2009

Improving Location Determination for non-GPS devices

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Improving Location Determination for non-GPS devices

A Writing Project

Presented to

The Faculty of the Department of Computer Science

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Varun Sud

Fall 2009

ABSTRACT

Location awareness is one of the most important information that an individual looks for, both in an outdoor and indoor environment. One of the primary location determination techniques is the Global Positioning system, though this system provides a good accuracy in an outdoor environment, its accuracy decreases in densely populated areas and in an indoor environment a GPS system ceases to provide location information since the satellite signal cannot permeate through the roof and the walls.

Various location estimation techniques have been proposed for location estimation in an indoor environment, some utilizing the signal strength of a wifi transmitter, while others using the time of arrival of a signal. In an indoor environment location can be estimated using either of the techniques or by using a hybrid approach.

In this paper I will study different algorithms to determine which algorithm is the best approach for indoor location determination is.

ACKNOWLEDGEMENT

I thank my advisor, Dr. Robert Chun, whose guidance, support and dedication is priceless. Dr. Chun has been a key factor in helping me work towards the completion of my work. I very much appreciate Dr. Mark Stamp's and Mr. Anthony Chan's participation as thesis committee members. I would also like to thank my manager Mr. Lakshmikanth Mangalore for his support during my project work, and being flexible with my work schedule to help me finish my project on time.

I would also like to thank my family for their never ending support.

Thank you.

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1.0 INTRODUCTION

With the increase in number of mobile assets it has become increasingly important to track the location of such items. Many companies have vehicles on the move throughout the city or the country or in some situations around the world, such as an airplane or a ship. Tracking of such assets can be best achieved by using GPS based tracking systems, but today there are various assets that never leave the confines of a building, and since the GPS system does not work in an indoor environment a different form of location tracking system is needed.

With the increase in the use of wireless technology in our daily life, new methods have been developed to determine the location of an asset using the signals we receive from the wifi transmitters placed at various locations in the building. Distance between the transmitter and the receiver can be determined using the time it takes for the signal to travel from the transmitter to the receiver or by using signal strength of the wifi transmitter.

Various methods have been proposed and implemented to answer the demand of location determination in an indoor environment. Some of the proposed techniques require specialized hardware and predetermined placement of such receivers and transmitters [1], [2], [3], [4]. A large number of these systems though improve the location estimation do so at other costs, such as cost of hardware implementation and the scale at which they can be implemented. The costs of procuring and installing specialized hardware adds additional burden on the existing infrastructure. Due to this reason a large amount of research is being done on utilizing the wifi signal for indoor location estimation [6], [7], [8], [9], [10], [11].

One of the primary methods of indoor location estimation is comparing Radio Signal Strength values detected from access points with those of known location. The mapping of radio signal strength (RSS) readings to a particular location is done in an offline phase. This phase of

RSS value collection, also known as fingerprinting is a time consuming process as it involves recording RSS values from all reachable access points at the particular location. The signal strength entry of a particular access point is usually a mean of RSS values collected over a period of time. A major limitation of this method is that fluctuations in the RSS values can result in the algorithm to incorrectly determine a position. Another method that is utilized in indoor location estimation is using the time of arrival of a signal. In this method, the time it takes for the signal to propagate between the transmitter and the receiver is used to calculate the distance. [12], [13].

1.1 Thesis Focus

A large number of algorithms have been proposed and developed to maximize the accuracy of indoor location estimation system; these systems either utilize specialized hardware or use additional technologies to compensate for the weakness of existing technologies. The aim of such algorithms is to have better location estimation, but not focus on the costs it adds to the implementation of such algorithms or how much computational resources the algorithm requires. In most cases, the device used for location estimation is a handheld device with limited computation capability and limited battery life, having a complex algorithm run on such devices can result in reduced throughput and battery life.

1.2 Overview of report

This thesis is organized as follows: Chapter 2 discusses the work related to this topic area. Chapter 3 discusses the analysis of the signal strength and time of arrival values in home environment. Chapter 4 discusses the four algorithms used for distance calculation and performance analysis. Chapter 5 discusses the experiments that were conducted with the algorithms. Chapter 6 discusses the results Chapter 7 contains the conclusion.

2.0 RELATED WORK

This section introduces indoor location estimation techniques such as those that rely on radio signal strength information using RSS fingerprinting, imaging, and hybrid.

In the following section we discuss some techniques that have been developed to provide indoor location.

2.1 Wifi signal based

Wireless technology is one of the most extensively used communication technology today. From cellular phones to wifi transmitters to shared network and internet can be seen almost everywhere, in offices, hotels, schools and houses. Number and type of wifi access points employed is largely determined by the area covered and network traffic expected on the wireless transmitter. Lately we can also see city wide wifi coverage provided either by internet service providers to its customers or an ad-based service provided by the local business community.

One of the techniques that have been used to determine user's location is based on a model of wireless signal propagation [7], [16]. This technique calculates the distance based on the signal strength calculated at the user's location in comparison to signal strength at a previously determined location. The signal propagation model is used to compare the loss in signal strength with possible distance between users current location and the previously determine location. Most of the models developed for such distance calculation are on assumption of ideal conditions, which are not possible in the real world scenario. Changes in temperature, wind, human density cause the detected signal strength to change and this can cause the signal propagation model to provide incorrect location calculation.

Another technique that uses empirical data to estimate location [4], [6], [8]. These systems have an offline phase where a radio map is created. This map contains signal strength distribution from each visible access point at predetermined locations. Though this method provides good results, there is an initial cost associated with them, which involves generating the radio map. Another problem that exists with this method is that it is prone to errors if there is a change in the access points that were mapped during the offline phase.

Another technique was developed that is an extension to the technique discussed above. In this technique, a mobile user while using system to determine his location at any given point also collects the signal strength values, these details are then transferred to the system. Any user can at a later point then download the updated radio map. Advantage of using such a system is that it continuously checks for changes in the access points and updates the system without the need for an offline phase otherwise required for maintenance. PlaceLab and WLocator are examples of such a system [12], [13].

2.2 Cell of Origin

This is one of the simplest techniques of location estimation, if accuracy is not of concern. In this system, the mobile device determines the signal strength of all the access points that it can communicate with; from this list of signal strengths it picks an access point with the maximum signal strength. This signal strength and the access point are then queried with database to determine the location of the user. This system cannot tell the user his or her position but can tell the user his or her location in terms of building and floor.

2.3 Trilateration

To determine the location of a user this system of location estimation uses the location of two or more known points, measured distance between these points and the mobile device. This distance can be calculated using Time of Arrival method. In order to get a good accuracy in a 2D place from this method, we need at least three known locations. [24]

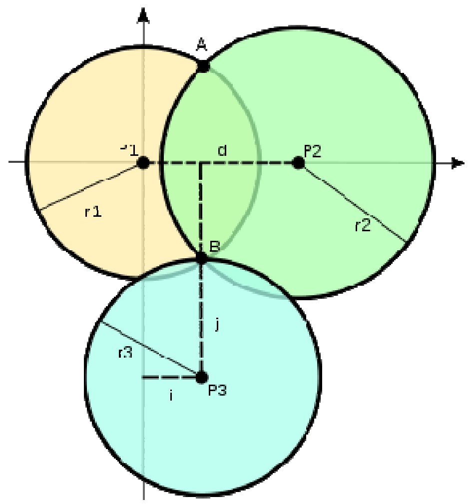


Figure 1: Trilateration

In the figure above we know the location of points P1, P2 and P3. Using methods such as time of arrival we can calculate the distance between the each point P1, P2, P3 and the mobile device, using the distance r1 between P1 and mobile device and distance r2 between P2 and mobile device, we can narrow down the location to point B and Point A. By using the distance from the third point P3, we draw another circle that intersects circles drawn from P1 and P2 we get a point where all three circles intersect, this point of intersection if the location of the mobile device.[26]

The result returned by this method is dependent on the accuracy of the distances determined by the underlying distance measurement algorithm, if the distances are calculated incorrectly; this algorithm will calculate the position incorrectly.

2.4 Image Analysis

In this method of location estimation, a camera, from a cell phone or web cam, is used to capture images of the environment the user is currently in, these images are then compared with a database of images that was created in an offline phase with the location where each image was taken. An image comparison algorithm is used to compare the images provided by the user with the ones in the database and a result is returned. The accuracy of this type of location estimation relies greatly on the number of images taken and assumption that each image stored in the database is different to a certain extent [14].

Drawback of using such location estimation scheme is that if there is a rearrangement of the furniture in the room, it can cause the algorithm to return a negative result. Also, there is a latency involved in sending pictures and receiving location information apart from the time it takes the backend system to process the imaging data.

2.5 Hybrid

Single technology systems pose somewhat of problem when one tries to use them beyond the environment that they were designed for. These systems often provide answer to only one side of the problem due to the technologies limitation, such as GPS which can only work in an outdoor environment, or time of arrival which can lead to inaccurate distance calculations if used in highly obstructed environment and radio signal strength that can result in inaccurate queries to the fingerprint database if there is a change in the distribution of the access points. To overcome such limitations various hybrid solutions have been developed that make use of the best of more than one world.

One of the hybrid location estimation techniques WHLocator [14], utilizes three technologies: signal strength, imaging and altimeter. At any unknown location x the mobile device captures the signal strengths from the access points it can communicate with, compares these values with the database of signal strength collected during an offline phase and determines the rough location of the user in a 2D plane. Readings from an altimeter are used to determine the third dimension of the user's location, namely the floor the mobile device is on. A camera attached to the mobile devices captures images of the location the user is in and compares them with the database of images. The size of image set for comparison is reduced by using the location determined from the signal strength values.

Another hybrid system that makes use of more than one technology is the Place Lab system. This location estimation system makes use of the signal strength values from various resources such as wifi transmitters, cellular towers, Bluetooth devices. This enables the device to be used practically everywhere, since either GSM and/or wifi signal is available almost everywhere. In order to determine location using this method, we need a database containing signal strength fingerprints that were collected during the offline phase [27].

3.0 SIGNAL STRENGTH AND TIME OF ARRIVAL ANALYSIS

Every radiating signal looses its intensity as the distance between the source and the receiver increases. Such as heat from the sun, signals from radio towers, all loose there signal strength with increase in distance. Our first work was to determine how this signal strength looses its intensity with the increase in distance within the household environment. To determine such data, a wireless transmitter was places in a corner room of the house and signal strength and the time of arrival values were gathered in three different directions, each direction with different amount of obstructions between the transmitter and the receiver. These values were gathered in an incremental distance starting at one meter, then two meters, four meters and at eight meters. At each location sixteen signal strength values and 48 time values were gathered. The time values were then split into a set of eight values from which minimum time was used to calculate the distance.

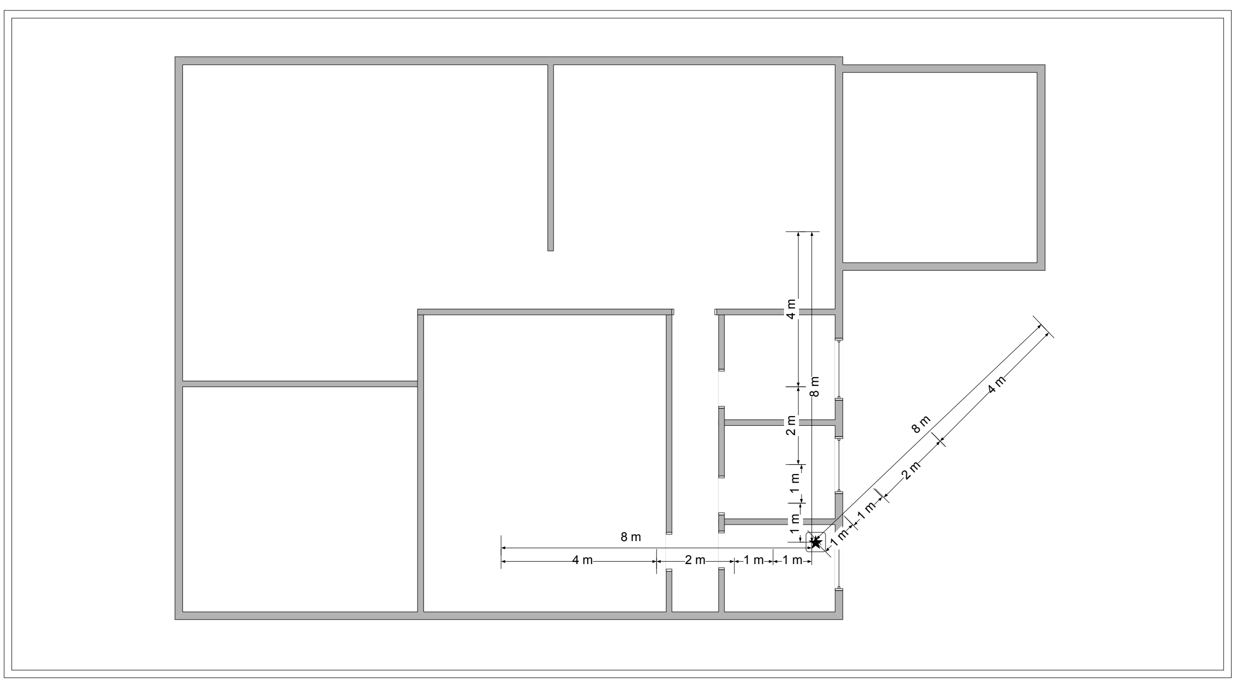
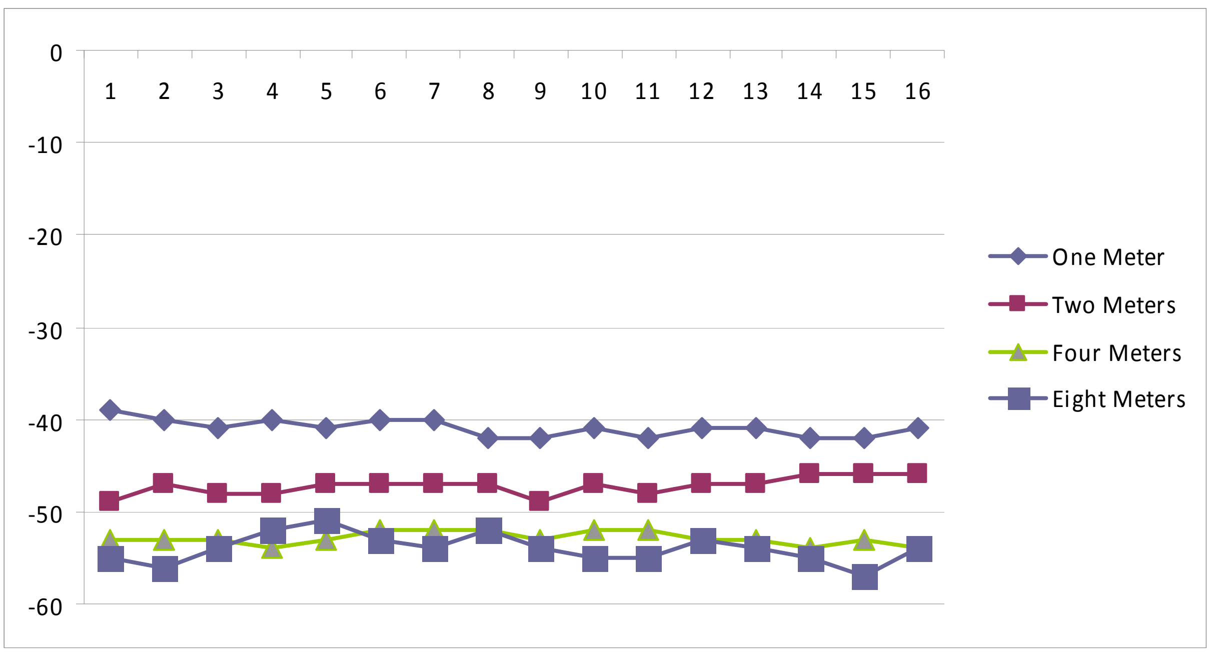


Figure 2: Map of the house for incremental distance

3.1 Scenario 1

First scenario where the data was gathered was in the open area towards the back side of the house. The transmitter was placed in the corner room of the house with a window overlooking the open backyard. A one meter distance was measure from the transmitter to a point in the backyard and receiver was placed at that point. Signal strength readings were gathered here followed by the round trip time values for the signal. This same procedure was repeated at a distance of two meters, four meters and at eight meters. At each of these locations sixteen signal strength values and forty eight time values were captured over same period of time.

