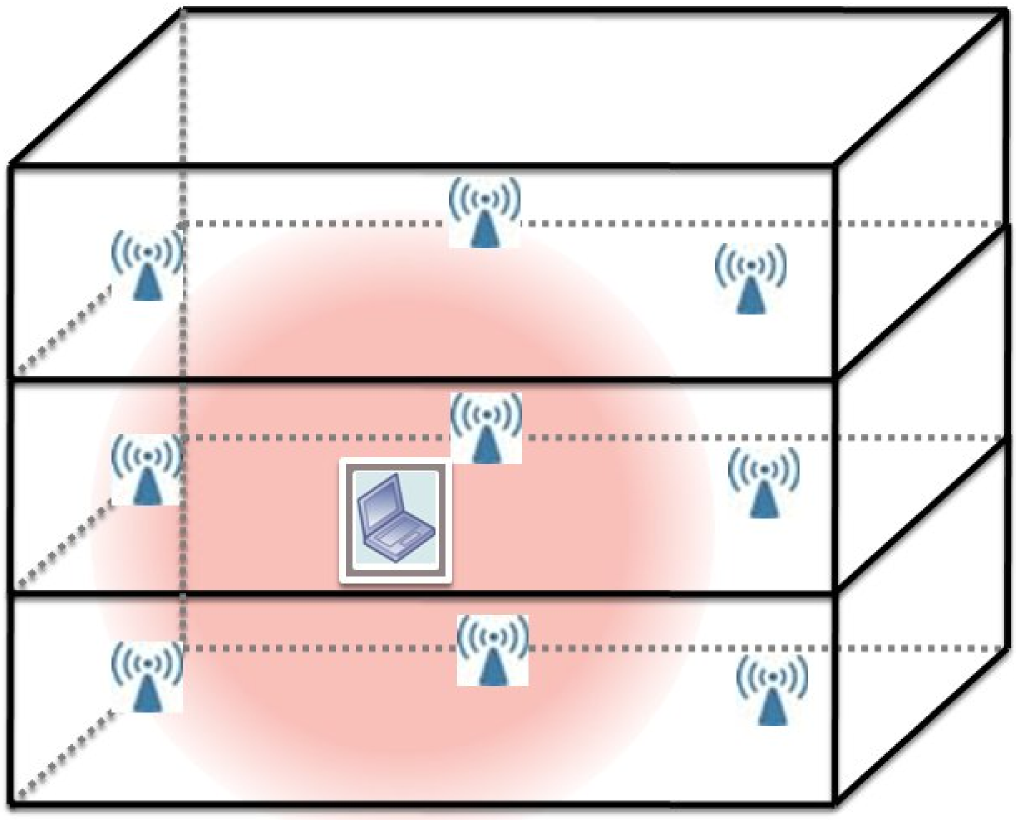


Figure.6. The Moving Station is Near The Window

Proposed Solution

The monitor access points could be deployed in similar shape in order to collect uniform signal strength. Once the wireless devices are close to the window, the wireless device has great probability to be received by multiple floor monitor access points. In order to solve this problem, these monitor wireless devices that have receive this wireless devices of different floors can be ranged by the RSSI. If the monitor access points are on the same floor of the wireless device, the RSSIs of the same floor have more chance to receive stronger RSSIs. After receiving all monitor access points of different floors that can hear the wireless device, these monitor access points could be ranged by RSSI. That is to say, among all monitor APs, select those with RSSI values higher than the average. The floor of the monitor access points that belong to half of the stronger RSSI finally could be chosen.

Case 2: Stair Well

The HOF algorithm will firstly determine which floor the wireless devices are, but in some special cases, the wireless devices are neither in the upper floor nor in the lower floor. That is to say, the wireless devices are in the stair wells of the building. For monitor access points, if the wireless devices can both be listened by the monitor access points of upper and lower floor, this kind of situation as “In-Between State” could be defined just like the Figure 7 shown.

Figure.7 Stair Well of the Building

Proposed Solution

Two methods are proposed to solve this kind of problem. The first solution is use the history of previous localization result. All positions of wireless device could be recorded according to the indoor topology. If the previous calculated location of wireless device is near the stairs, then the next time both monitor access point of upper floor and lower floor either cannot detect this wireless device or both can detect the wireless device with more or less RSSI. Because the previous location is near the stair well, the next position may have great possibility to be in-between state.

Another solution is to place a Monitor AP in all possible stair wells. In other words, a monitor AP could be placed in all stair wells before starting to localization. If the RSSI is especially the biggest than those of other the stair-well APs, the device must be in stair well. But on the contrary, it wastes many hardware resources on the monitor access points.

Oscillations of RSSI Signals

In reality, the RSSI signal represents a range of areas that the wireless devices may be. Ideally, all the possible positions that have equal RSSI to the monitor AP are a circle as the Figure.8 shown

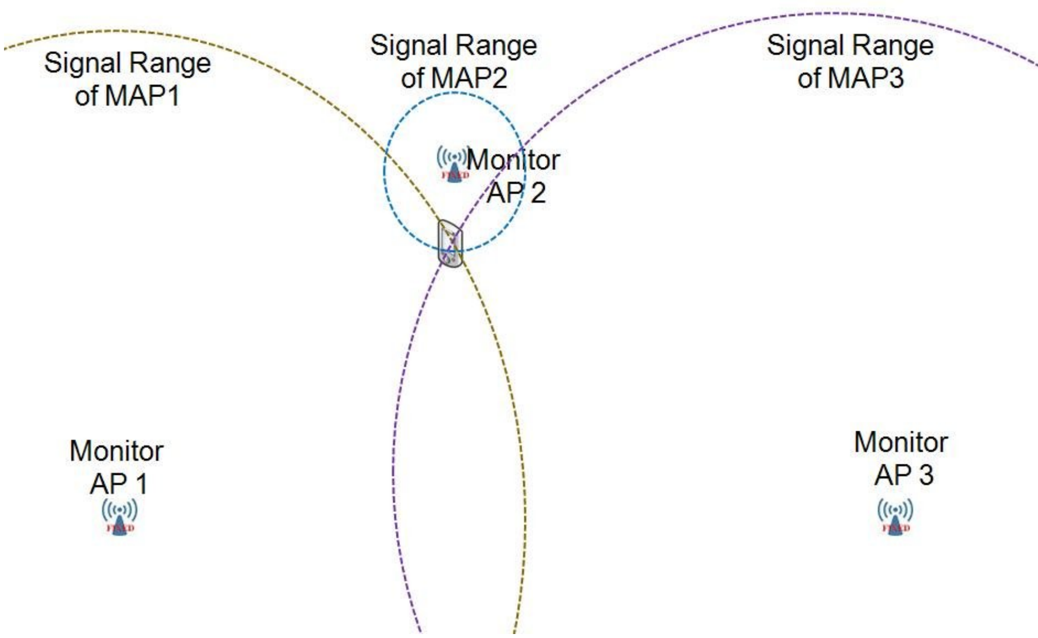


Figure.8 the Most Ideal Situation of Signal Overlapping

But owing to the attenuation of RSSI signal and many obstacles in the indoor environments, the real range of receive signal strength is an abnormal curves as the

Figure.9 shown.

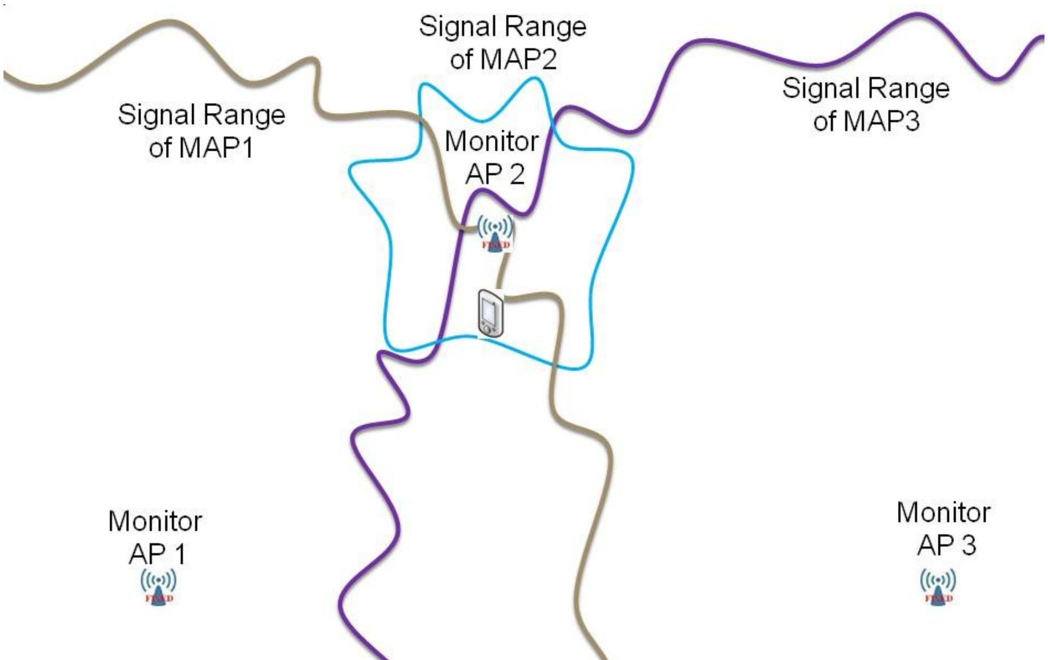


Figure.9 Real Range of RSSI of 3 Monitor APs

Consequently, in order to evaluate the influence that the obstacle will produce, the experiment should be design to measure how much influence that the obstacles made. And the result would result in such abnormal circle. An experiment to measure how much the effect of single wall should be designed. Firstly, a monitor access point place is beside the wall and on the other side of the wall, the wireless devices is place in different angles. For the sake of precisely measuring the signal attenuation by the obstacles through field experiments, the wireless device could be placed at different angles from 0^o to 180^o every 10 degrees as the Figure.10 and Figure.11 shown.

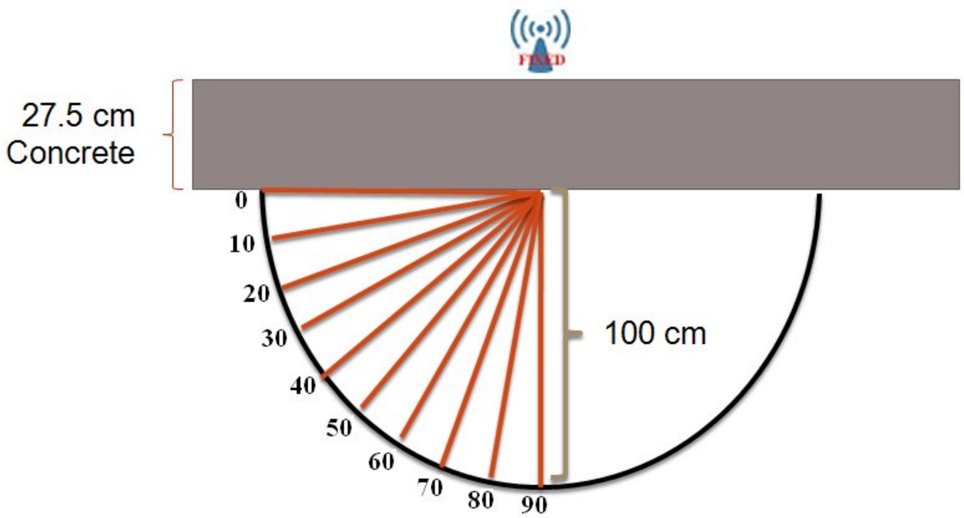


Figure.10 Place the Wireless Device at Different Angles with Radius 100 cm

Besides, the effect of different angle could be measured as the Figure.11 shown. The signal strength of 0^o is use as a datum to compare signal strength from 0^o to 90^o every ten degrees. In addition, we reversely take 90^o as a datum to compare signal strength from 90^o to 180^o every ten degrees as the Figure.13 shown.

