CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Electrical Engineering
Department of Telecommunication Engineering

Indoor Positioning System with BLE and Wi-Fi technology

Data Analysis and Accuracy Improvement

Ing. Programme: Communication, Multimedia and Electronics
Specialisation: Electronic Communication Networks

May 2017

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Prof. Jenq-Shiou Leu

I hereby declare that this master's thesis is completely my own work and that I used only the cited source in an accordance with the instruction about observance of ethical principles of preparation of university final projects.

Prague, May 26, 2017

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Signature

ZADÁNÍ DIPLOMOVÉ PRÁCE

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

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Studijní program: **Komunikace, multimédia a elektronika**

Studijní obor: **Sítě elektronických komunikací**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Indoor Positioning System with BLE and Wi-Fi technology - Data Analysis and Accuracy Improvement

Název diplomové práce anglicky:

Indoor Positioning System with BLE and Wi-Fi technology - Data Analysis and Accuracy Improvement

Pokyny pro vypracování:

Design an indoor positioning system utilizing Wi-Fi and BLE communication technologies and corresponding infrastructure. Focus on comparison of different methods of data processing obtained by measurement of levels of received signals and evaluate these methods. Realize a DEMO of indoor positioning system. Communicate the details with your supervisor.

Seznam doporučené literatury:

[1] Yaqian Xu: Autonomous Indoor Localization Using Unsupervised Wi-Fi Fingerprinting, ISBN: 978-3-73760-070-5.
[2] Dokumantace k WiFi Localization and Navigation for Autonomous Indoor Mobile Robots dostupná na http://www.cs.cmu.edu/~mmv/papers/10icra-joydeep.pdf [on-line]
[3] Dokumentace k Implementation and analysis of Hybrid Wireless Indoor Positioning with iBeacon and Wi-F dostupná na http://ieeexplore.ieee.org/document/7765336/ [on-line]

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Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) diplomové práce:

Datum zadání diplomové práce: **01.03.2017** Termín odevzdání diplomové práce: **26.05.2017**

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III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

.

Datum převzetí zadání   Podpis studenta

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First of all, I am strongly appreciated to my supervisor Ing. Lukáš Vojtěch, Ph.D for his invaluable help and instructions on my individual project and my thesis during my Double-Degree Study in CVUT. A lot of thanks to doc. Ing. Zdeněk Bečvář, Ph.D for helping all administrative matters and courses studying.

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ABSTRACT

Abstract —Nowadays, the demand for indoor position and navigation with location based services (LBSs) is increasing. Many applications on smartphones exploit different techniques and inputs for positioning. However, the indoor environment is really complex so that the accuracy of indoor positioning is affected by severe signal interference. Most of the wireless indoor positioning systems have relied on received signal strength indicators(RSSIs) from wireless radio emitting devices. In this thesis, we propose a hybrid system assisted by the RSSI fingerprint, utilizing iBeacon to assist Wi-Fi indoor positioning. In this hybrid system, Wi-Fi APs can divide the space into different sections, and iBeacon can accurately locate where the user is in an indoor environment. We aim to provide a more accurate, effective hybrid wireless indoor positioning system using Wi-Fi and iBeacon radio signals. Our result show advantages to the hybrid indoor positioning system.

Our experiment results show advantages to our proposed hybrid system. We achieve < 2.8m error and 90% accuracy for the hybrid system, compared to < 3.5 m for iBeacon and <4.2m for Wi-Fi system in the same environment. According to the analysis, the hybrid system is proven to be an effective solution to indoor positioning.

Key words: *Wi-Fi, iBeacon, Indoor Positioning, Fingerprinting, K-Nearest Neighbors (KNN), Hybrid System, Mobile Application, Received Signal Strength Indication (RSSI)*

ABSTRAKT

Současný stav ve vývoji moderních aplikací a služeb zvyšuje poptávku po systémech určování polohy ve vnitřních prostorách s následnou možností navigace (s lokalizačními službami (LBS)). Mnoho aplikací určených pro smartphony využívá různé techniky a často i senzorovou fúzi. Vnitřní prostředí je však velice složité, takže přesnost vnitřního polohování je zásadně ovlivněna silným rušením a komplikovaným šířením analyzovaných signálů. Většina bezdrátových vnitřních lokalizačních systémů se spoléhá na analýzu přijatých signálů, zejména analýzu intenzity signálu (RSSI). V této práci navrhujeme hybridní systém s využitím metod fingerprint RSSI, který využívá iBeacony pro zpřesnění lokalizace Wi-Fi přístupových bodů. V tomto hybridním systému mohou přístupové body Wi-Fi rozdělit prostor na různé sekce a iBeacony mohou pomoci lokalizovat polohu uživatele ve vnitřním prostředí. Naším cílem je poskytnout přesnější a účinnější hybridní bezdrátový systém vnitřního polohování, využívající rádiové signály technologií Wi-Fi a iBeacon. Náš výsledek ukazuje výhody hybridního systému vnitřního polohování, tedy určení polohy.

Výsledky experimentu ukazují, že navrhovaný hybridní systém může dosáhnout přesnosti lepší než 2,8m, ve vnitřních prostředích. Podle analýzy se hybridní systém osvědčil, jako možné efektivní řešení úlohy lokalizace uvnitř budov.

Klíčová slova: *Klíčová slova: Wi-Fi, iBeacon, hybridní systémy, lokalizace, vnitřní prostředí, RSSI fingerprint, mobilní aplikace*

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List of Acronyms

AOA	Angle of Arrival
ANN	Artificial Neural Network
AP	Access Point
BLE	Bluetooth Low Energy
BS	Base Station
GPS	Global Positioning System
IPS	Indoor Position System
IR	Infrared radiation
KNN	K nearest neighbor
LBS	Location based services
LOS	Line of Sight
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indicator
SIG	Special Interest Group
SVM	Support Vector Machine
TDOA	Time Difference of Arrival
TOA	Time of Arrival
TTFF	Time-to-first-fix
UUID	Universally Unique Identifier

Chapter 1. Introduction

1.1 Background

In recent years, intelligent handheld devices become more common and popular. And the Internet has been rapidly developed, many different extended services have shown up. Location based services(LBS) has been prevailing all around the world with the rising of mobile devices networks, since these services can provide many practical information which ease people from searching access to a particular product or a very piece of knowledge. [1, 2] LBS not only can saving the time to find the products in the department stores, but also can promote the interaction and promotion between consumers and company to bring greater business opportunities [3]. Or when the consumer can easily and quickly find their own their parking position in the huge parking lot, through the positioning of the indoor space.

As we know, one of the mainstream positioning technologies is Global Positioning System (GPS), which is established and very accurate for most of outdoor positioning. Nevertheless, caused by the significant loss of the reception of satellite signals inside modern buildings, it is difficult to get a reasonable positioning result using GPS in indoor environments.

Figure 1-1. The applications of indoor position [3]

In general, we can divide positioning into outdoor and indoor positioning. Although outdoor positioning has been extensively studied and applied, indoor positioning is still facing some challenges and some of its techniques and methods have shortages. For example, GPS does not work properly inside buildings, therefore the alternative technologies are needed. Many different kinds of signals are used for indoor positioning. The indoor positioning techniques mostly utilize RFID, ZigBee, Image, Wi-Fi, and Bluetooth Low Energy (BLE).

RFID [4] and ZigBee [5] its positioning accuracy is affected by the number of RFID Base Station and ZigBee Sensor Node. The main disadvantage of these two methods is the require of special equipment to reach positioning, such as RFID Tag, ZigBee Sensor Node and other less accessible equipment, it is not widely used and more expensive.

Figure 1-2. The RFID indoor positioning system [4]

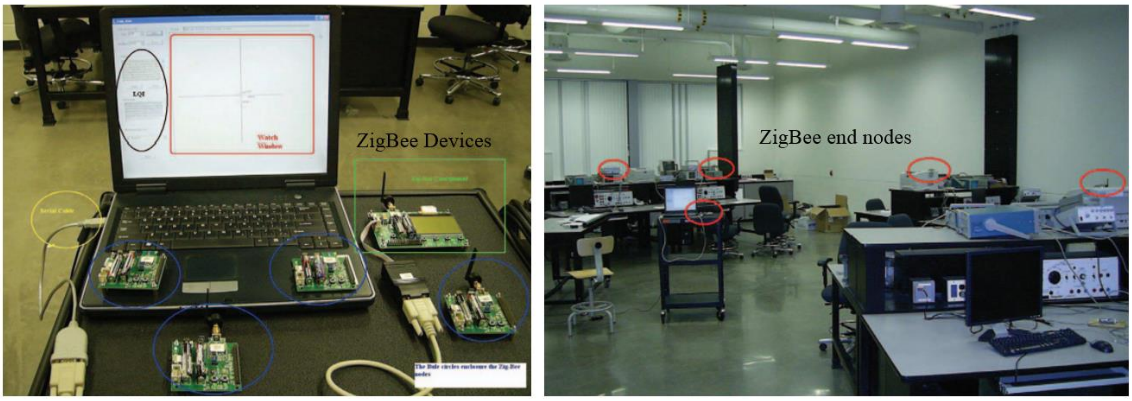

Figure 1-3. The ZigBee indoor positioning system [5]

For the above reasons, there are some indoor positioning technology research tends to use a wider-range of equipment can achieve the indoor positioning, such as using camera Image identification or more common technology Wi-Fi, Bluetooth signal to do indoor positioning.

As shown in Figure 1-4, Using Image as the basis for indoor positioning [6,7], the advantage is used to make the positioning of the image is more specific. We can easily know our location after extracting the eigenvalues. And the disadvantage is that the image is very vulnerable to interference with light and obstacles, resulting in miscarriage of justice, and environmental imaging database in addition to difficult to build, the storage space demand is also very large.

Figure 1-4. The indoor positioning system in using Image technology [6]

In recent years, Wi-Fi[8-10] and Bluetooth[11, 12] began to be widely used in indoor location services, many businesses and customers are beginning to pay attention to its related applications. Wi-Fi indoor positioning can provide meticulous service in any location where Wi-Fi signal is accessible, but it has many limitations. Unlike Bluetooth, Wi-Fi devices usually don't have to change batteries. So in the maintenance and installation of large stores and shopping malls, Wi-Fi positioning and navigation have an absolute advantage, but the relative hardware costs are higher.

Recently, Apple has proposed a wireless communication method called iBeacon, iBeacon contains low-power Bluetooth (Bluetooth Low Energy, BLE) -based wireless communications technology, which is characterized by cross-platform, easy to build, low cost, iBeacon is a very good alternative to building costly Wi-Fi technology. The most important advantage of iBeacon is energy efficient. This translates to possible quick deployment of small size beacons only need to be powered by battery and eliminates the necessity to rely on any existing infrastructure such as a Wi-Fi access point networks. On the other hand, according to many researches, Wi-Fi devices consume more energy than BLE devices. And also Wi-Fi has been shown to be fairly accurate. Therefore, with good positioning algorithm, Hybrid Wireless Indoor Positioning with iBeacon and Wi-Fi technology serves a better candidate for localization purpose.

1.2 Research Purpose

This thesis focuses on using Wi-Fi and iBeacon low-power Bluetooth (BLE) technology to implement indoor positioning issues. When the GPS signal is affect by the building in the indoor environment, we can use Wi-Fi and iBeacon equipment to help or replace GPS in the application of indoor positioning technology, providing mobile devices and users seamless service.

How do we design and implement an indoor positioning system in an indoor environment where fill Wi-Fi signals? We examine the hybrid indoor positioning of Wi-Fi and iBeacon signal. We use existing Wi-Fi signals in the environment, with self-iBeacon to enhance the accuracy and efficiency of indoor positioning. Through the signal processing and alignment adjustment to improve the positioning accuracy, a more stable positioning system, and we developed the indoor positioning application in the smart phone, with readily available mobile devices to store indoor location service.

The purpose of this thesis is in following:

1. Use the existing Wi-Fi signal and iBeacon equipment to design and build the indoor positioning environment.
2. Set the machine-related experiments and applications to verify its positioning effect, and compare with the traditional Wi-Fi indoor positioning.
3. Implement an application can provide users in the indoor environment.

1.3 Organization

The architecture of this thesis consists of five chapters, each of which are in following:

Chapter 1 Introduction:

The first chapter will explain the research background, motivation, purpose and thesis structure of this thesis.

Chapter 2 Locating Related Technologies

Describe the relevant techniques and algorithms used in existing indoor positioning.

Chapter 3 Design of Indoor Positioning System:

This thesis describes the system architecture and the method of its design.

Chapter 4 Experimental Test and Evaluation Results:

The experiment and analysis of the results of this thesis will show how to evaluate the effectiveness of the system in the real environment and compare it with other positioning methods. analysis.

Chapter 5 Conclusion and Future Development:

A conclusion and future research direction for this thesis.

Chapter 2. Positioning Technology

2.1 Algorithms for Location Determination

There are several ways proposed to be utilized as means to do accurate positioning by taking advantages of Wi-Fi and iBeacon signals, and their own characteristic as well as operating method will be introduced as followed.

2.1.1 Time of Arrival, TOA

Time of Arrival (TOA)[13] mainly to measure the time difference between the base station and the object transmission signal. Then calculate the relative distance between the object and the base station, see in figure2-1. After object received time difference from more than three known base station, we can calculate the distance between the object and each base station, as shown in formula (2.1)

The distance between the object and the base station:

$$r_i = (t_i - t_0)c \qquad (2.1)$$

t_0 is the starting time of signal from base station to object, t_i is the arrival time of signal from base station to object. Coefficient C is constant that equal to 3×10^8m/s.

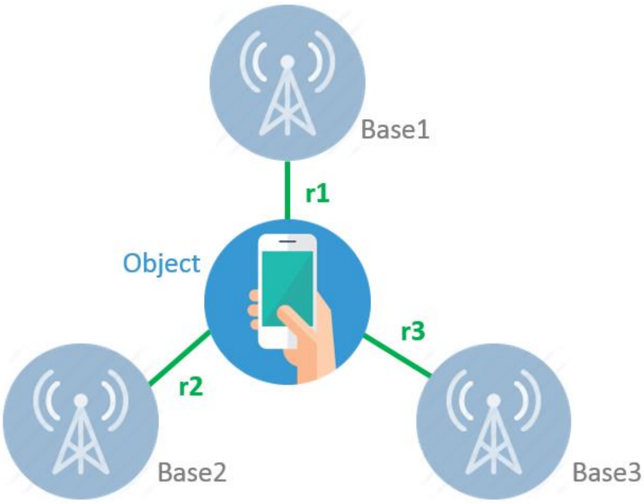

Figure 2-1. Time of Arrival

There are three base Station BS1, BS2, and BS3. We can locate an estimated location called Mobile Station in the range of this three base station. According to the transmit signal strength, we can know the value of distance d1, d2, d3. The coordinates (x, y) of the Mobile Station can be solved by the three circular equations, as shown in formula (2.2)

$$\begin{cases}(x-x_1)^2+(y-y_1)^2={d_1}^2\\(x-x_2)^2+(y-y_2)^2={d_2}^2\\(x-x_3)^2+(y-y_3)^2={d_3}^2\end{cases} \tag{2.2}$$

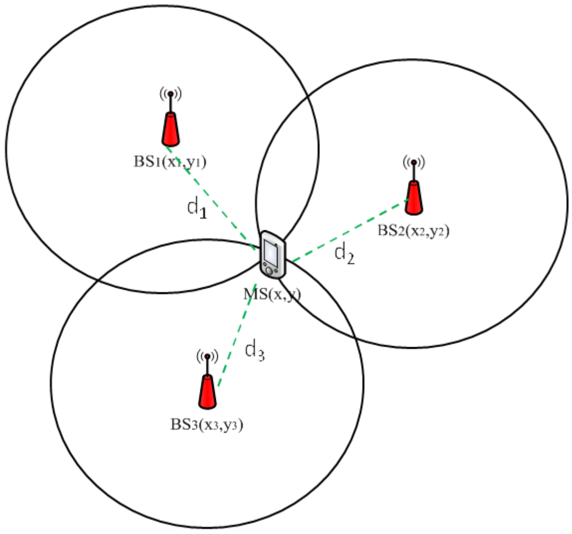

Figure 2-2. The coordinates (x, y) of Time of Arrival

But from the relationship between time and distance, we can know that the TOA positioning method is very sensitive to the time, it must be close to keep the receiver and the transmitter side of the synchronization. (For example, if there is a microsecond time error, it will cause distance error about 300 meters.)

And the TOA is affected by the non-linear-of-Sight (NLOS) [14] environment, resulting in the fact that the three circles produced by the three base stations do not intersect at a single point and form an MS Falling area, as shown in Figure 2-3.

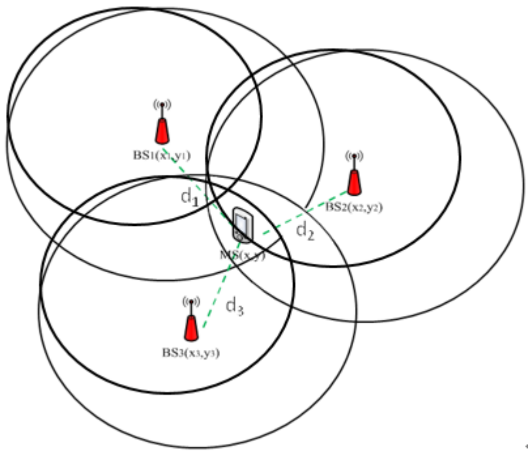

Figure 2-3. The non-linear-of-Sight effect.

2.1.2 Time Difference of Arrival, TDOA

Time Difference of Arrival (TDOA) [15] is using the time difference between the base station signal and the object to find the distance between the base station and the object. The two signals are simultaneously sent via the object after receiving, using a different time difference to draw the hyperbola curve, as shown in Figure 2-4.

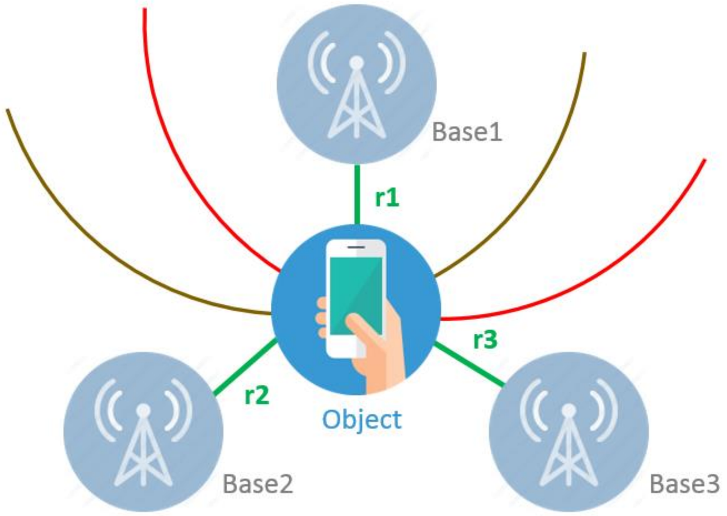

Figure 2-4. Time Difference of Arrival

TOA can't calculate the time difference between the nearest base station and the nearest base station. TDOA can use the triangulation method to determine the location of the mobile client, record the time the mobile terminal signal is served to the base station, and the same signal arrives at the other two Base station time.

The distance from the mobile station to the base station can be calculated thought the transmitted signal. The arc and the intersection of the base stations are the position of the mobile client, as shown in Figure 2-5.

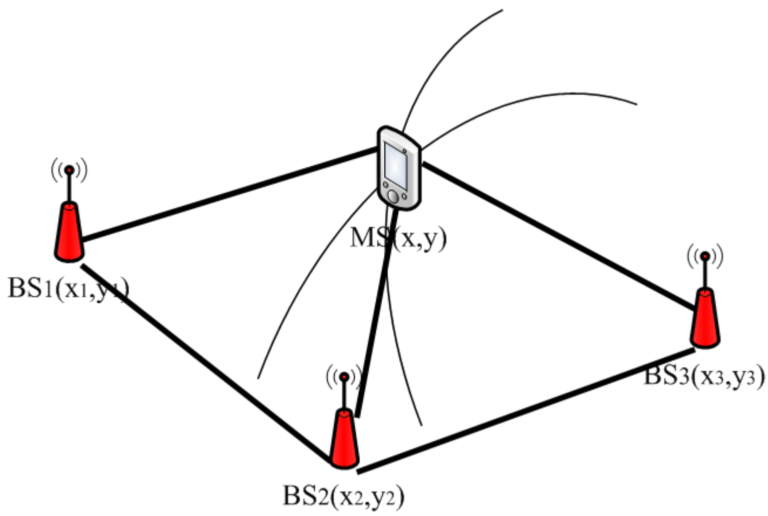

Figure 2-5. The coordinates (x, y) of TDOA

Assume that the object coordinates are (x, y) in Figure 2-5, the base station BS1.BS2.BS3 coordinates (x1, y1). (X2, y2). (X3, y3), the base station The distance can be expressed as a geometric function by following formula.

$$d_1 = \sqrt{(x - x_1)^2 + (y - y_1)^2} \quad (2.3)$$

$$d_2 = \sqrt{(x - x_2)^2 + (y - y_2)^2} \quad (2.4)$$

$$d_3 = \sqrt{(x - x_3)^2 + (y - y_3)^2} \quad (2.5)$$

Object measurement time difference and distance can be expressed as

$$d_{12} = d_1 - d_2 \quad (2.6)$$

In the above relation, the difference between the base stations BS1 and BS2 is observed to obtain the formula (2.7)

$$d_1 - d_2 = \sqrt{(x - x_1)^2 + (y - y_1)^2} - \sqrt{(x - x_2)^2 + (y - y_2)^2} \quad (2.7)$$

Simplified by a pair of curves, so the two base stations can provide a double curve, plus the base station BS2 and BS3 difference, as shown in (2.8):

$$d_2 - d_3 = \sqrt{(x - x_2)^2 + (y - y_2)^2} - \sqrt{(x - x_3)^2 + (y - y_3)^2} \quad (2.8)$$

We can know another hyperbolic curve, the intersection of two hyperbolic curves can be calculated where the mobile client. It is the same as the TOA method, easily due to a slight difference in time, resulting in a huge distance to calculate the fallacy, so that the impact of positioning accuracy.