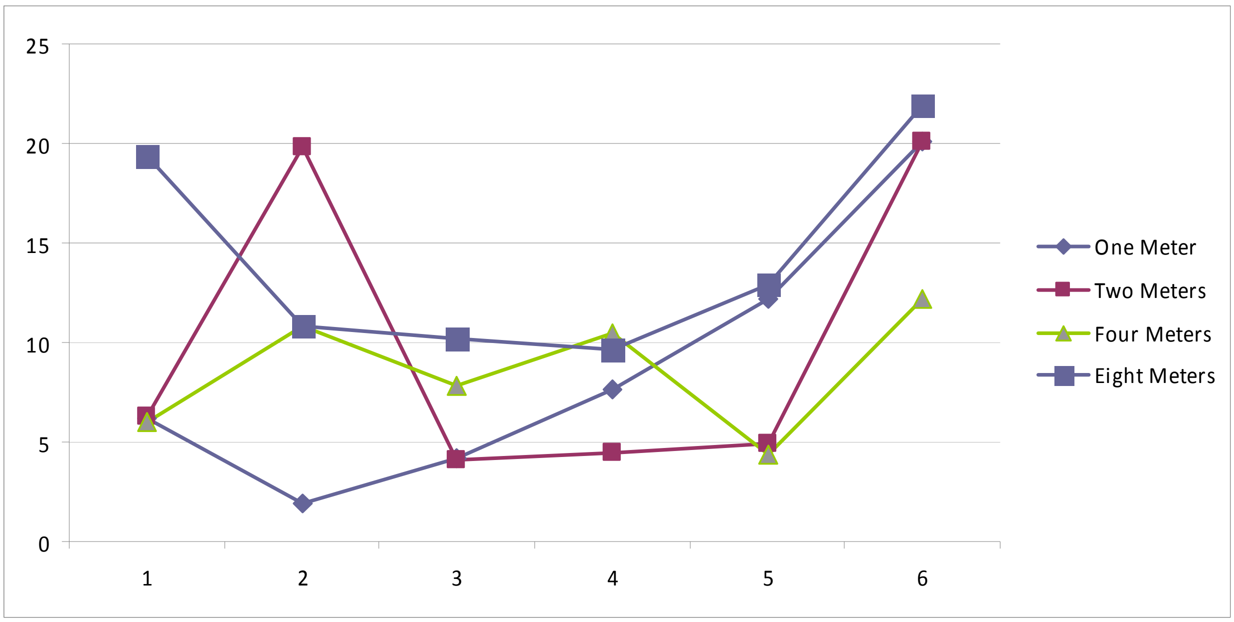


Graph1: signal strength values in open area

Reading→ Distance↓	1 (dB)	2 (dB)	3 (dB)	4 (dB)	5 (dB)	6 (dB)	7 (dB)	8 (dB)	9 (dB)	10 (dB)	11 (dB)	12 (dB)	13 (dB)	14 (dB)	15 (dB)	16 (dB)
1 Meter	-39	-40	-41	-40	-41	-40	-40	-42	-42	-41	-42	-41	-41	-42	-42	-41
2 Meter	-49	-47	-48	-47	-47	-47	-47	-47	-49	-47	-48	-47	-47	-46	-46	-46
4 Meter	-53	-53	-53	-54	-53	-52	-52	-52	-53	-52	-52	-53	-53	-54	-53	-54
8 Meter	-55	-56	-54	-52	-51	-53	-54	-52	-54	-55	-55	-53	-54	-55	-57	-54

Table 1: Signal strength values in open area

We can see from the data above that even though we expect the signal strength to decreases with the increase in distance between the transmitter, we see that the signal strength values gathered at four meters and eight meters are very similar and intersect at some points. What we expected here was to see a drop in strength as we saw from one to two meters distance.



Graph 2: time of arrival values in open

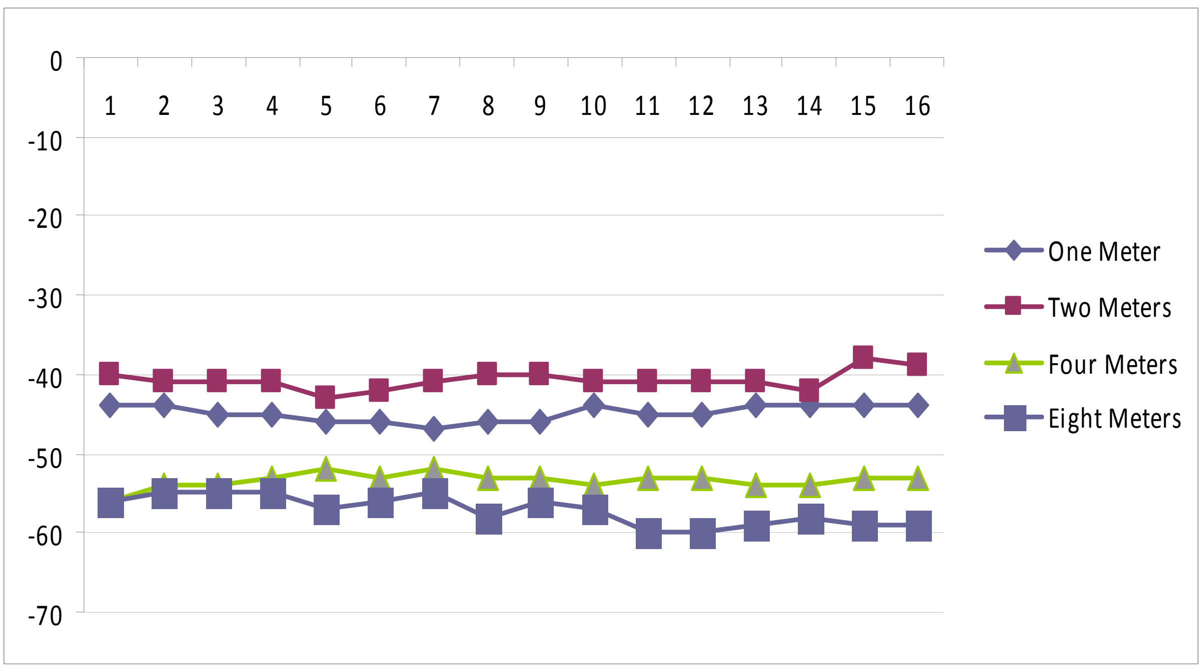
Distance	Reading 1		Reading 2		Reading 3		Reading 4		Reading 5		Reading 6	
	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)
1 Meter	0.0205	6.15	0.0065	1.95	0.014	4.2	0.0255	7.65	0.0405	12.15	0.066	20.1
2 Meter	0.021	6.3	0.066	19.8	0.0135	4.05	0.015	4.5	0.0165	4.95	0.067	20.1
4 Meters	0.02	6	0.036	10.8	0.026	7.8	0.035	10.5	0.0145	4.35	0.0405	12.15
8 Meters	0.0645	19.35	0.036	10.8	0.034	10.2	0.032	9.6	0.043	12.9	0.073	21.9

Table 2: Time values in open area

As can be seen from the data above regarding time values that were captured at a distance of one, two, four and eight meters, we can see that there is a large fluctuation with no specific pattern to how the time changes. We can see that with the values gathered at two meters, there is a distance calculation that provides a distance smaller than what was calculated at one meter, similarly two distance calculations at a distance of four meters have values smaller than those gathered at one meter.

3.2 Scenario 2

Second scenario where the signal strength and the time values were captured is moving away from the transmitter into another room through a Hallway. One and two meter reading are taken in the same room as the transmitter, four meter readings are taken at the location just inside the door to the second room and the eight meter reading is between the centre and the wall of the second room.

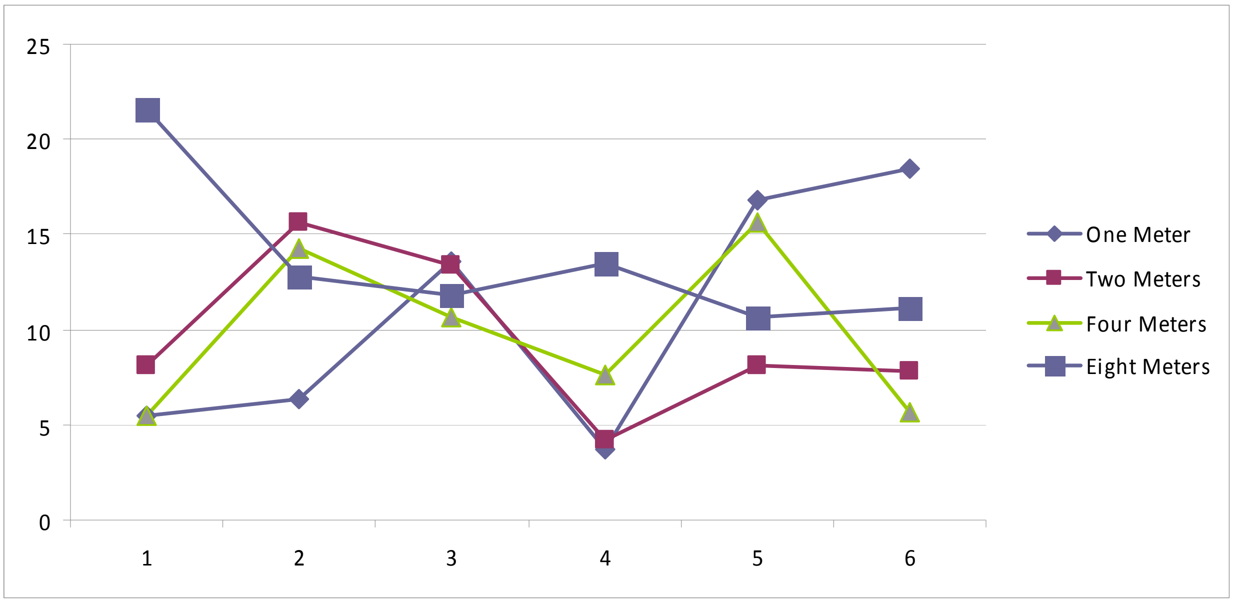


Graph 3: Signal Strength values through room

Reading→ Distance↓	1 (dB)	2 (dB)	3 (dB)	4 (dB)	5 (dB)	6 (dB)	7 (dB)	8 (dB)	9 (dB)	10 (dB)	11 (dB)	12 (dB)	13 (dB)	14 (dB)	15 (dB)	16 (dB)
1 Meter	-39	-40	-41	-40	-41	-40	-40	-42	-42	-41	-42	-41	-41	-42	-42	-41
2 Meter	-49	-47	-48	-47	-47	-47	-47	-47	-49	-47	-48	-47	-47	-46	-46	-46
4 Meter	-53	-53	-53	-54	-53	-52	-52	-52	-53	-52	-52	-53	-53	-54	-53	-54
8 Meter	-55	-56	-54	-52	-51	-53	-54	-52	-54	-55	-55	-53	-54	-55	-57	-54

Table 3: Signal strength through the room

As we can see from the values above, even though we expect the signal strength to drop with the increase in the distance, the signal strength values gathered at a distance of two meters are stronger than that at one meter. Readings at four meters has a drop in signal strength and those captured at eight meters are close to those captured at four meters.



Graph 4: Time of arrival values through room

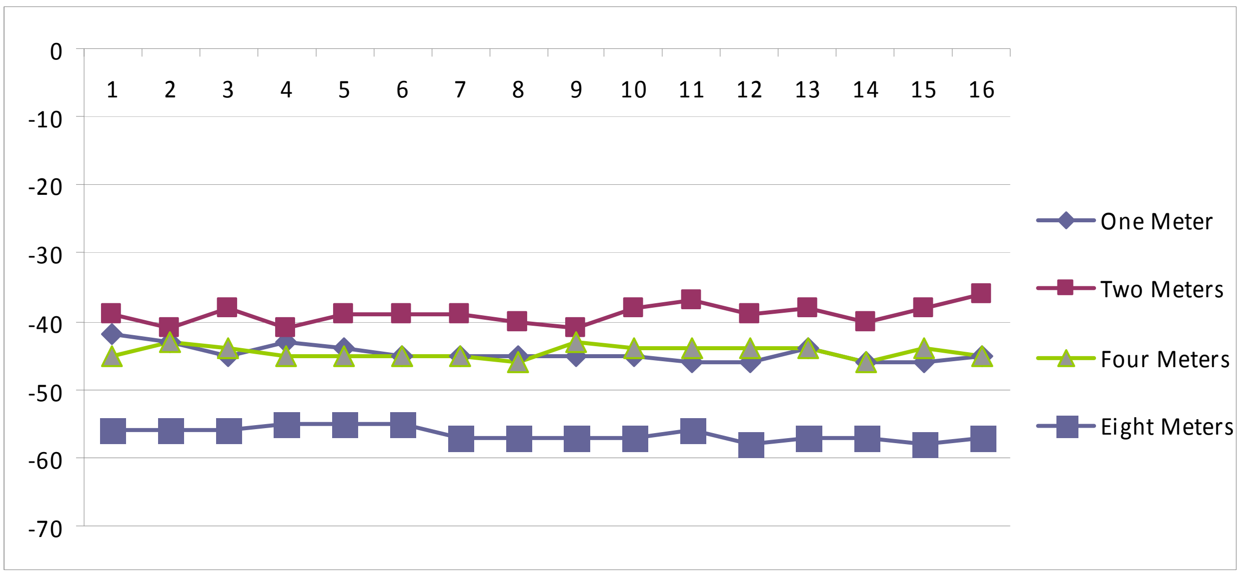
Distance	Reading 1		Reading 2		Reading 3		Reading 4		Reading 5		Reading 6	
	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)
1 Meter	0.018	5.5	0.021	6.3	0.045	13.6	0.012	3.7	0.056	16.8	0.061	18.45
2 Meter	0.027	8.1	0.052	15.6	0.044	13.35	0.014	4.2	0.027	8.1	0.026	7.8
4 Meters	0.018	5.5	0.047	14.25	0.035	10.65	0.025	7.65	0.052	15.6	0.019	5.7
8 Meters	0.072	21.6	0.042	12.8	0.039	11.85	0.045	13.5	0.035	10.65	0.037	11.1

Table 4: Time of arrival values through room

As we can see from the time data that was gathered while moving from the room with the transmitter to another room, there is a variation in the time gathered at each location. Distance calculated using the time values has more variation at one two and four meters as compared to distance calculated at eight meters. We also see that the signal strength at four and eight meters is closer to each other but the distance calculated using the time values have greater variation.

