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Analysis of The Relationship Between Received Signal Strength and Displacement

A Final Project:MINT 709 Submitted by

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ABSTRACT

Currently, outdoor localization can be done using a GPS device which obtains positions from satellites. However GPS signals are not available in indoor environments. We can precisely measure signal levels on the devices in a wireless sensor network (WSN). Various room conditions and radio interference may attenuate received signal strength in unknown ways. Consequently, the accuracy of distance estimation and thus localization is reduced. This project will quantify the magnitude of the resulting localization errors and point out potential factors which might cause the errors. In addition, this project presents an alternative technique for indoor localization on WSN.

Chapter 1: Introduction and Background

The **Global Positioning System (GPS)** is a navigation system which receivers can process data obtained from satellites to determine its current position on Earth. Presently, GPS has been widely used for map-making, land surveying, athletes, military and civilians. The core of the navigation system is to localize receivers accurately. The GPS receivers communicate to the satellites by sending and receiving radio frequency (RF) therefore the GPS receivers should be in outdoor and open space to gain signal sensitivity. Indoor localization could be very tricky for GPS due to poor signal or signal loss which affect on accuracy of localizations. According to propagation models, greater signal loss implies a longer distance of propagation. Position evaluation via signal strength measurements may be an efficient and low cost method for localization due to the availability of inexpensive radio devices. However, this technique needs more research and experimentation to obtain accurate results. Wireless sensor networks (WSN) can be used in localization to simulate a large geographical area in a lab. Also, we can precisely measure signal levels on the devices in a WSN.

Problem Statement:

Various room conditions and radio interference may attenuate received signal strength in unknown ways. Consequently, the accuracy of distance estimation and thus localization is reduced. The purpose of this project is to begin to understand the magnitude of errors in distance estimation using received signal strength (RSS) measurements from wireless sensor devices (WSD) in a designated room. In order to estimate the distances, RSS measurements will be used as inputs to an indoor propagation model which describes the relationship between signal strength and distance. This project will quantify the magnitude of the resulting localization errors and point out potential factors which might cause the errors. The results will be used for research in sensor network localization.

Method:

This project can be divided into four steps:

1. Perform experiments moving a node within a WSN.
2. Extract RSS data from WSN management program text files.
3. Find predicted distances and locations from the RSS data.
4. Compare theoretical results with known locations.

Project Scope:

These following are the scope of this project:

First experiment

My primary focus is to collect adequate RSS data to compare with recognized distances. First we will set up a WSN in a 6x6 matrix. A sensor will be positioned on each intersection within the matrix, resulting in a total of 36 nodes with a distance of one meter between each node. This arrangement will let us know the exact location of each device. Then we will collect an initial set of RSS data.

Second experiment

In the second experiment, we will try to determine the appropriate number of reference points (called "pegs", of which there will be 4, 6 or 9) to use for receiving signals to be used in localization. A transmitter will be placed at various points in the matrix to transmit signals to pegs. Data will be collected from the pegs.

Third experiment

The data from this experiment will be used for the final analysis. The experiment will use the 6x6 matrix outlined above. Then a transmitter will be moved along the lines within the matrix to collect RSS data at all intersections except the intersection that pegs locate.

Fourth experiment

The last experiment will be the same as the third experiment but instead of moving the transmitter along the intersections, it will be moved to the center of each square within the matrix. Data will be collected in each of the 36 squares.

Data extraction

The sensors come with software which outputs signal strengths between devices to a text file. There is a lot of additional output data in the output file. As a result, we will write a C program to extract only the essential signal strength data.

Analysis

We will determine peak received signal strength, standard deviations, and plot graphs of received signal strength as a function of distance. Theoretical signal strength from known distances will be plotted along with the experimental results. A simple linear least squares correlation will be used to derive a first-order linear model relating the theoretical results to those from the experiments. That is, the correlation model will be of the form:

$$y = ax + b$$

Where y is the actual distance and x is the theoretical distance predicted from the propagation model, and a and b are the coefficients from the correlation analysis. This analysis will be done using Excel.

Limitations:

- These experiments will be completed in the Research Seminar room.
- The analysis will point out errors and suggest possible further research on Wireless Sensor Localization.

Chapter 2: Methodology

I will clarify the procedure for the experiment to obtain signal strength via wireless sensor devices. The estimation of distance will be calculated on the signal strength based on three empirical models. These three models involved in this research are COST 231 [1] indoor model, ITU-R [1] model and The Empirical Model For Propagation-Loss Prediction In Indoor Mobile Communications Using The PADE' Approximant [2]. The ITU-R model is considered as a base equation to find the distance power loss co-efficient from measurement. While COST 231 and another model will give the result of the distance estimation to compare to the result from the ITU-R measurement based. Finally the accuracy of localization proposed by this project will be the major key to justify this comparison.

2.1 Localization Area Setup

By propagation models, localization is split into four categories which are indoor-to-indoor, indoor-to-outdoor, outdoor-to-indoor and outdoor-to-outdoor depending on where the transmitters and the receivers are. This project will focus only indoor-to-indoor localization that means both receivers and transmitters are in the building. The seminar room in Computer Science Center and the room next to MINT Labs are carefully chosen to perform the experiment as seen in Fig.2.1. To be able to trace the positions, it's necessary to build a 2 dimension grid consisting of x and y co-ordinating system.

Figure 2.1 The experiment room

Due to the limit of space and time, 6x6 meters grid with a maker on each one meter distance on x or y are setup on the open single floor. Consider the grid, the sensor devices installed on each maker form a network on the area of $36m^2$ for data exchange and signal collection. This project intentionally conducts localization only within this area. Fig2.2 illustrates the grid and the area of localization.

