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# Improving Accuracy of WiFi Positioning System by Using Geographical Information System (GIS)

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## *Abstract*

*WiFi positioning system with knowledge of GIS can achieve higher accuracy in terms of distance error comparing with the one without it. Positioning algorithm expectedly gets rid of unlikely crossing area in the region while selecting others. Minimization of crossing area determination with constraint of geographical information is a key contribution. Proper placement of access points in service area is another issue of concern yielding the same consequence as optimal coordinate fitting.*

*Learning process for determining environment characteristics is essential to enable accurate calculation on distance from measured signal strength. Variation of obstructions in one environment can mainly reflect inconsistent profile, especially for indoor environment.*

***Keywords:*** *Wireless positioning, WiFi, GIS, constrained optimization.*

## Introduction

The proliferation of WLAN starts from being widely known as so-called "WiFi", which is one of the Institute of Electrical and Electronics Engineers or IEEE standards for WLAN. WiFi stands for "Wireless Fidelity" and it is truly a freedom to make a connection to Internet without hassle of old-fashioned network cable. WiFi or 802.11b is one of 802.11 specifications family and it is also the first dominating standard in the market. Nowadays new wireless networking devices are adopting the new standard of IEEE 802.11g, which offers higher data speed, namely driving from 11 Mbps to 54 Mbps, while sharing common operating frequency of 2.4 GHz.

This innovative technology is evolving technically and practically in couple of years leading WLAN to be a common sight at universities, airports, coffee shops, offices and organizations. That service point or access point is often referred to as "wireless hotspot" or "hotspot" in short.

Incentives for developing and standardizing WLAN are definitely mobility and flexibility. This phenomenon stimulates the creation of supportive features for new-age laptops. However, anything has pros, it will also have cons. This issue is largely discussed and activating research group to concern about.

## Related works and Background

Recently, direction of research in WLAN field largely varies from pure theory to real-life applications. Pure theory is a factory of innovative ideas activating manufacturer to commercialize after those ideas are proven and standardized. For real-life application, one of the issues currently in concern of wireless security is wireless positioning application. Vulnerability of encryption algorithm of both WEP and WPA is globally realized. Therefore another development for wireless security turns to be positioning technique.

Many past researches contributed creative and innovative concept of indoor positioning system with various platform and architecture. Some of them were that of high accuracy, but were not practical and cost effective. Structural investment or dedicated platform for merely a positioning facility is initially a main interest.

Early and significant contribution to location-aware system was the Active Badge System (Want 1992). The badge is attached to people or objects and it is programmed to periodically emit infrared signal out with unique identifier. Sensors are placed at known location indoors to pick up radiated infrared signal and transfer those data for further location processing. Further improvement was done to eliminate line-of-sight and limited range of operating distance of infrared. Active bats, Cricket, Motionstar, and some others are concrete examples of developing activities in positioning field (Hightower 2001).

New research trend is shifted as soon as WiFi technology emerges and appears to be a future wireless technology. RADAR, project from Microsoft Research Group initially develops positioning system on WiFi or WLAN platform (Bahl and Padmanabhan 2000). Obviously, this research approach is cost effective and positioning facility coexists with normal wireless networking architecture. In this aspect, any points of in-building area can be pointed out provided that coverage area of access point is wide enough.

Positioning techniques can be divided into two broad types (Jan and Lee 2003), which are location fingerprinting and propagation-based computation. For a location fingerprinting, site survey is required to collect signal strength samples at every single equally divided area of that building to build up a signal strength database. After learning and surveying process is done, real-time signal strength is captured and mapping process is started. This type of positioning technique can be visualized as a scene analysis.

For propagation-based computation technique, no signal strength database is required beforehand. Positioning computation is done according to different propagation models with different techniques of triangulation (Hightower and Borriello 2001). Triangulation is a basic geometric concept for finding crossing point on basis of distance or angle. Each user's position can be calculated at any instant. And the accuracy of user's position is quantified by Euclidean distance as

$$\sqrt{(ss_1 - ss_1')^2 + (ss_2 - ss_2')^2 + \ldots + (ss_n - ss_n')^2}$$

Eq.1

Half-wavelength dipole antenna is the most basic kind of antenna you can get (Anon. 2006a). This is basically two bits of wire of a special length, and is the type of antenna most commonly found built-in to those PCMCIA wireless cards. Its radiation pattern looks like a fat doughnut; you get no signal when you look through the "hole" (i.e. down the wire). Therefore it is radiating circularly in horizontal direction and this is the reason that we assume distance from access point in the pattern of circle.