3.3 Scenario 3

Third scenario where the signal strength and the time values were captured is moving from the room with the transmitter towards the hall through two other rooms. One and two meter readings are taken in the room adjacent to the room with the transmitter, four meter readings are taken in the next room and the eight meter readings are taken inside the hall. The one meter reading is close to the wall separating the room with the transmitter and the first room.

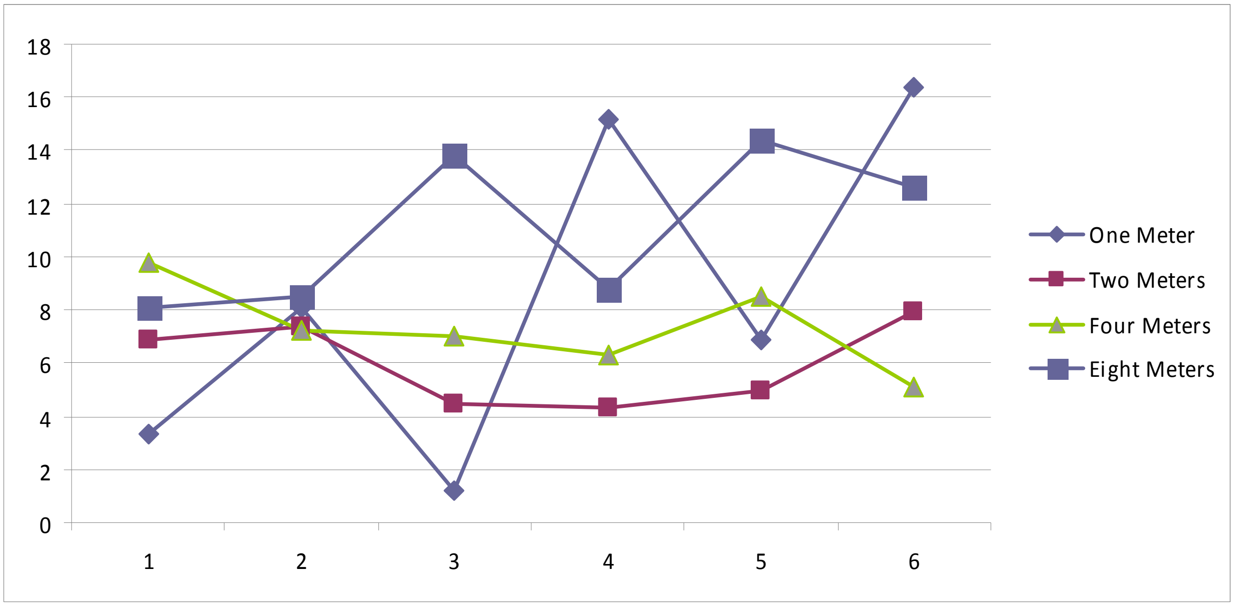


Graph 5: Signal Strength through rooms to hall

Reading→ Distance↓	1 (dB)	2 (dB)	3 (dB)	4 (dB)	5 (dB)	6 (dB)	7 (dB)	8 (dB)	9 (dB)	10 (dB)	11 (dB)	12 (dB)	13 (dB)	14 (dB)	15 (dB)	16 (dB)
1 Meter	-39	-40	-41	-40	-41	-40	-40	-42	-42	-41	-42	-41	-41	-42	-42	-41
2 Meter	-49	-47	-48	-47	-47	-47	-47	-47	-49	-47	-48	-47	-47	-46	-46	-46
4 Meter	-53	-53	-53	-54	-53	-52	-52	-52	-53	-52	-52	-53	-53	-54	-53	-54
8 Meter	-55	-56	-54	-52	-51	-53	-54	-52	-54	-55	-55	-53	-54	-55	-57	-54

Table 5: Signal Strength through rooms to hall

We can see from the data above that the signal strength captured at two meters is stronger than the signal strength at one meter close to the wall. Another set of reading at a distance of four meters gives signal strength values which are similar to those captured at one meter distance in spite of a three meter difference between the two locations and the fact that two readings are taken in two different rooms.



Graph 6: Time of arrival values from rooms to hall

Distance	Reading 1		Reading 2		Reading 3		Reading 4		Reading 5		Reading 6	
	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)	Time (µsec)	distance (meters)
1 Meter	0.011	3.3	0.027	8.1	0.004	1.2	0.050	15.15	0.023	6.9	0.054	16.35
2 Meter	0.023	6.9	0.024	7.35	0.015	4.5	0.014	4.35	0.016	4.95	0.026	7.95
4 Meters	0.032	9.75	0.024	7.2	0.023	7.05	0.021	6.3	0.028	8.5	0.017	5.1
8 Meters	0.027	8.1	0.028	8.5	0.046	13.8	0.029	8.8	0.048	14.4	0.042	12.6

Table 6: Time of arrival from rooms to hall

We can see from the data above, that with a stronger signal at two meters we also have smaller time values, which in turn are giving us a distance with a less fluctuation. Time captured at four meters has less fluctuation compared to that captured at one meter, even though the signal strength is similar.

3.4 Observations

This experiment was conducted to study the behavior of signal strength and time it takes for signal to travel between the receiver and the transmitter.

As we can see from the data in the three scenarios above, signal strength values recorded at greater distances were stronger than that recorded at distance closer to the transmitter, and in places we can also see that the signal strength gathered at a distance of four meters and eight meters are very close to each other, also in scenario 3 we can see that the signal strength recorded at 4 meters is similar to that gathered at 1 meter.

These readings show that even though we expect to see a certain decrease in signal strength with increase in distance, the signal strength does not behave so in an indoor environment. Also, the time of arrival values that were gathered at each location have a lot of variation, which raise a question of how reliable such values are.

4.0 COLLECTION OF DATA

In order to collect the signal strength and time data for the signal, two access points were used at a time. While both of the transmitters were on, connection was established with one transmitter and signal strength data was collected. Once the signal strength data was captured, timing data was collected, and a connection was established with the second transmitter. Once the data was collected, these transmitters were moved to next two locations.

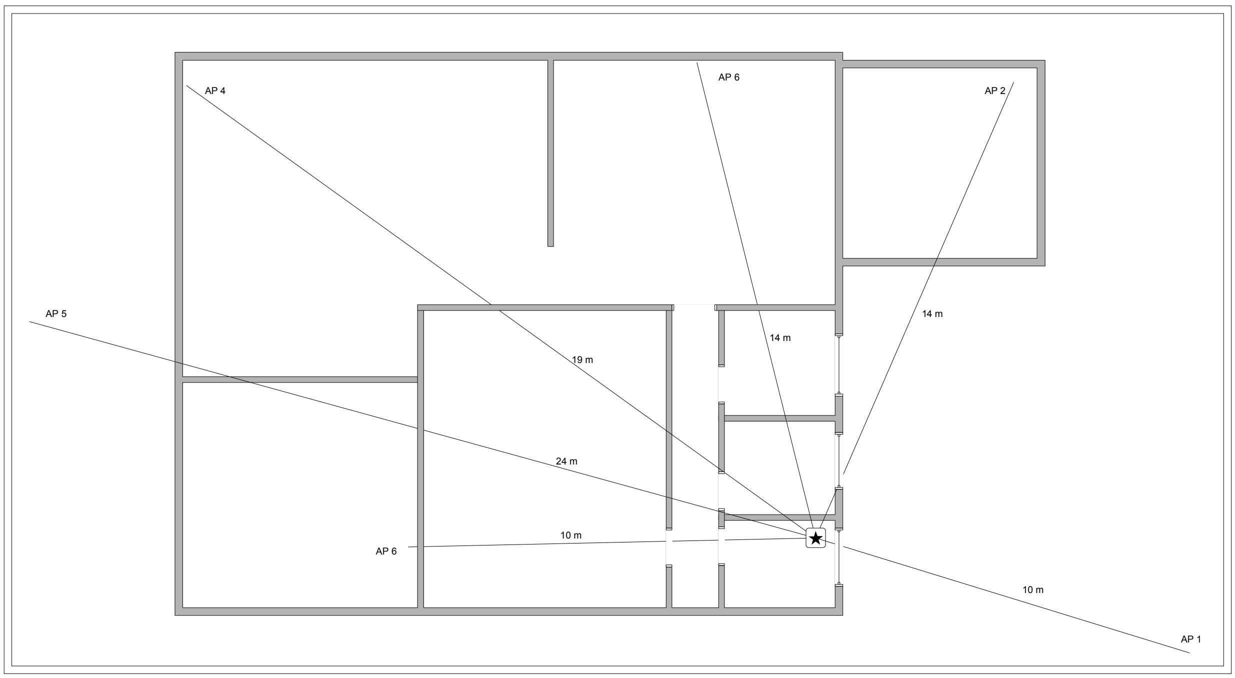


Figure 3: Map of the house with six access points

Access Points	Distance between AP and Receiver
AP1	10 meters
AP2	14 meters
AP3	10 meters
AP4	19 meters
AP5	24 meters
AP6	14 meters

Table 7: Distance between receiver and access points

At each of the six locations, we first ran a program written in C# to measure the signal strength at the current location. This program makes use of WMI (Windows Management Instrumentation), which enables us to capture signal strength of the access point the receiver is connected to. This program was run for approximately eight minutes at each location capturing sixteen signal strength values. These values were then divided into a set of four values each, in each set mean of the signal strength was calculated and the result was then used as the signal strength to calculate distance.

Access Point	1st Reading (dB)	2nd Reading (dB)	3rd Reading (dB)	4th Reading (dB)
AP 1	-59.25	-59.25	-61.25	-57.25
AP 2	-64.5	-65.25	-65.75	-65.5
AP 3	-56	-55.5	-56.5	-56.25
AP 4	-72.25	-72.5	-72	-71.5
AP 5	-82.75	-83.25	-81.5	-81.75
AP 6	-59.75	-61	-62	-60.25

Table 8: Signal strength values at six access points

Once the radio signal strength was captured, we needed the time values from each of the transmitters. In order to gather the time values, a ping utility called hrPing was used. This utility provides microsecond level results which are required to calculate the distance using time.

The time value that we gathered using the hrPing utility is a round trip time for the signal from the receiver to the transmitter and back to the receiver. In order to get time taken by the signal in one direction, we needed another value called the zero meter value. This value represents the time it takes for the transmitter to respond to a ping request [22]. This time is measured by keeping the receiver and the transmitter face to face and recording the time it takes the echo packet to return. Once we have the zero meter time, we can subtract this value from the round trip time we have from the ping request and divide the value by 2, the result is the time it takes the signal in one direction.

hrPing was used to gather time data for about ten minutes time, the resulting set was divided into four equal parts. In each of this part we looked for the minimum time value, subtracted zero meter distance and divided the result by two. Gathering time data over 10 minutes provided us with a set large enough that we found minimum time values that were close enough to each other such that the distance calculated using them was close to each other as well.

Access Point	1st Reading (μsec)	2nd Reading (μsec)	3rd Reading (μsec)	4th Reading (μsec)
AP 1	0.045	0.044	0.04	0.045
AP 2	0.066	0.065	0.067	0.068
AP 3	0.048	0.047	0.052	0.0476
AP 4	0.085	0.083	0.084	0.087
AP 5	0.104	0.102	0.101	0.102
AP 6	0.065	0.06	0.066	0.064

Table 9: Time of arrival values at six access points

5.0 ALGORITHMS FOR LOCATION DETERMINATION

For the experimentation, we use two location determination algorithms. Radio Signal Strength and Time of Arrival. Information needed to implement each of these algorithms is available in almost all indoor environments using the wifi transmitter.

Distance calculation using Time of Arrival is based on measuring the time it takes for the signal to travel from its source to the receiver. Once we have the time it takes for the signal to travel, we can multiply it with the speed at which it travels, - speed of light- and get the distance.

Radio Signal Strength based calculations are done by measuring the signal strength at various locations and using the drop in signal strength to estimate the distance between the source and the receiver.

The data collected for experiment purposes is stored in two tables; one table contains the Signal strength data, while the second one contains the timing data. Based on what algorithm is being used to calculate the distance, data is retrieved from the database and used for calculations.

5.1 Time of Arrival (TOA)

Time of arrival, as the name specifies makes use of the time it takes for the signal to travel in one direction to calculate the distance. We know that the speed of the wifi signal is that of the speed of light. In order to calculate the distance we multiply the time it takes the signal in one direction with the speed of light (300 meters per microsecond). In order to get an accurate distance using TOA we need as accurate as possible time value, since a difference of one microsecond can offset the calculated distance by 300 meters.

As we can see from the map of the house, there are six access points. In order to get location of the receiver, we utilize the values from three access points. When the program is executed, a query is passed to the database which contains the MAC addresses of the access points the receiver is talking to. Time values corresponding to the said MAC address are retrieved from the database and are used to calculate the distance of the receiver from each of the wireless transmitter being queried.

5.2 Radio Signal Strength (RSS)

5.2.1 Formula Based

One way to determine position using the Radio Signal Strength is to know how the signal drops in an environment and use this drop in signal strength to calculate the distance. This can be used to calculate distance using the formula below.

The formula we decided to use is [21].

$$d = 10^{\frac{TX_{PWR} - RX_{PWR} - Loss_{TX} + Gain_{TX} - PL_{1meter} + s + Gain_{RX} - Loss_{RX}}{10n}}$$

TX_{PWR} = Represents transmitter output power.

RX_{PWR} = Represents signal strength detected at receiver.

$Loss_{TX}$ = Represents the sum of all transmitter side losses.

$Gain_{TX}$ = Represents the transmitter side gain.

PL_{1Meter} = Represents the reference path loss in dB when distance between transmitter and receiver is one meter.

s = Represents the measure of signal variation from the source

$Gain_{RX}$ = Represents receiver side gain.

$Loss_{RX}$ = Represents sum of all receiver side losses.

n = Represents the rate at which path loss increases with distance.

One advantage of using this formula is that it takes into account the loss in signal strength that can occur due to the antenna and the wiring in the transmitter and the receiver. In order to use this formula for distance calculation we need certain details like TX_{PWR}, $Gain_{TX}$, $Gain_{RX}$, $Loss_{RX}$. These details can be determined from the manufacturer's technical details of the transmitter and the receiver.

$Loss_{TX}$ can be determined by subtracting the signal strength at the face of the transmitter and the signal strength given by the manufacturer.

PL_{1Meter} can be determined by subtracting the signal strength at the face of the transmitter and the signal strength at a distance of one meter from the transmitter.

s value varies between 3 and 7 dB and the value can be determined by substituting values in the formula above with a known distance.

n has a value of 2 for open spaces, 3.5 for indoor office, 3.7-4 for dense commercial environment and 4.5 for dense home environment.

When using the RSS algorithm, the database is queried with the MAC id of the wifi transmitters the receiver can communicate with; the database returns the required values for the formula which are then used to calculate the distance.

5.2.2 Signal Strength Pattern

Another RSS based method that we tested was to determine the pattern of change in the signal strength from each access point within the indoor environment. The motive behind using such a method was that, if we know how the signal strength behaves indoors, we can compare this pattern of change previously recorded with the pattern of change that the user is facing and use this information to determine the distance between the user and the access points.

5.2.3 Fingerprinting

One more method we are going to test is fingerprinting. In this method, we can store the signal strengths at a known location and compare these signal strength values to ones that the user is capturing at the moment. If we find a match to the signal strength being captured by the user, we return the location that is associated with this signal strength.