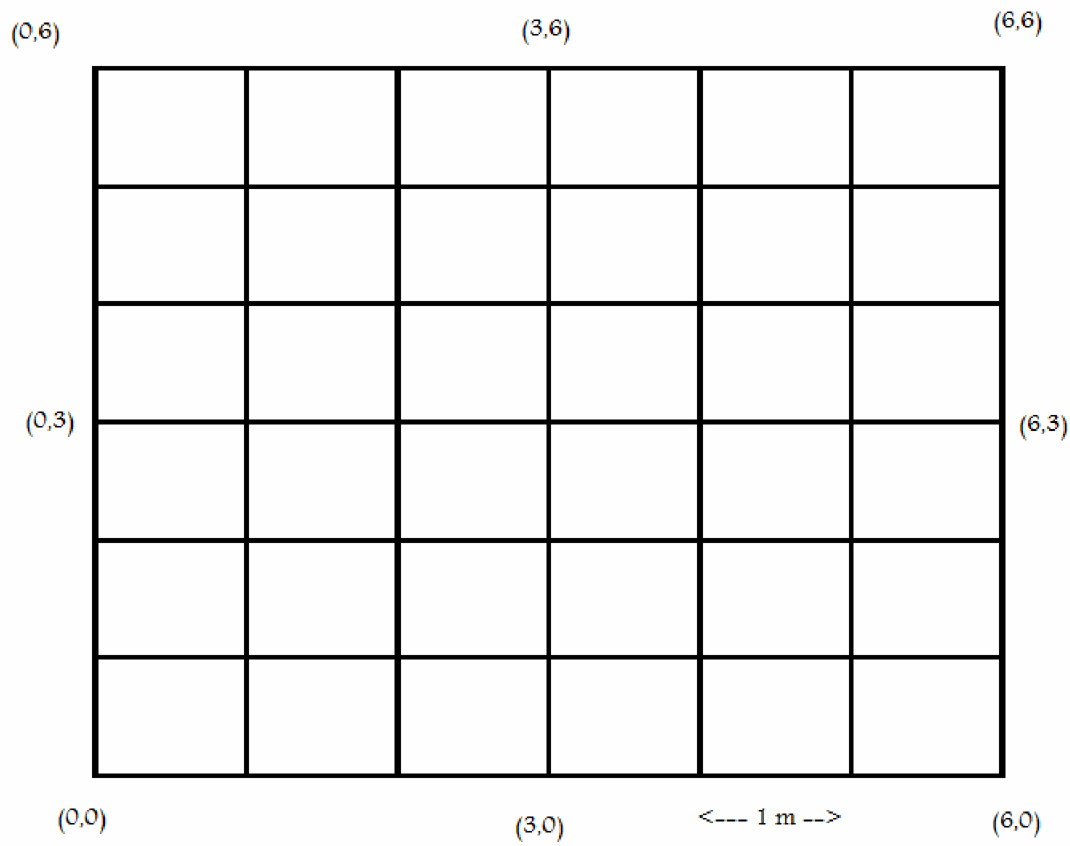


Figure 2.2 The area of localization

2.2 Equipment Preparation

The department of Computing Science provides 50 + 1 WSDs from Olso Net Communications Corp. for this project which consists of collaboration experiments with Ph.D's research. Each WSD has a unique id number chosen from 1-50 which number 0 is assigned to a master node [3]. Fig.2.3 demonstrates the logical connection, the master node is connected to a computer via USB port to control, report and store the data from every nodes to the computer.

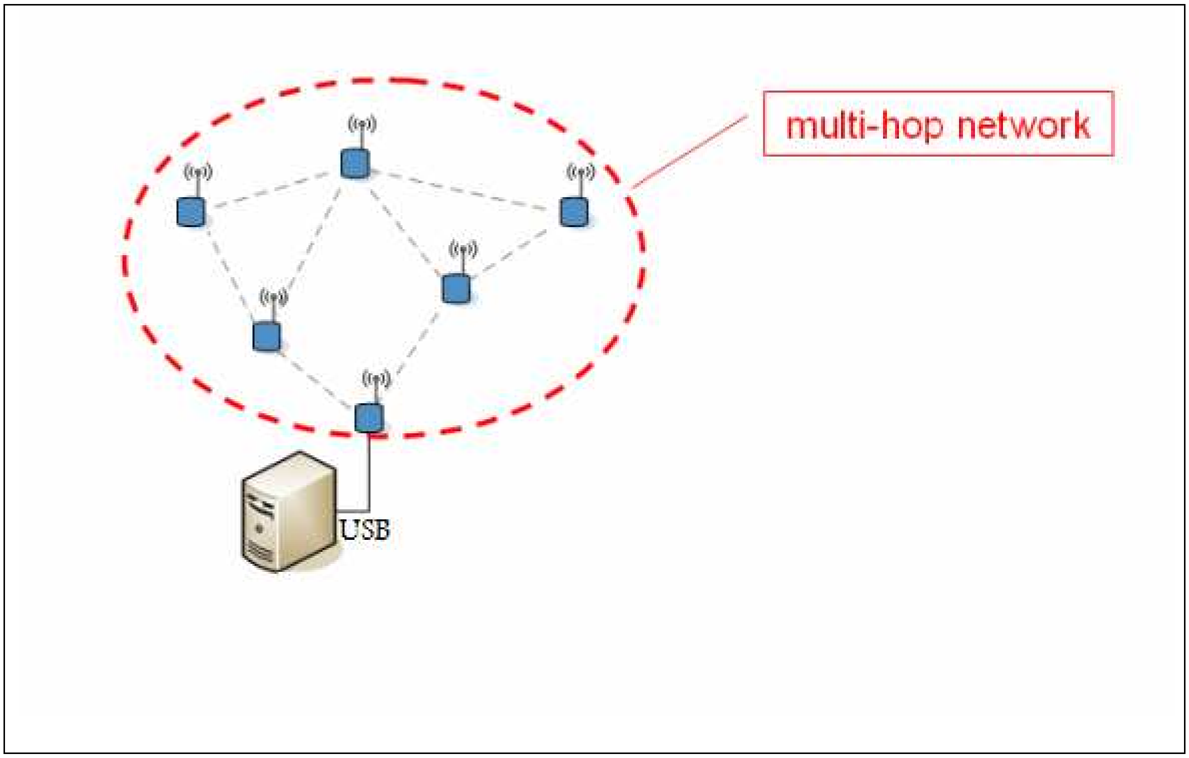


Figure 2.3 Logical link [4]