## Signal Strength Preprocessing

Relationship of physical position and received signal strength at different distances away from access points or hotspots is a key criterion for computing user's position in WLAN. Indoor environment induces a multipath fading and it heavily deteriorates signal strength in various patterns.

### Signal Strength Collection

The test site for our experiment is on 5th floor of Q-building, Huamark campus, Assumption University of Thailand as shown on the following figure. Scale for the floor plan is 1:250 and note that origin point can be taken arbitrarily. Therefore it is taken at the left corner of Q-building itself in this case.

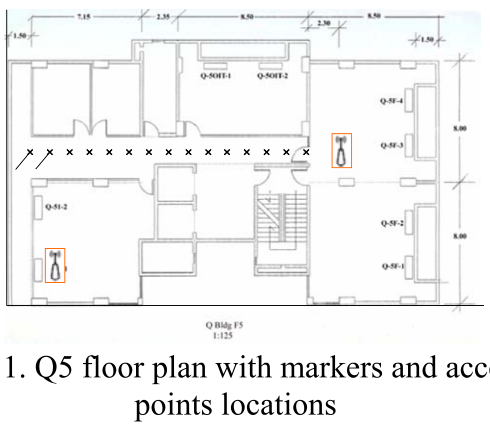

Fig. 1. Q5 floor plan with markers and access points locations

Predetermined location of access points named DSP-Q52 and NAL-Q51 is also included in the figure together with markers along the corridor. Those fifteen markers are points of interest in our experiment to be used for learning and testing purposes. They are 1.25 meters apart from one another.

***Multipath Fading Minimization:*** Signal strength is collected in four directions, namely, North, Earth, West and South to minimize multipath fading effect. Issue of signal strength sampling also directly reflects multipath effect in terms of direction sensitivity and angle of reception. Higher resolution of sampling, higher accuracy can be achieved in principle. Limitation of software being used in this experiment will be discussed shortly in Experiment Methodology session.

***Experiment Methodology:*** Equipments required for capturing signal strength, raw data processing and position determination are listed in categories of Hardware and Software accordingly.

*1. Hardware:*

- Access Point or Hotspot: Two boxes of any brand and model of access points are required to function as signal transmitter.
- Wireless Network Interface Card (Wireless NIC) or WiFi card: This can be considered as wireless LAN signal receiver in this application. Wireless NIC is available in various interface types and it can operate on both laptop or desktop computer and Personal Digital Assistant (PDA) correspondingly. Latest laptop computer and PDA are equipped with internal Wireless NIC.
- PDA or laptop computer: Desktop computer is not suitable due to obvious reason of mobility from point to point around the floor.

*2. Software:*

- NetStumbler (Anon. 2006b): This freeware program is one of the most widely used wireless network auditing tools allowing detection of 802.11b, 802.11a, and 802.11g networks. It offers two versions for both Windows and WindowsCE platform, which are Netstumbler 0.4.0 and Ministumbler 0.4.0 correspondingly. Signal strength samples are saved into NS1 file and can be further exported into Microsoft EXCEL for calculation, but Ministumbler does not have that feature.
- EXCEL: Signal strength average is calculated for each particular point on the floor plan.
- MATLAB: Characterization of wireless propagation model and minimization of error distance.

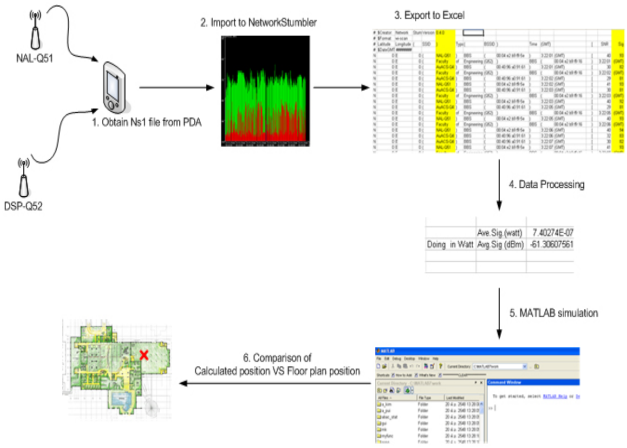


Fig. 2. Processing steps for ministumbler

## Position Computation

### Conceptual Overview

Conceptual overview for determination of WLAN user position is presented in the figure as follows.