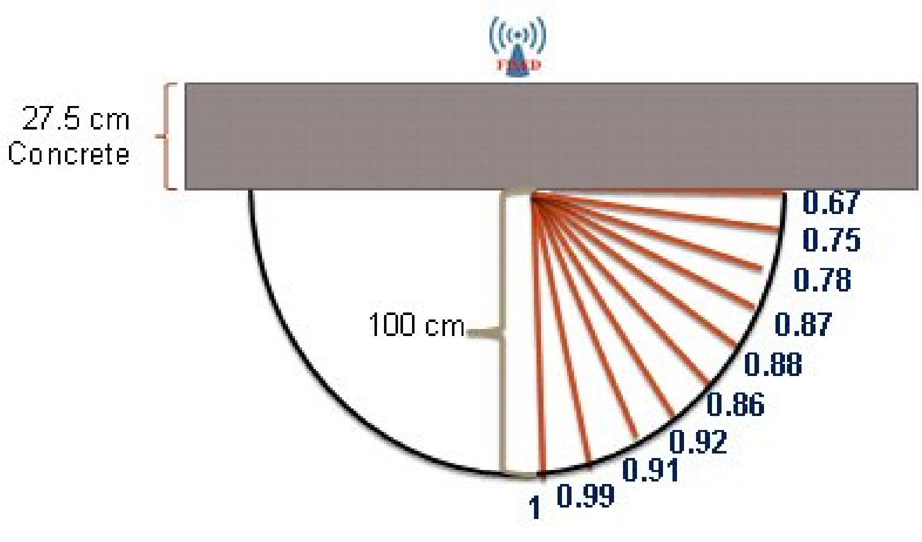


Figure.11 Take the Signal Strength of 90 degree as Datum Point

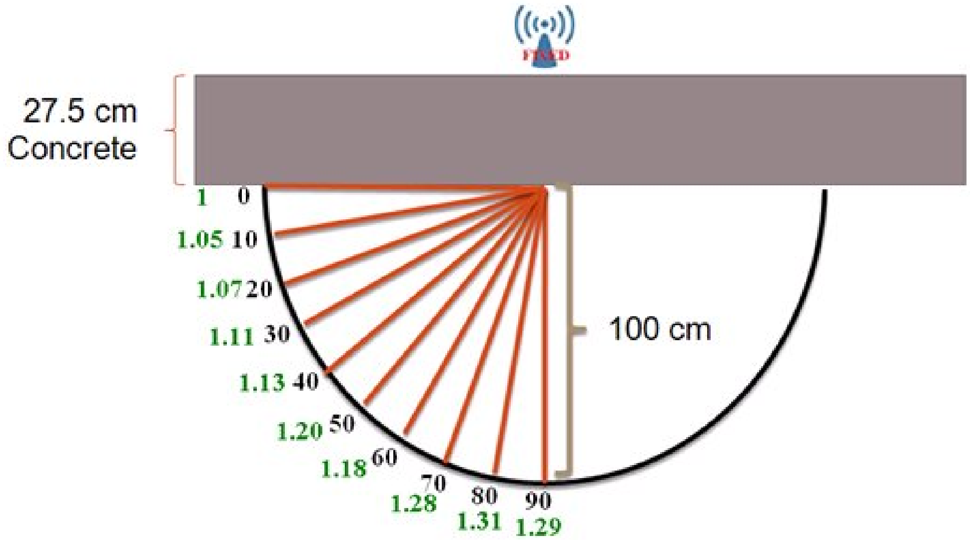


Figure.12 Take the Signal Strength of 0 degree as Datum Point

After measuring the effect of one single wall made of 27.5cm-concrete wall from different angles, an important conclusion is reached that signal strength through one single wall at different angles will decrease at most 31 %~ 33%. In average, the signal strength will decrease about 12%~15%. The experiment let us know how much effect the single wall made of 27.5cm-concrete wall will not make a great impact on the signal strength. In other words, these walls could be simplified since how much effect it would make has known by experiments.

Because our method is based on the signal overlapping to implement RSSI fingerprinting in indoor environment, the map has to be divided into the appropriate size. Due to the sensitivity of our experiment devices, the least distance that can make the RSSI change is about 1.5 meter. For the simplicity of implementation, the indoor map could be divided into uniform grid that we called Divide Unit (DU) in this paper as the Figure.13 shown.

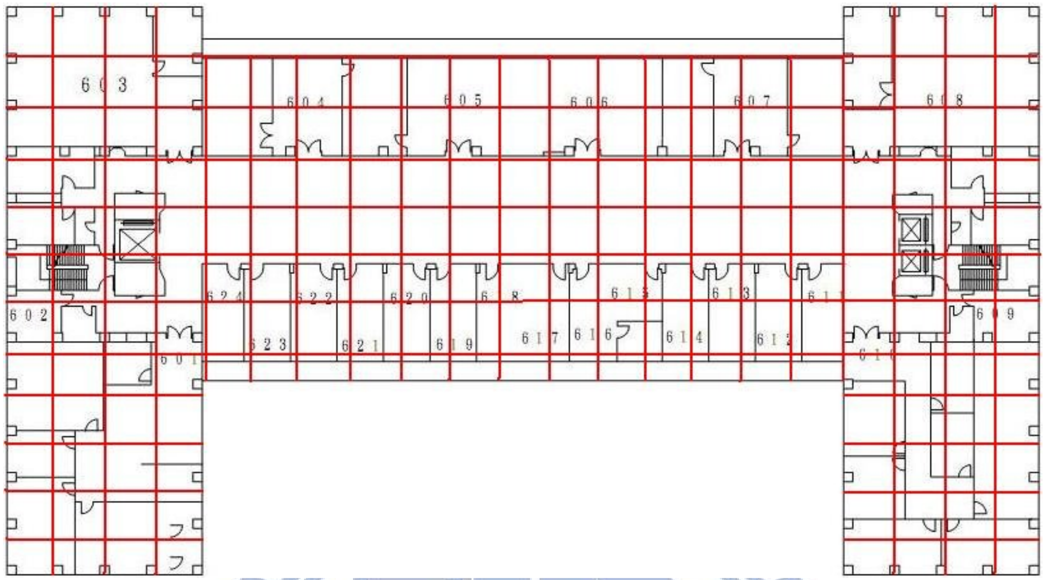


Figure.13 Divide the Map into uniform 1.5m x 1.5m Divide Unit

From the reasons given above, many problems have to be solved in real environment to make the more accurate localization results. So, in the following paragraph, a novel scheme according to the phenomenon that the indoor obstacles will produce would be produced. Our algorithm is to solve these problems that the related papers have not totally solved. Our method only needs online phase and let the program to learn without manually collecting the information from the environment.

3-2. Observatoin

The proposed scheme is based on the Triangulation method, so there is one thing that needs to check at first. Is the wireless device is under the intersection of three monitor access points? We have tried to do experiments to verify this idea. Through experiments, devices locate in the intersection of signal range of monitor access points with high possibility (>95%) as the Figure 14-1 shown below.

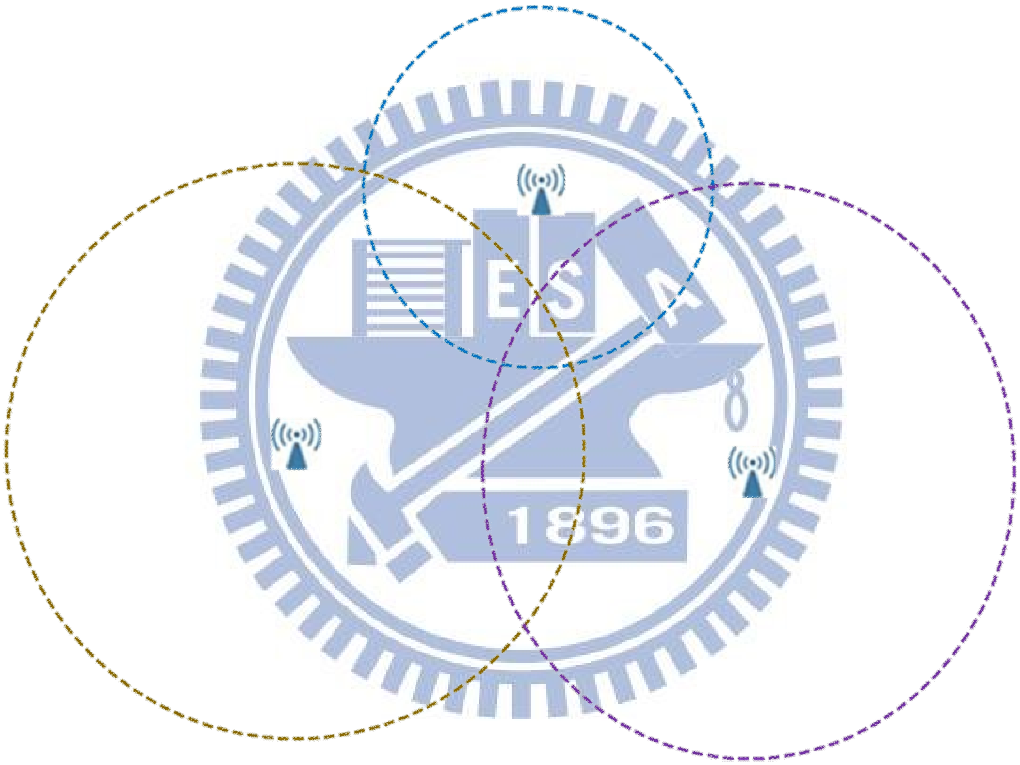


Figure.14-1 Devices locate in the intersection with high probability

After checking the wireless devices is under the intersection of signal range of the three monitor access points, we could use the fingerprinting method in the intersection with the information of our indoor map to improve the accuracy of localization as the figure 14-2 shown below.