The company gives application software running under Linux to operate the devices. When start running the devices, every node on each position will transmit and receive data each other. In a time, signal strength in forms of RSSI values [5] will be measured and send to the master node along with source id and destination id of the devices acting as a transmitter and a receiver in order. The master node will command to all nodes to execute the data exchange process in cycles until stop by the software control. Fig. 2.4 shows the example of raw RSSI data sent from the master node to the computer. The numbers of data for one reading may vary by actual environment, lights, signal collisions and the receiver sensitivities at a moment.

```
ENV = (0, 0, 0) FROM (0, 11) TO (0, 1) : 102

ENV = (0, 0, 0) FROM (0, 11) TO (0, 12) : 133

ENV = (0, 0, 0) FROM (0, 11) TO (0, 13) : 113

ENV = (0, 0, 0) FROM (0, 11) TO (0, 16) : 120

ENV = (0, 0, 0) FROM (0, 11) TO (0, 17) : 111

ENV = (0, 0, 0) FROM (0, 11) TO (0, 2) : 109

ENV = (0, 0, 0) FROM (0, 11) TO (0, 24) : 104

ENV = (0, 0, 0) FROM (0, 11) TO (0, 25) : 106

ENV = (0, 0, 0) FROM (0, 11) TO (0, 17) : 109
```

Figure 2.4 Example of raw data

2.3 The device specifications

These WSDs integrate microchips from Texas Instruments [6] Table 2.1 shows some of the specifications related to this project. All devices can communicate each other via wireless channels.

3 General Characteristics

Parameter	Min	Typ	Max	Unit	Condition/Note
Frequency range	300		348	MHz	
	400		464	MHz	
	800		928	MHz	
Data rate	1.2		500	kBaud	2-FSK
	1.2		250	kBaud	GFSK, OOK, and ASK
	26		500	kBaud	(Shaped) MSK (also known as differential offset QPSK)
					Optional Manchester encoding (the data rate in kbps will be half the baud rate)

Table 2.1 The device's characteristics [6]

In the experiment the device will be setup to operate at 800 MHz and a constant bit rate of 5Kbps with a Tx power at -15 dBm.

2.4 Data Extraction

As shown in Fig. 2.4, data output from the master node are not sorted. Data from each node which reaches the master node early will be stored first. However, the analysis needs to pay interest on a particular source/destination node. Further more, the desired time length of process may take several reading cycles as a result of multiple RSSI values between the same source and destination nodes [5]. One desired process should give the average of the multiple RSSI values associate with its source id and destination id. Therefore, the C programming for data extraction is necessary to pull out some interesting data and calculate the average RSSI from the database. The output file after execution of the command contains the average RSSI values and its source/destination ids shown below:

```
0.5 0.5   50  1  119.666667  2  130.000000  3  121.800000  4  121.500000  5  121.000000
6  118.000000  7  117.000000  8  101.000000  9  104.500000
0.5 0.5   50  1  133.500000  2  131.571429  3  127.400000  4  128.800000  5  115.000000
6  122.250000  7  121.666667  8  109.000000  9  113.750000
0.5 0.5   50  1  125.333333  2  127.200000  3  119.000000  4  124.000000  5  123.666667
6  119.833333  7  119.666667  8  88.333333  9  100.500000
```

```
0.5 0.5   50  1  125.333333  2  127.200000  3  119.000000  4  124.000000  5  123.666667
6  119.833333  7  119.666667  8  88.333333  9  100.500000
0.5 0.5   50  1  136.000000  2  125.500000  3  121.000000  4  118.000000  5  115.000000
6  124.000000  7  128.000000  8  103.000000  9  92.000000
1.5 0.5   50  1  112.000000  2  135.846154  3  122.800000  4  131.833333  5  127.166667
6  129.500000  7  101.125000  8  121.333333  9  110.000000
1.5 0.5   50  1  108.500000  2  129.888889  3  113.500000  4  136.000000  5  122.500000
6  123.333333  7  109.000000  8  120.000000  9  113.000000
```

Here is the command syntax:

```
saverage <source file> <destination file> <X> <Y>

X,Y are the co-ordinates of the transmitter
```

2.5 Data interpreting

As mentioned in 2.3 and 2.4, the measured signal strength from the devices will output to the computer in form of RSSI values which can indicate the levels of signal strength. However, RSSI must be converted to a regular power unit in dBm before applying to the equations in path loss model for analysis purpose. The formula to convert RSSI into dBm with 800 MHz carrier and data rate at 5Kbps is :

$$\text{Power (dBm)} = (\text{RSSI}/2) - 74 \quad \text{-------------Eq.(1)} \quad [6]$$

2.6 Path Loss Model

The attenuation of the signal can be described by path loss models. The relationship in path loss models can predict a distance from known signal loss. There are three types of empirical models involved in this project.