6.0 EXPERIMENTS

In the heterogeneous home environment, we have placed six access points which we have used to gather signal and time information. When executing an algorithm, we call a query with three MAC ids of the access points we want to use to determine the distance between the access point and the receiver.

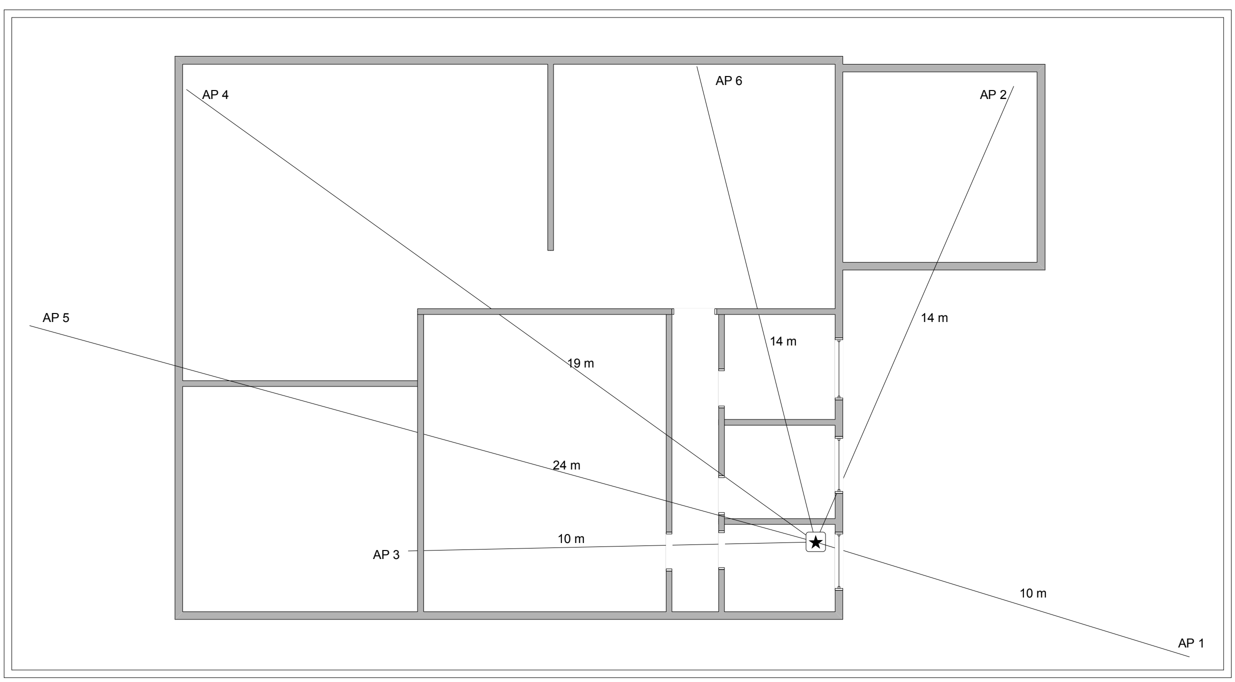


Figure 4: Map of house with access points

In the database, each of the time and RSS values has been associated with a MAC id. Since we have six access points and four values associated with each access point, we have 24 MAC ids stored in the database, which represent each of the captured value.

Four values from AP1 are represented by AP1, AP7, AP13, and AP19

Four values from AP2 are represented by AP2, AP8, AP14, and AP20

Four values from AP3 are represented by AP3, AP9, AP15, and AP21

Four values from AP4 are represented by AP4, AP9, AP16, and AP22

Four values from AP5 are represented by AP5, AP10, AP17, and AP23

Four values from AP6 are represented by AP6, AP11, AP18, and AP24.

When executing one of the algorithms, the MAC ids of three access points are passed to the query; this query retrieves the required details of the Access Point and uses the details to calculate the distance between the access point and the receiver.

Access Point	Distance between Access Point and Receiver
AP 1, AP7, AP13, and AP19	10 meters
AP 2, AP8, AP14, and AP20	14 meters
AP 3, AP9, AP15, and AP21	10 meters
AP 4, AP9, AP16, and AP22	19 meters
AP 5, AP10, AP17, and AP23	24 meters
AP 6, AP11, AP18, and AP24	14 meters

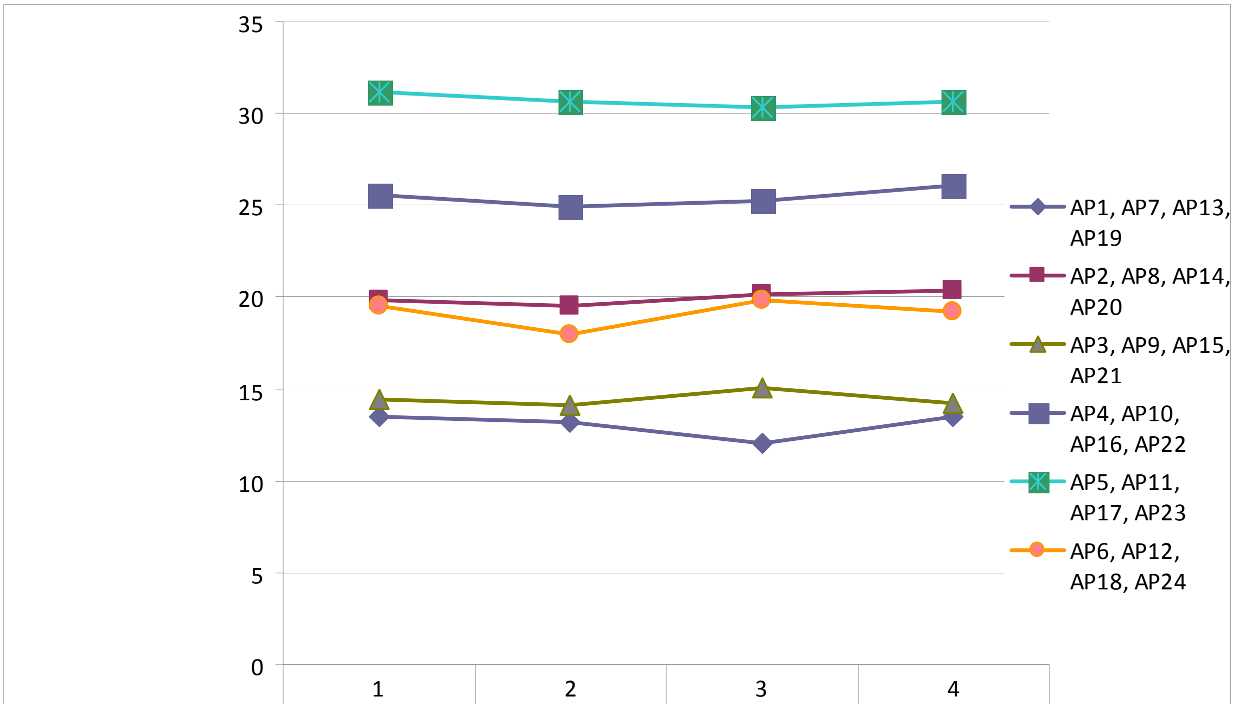
Table 10: Distance between all access points and receiver

6.1 TOA Experiment

In case of TOA algorithm, the program retrieves the values of the access points from the database for three access points at a time.

```
calculateTOADistance(FinalString.AP_1,FinalString.AP_2,FinalString.AP_3);
calculateTOADistance(FinalString.AP_4,FinalString.AP_5,FinalString.AP_6);
calculateTOADistance(FinalString.AP_7,FinalString.AP_8,FinalString.AP_9);
calculateTOADistance(FinalString.AP_10,FinalString.AP_11,FinalString.AP_12);
calculateTOADistance(FinalString.AP_13,FinalString.AP_14,FinalString.AP_15);
calculateTOADistance(FinalString.AP_16,FinalString.AP_17,FinalString.AP_18);
calculateTOADistance(FinalString.AP_19,FinalString.AP_20,FinalString.AP_21);
calculateTOADistance(FinalString.AP_22,FinalString.AP_23,FinalString.AP_24);
```

With each query, distance is calculated between the access point whose value are being queried and the receiver.



	1	2	3	4
AP1, AP7, AP13, AP19	13.5	13.19	12	13.5
AP2, AP8, AP14, AP20	19.79	19.5	20.1	20.4
AP3, AP9, AP15, AP21	14.4	14.09	15.06	14.28
AP4, AP10, AP16, AP22	25.5	24.89	25.19	26.09
AP5, AP11, AP17, AP23	31.2	30.59	30.3	30.59
AP6, AP12, AP18, AP24	19.5	18	19.79	19.2

Graph 7: Distance calculated using Time of Arrival

From the graph above, we can see the distance that was calculated between the six access points and the receiver.

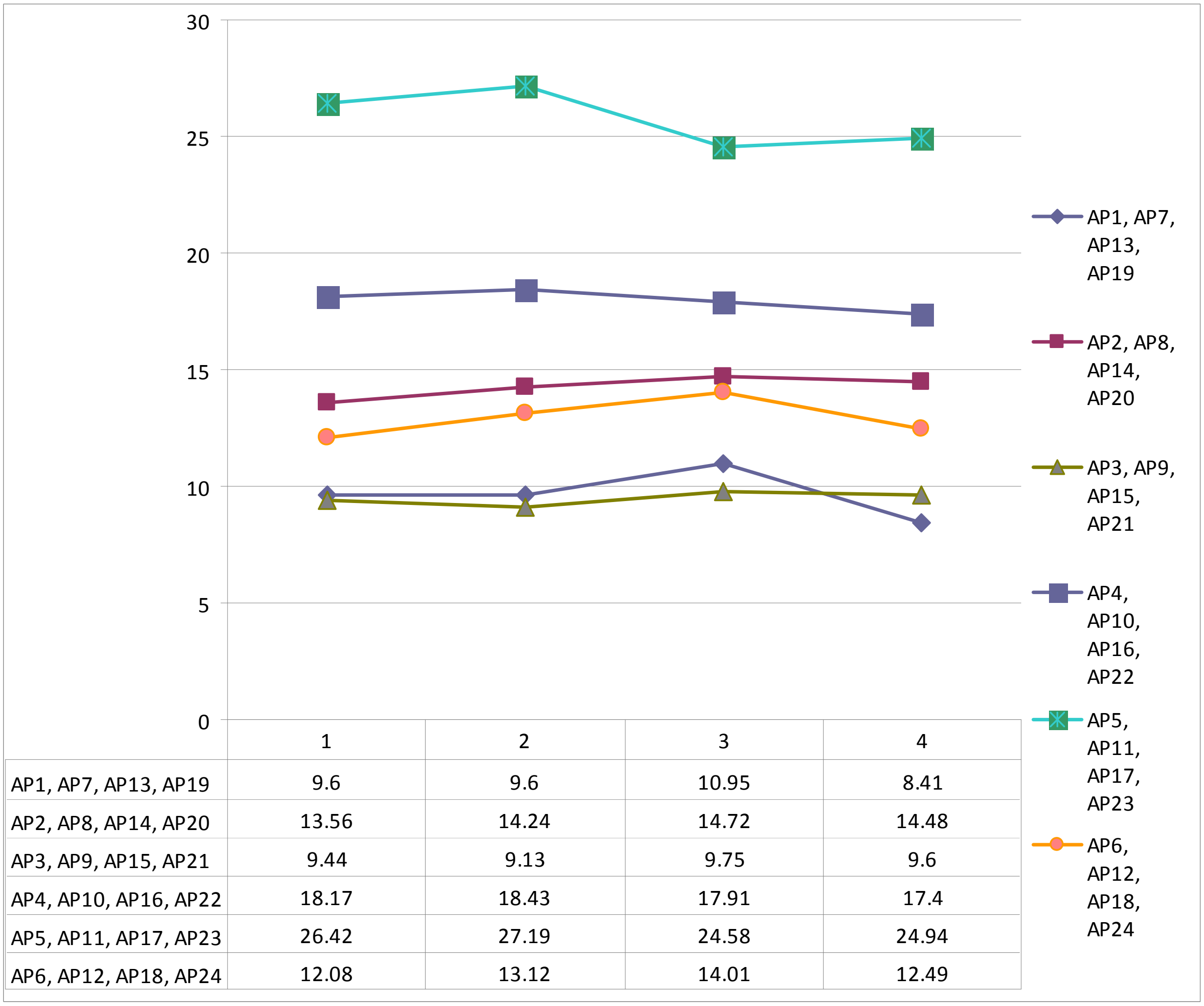
If we compare the time values that we have gathered above over 10 minutes of time and the values that were gathered in Section 3, we see that with increase in time to capture time values, we did get time values that were consistent. But the question remains, can a wireless transmitter maintain its consistency. The data that was captured in section 3 was done with one other user connected to the access point and accessing the web, this will be the case in case of any access point, since other users will be connected to it. The data in Graph 7 above was captured with no other user, except the receiver connected to the access point. This leads us to the conclusion that even though time values can be used to calculate distance, the time values returned by the wireless access point is largely dependent on the load that the access point has, and since this load can change unexpectedly the time values returned can also change.

6.2 RSS Experiment

6.2.1 Formula Based

In RSS algorithm, the program retrieves the complete access point data from the database; this data is used as values for the formula and used to calculate the distance based on the signal strength of access point detected by the receiver.

```
calculateRSSDistance(FinalString.AP_1,FinalString.AP_2,FinalString.AP_3);
calculateRSSDistance(FinalString.AP_4,FinalString.AP_5,FinalString.AP_6);
calculateRSSDistance(FinalString.AP_7,FinalString.AP_8,FinalString.AP_9);
calculateRSSDistance(FinalString.AP_10,FinalString.AP_11,FinalString.AP_12);
calculateRSSDistance(FinalString.AP_13,FinalString.AP_14,FinalString.AP_15);
calculateRSSDistance(FinalString.AP_16,FinalString.AP_17,FinalString.AP_18);
calculateRSSDistance(FinalString.AP_19,FinalString.AP_20,FinalString.AP_21);
calculateRSSDistance(FinalString.AP_22,FinalString.AP_23,FinalString.AP_24);
```



	1	2	3	4
AP1, AP7, AP13, AP19	9.6	9.6	10.95	8.41
AP2, AP8, AP14, AP20	13.56	14.24	14.72	14.48
AP3, AP9, AP15, AP21	9.44	9.13	9.75	9.6
AP4, AP10, AP16, AP22	18.17	18.43	17.91	17.4
AP5, AP11, AP17, AP23	26.42	27.19	24.58	24.94
AP6, AP12, AP18, AP24	12.08	13.12	14.01	12.49

Graph 8: Distance calculated using RSS

From the graph above we can see the distance that was calculated between the access points and the receiver. Comparing this distance to the actual distance given in the table above, we can see that though the error here is smaller than that calculated using TOA, but the distance calculated in most cases is shorter than the actual distance.

Even though the formula did calculate the distance fairly accurately for the six different locations in the indoor environment, if we take into consideration the signal strength values from section 3, we see that signal strength increases in some situations. Since the formula assumes that the signal strength will only decrease in strength with increase in distance and takes into consideration the rate at which it is going to decrease by using the values of ‘n’ and‘s’, this formula fails to provide us with correct distance calculation in situations where the signal strength has increased with increase in distance rather than decreasing.

6.2.2 Signal Strength Pattern

In section 3, we have seen that signal strength does not always decrease with increase in distance; there are situations where the signal strength increases within the room. Since this particular behavior of the signal strength results in incorrect distance measurements, we decided to determine if we can set a pattern to the way the signal strength behaves in the indoor environment. Once we have the pattern, we can compare the stored pattern with the pattern that the user is experiencing and determine the distance from the access points.

