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This thesis provides a method for finding a location of a mobile robot based on the signal strengths obtained from the IEEE 802.11 standard wireless Access Points. In this method a set of eight signal loss functions is proposed to enable the robot to determine its current distance and direction using its known location of the Access Points. Recently a series of techniques have been proposed to address this problem, however they require a significantly larger number of data signals to determine the robot's current location. The experimental results show that the proposed approach provides better or equal accuracy of location to the existing approaches with an added advantage of the reduced computational complexity. Another advantage is that this positioning system can also be applied to the standard mobile clients using the wireless network.

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WI-FI802.11 BASEC MOBILE ROBOTICS POSITIONING SYSTEM
by

Robert Misior

A Thesis Submitted to
The Faculty of The Graduate School at
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Approved by

____________________________________
Committee Chair

To my wife, for her encouragement and great support.

APPROVAL PAGE

This thesis has been approved by the following committee of the

Faculty of The Graduate School at The University of North Carolina at Greensboro.

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Date of Acceptance by Committee

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Date of Final Oral Examination

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# CHAPTER I

# INTRODUCTION

Fifty years ago people have imagined a life in 2010 as dependent on computers and robots. The last few decades have seen great advances in electronics and in fact computers are now inseparable part of our everyday life. However, application of mobile robots has significantly lagged behind in large part due to inability to develop a reliable system for indoor localization.

For most people robot is not just a stationary object but a movable machine that possesses some type of intelligence. By definition, mobile robots are a combination of a computer and moving machine. Mobile robot must be able to perceive (sense) its environment and have ability to respond to it. Thus its ability to localize itself is one of the basic requirements for a functioning machine. Unfortunately, robot localization is also recognized as the most fundamental problem in mobile robotics. Development of advanced localization systems, such as global positioning system (GPS) [1], does allow for reliable robot localization. Unfortunately, it can only be applied in an outdoor setting and localization within a building still remains one of the main hurdles to be overcome in mobile robotics.

Humans and animals are equipped with a wide range of sensors that help us navigate through our environment. Sight and touch are primarily used for mid range navigation by living beings and location is identified by use of reference points established by these senses. Since the ultimate goal for mobile robots is to exist and function in an environment, they also need sensors to correctly identify their location. Unfortunately, limits in computing power of individual robot do not allow for development of sensing methods based on those of living beings. The amount of data that would have to be processed in real time to simulate vision for example is still overwhelming even for the most powerful computers. Currently robots need different types of sensors to function. Options that have been explored range from electro-magnetic detectors to lasers. One attractive option is a sensor that could detect radio waves from the electronic devices currently in use, such as the wireless network access points.

## Thesis Statement

One possible approach to this problem is use of an IEEE 802.11 standard wireless signal for mobile robot positioning. This method will use a limited number of sample point readings of signal strength to create a set of signal loss functions for that particular environment. This will allow the mobile robot to use the 802.11-based access points as reference points for a mid range indoor positioning system.

The main reason for developing a new method used for position localization is that the traditional wireless methods used for object positioning such as GPS work only outside and require a clear view of the sky [1]. In current industrial deployment of robots most installations use a specialized network of electronic sensors or magnetic guidance systems built into the building. This approach is very expensive and requires installation of a specialized sensor network. This cannot be justified for everyday applications and does not allow for building retrofitting, making mobile robots usable only in small percentage of situations.

# CHAPTER II

# IEEE 802.11 WIRELESS NETWORK OVERVIEW

IEEE 802.11 networks are common place in most schools, office and other commercial and noncommercial buildings.  The 802.11b standard is still the most widely used wireless network and it uses a 2.4 GHz (gigahertz) band.  This is an unlicensed, open, industrial, scientific, and medical (ISM) band used by many other devices.  The 802.11b standard has 11 possible channels available starting at channel 1 at 2.412 GHz to 11 at 2.462 GHz.  The maximum equivalent isotropic radiated power (EIRP) for a PC card with 0 dBi antenna gain is 100 mW or 20 dBm.  The typical indoor range is about 30m (100 ft).  The standard media access protocol used by the 802.11b is carrier sense multiple access with collision avoidance CSMA/CA.  A newer backward compatible 802.11g standard is starting to replace the 802.11b.  It also uses a 2.4GHz band and adds additional channels and possible bandwidth from the original 11 Mbps to 54 Mbps. [2]

In a deployment of 802.11b/g wireless network a number of access points (AP) is physically mounted throughout the area to provide an adequate signal to the clients for data network access.  In most cases the client has a choice of selecting the best possible AP for the connection.  The choice is usually made by analyzing the signal strength, the signal quality and signal to noise ratio (SNR) [3].

SNR is a ratio of the signal power to the noise power interfering with the signal. High noise power requires a high signal power for the signal to be received. The SNR [3] is defined by:

$$\text{Signal/Noise Ratio [dB]} = 10 * \text{Log10 (Signal Power [W] / Noise Power [W])}$$

There exist many different sources of the noise such as: white noise, microwave ovens and other devices that create magnetic waves. Other devices that operate on the same spectrum wavelength can also be a source of the noise. Devices in the same spectrum can play a major role in the 802.11b/g network since there are many other home and office appliances that use this spectrum.

## Other benefits of 802.11 Localization

Knowing physical location of wireless network devices is not only useful in mobile robotics but also in many other computer applications. Location aware applications can be applied to physical device tracking for asset management or security purposes: for example laptop or a PDA user could be guided to a nearest exit in case of fire or other emergency or users could find their location on a map of a big shopping mall and locate their favorite stores. Other possibilities could include printing to the physically closest printer.

## The Challenge in using 802.11 for Localization

802.11 wirelesses network is a logical possibility for the mobile robot localization system. The APs are stationary and can be used as reference points by the robot. Further, the deployment of the network is relatively inexpensive and easily justifiable. But since the 802.11 standard was developed for data transmission and was not meant to be used for positioning system this makes this task challenging.

One of the big challenges of using the 802.11 network for localization is the nature of the wireless signal, especially in the indoor environment. Signal strength is a function of distance, so the calculation of the distance from the AP should be easy. However, possibility of other interferences such as reflection, diffraction or high SNR may complicate the use of this system for positioning.

Reflections and delay spread occurs when radio waves reflect off of surrounding objects. This phenomenon causes the receiving device to detect the same signal at possible different times. Reflection can also cause self-cancellation of the signal if two copies of the same signal arrive at the same time at the receiver. This may lead to overall system performance degradation. For example, a wave traveling at the speed of light refracted by 50 nanoseconds would result in a path length difference of 15 meters [4].

The diffraction occurs when an obstacle is located between the transmitter and the receiver and causes some of the energy to pass through the object and some over the top edge of the obstacle. This results in signal shape modification.

Signal attenuation is a reduction in signal strength. Different building materials have different effects on signal attenuation, as demonstrated by the following table which illustrates how different materials affect a 900MHz frequency. The results presented here would be very similar to the performance of 2.4GHz frequency.

| Material | Attenuation @ 900 MHz |
|---|---|
| Glass 0.25" (6mm) | 0.8 dB |
| Glass 0.5" (13mm) | 2 dB |
| Lumber 3" (76mm) | 2.8 dB |
| Brick 3.5" (89mm) | 3.5 dB |
| Brick 7" (178mm) | 5 dB |
| Brick 10.5" (267mm) | 7 dB |
| Concrete 4" (102mm) | 12 dB |
| Masonry Block 8" (203mm) | 12 dB |
| Brick faced concrete 7.5 " (192mm) | 14dB |
| Masonry Block 16" (406mm) | 17dB |
| Concrete 8" (203mm) | 23dB |
| Reinforced Concrete 3.5" (203mm) | 27dB |
| Masonry Block 24" (610mm) | 28dB |
| Concrete 12" (305mm) | 35dB |

**Table 1: Material Attenuation**
**(Credit to AvaLAN [5] for the above table)**

# CHAPTER III

# OTHER TECHNIQUES

Research conducted on the 802.11-based positioning system provides very promising results. Studies indicate that this approach may not be able to pin point location to few centimeters but it should be able to narrow down the possible location to about 1.53 m [6]. This accuracy should be sufficient for a mid range robot localization, where the robot would be able to know its general location but would still require a close range sensors to detect objects in close proximity.

Increasing the precision of localization using the 802.11 standard will require however some changes to the system or use of specialized equipment. Techniques used in other wireless environments such as the angle of arrival (AoA) and time difference of arrival (TDOA) are not possible in the 802.11 environment. The AoA and TDOA are currently used in outdoor applications such as wireless cell phone emergency 911 (E911) localization.

## Vendor Specific Approach: Server Centric

Same hardware vendors offer 802.11 based localization systems for their equipment. Cisco offers the Wireless Location Appliance that works with Cisco based AP to determine location of wireless clients on the network by using the signal received by multiple APs.  These serve as the sensors for triangulation of the wireless clients.  This approach is server-centric and requires vendor dependent equipment [7].

The server-centric approach is not very suitable for robot localization, unless a standard API for reading the current location was developed that would allow the robot to work with vendor independent system.  Otherwise the localization from the client side would only work with that particular vendor's equipment.  Otherwise, application that could support many different interfaces would be required, likely adding additional costs.