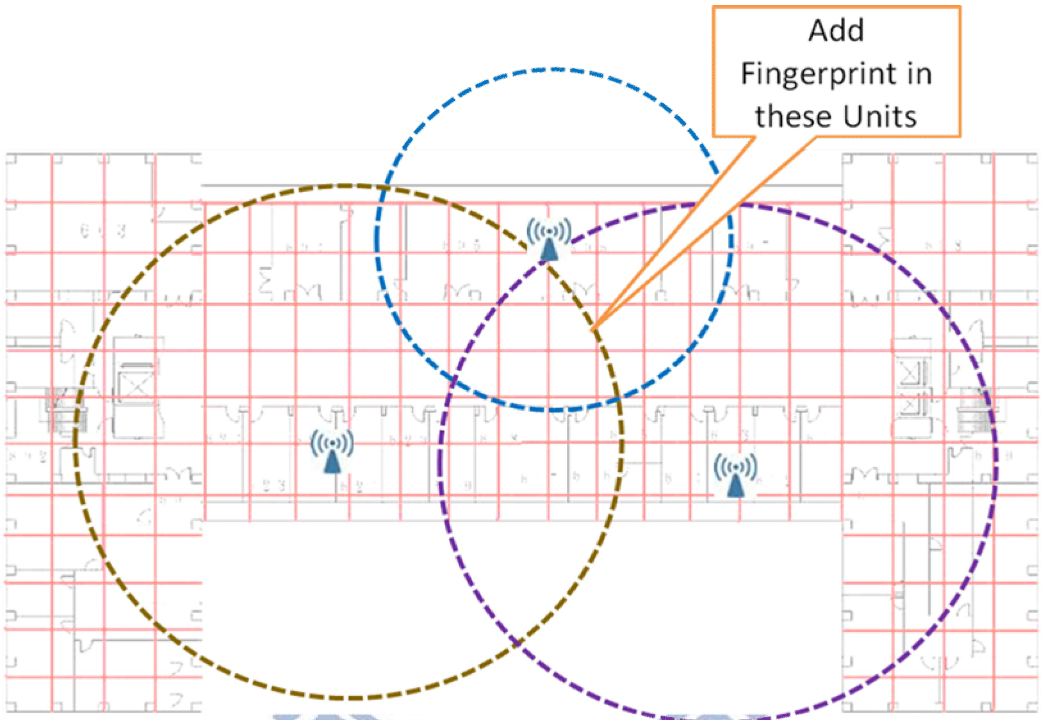
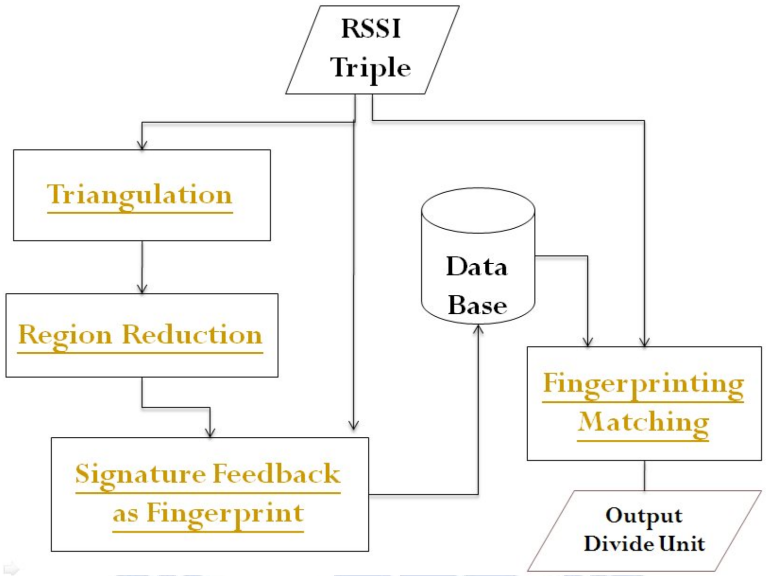


Figure 14-2. Add Fingerprint in the divide units of intersection of 3 monitor APs

3-3. Proposed Scheme Architecture



The picture given above represents the system architecture of proposed scheme, and the arrow means the **data flow** of our system. RSSI triple will firstly be used to Triangulation and Fingerprinting Matching, the difference between Triangulation and Fingerprinting Matching is according to the previously collected data enough or not. If the previously collected data is not enough, the system will only work by Triangulation method. Through Triangulation method in most cases, we could reduce the possible area of the devices, which is what we call Region Reduction, then we try to work with Fingerprinting method by the RSSI triple and reduced region together. We called the step as Signature Feedback as Fingerprint. Once the previously collected data is not enough, the system will work both Triangulation and Fingerprinting Matching based on the Data Base and the latest RSSI triple. By the way, two methods are working simultaneously and going to get two different results. But we will only adapt the result of Fingerprint methods owing to the method is generally more accurate than the Triangulation method. The last step is output the most possible divide unit of the device.

3-4.Localization Algorithm

Error Distance: ED

Moving Station: STA

Wireless Access Point: AP

Divide Unit: DU, 1.5 meters X 1.5 meter Square Unit

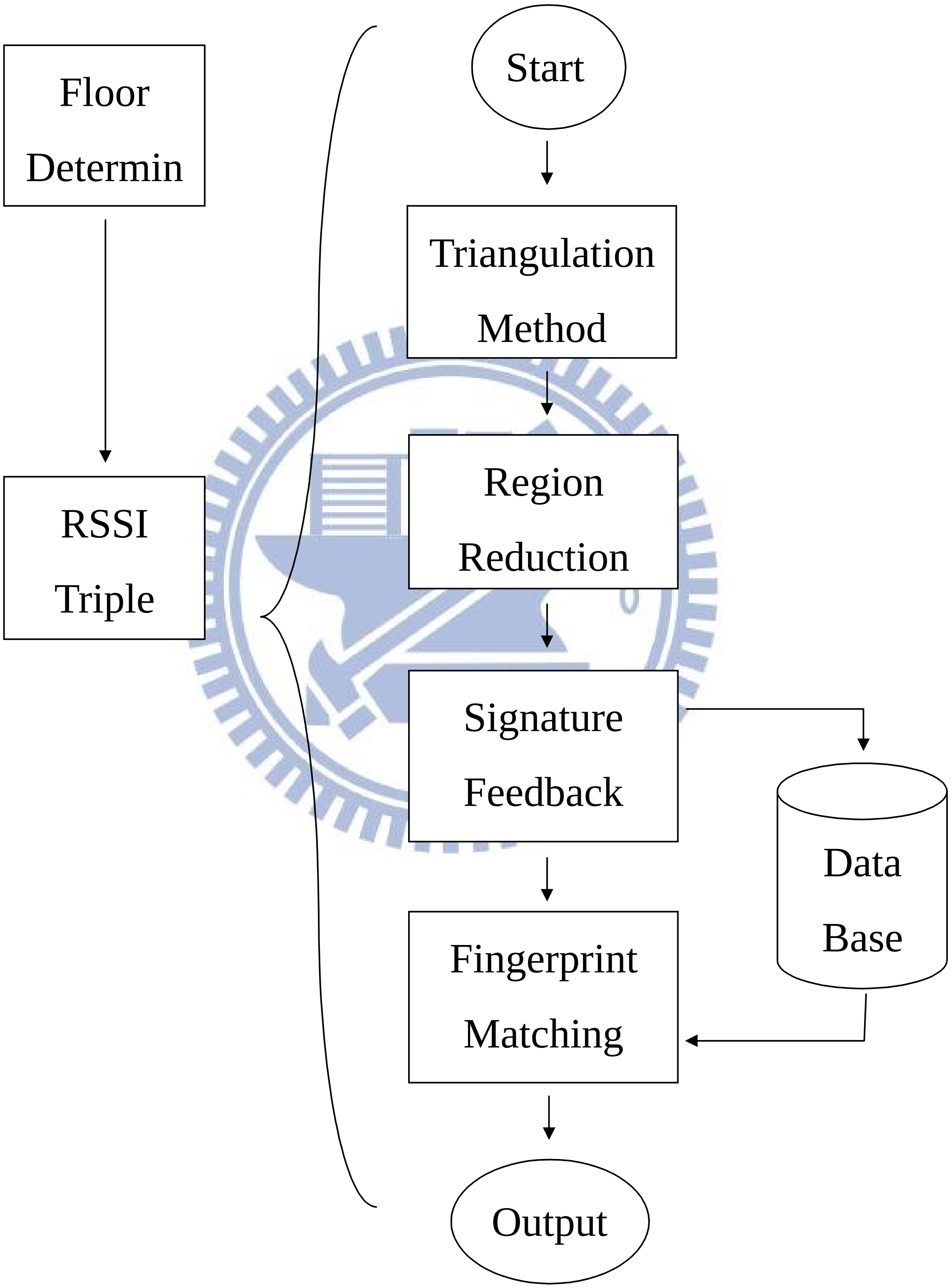
Input Argument:

$RSSI_n$: RSSI of the target measured by AP_n

```
Localization Algorithm (RSSI_1, RSSI_2, RSSI_3)
    Determine which floor the wireless device is
    Triangulation Method
    Region Reduction
    if( Intersection region DU < N) // N : Reasonable DU Num of Intersection ex: 10
        if(exist DU has enough RSSI) // enough means 20 or more RSSI data
            for each (DU that has enough RSSI)
                Find the least difference between & received RSSI_n of stored DU
        else // Start up phase => inaccurate data
            Add RSSI to all divide unit of Intersection of 3 MAP
            Use original (x, y) as output
    else if ( Intersection region DU > N) // too much DU, Signal unstable need adjust
        //Fail data => need to Adjust
        Adjust Algorithm (RSSIn, real (x, y)) // Improve Accuracy by the real pos
            Input the real (x, y) of wireless devices
            Add RSSI to DU corresponding to real (x, y)
    Record final (x, y) and MAC of STA to DB

    // provide admin to manually adjust accuracy
    Adjust Algorithm (calculated (x, y), real pos (x, y), expected error distance)
```

Localization Flow Chart



In order to explain the working process of our proposed method Hybrid Overlapping Fingerprinting more precisely, the diagram illustrates the flow of proposed scheme.

In the first place, the possible region is required to decide that the wireless could be. So the possible position could be found by the range of signal coverage. For any specific monitor access point, the RSSI fluctuates continuously with time. In reality, the range of the same signal strength should be an abnormal circle as the Figure15 shown.

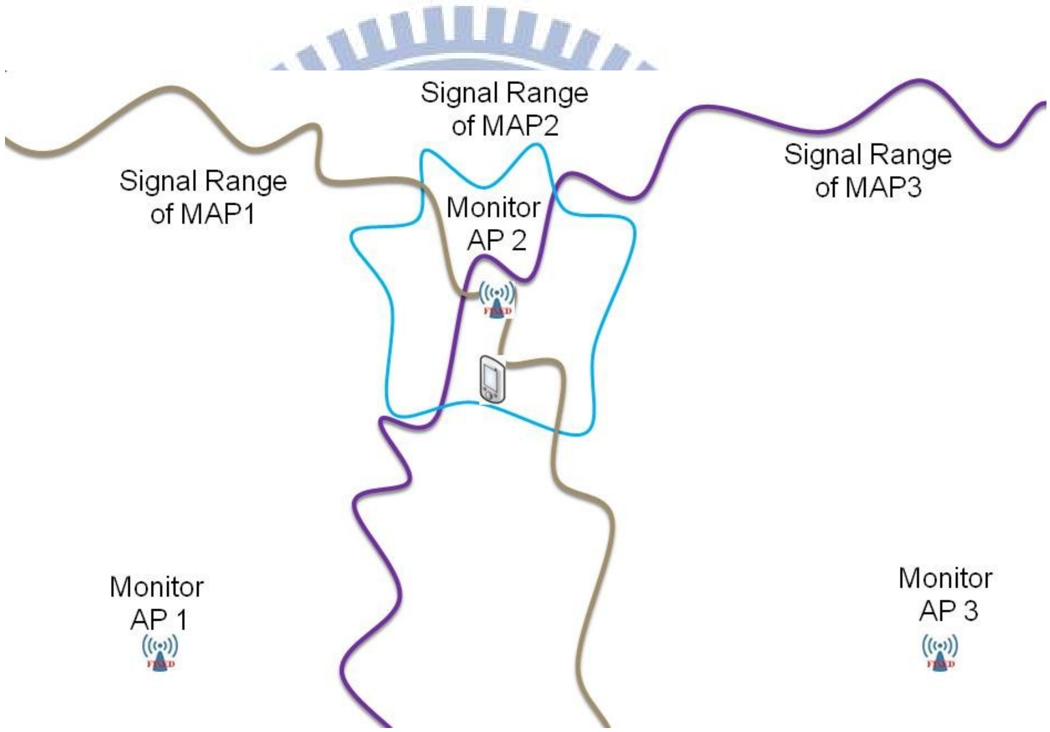


Figure.15 Real Range of Same Signal Strength

However, this kind of intersection is hardly to calculate the intersection of the range of signal. But the signal fluctuation range must have its mean, max variation, min variation. Because the signal attenuation by the wall has been measured, the max attenuation of variation range of these indoor obstacles is also recorded. If the region of max variation intersection range is chosen, the high possibility could be derived to contain the real position of the wireless devices as the Figure.16 shown