In order to determine this patter, we placed the access points in three different locations in the house and captured signal strength at every one meter distance while moving from one access point to another.

The advantage of setup is that we not only get to determine how the signal strength changes while moving from one access point to another, but we also see how the signal strength changes when the angle between the access point and the receiver is changed.

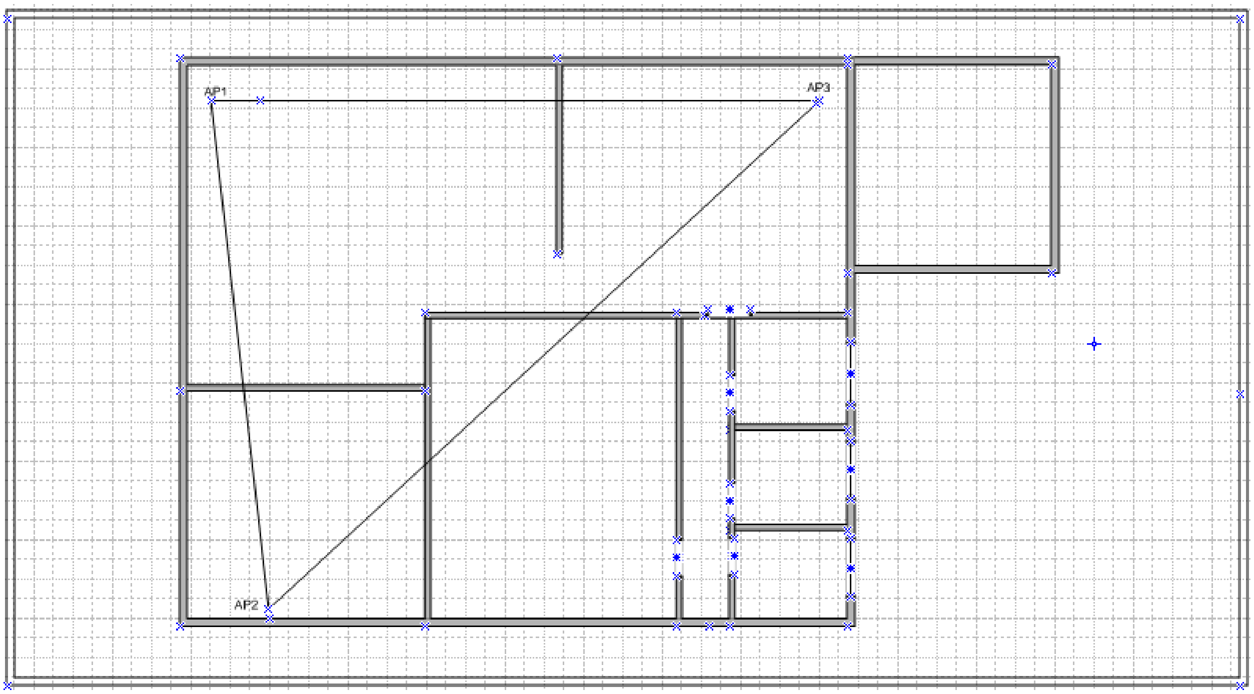
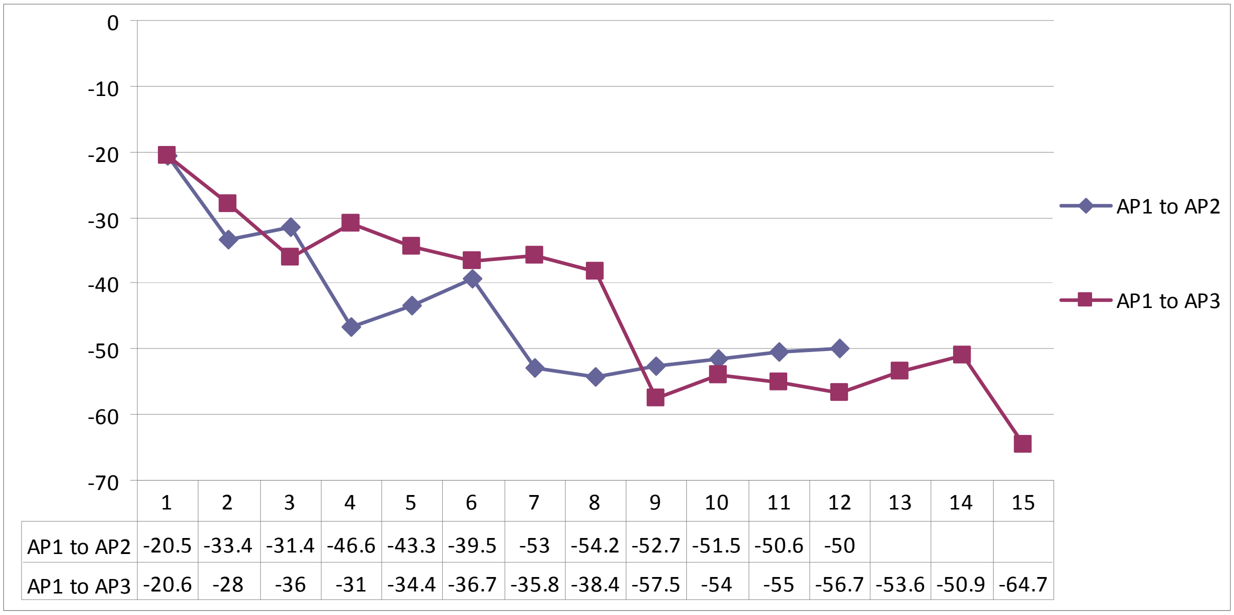


Figure 5: Three Access Points in Indoor Environment.

We have placed three access points in the three locations shown above; as we move from AP1 to AP2 and then from AP1 to AP3, we capture the signal strength values from AP1. When we move from AP2 to AP1 and then from AP2 to AP3, we capture the signal strength from AP2, moving from AP3 to AP1 and then from AP3 to AP2, we capture the signal strength from AP3.

In the graph below we see the signal strength that has been captured from AP1 while first moving to AP2 and then AP3.

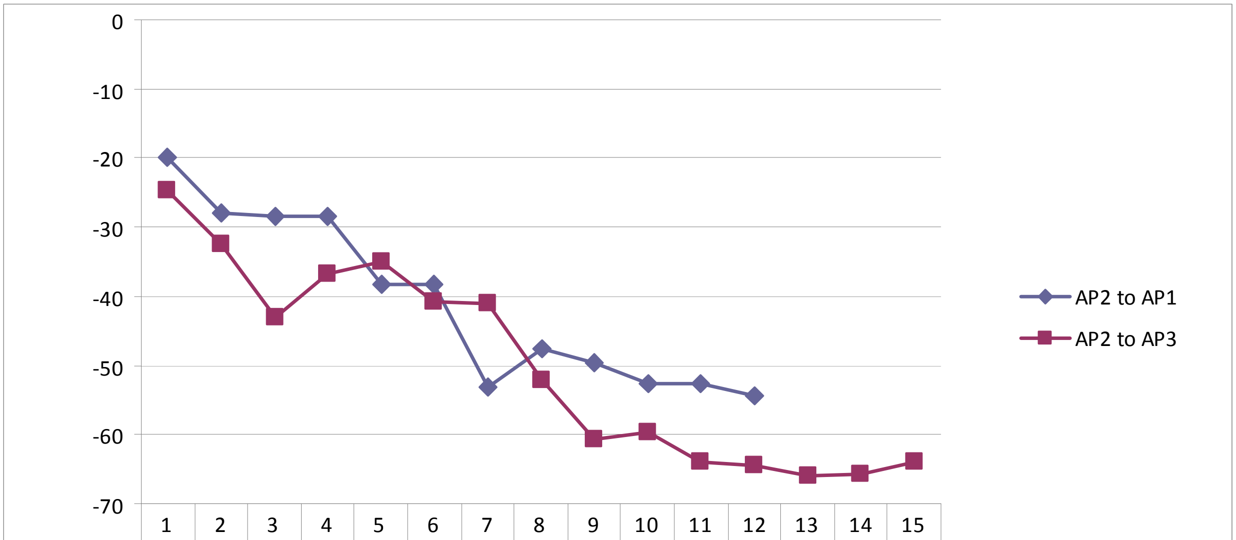


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AP1 to AP2	-20.5	-33.4	-31.4	-46.6	-43.3	-39.5	-53	-54.2	-52.7	-51.5	-50.6	-50			
AP1 to AP3	-20.6	-28	-36	-31	-34.4	-36.7	-35.8	-38.4	-57.5	-54	-55	-56.7	-53.6	-50.9	-64.7

Graph 9: Signal strength, moving from AP1 to AP2 and AP3

From the graph above we can see that as expected there are situation where the signal strength increases in strength with increase in distance.

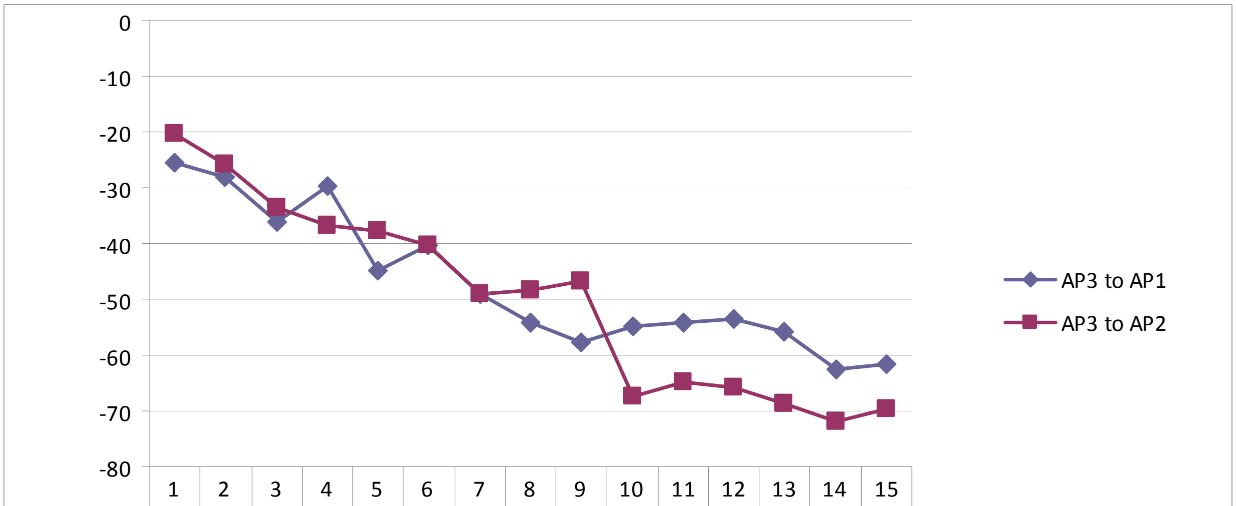
The first five readings in the graph above are in the same room (Main Hall) but at different angles from the access point, we can see from the readings in the graph above that there is a change in signal strength values with change in the angle at which the receiver communicated with the access point.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AP2 to AP1	-20	-28	-28	-28	-38	-38	-53	-48	-50	-53	-53	-54			
AP2 to AP3	-25	-33	-43	-37	-35	-41	-41	-52	-61	-60	-64	-65	-66	-66	-64

Graph 10: Signal Strength, moving from AP2 to AP1 and AP3

As we had seen in Graph 9, we also see in the graph above that the signal strength increases in some areas with the increase in distance from the access point. Also, we can see that the signal strength for the first five values which are in the same room is different while moving towards AP1 and AP3, and the only difference is the angle at which the receiver is communicating with the access point.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AP3 to AP1	-26	-28	-36	-30	-45	-40	-49	-54	-58	-55	-54	-54	-56	-63	-62
AP3 to AP2	-20	-26	-34	-37	-38	-40	-49	-48	-47	-67	-65	-66	-69	-72	-70

Graph 11: Signal Strength, moving from AP3 to AP1 and AP2

As we have seen from Graph 9 and Graph 10, we can see that there are situations where the signal strength increases with the increase in distance and like in previous two graphs we can also see that there is a change in the signal strength captured for the first five meters in the same room.

The purpose of capturing signal strength while moving from one access point to another was to see if we can have a pattern in signal strength, which we can compare the signal strength from a user with to determine the users distance from the access points. But as we can see from the data in the graphs above, we see that when we move from AP1 to AP2 and then from AP2 to AP1 or AP1 to AP3 and AP3 to AP1, we see that the signal strength values are different at each extreme, this shows us that signal strength is varying with the environment as well as distance, and from the graphs above, we can also see that there is a difference in captured signal strength value with change in angle between the receiver and the access point.

This information from the captured data leads to conclusion, that if want a signal strength pattern to determine distance between access point and receiver, we need to have signal strength variations in all possible environments and all possible angles of approach to each of the access points.

6.2.3 Fingerprinting

We have seen from the experiments discussed above, that using formula to calculate distance between access point and receiver does not always give us accurate value because of sudden increase in signal strength. Determining a pattern of signal strength change to determine the distance between access point and the receiver requires the signal strength pattern from every conceivable approach a user can take since the signal strength is varying with environment and the angle between the receiver and the access point. This leads us to another approach called the fingerprinting.

In this approach, we do not need to worry about how the signal strength changes within environment, or what the angle is between the receiver and the access point. Fingerprinting involves recording the signal strength values at predetermined locations, such as outside a door, in front of elevator and storing these values in the database. When a user approaches these locations, he queries the database with the signal strength and if we have a match, then the corresponding location is returned.

In the figure below we can see the three points where the signal strength values were capture for fingerprinting. Each of the three locations are in the main hall, at each of the location the signal strength values were captured from the three access points AP1, AP2 and AP3. These values are a mean of sixteen signal strength values.

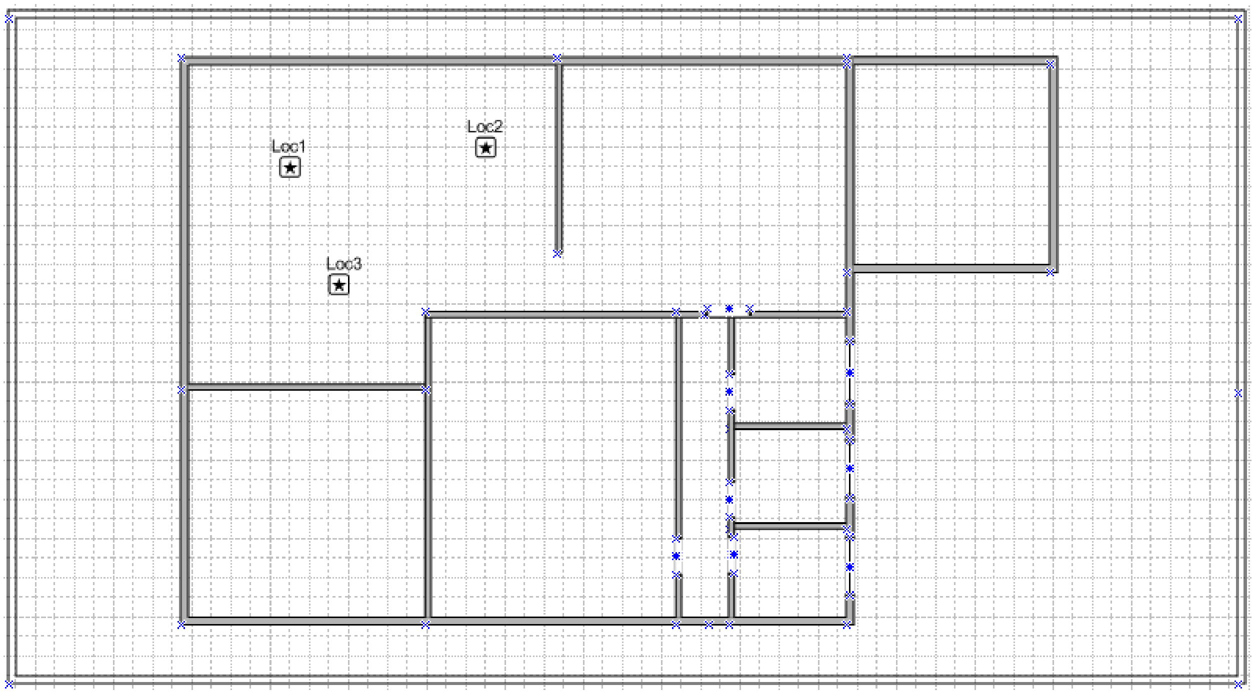


Figure 6: Location for fingerprinting

	Loc1(signal strength in dB)	Loc2(signal strength in dB)	Loc3(signal strength in dB)
AP1	-29.56	-35.37	-30.75
AP2	-42.37	-47.25	-42.62
AP3	-51.12	-53.37	-55.37

Table 11: Signal strength at three locations

In the table above we can see the signal strength values that were captured at the three locations mentioned in figure 6.