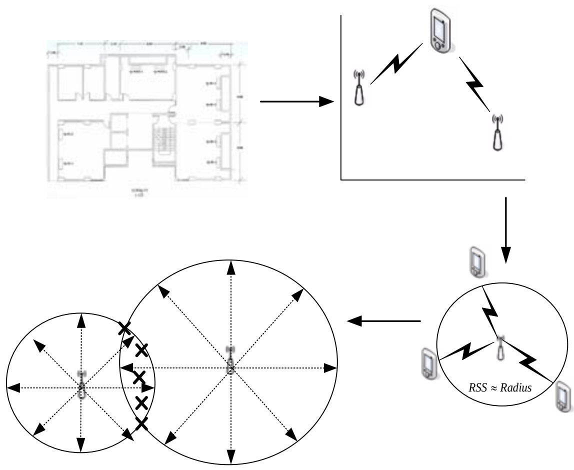


Fig. 3. Position determination overview

Starter for this task is to request for a floor plan of the building under interest. Then try to locate access point's position accordingly and note that origin point of x-y coordinate is arbitrarily chosen. Awareness of any measurement with exact reference to the corresponding floor plan has to be taken care of. Distance error is calculated with respect to the exact location on the floor plan in hand.

Now signal strength measurement is done as aforementioned instructions. After that, signal strength collection from the access points, NAL-Q51 and DSP-Q52 are interpreted with two propagation models which are free-space and wall attenuation factor model. Signal strength – distance relationship directly affects the accuracy of positioning system and reveals a surrounding attenuation characteristic.

**Radio Propagation models**

For a radio channel, there exists a reflection, refraction, diffraction and scattering of radio waves that influence propagating paths. Arrival of radio wave from different path traveled causes multipath fading phenomenon. Transmitted signal from direct and indirect propagation path are combined either constructively or destructively causing variation of received signal strength at the receiving station. The situation is even more severe for indoors communication. In-building environment has different building layout, construction material, and partition placement resulting in challenging and unpredictable nature of received signal.

***Free-space Model:*** It is primarily used for the worst case consideration. At least this model proves new concept of positioning system with GIS and unveils a trend for further improvement. Free-space model or Friis transmission model is described as follows.

$$P_R = P_T G_T G_R \left( \frac{\lambda}{4\pi d} \right)^2 \quad \text{........................ Eq.2}$$

Where $P_R$ and $P_T$ are receiving and transmitting power in unit of watts respectively. $G_R$ and $G_T$ are receiving and transmitting antenna gain. λ is a wavelength and d is a distance between transmitter and receiver. The exponent value of 2 represents a path loss exponent. This can be interpreted as the rate of signal decrement relative to distance. Factory values of operating antenna gain at different distances are required for calculation but they are rarely found in attached manuals. As a result, it might be inconvenient to use the above equation.

Equivalently, free-space model is characterized in terms of reference distance as follows after few steps of mathematical manipulation.

$$P_R[dBm] = P_0[dBm] - 10\log\left( \frac{d}{d_0} \right)^2 \quad \text{.... Eq.3}$$

Signal strength – distance relationship of free-space model is a foundation as the worst case to consult with. Maximum error distance from other models that exceeds the one calculated from free-space model is definitely invalid. Some segment in the floor under experiment is applicable to this equation, for example, corridor, and hallway and so on. This model is not universally appropriate for indoors, in particular, in-building environment.

***Wall Attenuation Factor Model:*** This model represents a common and reliable in-building characteristic. Attenuation due to an intervening wall or partition is described as follows.

$$P_R[dBm] = P_0[dBm] - 10\log\left( \frac{d}{d_0} \right)^n - WAF \quad \text{.... Eq.4}$$

Where n is a path loss exponent and WAF is a Wall Attenuation Factor. Overall, WAF is a number of attenuation from intervening walls and partitions. Principally, different types of material possess different electrical and physical characteristics. In-building obstruction varies from place to place and considered to be specific. These values can be obtained by experiments.

**Learning Process**

Practically, position determination based on free-space model is straightforward and does not require learning process as universal relationship is implied in every environment considered. Path loss exponent for free space is fixed at the value of 2 as shown in Eq.2. This statically represents unrealistic environment of free space regardless of the surrounding obstructions. Obviously, applying this free-space model yields higher error distance.

To achieve more accurate result and to represent more realistic indoor environment, we adopt WAF model. In this case, values of WAF and n have to be computed from experiment before positioning service. This is considered to be a learning process of environment by which clients are residing in. Once the measurement of signal strength at marking points is done, linear regression is applied to those data sets resulting in WAF and n parameters. In my experiment, eight points or odd-numbered points on our test area are used for learning process.