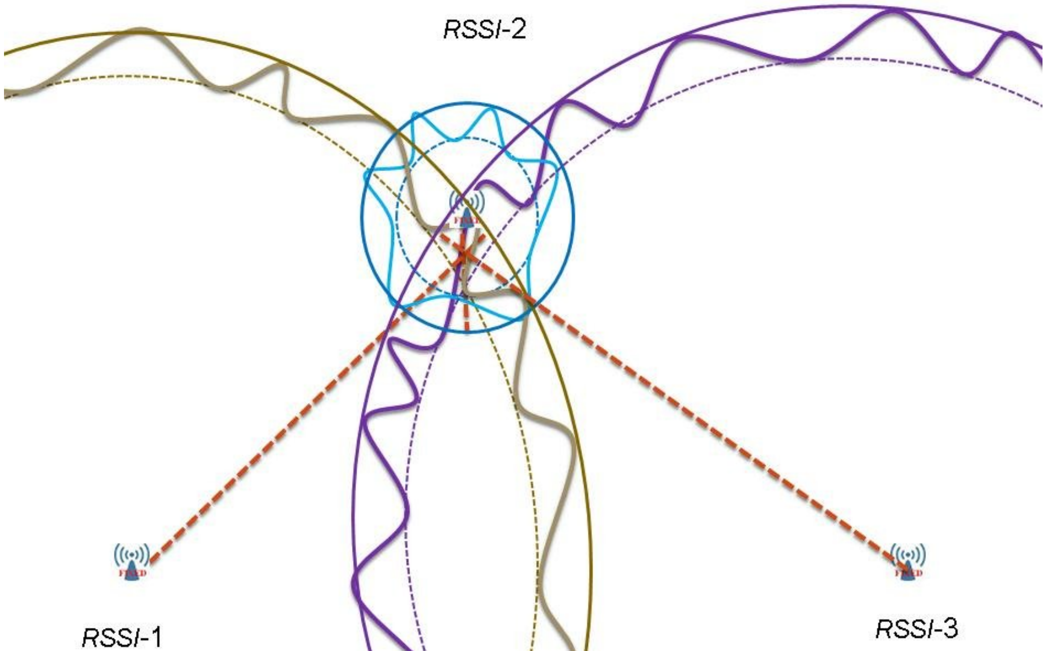


Figure.16 the Oscillation Range of RSSI

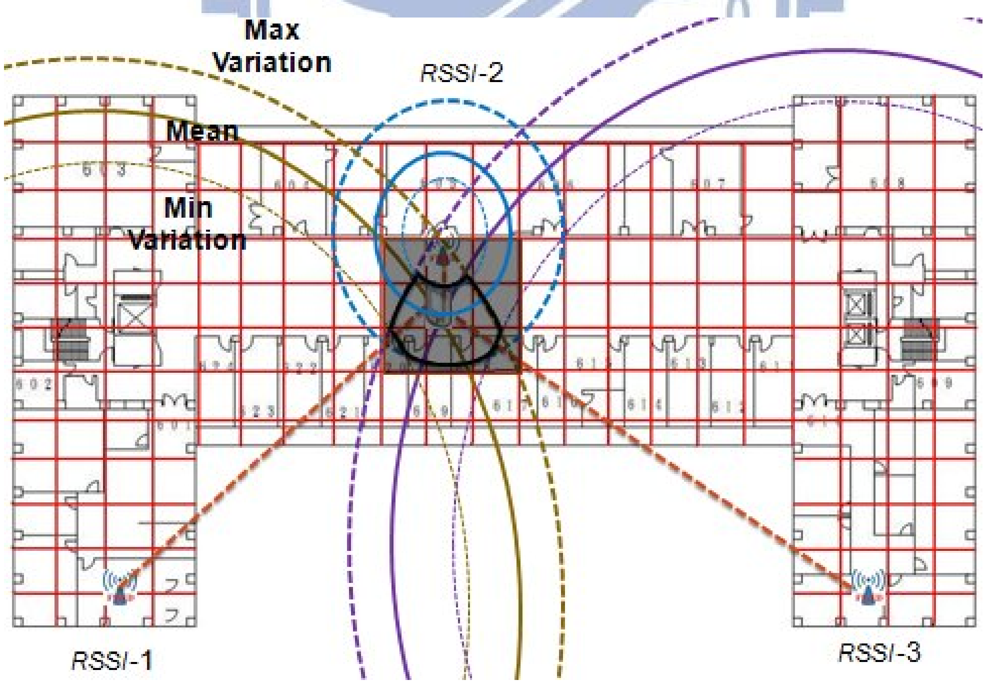


Figure.17 Ideally Max Intersection of Coverage Range of Monitor APs

But for the simplicity of implementation, it’s hardly to use the original intersection to record the RSSI data. Consequently, the intersection of coverage range will be decided and translated to the corresponding divide units as the Figure.18 shown.

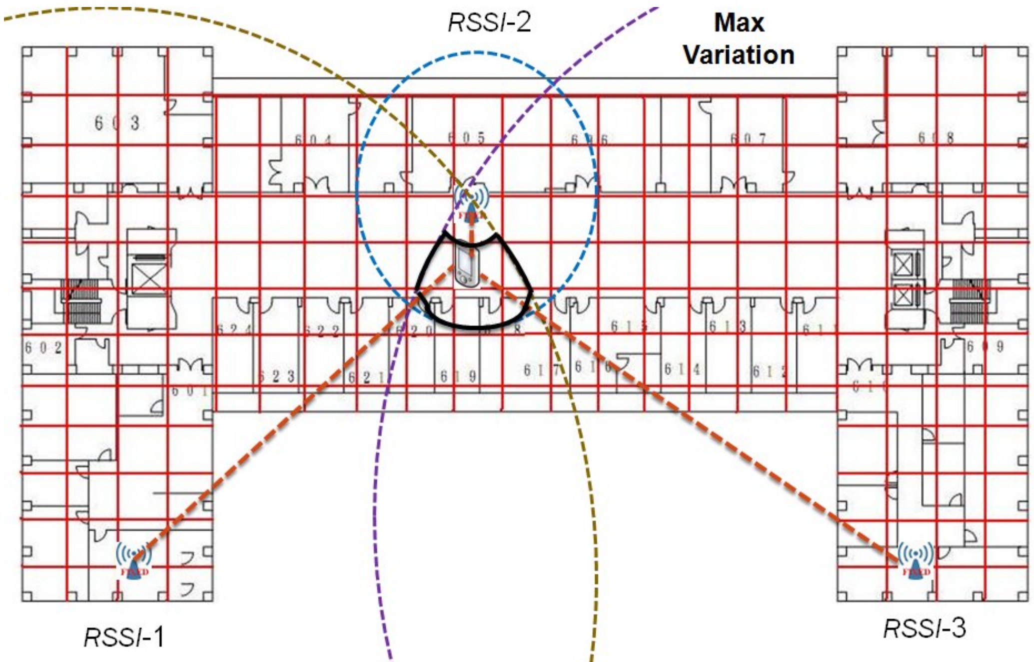


Figure.18 Possible Range of Wireless Devices in Divide Units

Subsequently, the range of intersection is going to be determined. Because once the intersection is too large (over 10 divide units), the coverage range must have great possibility that may lead to larger error distance. So only the data that the coverage range is smaller than the pre-defined threshold is adapted. Then it can be two possible cases. The first case is these intersection units have no enough RSSI fingerprinting data, so the data in these divide units of intersection range have to be recorded. Since the range that the wireless device may be only known, so the RSSI triple is uniformly added to all divide units of intersection. A data structure is designed to store these online collecting RSSI data, the format of the RSSI data is a triple such as (RSSI1, RSSI2, RSSI3), ex: (20, 41, 15). In the beginning of our Hybrid Overlapping

Fingerprinting method, these data from the range of three monitor access points' signal overlapping will be collected and stored these triples in the corresponding divide units.

The second case is that once the intersection of some divide unit's RSSI triple is enough, then many methods could be used to find the most possible position of the wireless device. Just like the Figure.19 shown, the intersection of this time has two divide units that have enough RSSI triple.

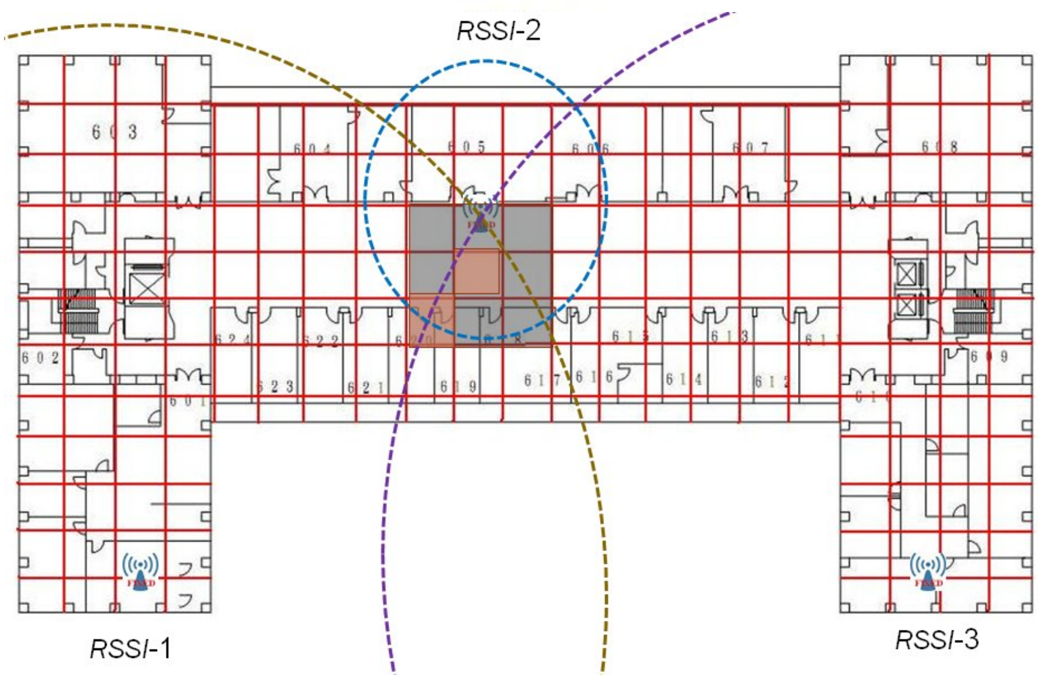


Figure.19 the DUs of Intersection Have Enough RSSI Triples

Firstly, in order to match the most possible divide unit from the divide units that have enough RSSI triples from the previously collected data. Here we use K-Nearest-Neighbor [13] algorithm to match the most possible divide unit. The next step, the only one point will be decided from the divide unit. Because the map information and the type of wireless devices have known, some impossible position of the divide unit could be excluded. In fact, a point from the selected divide unit is randomly selected and then check if the point is on the impossible position such as walls or pillars. If not, the point is our final output. By contraries, if the point is on the impossible position, another point from the selected divide unit has to be randomly selected again until the point is not on the impossible position.