COST 231 Indoor Model

Consider the attenuation in indoor office with wall penetration factors for 800-1900 MHz. The useful European COST 231 is proposed to explain the attenuation linearly grows the number of walls passed through and non-linearly grows the number of floors. Table 2.2 illustrates COST 231 Indoor equation.

$$\boxed{L = L_{fs} + 37 + 3.4\, kw1 + 6.9\, kw2 + 18.3\, n^{((n+2)/(n+1)-0.46)}\ [7]}$$

With

Lfs is the free space loss (=20log(d)+20log(f)+32.44) which d is a distance (km)

n is the number of traversed floors (reinforced concrete, but not thicker than 30 cm)

kw1 is the number of light internal walls (e.g. plaster board), windows etc

kw2 is the number of concrete or brick internal walls

Table 2.2 COST 231 Equation

Note that the environment in both experiment rooms will give n, kw1 and kw2 equal to 0. We can rewrite the equation to

$$L = 20\log(d) + 20\log(f) + 32.44 + 37 \quad \text{-------------------Eq.(2)}$$

When we substitute f=800 MHz and convert d from km to m:

$$L = (20\log(dm) - 20\log(103)) + 20\log(800) + 32.44 + 37$$

Finally, the final equation used in the project is

$$L = 20\log(d_m) + 67.5 \quad \text{-------------Eq.(3)}$$

The Empirical Model For Propagation-Loss Prediction In Indoor Mobile Communications Using The PADE'

Originally, this model is proposed to express the indoor radio propagation loss by adding some parameters to the free-space loss model equation [2]. These parameters which are the empiric function of the number of floors and signal randomness will improve the accuracy of indoor loss prediction. The equation shown below:

$$PL = PL_0\ 10\gamma\log(d/d_0) + X + f(np, a, b) \quad \text{-------------------- Eq.(4)} \quad [2]$$

By

PL is the propagation loss (dB)

PL_0 is the propagation loss at a reference distance d_0 (dB)

γ is the path-loss exponent

d and d_0 are a distance and a reference distance in order

X is a random variable apply to a specific floor

$f(np, a, b)$ is the function of the number of floors

Consider to the experiment rooms, X and $f(np, a, b)$ can be ignored. The path loss exponent γ can be substituted with 1.59 due to the transmitters and receivers located on the same floor [2]. Then, the final form of this equation should be:

$$PL = PL_0\ 15.9{*}\log(d/d_0) \qquad \text{----------------Eq.(5)}$$

The frequency used in this model is 850 MHz which is very close to my experiment (800 MHz) in the next chapter.

ITU-R Model

Another well-known Indoor Propagation model is ITU-R Model for Indoor Attenuation. The model explain signal loss depending on distance (d), frequency (f) and the floor-penetration factor $Lf(nf)$. The path loss exponent (x) indicates how fast the signal attenuated at a distance (d).

$$L = 20 \log(f) + 10x\log(d) + Lf(nf) - 28 \quad \text{----------------Eq.(6)}\ \ [1]$$

Again, the experiments perform in an open single floor so the floor-penetration factor will not be considered. Thus $Lf(nf) = 0$; After we substitute f=800 MHz The equation shrinks to:

$$L = 58.06 + 10x\log(d) - 28 \quad \text{----------------Eq.(7)}$$

Unlike other two models, ITU-R proposes both the path-loss exponent (x) as a variable in its equation and the frequency (f) term which is taken into account [10]. Also, this model is the linear attenuation model therefore finding the distance power loss co-efficient from measurements based on this model is the most appropriate. This model is applicable to indoor environments with frequency coverage from 900 MHz to 5.2 GHz.

2.7 Multipath Propagation

Multipath propagation to receivers may cause either decrease or increase signal strength. Consequently, measurements signal strength at the same distance between a receiver/transmitter may give various values signal strength even though the transmitter use a constant transmission power as seen in Fig. 2.5