2.1.3 Angle of Arrival, AOA

Angle of Arrival (AOA) [16] mainly determine the source position through the measurement of the base station signal to the object's azimuth, as shown in Figure 2-6. AOA must use the directional antenna to determine the source of the signal, so that the accuracy of antenna direction is important. The advantage of AOA is that can improve the positioning accuracy, but the directional antenna for the angle of the resolution is severely limited. When the signal source is too far, it will have errors that cause less accurate.

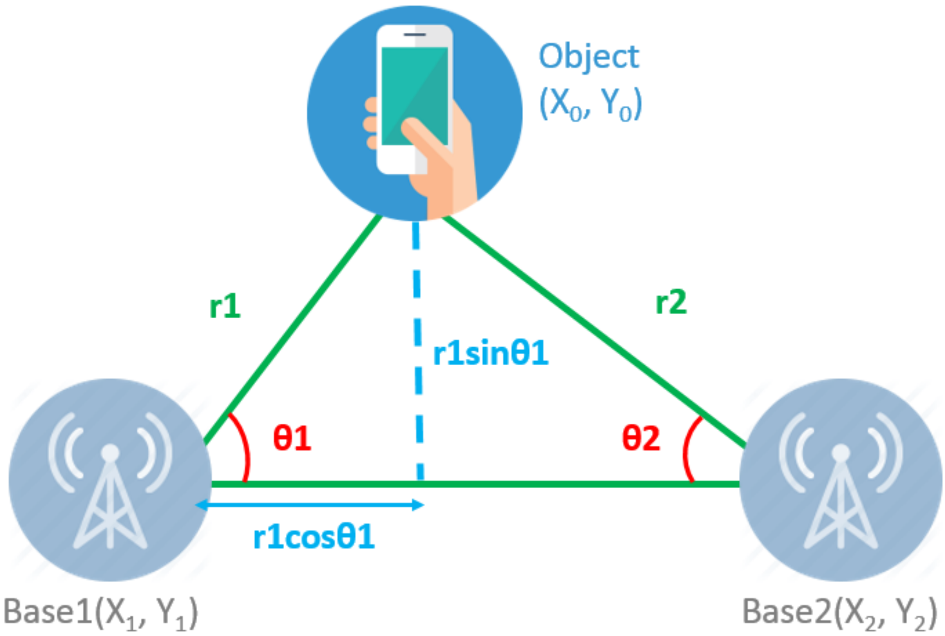

Figure 2-6. Angle of Arrival

Assume that the coordinates of base station BS1 and BS2 are (X1, Y1). (X2, Y2), and the position (X, Y) is the object which can calculated by the following formula:

$$X = r_1 \cos\theta_1 = r_2 \cos\theta_2 \qquad (2.9)$$

$$Y = r_1 \sin\theta_1 = r_2 \sin\theta_2 \qquad (2.10)$$

2.1.4 Triangulation Technique

Most of the outdoor positioning techniques use Triangulation Technique as the basic theory of positioning [17, 18] to find the user's location. On the other hand, Use the distance between the three base station to find the only intersection, which can be viewed as a user's location, shown in Figure 2-7.

We already know (X_1,Y_1), (X_2,Y_2), (X_3,Y_3) which represent a, b, c, and d. According to Bitzer theorem, we can get the equation in following:

$$\mathrm{b}^2 = \mathrm{x}^2 + \mathrm{y}^2 \quad => x = \frac{b^2 + a^2 - c^2}{2a} \tag{2.11}$$

$$\mathrm{c}^2 = \mathrm{y}^2 + (\mathrm{a} - \mathrm{x})^2 => y => \pm\sqrt{\mathrm{b}^2 - \left\{\frac{\mathrm{b}^2+\mathrm{a}^2-\mathrm{c}^2}{2\mathrm{a}}\right\}^2} \tag{2.12}$$

After know the two points made by two circle, we can determine the intersection of three rounds of the location through the formula (2.13).

$$\mathrm{d} = \sqrt{(\mathrm{X}_3 - \mathrm{X}')^2 + (\mathrm{Y}_3 - \mathrm{Y}')^2} \tag{2.13}$$

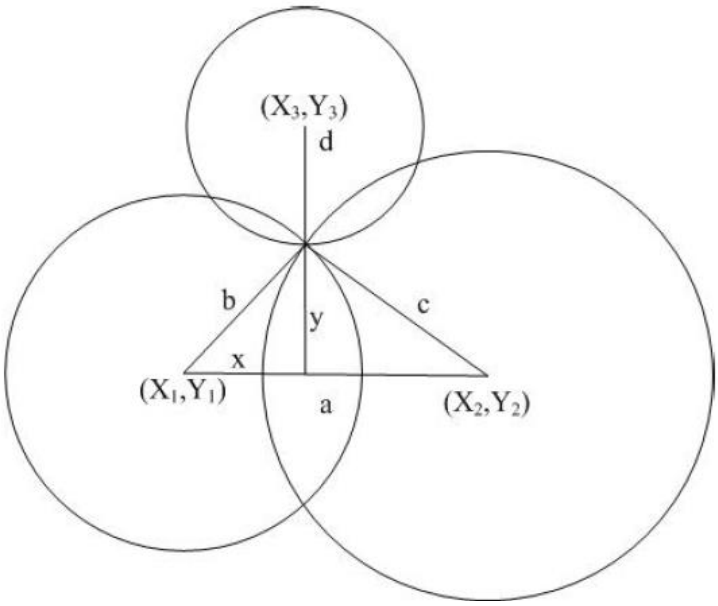

Figure 2-7. Triangulation Technique

2.1.5 Received Signal Strength Indicator, RSSI

Received Signal Strength Indicator (RSSI) [19] is the relative received signal strength in a wireless environment. It is an indication of the power level being received by the antenna of the user. Therefore, the higher the RSSI, the stronger the signal is, as we list in formula (2.13) We can calculate the position of the object by using three sets of distance data and the algorithm, as shown in figure2-8.

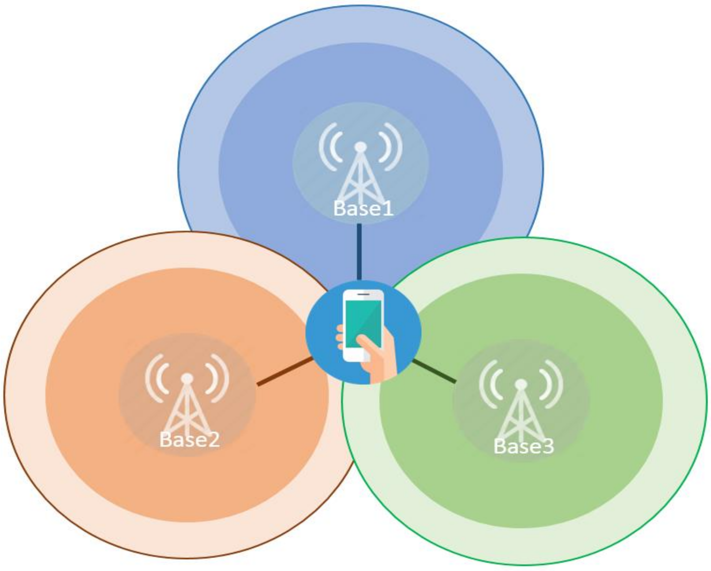

Figure 2-8. RSSI

$$\mathrm{RSSI} = -10\mathrm{n}\log_{10}(d) + A \qquad (2.13)$$

According to the formula (2.13), constant A represent the RSSI value received by 1 meter of the Node. Constant n is Propagation, and d is the distance between transmitter and the receiver (m), as shown in figure 2-9.

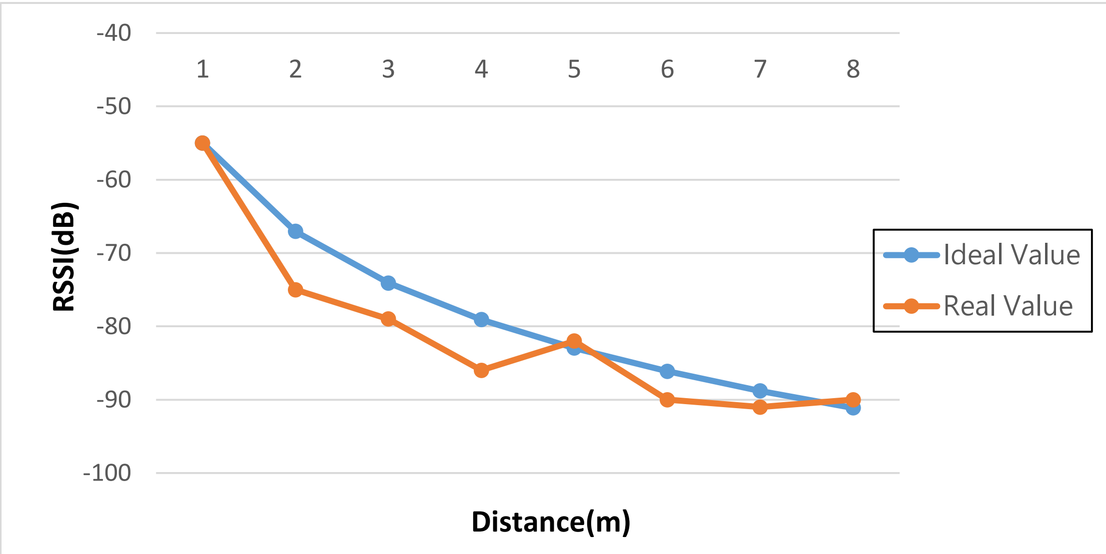

Figure 2-9. The relationship between RSSI and distance

2.1.6 Comparison of Algorithms

There are several techniques have been imposed on deciding the objects real-time location: Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA), and Received Signal Strength Indicator (RSSI), which have been proposed for a while. Although these systems turn out to be effective in outdoor environments, their performances indoors are relatively poor because of the multiple reflection and attenuation of RF signals. Not only for its trait that can be modified easily, but also don't require the synchronized signals to validate the results of positioning.

In this thesis, the indoor positioning algorithm is based on using Wi-Fi wireless network and iBeacon low-power Bluetooth (BLE) sensing network witch send and receive signal strength. After the signal processing, we can calculate the user's location (the location of the device).

Table 2-1. The table of Comparison in different algorithms

Positioning Algorithms	**Positioning basis**	**Restriction**
Time of Arrival (TOA)	Time of Signal Transmit	Requirement of Time synchronization device
Time Difference of Arrival (TDOA)	Time of Signal Transmit	Requirement of Time synchronization device
Angle of Arrival (AOA)	Angle of Received Signal	Requirement of High Accuracy Directional antenna
Received Signal Strength Indicator (RSSI)	Signal Strength	Need time to do signal acquisition

2.2 Positioning Sensor Technology

The vast majority of the positioning system must use the combination of sensing technology and positioning principle to achieve positioning. For example, the Global Positioning System (GPS) is a global satellite reservation system that provides a worldwide reservation of 24-sync orbit satellites throughout the world, with the TOA positioning principle [13] to calculate the location of the receiver. However, In the indoor positioning system must also use the sensing technology combined with the positioning principle can be achieved.

Due to the complexity of the indoor environment, such as shopping malls, airport lobbies, museum halls, warehouses, underground parking lots, libraries often require a handheld device or article with their users, facilities, etc. According to the limitation of positioning time, positioning accuracy and complex indoor environment and other conditions, there are many positioning sensor technologies used in indoor positioning.

Therefore, many studies propose the indoor positioning technology. We can see that the indoor positioning system (Indoor Position System, IPS) technology is actually used quite widely. But the vast majority of positioning system are using the wireless Sensing technology combined with the positioning principle to achieve the purpose of positioning.

In recently years, there are some common wireless technologies, such as Infrared Radiation [20, 21], Ultrasound[22], ZigBee[23], RFID[4, 24], Wi-Fi and Bluetooth. However, Wi-Fi and Bluetooth wireless transmission technology is the easiest way to achieve. Because these two technologies are the standard equipment inside the smart mobile device which also makes lots of application with indoors Positioning.

2.2.1 Global Positioning System, GPS

GPS is a satellite positioning system developed by the American government which has been widely used around the world. Main principles are to utilize over 24 satellites around the Earth which continuously broadcast radio signals. While the local surface GPS receiver simultaneously receives 3 or more satellite signals, it takes the satellites as the centers, and obtains the distances between GPS satellites and the ground using TOA as the radiuses, and produces three or more round faces. And then identifies the point of intersection of the round faces by the triangulation method which is therefore the location of the GPS receiver, as shown in figure 2-10. In general, it can be achieved by using four positioning satellites, and only requires the line of sight (LoS) between the GPS receiver and the satellites to increase the accuracy of about 5 meters to 40 meters. However, due to the impact from the shelter and multi-path delays of the satellite signals, it is not likely to implement the positioning for mobile users indoors [13]

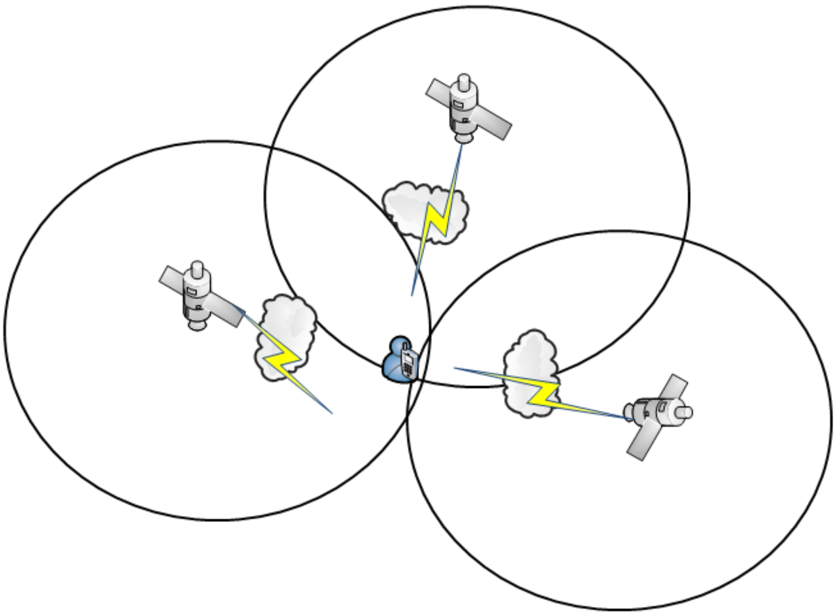

Figure 2-10. Global Positioning System

The technologies about GPS application have rapidly developed, not to mention the in- creasing demands for related services. Since the GPS can be easily operated and provide accurate positions, the use of it is very extensive. In addition to military uses, it can be applied to aerial, nautical, and terrestrial navigation. Alternatively, it aids the environmental, ecological, other information managements or land survey measurements and so on. Today GPS has become a basic mobile phone function. There are a lot of smartphones and handheld computers equipped with GPS, gradually bringing GPS into people’s daily lives.

2.2.2 Assistant Global Positioning System, AGPS

AGPS is a system that often significantly improves startup performance—i.e., time-to-first-fix (TTFF), of a GPS satellite-based positioning system. A-GPS is extensively used with GPS-capable cellular phones, as its development was accelerated by the U.S. FCC's 911 requirement to make cell phone location data available to emergency call dispatchers.

Standalone/self-ruling GPS devices depend solely on information from satellites. A-GPS augments that by using cell tower data to enhance quality and precision when in poor satellite signal conditions. In exceptionally poor signal conditions, for example in urban areas, satellite signals may exhibit multipath propagation where signals skip off structures, or are weakened by meteorological conditions or tree canopy. Some standalone GPS navigators used in poor conditions can't fix a position because of satellite signal fracture, and must wait for better satellite reception. A GPS unit may need as long as 12.5 minutes (the time needed to download the GPS almanac and ephemerides) to resolve the problem and be able to provide a correct location.

An assisted GPS system can address these problems by using external data. Utilizing this system can come at a cost to the user. For billing purposes, network providers often count this as a data access, which can cost money depending on the plan.

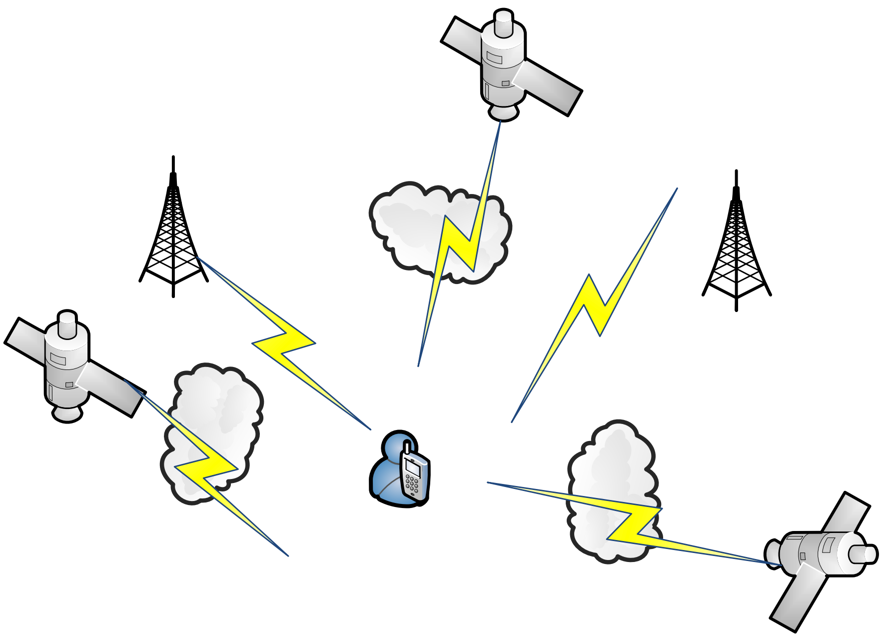

Figure 2-11. Assistant Global Positioning System

2.2.3 Infrared Radiation, IR Positioning

Infrared radiation, or simply infrared or IR, is electromagnetic radiation (EMR) with longer wavelengths than those of visible light, and is therefore invisible, although it is sometimes loosely called infrared light. It extends from the nominal red edge of the visible spectrum at 700 nm (frequency 430 THz), to 10 mm (300 GHz) (although people can see infrared up to at least 1050 nm in experiments). Most of the thermal radiation emitted by objects near room temperature is infrared. Like all EMR, IR carries radiant energy, and behaves both like a wave and like its quantum particle, the photon.

Besides, infrared radiation is also the first wireless sensor technology used in indoor positioning methods [25]. The Active Badge system provides a means of locating individuals within a building by determining the location of their Active Badge. This small device worn by personnel transmits a unique infra-red signal every 10 seconds. Each office within a building is equipped with one or more networked sensors which detect these transmissions. The location of the badge (and hence its wearer) can thus be determined on the basis of information provided by these sensors. As shown in figure 2-12.

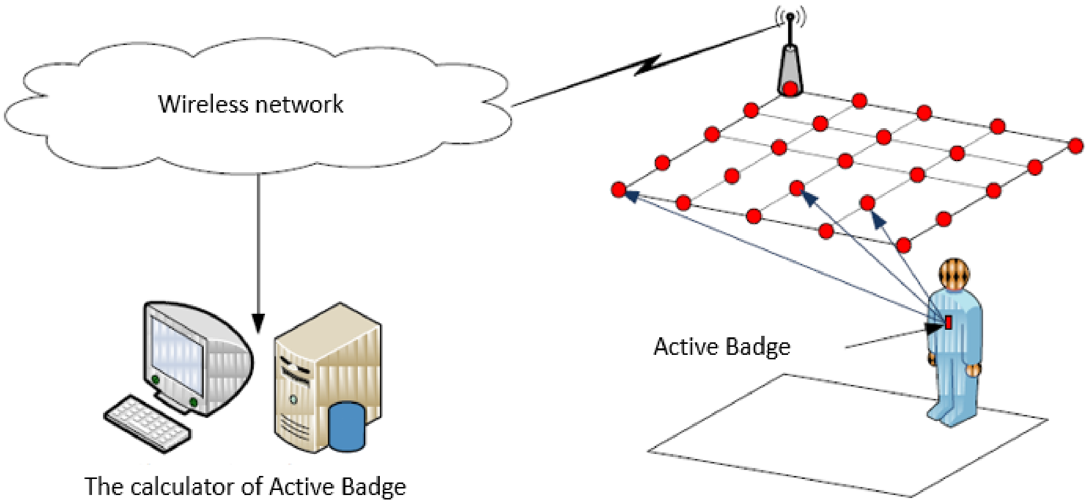

Figure 2-12. Active Badges System

Infrared positioning system has a good positioning accuracy, in the absence of interference under the conditions of light, infrared can locate the exact distance. But the infrared is easily disturbed by light, and can’t pass through the wall, items, Obstacles to the clothes, or the indoor wall or object barrier. And its power consumption is very high. To solve these shortcomings will greatly increase the system cost.

2.2.4 Ultra Sound Positioning System

The concept of the ultrasound positioning system is from the whales in the seabed through the ultrasound as a medium to communicate with each other, or bats using ultrasound to guide the flight and feeding, through the sound waves can be flying in the night inside. The principle of ultrasound is the vibration of the object and the vocal cords, the sound waves in the atmosphere, the human body can hear the audio from 15Hz to 20kHz, once more than 20Hz, then called him ultrasound. Ultrasonic signals can’t cross the wall, each room of the ultrasound signal will not interfere with each other, so commonly used as a regional identification.

In 1999, AT&T Cambridge researchers proposed the "Active Bat" positioning system [22], which uses time delay technology for ultrasonic transmission. Positioning principle is in the controller to send the frequency packet signal at the same time, the use of wired network to send a synchronization signal to the sensor to be targeted to carry the Active Bat tag received RF packet, the sensor to send ultrasonic pulse. The sensing gas measures the time difference (TOA) of the ultrasound, calculates the distance from the label and returns it to the controller. The controller calculates the time delay based on the distance measurement.