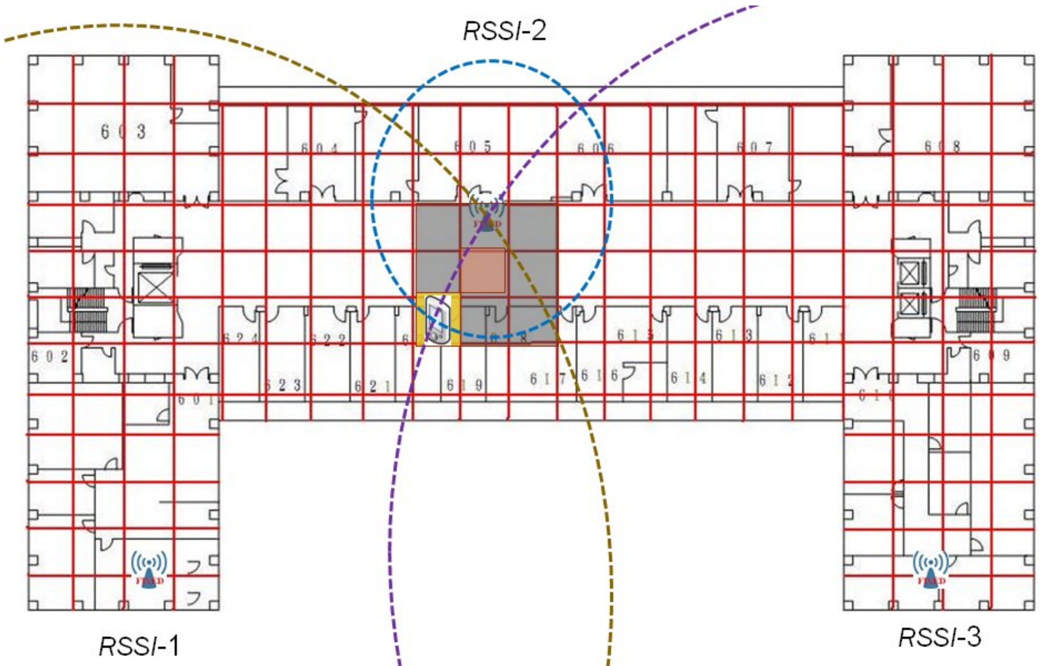


Figure.20 Determine the Divide Unit from DU that has Enough RSSI Triple

3-5. Weight Localization Algorithm

In the previous algorithm, a problem is found that all the divide units will have the same RSSI triple is unreasonable. Because the edge of intersection is only a little range in the intersection, so the probability that the wireless device in different divide unit is not equal. Consequently, a Weighted HOF algorithm should be designed to solve this problem.

As the Figure.20 shown blow, the divide units in the intersection of signal coverage range should initially be determined, then give the weight by the following 4 cases

Case 1: Only Vertex of the DU in Intersection

Weight = 1

Case 2: Two Vertices of the DU in Intersection

If Centroid is in Intersection

Weight = 2

Else // Centroid is Outside Intersection

Weight = 1

Case 3: Three Vertices of the DU in Intersection

Weight = 3

Case 4: Four Vertices of the DU in Intersection

Weight = 4

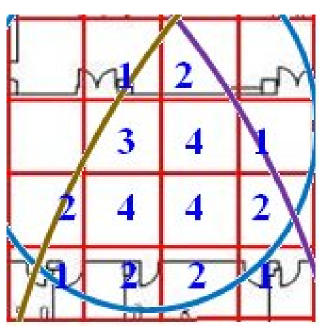


Figure.21 The Example of Weighted HOF

The stored RSSI triple is $RSSI * \frac{Wi}{\sum Wi}$, so the RSSI data in divide units will look like the Figure.22 shown.

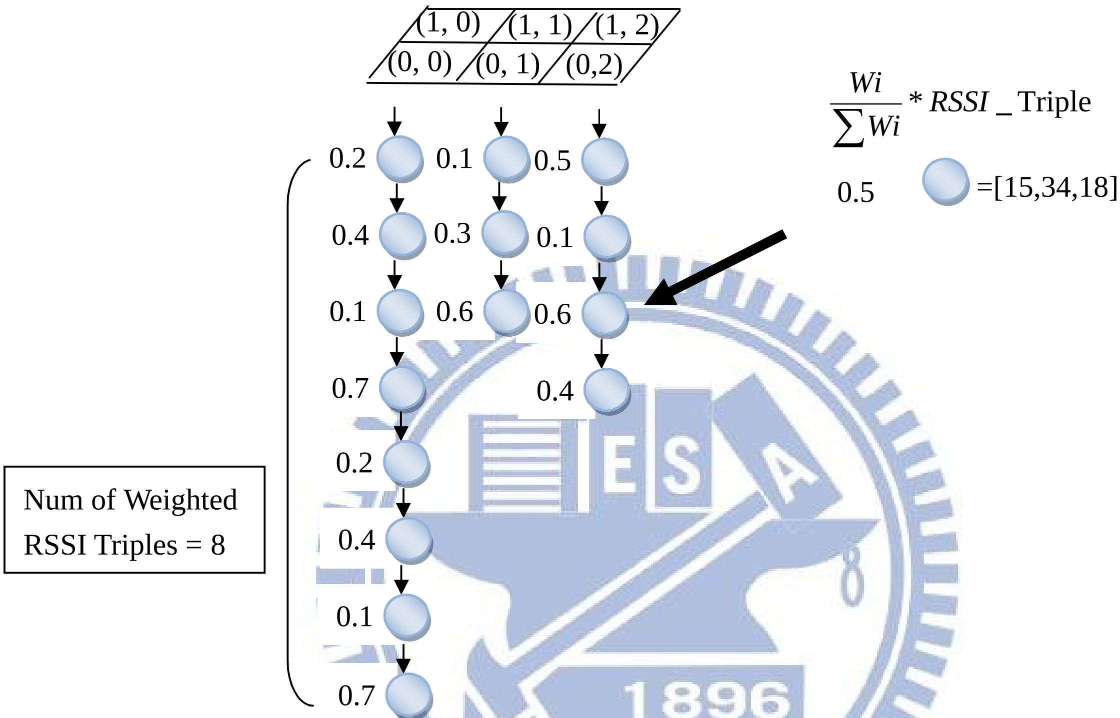


Figure.22 The Data Structure to Store Weighted Triple

Another case is that once the intersection of divide unit is too large, which means the signal strength is highly oscillated by some reason. So under this situation, some improved algorithm has to be done to solve this problem just like the Figure.23 shown.

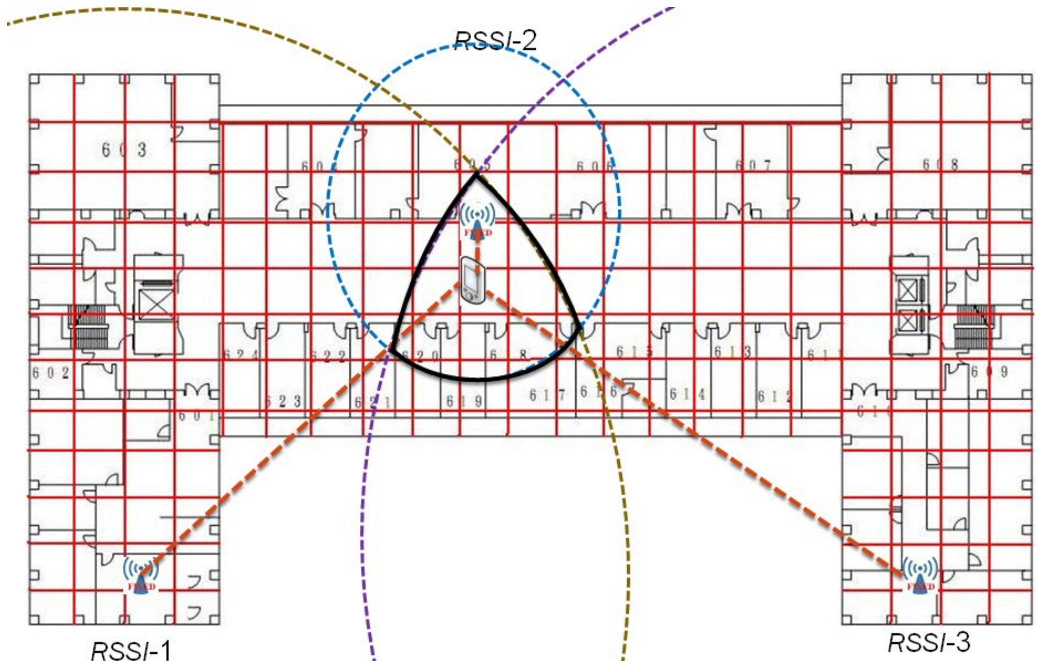


Figure.23 The Range of Overlapping is Too Large

When the overlapping range is too large, which means the localization result of this time is very inaccurate. Consequently, localization result of this time has to be discarded or use the adjust algorithm to improve the inaccurate result.

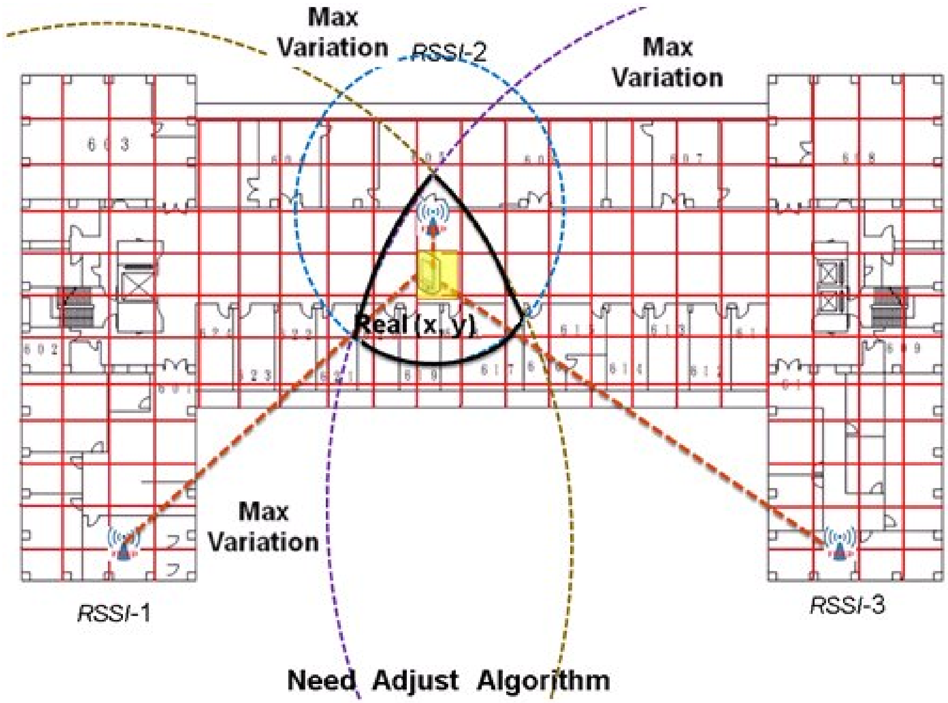


Figure.24 The Situation Need Adjust Algorithm

Adjust Algorithm

Because the unstable data cannot be judged is an abnormal case or a normal case, this triple discard may be a kind of fault. So once the user could report the real position (x, y) to our server, the triple could be added to the corresponding divide unit of the real (x, y) of the user.

Adjust Algorithm

User Report Real (x,y)

Add the RSSI triple to the DU corresponding to Real (x, y)

CHAPTER 4: FIELD EXPERIMENTS

In order to evaluate our scheme, we decided to implement the system in real environment instead of simulations. For most simulations, the conditions mostly are simplified too much so that the localization result is too ideal. Therefore, the whole system is field implemented in the National Chiao Tung University instead of using simulations. In the following paragraphs, the environments of our field experiments will be introduced including software and hardware as follows.

4-1. Field Experiment in NCTU

Our environmental platform is the NCTU EC building 6F and MISRC 6F; all the related dimension of the EC building is going to be listed as Table1 and the floor plan shown as the figure 25.