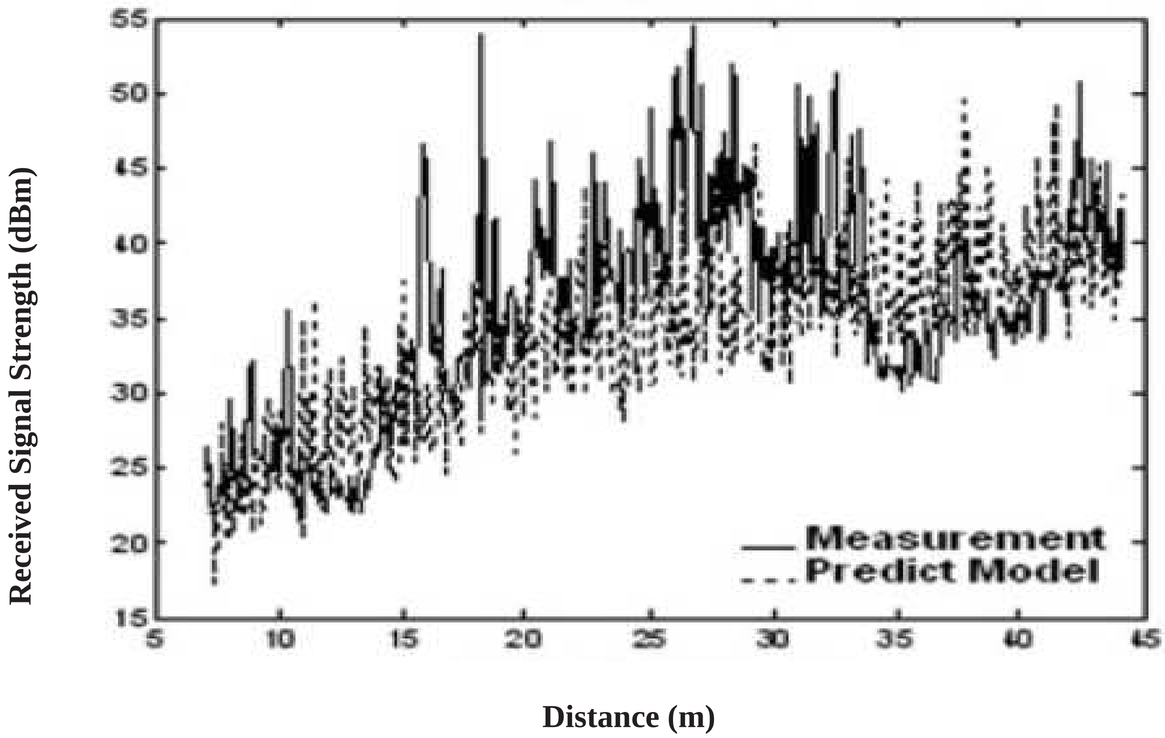


Figure 2.5 Multipath Propagation Effect [2]

2.8 Distance Power Loss Co-Efficient

One of this project's goals is to suggest suitable distance power loss co-efficient applying to the experiment's rooms for further research in localization. The best way to discover the co-efficient in a specific environment is to evaluate from received signal strengths collected from that environment. The best-fit line can be determined from the scatter graph plotted from received signal strength against a range of distances. This line will be of the form: y=ax+b. The slope of the best-fit line and its intercept indicate the power loss co-efficient and the constant in Eq.(7) consecutively. All calculation could be done in Excel by using LINEST function.

For instant:

If we get a slope of 0.6 and an intercept of 4.7 estimated from LINEST the path-loss exponent in Eq.(7) should be 0.6 and the final term (constant) is 53.36 rather than 28 as shown below

$$\boxed{L = 58.06 + 0.6 \log(d) - 53.36}$$

It is what the data from measurement point out. The method to compare the measurement-based power loss co-efficient to the standard-based will be stated in the next part.

2.9 Localization With Path Loss Prediction

To localize an unknown position transmitter in WSN, there are two approaches. Using triangulation technique [8] with at least 3 reference nodes can determine the location of the transmitter. The alternative way is to compare time-of-arrival and angle-of-arrival for a transmitter/receiver [9]. This project will suggest the third simple way to estimate the location of the transmitter node.

Intersection area localization:

Consider Fig. 2.6, the transmitter should locate somewhere on the circle line which is the range of signal if the estimated distance from path loss prediction is error-free.

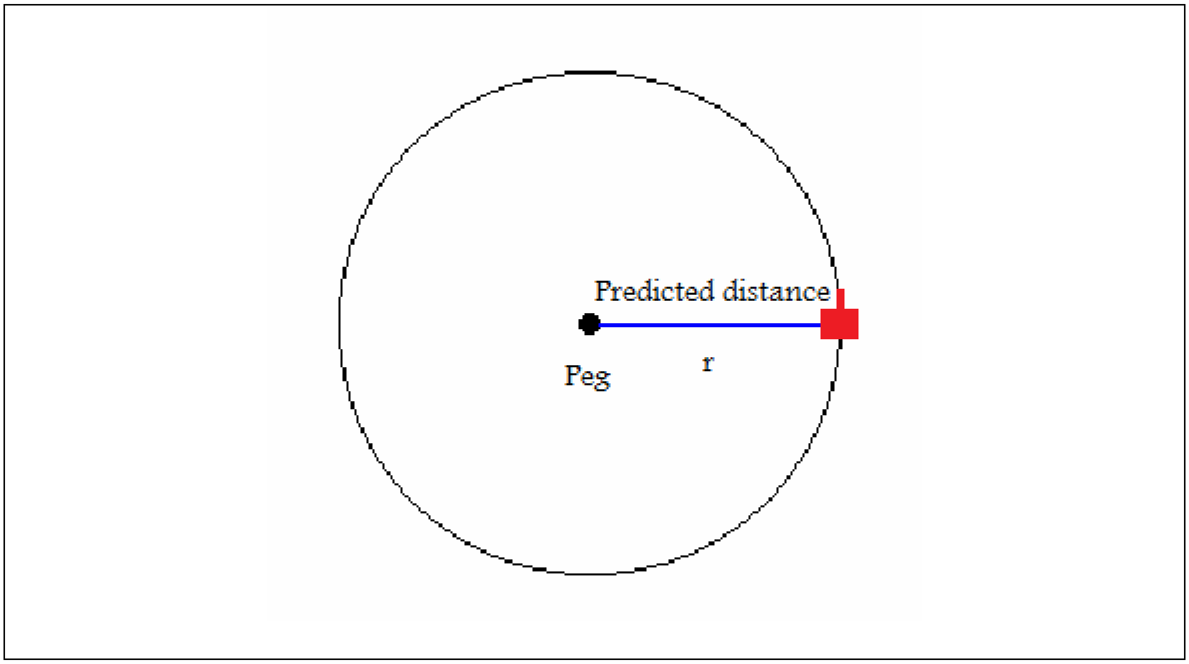


Figure 2.6 Range of the signal

Suppose that, we have two reference points with error-free distance prediction. The intersection point between these two circles is the exact location of the transmitter (Fig.2.7). Originally, this idea is from Professor MacGregor who supervises this project.