Cricket improved the "Active Bat" positioning system in 2000 [26]. Its design concept is composed of ultrasonic transmitter and positioning target embedded receiver, the use of triangulation [17, 18] to calculate the target positioning. Like the Active Bat system, the Cricket system utilizes ultrasound transmission time and radio frequency control signals, but the difference is that the positioning and calculation on the mobile receiver changes the shortcomings of the Active Bat system requiring a fixed sensor point.

The biggest problem of Ultrasonic positioning system is that encounter obstacles in the reflection characteristics will lead to systematic measurement results are not accurate, and the system is complex and expensive installation is also one of the factors considered.

The advantages of the Cricket system are privacy and the scalability of the scattered objects. The disadvantage is that the timing and processing of the ultrasonic and RF data are above the mobile receiver. The system lacks central management and monitoring, and the power consumption of the receiver is also very large. So it is not suitable for our indoor positioning.

2.2.5 ZigBee Positioning System

ZigBee, the name comes from the bee painting powder will jump “ZigZag” dance, the pollen position information effectively passed to other bee companions. ZigBee is a short-range, low-rate wireless network emerging technology, its biggest feature is the low power consumption and the cost is not high.

ZigBee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection.

ZigBee's network consists of three devices: the device for the coordinator, the device for the router and the node of the terminal[23].The coordinator is a node that can be initialized with the maintenance network. In each ZigBee network, there will only be one coordinator. When the coordinator to establish a network, it will broadcast the transmission frame. If there is a routing node received, it will send the frame and then join the network. The router is the primary connection and communication device of the ZigBee network and maintains a routing table that records the nodes that can communicate in the surrounding environment. The router periodically sends a message to the surrounding node to confirm whether a new node or an old node exists. Terminal nodes in the ZigBee network has no ability to establish routing, it is often regarded as the beginning and end of the network transmission.

Thousands of tiny sensors can communicate with each other for positioning through ZigBee wireless transmission technology. The sensor requires only a small amount of energy to transfer data from one sensor to another. The communication efficiency is quite good, with low power, low transmission green and short delay time.

Because of its transmission distance of 10 ~ 75 meters, more suitable for the use of several ZigBee network detection nodes to cover the entire indoor, compared to the Wi-Fi network, ZigBee network through three or more network detection node Received signal strength, coupled with the environment of the signal attenuation model, you can use the three-point moving object positioning.

However, when the signal attenuation model is not accurate due to the complexity of the indoor environment, it will lead to inaccurate positioning. Although the ZigBee network is very suitable for indoor positioning, the positioning signal attenuation model is susceptible to the indoor environment [5].

2.2.6 Radio Frequency Identification, RFID

Radio frequency identification usually contain three parts: tags, reader and the antenna. The reader will send a specific frequency of the radio signal to the RFID tag, and RFID tags (as shown in Figure 2-14) can sense the energy generated by the current, and send the location information which stored in chip back to achieve the purpose of indoor positioning.

So that a large number of RFID readers can be arranged in the indoor space. When the mobile device with RFID tags pass, you can know the approximate location of the mobile device. For general RFID devices, the effective distance is about 1 to 2 meters.

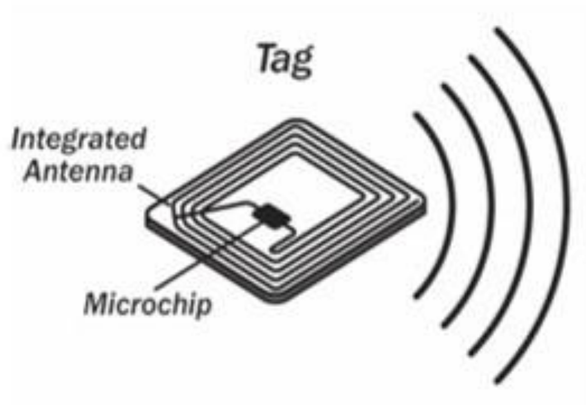

Figure 2-13. Tag of Radio Frequency Identification [24]

LANDMARC system is a typical indoor positioning system which using RFID [24].The system calculates the coordinates of the tag with the nearest neighbor algorithm and the empirical formula by analyzing and calculating the signal intensity RSSI of the reference tag and the pending tag. The system uses two different RFID Tags: reference Tags and tracking Tags. In the environment to arrange the known and fixed location of the reference Tags, RFID readers receive reference Tags signal strength data, by the system to determine the possible location of tracking Tag information.

LANDMARC system has several aspects of defects, first of all, the system positioning accuracy by the location of the reference label, the reference label position will affect the positioning accuracy; Second, the system in order to improve the positioning accuracy need to increase the density of reference labels, but higher density will produce the greater the interference, the impact of signal strength; third, because the formula to calculate the Euclidean formula to get the reference label and the distance to be determined, so the amount of calculation.

2.2.7 Wi-Fi Positioning Technology

Wi-Fi is a technology for wireless local area networking with devices based on the IEEE 802.11 standards. Wi-Fi is a trademark of the Wi-Fi Alliance, which restricts the use of the term Wi-Fi Certified to products that successfully complete interoperability certification testing. Devices that can use Wi-Fi technology include personal computers, video-game consoles, smartphones, digital cameras, tablet computers, digital audio players and modern printers. Wi-Fi compatible devices can connect to the Internet via a WLAN network and a wireless access point. Such an access point (or hotspot) has a range of about 20 meters (66 feet) indoors and a greater range outdoors. Hotspot coverage can be as small as a single room with walls that block radio waves, or as large as many square kilometers achieved by using multiple overlapping access points.

Location Technology Wireless Local Area Network (WLAN) is very suitable for outdoor positioning because of the relatively low cost of construction. WLAN positioning technology is using triangular positioning: signal strength as a reference data, with the signal attenuation model to calculate the degree of attenuation of the signal to reach the distance of the projections, and then use this information to locate. This approach requires prior construction of the signal attenuation model of the environment in order to accurately estimate the propagation distance by the degree of signal attenuation.

The feature of Wi-Fi network is the fast transmit speed but short distance, so the coffee shop or airport and other indoor environment provide stable and smooth wireless internet communications. Because there are so many Wi-Fi devices and signal, we can use these to provide location services by using positioning algorithms.

Most of the current wireless network positioning system using Received Signal Strength Indication, RSSI as a benchmark for comparison. When the radio wave signal is transmitted in the air, the signal has a relative attenuation due to the influence of the propagation medium along with the distance of the receiving distance. So we can use this coefficient to estimate the scope of the signal, but can’t determine the direction of the signal source, it developed a number of RSSI based on the value of the positioning method to locate the positioning method.

2.2.8 Bluetooth Positioning Technology

Bluetooth is a wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices, and building personal area networks (PANs). Invented by telecom vendor Ericsson in 1994, it was originally conceived as a wireless alternative to RS-232 data cables.

Table 2-2. Recent development of Bluetooth Technology

	1.1	**2.0+EDR**	**3.0+HS**	**4.0**
Release time (years)	2001	2004	2009	2010
Transfer rate	1Mbps	1-3Mbps	24Mbps	1-24Mbps
Feature	IEEE802.15.1	EDR transfer rate increased to 3Mbps	HS transfer rate increased to 24Mbps	Low power technology

Bluetooth is managed by the Bluetooth Special Interest Group (SIG), which has more than 30,000 member companies in the areas of telecommunication, computing, networking, and consumer electronics. The IEEE standardized Bluetooth as IEEE 802.15.1, but no longer maintains the standard. The Bluetooth SIG oversees development of the specification, manages the qualification program, and protects the trademarks. A manufacturer must meet Bluetooth SIG standards to market it as a Bluetooth device. A network of patents applies to the technology, which are licensed to individual qualifying devices.

The advantage of Bluetooth is easy to integrate in the mobile device, this technology is not only easy to promote and popularize and also a low-power and short-range wireless transmission technology that allows the terminal equipment to work longer, through the measurement of signal strength to locate.

At present, In-Location Alliance dominated the localization technology as Bluetooth. The reason is that using Bluetooth technology for TOA and triangulation algorithms is more efficient, lower cost compared to the Wi-Fi triangle positioning. Generally, the mobile phone which has a Bluetooth-enabled will be able to to achieve the function of positioning, and now the Bluetooth positioning technology is mainly used in small-scale positioning.

2.2.9 Comparison of Positioning Sensing Technology

This chapter compares various typical positioning systems. Because Infrared radiation (IR) and ultrasonic technology vulnerable to environmental barrier and interference, prone to energy loss in application and real-world., and ultra-wide frequency technology is relatively high cost. We compare the following wireless technology: ZigBee, RFID, Wi-Fi and Bluetooth Technology[27, 28]. Bluetooth wireless communication technology in the construction cost, practical application, power consumption and other performance, overall better than other technologies, as shown in Tabl.2-3.

Table 2-3. Comparison of each wireless communication technology

	RFID	**ZigBee**	**Wi-Fi**	**Bluetooth**
Transfer speed	106kbps	250kbps	300Mbps	1Mbps
Transmission distance (m)	1.5	50-300	100-300	1-50
Power consumption (mA)	0	5	10-50	<15
Error	<2m	<5m	<4m	<2m
Accuracy	Low	Medium	Medium	Medium
Cost	Medium	Medium	High	Low
Advantage	Wide applicability	Low power consumption. Low cost. Programmability	Fast speed, high popularity, high integration	Low power consumption, low cost, integrated, cross platform
Application	Electronic payment. Identification card. Commodity logistics tracking.	More partial industrial and engineering applications	In the personal intelligence device wireless Internet application	Easy to integrate with mobile devices and consumer electronics products.

In recent years, Wi-Fi and Bluetooth wireless transmission technology are the most used, because these two technologies are very common on the smart phone components, which also makes the application based on mobile phone positioning.

In this thesis, we focus on Wi-Fi and Bluetooth technology for the application of indoor positioning. And also we will do some experiments in these two technology in order to achieve higher accuracy.

2.3 Radio Wave Transmission

Due to the characteristics of the hardware and electromagnetic waves, it is possible to measure the different signal strength compared with the actual distance between the sensing nodes, even in the indoor positioning of the network. Because of the obstacles in the indoor environment, climatic factors, walls, beams and columns, or narrow aisles cause such a situation. Even if the signal is slightly unstable, it will also seriously affect the overall positioning results. For the attenuation effects of radio waves in the indoor environment, such as path attenuation, shadowing effect and multi-path effect, we will have some discussion in this chapter. [29, 30].

2.3.1 Reflection and Refraction

Reflection is the abrupt change in the direction of propagation of a wave that strikes the boundary between two different media. At least some part of the incoming wave remains in the same medium. Assume the incoming light ray makes an angle θi with the normal of a plane tangent to the boundary.

Then the reflected ray makes an angle θr with this normal and lies in the same plane as the incident ray and the normal. Refraction is the change in direction of propagation of a wave when the wave passes from one medium into another, and changes its speed. Light waves are refracted when crossing the boundary from one transparent medium into another because the speed of light is different in different media.

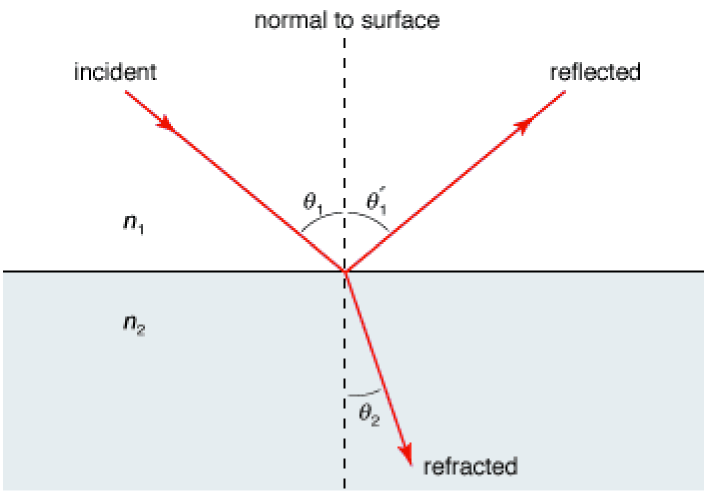

Figure 2-14. The Reflection and Refraction of Radio Wave [29]

2.3.2 Diffraction

The diffraction takes place between the transmitter and the receiver. Diffraction manifests itself in the apparent bending of waves around small obstacles and the spreading out of waves past small openings, as shown in Figure 2-15. Diffraction is a transmission of electromagnetic waves when there is no direct path to transmit and receive.

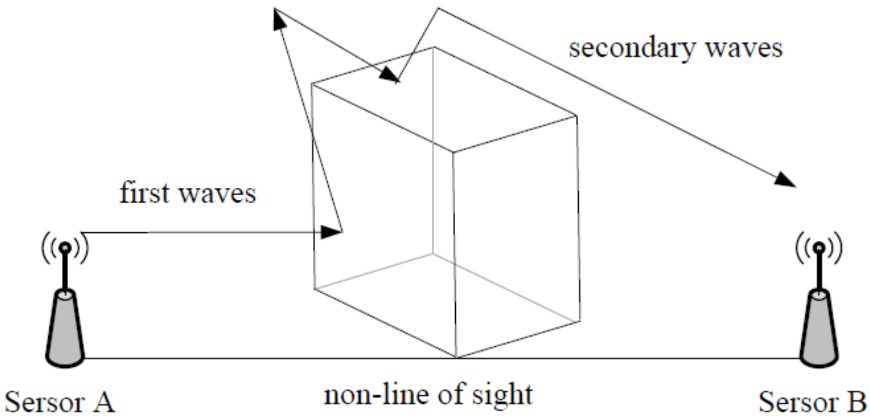

Figure 2-15. The diffraction of radio wave [30]

2.3.3 Scattering

When the size of the object hit by the electromagnetic wave and the propagation of the wave wavelength is almost or less than the wavelength, the impact of radio waves for the object as a multi-faceted reflector, so that the energy of electromagnetic waves scattered to the direction, as shown in Figure 2-16.

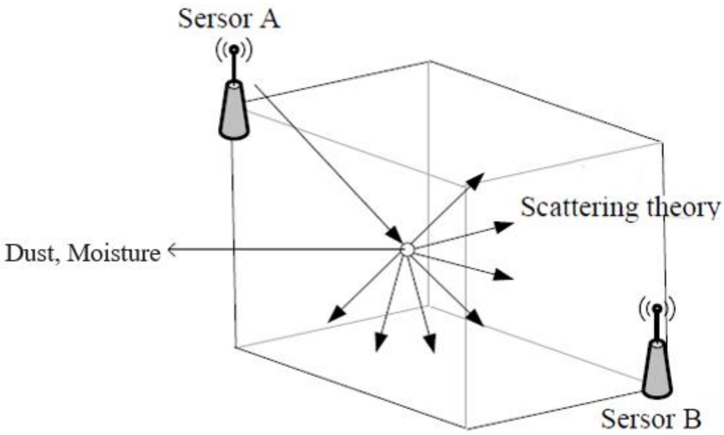

Figure 2-16. The scattering of radio wave [30]

2.3.4 Multipath Effect

When the electromagnetic wave signal in the process of transmission encountered obstacles and reflection, diffraction and other phenomena, so that the original signal sent by the original path with the original path to the receiving end of the phenomenon, we call it "Multipath Effect", as shown in Figure 2-17.

In a Global Positioning System receiver, Multipath Effect can cause a stationary receiver's output to indicate as if it were randomly jumping about or creeping. When the unit is moving the jumping or creeping may be hidden, but it still degrades the displayed accuracy of location and speed.

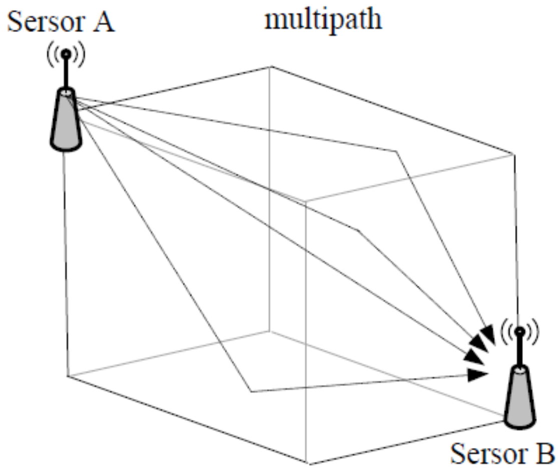

Figure 2-17. Multipath Effect [30]

Multiple path effects can affect the main signal in different situations, so that the signal received by the receiver to reduce the signal strength, signal enhancement, signal damage or signal offset each other. When the electromagnetic waves propagate in the indoor environment, the indoor environment is more complex than the general environment, and also in the general indoor space is often the movement of personnel, making the multi-path effect is more serious and unpredictable. It is not possible to use a simple mathematical formula to signal the relationship between the signal strength and distance between the sender and the receiver, which also increases the difficulty of using the radio wave to provide the indoor location service

At present, the most common way to reduce multipath effect is using multi-antenna at the receiving end to receive the signal, but this will increase the manufacturing cost and take up more space.

Chapter 3. Indoor positioning system design

3.1 Design steps

According to the relevant literature to explore and reference, we proposed based on iBeacon and Wi-Fi indoor positioning system of several steps process

Step.1：Deploy the device and scanned the signal for analysis.

(1) iBeacon transmitter

We have to deploy some iBeacon devices in the target indoor area environment to enhance the positioning accuracy. After setting up iBeacon devices, we collect the signal strength (RSSI) of each point in the target area and analyze the signal strength results, including signal strength, error distance range. Consider the factors that affect the decision before we decide to build the number of Beacon

(2) Wi-Fi wireless network base station

Then we scan the existing Wi-Fi wireless network base station(AP) in the target indoor area environment of the signal strength, stability, error distance range. Finally, we select the number and location of the Wi-Fi wireless base stations that we are going to use.

Step.2：Draw the Indoor environment map

Then, an indoor map for displaying the user's path and location is prepared, and the indoor positioning is not only used to guide the user, but also to mark the user's location. Although mapping the interior map is neither difficult nor complicated, the map should be carefully prepared to make the indoor positioning system more accurate and convenient. Good indoor map presentation, can provide users with a better experience.

Step.3： Radio Map Construction

After marking the measurement points on the map, then we have to collect accurate iBeacon signal fingerprints at each measurement point. This is a very critical step in which at least 20 to 30 fingerprints are collected at a measurement point. Beacon signal fingerprint collection in a large indoor space may be difficult and time consuming. When we collect the fingerprint of iBeacon signal, we have to pay attention to the collection of signal interval, the number of collection, and each device height.

Step.4： System Construction

After preparing the indoor map and collecting the fingerprint, we can build the system. And then the system for repeated testing and correction.

3.2 System Structure

In this chapter we will explain the thesis presented in this thesis on the indoor positioning system processing process on the concept and the main application of several modules. This thesis uses the fingerprint positioning system, which mainly includes two stages as shown in Figure 3-1 and Figure 3-2, including Offline Training stage and Online Run-time stage.

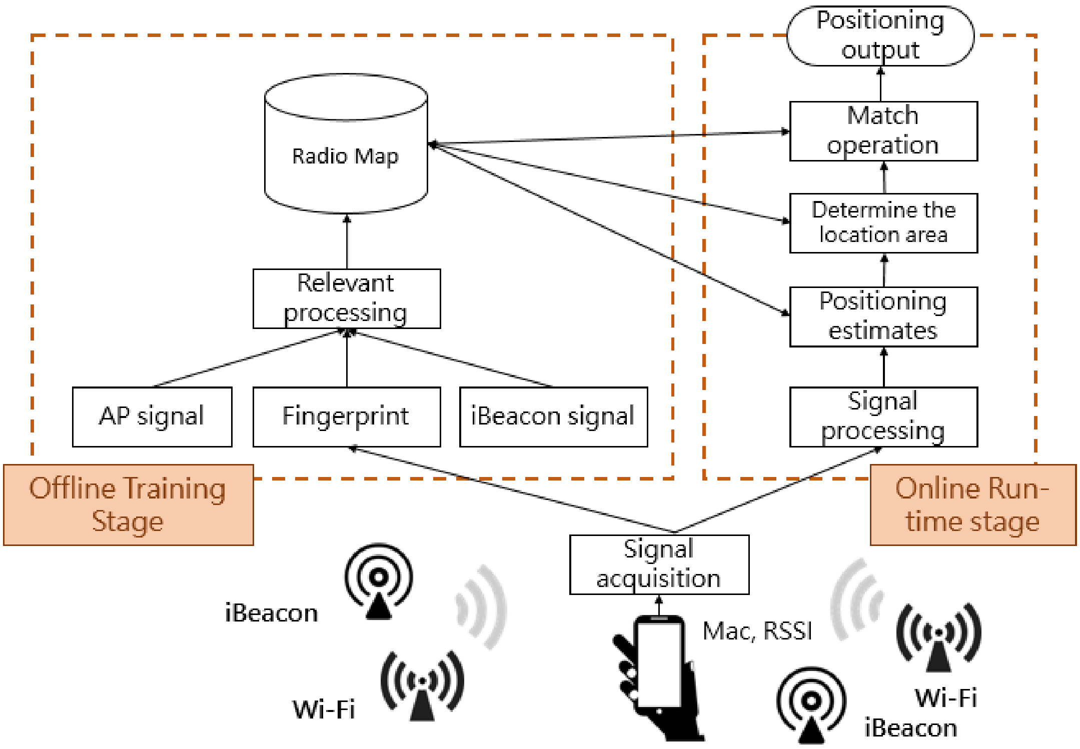

Figure 3-1. The process of the indoor positioning system

The goal of offline training stage is to build a location fingerprint database or a radio map. In other words, we have to establish a database on the relationship between signal strength and acquisition point location. The mobile user sequentially collects the wireless signals from different signal sources at each reference point, stores the information of the RSSI, the MAC address and the reference point position into the database, and processes the collected data to reduce the data to improve the positioning accuracy.

Smartphones with Wi-Fi and Bluetooth capabilities are used to collect information on RSSI Fingerprints at all training sites, and this receive signal strength fingerprint contains all the media that is scanned around the base station and iBeacon Control address (MAC) information and the received signal strength (RSSI) corresponding to these MACs, and these received signal strength must be filtered to remove the more severe beating signals and to exclude the effects of the smartphone in different directions.