When these values are recorded into the database, we also record the location where these signal strength values were captured. So when a user queries the database with the signal strength values that he or she has detected, they are compared to the stored signal strength values. Once a match is found, the corresponding location is returned. In performing fingerprinting there can be situations where the signal strength gathered by the user and those stored in the fingerprint database differ by a few dB. To overcome this problem, we sample the signal strength at the locations over and over again to determine by how much value the signal strength at the same location varies. In our case we found that the signal strength varied by a maximum of 3dB. So when we query the database for the signal strength, we query it for signal strength within 3dB of the captured value.

	Loc1(signal strength in dB)	Loc2(signal strength in dB)	Loc3(signal strength in dB)
AP1	-28.47	-37.37	-32.05
AP2	-41.45	-48.45	-44.41
AP3	-53.12	-51.20	-53.70

Table 12: Signal strength at three locations for user

The signal strength values in the table above show the signal strength values there were captured when the receiver was used in a user mode, meaning when a user wants to find his or her location. When these signal strength values are queried from the database with the 3dB fluctuation factored in, the database returns the corresponding location.

The advantage of using such a method is that we now do not have to worry about the signal strength fluctuations caused due to environment, and also we do not need to know the location of the individual access points to determine the current location of the user, since we are not measuring the distance between the receiver and the access point in question. One disadvantage of this method though is that we need to map the fingerprints of all the locations that we want to return the location for, like say we are in a room, so if a user wants to know where he or she is, we need to have the fingerprint values for that entire room. To overcome this problem, we propose another method that takes into account the difference in signal strength value with in the area in question.

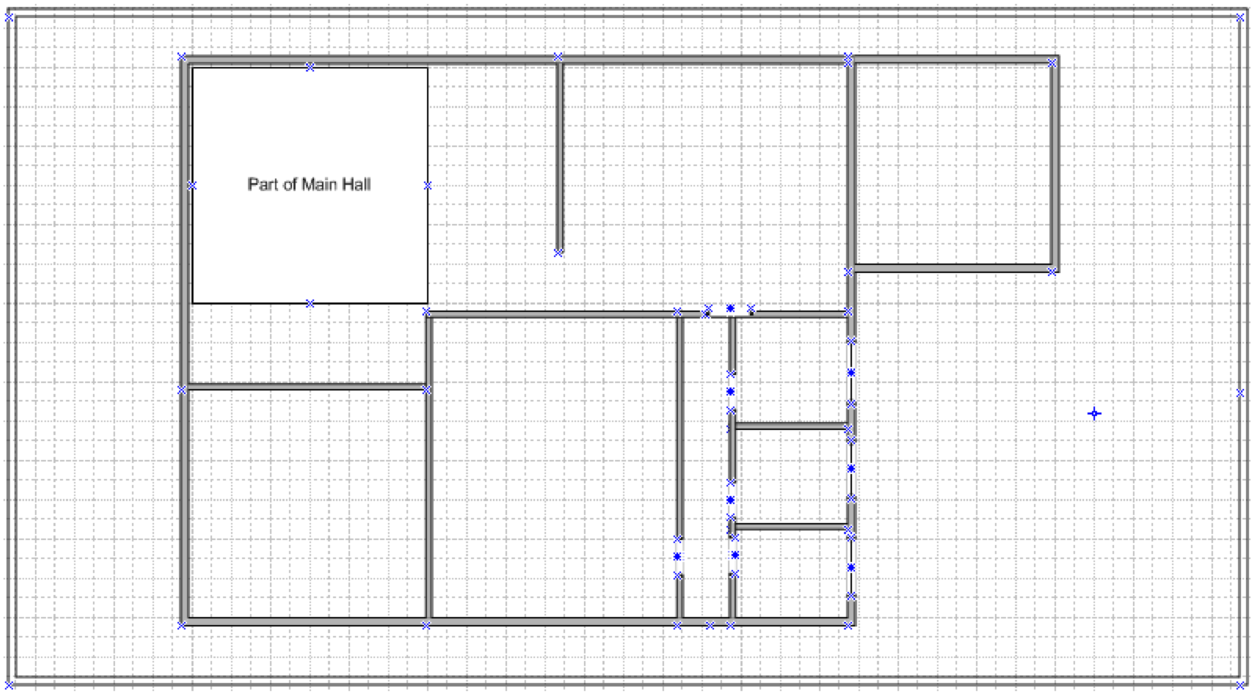


Figure 7: Area of Main Hall for Fingerprinting

In this fingerprinting technique, we have considered a part of the main hall. Here we capture the signal strength at the corners of the room, from the signal strength we captured; we determine the minimum signal strength and the maximum signal strength values. So, when a user walks into the main hall and captures the signal strength, we can compare it against the extremes and check if the captured signal strength from each access points is within the pre-calculated extremes, once we have determined that the signal strength lies within these extremes then we can safely say that the user is within the said room.

One limitation of this method is that the system needs to know where the user is, in order to compare against the correct extremes for the said room. Our way of doing this is to keep track of the user's previous location that has been determined using fingerprinting. Say the last query by the user placed him outside a room, as shown in the figure above, when the user queries the database again with a new set of signal strength values we check the fingerprint database for a match, if no match is found, we use the last location as the area user can possibly be in, in this case inside the area of main hall, we then compare the captured signal strength values with the extreme signal strength values that have been captured before. If the users signal strength values are within these extremes, then it is safe to say that the user is in the main hall.

	Strongest Signal (dB)	Weakest Signal (dB)
AP1	-20.5	-39.37
AP2	-49.75	-54.42
AP3	-54.5	.65.18

Table 13: Strongest and Weakest signal strength in main hall area

In the table above we can see the strongest and the weakest signal strength from the three access points within the main hall area. These values will be used to compare the signal strength values captured by the user to determine weather he is inside the room or outside.

	Signal Strength (dB)
AP1	-30.75
AP2	-52.62
AP3	-55.37

Table 14: Signal Strength from user inside main hall

In the table above, we have the signal strength values that were captured by a user inside the main hall area shown in the figure above. The algorithm knows that the previous location of the user is the main hall, and that these signal strength values do not match the fingerprinting database. Signal strength values from each access point is compared to the strongest and the weakest signal strength, if the captured signal strength value for each access point lies within the extreme values, then the location is returned as main hall.

7.0 CONCLUSION

Time of Arrival (TOA) though is a reliable method of distance calculation in an open environment (GPS), has certain limitations indoors. As we have seen from our experiments, the time it takes for the signal to travel from the transmitter to the receiver is not constant. The time graph that we can see in section 3 was constructed with time values that were captured from the access point when another user was connected to the internet using the access point. In a practical scenario, there will always be a situation when someone is connected to the access point and is accessing the web, this result in the access point responding to the ping requests with some delay, and since this delay is not constant and depends on how much load is on the access point the time the signal takes to travel between the access point and the receiver will vary.

Radio signal strength is the other method that can be used to determine the location by measuring the distance based on drop in signal strength. As we can see from section 3, we see that the signal strength does not always drop with the increase in distance. There are some situations where the signal strength increases with increase in distance. Using the formula that we used in section 6.2.1, we see that for a certain location we can determine the values for ‘s’ and ‘n’ and measure the distance as accurately as possible, but in situations where the signal strength increases instead of decreasing this formula results in incorrect calculation of distance.

In section 6.2.2 we tried to form a pattern to the signal fluctuation in the indoor environment which could then be used to determine between the receiver and the access point. In the readings discussed in the section 6.2.2 we can see that signal strength varies based on the environment and the angle at which the receiver is communicating to the transmitter. These variations with different environment and angles results in the fact that in order to use the signal pattern to determine distance from the access point, we will need signal strength patter for all the different environment the indoor locations has to offer, and when a user queries the signal strength with the existing pattern we need to compare it against all pre collected patterns. It is also very difficult to determine what route the user will take inside the house, and in case a signal strength pattern for that route has not been determine, the system can return either incorrect result or no result at all.

In section 6.2.3 we use fingerprinting as a method for location estimation. The advantage of using such a method is that we do not need to know the location of the access points, or worry about the affect the environment will have on the signal strength. In order to determine the location, the signal strength values the user gets are compared to the signal strength values for different locations determined in an offline phase. The location corresponding to signal strength is returned.

Fingerprinting is the best method for location determination in an indoor environment, as it does not suffer from load on an access point, or how the signal strength varies with different environment or the angle at which the receiver is communicating with the access point.

8.0 FUTURE WORK

The algorithm discussed in the second half of fingerprinting deals with a situation when the signal strength that is compared to the strongest and weakest signal strength for that area is within the range. There can be situations when the user queries the system just inside the room and the signal strength captured is outside the range that has been determined in the offline phase.

There will be continued work to determine when and how often this situation can arise, and develop a method to insure that the user is not provided with incorrect results due to this condition.

9.0 APPENDIX A

Additional experiments were preformed based on the results we got from the time of arrival and radio signal strength algorithm using the formula from section 6.2.1.

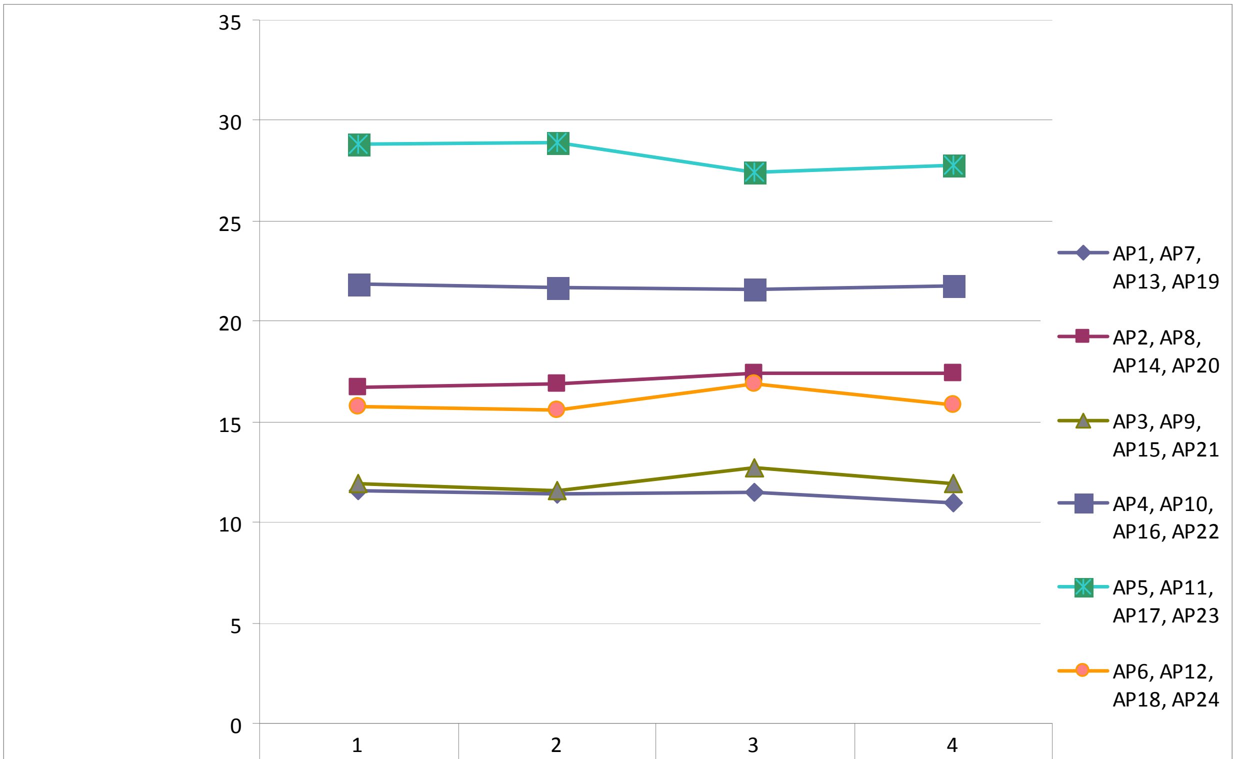
In the TOA experiment we saw that the distance calculated had a very consistent error and the distance calculated was always greater than the actual distance. In the RSS experiment using the formula, we found that the distance calculated between the access points and the receiver was always shorter than the actual distance.

So, keeping these distance measurements in mind, we thought of a hybrid algorithm that will make use of the distance measured using TOA and RSS and use the mean value as the distance.

Hybrid Experiment

In the Hybrid algorithm, the program retrieves the time and RSS data from the database for the given access point. Once we calculate the distance using the TOA and the RSS, we use the mean of this distance as the final distance of the hybrid algorithm.

```
calculateHybridDistance(FinalString.AP_1,FinalString.AP_2,FinalString.AP_3);
calculateHybridDistance(FinalString.AP_4,FinalString.AP_5,FinalString.AP_6);
calculateHybridDistance(FinalString.AP_7,FinalString.AP_8,FinalString.AP_9);
calculateHybridDistance(FinalString.AP_10,FinalString.AP_11,FinalString.AP_12);
calculateHybridDistance(FinalString.AP_13,FinalString.AP_14,FinalString.AP_15);
calculateHybridDistance(FinalString.AP_16,FinalString.AP_17,FinalString.AP_18);
calculateHybridDistance(FinalString.AP_19,FinalString.AP_20,FinalString.AP_21);
calculateHybridDistance(FinalString.AP_22,FinalString.AP_23,FinalString.AP_24);
```



	1	2	3	4
AP1, AP7, AP13, AP19	11.55	11.4	11.47	10.95
AP2, AP8, AP14, AP20	16.68	16.87	17.41	17.44
AP3, AP9, AP15, AP21	11.92	11.61	12.67	11.94
AP4, AP10, AP16, AP22	21.83	21.66	21.55	21.75
AP5, AP11, AP17, AP23	28.81	28.89	27.44	27.77
AP6, AP12, AP18, AP24	15.79	15.56	16.9	15.84

Graph 12: Distance calculated using Hybrid algorithm

From the graph above we can see the distance that was calculated using the hybrid algorithm. If we compare the distance calculated using the TOA algorithm to distance calculated using hybrid algorithm, we see that the distance calculated using hybrid algorithm are closer and greater to the actual distance.