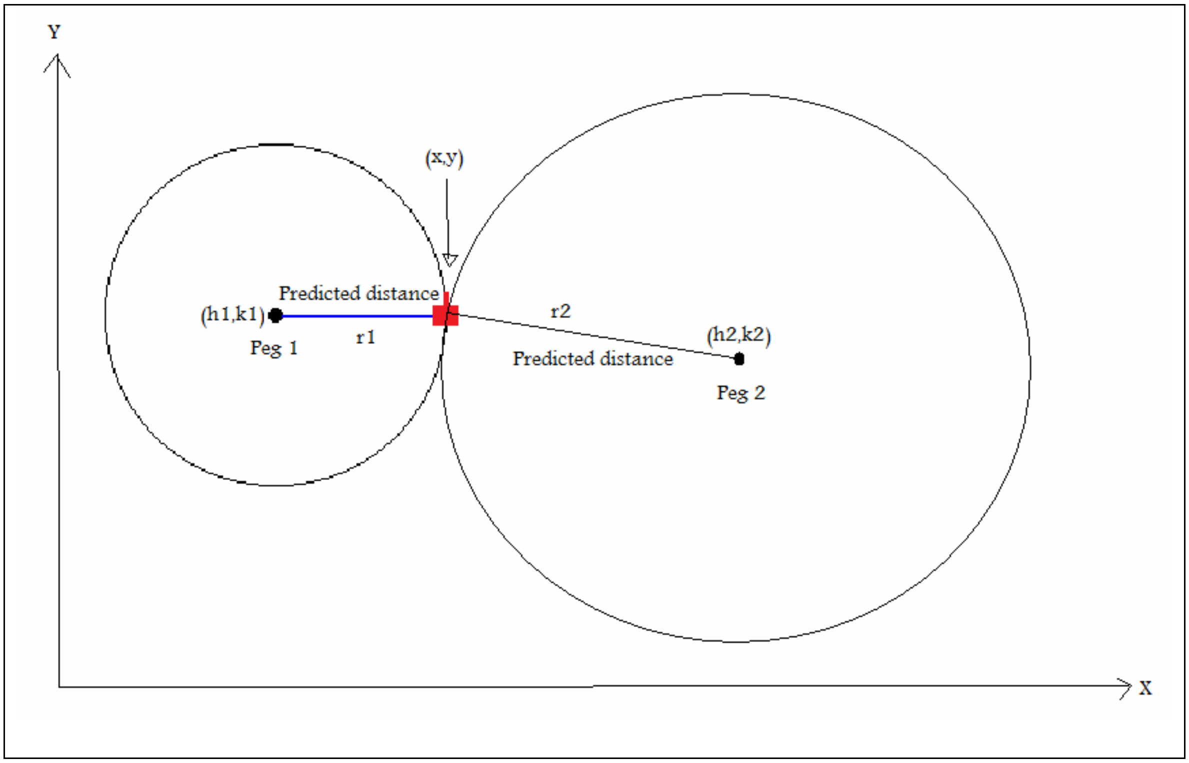


Figure 2.7 The error-free intersection point of two circles

We can solve two equations of circles below to find the intersection x,y where the transmitter locate because we know h,k,r from location of the reference points.

$(x - h_1)^2 + (y - k_1)^2 = r_1^2$ ---------------------------- Circle (1)

$(x - h_2)^2 + (y - k_2)^2 = r_2^2$ ---------------------------- Circle (2)

Where

h and k are the x- and y-coordinates of the center of the circle (Reference points) and r is the radius (Predicted distance)

However, errors from prediction can be expected in practical. We divide errors into two cases.

Case 1: The actual distance is less than the predicted distance

Localization by using intersections of two circles is still possible but the result will be the potential area that the transmitter may locate. In fact, this area is the area of the intersection of two circles. We can use the same equations above (Circle (1), Circle (2)) to find the intersection on x,y co-ordinates but the equation will give 2 values each of x,y variables (Fig. 2.8). Note that r1 and r2 are predicted distances, a1 and a2 are the actual distances