Commonly used fingerprint matching algorithms include nearest neighbor algorithm, K nearest neighbor algorithm(KNN), neural network, and support vector machine (SVM), etc. These methods are used to get the RSSI vector that best matches the measured RSSI vector in the Radio-map.

However, when the fixed area increases, the reference point acquisition density increases, Radio map data will continue to increase, then the calculation of the matching calculation of a sharp increase. This is a significant challenge for mobile devices with relatively limited resources and computing power, which severely limits the positioning of mobile handsets. Therefore, it is necessary to reduce the fingerprint data of the collected Radio map after ensuring the accuracy of positioning.

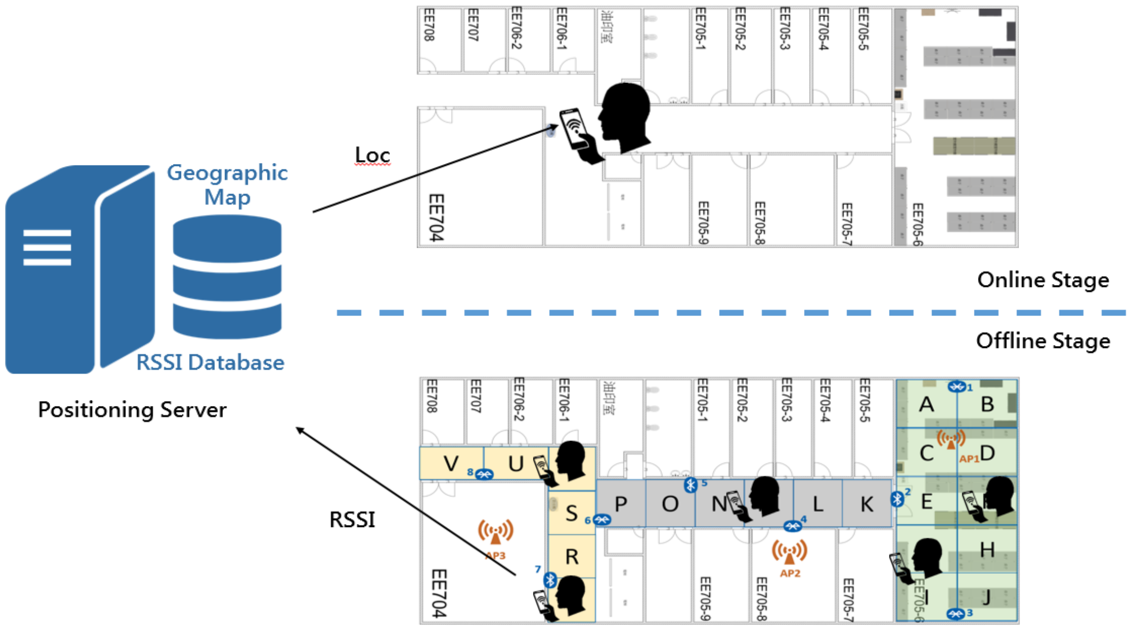

Figure 3-2. The concept of the indoor positioning system [37]

In online Run-time stage, when a user who first comes to this unfamiliar space wants to know where he is, the user can use the smartphone to scan the wireless signal around the location by the application. After that, the application will send the received signal strength, direction and other information back to the positioning system.

The positioning system will filter the signal and take it as the value of received signal strength.

And based on the direction of the smart phone, the positioning system will calculate the user's location by referring to the database of the received signal strength fingerprint and the signal footprint previously established in the same direction. The relevant processing flow and the design of the module will be described in detail below.

We divide the entire system into two parts: Mobile Application and Server Application, as shown in Figur3-3. We will first receive the signal information, including the MAC address of each device and the signal strength transmitted to the server inside, and the developers can use the back-end platform to see our server which collected data of.

And our data will be matched with the original collection of samples collected by the fingerprint signal in the server. We can calculate the user's location through the positioning algorithm and the comparison of the model, and the results will be calculated and send back to the phone as well.

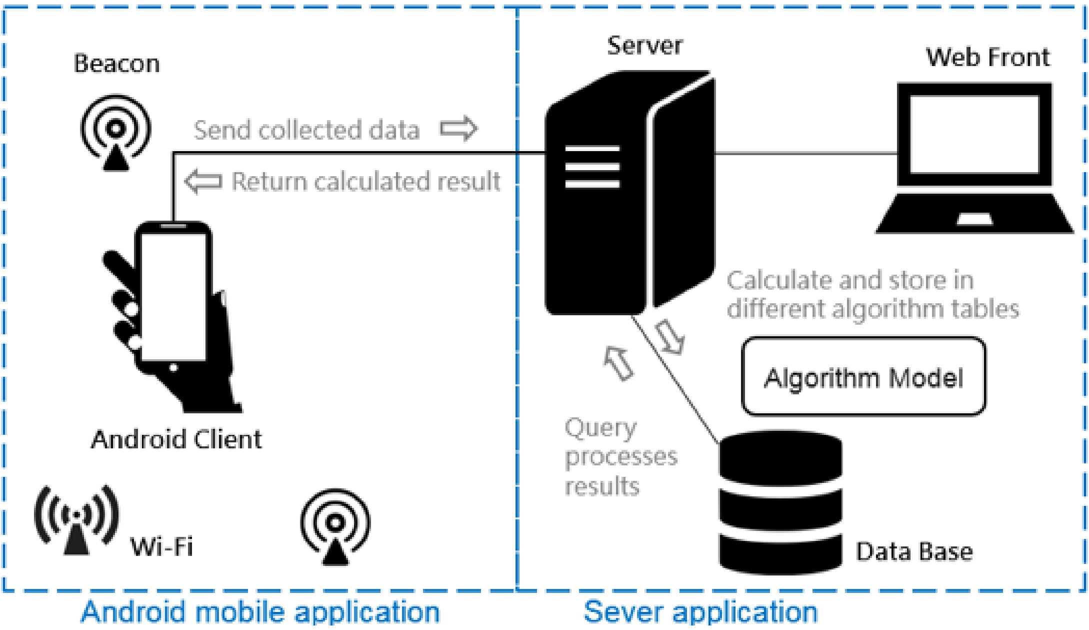

Figure 3-3. Positioning system flow diagram [37]

Wi-Fi has had congenital conditions for indoor positioning system, but there are also a lot of problems difficult to solve, such as that for most of the indoor environments, there are often many existing Wi-Fi signals, but the location of Wi-Fi access point (AP) does not meet the demand for indoor positioning. Adding other APs not only makes interference to the existing signal, but also cannot ensure the positioning accuracy of the actual upgrade. As the latest Bluetooth technology applied to the indoor positioning, although there are still some problems, the relatively stable signal and the short coverage distance of iBeacon can precisely make up the shortages of Wi-Fi positioning system.

3.3 Hybrid System Architecture

3.3.1 Use iBeacon signal as the basis for indoor positioning

We built a number of Beacon signals in the interior space. The principle of beacon deployment is covering the general fine construction so that each one Beacon can be appropriate to cover the signal to the indoor area. As Beacon can transmit the distance of 1 ~ 15m (radius 6 ~ 7m), so the laying of each Beacon distance of about 5 ~ 6m.

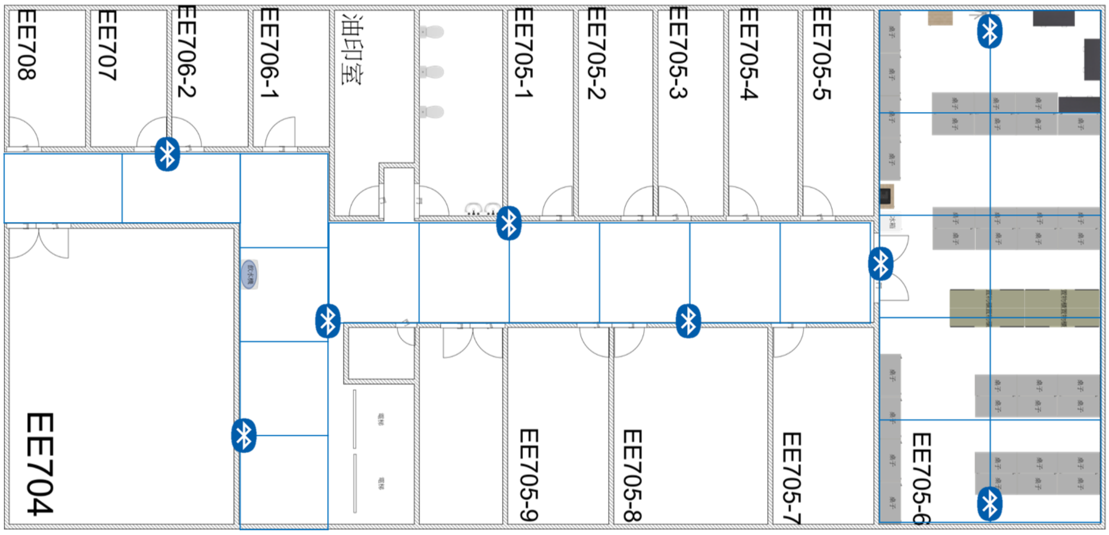

Figure 3-4. .iBeacon deployment in the interior space

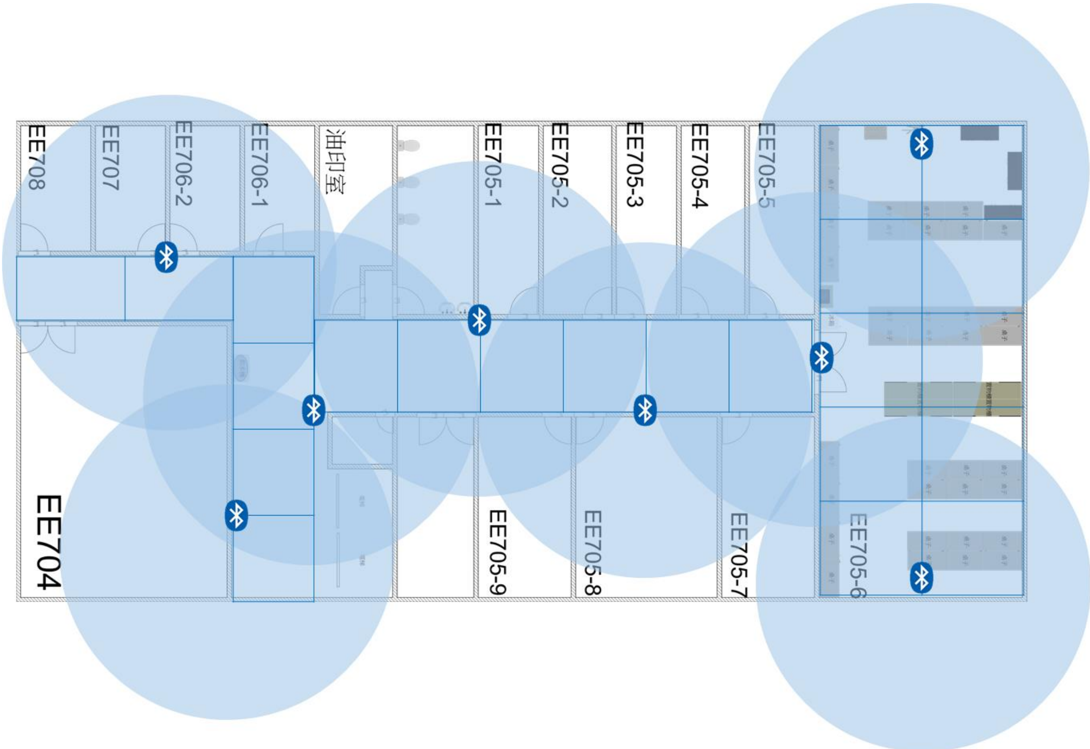

Figure 3-5. iBeacon signal coverage in the interior space

3.3.2 Use Wi-Fi AP signal as the basis for indoor positioning

In today's surroundings are full of Wi-Fi signal environment, first of all we go inside the interior space to scan the existing Wi-Fi signal, as shown in Figure 3-6. We found that there were very many and messy Wi-Fi signals in a floor, but these Wi-Fi signals were self-built and could not provide a permanent stable signal.

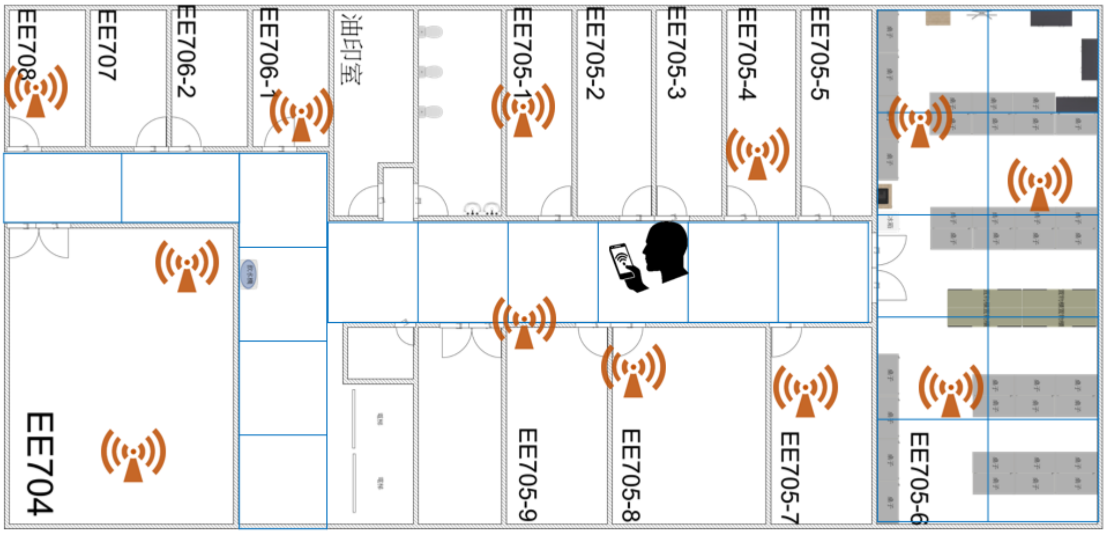

Figure 3-6. Scan the Wi-Fi AP signal in interior space

We do not increase the cost and not let this environment signal more mess, we chose a compromise method. We select a few stable signal source as a fingerprint feature access basis, as shown in Figure 3-7. The green Wi-Fi Aps are chosen as a fingerprint feature built signal source.

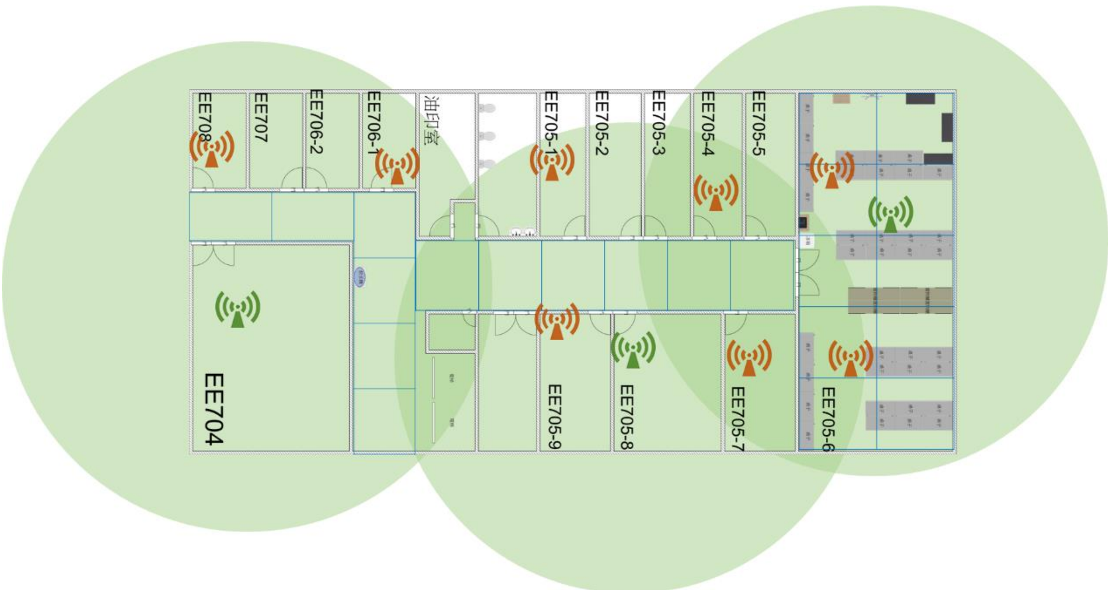

Figure 3-7. Wi-Fi signal coverage in the interior space

3.3.3 Use Wi-Fi and iBeacon signal as the basis for indoor positioning

This thesis presents an indoor hybrid system architecture that is intended to make up for their own deficiencies with Wi-Fi and BLE. The power consumption of Wi-Fi is much larger than iBeacon. While the Wi-Fi positioning limit of 3 to 5 meters, iBeacon accuracy can be within 1 meter of error. But if we use iBeacon signal as a signal basis for indoor positioning, the maintenance costs and construction time will become more complicated.

Wi-Fi can achieve greater coverage (current standard, Bluetooth 10 meters, Wi-Fi up to 100 meters), but Bluetooth can complement it. For example, in the Wi-Fi coverage of the place, there are many real estate is not covered by Wi-Fi, you can through the Bluetooth to achieve precise positioning.

Now the solution requires only 1-2 small BLE tags. iBeacon only trigger itself does not have the data transmission function, and Wi-Fi is equipped with data transmission function based on indoor navigation shopping and information push, must have the data transmission function, so as to achieve push function.

Wi-Fi implement the regional positioning and iBeacon achieve the meticulous positioning, as shown in Figure 3-10.

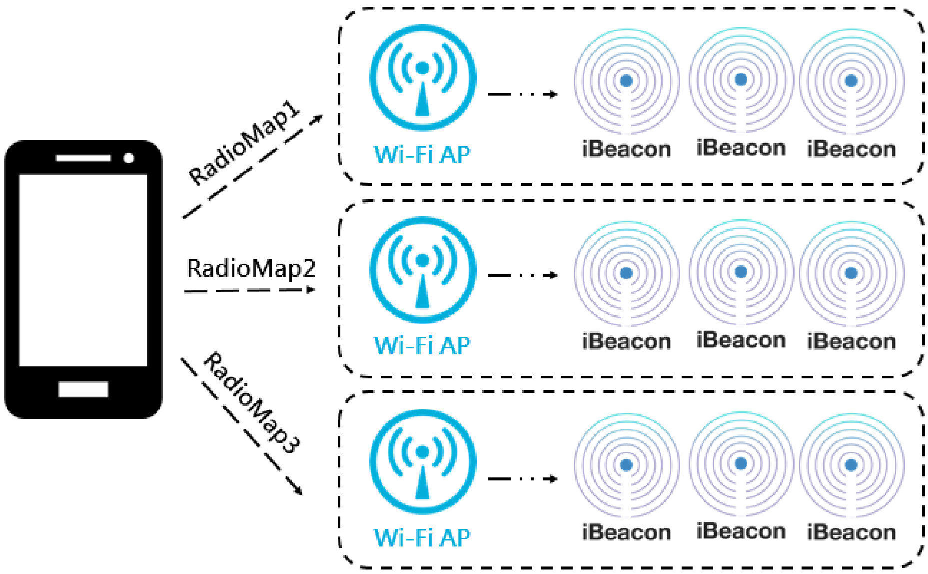

Figure 3-8. The concept of the hybrid indoor positioning system architecture [37]

Therefore, this thesis presented the indoor hybrid system architecture, which is to use Wi-Fi signal as a large area of the foundation. After the division of the region, by the more accurate iBeacon signal to do accurate positioning, as shown in Figure3-8. Beacon can also be used as a fingerprint feature for our indoor positioning at the same time, as shown in Figure 3-9.

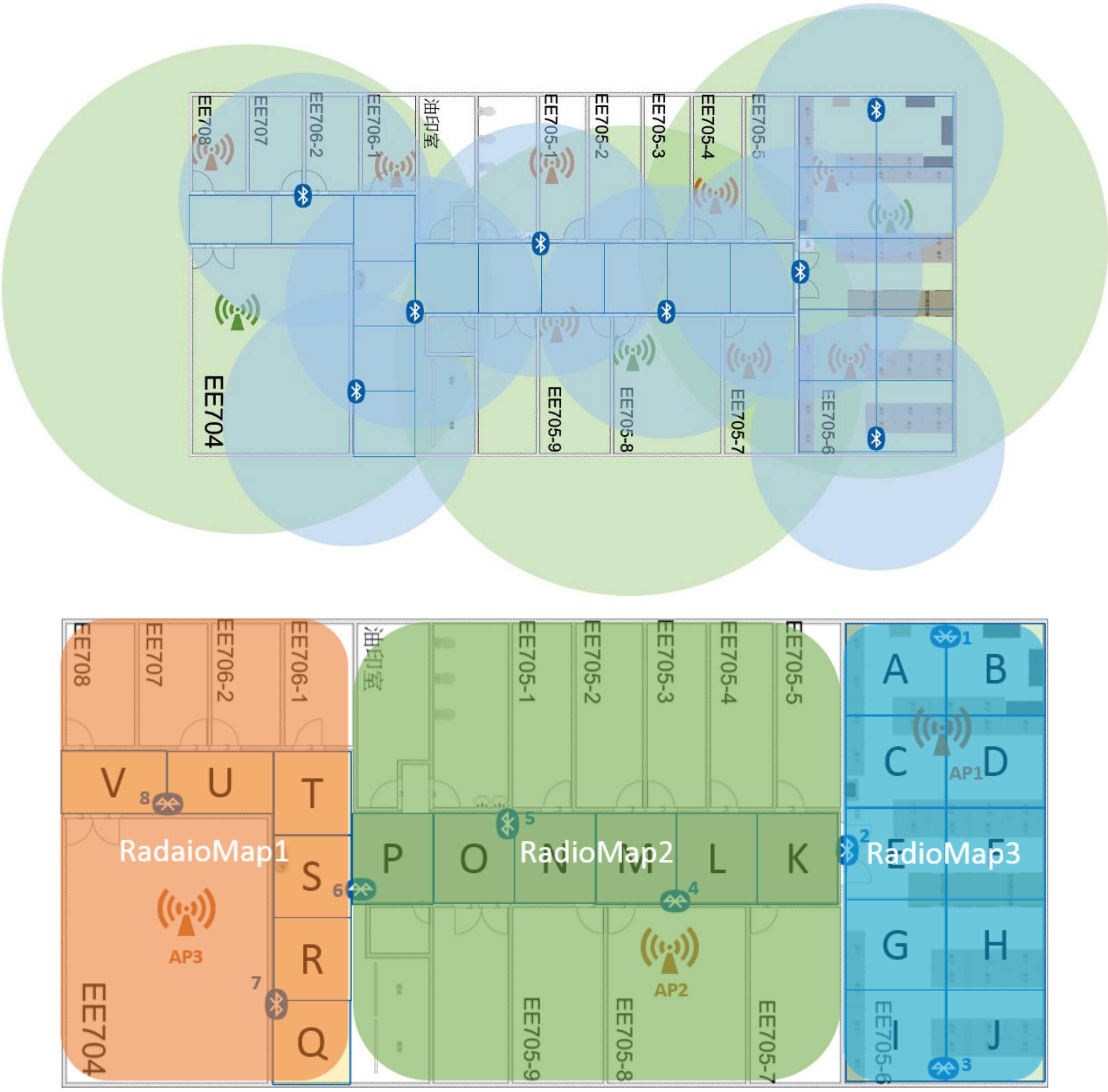

Figure 3-9. The Radio Map of hybrid indoor positioning system

Figure 3-10. The Situation of hybrid indoor positioning system [3]

3.4 Construct the database of RSSI fingerprint

3.4.1 iBeacon

Apple announced iBeacon [31] which provides a higher level of location awareness in 2013. iBeacon is an efficient, cross-platform, built-in, technology for both Android and iOS devices, which uses Bluetooth Low Energy (BLE) for indoor positioning. Since the technology utilizes the BLE, it offers users less power consumption, showed in Fig1. The technology requires devices supporting BLE, which is the 4th major vision of the Bluetooth specification. A device which generates iBeacon advertisements is called beacon. Beacons establish a region around them by iBeacon signals.