## Client Centric Approaches

Other option, which would circumvent the server-centric requirement for vendor specific hardware, is a client-centric concept.  In this approach the robot would establish reference points based on the signal received from APs in the environment and localize based on the information provided about the surrounding environment.  System of this type would be vendor independent and could be used in any environment where 802.11 network is already used.  There exist few methods that could be used to accomplish this task.  I will provide short review of the already studied methods and some of their shortcomings, then I will present my own approach to accomplish this task.

Currently used client-centric methods for 802.11 localization require two major steps:

Step 1)  The calibration phase: Wirelesses map creation.

Step 2)  The operating phase: Location approximation based on the provided map.

## Location Fingerprinting Approach

The oldest method used is based on creating a histogram of a small cell sample representing the wireless map of the area. The area of interest is divided into squares ranging in size from the entire room to 1.5 m squares, and each square is labeled with a unique name or number. The signal-strength map is then created by moving the mobile client to each sample location and measurement of the signal strength. These data are then stored as a tuple of signal strengths or SNR from all visible APs at each particular location. The sample size taken at the location requires between 20 [8] to 200[6] samples readings. The position calculation is done by "determining a client's state (or position), $s*$, given one or more observations. The problem can be modeled by using a finite state space $S = \{s1, . . . , sn\}$ and a finite observation space $O = \{o1, . . . ,om\}$. Each state si corresponds to the case of the agent being in cell i. histogram method since for each si, the P(oj |si) are determined by the normalized signal intensity histograms recorded during the training phase". (quote) This method can yield proximity error of about 2.37 meters. If a much smaller sample size is used for the map creation the accuracy decreases to about 87.5 % [6].

The biggest drawback for this method is the amount of time it takes to create the wireless map. It requires recalibration in case any of the APs are moved or added. This makes this approach unfeasible for wide deployments due to the actual time required to maintain the wireless map. Another problem is that only previously visited locations can be determined. If a location is skipped during the calibration of the system this location will remain unknown to the clients that will try to determine their position.

It is also possible to create a wireless map based on the SNR instead of the signal strength, but previously done research indicates that the signal strength was more indicative[8]. Nevertheless, the method using SNR can predict correct location in 97%.

## Signal Strength Function Approach

Another approach to determine location based on the signal strength is the interpolation method published by Krumm and Platt [6]. Previously done research provides one method that uses interpolation formula using the signal as an input and provides x,y coordinates of the location. In this method the radial basis function is used with an isotropic Gaussian kernel function. The first step in this method also requires a set of samples, 60 seconds is spend at each sample location to collect signal strengths. The size of the sample location is the entire room. In the example provided 137 sample points were used. Each sample is used as the kernel center of the Gaussian function.

This method provides and error of about 3.75 meters, looks little worst then 2.37 accomplished by the RADAR[8] method. But it provides significant improvements by allowing to completely skip some locations. This is not possible in the pure location fingerprinting because locations that were never visited during the training phase would never be determined during the operation phase.

## Modeling Software Approach

One way to avoid wireless map creation would be to use modeling software that could use the floor plan layout and the location of the APs as the input. This approach sounds very promising, unfortunately in most cases the detailed floor plan required to accomplished this is not available. The floor plan would have to include the types of materials used in the construction and thickness of the material. This sort of plan may be available in the new construction but in most other cases would be difficult to compile for existing buildings. The work currently done in this area is mainly focused on the planning of wireless network deployment and the simulation software is used to find the best possible location for the AP to provide sufficient area of coverage.

# CHAPTER IV

# RADIO SIGNAL PROPAGATION

The best solution to the 802.11 based localization system would be one that does not require a large amount of time needed to maintain a wireless map, and would allow the client to learn about new locations as it moves around. A system of this type could be possible if the radio wave propagation could be calculated.

The most basic radio wave propagation is called the free space loss, as with any signal loss it is due to absorbing, diffracting, obstructing or refracting. In case of free space loss it is assumed that the transmitter and the receiver both are in the free space and no other obstructions exist between them and the wave propagation is assumed to travel in all directions in a straight line.

The formula used for free space loss calculation is [9]

$$\text{free space loss} = \text{FSL} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2;$$

"Where **λ** is the signal wavelength, **f** is the signal frequency, **d** is the distance or radius of the signal from the transmitter, and **c** is the speed of light (299792.458 km/s) in the signal transmission medium the units used should be consistent, e.g., $\lambda$ and R in meters, and c in meters per second)"[9].

The more useful representation of this formula is in terms of dB that is based on Hz and meters[9]:

$$\mathrm{FSL(dB)} = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - 120,$$
$$\approx 20\log_{10}(d) + 20\log_{10}(f) - 147.55;$$

Based on this formula it is possible to calculate the signal strength at the particular distance if the frequency is known. In 802.11 b/g networks we know that the frequency used is 2.4Ghz = 2400MHz.

Unfortunately in a real world there exist other forms of interference that increase the signal fading, especially in the indoor environment. Most of the buildings are not radio frequency friendly and the signal propagation inside of a building is never included in the building design.

Another set of information that also needs to be included in measuring the received signal strength is the transmission power of the AP and the gain from the antenna used. Here is the modified formula:

Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) - Losses (dB)

In our case the Received Power is one of the known variables and can be read from the wireless network card used by the client. The transmitted power and the gain is also a known parameter since that information is provided by the manufacturer of the AP. Still the problem exists with the free space loss formula due to interference of the environment with the signal.

However, there was an attempt to modify the free space loss formula for indoor application. Research found that if the indoor propagation of the 2.4 GHz signal follows an approximate 1/(range^3.5) power rule instead of the 1/(range^2) in the free space loss formula then the propagation loses can be predicted with the following relationship[10]:

$$\text{Path Loss (dB)} = 40 + 35 * \log (D)$$

D – is the distance in meters

The 40 is a constant that includes both the output power and the static cumulative gains and losses. (802.11 tracking quote) Because this the value 40 may not be the same for all situations, it is substituted by a constant variable “V”

$$\text{Path Loss (dB)} = V + 35 * \log (D)$$

# CHAPTER V

# THE DESCRIPTION OF THE METHOD

The basic approach to my method will use the indoor propagation formula listed above as the base for determining the signal strength propagation in the particular direction. A new formula will be derived from experimental data samples, and the gathered data will be used to find best fitting logarithmic formula of the form:

$$\text{Path Loss (dB)} = V + C*\log(D)$$

Where D is the distance in meters, C and V constants calculated from the data measurements.

## The Wireless Map Creation

This method requires a small number of sample readings in a well picked location. The sample readings would be used to modify the indoor propagation formula to determine the values that fit the particular location. Another set of inputs required is the location of all APs used in the particular plane, their type, and their transmitting power.

The initial location will represent the starting point that can be used to learn more about the surrounding environment.  The starting point is a center of our coordinate system, we place it at point (0,0).

This will allow the robot to poses knowledge about particular zone, “the comfort zone”. This zone then can be used as a reference point to learn more about surrounding environment, the more robot is exposed to the areas outside of the comfort zone the bigger the zone will be until it will know the entire operating environment.  This process will allow the robot to be operational in a very short amount of time.

The comfort zone is selected by choosing the AP that is in the central position of the robot’s operating environment.  The initial reading is taken right next to the central AP (AP1) to measure the actual signal strength based on a near to free space loss conditions. This is done to determine the possible difference from the actual signal strength reading and the value derived from the free space formula.

## Step 1 The AP Location on the Map

The first step is to overlay the area map with the location of the access points with respect to our coordinate system. The floor plan of the area is needed for this step, on the floor plan the location of the APs needs to be located.

## Step 2 Create Circles

The next step is creation of 4 imaginary circles with the AP1 at the center. Each circle has a radius 5 m larger then the previous one starting initially with a radius of 5 m.

## Step 3 Create The Lines of The Coordinate System

The next step is slicing the circles with 4 lines passing through the center; AP1. Each line is rotated by 45 degrees from the pervious one at the center point. The fist one cuts through the area horizontally East – West similar to the x-axis in the coordinate system. This step is illustrated in Figure 1.