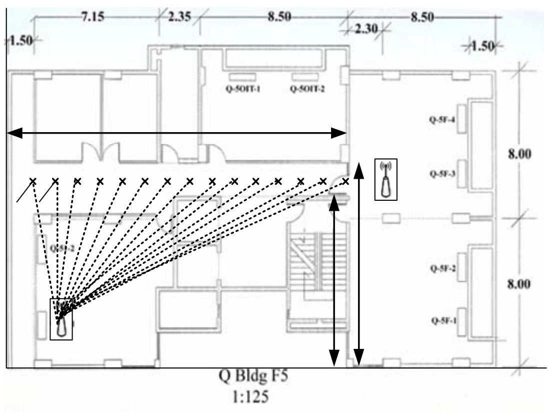


Fig. 4. Line of sight for NAL access point

Consideration of straight line joining between these two access points to every single point of interest on the floor plan can at least differentiate amount of signal attenuation due to variety of obstructing objects. It is very obvious that signal strengths received at DSP-Q52 access point are commonly blocked with the same obstacle and reflects in consistent attenuation pattern as shown in the following figure. On the contrary, signal attenuation trend for the case of NAL-Q51 access point is inconsistent.

Note that a line with rectangle marker represents experimental result, while triangle marker represents calculated result due to linear regression.

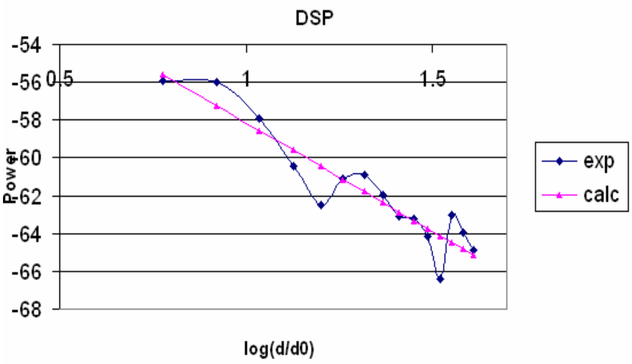


Fig. 5. Signal strength at DSP-Q52 access point

Theoretically, the longer the range from a transmitter, the lower signal strength a receiver can perceive. Shorter range from transmitter can yields lower signal strength only in the case of presence of a large barrier between transmitter and receiver. And that is applicable for the case of NAL-Q51 access point. Physical realization of floor plan helps predicting received signal strength in corresponding points of field.

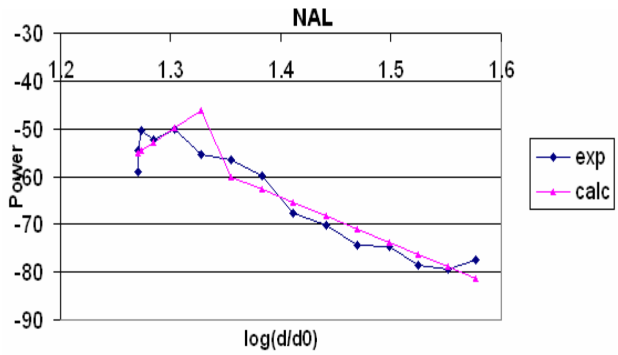


Fig. 6. Signal strength at NAL-Q51 access point

Region division is essential for the case of NAL-Q51 access point as received signal strength does not undergo common obstruction as the case of DSP-Q52 access point. Piecewise linear concept appears to be applicable for this inconsistent characteristics. Essentially, Geographical Information is now used to separate region under consideration. First region constitutes point 1 up to point 6, while second region constitutes point 7 up to

y

point 15. Linear regression is then applied to each region accordingly yielding piecewise linear from point 1 to point 6 at a corner and from point 7 to point 15 at a corner.

**System Simulation**

Signal strength collection can now be translated into transmitter-receiver distance with the aid of two radio propagation models. Transmitter-Receiver distance is the separation distance of access point from user. This value of distance can be visualized as a radius of antenna radiation circle with the center at that access point of signal reception. From access point of view, user location can be at any points on that antenna radiation circle. The following figure illustrates received signal strength from NAL-Q51 access point.