Apple's iBeacon is an indoor positioning technology that is meant to be used with the BLE enabled beacons, it uses latest BLE4.0 technology, with low power consumption, low latency and transmission distance characteristics. The requirement of high-precision indoor positioning technology was best to meet with combination of software and hardware. As compared to previous Bluetooth technology, iBeacon periodically transmits a broadcast signal that accurately determine user's current location by using positioning algorithm.

Figure 3-11. The Estimote iBeacon [31]

iBeacon is Apple's version of the Bluetooth-based beacon concept, which allows Bluetooth devices to broadcast or receive tiny and static pieces of data within short distances. In simplistic words, it consists of two parts: a broadcaster (beacon device) and a receiver (smartphone app). The broadcaster is always advertising "I am here, and my ID is…", while the receiver detects these Bluetooth radio packets and does whatever it needs to do based on how close or far it is from them.

With iBeacon, Apple has standardized the format for BLE Advertising. Under this format, an advertising packet consists of four main pieces of information. Beacons transmit advertisement data frames containing three identifying fields:

- **UUID：**

  Universally Unique Identifier is a 16 bytes string (128 bits integer) used to differentiate a large group of related beacons. UUID can be used as an ID for all beacons used in an application.

- **Major /Minor Number：**

  Major value is a 2 bytes string (16 bits integer) used to distinguish a smaller subset of beacons within the larger group. Major can be used to differentiate between beacons with same UUIDs.

  Minor value is a 2 bytes string (16 bits integer) meant to identify individual beacons. Minor can be used to differentiate between beacons with the same UUIDs and Major values.

- **TX Power：**

  TX Power is used to determine proximity (distance) from the beacon. How does this work? TX power is defined as the strength of the signal exactly 1 meter from the device. This has to be calibrated and hardcoded in advance. Devices can then use this as a baseline to give a rough distance estimate.

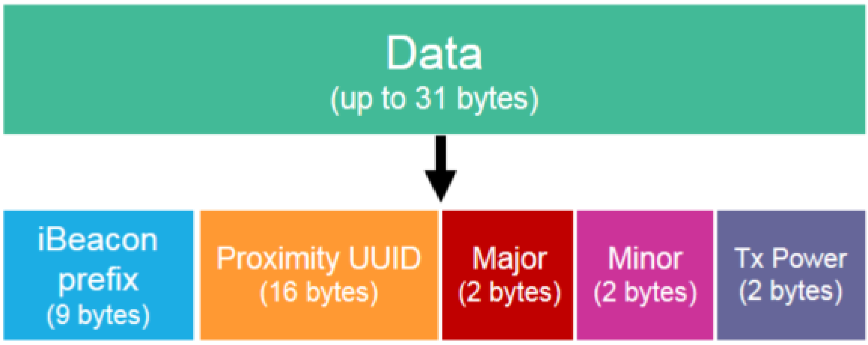

Figure 3-12. Beacons transmit advertisement data [31]

Beacons can be attached to the movable objects which are not tied to a location. For example, a beacon can be used in a temporary booth of an organization and define it as a region of the organization.

3.4.2 Collecting Data

There are three stages during measurement phase. Because our positioning method is based on RSSI, we mainly use RSSI values of the beacons and Wi-Fi APs to estimate the location. The first stage is signals collection. The application collects RSSI from each iBeacon {B1, B2, …, BN} and Wi-Fi APs {W1, W2, W3} in different subarea(A-V), where N is the total number of beacons.

As showed in the Figure 3-2, the mobile application collects the scene features and the coordinates of a specific location and transfers them to the server. Then the server calculates the result and returns it to the mobile client. During the calculation, the server calculates needed parameters and stores them in the database. A typical table for Collecting Data in the database is as below.

Table 3-1. The Pattern of Collecting Data Table

	Field	**Type**	**Length**
Wi-Fi	SSID	VARCHAR	255
	BSSID	VARCHAR	255
	RSSI	INT	16
iBeacon	UUID	VARCHAR	255
	Major	INT	16
	Minor	INT	16
	RSSI	INT	16

After signal collection, we store RSSI signals into database file. The second stage is selection of the nearest beacon.

$$\boldsymbol{D_L} = \sqrt{\sum_{i=1}^{N} \frac{(r_{Bi} - R_{Bi})^2}{N}} \quad (3.1)$$

In this thesis, we derive training data RBi (RSSI of beacon ID B at observation point), by counting all beacon messages. Then, a testing data is selected from beacon messages. Testing data rBi (RSSI of beacon ID B), is derived by counting all beacon data in the testing messages. The formula represents difference of training and testing data, as shown in Eq.3.1.

$$R_L = \arg\min(D^k)_{\mathrm{k=1,2,3...p}} \quad (3.2)$$

In order to deal with RSSI variation, we firstly use the filter, which pick up the minimum distance as the location point, as shown in Eq. 3.2

When positioning the user's location, the received signal strength fingerprint is used as a reference for indoor location discrimination. In order to collect the received signal strength fingerprints consisting of the received signal strength of any Wi-Fi APs and Beacons scanned by the surroundings, smartphones with Wi-Fi and Bluetooth functions are used to collect images that are scanned around the training site of the received signal strength information, including the AP's Mac, RSSI, Beacon's Mac, UUID, RSSI and so on.

If the received signal strength can be collected at the training site, the received signal strength fingerprint will be able to discern the target position and distinguish the received signal strength in different directions and rotations to a higher level positioning accuracy. When collecting the received signal strength, we use the gyroscope and gravity sensor on the smartphone to distinguish the received signal strength collected in different orientations and rotations.

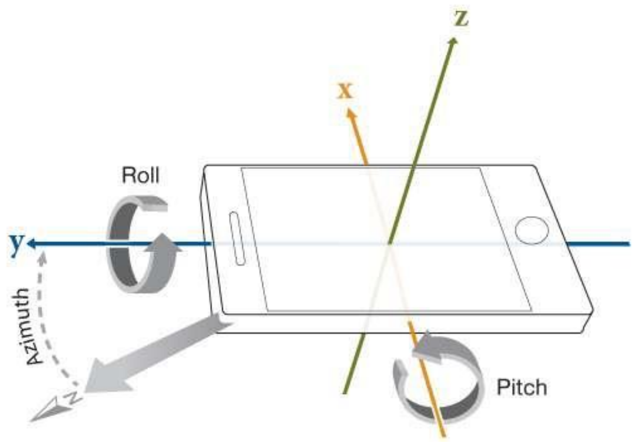

Figure 3-13. The gyroscope and gravity sensor on the smartphone

Azimuth (γ) and the direction of rotation (θ) based on the gyroscope and gravity sensor, and the azimuth of the collected received signal strength is calculated by (3.3) and (3.4).

$$\text{Orientation}=\begin{cases} \text{North(N), if } 315 < \gamma \leq 45 \\ \text{East(E), if } 45 < \gamma \leq 135 \\ \text{South(S), if } 135 < \gamma \leq 225 \\ \text{West(W), if } 225 < \gamma \leq 315 \end{cases} \tag{3.3}$$

$$\text{Rotation}=\begin{cases} \text{Horizontal(H), if } -22.5 \leq \theta < 22.5 \\ \text{Rotate 45(R) , if } -67.5 \leq \theta < -22.5 \\ \text{Vertical(V), if} -112.5 \leq \theta < -67.5 \end{cases} \tag{3.4}$$

3.4.3 Signal Filtering

In the wireless signal transmission process, the signal is easily due to external factors such as the situation of noise (such as the impact of multiple path propagation). So we have to filter the signal for the processing, so that most of the normal distortion of the signal through the system, and other errors in the larger noise filter to enhance the use of signal-based indoor positioning system correctness.

- **Mean Filter**

The mean filter is a linear filter, a simple and widely used filtering method. Mean filter is the measured value of the signal after the sum of the average value. This filter can remove the error of relatively large signal noise value, the signal will become more smooth, as shown in Figure3-7. So the filter has a "low pass" effect, the formula is as follows:

$$RSSI_{avg} = \frac{1}{n+1}\sum_{i=1}^{j=n} RSSI_{ij}\,, i = 1,2,3 \ldots \ldots M \qquad (3.5)$$

i is the number of signal transmitter, M is the number of signal transmitter, j is the index of measurement time of the RSSI, n is the total number of RSSI.

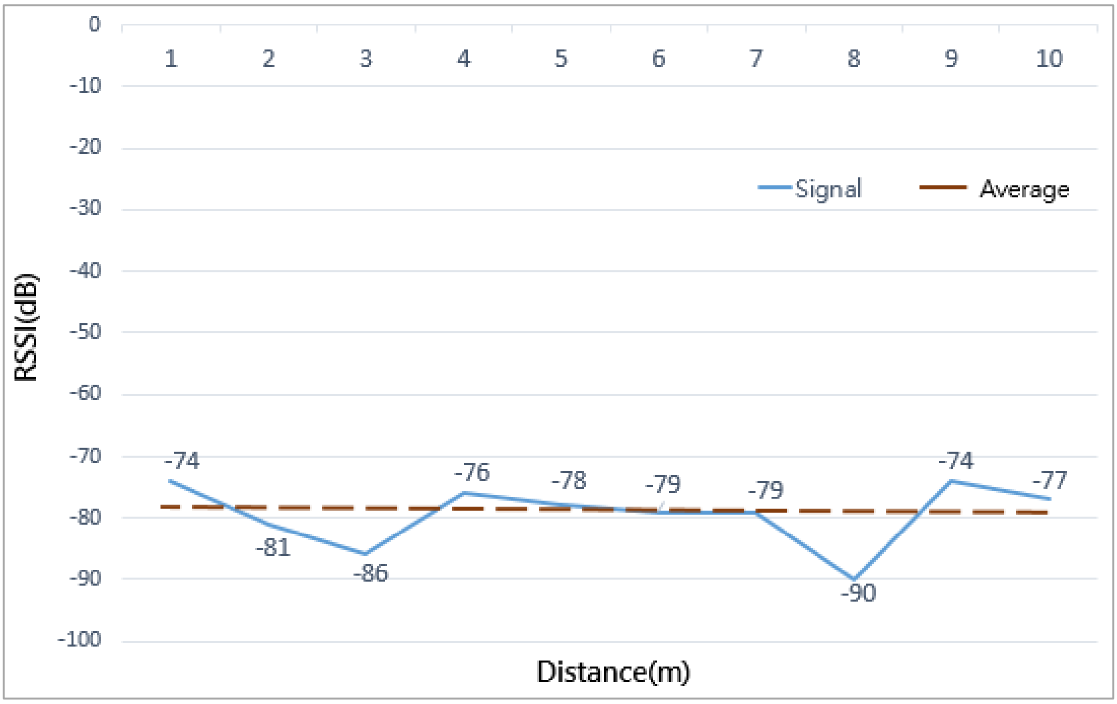

Figure 3-14. The result of Mean filter

- **Median Filter**

The median filter is a non-linear filter, which proposed by Tukey in 1974 [32]. Median is also a low-pass filter, it can eliminate the noise of the surge. The signal value of the measurement record is sorted by the sorting method from small to large order, and then the intermediate value is the output value.

If the sampling data of the statistical data RSSI (i) is {RSSI(i)| i=1,2,3……N}. using the sorting method from small to large order, and then sorted after the middle of the output value, the formula is as follows:

$$\text{RSSI}_{(\text{med})}=\begin{cases} RSSI_{(N/2)} & ,\text{n} \in \text{odd number} \\ \frac{RSSI_{(N/2)}+RSSI_{(N/2)+1}}{2} & ,\text{n} \in \text{even number} \end{cases} \quad (3.6)$$

For example, when we obtain a set of RSSI data sets N:

$$RSSI(\text{N}) = \{-80, -69, -72, -79, -74, -68, -76, -78, -71 - 78, -79\}$$

Then use the sorting method from small to large order, we can get:

$$RSSI(\text{N}) = \{-68, -69, -71, -72, -74, -76, -78, -78, -79, -79, -80\}$$

Then take the middle value:

$$\text{RSSI(med)} = RSSI_{(N/2)} = -76$$

When the statistics are even, as follows:

$$RSSI(\text{N}) = \{-68, -69, -71, -72, -73, -74, -76, -78, -78, -79, -79, -80\}$$

Then we average the two intermediate values of the data

$$\text{RSSI(med)} = \frac{RSSI_{(N/2)} + RSSI_{(N/2)+1}}{2} = \frac{(-74) + (-76)}{2} = -75$$

The median filter can be smooth filtered because it is not affected by particularly large or particularly small values in the data.

3.5 Selection of Algorithms

This thesis uses the K-Nearest Neighbor (KNN), support vector machine (SVM), and the neural network (ANN) to train the collecting data in the actual situation and we use these as a model of indoor positioning.[33]

In order to understand whether the method is used for indoor positioning classification mechanism, in the fourth chapter we will do some experimental analysis.

3.5.1 K-Nearest Neighbor, KNN

In pattern recognition, the k-nearest neighbor's algorithm (k-NN) is a non-parametric method used for classification and regression. In both cases, the input consists of the k closest training examples in the feature space. The output depends on whether k-NN is used for classification or regression:

K-Nearest Neighbor classification is based on the fact that the characteristic distance of the same category is relatively close. Therefore, for an unknown category of information, as long as the identification of the training data and the data closest to the point, you can determine the type of this data should be the closest and the type of point is the same. KNN is one of the most intuitive classifications that, when measuring various classifiers, is considered the most basic classifier to compare performance with other more complex classifiers.

The similarity of KNN is generally judged by the size of the Euclidean distance, and the smaller the Euclidean distance in the same category.

The input data is based on the intensity characteristics and the nearest neighbor method is used to find the most similar K sample data, and the spatial position of the input data is estimated by using the known spatial position of the sample data, as shown in Figure3-15.

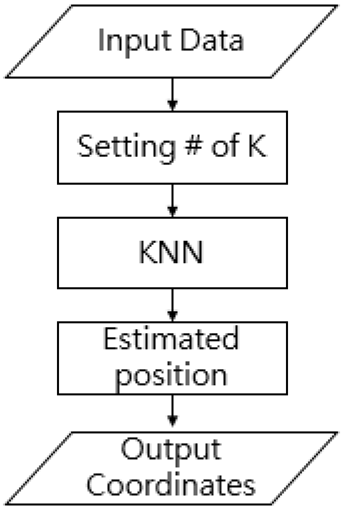

Figure 3-15. KNN-based flow chart

Step.1

Set the number of neighbor K in the nearest neighbor law, where K > 0.

Step.2

According to the signal strength to the nearest neighbor law to find the closest input with the data of the K neighbors sample point

$$\|x - x_i\| \tag{3.5}$$

Calculate the difference between the input data and the sample data according to Euclidean distance (formula 3.5), where x is the input data, xi is the i-th sample data.

Step.3

From the K neighbor sample points, using the formula 3.5 and the formula 3.6 to estimate the position of the input data in space, where x is input data, xi is the i-th sample data, c is a constant.

Sort the training data according to the difference, the former K is from the input information of the nearest K neighbors.

$$\mathrm{x} = \frac{1}{k}\sum_{i=1}^{k} x_i \tag{3.6}$$

$$\mathrm{x} = \frac{\sum_{i=1}^{n}\left(\frac{1}{\|x-x_i\|}+c\right)*x_i}{\sum_{i=1}^{n}\frac{1}{\|x-x_i\|}+c} \tag{3.7}$$

3.5.2 Support Vector Machine, SVM

Support Vector Machine(SVM)[34] is a machine learning algorithm based on statistical theory analysis. Support Vector Machine is a supervised learning method, mainly used in classification and regression (Regression) above.

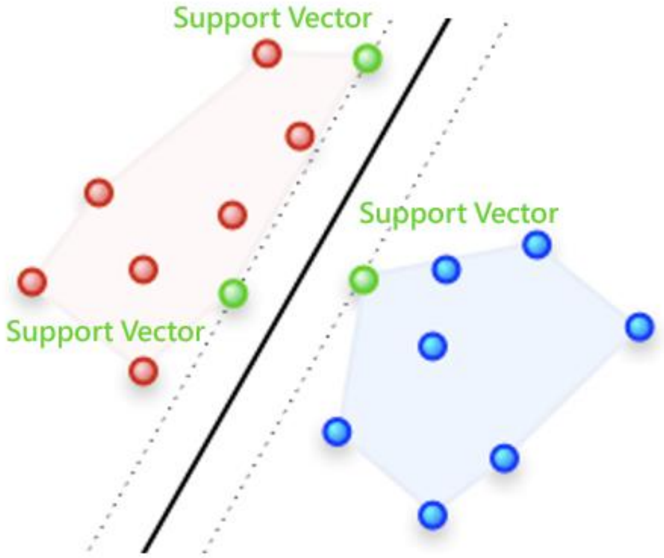

Figure 3-16. The classification of SVM [34]

The main idea of SVM is that it is possible to find an optimal hyperplane based on a number of different types of data that are separated by different categories. The best hyperplane is the distance between the two categories of boundaries that can reach the maximum value, and the closest to the border of these sample points, to provide SVM maximum classification information is called support vector.

SVM has many unique advantages in solving small sample, nonlinear and high dimensional pattern recognition problems. At present, SVM has been applied to practical problems such as handwriting recognition, 3D target recognition, face recognition and text image classification. The performance is superior to the existing learning methods. The decision rules obtained from the limited training samples are still subject to smaller errors for independent test sets. In this thesis, we used the MATLAB SVM module to carry out the establishment of the positioning model.

3.5.3 Artificial Neural Network, ANN

Artificial Neural Network (ANN), referred to as Neural Network (NN) or neural network, is a mathematical model that mimics the structure and function of biological neural network (the central nervous system of animals, especially the brain) or calculation model. The neural network is calculated by a large number of artificial neurons. In most cases, artificial neural networks can change the internal structure on the basis of external information

Neural network is an arithmetic model [35], composed of a large number of nodes and interconnected. Each node represents a specific output function, called Activation Function. The connection between each of the two nodes represents a weighted value for the signal passing through the connection, called Weight. This is equivalent to the memory of the artificial neural network. The output of the network is different depending on the connection mode of the network, the weight value and the excitation function. And the network itself is usually a natural algorithm or function of the approximation, it may be a logical strategy of expression.

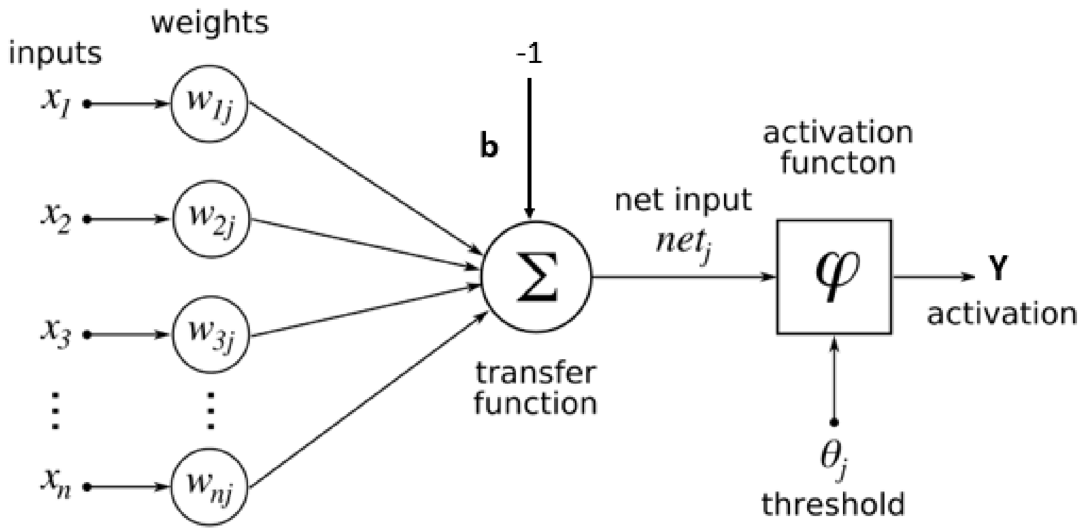

Figure 3-17. The model of Artificial Neural Network [35]

X：Input of Artificial Neural Network.
W：Weights.
b： Bias, which is a shift effect.
S(Σ)： Summation, each input is multiplied by the key value to do the total action.
φ **( )**：Activation Function is usually a nonlinear function, there are several different types, the purpose is to map the value of S to get the required output.
Y：Output of Artificial Neural Network.