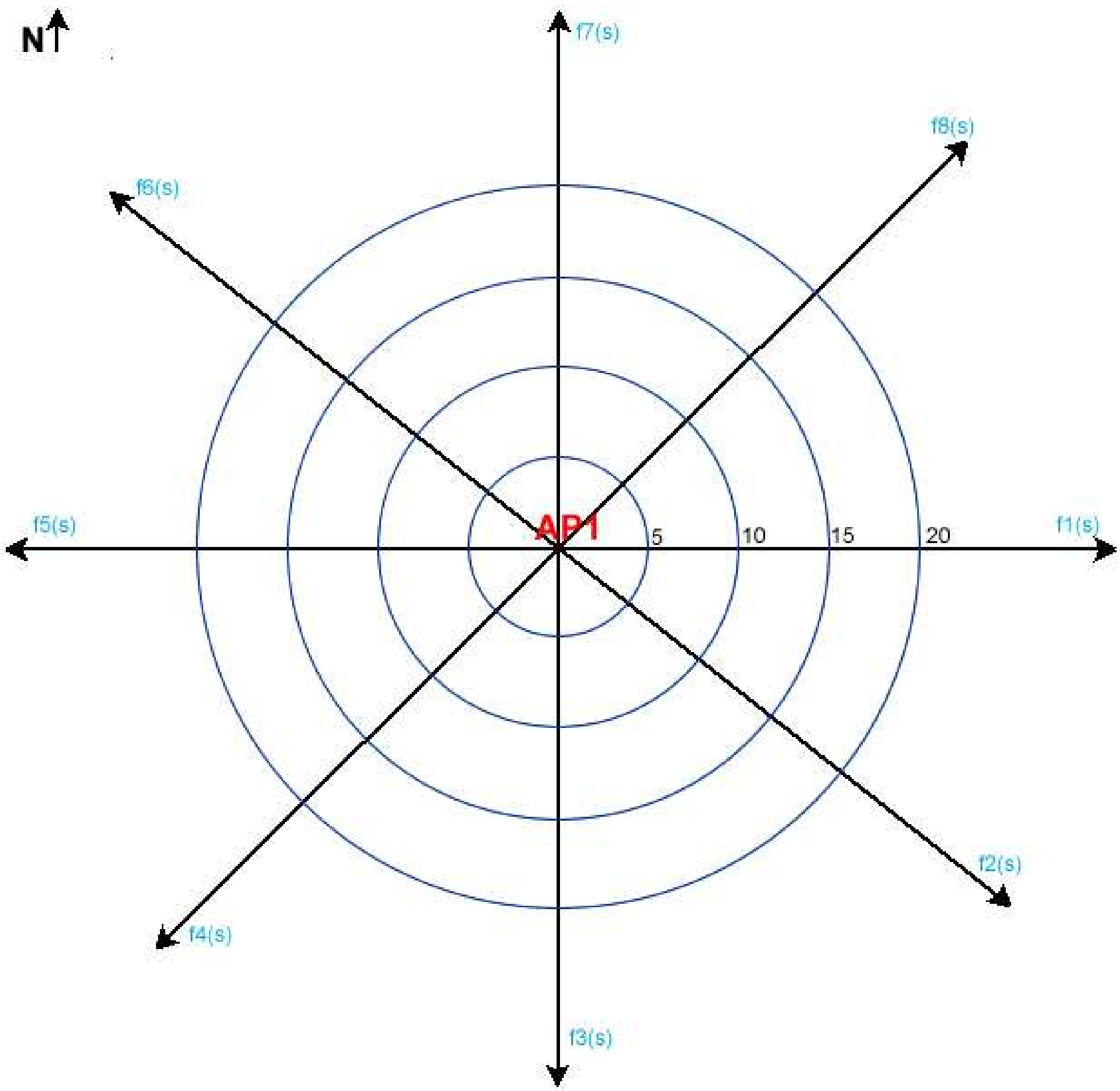


**Figure 1: The signal loss functions**

## Step 4 The Sample Measurements

The initial sample measurements are taken at the intersection of the lines and the circles, the total of 33 measurement points is created, each point is assigned a unique number for identification.  At each point 120 sample measurements are taken 2 samples per second. The signal strength from each detectable AP is recorded.  Based on the research done in the 802.11 location finger printing spending 1 minute provides enough data samples for the particular location. [8]

The radius increases of five meters are selected due to the fact that 30 meters is about the maximum operating range for 802.11 and at 50 meters the signal may be completely invisible in the indoor environment.  The initial 20 meters consist of the majority of the operating signal strength degradation.  At the same time we can measure the signal penetration in that building in the multiple directions covering an area of $\pi 40^2$ meters.

The 4 lines are selected to slice the area to allow measurements in most possible directions at the same time and to keep the amount of measurement samples to the least possible number.

## Step 5 Function Creation

The taken measurements allow us to find the best value for “V” and “C” and to create 8 individual base propagation loss functions f1(s) to f8(s) in the particular direction. These functions are combined to create the wireless network coverage signal strength cloud from AP1 in the comfort zone.

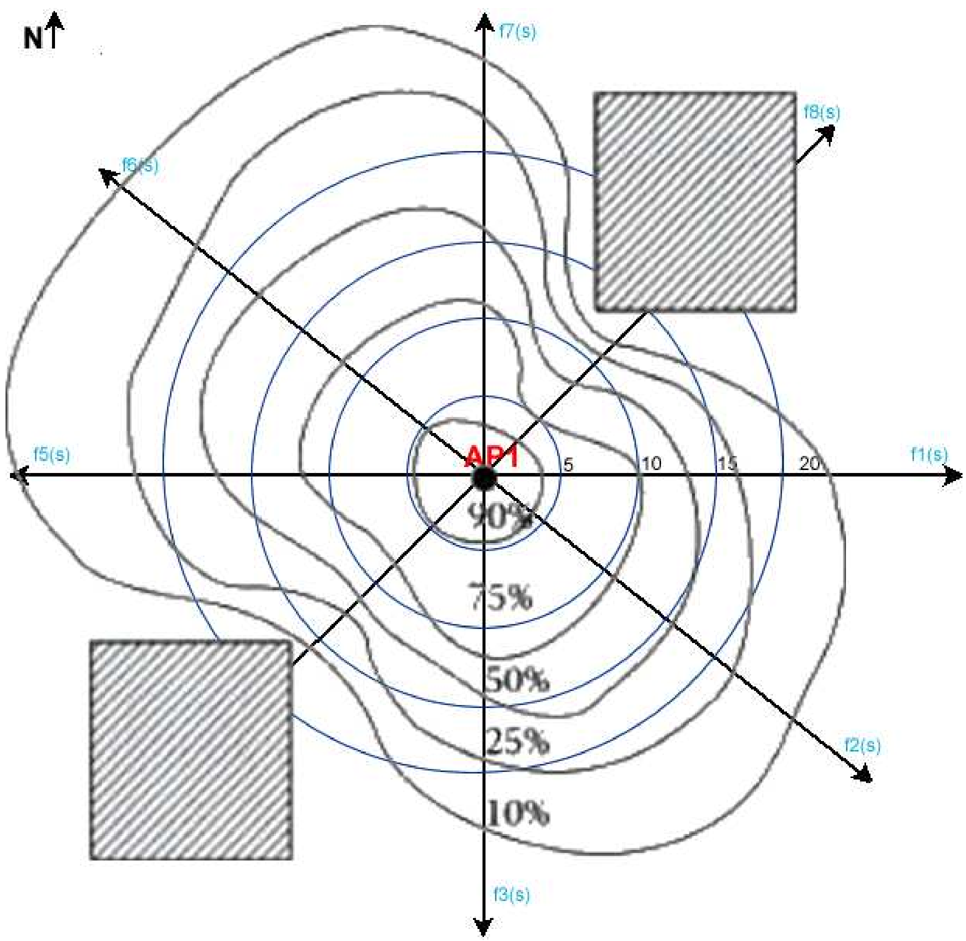


**Figure 2: Signal propagation against objects**

**(The signal strength for this image comes from Local Positioning Systems: LBS Applications and Services [11])**

At this time we can find our possible distance away from the AP1.

We can also compare the actual signal loss at that particular distance going in the particular direction to the signal loss value produced from the formula. In most cases the shape of the wireless cloud created by the AP1 in the comfort zone will not be circular.

Each direction may have a different set of obstacles present that will absorb and interfere with the transmitted signal. We also will have a direction that has the strongest signal penetration and a direction that has the weakest signal penetration giving us the currently known best possible penetration and worst penetration for that environment at the range of 20 m.

## Step 6 Finding Functions For The Reminding APs

By using the remaining data collected at the sample locations and the map of existing APs (in relation to AP1) we can calculate the distances between the sample point and the other APs using a simple triangulation method. Based on the signal strength values received we can compare that to our best possible formula and the worst possible formula and see how close the values are. If the value from the formula is close to the value of the actual reading we can be confident that the signal penetration in that direction can be predicted with a high accuracy. If the difference in values is significant, the location prediction may have a grater error of possibility and the function that produces the best result is selected until a better function is found.