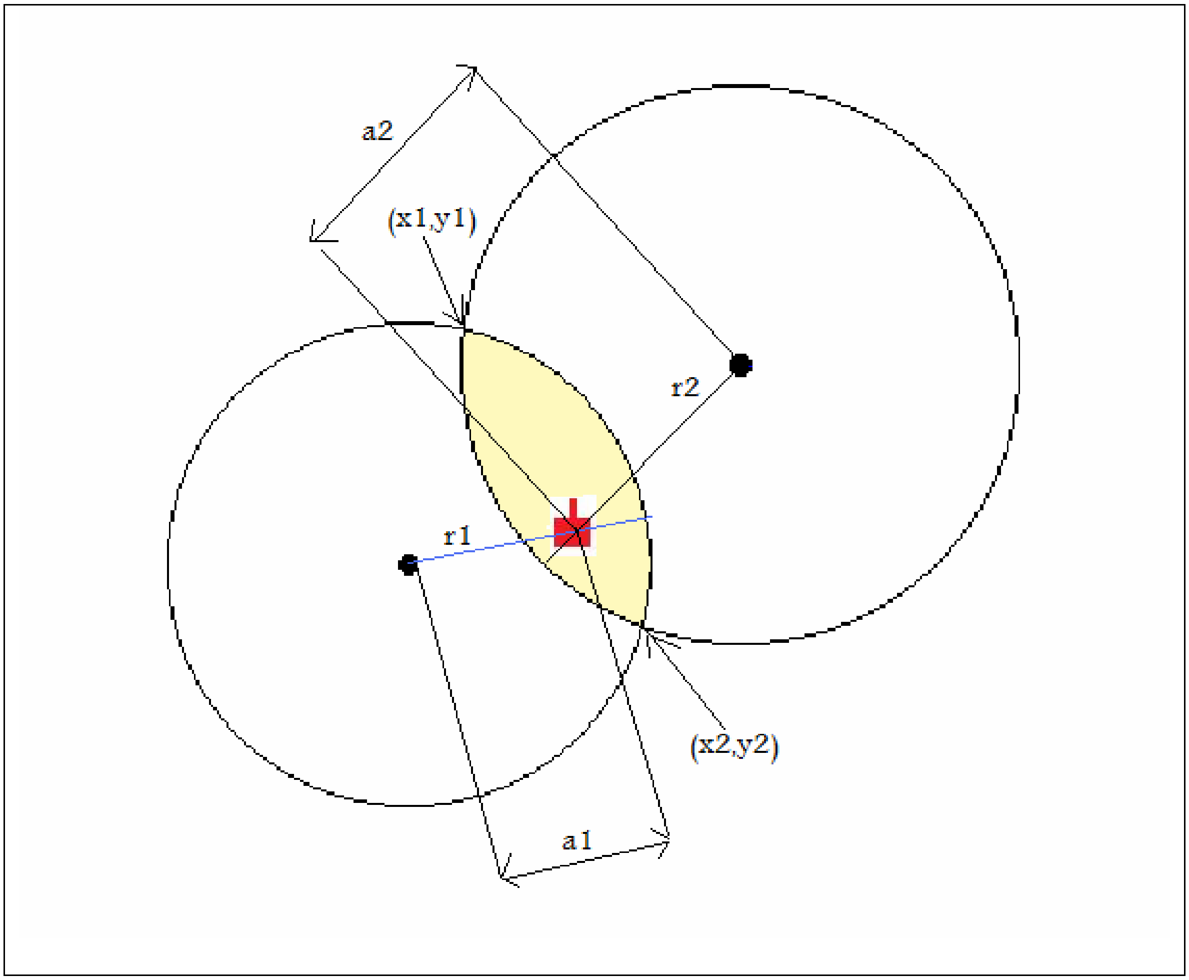


Figure 2.8 Co-ordinates of the intersection

Case 2: The predicted distance is less than the actual distance

If this case happens in any of a prediction the localization can't be done. Because the transmitter's actual location is out of the circle (either one) the area of the intersection will never enclose the transmitter's actual location as seen in Fig. 2.9.

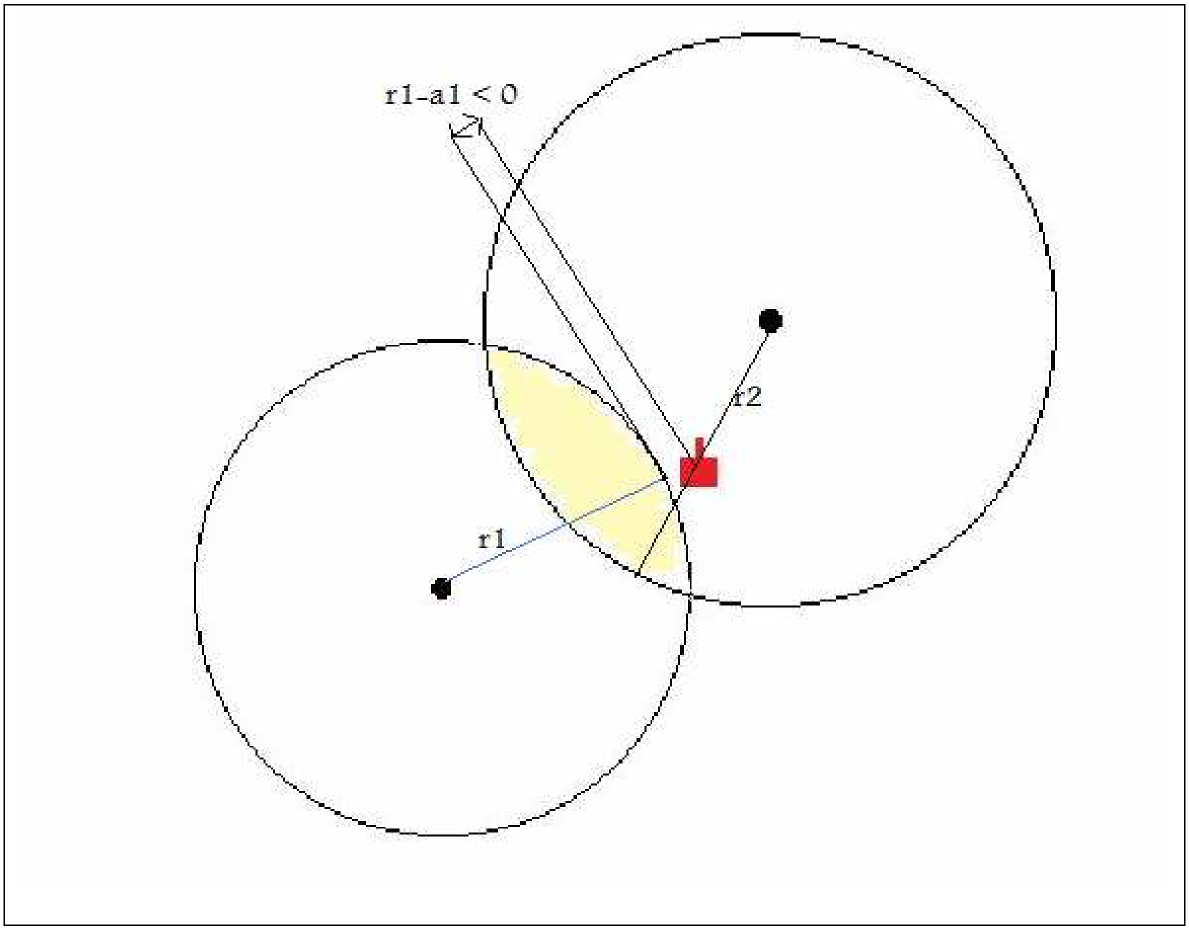


Figure 2.9 Errors on localization

In conclusion, the correctness of the distance prediction will state the success of localization. If the prediction is very precise we will get a tiny area or a point of transmitter located.