In a simple neural network architecture, contains an input layer (Input Layer), a hidden layer (Output Layer) and an output layer (Hidden Layer), as shown in Figure 3-18.

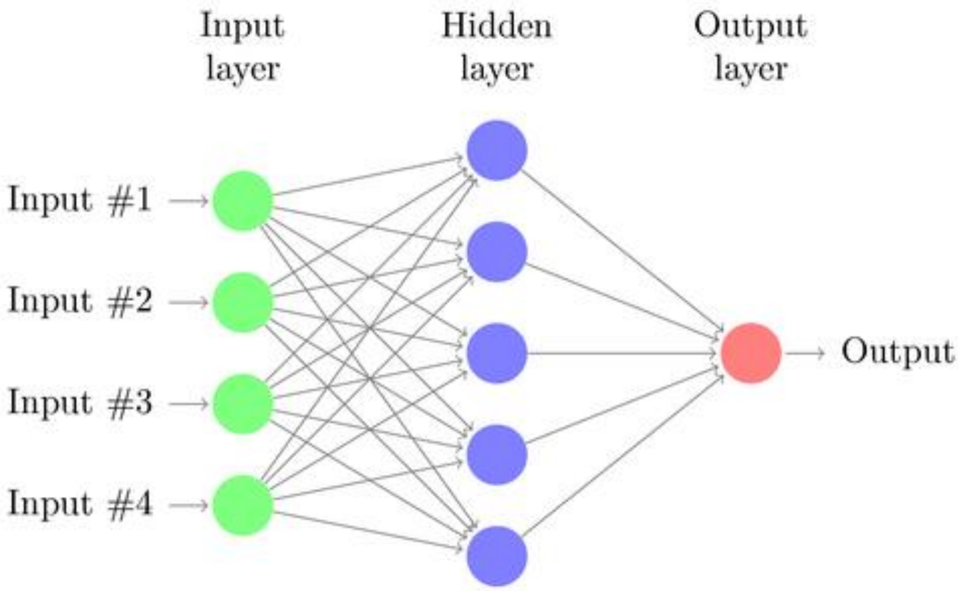

Figure 3-18. Neural network architecture [35]

- **Input Layer**

"Layer" is composed of multiple nodes, so that the link within the network can be simplified as a layer between the layers and layers. Input layer in the network architecture to accept information and enter the message side, usually in a layer that the number of processing units as shown in Figure 3-18 Input # 1 ~ Input # 4 depending on the input content, to express the network Enter the variable.

- **Output Layer**

In the network architecture does not provide information on one of the parties, usually in a layer that the number of processing units depending on the contents of the output, to express the network output variables.

- **Hidden Layer**

Between the input layer and the output layer, the use of non-linear transfer function, the number of nodes within its layer is not a standard method can be determined, usually need to test the way to determine the optimal number and provide the neural network processing unit The role of exchange and the inherent structure of the problem,In addition, there is no standard method of hiding the number of layers, and more hidden layers usually indicate that the class of neural networks deal with problems that are more complex.

Chapter 4. Experimental and Results

In this chapter, we will discuss the results of our assessment. First of all, we will introduce the equipment and environment used in our experiments, and then we will do for the system and the existing other indoor positioning method to do some performance evaluation.

4.1 The device of indoor positioning system

Introduce the hardware used in the experimental and research week, including intelligent mobile devices, two iBeacon Bluetooth launchers and wireless network base stations.

4.1.1 Smart Phone

Apple's iBeacon is an indoor positioning technology that is meant to be used with the BLE enabled beacons,Smart mobile devices are supported as long as iOS7, Android 4.3 and above, and Bluetooth technology can support more than 4.0. In this thesis, we use Samsung Galaxy S4 as our smart phone, as shown in figure4-1.

- Processor: dual quad-core Exynos 5 Octa 5410
- Memory: 2GB RAM
- Built-in capacity: 16GB
- Camera: the first 2 million / after 13 million pixels
- Screen size: 5 inches 1920 x 1080
- Wireless network: 802.11a / b / g / n
- Ips (integrated dual band 2.4G / 5G)
- Bluetooth: Bluetooth 4.0
- Operating system: Android 5.0
- Weight: 130g
- Size: 136.6 x 69.8 x 7.9 mm

Figure 4-1. Samsung Galaxy S4

4.1.2 iBeacon Device

Each iBeacon Bluetooth transmitter will have a Universally Unique Identifier (UUID). By receiving the wireless signal strength and the identity code of the iBeacon Bluetooth launcher, the intelligent mobile device can estimate the distance from the Bluetooth emitter to obtain the current location of the device. In this thesis, we used two iBeacon Bluetooth emitters, namely Estimote Beacon and Here-Beacon, and we did some comparison in its characteristics.

Table 4-1. The comparison of Estimote Beacon and Here-Beacon

	Estimote Beacon	Here-Beacon
Size	30mm*10mm	68mm*26mm
Transmit Distance	30m	10~30m
Power supply	CR2477	AA
Endurance	3 years	2 years
Applicable system	iOS/Android	iOS/Android

Figure 4-2. Estimote iBeacon [31]

Figure 4-3. Here-Beacon

4.2 Software tools

4.2.1 Mobile device development platform

Use the Java language to develop under the Android Studio environment and use the Android SDK to write features, as shown in Figure4-4.

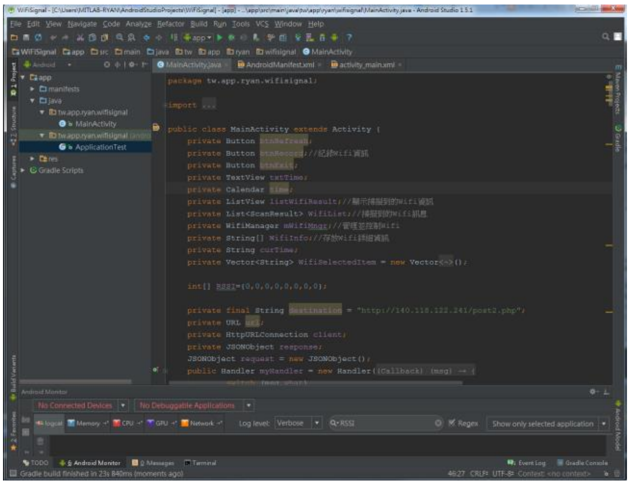

Figure 4-4. Android Studio Development environment

4.2.2 Simulation Platform

MATLAB is a high-end technology computing language and interactive environment for algorithm development, data visualization, data analysis and numerical calculation. The program development interface is shown in Figure 4-5.

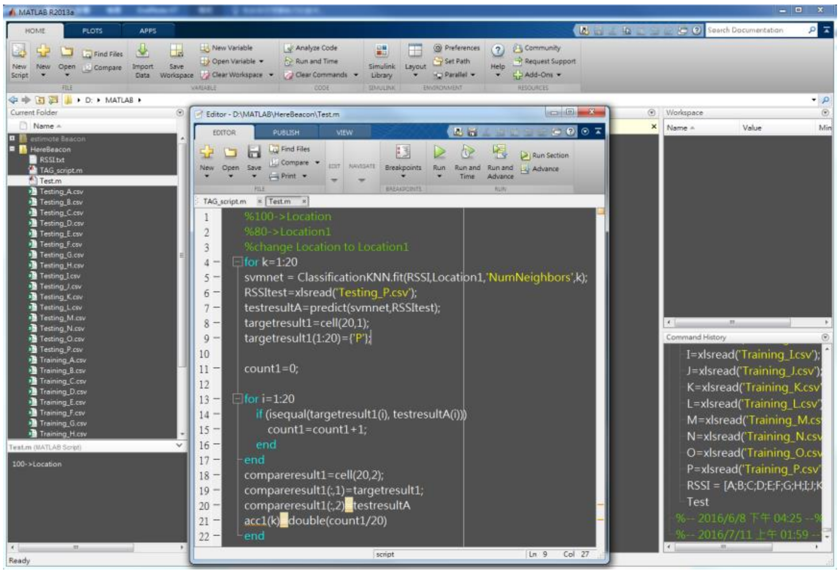

Figure 4-5. MATLAB Development environment

In this thesis, we use Matlab to develop simulation program under MATLAB 2013, use MATLAB to carry out training data and testing Data simulation and analysis, respectively, for KNN, SVM, Neural network training model for precision analysis and signal strength visualization action.

4.3 Experimental environment

In order to evaluate our proposed indoor positioning system in real-world environments, we designed targeted applications on Samsung Galaxy S4. In order to evaluate the proposed positioning technology performance, we collected wireless networks in real-world environments Signal.

In this thesis, two different indoor space environments will be used as experimental sites to collect and analyze the results. One is the EE705-6 laboratory in DECE Building of NTUST, which field length and breadth is 7m x 8m x 3m, as shown in Figure 4-6. The other one is the 7th floor of DECE Building of NTUST, which field length and breadth is 30m x 15m x 3m, as shown in Figure 4-7.

Figure 4-6. EE705-6 laboratory in DECE Building of NTUST

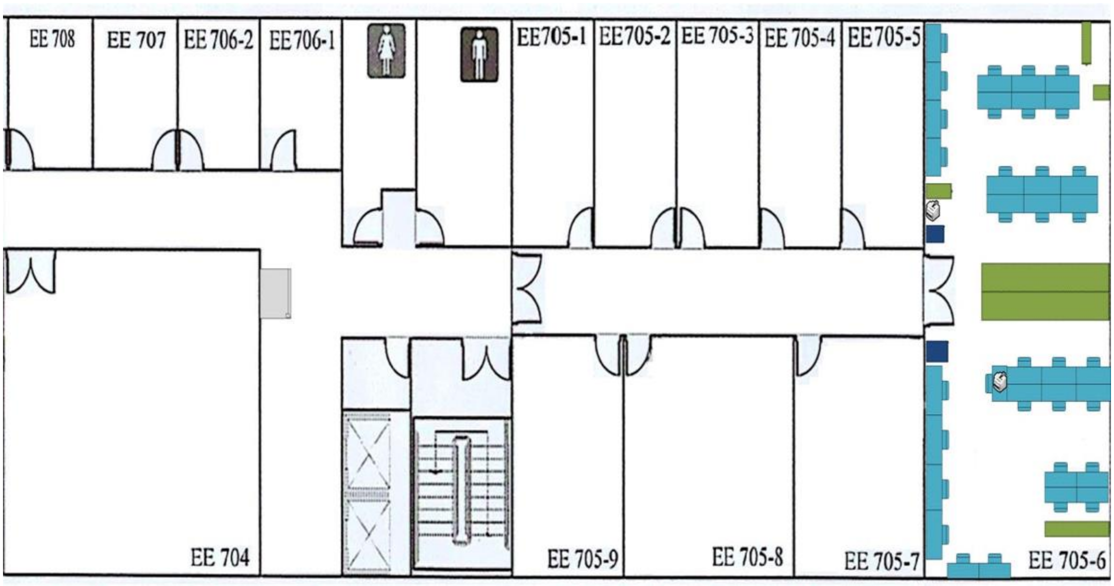

Figure 4-7. 7th floor of DECE Building of NTUST

4.3.1 EE705-6 Experimental Environment

We constructed a different number of iBeacon Bluetooth emitters in the EE705-6 experimental field and analyzed the interference intensity and positioning accuracy of their source, as shown in Figure 4-8. We divided the labs into different sizes to explore the accuracy of the different squares.

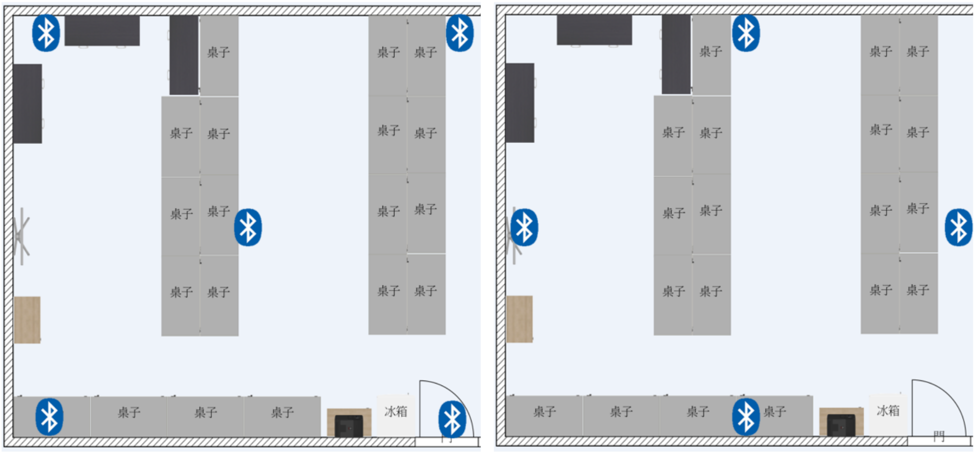

Figure 4-8. Different number of iBeacon in EE705-6

Figure 4-9. Different sizes of Lab

4.3.2 7th Floor of DECE Experimental Environment

In order to evaluate the proposed localization approach, several experiments were conducted in the experimental test-bed. The experimental test-bed was located in the seven-floor of the DECE building at National Taiwan University of Science and Technology. The tracking area is divided into 22 subareas (A-V), including two rooms and 2 hallways.

The dimension of the rooms (A-J) is 7m x 15m x 3m, the horizontal hallways (K-P) is 15m x 2m x 3m, and the vertical hallways (Q-V) is 2m x 6m x 3m.

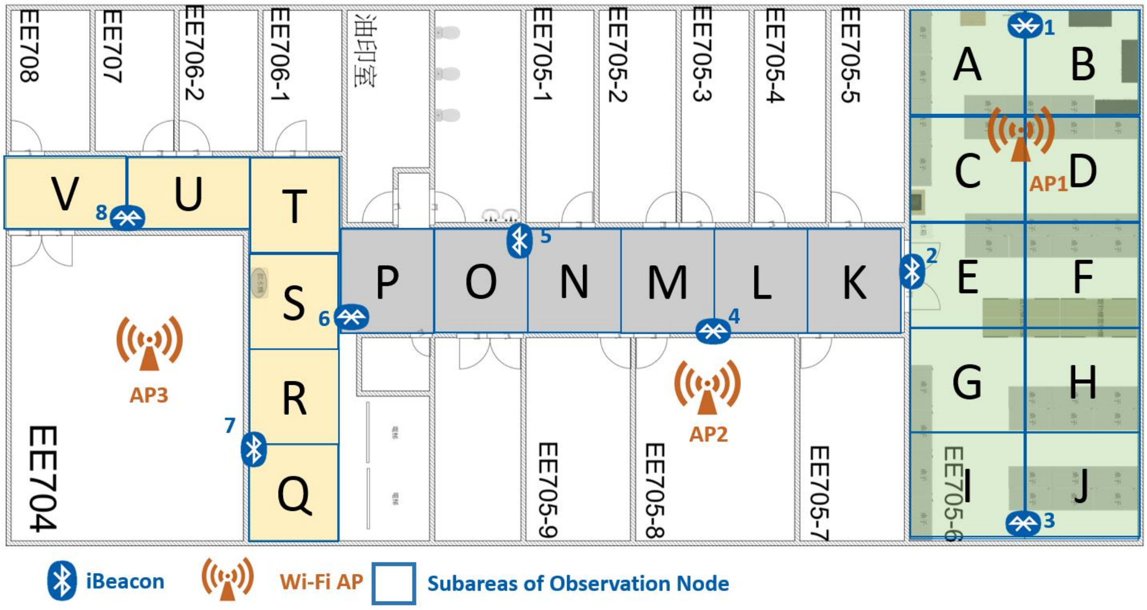

Figure 4-10. Test-bed and iBeacon deployment

The blue icon which is shown in this figure is iBeacon built on the wall of 2 meters above ground level. Three of these APs use the existing Wi-Fi source.

In the offline phase, we collected the signal strength fingerprints of the different directions at each training site (AV), with a total of 22 different locations, each of which contains 100 signal data for each iBeacon and Wi-Fi AP, the total signal of about 24,200 information.

4.3.3 Mobile Application

We successfully implemented our app on smartphones, and by using this targeting app to connect our positioning system to evaluate the performance of our proposed positioning system, as shown in Figure 4-11.

Figure 4-11. The mobile application

Figure 4-12. Signal Collecting APP

4.4 iBeacon Deployment

4.4.1 The comparison of different grids

In order to simulate the location of the consumer in the real mall environment and to do effective product delivery, we built a number of iBeacon in the real laboratory environment (7m x 6m) to measure its positioning accuracy. The size of the squares is: 6x6 (about 1 square meter per grid), 3x3 (about 2 square meters per grid), 2x2 (each about 3 square meters).

- **4 iBeacons with different size of square**

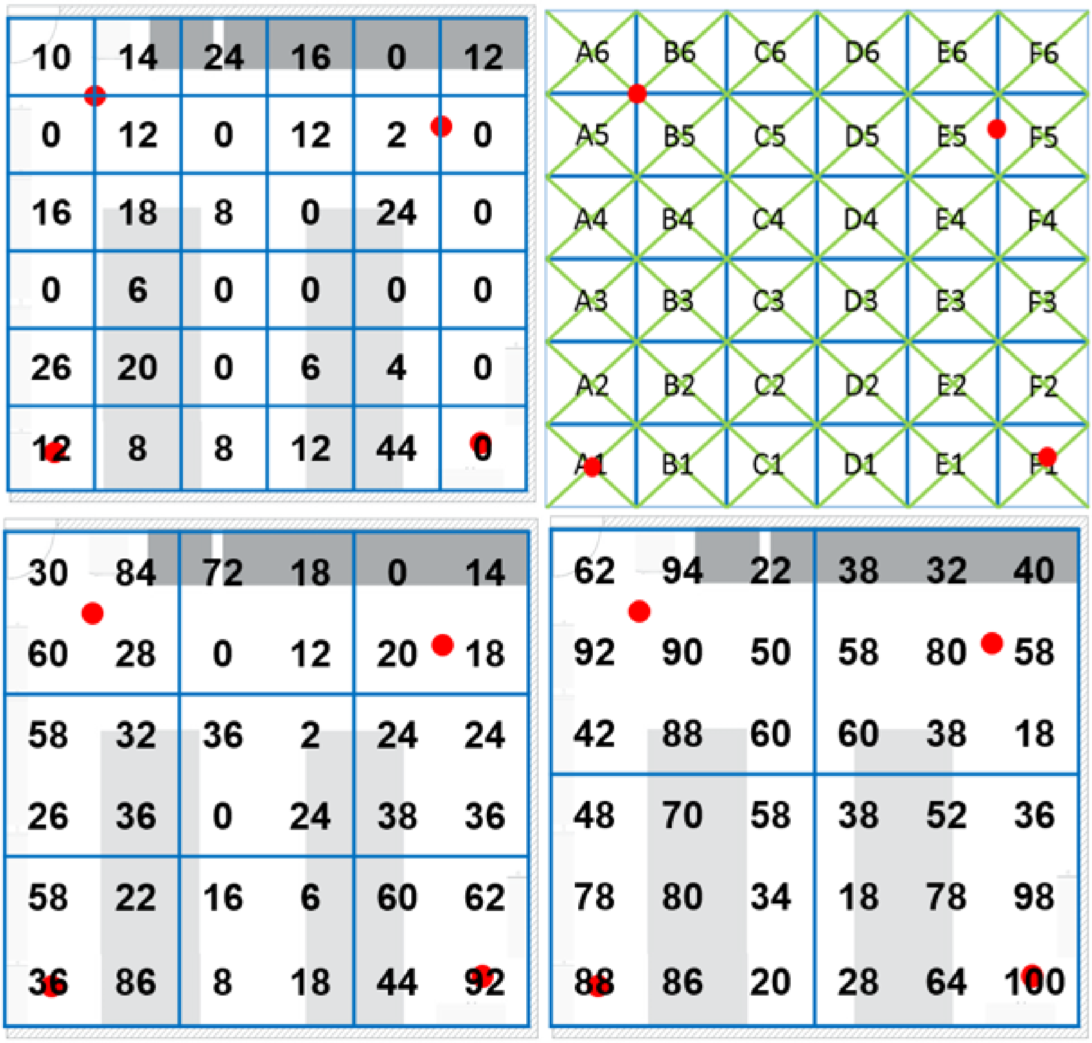

Figure 4-13. The accuracy of 4 iBeacons with different size

As shown in Figure 4-13, it is obvious that errors are easily generated in the lattice staggering, and if you want to deploy Beacon in the room, a 2 to 3 meters' size is better (higher precision). And if the grid is more dense, it will make more errors.