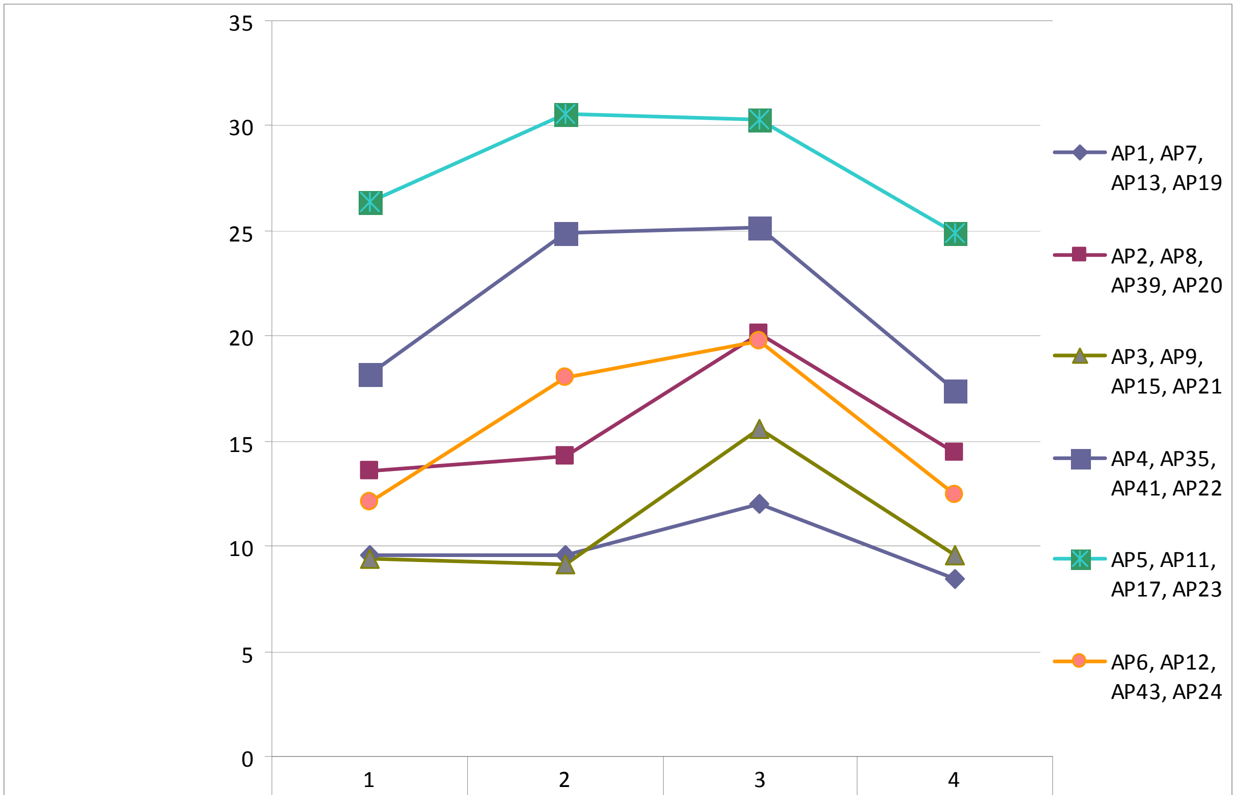
Selective Experiment

Another experiment that we performed was to use each technology where it performs its best. Since we had seen from the formula based RSS that the distance calculated was the closest to the actual distance, we use this method in a indoor environment, and since Time based distance calculation suffers from least variations in an outdoor environment, we use this in an outdoor environment.

In the Selective algorithm, the program retrieves values from the database based on the condition whether it can find required RSS information for the access points the receiver is talking to. If the query finds records for the said access point, then distance are calculated using RSS, else distance is calculated using TOA.

In case of selective, 18 more access points were added to the TOA database, when a query is executed with a MAC id that does not exist in the RSS database, then distance will be calculated using TOA algorithm.

```
calculateSelectiveDistance(FinalString.AP_1,FinalString.AP_2,FinalString.AP_3);
calculateSelectiveDistance(FinalString.AP_4,FinalString.AP_5,FinalString.AP_6);
calculateSelectiveDistance(FinalString.AP_7,FinalString.AP_8,FinalString.AP_9);
calculateSelectiveDistance(FinalString.AP_35,FinalString.AP_11,FinalString.AP_12);
calculateSelectiveDistance(FinalString.AP_13,FinalString.AP_39,FinalString.AP_15);
calculateSelectiveDistance(FinalString.AP_41,FinalString.AP_17,FinalString.AP_43);
calculateSelectiveDistance(FinalString.AP_19,FinalString.AP_20,FinalString.AP_21);
calculateSelectiveDistance(FinalString.AP_22,FinalString.AP_23,FinalString.AP_24);
```



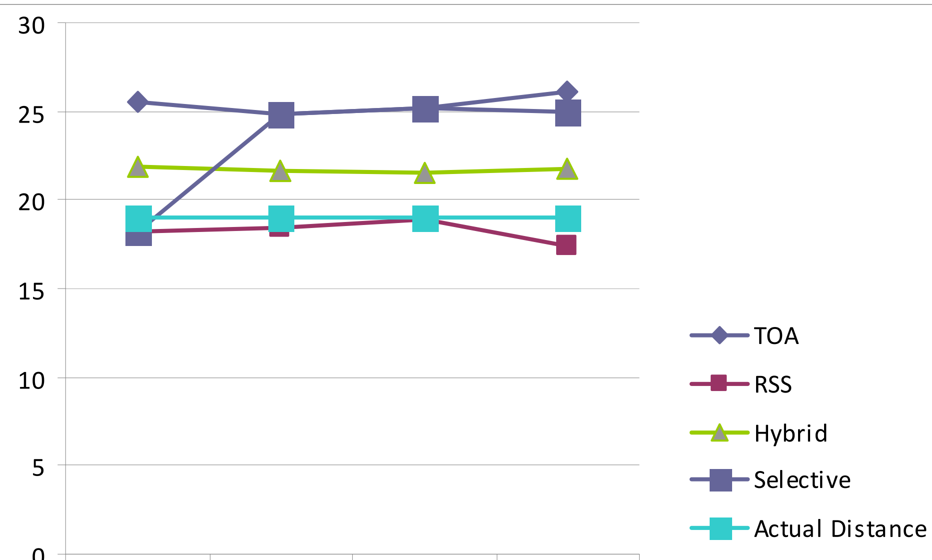
	1	2	3	4
AP1, AP7, AP13, AP19	9.6	9.6	12	8.41
AP2, AP8, AP39, AP20	13.56	14.24	20.1	14.48
AP3, AP9, AP15, AP21	9.44	9.13	15.6	9.6
AP4, AP35, AP41, AP22	18.17	24.89	25.19	17.4
AP5, AP11, AP17, AP23	26.42	30.59	30.3	24.94
AP6, AP12, AP43, AP24	12.08	18	19.79	12.49

Graph 13: Distance calculated using selective algorithm

From the graph above, we can see the distance calculated using the selective algorithm. In this case the queries were run such that first three queries found a match in the RSS database, meaning the readings were taken indoors, next three readings had MAC ids that were not found in the RSS database and so the program calculated distance based on TOA data, after this the last two queries were again such that the MAC id was present in the RSS database suggesting the user is back indoors and the distance was calculated using RSS algorithm.

RESULTS

The system was tested using six access points placed in different corners of the house. Each location presented a different amount of obstruction to the signal between the receiver and the access point. The time and the signal strength values were used to calculate distance between the access point and the receiver in all four algorithms.



	1	2	3	4
TOA	25.5	24.89	25.19	26.09
RSS	18.17	18.43	18.91	17.4
Hybrid	21.83	21.66	21.55	21.75
Selective	18.17	24.89	25.19	24.94
Actual Distance	19	19	19	19

Graph 11: Distance calculated using all four algorithms

In the graph above we can see the distance that was calculated between AP4 (main hall) and the receiver. Actual distance between AP4 and receiver is 19 meters.

We can see that the distance calculated using RSS results in distance that is slightly lower than but closest to the actual distance of 19 meters. These values can be attributed to the fact that signal strength at certain locations can be stronger than what is expected, as shown in the

Analysis of signal strength and time of arrival section. Distance calculated using TOA has maximum error.

Distance calculated using TOA has an error of roughly six meters; this distance has been measured using the smallest time detected from a large set of time values

TOA

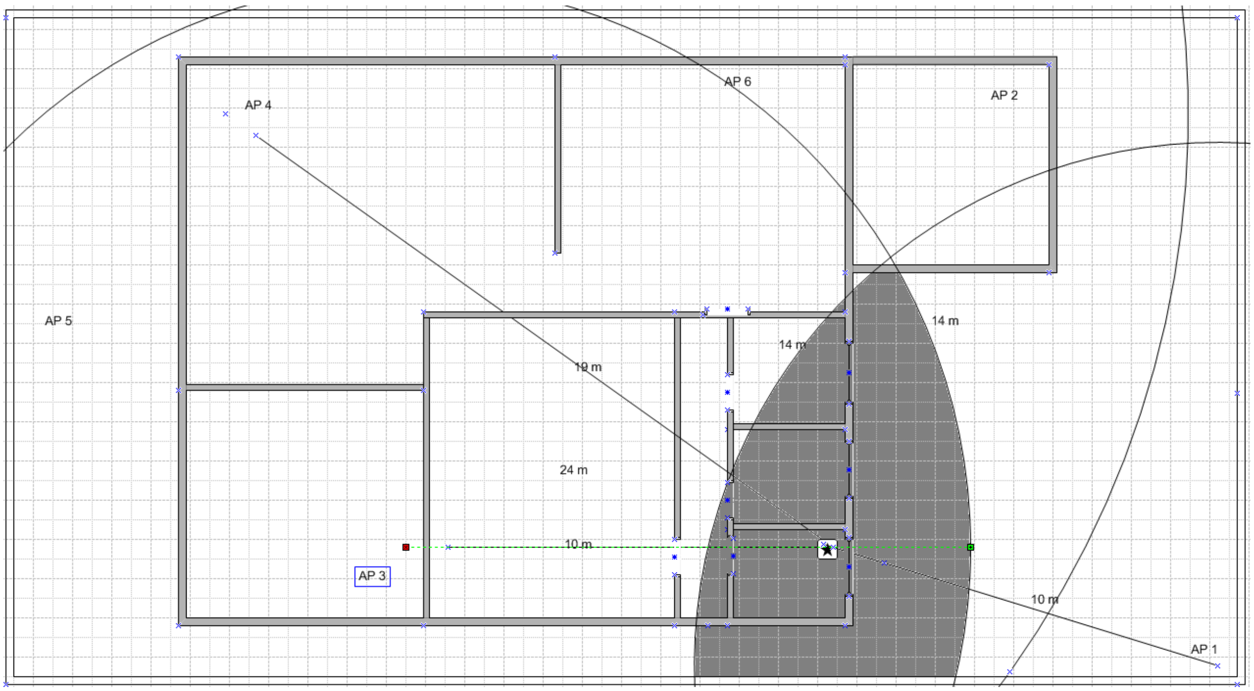


Figure 5: Location accuracy using TOA algorithm

Access Point	Calculated Distance between Access Point and Receiver
AP 1	13.5 meters
AP 3	14.4 meters
AP 4	25.5 meters

Table 11: Calculated distance between access point and receiver using TOA

In the figure above we can see the area detected as the position (grey shaded area) of the user using the TOA algorithm. The shaded area covers almost three rooms and part of the back yard. Suggesting that the user can be anywhere from the wall of the outside room to the neighbors house.

RSS

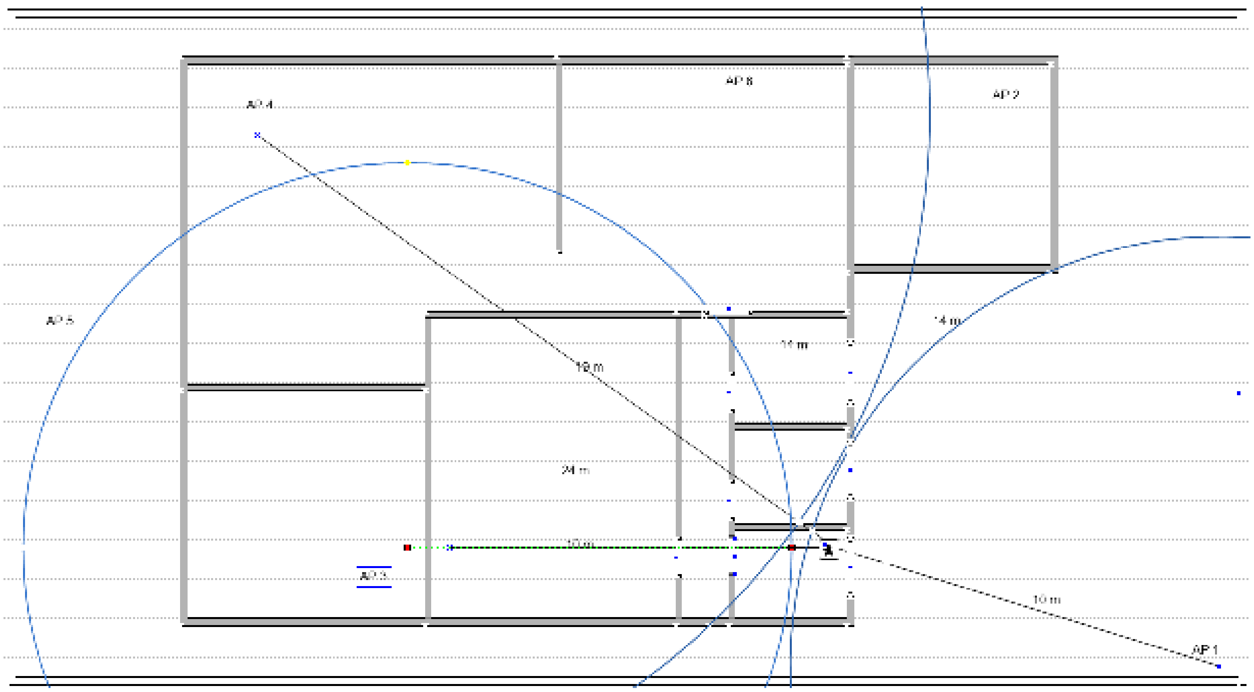


Figure 6: Location accuracy using RSS algorithm

Access Point	Calculated Distance between Access Point and Receiver
AP 1	10.95 meters
AP 3	9.75 meters
AP 4	17.91 meters

Table 12: Calculated distance between access points and receiver using RSS

In the figure above we can see that even though the distance measured using RSS algorithm is close to the actual distance, we can't find a common intersection area for all the three circles. This makes it difficult to determine the position of the receiver, since the position can be estimated using area of intersection.