Length	60.4 m
Width	37.6 m
height of each floor	4.00 m
Wall material	Cement
Number of rooms of 6F	25 rooms

Table1. The information about the EC building

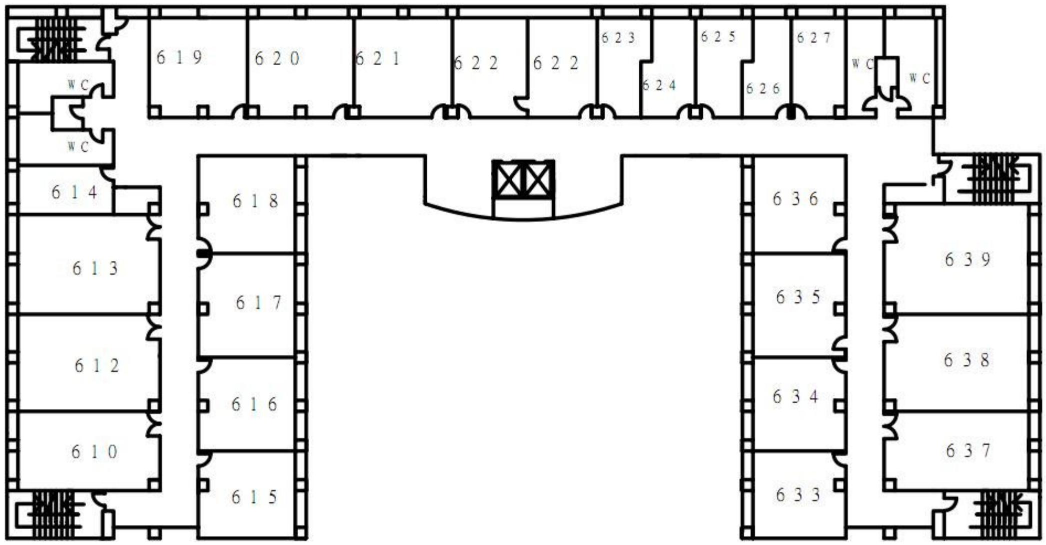


Figure.25 Floor Plan of EC 6F

4-2. Hardware & Software

Hardware

The hardware consists of access points that are used to monitor and sniff all the packets under the wireless area network of our environment. The system are composed of two main parts, the first part is the monitor access points. The monitor access point means some special access points that support monitor mode. The purpose of monitor access points is to receive all the traffic under its wireless network interface, and these monitor access points can also change the channels to listen. By the way, once the access point change to the monitor mode, it cannot to let wireless devices to connect and can only listen the traffic under the monitoring channel. The wireless interface of the monitor access point don’t need to connect to the listening access point or ad-hoc network, and it just listen to the traffic of monitored devices. Not all the wireless interface card support monitor mode, it dominates by the manufacture of wireless interface card.

The manufactory of our monitor access point is D-Link 1353[14]. The access point can cooperate with IEEE 802.11b [15-17], IEEE 802.11g[15-17], IEEE

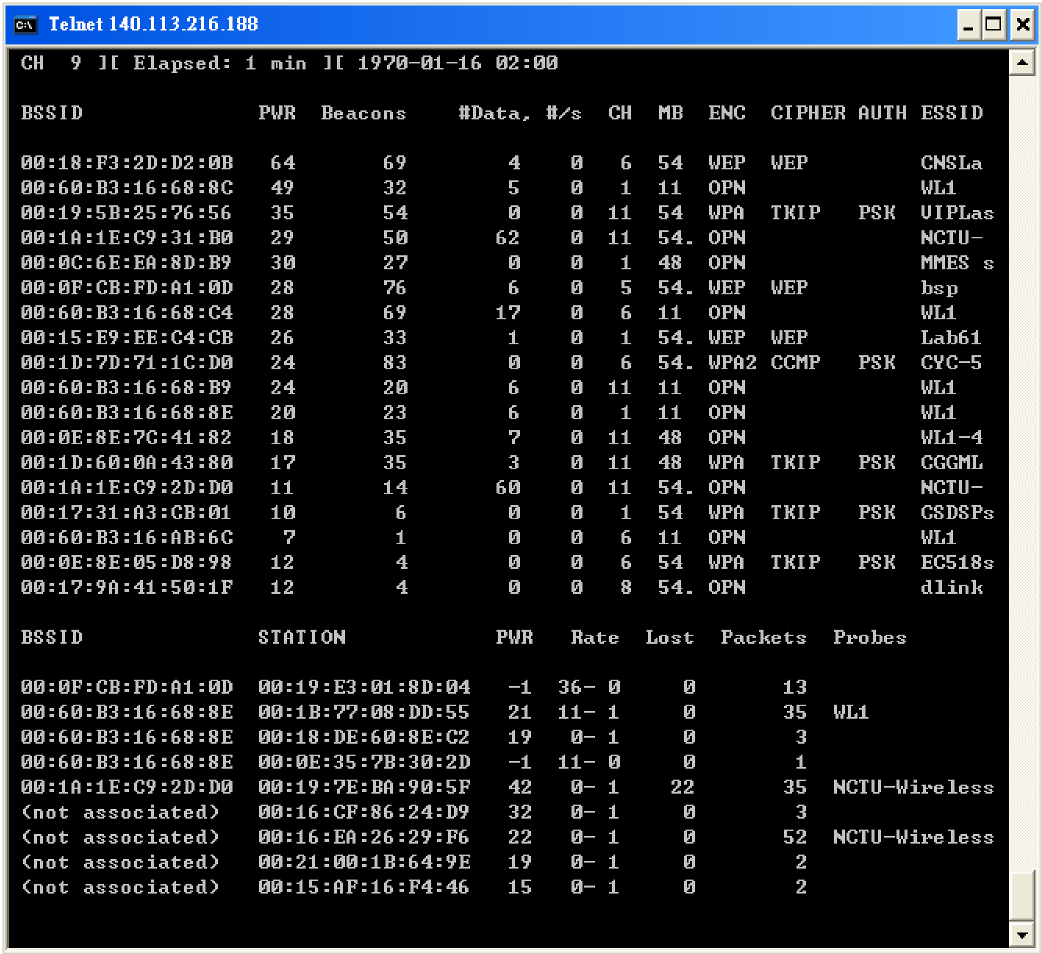
802.11n[15-17], IEEE 802.3, and IEEE 802.3u and the maximum transmission rate could reach 300Mbps. The most improvement of D-link DAP 1353 is wireless coverage range is much better that it could effectively decrease the wireless signal dead space. As for security specification, it support 64/128 bit WEP [18-20], WPA [18-20], WPA2 [18-20] standards. It is also adequate for 802.11b, 802.11g, and even the latest standard 802.11n to use. The specification also list in the table 1 below.

AP manufactory and Type	D-link DAP-1353
Standards	IEEE 802.11n (draft), IEEE 802.11g, IEEE 802.11b, IEEE 802.3, IEEE 802.3u
Frequency range	2412 to 2462MHz (North America) 2412 to 2472MHz (General Europe)
Security	64/128-bit WEP data encryption Wi-Fi Protected Access (WPA, WPA2) MAC Address Filtering 8 SSID for Network Segmentation SSID broadcast disable Function 802.1Q VLAN Tagging
Data rates	802.11g: 6/9/12/18/24/36/48/54Mbps 802.11b: 1/2/5.5/11Mbps 802.11n: 30/60/90/120/180/240/270/300Mbps
Ethernet Interface	10/100BASE-TX port

Table1. The specification of Monitor Access Point

Software

The monitor software in access point that can collect packet under WLAN is Airodump-ng [21-23]. It cannot work in managed mode, so you need to change the mode into monitor mode. Airodump-ng could be used to capture the 802.11 format frame and will display a list of detected wireless devices, like access points and connecting stations. The Airodump-ng can know the information including Basic Service Set ID (BSSID), Power Range (PWR), Used Channel, Cipher text mode and it's Extended Service Set ID (ESSID). This paper mainly depends on the PWR to locate the wireless devices. PWR in Airodump-ng means the signal level reported by the wireless network card. Its significance relies on the driver, but as the signal gets higher you get closer to the access point or the moving station. If the PWR equals -1 may have three cases. The first case for AP is that the driver on the AP doesn't support signal level reporting, and the second case for station is that if the PWR is -1 then this is for a packet which came from the AP to the client but the client transmissions are out of range for your card. It means that you are hearing only 1/2 of the communication. And the last case is that if all clients have PWR as -1 then the driver doesn't support signal level reporting. The figure.25 below is a snapshot of Airodump-ng report result in the NCTU EC6F building.



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Telnet 140.113.216.188
CH  9 ][ Elapsed: 1 min ][ 1970-01-16 02:00

BSSID              PWR  Beacons    #Data, #/s  CH  MB  ENC  CIPHER AUTH ESSID

00:18:F3:2D:D2:0B   64       69        4    0   6  54  WEP  WEP         CNSLa
00:60:B3:16:68:8C   49       32        5    0   1  11  OPN              WL1
00:19:5B:25:76:56   35       54        0    0  11  54  WPA  TKIP   PSK  VIPLas
00:1A:1E:C9:31:B0   29       50       62    0  11  54. OPN              NCTU-
00:0C:6E:EA:8D:B9   30       27        0    0   1  48  OPN              MMES s
00:0F:CB:FD:A1:0D   28       76        6    0   5  54. WEP  WEP         bsp
00:60:B3:16:68:C4   28       69       17    0   6  11  OPN              WL1
00:15:E9:EE:C4:CB   26       33        1    0   1  54. WEP  WEP         Lab61
00:1D:7D:71:1C:D0   24       83        0    0   6  54. WPA2 CCMP   PSK  CYC-5
00:60:B3:16:68:B9   24       20        6    0  11  11  OPN              WL1
00:60:B3:16:68:8E   20       23        6    0   1  11  OPN              WL1
00:0E:8E:7C:41:82   18       35        7    0  11  48  OPN              WL1-4
00:1D:60:0A:43:80   17       35        3    0  11  48  WPA  TKIP   PSK  CGGML
00:1A:1E:C9:2D:D0   11       14       60    0  11  54. OPN              NCTU-
00:17:31:A3:CB:01   10        6        0    0   1  54  WPA  TKIP   PSK  CSDSPs
00:60:B3:16:AB:6C    7        1        0    0   6  11  OPN              WL1
00:0E:8E:05:D8:98   12        4        0    0   6  54  WPA  TKIP   PSK  EC518s
00:17:9A:41:50:1F   12        4        0    0   8  54. OPN              dlink