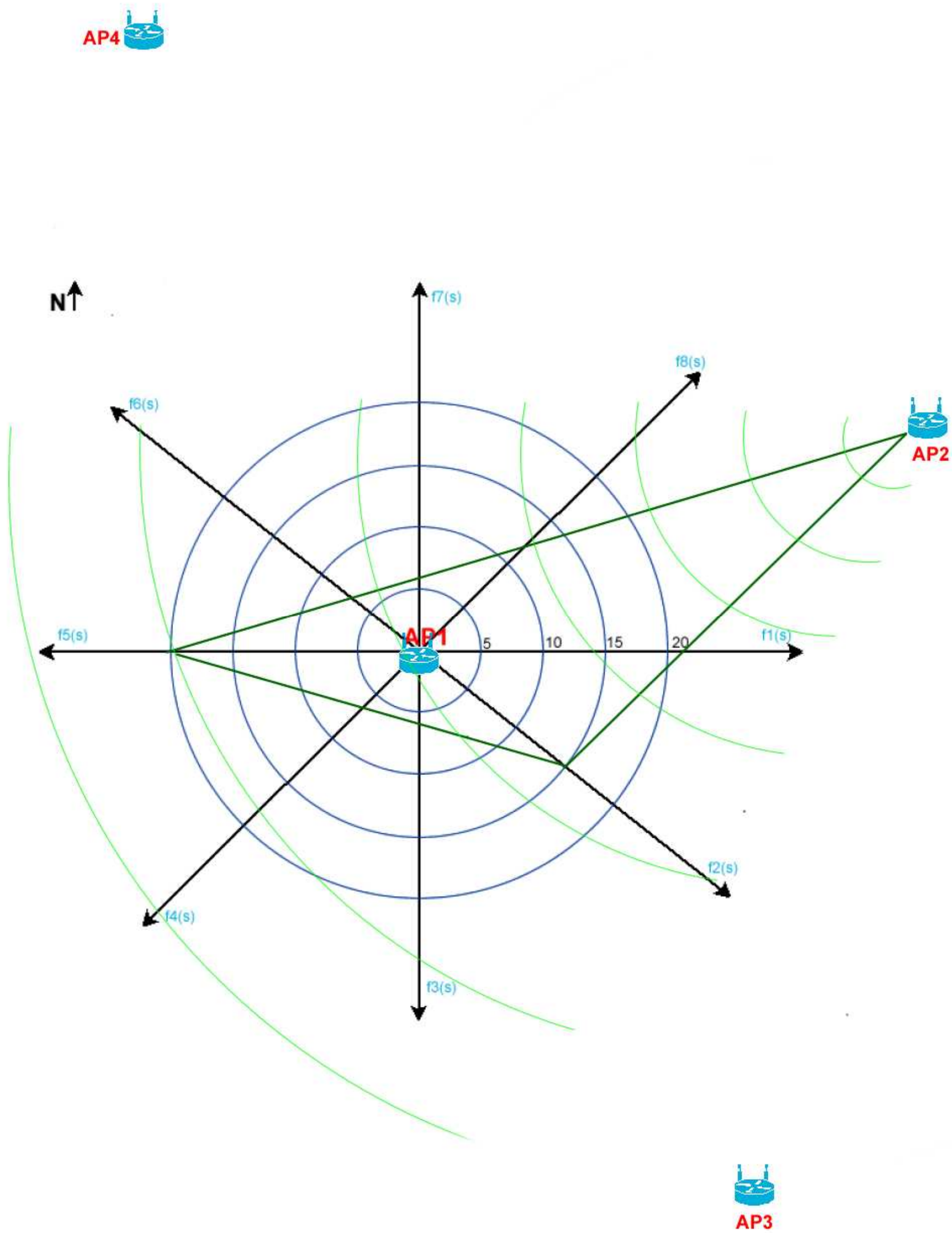


**Figure 3: The distance form sample point to AP2**

By using the received signal strength from all other detectable APs, other than AP1, at each sample location we can apply our formulas to find out how close the value derived from the formulas is to the actual distance of that AP from our current position. If one of the formulas provides a calculated distance that is very close to the actual distance we can confidently associate that formula for this AP coming from the direction of our sample point.

## The Operation Phase

Once we have a set of logarithmic functions that can predict signal loss in all directions from the AP1 the training phase is finished.

We also have generated a set of functions that can predict signal loss of the neighboring APs coming in the direction of the confidence zone.

In the operation phase the robot should start inside of the confidence zone. Its initial location is calculated by looking at signal strengths from all visible APs. First the signal strength form AP1 is used to calculate possible distance away from the AP1. This is accomplished by using the functions associated with AP1. Next we use functions associated with the other APs that are detectable at the same location. This will allow for calculation of the possible distances from these APs. Once the distances from at least 3 APs are known, current location can be calculated.

The robot is also ready to increase the size of the comfort zone by venturing outside of the 20 m radius around the AP1. Since we have some of the signal loss functions already associated with the other APs that can predict distance coming from the direction of the comfort zone. The robot can venture out into the direction of the access points that provide the best available distance prediction. While it is moving in that direction it can take signal samples on the way to fill in missing gaps “functions” that can be associated to the other access points that are visible.

# CHAPTER VI

# TEST ENVIRONMENT

The test was conducted on the 3rd floor of the Bryan Building on the University of North Carolina at Greensboro campus. The total of 4 access points was setup to cover the area of the Department of Computer Science and part of the Mathematics Department. The three access points were Cisco AP 1200 with a 2.2 dBi dipole antennas, the forth AP was a Cisco 340 with a built in antenna. All of the devices used the 2.4GHz 802.11b. The devices were placed about 3 to 4 feet of the ground. The test area also had already present wireless network that is 802.11 bg, the entire building is covered with this network. The decision was made to use another set of access points because the exact locations and types of the school's access points were not know. The location of access points was selected as if it was setup to provide data access for that area.

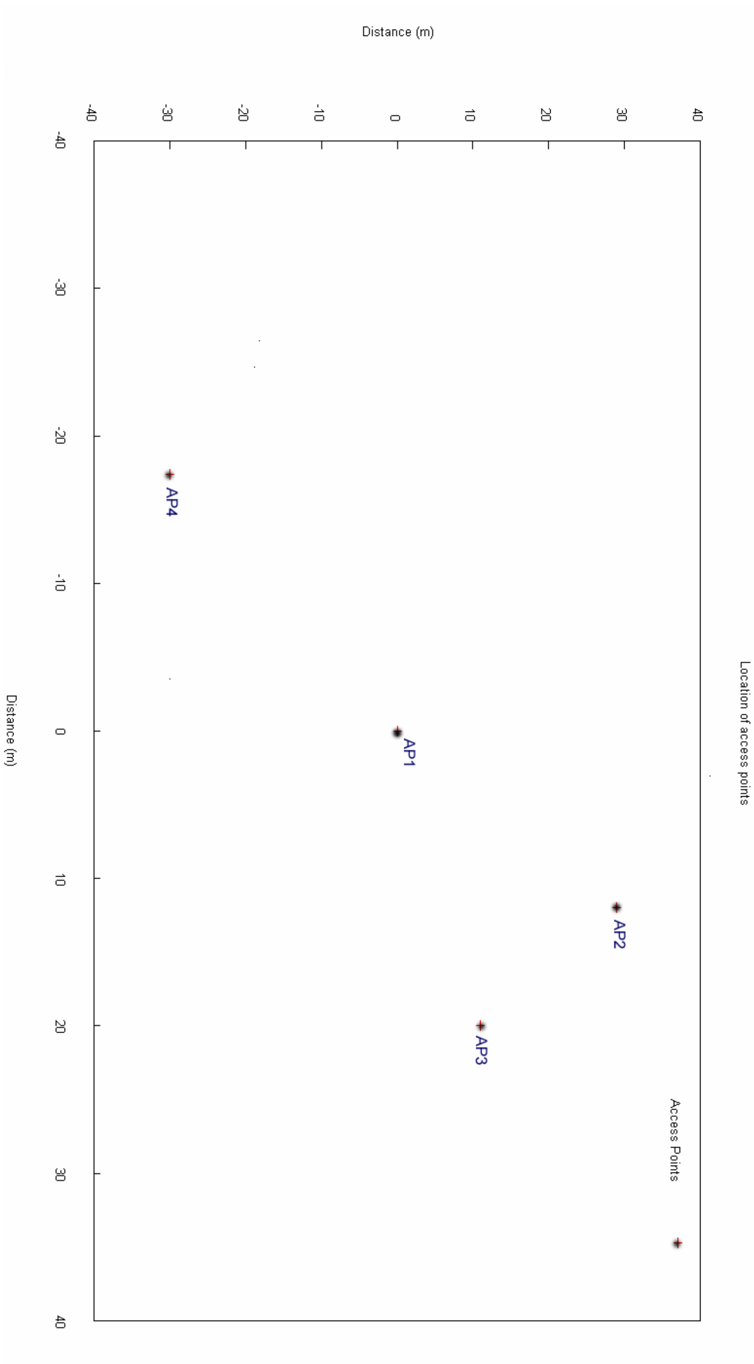


**Figure 4: The location of test APs**

The AP1 was selected as the center point of reference. The coordinate system was created and 33 intersection points where found. AP1, AP3 and AP4 are the Cisco 1200 the AP2 is the Cisco 340