- **5 iBeacons with different size of square**

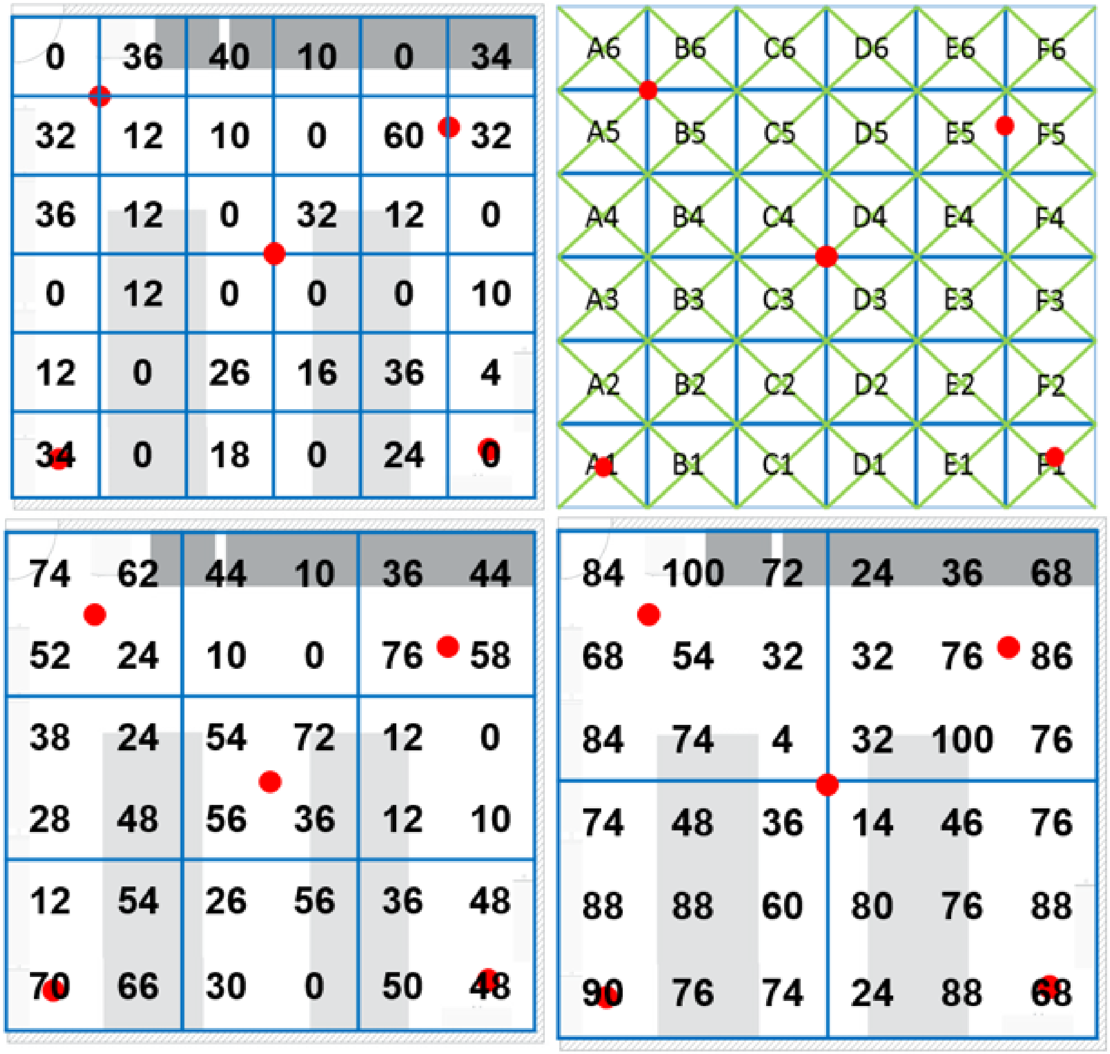

Figure 4-14. The accuracy of 5 iBeacons with different size

From Figure 4-13 and Figure 4-14, we can see that the accuracy of the surrounding gird can improve by putting an iBeacon in the center. The deployment of iBeacon can be done in advance in the environment, to each Beacon can completely cover the space, will produce less interference and overlap of the part.

Based on the results of this experiment, we can select a better Beacon deployment, including the distance between each iBeacon and the layout of space.

4.4.2 The Radio Map of iBeacon Signal

We used MATLAB to convert the RSSI signal strength to color class as radio map, as shown in Figure 4-15. It is easy for us to more quickly understand the distribution of Beacon signal situation. The solid red dot represents the point where the Beacon is the emitter, and the hollow is the place where the other Beacon is set.

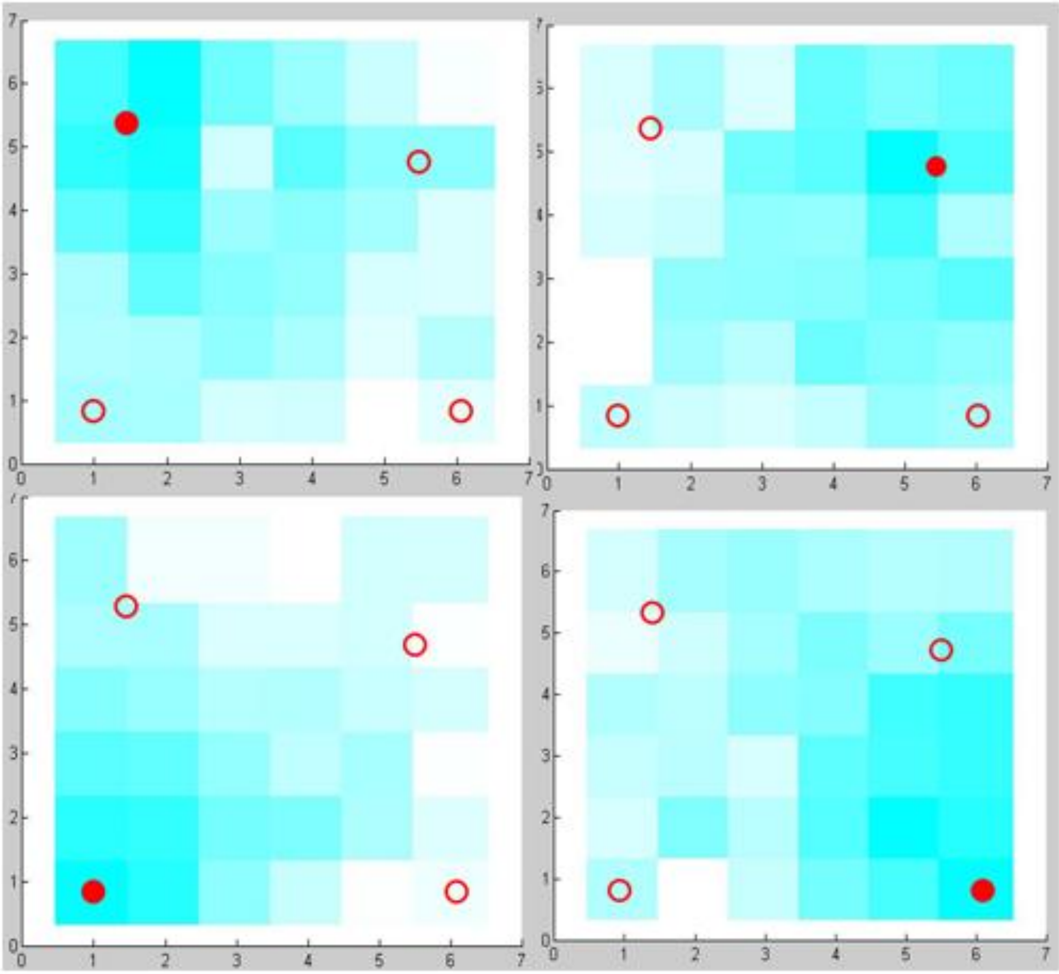

Figure 4-15. The Radio Map of iBeacon Signal

4.4.3 The Signal in Different Section

According to previous result, we deploy 8 iBeacons in the experimental test-bed, as shown in Figure 4-10. And we use 3 exiting Wi-Fi AP as our Wi-Fi Signal sources. The sample of RSSI mean value in each subarea shown in Figure 4-16 and Figure 4-17.

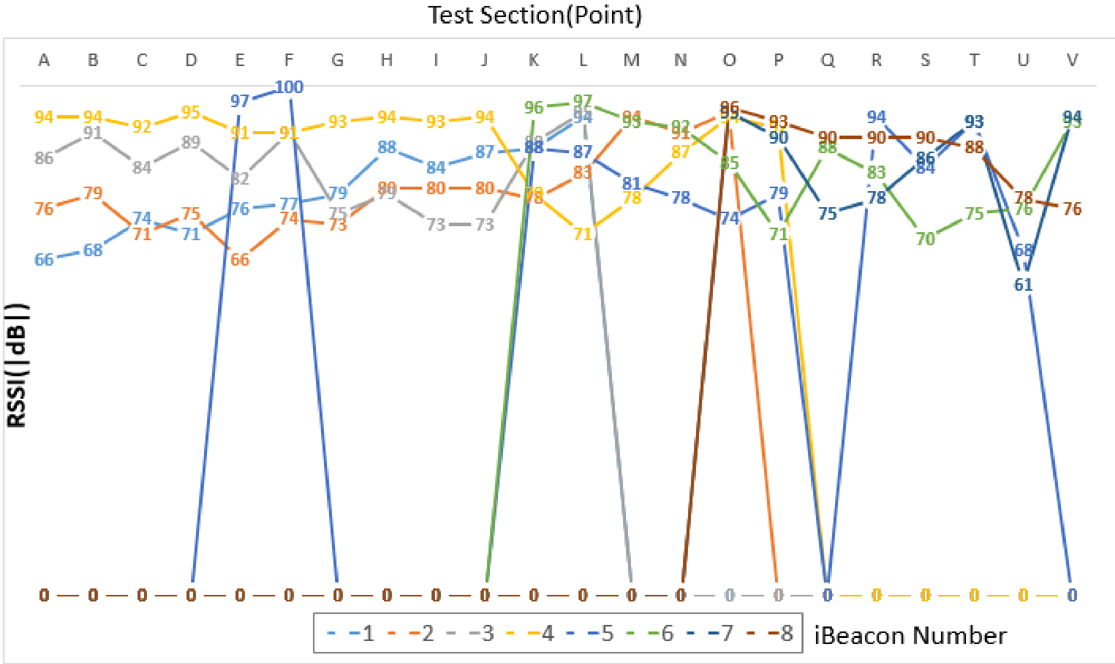

Figure 4-16. The Mean Value of iBeacon's RSSIs in each subarea

In Figure 4-16, we can see that each test section (point) can receive different value of 8 iBeacons, and every signal has significant differences, and the same as Wi-Fi signal, shown in Figure 4-17.

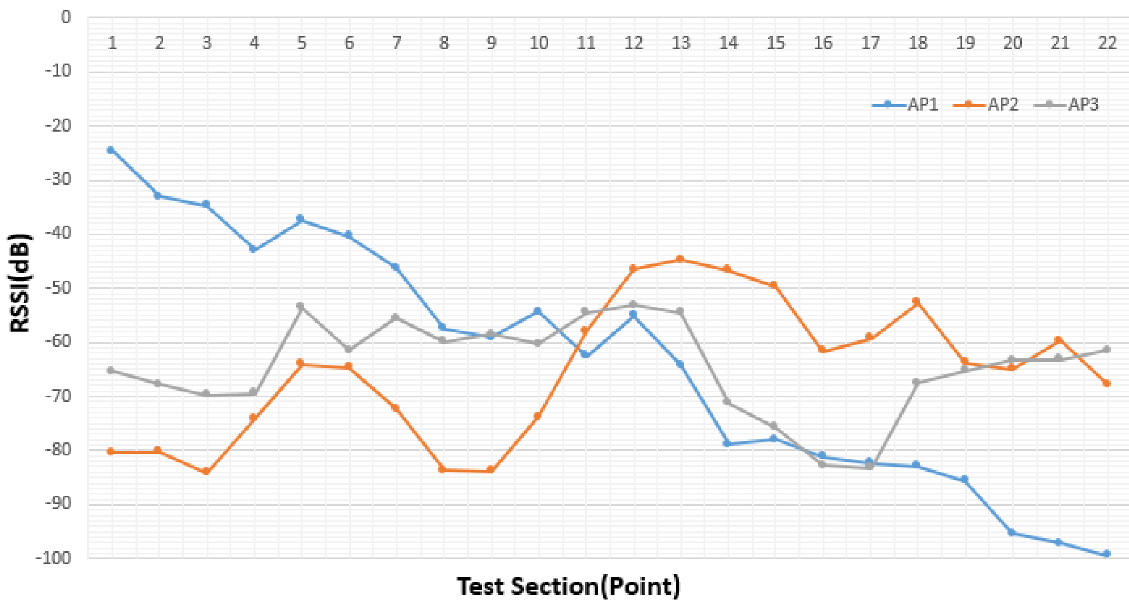

Figure 4-17. The Mean Value of iBeacon's RSSIs in each subarea

4.5 Experiment Analysis with Different Parameters

In order to achieve higher accuracy, we have to do some experiments to make sure the parameters are the best situation. The parameters include the filter of signals, the acquisition time of data collecting, the k value of the K-NN algorithm, the training time and accuracy of different selection algorithms.

4.5.1 The comparison of Filters

We use the self-developed application to measure the iBeacon signal and record the signal. Because of the impact of obstacles, we can observe the Bluetooth signal is very unstable, as shown in Figure 4-18. The x-axis represents the time, and the y-axis represents the Beacon signal strength. It is clear that every Beacon signal has been changing at the same location.

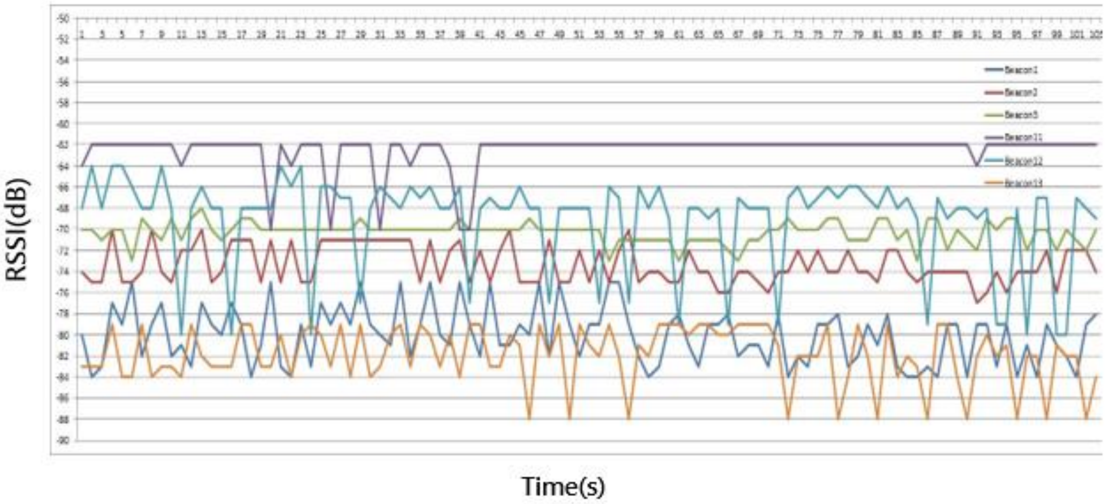

Figure 4-18. The signal of iBeacon

Then, we use the spatial filter to eliminate and deal with the Beacon signal. The purpose of this experiment is using the median filter and the mean filter to carry out the signal filtering analysis. After that, we'll do the comparison the results of the average error and the standard deviation.

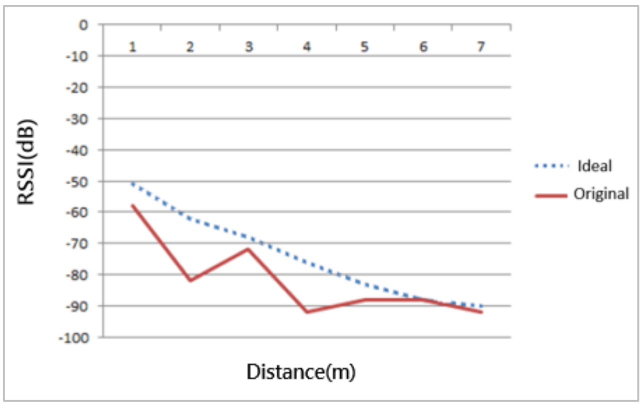

Figure 4-19. The curve of ideal logarithmic curve and measurement signal

First, we are using a smart mobile device to receive signals from the iBeacon transmitter. We measured the signal from 1 meter to 7 meters (the interval is 1 meter), and we recorded the RSSI value at each measurement point. After that we using the mean filter and the median filter for filtering analysis. The original value is the actual measurement of the first signal strength value.

Table 4-2. Comparison of signal strength before and after filtering

	Ideal Value	Original Value	Mean Filter	Median Filter
1 m	-69	-70	-72	-70
2 m	-74	-80	-78	-76
3 m	-78	-76	-88	-77
4 m	-81	-88	-83	-81
5 m	-83	-88	-84	-82
6 m	-85	-92	-90	-87
7 m	-87	-90	-89	-88

Use the distance conversion formula to find the distance, as shown in Table 4-3.

Table 4-3. Comparison of distance before and after filtering

	Ideal Value	Original Value	Mean Filter	Median Filter
1 m	1.0	1.15	1.51	1.15
2 m	2.0	3.64	2.98	2.41
3 m	3.0	2.41	7.57	2.68
4 m	4.0	7.57	4.84	4.01
5 m	5.0	7.57	5.30	4.41
6 m	6.0	10.65	9.0	6.94
7 m	7.0	9.0	8.26	7.57

And then converted the signal distance after the conversion of the ideal distance value.

Table 4-4. Comparison of distance error before and after filtering

	Ideal Value	Original Value	Mean Filter	Median Filter
1 m	0.0	0.15	0.51	0.15
2 m	0.0	1.64	0.98	0.41
3 m	0.0	0.59	4.57	0.32
4 m	0.0	3.57	0.84	0.01
5 m	0.0	2.57	0.3	0.59
6 m	0.0	4.65	3.0	0.94
7 m	0.0	2.0	1.26	0.57

Finally, the conversion distance value is compared with the mean error and the error standard deviation of the ideal calculation.

Table 4-5. Comparison of Average error and Error standard deviation

	Ideal Value	Original Value	Mean Filter
Average error (m)	2.16	1.63	0.43
Error standard deviation (m)	1.44	1.25	0.30

Experiment Analysis

From Figure 4-18, we can observe that the filtering effect of the mean filter is better than that of the median filter. There is 20 to 30 cm correction error after filtering. The results of the median filter are shown in Figure 4-18. The results of the mean filter are shown in Figure 4-19.

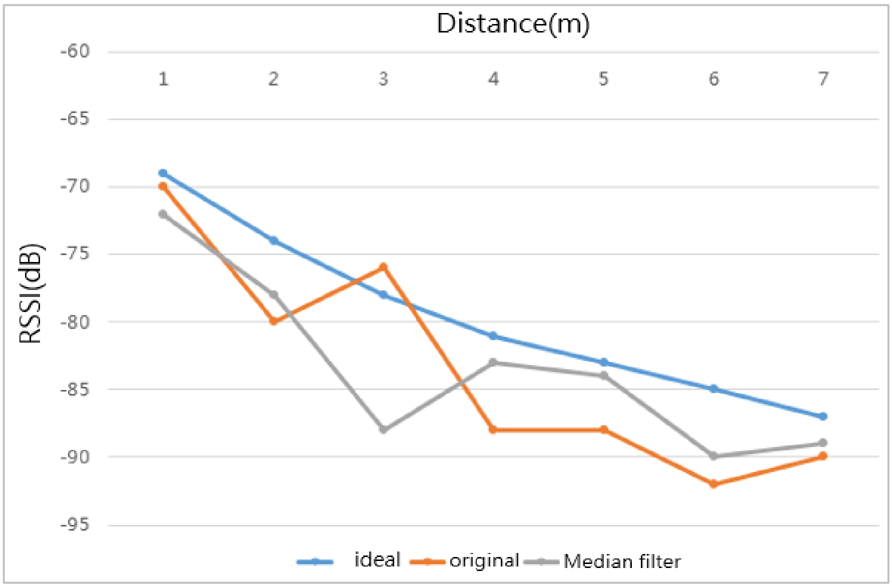

Figure 4-20. The results of Median filter

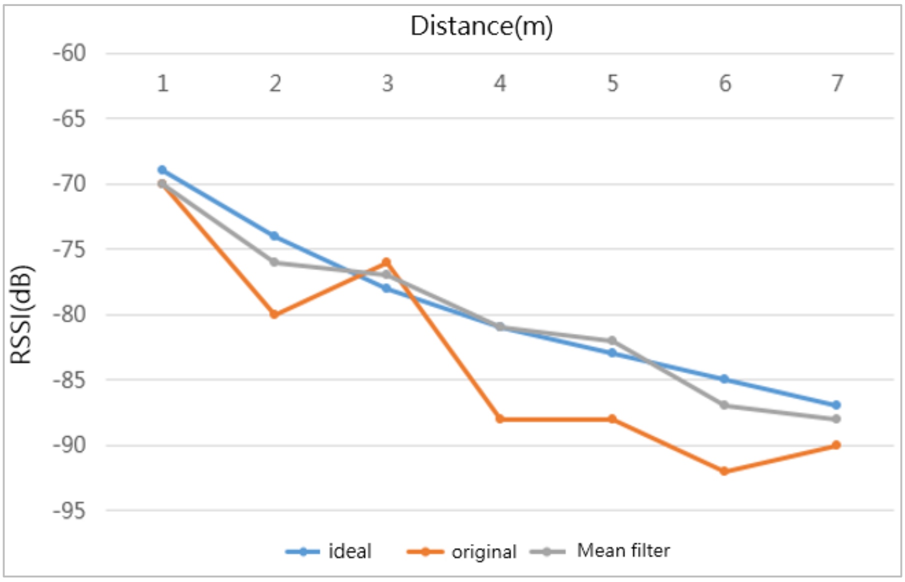

Figure 4-21. The results of Mean filter

4.5.2 The comparison of acquisition time

We have a great interest in collecting the time and positioning accuracy of the signal, so in this thesis we aim different acquisition time to measure a different curve to express the collection time and positioning accuracy of the relationship. As shown in Figure 4-20, the curves of different colors represent the relative relationship between the different collection time and the positioning accuracy. The error distance represents the maximum tolerable position of the user when the user locates in the room.

We can find that in the same error distance (under the standard), a certain collection time can improve the positioning accuracy. For example, the accuracy of the 3S (acquisition time) is better than the 2S, and the accuracy of the 2S is better than the 3S. But when reach a certain collection time, the impact of positioning accuracy is not too big.

For example, for the acquisition time of 4S, 5S, and 6S, these three collection time positioning accuracy is about the same. Based on the results of this experiment, we can write a better positioning algorithm, which selecting a better acquisition time to achieve the best positioning effect.