BSSID              STATION            PWR   Rate  Lost  Packets  Probes

00:0F:CB:FD:A1:0D  00:19:E3:01:8D:04   -1  36- 0     0       13
00:60:B3:16:68:8E  00:1B:77:08:DD:55   21  11- 1     0       35  WL1
00:60:B3:16:68:8E  00:18:DE:60:8E:C2   19   0- 1     0        3
00:60:B3:16:68:8E  00:0E:35:7B:30:2D   -1  11- 0     0        1
00:1A:1E:C9:2D:D0  00:19:7E:BA:90:5F   42   0- 1    22       35  NCTU-Wireless
(not associated)   00:16:CF:86:24:D9   32   0- 1     0        3
(not associated)   00:16:EA:26:29:F6   22   0- 1     0       52  NCTU-Wireless
(not associated)   00:21:00:1B:64:9E   19   0- 1     0        2
(not associated)   00:15:AF:16:F4:46   15   0- 1     0        2
```

Figure.25. Snapshot of airodump-ng in NCTU EC Building 6F

4-3. Factors that Affects Experiments

1. Error of translating the real distance to the scale of the map

   The error from calculating between distance real and logical distance is also a problem. Measure wireless devices are placed in the place which three WiSec Agent can detect. Owing to the error of translating the real distance to the scale of the map, showed distance in the map will have some inaccuracy.

2. Interference between Normal Access Points & Monitor Access Points

   The Monitor Access Points and normal access points may use the same channel so that they will affect power rate of microwave one another.

3. Difference of Wi-Fi chip

   Once the chips of wireless devices are different, and it will lead to different localization results and different accuracy.

4. Temperature

   Monitor AP will be unstable and the temperature of them will rise under the long-time use.

5. Power Rate of the Access Point is Unstable

   After our observations, we found that the signal strength of access point in the same place is unstable. The maximum error range is +-20, and the closer to the Monitor AP the lower the range of the error.

6. Interference of Barriers

   When wireless signal passed through some barriers made of special materials, the signal of access point will decrease rapidly. For example, elevators, concrete walls, windows and so on.

7. Other Special Case

   In some cases, the signal strength of the access points will increase instead of decrease owing to the nearby electric wire.

CHAPTER 5: EVALUATION

In order to evaluate the performance of our scheme, our proposed Hybrid Overlapping Fingerprinting method (HOF method) could be evaluated by the most common index – error distance. Generally speaking, the average error distance means the distance between the real position and the position calculated by our HOF methods; In order to evaluate the error distance, the real position of the observed devices has to be known. The positions of some wireless access points need to be pre-recorded and translated their real positions to logical positions. Since the program can only calculate the logical position of the observed devices, the logical distance between the pre-record logical positions has to be translated and the position that we calculate by the program base on our scheme. The translation equation is according to the real dimension of our observation environment as the figure26 shown below.

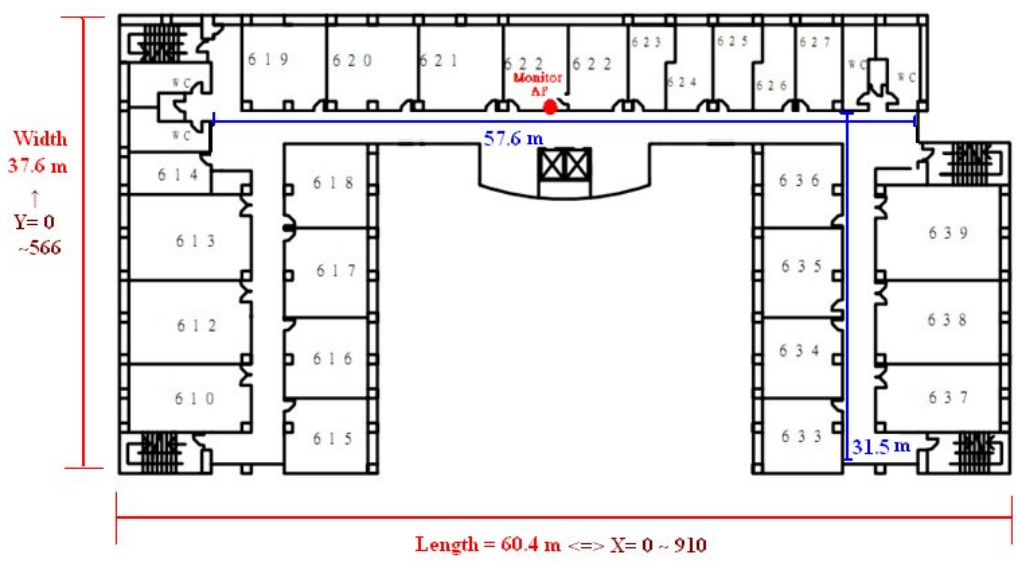


Figure.26 Floor Plan of NCTU EC 6F

Supposing that real coordinate and logical coordinate has known, the real Coordinate (X_0, Y_0) and the calculated coordinate is (X, Y), the logical distance is the Euclidean distance. But the real Error Distance needed to translate to Euclidean distance [24-27] by timing the proportional scale. Consequently, the Error Distance can be written as the following equations:

$$\text{Error Distace} = \frac{\text{Real Distance}}{\text{Logical Distance}} * \sqrt{(X - X_0)^2 + (Y - Y_0)^2}$$

We use the C# as our implementation language and design a friendly GUI to show the result of our localization scheme.

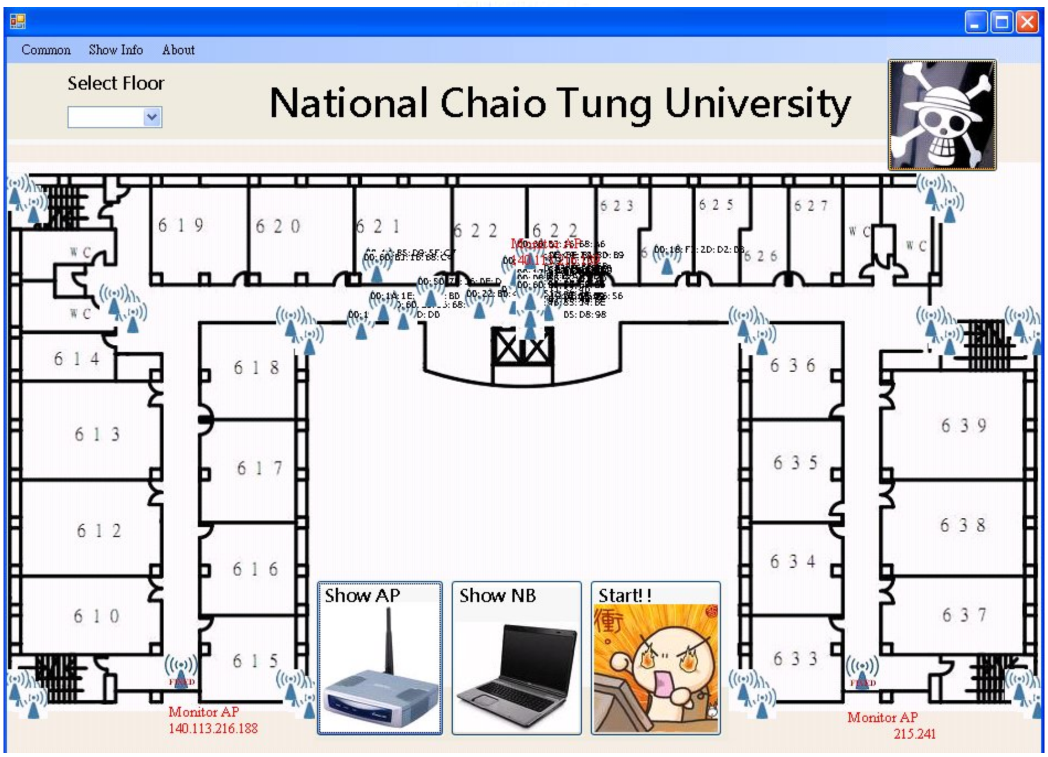


Figure.27 Snapshot of Field Localization Result in NCTU EC 6F

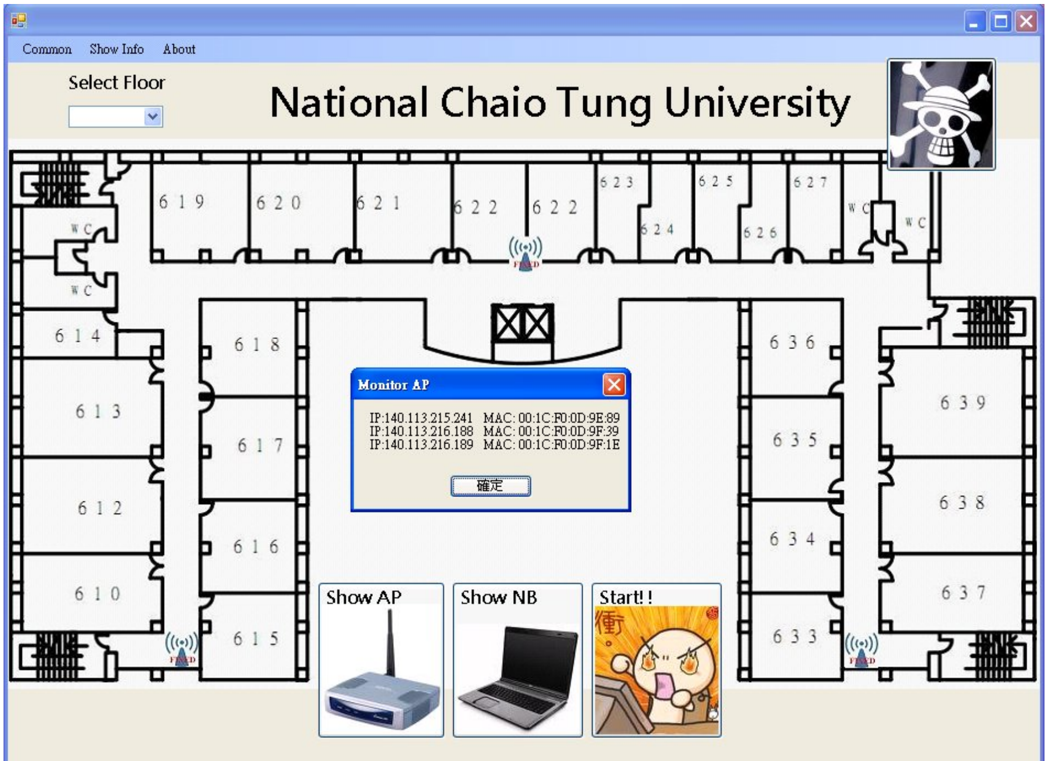


Figure.28 Snapshot of Monitor APs in NCTU EC 6F

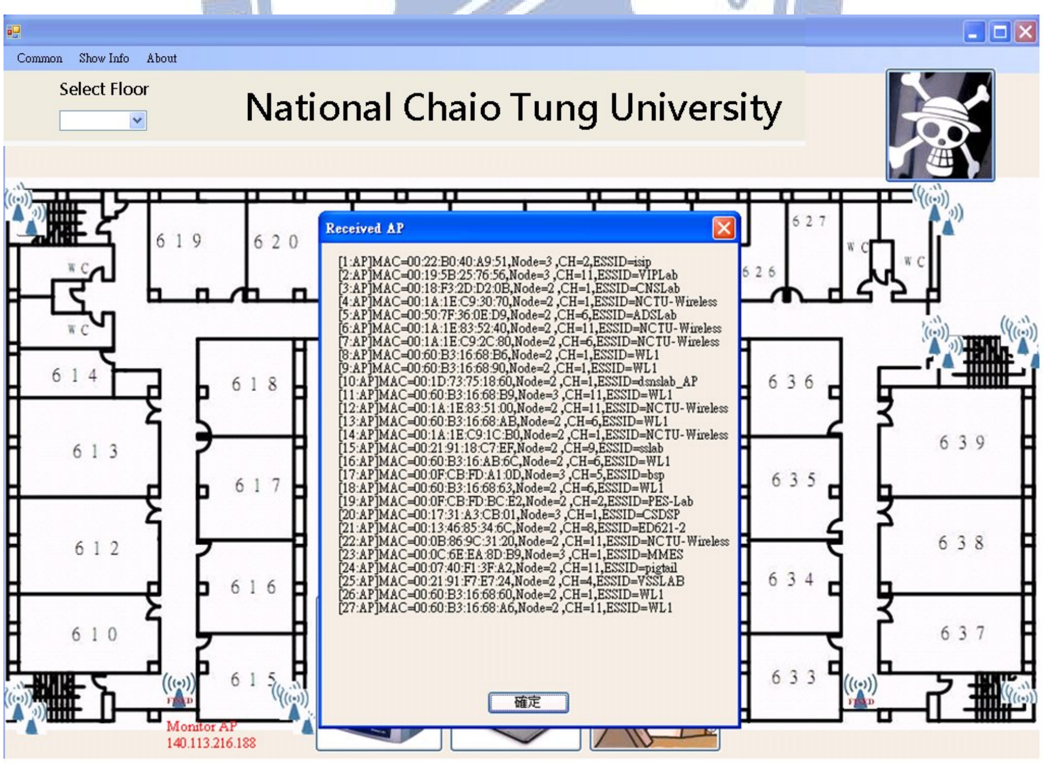


Figure.29 Snapshot of Received APs in NCTU EC 6F

We sample every one hundred times to measure the error distance by the method mentioned before.

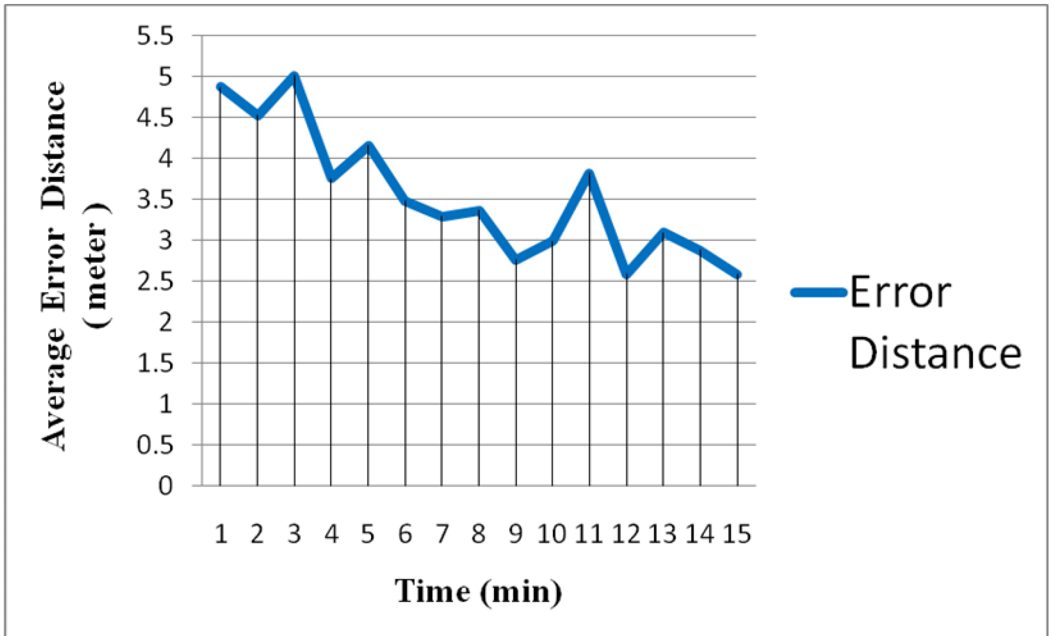
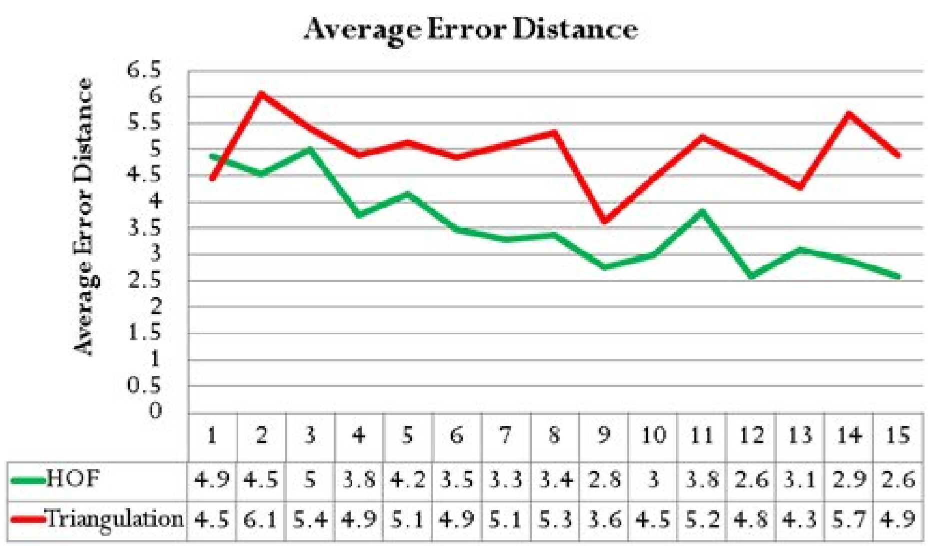
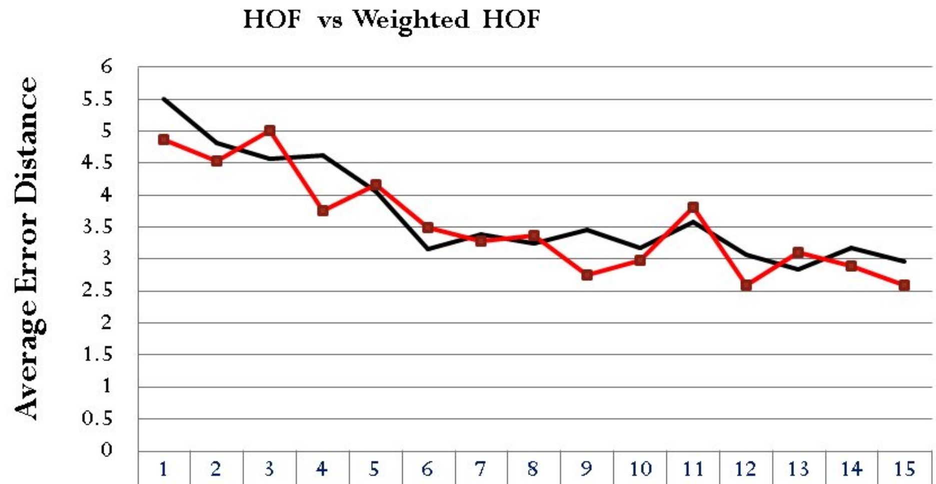


Figure.30 Average Error Distance Every 100 Times of HOF Method



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
HOF	4.9	4.5	5	3.8	4.2	3.5	3.3	3.4	2.8	3	3.8	2.6	3.1	2.9	2.6
Triangulation	4.5	6.1	5.4	4.9	5.1	4.9	5.1	5.3	3.6	4.5	5.2	4.8	4.3	5.7	4.9

Figure.31 Average Error Distance between HOF & Triangulation Every 100 Times



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Weighted HOF	5.51	4.82	4.57	4.62	4.06	3.16	3.38	3.24	3.46	3.17	3.59	3.07	2.84	3.18	2.97
HOF Algorithm	4.87	4.53	5.01	3.76	4.16	3.49	3.29	3.37	2.76	2.99	3.82	2.59	3.1	2.89	2.59

Figure.32 Average Error Distance between HOF & Weighted HOF Every 100 Times