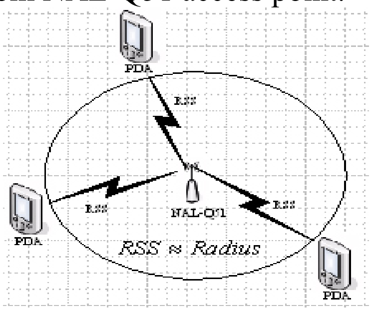


Fig. 7. Antenna radiation circle

In the same manner, received signal strength from DSP-Q52 is translated into radius of antenna radiation circle with the center at the access point itself. We now have two circular equations with known center point and radius value. Access point's positions are initially assigned before laying coordinate system onto the floor plan of interest. Simultaneous equation solving is required to be done successfully to find those two crossing points. Unlikely crossing points output from equations solving will be eliminated with the aid of Geographical Information System later.

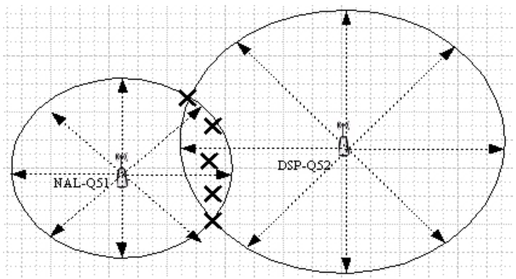


Fig. 8. Crossing of two radiation circles

Mathematics expression representing those two circular equations with slight manipulation is as follows.

$$(x - x_1)^2 + (y - y_1) - r_1^{\,2} = 0$$
$$(x - x_2)^2 + (y - y_2) - r_2^{\,2} = 0$$
$$\vdots$$
$$(x - x_n)^2 + (y - y_n) - r_n^{\,2} = 0$$

Eq.5

Where $x_1$ and $y_1$ are x-y coordinate of DSP-Q52 access point, while $x_2$ and $y_2$ are x-y coordinate of NAL-Q51 access point. $r_1$ and $r_2$ can be calculated from eq.4 in terms of d.

Transfer all variables to the left hand side and leave right hand side with zero. Define $\overline{f}(x,y)$ in a form of matrix as shown below.

$$\overline{f}(x,y) = \begin{bmatrix} f_1(x,y) \\ f_2(x,y) \\ \vdots \\ f_n(x,y) \end{bmatrix} \qquad \text{Eq.6}$$

$$\overline{f}(x,y) = \begin{bmatrix} (\mathrm{x} - \mathrm{x}_1)^2 + (y - y_1)^2 - r_1^{\,2} \\ (\mathrm{x} - \mathrm{x}_2)^2 + (y - y_2)^2 - r_2^{\,2} \\ \vdots \\ (\mathrm{x} - \mathrm{x}_\mathrm{n})^2 + (y - y_n)^2 - r_n^{\,2} \end{bmatrix}$$

Eq.7

$$\left\|\overline{f}(x,y)\right\| = \sqrt{f_1(x,y)^2 + f_2(x,y)^2 + \ldots + f_n(x,y)^2}$$

Eq.8

$\left\|\overline{f}(x,y)\right\|$ represents the error matrix due to the incalculable effect such as multipath fading, reflection, refraction and attenuation for radio channel.

$\min\left\|\overline{f}(x,y)\right\|$ with constraints of

$$0 \le x \le 19.125$$
$$9.25 \le y \le 11.125$$

Eq.9

Hallway boundaries for both horizontal and vertical dimension are taken to be constraint for minimization.

Constraints of x and y coordinate are based on Geographical Information of floor plan in our test site. It scopes down and eliminates unlikely intersection area resulting from positioning algorithm in optimization stage. The following figure displays a floor plan of our test site along with specific x and y dimension of corridor section. It is obviously seen that for corridor section, x and y ranges from 0 to 19.125 meters and from 9.25 to 11.125 meters respectively. This yields the expression shown in Eq.9.

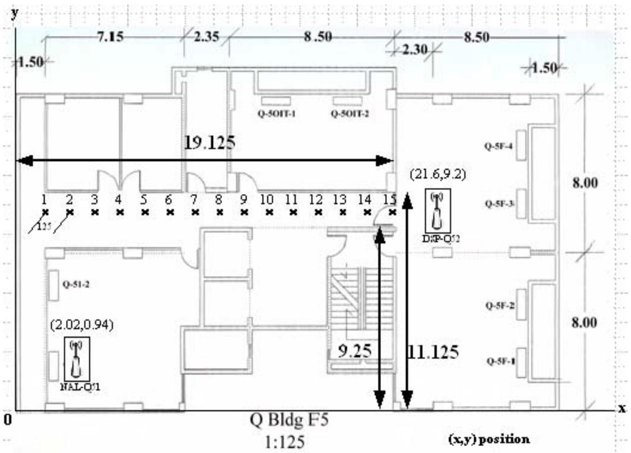


Fig. 9. Floor plan with corridor dimension

## Results and Discussion

The constraint for minimization with the knowledge of geographical information decreases error distance in comparison with unconstrained minimization as expected. This result emphasizes that with notion of unlikely location for that user, the error distance in determining that user's position can be achieved with better performance.