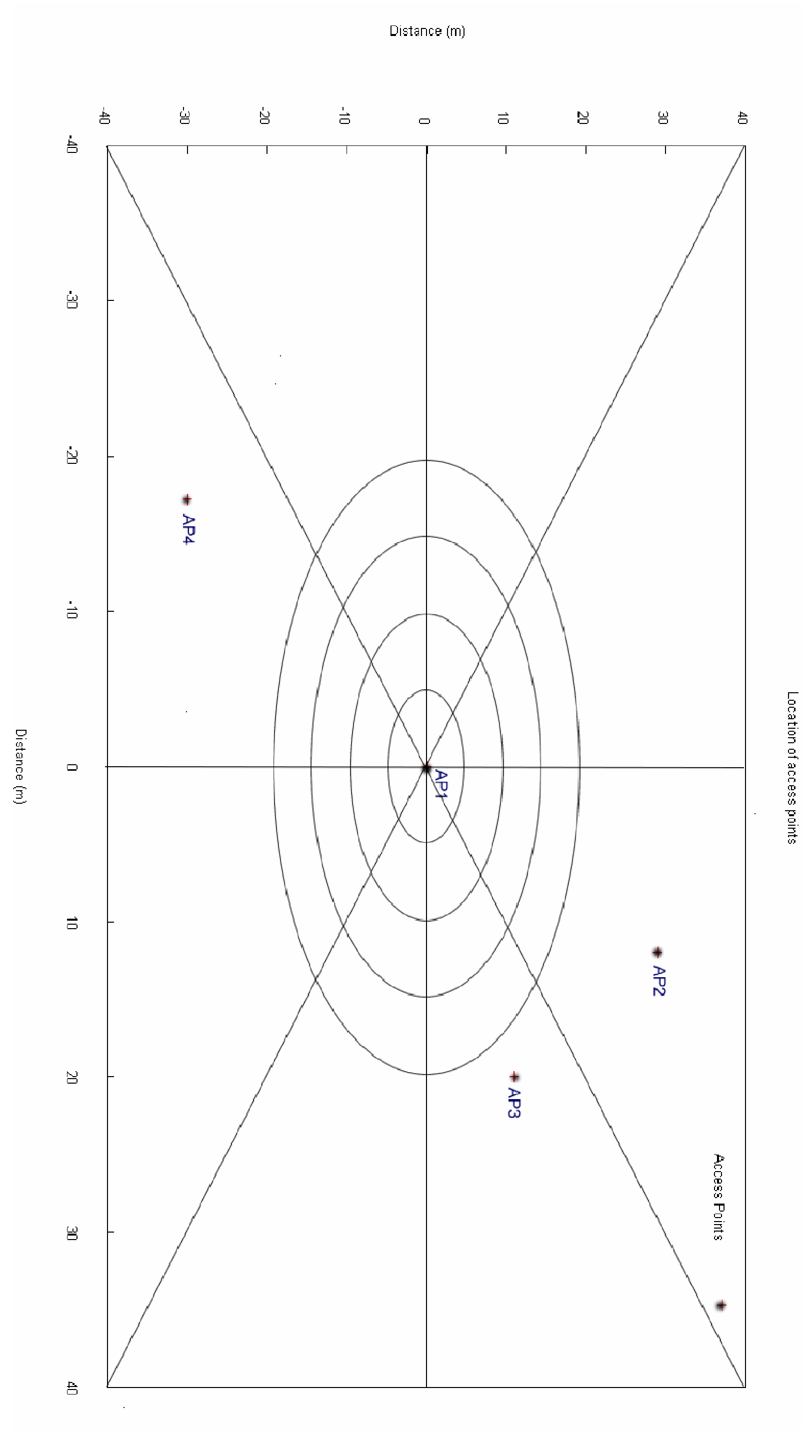


**Figure 5: The coordinate system and the APs**

The next step is the determination of the signal loss functions in each direction away from the AP1.

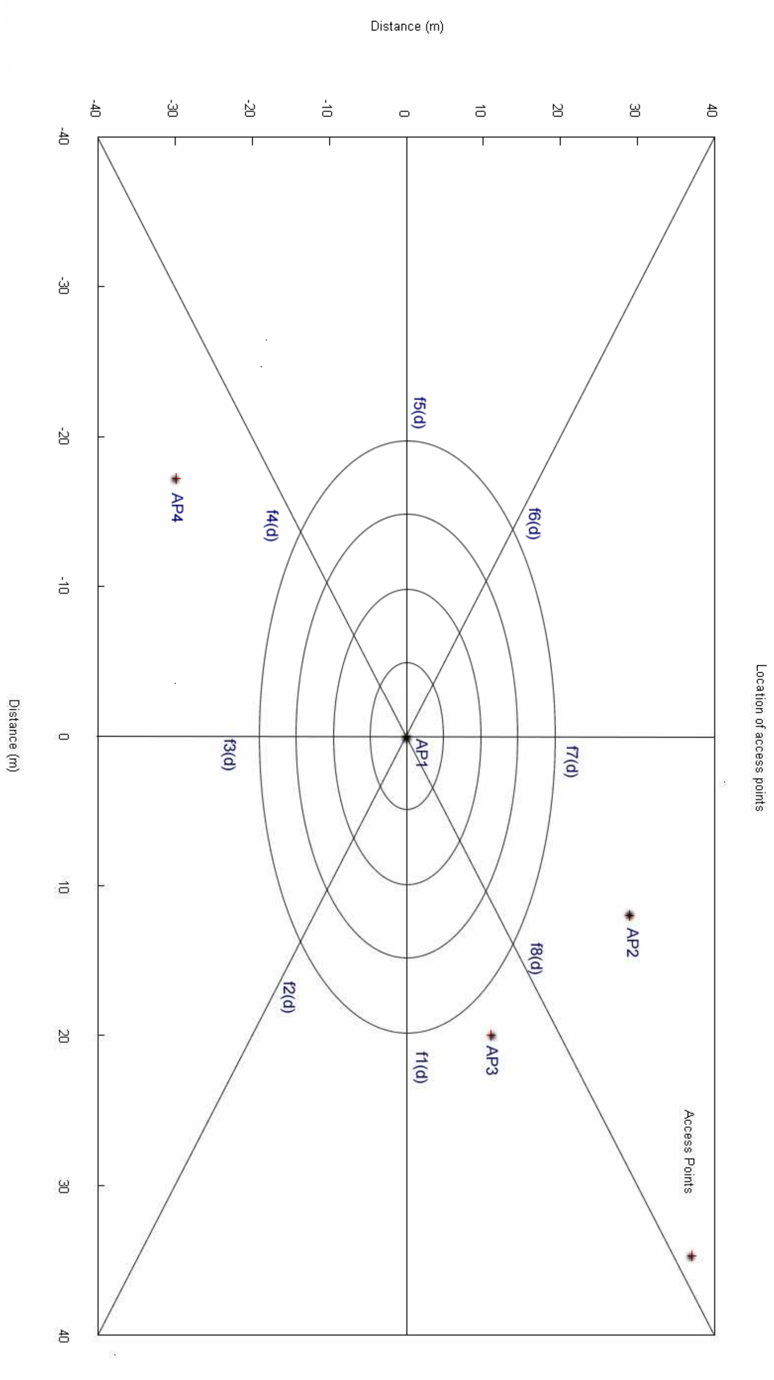


**Figure 6: Signal loss functions**

Do to the physical layout of the building not all of the directions required measurements for example function f6(d) and f7(d)were actually pointing outside of the building. The locations where function f3(d) and f2(d) point to were not accessible to take the measurements.

The remaining functions were created by taking sample data readings at each location. The samples were taken with a Dell laptop with a Centrino 802.11bg wireless card. The laptop was running Linux Fedora Core 6. A program was written to make this task easier, the program interacts with the “Wireless Tools for Linux”[12] commands and save the output in the MySQL database.

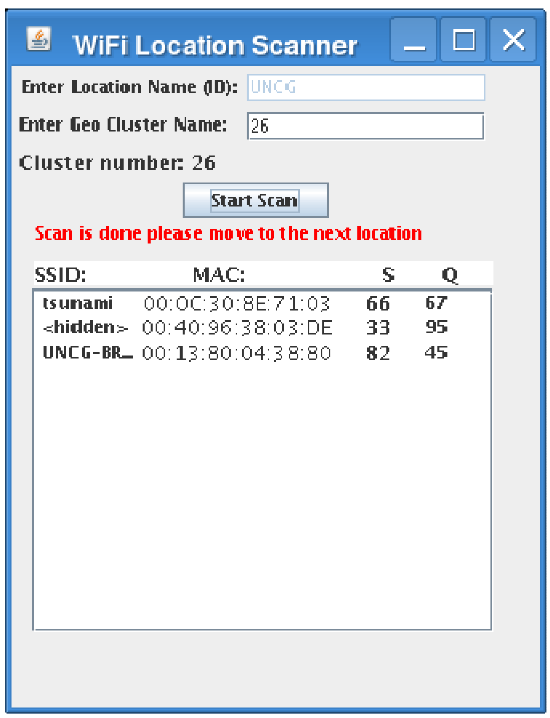


**Figure 7: The program used to collect sample data**

Each sample point was marked by a unique number to represent that location, the data read from all visible points was saved in the database.

## Determining The Value of “C”

All functions were created to fit the Path Loss (dB) = V + C*log(D) formula.

The C constant was created out of the average signal strengths out of the data samples from each location that are part of the function’s direction to test this idea a simple test was conducted to compare the results with the ones from the “Indoor Radio Propagation”[13].

This test was done to see how close the data and the way of determining signal loss functions in this experiment is to the function from the paper [13] that was later used in the “A Practical Approach to Identifying and Tracking Unauthorized 802.11 Cards and Access Points”[10].

Since the Bryan building is constructed with mainly hard partitions such as cinderblock walls The test was done in a long hallway about 40 meters long and 3 meters wide with no hard partitions in the way, the surrounding walls would be the main cause of the signal diffractions. Measurements were taken in 7 points, at 5 meters apart. The value of C was determined to be 33.23384 a very close value to 35 from the Study. In our case the V constant was 0.