From the experiments given above, we could realize the fact that our HOF indeed will make the error distance decrease with time. From the Figure.31, the error distance of proposed scheme is much better than the triangulation method. But as for the HOF method and Weighted HOF method, the error distance is not necessarily better with each other as the Figure.32 shown.

Comparison

We are going to compare our proposed scheme – Hybrid Overlapping Fingerprinting Method with other indoor localization method in the following table.

Method / Property	AOA / TOA /TDOA	RSSI Triangulation	RSSI Fingerprint	Hybrid Overlapping Fingerprint
IMPACT of Time Synchronization	HIGHLY IMPACT	None	None	None
INFLUENCE of Line of Sight	HIGHLY AFFECTED	LOW	LOW to NONE	LOW to NONE
Normal Wi-Fi Device can use	NO	YES	YES	YES
Training Effort for Human Resource	None	Low	HIGH	Low (Online Training)
Error Distance	(Indoor) High (Outdoor)Low	High	Low	High to Low (Decrease with time)

CHAPTER 6: CONCLUSION

In this paper, a new localization method is proposed according to the signal overlapping in WLAN. A hybrid online training algorithm is proposed to improve the drawbacks of both RSSI based algorithm. In traditional RSSI-based fingerprinting method cannot avoid the great training effort in training phase. But in our scheme, the Hybrid Overlapping Fingerprinting Algorithm needn't to pre-collect all the divide unit's RSSI signals as fingerprinting. In other words, this is a new method uses on-line training to adjust accuracy with time base on the previous collected RSSI. More importantly, some special cases are also discussed in indoor environments, such as the devices are near the windows or wireless devices in the stair well. The HOF Algorithm can also determine which floor and provide a solution to solve such uncertainty problem.

References

[1] http://en.wikipedia.org/wiki/Global_Positioning_System

[2] http://en.wikipedia.org/wiki/GPS_Phone

[3] http://en.wikipedia.org/wiki/Satellite_navigation_system

[4] Ekahau, Wifi Positioning Engine, http://www.ekahau.com/

[5] P. Rong and M.L. Sichitiu. "Angle of Arrival Localization for Wireless Sensor Networks," in Proc. of Sensor and Ad Hoc Communications and Networks, 2006. vol. 1, pp. 374-382, Sept. 2006

[6] Nissanka B. Priyantha, Anit Chakraborty, and Hari Balakrishnan, "The Cricket Location-Support System," 6th ACM International Conference on Mobile Computing and Networking (ACM MOBICOM), Boston, MA, August 2000

[7] P. Bahl and V. N. Padmanabhan, "RADAR: An In-Building RF-Based User Location and Tracking System," in Infocom 2000, pp 775–784, 2000.

[8] http://en.wikipedia.org/wiki/Received_Signal_Strength_Indication

[9] S Meguerdichian, S Slijepcevic, V Karayan, "Localized algorithms in wireless ad-hoc networks: location discovery and sensor exposure," Symposium on Mobile ad hoc networking & computing, 2001

[10] X Shen, JW and Mark, J Ye, "Mobile location estimation in cellular networks using fuzzy logic," Vehicular Technology Conference, 2000. IEEE VTS-Fall VTC, Vol.5, Sept. 2000

[11] S Valaee, B Champagne, P Kabal, "Localization of wideband signals using least-squares and totalleast-squares approaches," IEEE Transactions on Signal Processing, 1999

[12] TS Stamoulakatos, ED Sykas, "Hidden Markov modeling and macroscopic traffic filtering supporting location-based services, " Wireless Communications and Mobile

Computing, 2007

[13] LBreiman, JH Friedman, R Olshen," Classification and regression trees," 1984

[14] D-LINK Product : WiFi Wireless Access Point, DAP-1353
http://www.dlinktw.com.tw/product_view.asp?subMenuCode=&sno=LPFMHS

[15] B O'Hara, A Petrick, "The IEEE 802.11 Handbook: A Designer's Companion," 1999

[16] Mustafa Ergen Ergenm, "IEEE 802.11 Tutorial," 1999

[17] Mangold, Berlemann, "QoS Support as Utility for Coexisting Wireless LANs," 2002

[18] Bruce Potter, "802.11 Security," O'Reilly & Associates Inc

[19] Nikita Borisov , Ian Goldberg , David Wagner, "Intercepting Mobile Communications: The Insecurity of 802.11," Proceedings of the 7th annual international conference on Mobile computing and networking, 2001

[20] N. Cam-Winget, R Housley, D Wagner,Jesse Walker "Security flaws in 802.11 data link protocols," Communications of the ACM ,Volume 46 , Issue 5 , May 2003

[21] X Yuan, OT Wright, H Yu, KA Williams, "Laboratory design for wireless network attacks," Proceedings of the 5th annual conference on Information security curriculum development, 2008

[22] K Swiat, " The travelling menace: rogue hotspots," Computer Fraud & Security, 2006

[23] http://www.aircrack-ng.org/doku.php?id=Airodump-ng

[24] PE Danielsson, "Euclidean distance mapping," Computer Graphics and image processing, 1980

[25] H Breu, J Gil, D Kirkpatrick, M Werman, "Linear time Euclidean distance transform algorithms," IEEE Transactions on Pattern Analysis and Machine, 1995

[26] I Ragnemalm (Linkoping Univ),"The Euclidean distance transform in arbitrary dimensions," International Conference on Image Processing and its Applications, 1992

[27] http://www.itl.nist.gov/div897/sqg/dads/HTML/euclidndstnc.html