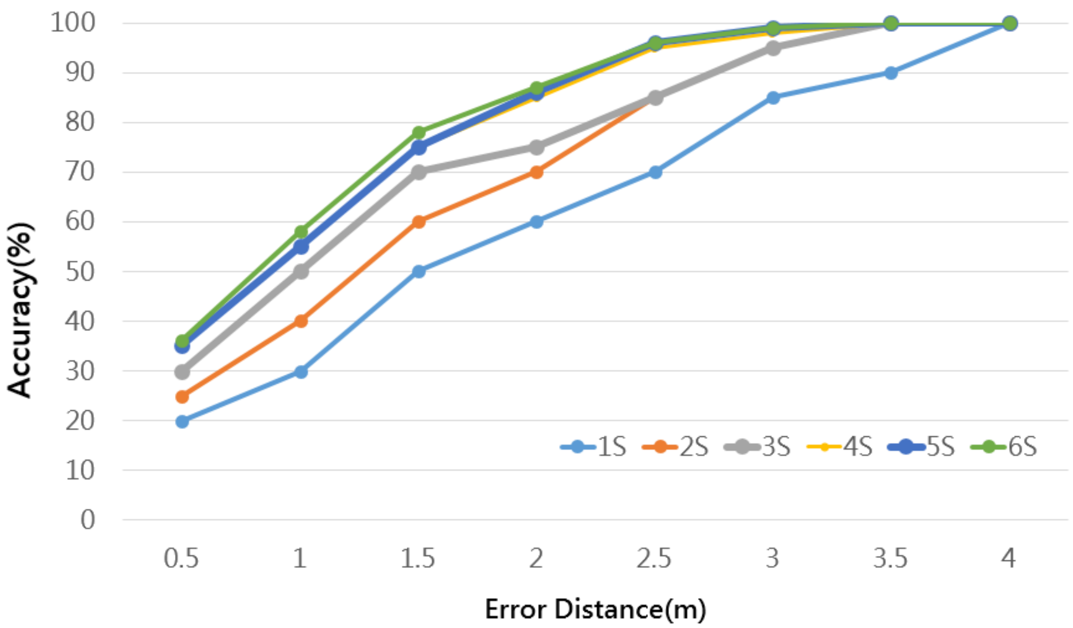

Figure 4-22. The effect of acquisition time and accuracy

4.5.3 The comparison of K value in K-NN

In the collection of the signal to the positioning model for the establishment and comparison of the time, we will use some selection algorithms, such as K-Nearest Neighbor(KNN), Support Vector Machine(SVM) and Artificial Neural Network (ANN) to estimate the indoor positioning space of the test data.

First of all, we use different k value of KNN to train the data itself, can be found when k = 5, all the data accuracy is maintained at 95% or more.

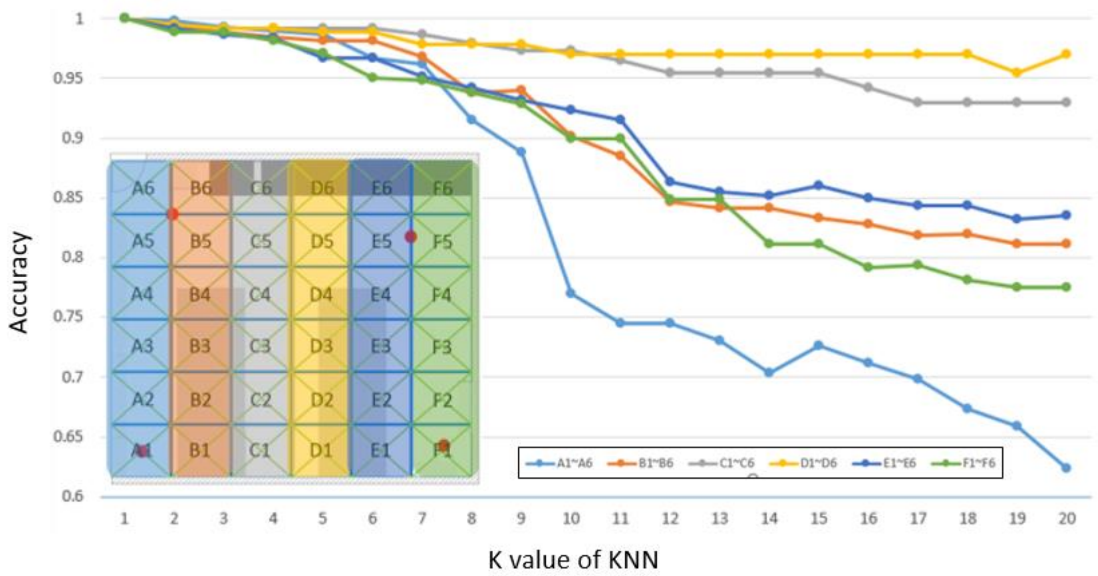

Figure 4-23. Different K Value and its Accuracy

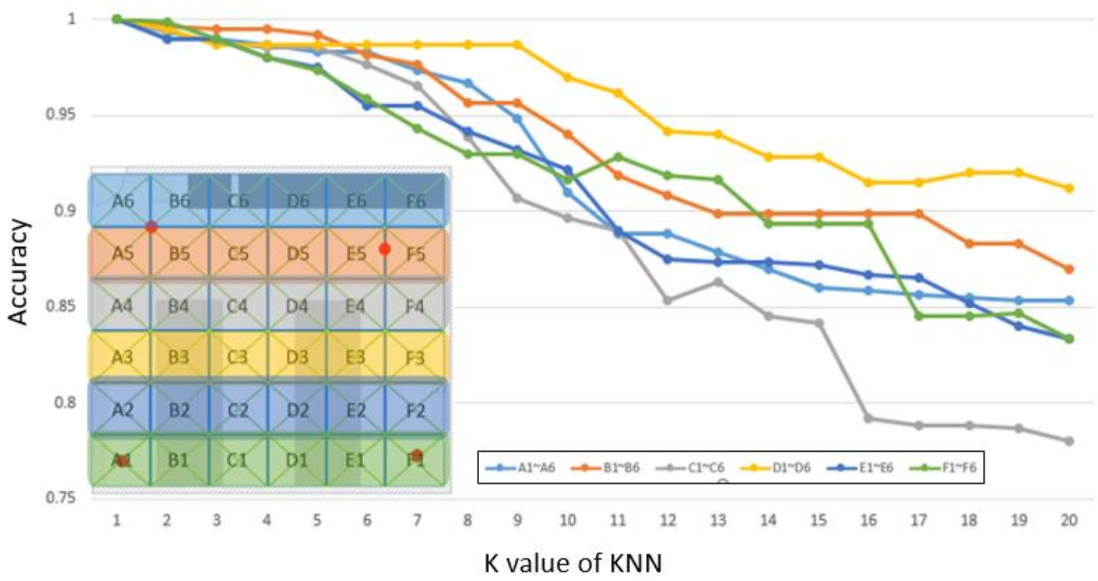

Figure 4-24. Different K Value and its Accuracy

4.5.4 The comparison of selection algorithms

Then, we according to different positioning training model to do comparison, and the algorithms that we used is KNN (K=3), KNN (K=5), SVM and Neural Network. We compared their training model time, as shown in Table 4-6.

Table 4-6. Training time under different models

	KNN=3	KNN=5	SVM	NN
TIME	400ms	500ms	2h20m30s	40m4s

From the Table 4-6 can be clearly seen out, KNN training time is the fastest, because KNN is a direct test for classification, coupled with our test data collection is not large. And SVM training time is the longest, it is because we have 22 reference points, with 8 different iBeacon, and SVM can only be divided into two categories to do classification. In this test, we need to split many times to cause training long time. Neural Network continuous do training and testing in the hidden layer, the longer, the accuracy gradually increased. And our collection of information is not large, training time and accuracy is also limited.

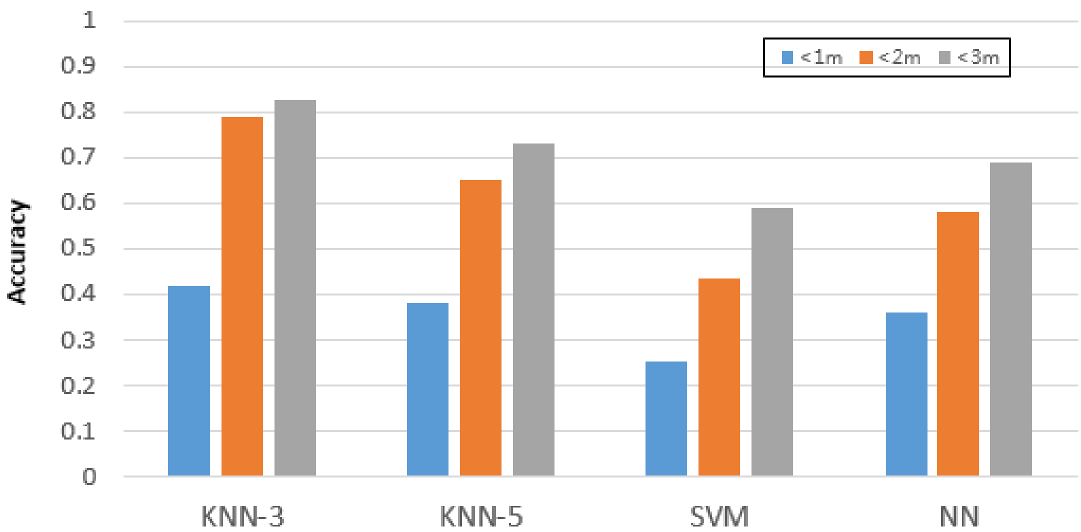

Figure 4-25. The accuracy of different positioning training models

As shown in Figure 4-23, the accuracy rate can reach 82.5% when the value of K is equating to 3 and the error is 3 meters. And KNN (K= 5) is 73%. On the other hand, SVM took 2 hours to reach About 59%, NN is 69%. According to the results of this experiment, we finally use KNN = 3 method to do the positioning model of training, more efficient, and the accuracy is also better.

4.5 Evaluation of Experimental Results

We have made a test of the positioning performance in the indoor environment shown in Figure 4-10, and have tried three models—iBeacon, Wi-Fi and Hybrid. Then we have compared the three model with different algorithms.

In order to test the performance further, we get large test data. Each point has been tested for 100 times and we calculated the error within 4 meters. We processed the data for five different walks and the results are shown in below.

Figure 4-26 and Figure 4-27 show the difference of each algorithm's accuracy in iBeacon and Wi-Fi system. In a short test sequence, KNN and 3 layer NN have similar positioning accuracy, but SVM model has a large difference.

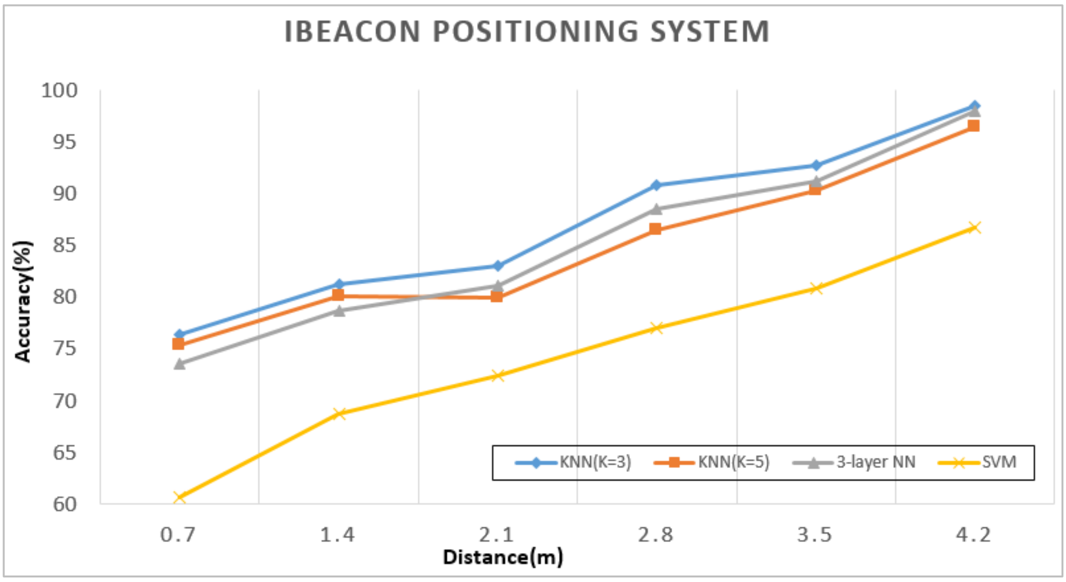

Figure 4-26. The accuracy of different training model with iBeacon System

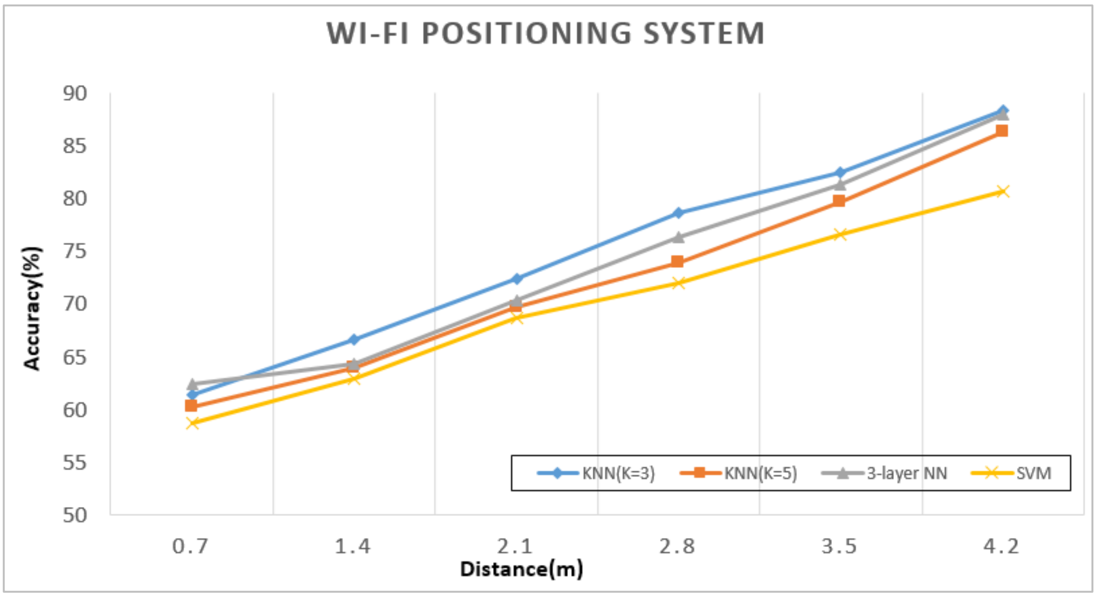

Figure 4-27. The accuracy of different training model with Wi-Fi System

From Figure 4-26 and Figure 4-28, we can see that the graph of Hybrid system is similar to iBeacon's. But the accuracy of Hybrid system is better than iBeacon's.

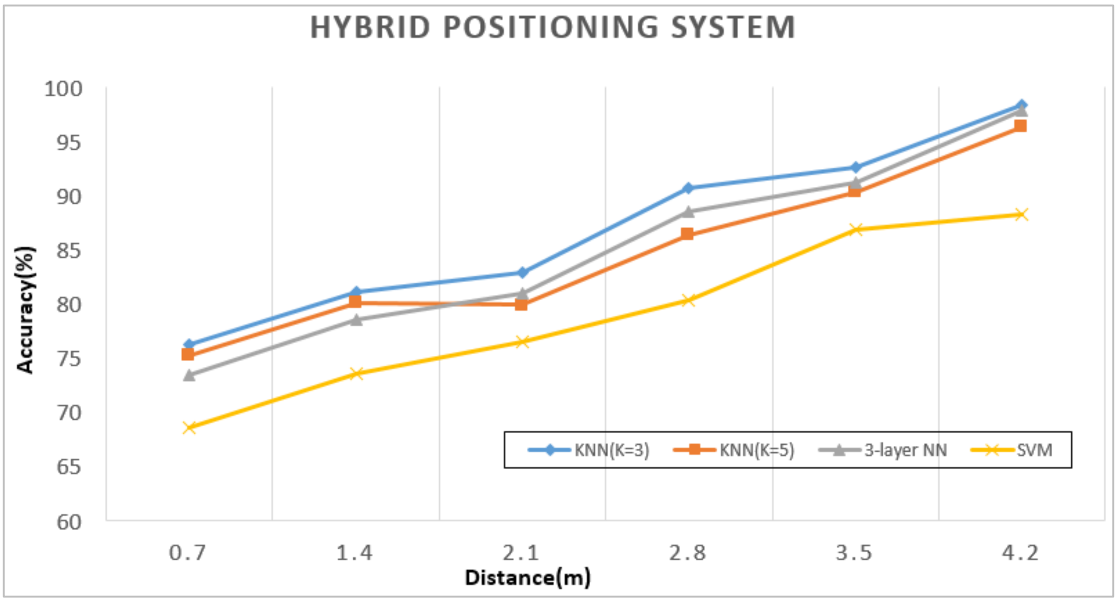

Figure 4-28. The accuracy of different training model with Hybrid System

From the experiment results above, the following conclusions could be drawn. First, SVM model has good accuracy but its total training time is too long to reasonable. And compare with other model, the accuracy is the worst. Judging by the appearance, KNN model is the best method for us using indoor positioning system. We select KNN K=3 as our training model, and we can see the result of three different indoor systems in Figure 4-29.

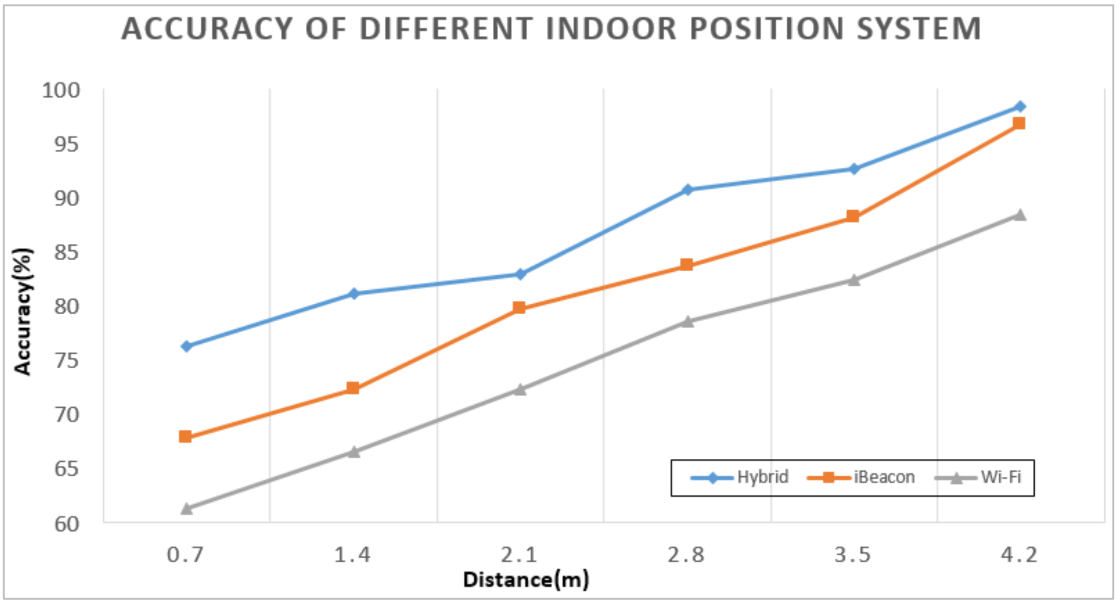

Figure 4-29. The accuracy of different positioning systems

We compare the positioning accuracy of the three positioning systems of Wi-Fi, iBeacon, Hybrid. As shown in Figure 4-29, we can see the positioning accuracy of the three positioning systems: The accuracy of the Wi-Fi is from <0.7m (61%) to <4.2 m (88%); the iBeacon positioning system is from <0.7m (67.8%) to <4.2 m (96.6%), the Hybrid is from <0.7m (76%) to <4.2 m (98%).

Chapter 5. Conclusions and Future works

5.1 Conclusions

In this thesis, we have implemented a prototype of hybrid indoor positioning system and obtained better results by using RSSI measurement. We also actually explain how to design and implement an efficient framework hybrid indoor positioning system. We have shown that significant positioning improvement over Wi-Fi is possible even using iBeacon as the characteristics.

Our approach combines the Wi-Fi and Bluetooth position methods, based on the wireless fingerprint positioning system, and uses Wi-Fi AP anchor as an auxiliary unit form to divide the location fingerprint database.

We achieve < 2.8m error and 90% accuracy for hybrid system, compared to < 3.5 m error and 85% accuracy for iBeacon and <4.2m error and 88% accuracy for Wi-Fi system in the same environment. According to the analysis, the hybrid system is proven to be an effective solution to indoor positioning.

Through the experimentation and implementation, we found the BLE is easy to deploy and also fits the lower energy consumption. One the other hand, using existing Wi-Fi access points can decrease the cost but we should avoid the noise disturbance. Analytical fingerprinting can be used to achieve higher accurate position. The accuracy with our hybrid system is acceptable and higher when compared with other systems working in indoor environments.

5.2 Future works

In this thesis, only three fingerprinting algorithms have been compared, more comparison between other algorithms can be conducted in the future, such as Random Forest algorithm, the Ensemble algorithm and so on. In addition, more fingerprinting algorithm can be discovered or proposed. Since iBeacon indoor positioning is still a quite new area, more works focusing on improving the performance of localization could be conducted. Hybrid indoor positioning is not only Wi-Fi and iBeacon these two technology. It could be different positioning sensor technology combined together, such as RFID and NFC, Wi-Fi and RFID and so on.

Moreover, about the improved collecting method, we used mobile application to collect signal at each test bed, while actually it could be different in real environment. For example, we should consider the situation of user who using mobile, the signal with be affect by the body, the movement rate, the beaconing rate (the frequency of the broadcast signal) and so on.

Besides, in the practical use, because of the difference of each mobile device's performance of hardware, the precision of the positioning system will be different. In the future, if considered with the differences of the terminals, and making a pre-processing of the hardware, it will keep the performance of the system same in each terminal, which will be one of future work.

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