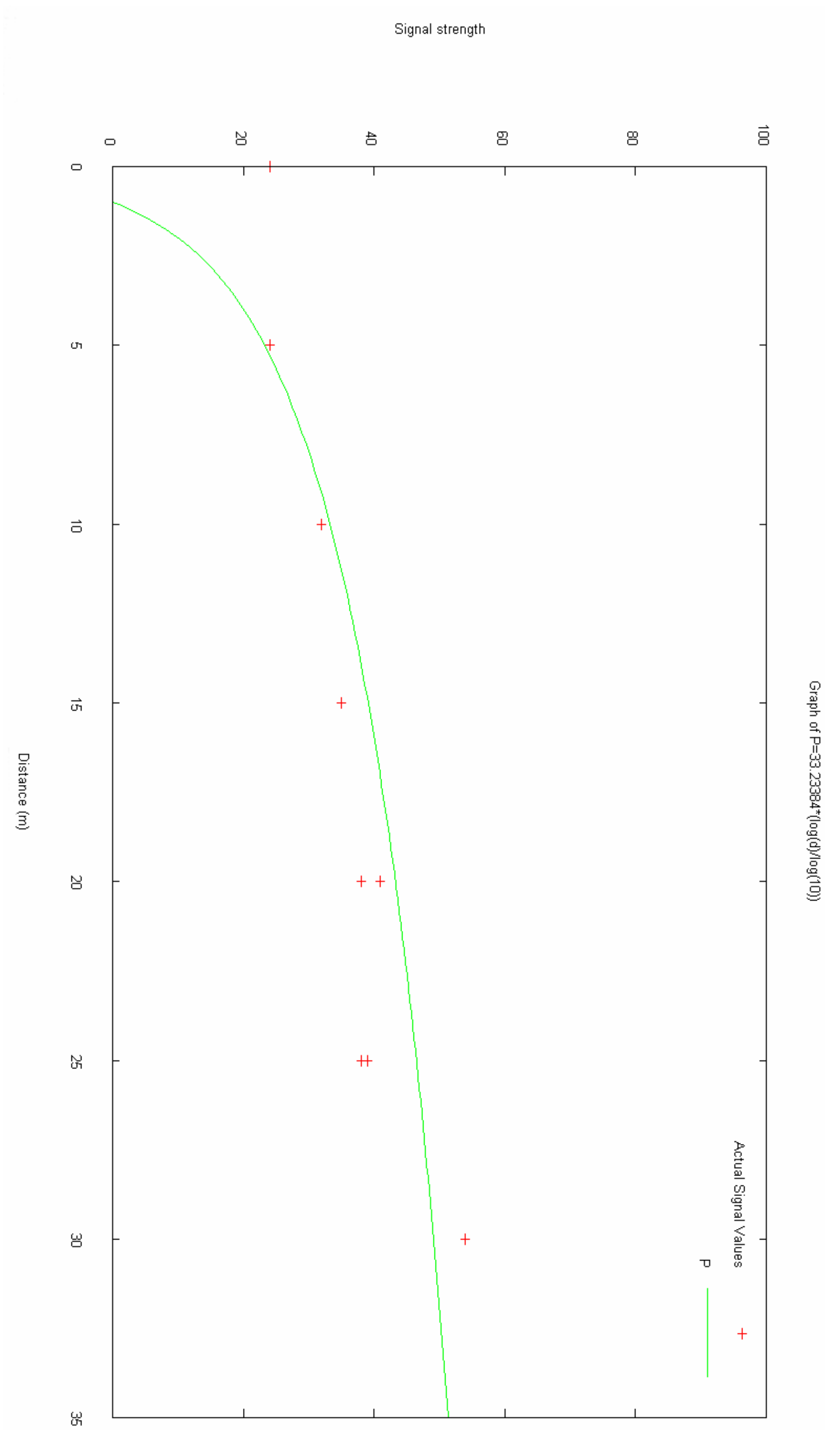


**Figure 8: The graph of the test function**

In the remaining functions even tho less number of sample points was used in each direction, the results from the test provided a support and confidence into the way the functions are created. The value of the constant V was determined by the data layout in the graph the constant was set at 15.

The function f1(d) was created out of 4 points, point at the 20 meters away was outside of the building.

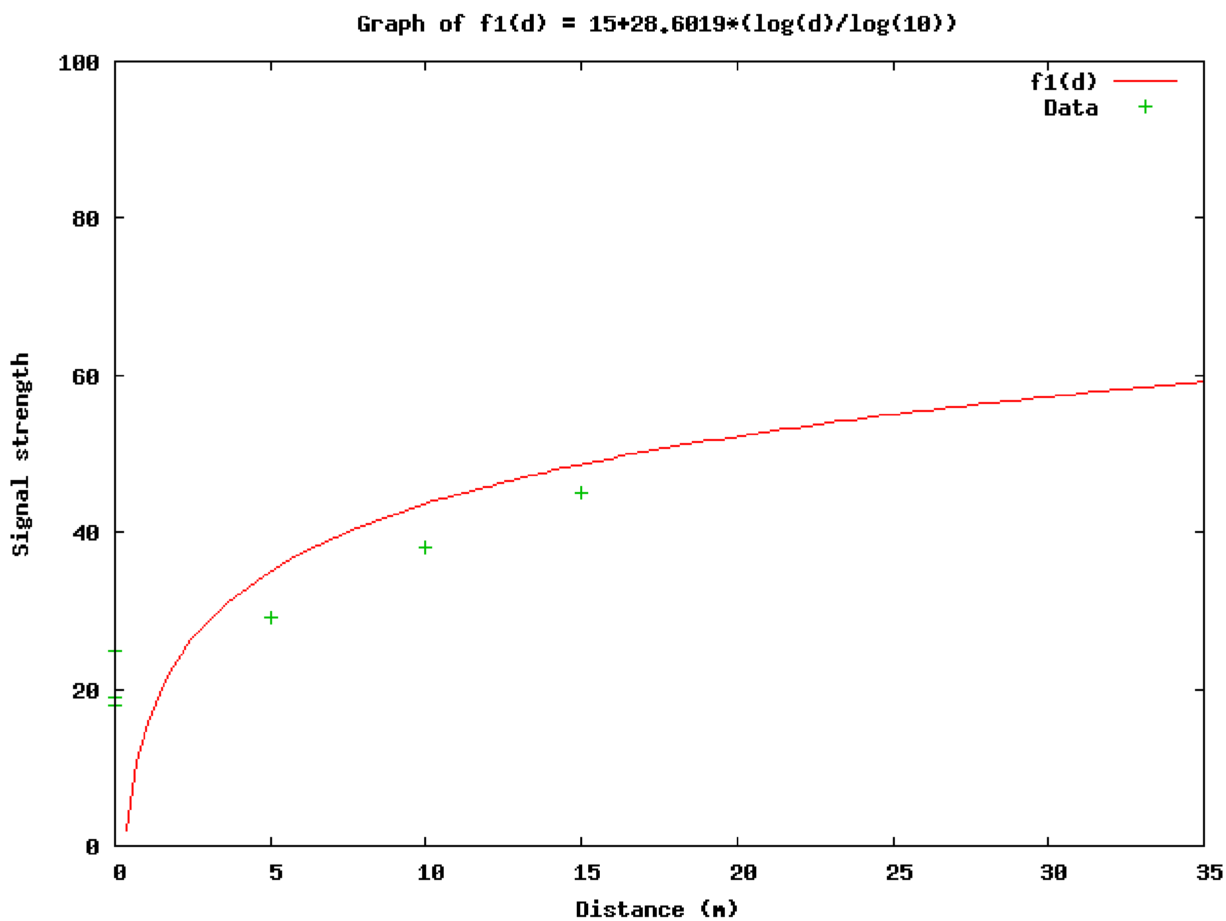


**Figure 9: The graph of the f1(d) function**

The function f4(d) was created:

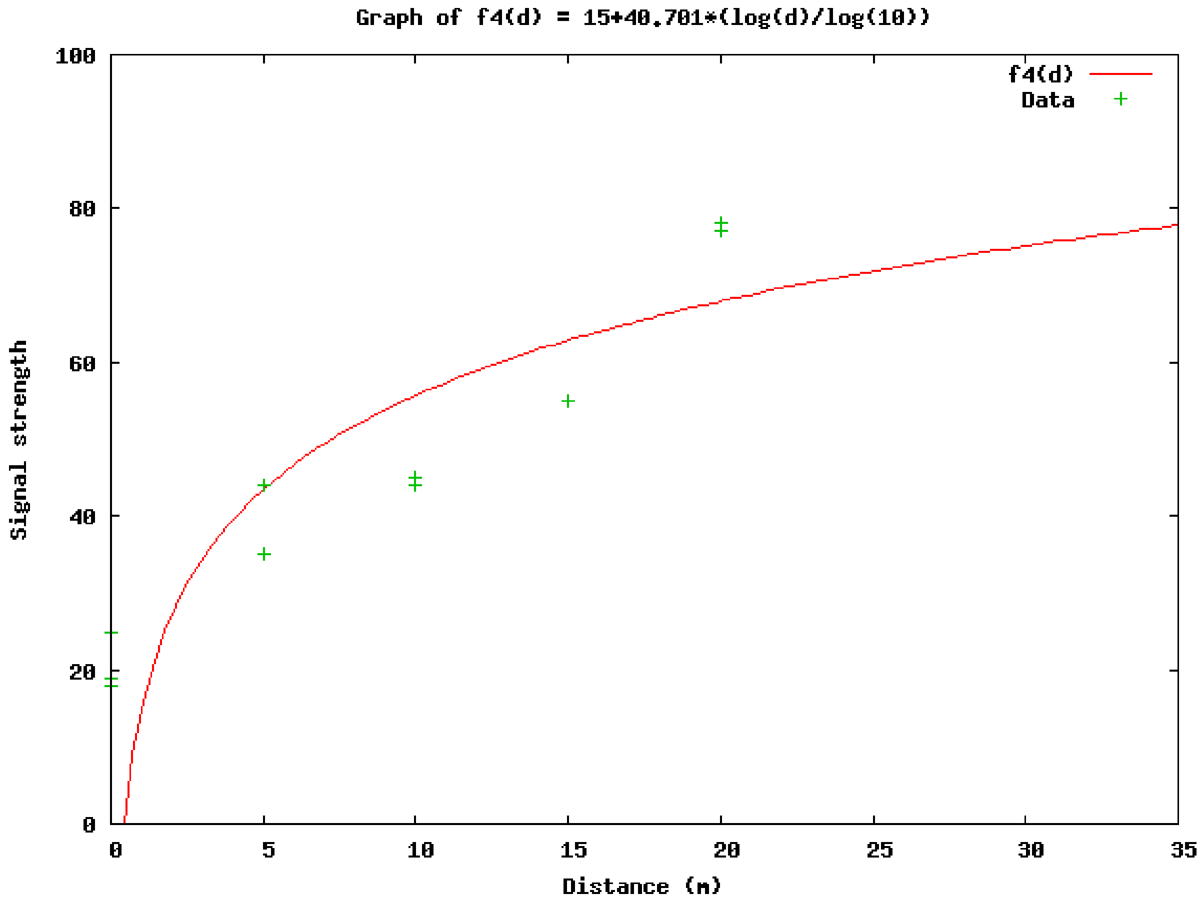


**Figure 10: The graph of f4(d)**

The function f5(d) was created without a measurement at the 10 meter point, that location was not accessible.