Table 1. Crossing points and error distance for the case of with and without constraint optimization

| Point | DSP Signal | NAL Signal | cross1 | | cross2 | | map | | Error Distance | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | x | y | x | y | x | y | With Constraint | No constraint |
| 1 | -64.85507 | -59.07457 | 2.523629 | 11.125 | 9.666466 | -5.80681 | 1.25 | 10.375 | 1.333211493 | 1.3332114 |
| 2 | -63.94484 | -54.66876 | 5.617157 | 9.598141 | 10.73165 | -2.52556 | 2.5 | 10.375 | 3.21250374 | 3.2125038 |
| 3 | -63.00348 | -50.35635 | 8.229423 | 9.25 | 12.30525 | -0.41158 | 3.75 | 10.375 | 4.618533479 | 4.9426032 |
| 4 | -66.44059 | -52.30559 | 0 | 11.125 | 7.905368 | -7.61436 | 5 | 10.375 | 5.055937104 | 8.9515312 |
| 5 | -64.12084 | -50.2152 | 5.085383 | 10.46667 | 10.98264 | -3.51254 | 6.25 | 10.375 | 1.16821932 | 1.1682201 |
| 6 | -63.24535 | -55.36887 | 7.770637 | 10.51847 | 12.89363 | -1.62537 | 7.5 | 10.375 | 1.110387298 | 1.1103867 |
| 7 | -63.06544 | -56.44277 | 8.253113 | 10.38039 | 13.13142 | -1.18344 | 8.75 | 10.375 | 1.244441717 | 1.2444414 |
| 8 | -61.94996 | -59.78199 | 10.68006 | 9.25 | 14.01541 | 1.343695 | 10 | 10.375 | 1.202574936 | 2.8661568 |
| 9 | -60.93159 | -67.57203 | 12.09993 | 9.25 | 15.00625 | 2.360678 | 11.25 | 10.375 | 1.900838183 | 2.0942778 |
| 10 | -61.12405 | -70.23036 | 12.53299 | 9.505269 | 15.4913 | 2.492719 | 12.5 | 10.375 | 0.374331312 | 0.3743317 |
| 11 | -62.50905 | -74.36375 | 11.50825 | 11.125 | 15.93632 | 0.628428 | 13.75 | 10.375 | 1.730753922 | 4.9330455 |
| 12 | -60.45897 | -74.71633 | 13.84669 | 10.90056 | 17.40744 | 2.459965 | 15 | 10.375 | 1.007012975 | 1.5815186 |
| 13 | -57.89583 | -78.43382 | 17.01084 | 10.39965 | 19.25673 | 5.075844 | 16.25 | 10.375 | 0.734284218 | 0.73428 |
| 14 | -55.9694 | -79.25992 | 15.85924 | 9.25 | 17.62966 | 5.053288 | 17.5 | 10.375 | 1.214398996 | 2.6762931 |
| 15 | -55.89362 | -77.52617 | 19.125 | 11.125 | 21.25162 | 6.083932 | 18.75 | 10.375 | 1.920881333 | 2.8488482 |
| | | | | | | | | min | 0.374331312 | 0.3743317 |
| | | | | | | | | max | 5.055937104 | 8.9515312 |

Error distance decreases from 8.95 meters to 5.05 meters after applying minimization with constraint of geographical information of our floor plan. This result reveals the goodness of geographical information in improving indoor positioning system accuracy.

## Conclusion

In this paper, WiFi positioning system with knowledge of Geographical Information is conducted to improve accuracy of indoor positioning system. Reliability and accuracy of the system mainly depends on numbers of learning points, optimization of crossing point finding algorithm and sufficient signal strength samples to represent each point with least error.

Applying the concept of reference position implicitly mitigate multipath fading effect by relying on a point in the field. Issue of reference point can be divided into static and dynamic type. The one used in this experiment is that of static type as the reference is fixed at position of 50 cm.

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