Hybrid

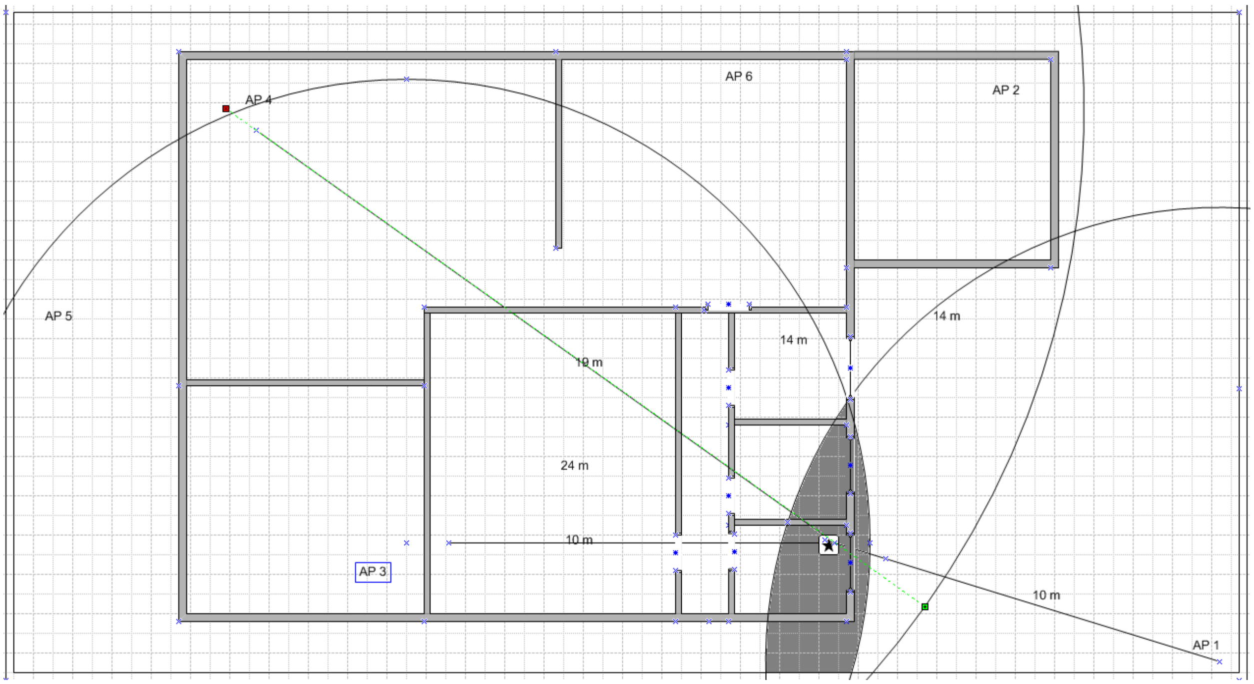


Figure 7: Location accuracy using Hybrid algorithm

Access Point	Calculated Distance between Access Point and Receiver
AP 1	11.55 meters
AP 3	11.95 meters
AP 4	21.8 meters

Table 13: Calculated distance using Hybrid algorithm

In the figure above we can see that the shaded area is smaller than what we saw for the TOA algorithm. Using the hybrid algorithm we were able to calculate distances between the access points and the receiver such that the intersection area of the three circles is smaller than the rest and this helps increase the accuracy in the given situation.

Selective

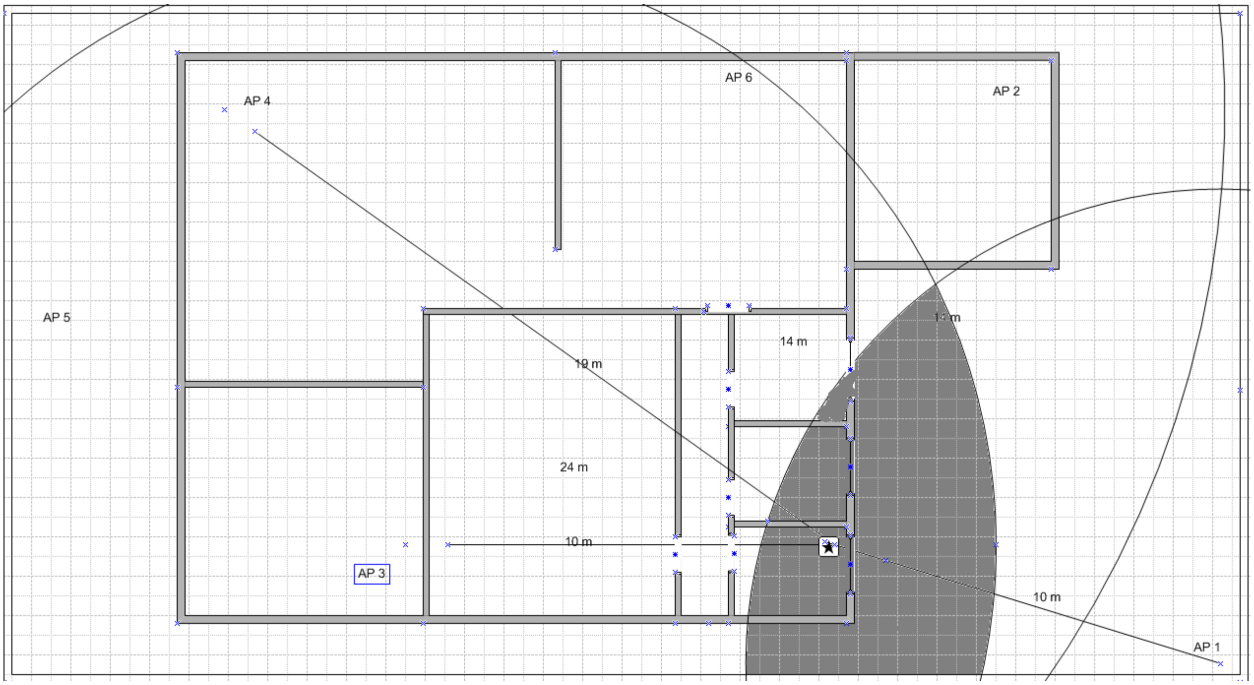


Figure 8: Location accuracy using Selective algorithm

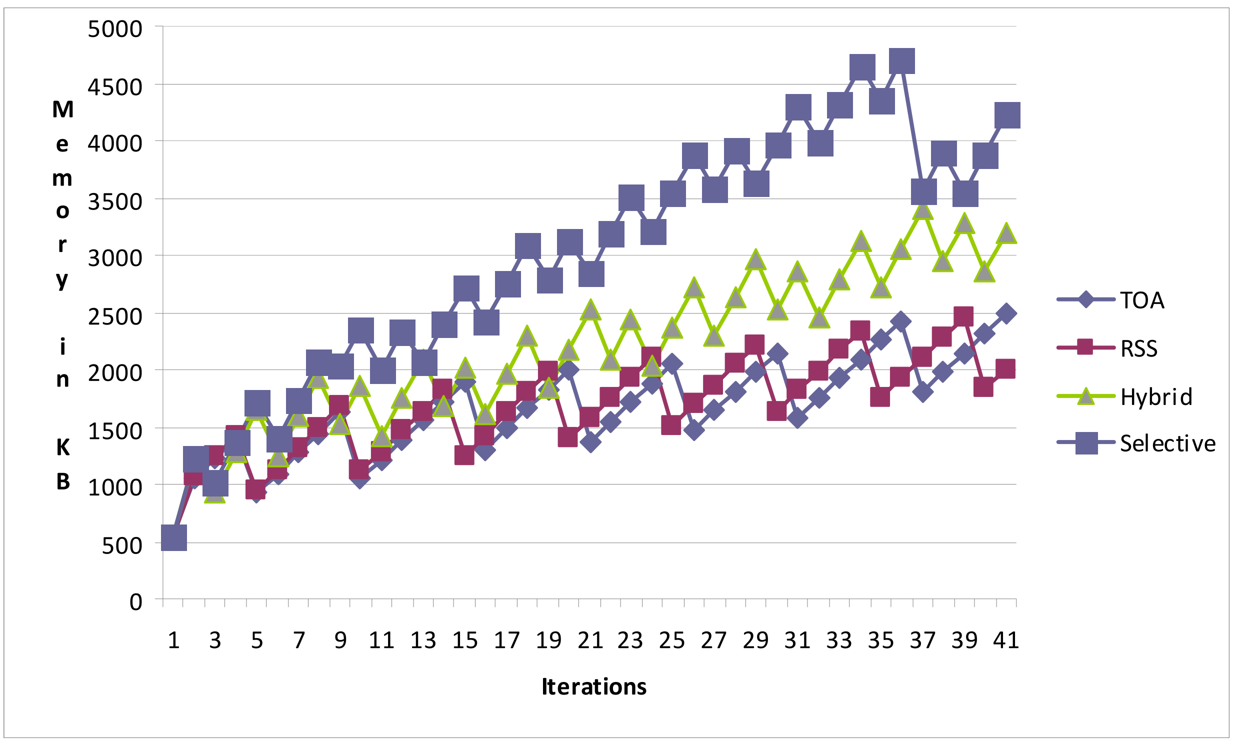
Access Point	Calculated Distance between Access Point and Receiver
AP 1	12 meters
AP 3	15.6 meters
AP 4	25.19 meters

Table 14: Calculated distance between access point and receiver using selective algorithm

In the figure above, we can see that the shaded area is similar to that for the TOA algorithm; this is due to the fact that the distance measurement for this algorithm depends on the accuracy of the TOA and RSS algorithm, and in this case the distance was measured using the TOA values.

Performance

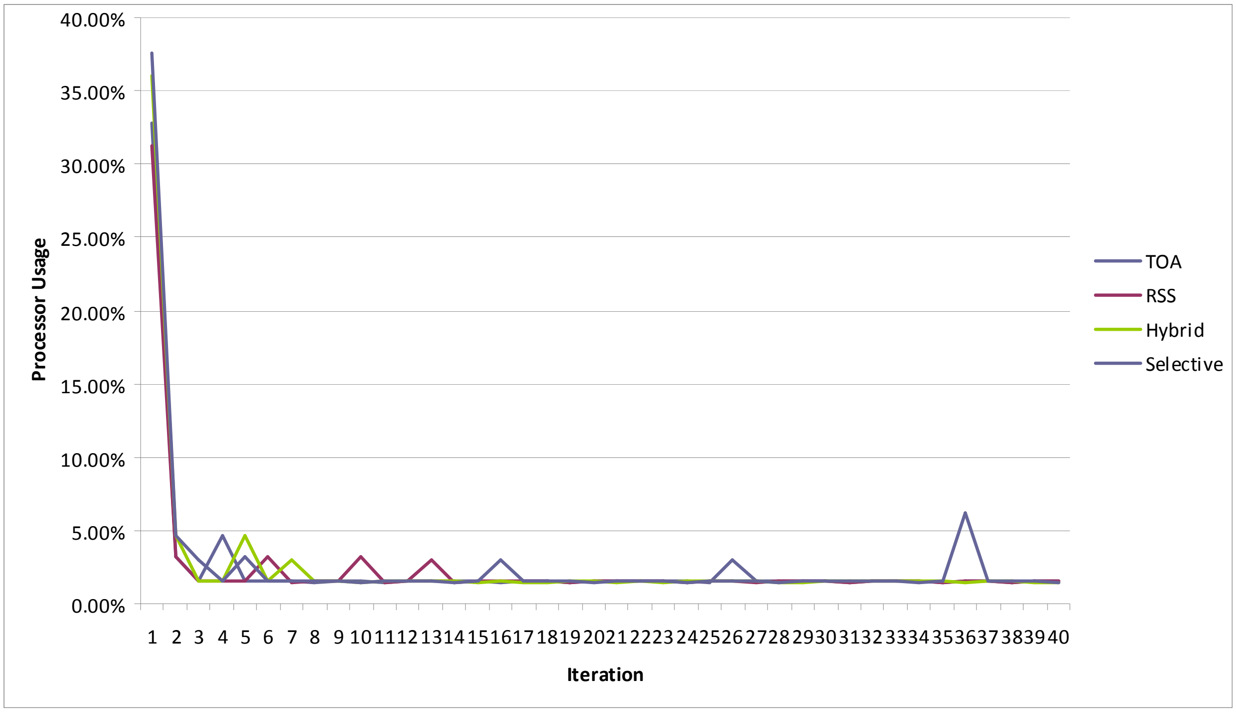
For the TOA, RSS, Hybrid and Selective algorithms, we had determined how much memory and CPU is required by each. Each of the four algorithms were written in Java. At each iteration, every time the program calculated the distance between the access point and the receiver, we captured the amount of memory being utilized and the amount of processor power being consumed. This analysis was done to determine which of the four algorithms is expensive to execute in terms of memory consumption and processor utilization.



Graph 14: Memory consumed by each algorithm

In the graph above we can see the memory utilization of the four algorithms. From the data we can see that RSS and TOA algorithms have similar memory consumption, with the highest memory consumption of TOA algorithm at 2487KB and 2452KB for the RSS algorithm. As can be seen from the graph, selective algorithm has the highest memory consumption at

4704KB and that for hybrid at 3404KB, making selective algorithm the most expensive algorithm to run in terms of memory.



Graph 15: Processor utilization by four algorithms

As we can see from the graph above, the processor utilization for all the four algorithms is similar. Starting processor utilization for the Selective algorithm is highest at 37%, but over all we do not find a large difference in the percentage processor utilization. Similarly other three algorithms also have high initial processor utilization but average out at 2% after 3 iterations.

	Memory Consumption (KB)	Processor Utilization (%)	Error (m)		Accuracy (%)	
			Indoor	Outdoor	Indoor	Outdoor
TOA	1662.024	2.49	6.5	3.5	34.21	35
RSS	1673.854	2.45	-1.09	1.95	5.73	19.5
Hybrid	2194.22	2.59	2.8	1.5	14.73	15
Selective	2971.854	2.77	6.19	2	32.5	20

In the table above we can see the processor utilization, memory consumption and accuracy in an indoor and outdoor environment for each of the four algorithms. The memory consumption and processor utilization are average values of data collected over 40 iterations of calculating distance between the access point and the receiver. The accuracy of each algorithm is determined by how close the calculated distance was to the actual distance, for outdoor, we measure the distance between the receiver and AP1, for indoor we measure the distance between the receiver and AP4. The negative values in accuracy column represents that the distance calculated was shorter than the actual distance and a positive value represents that the distance calculated was greater than the actual distance. The accuracy values are a difference of calculates distance and actual distance (calculated distance – actual distance) in meters.

With the data in the table above, we can see that TOA algorithm utilizes the least amount of memory followed by RSS algorithm, even thought the difference in memory consumption is only about 90 KB. Hybrid algorithm utilizes 500KB more memory followed by the Selective algorithm which is most expensive in terms of Memory consumption. Processor utilization in each case is very close to each other with a difference of only 0.2% between the Hybrid and Selective algorithm.

In terms of calculating the distance between the access point and the receiver in an indoor environment, we see that RSS algorithm provides us with distance which is closest to the actual distance in comparison to other algorithms. Since the distance calculated using RSS is shorter than actual distance we cannot use this to determine the current location of the user using Trilateration in an indoor environment as shown in figure 6.

Distance calculate using the Hybrid algorithm provides us with the next best distance to the access point, and when we use this distance to determine position of a user using Trilateration we get the best accuracy as can be seen from figure 7.

Distance calculated using TOA and selective algorithms provide similar distance between the access point and receiver, when we use this distance to calculate position we get an accuracy which is much lower than what we got using the Hybrid algorithm as can be seen from figure 5 and figure 8.

Using the four algorithms to calculate distance between the access point AP1 (outdoor) and receiver, we can see that Hybrid provides us with the best accuracy followed by RSS algorithm. The accuracy of the selective algorithm depends on what algorithm is being used to calculate the distance. If the RSS algorithm is being used then the accuracy will depend on that of the RSS algorithm and if TOA algorithm is being used then accuracy will depend on that of TOA algorithm.

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