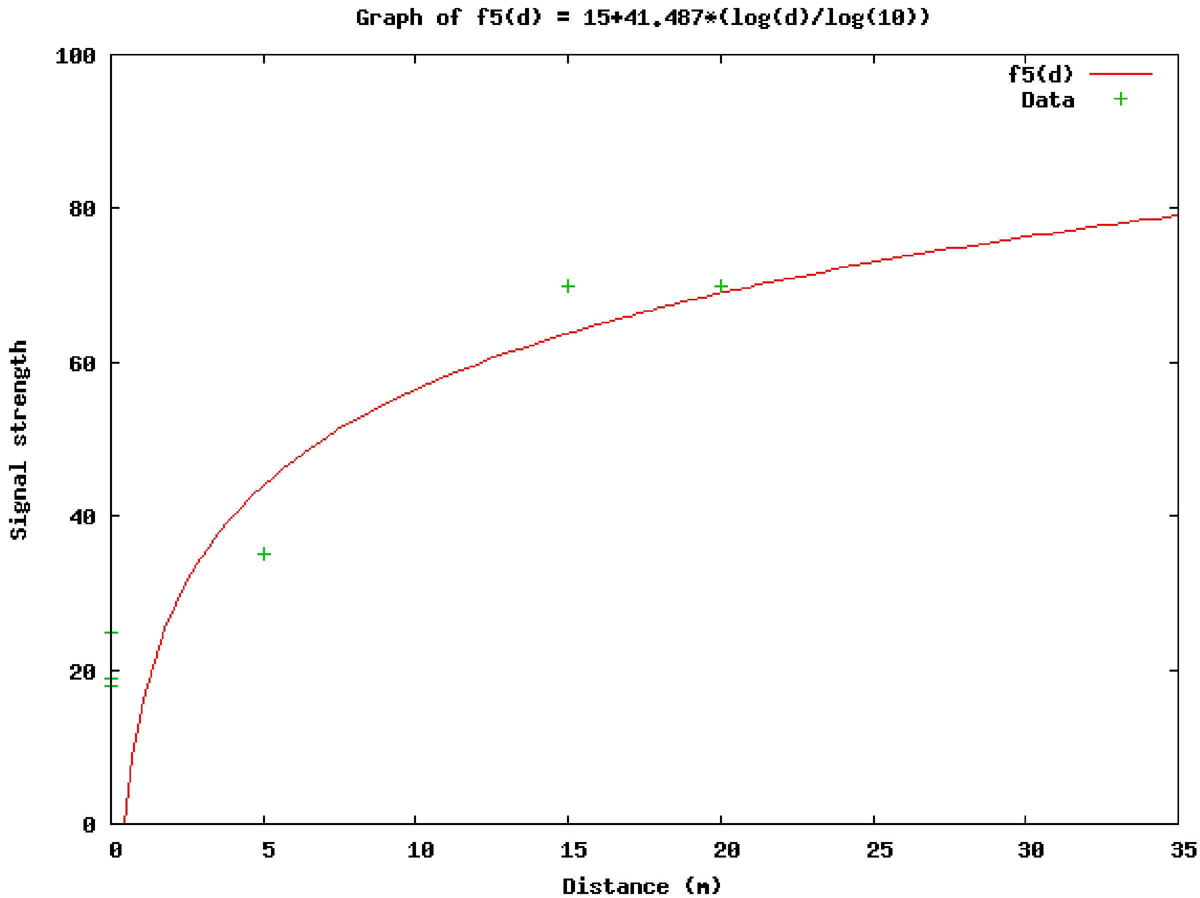


**Figure 11: The graph of f5(d)**

The function f8(d) was created:

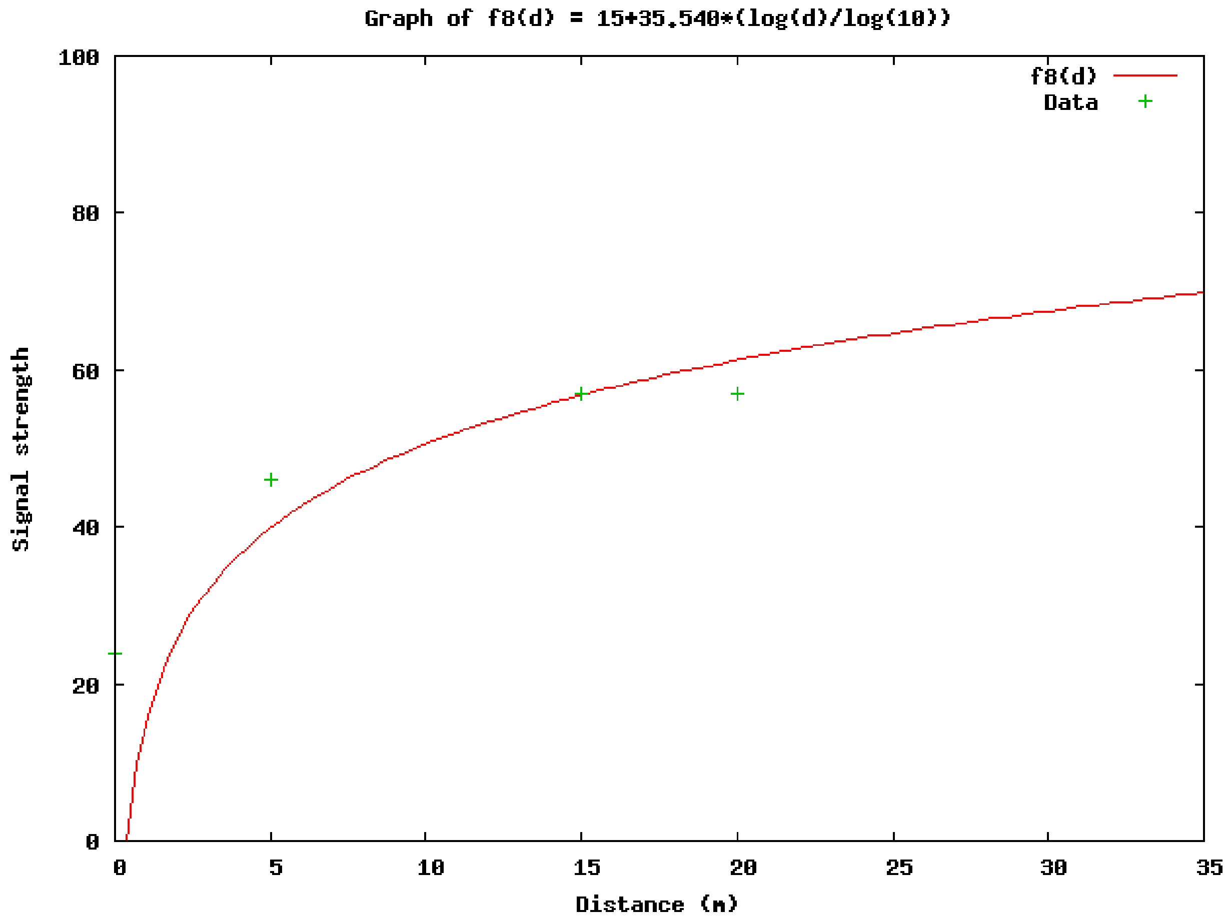


**Figure 12: Graph of function f8(d)**

Graph of all the functions associated with the AP1:

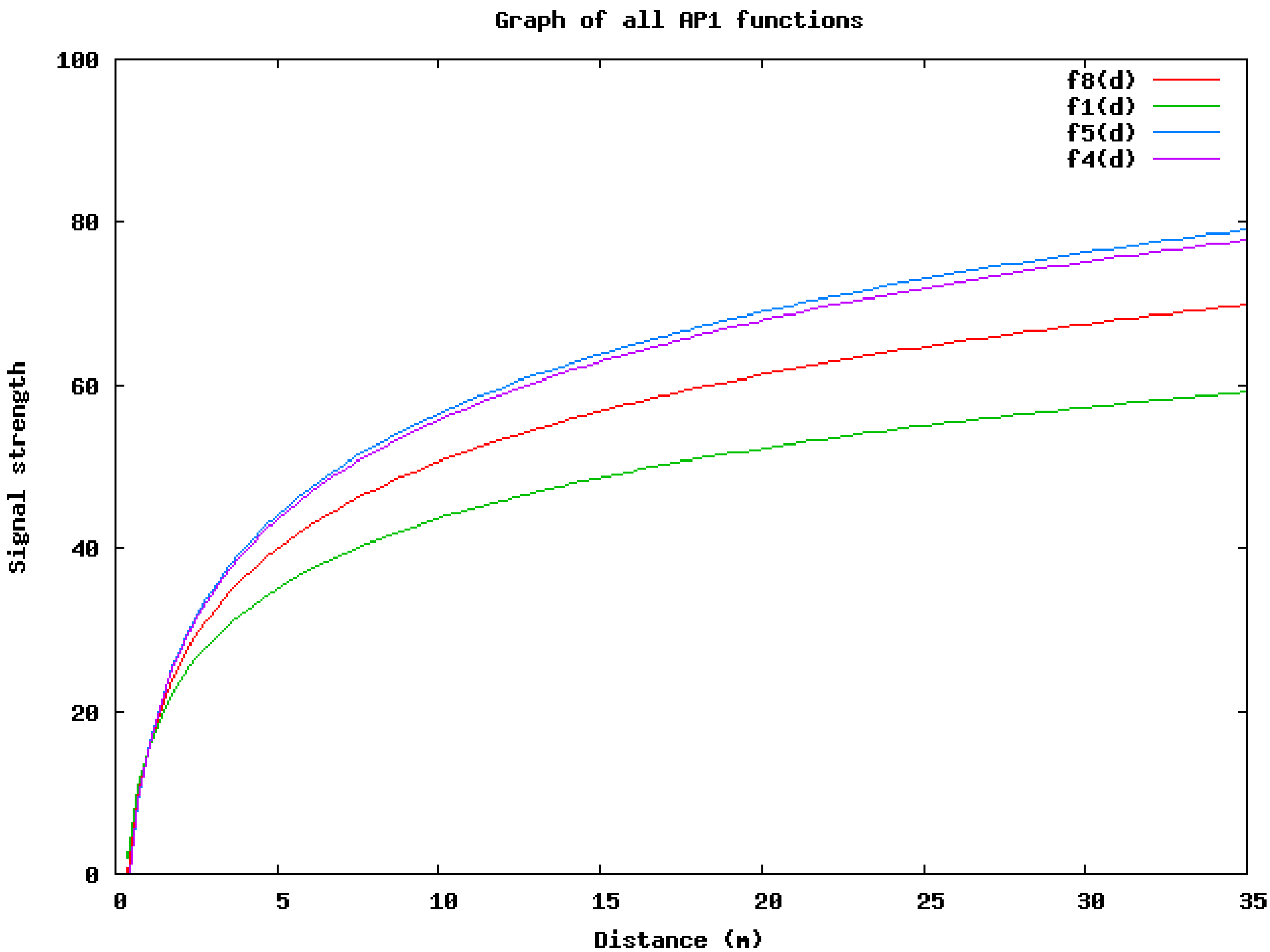


**Figure 13: The graph of all AP1 functions**

We can see that f1(d) is our best signal penetration function and f5(d) is the worst signal penetration.

| Direction | Function |
|---|---|
| → | $f1(d)$ |
| ↓ | $f3(d)$ |
| ↙ | $f4(d)$ |
| ← | $f5(d)$ |
| ↗ | $f8(d)$ |

**Table 2: The AP1 functions and their direction**

At this point we have all possible functions associated with the AP1 out of the samples provided; we also have signal strength readings from all other visible access points. We can calculate straight line distance from the sample points back to the other access points. Then we can use our functions from AP1 to see if any of them provide correct distance to that AP, if they do we can associate our function with the other access points.

Here is the example of distances from the sample points to the AP2 :

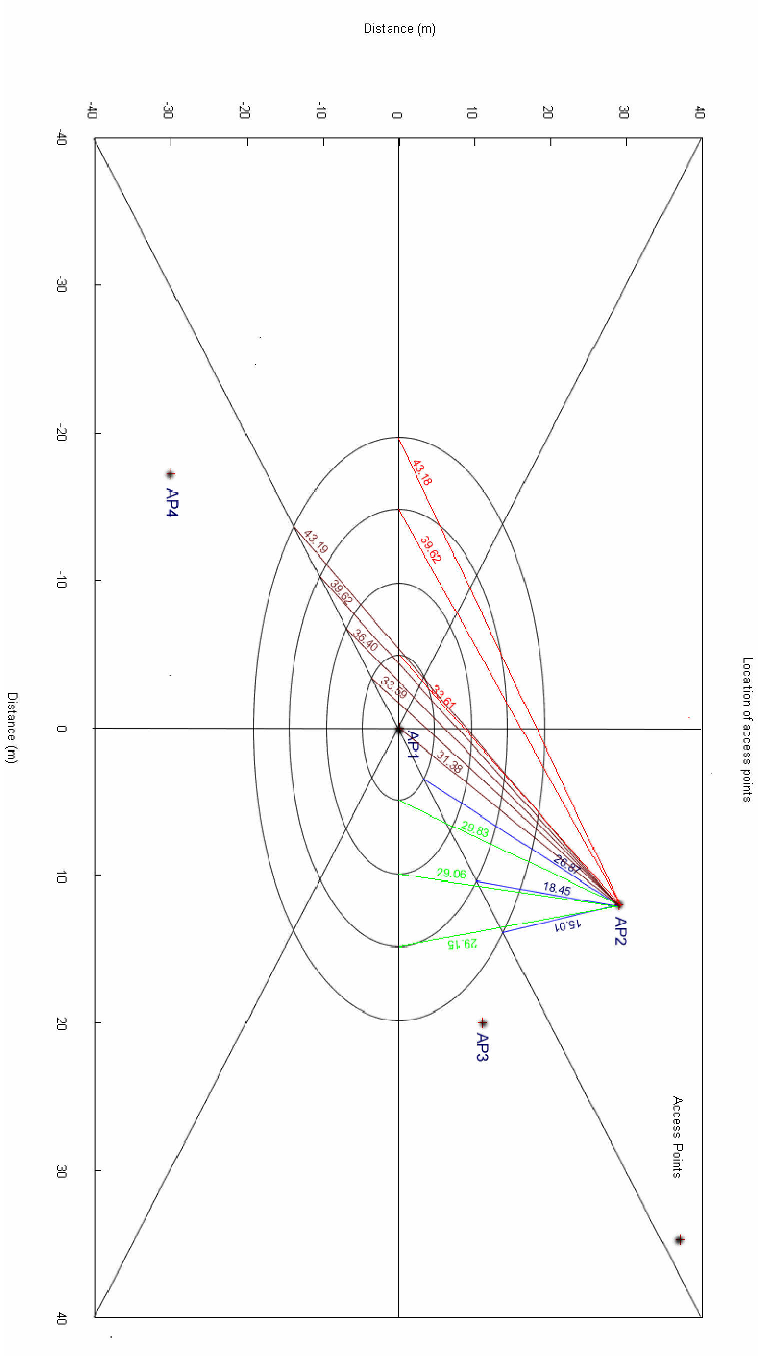


**Figure 14: Distances from sample points to AP2**

Next we check the received signal strengths from AP2 at the sample point locations, and we use our functions associated with the AP1 to see if they provide distance values close to the actual distance from the sample point back to the AP2. The data indicates that function f4(d) is the best choice for the south direction and f5(d) for the south west direction.

| Direction | Function |
|---|---|
| ↓ | $f4(d)$ |
| ↙ | $f5(d)$ |

**Table 3: The AP2 functions**

We repeat this process for the remaining access points. By doing this we associate f1(d) in the west direction and f5(d) with the south west to AP3.

| Direction | Function |
|---|---|
| ← | $f1(d)$ |
| ↙ | $f5(d)$ |

**Table 4: The AP3 functions**

## Location Determination

The position is determined by calculating the distance away from all visible APs using the functions associated with these APs. The intersection area created is the position of the client. The experiments conducted provide and error rate of about 2 to 4 meters. In the test environment the area in the neighborhood of the AP1, AP3 and AP2 was mainly used for the location testing. Do to the physical layout of the building another access point would have been needed in the area of AP4, since only the AP1 and AP4 were detectable. Signal from only 2 access points is not enough to find the location of the client.

# CHAPTER VII

# CONCLUSIONS AND FUTURE WORK

The method provided in this thesis is definitely suitable for midsize locations a further experiments would be required to determined how easily the comfort zone can be extended without human intervention. From the concluded experiment it is possible that not all of the eight functions must be created for the system to be still usable the explanation why that could be a case is provided in the “Test Environment” section. When that accrues the system will not produce satisfactory results in the directions were the functions are missing. The experiment also showed the importance of having a good floor plan of the location where the system will be used, this allows the actual position of the sample points to be easily identified.

The future work will include further analyses of the equation used to predict signal loss. It would be good to include possible exceptions at curtain distances to the functions. Currently the system may provide incorrect location if one of the partitions has an extremely high signal absorption and if that partition is located few meters after the most external signal sample point. In this situation derived function will assume the continue signal strength loss in that direction which will not be true. Currently this situation may be avoided by adding if possible another access point on the other side of the hard partition. The system could be additionally enhanced by adding artificial intelligent algorithms that could predict hard partitions by using the knowledge of the access point location and assumptions could be made when the signal from the APs should be visible.

The error rate in the experiment environment corresponded to the distance between the samples in the particular direction, it may be possible if the distance was narrowed down to 1m instead of 5 the precision may be increased.

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