Implementation to this project:

The purpose of this project is not to suggest the technique to improve the precision of localization in WSN but to adapt this technique for standard-based and measurement-based distance prediction comparisons. Therefore, calculations on the area of the intersection will change to a simpler way. Let r be a predicted distance, a is the actual distance. We get r-a is the error from the prediction. Suppose that there are two reference points and $r_1>r_2$. If we draw a circle using r_1 as a radius the area of this circle can imply the area of the intersection roughly as illustrated in Fig. 2.10. At least, we can compare a success of localization between standard-based and measurement-based prediction.

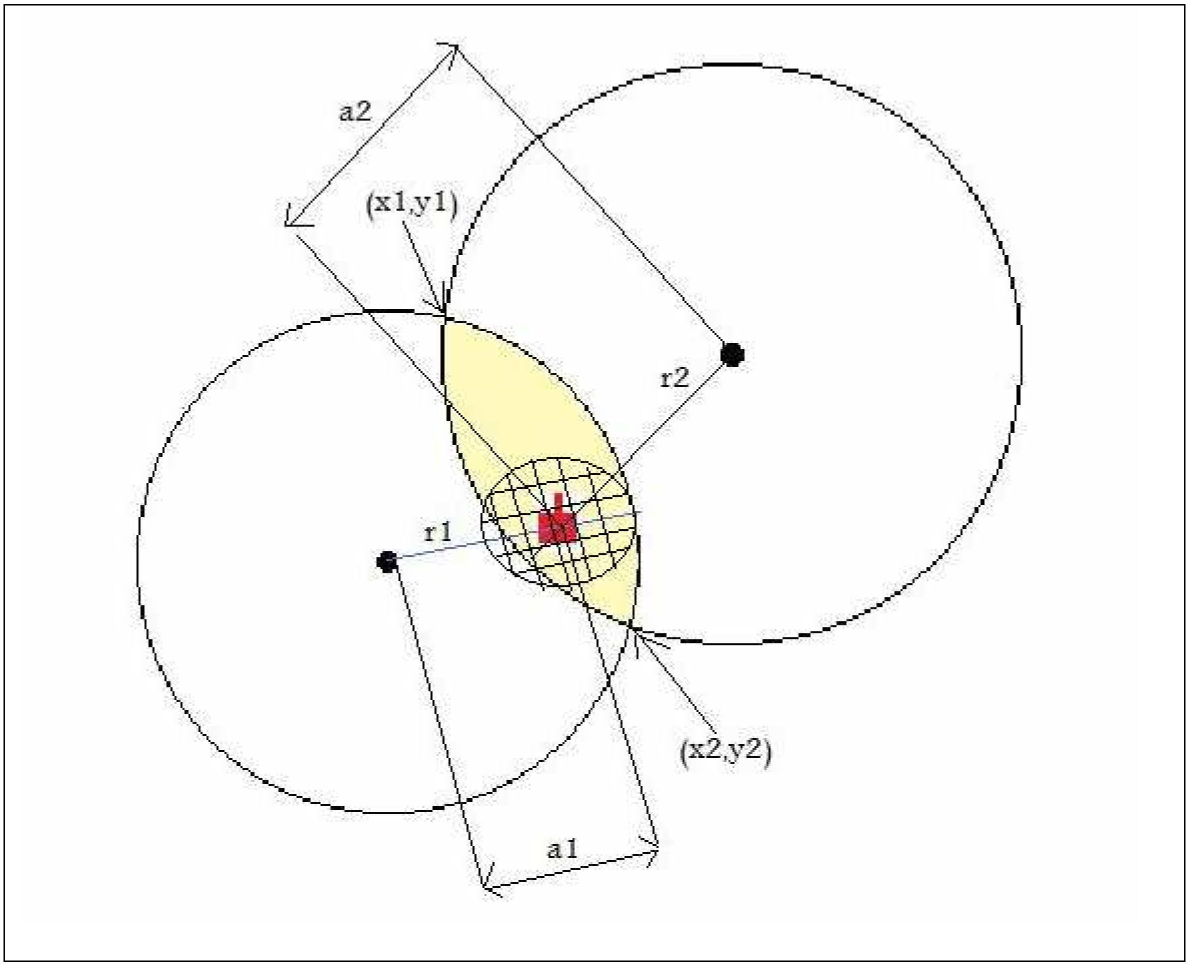


Figure 2.10 Rough area of the intersection

Chapter 3: Experiment and Analysis

This chapter will clarify details of the experiment on this project and analysis from data collection. All experiment setup will base on the environment declared in the previous chapter. There are total of four experiments plus analysis parts. The results may lead into a conclusion of using path-loss co-efficient with suggestions for further research.

3.1 Observing of signal behaviour from multiple running WSDs

The first experiment will allow all WSDs installed on every intersection in the grid to transmit/receive data as much as possible within a limit time. This means 36 devices are working at the fix point with out interrupt by limit the cycles of running, no objects other than the 36 devices staying in the matrix, no devices moving. We let the devices work about 10 minutes and expect to collect masses of data. However, the RSSI data collected are too less and messy.

3.2 Analysis of data

From the first experiment we found that data collision is a major concern if we let many devices working at the same time. As a result, only a few of data can be collected and the data are not good enough to perform another analysis. It’s a good idea to let only a small number of devices exchange and collect RSSI data to avoid collisions.

3.3 Determine appropriate number of reference points

As we know from the first experiment, placing all devices on every intersection will cause collision. Subsequently, we need to figure out the best amount of devices. If we have too less devices we'll have less sample data. With this areas of 36 m^2, my colleague advice from her experience that there should be 4,6 or 9 devices acting as receivers called "pegs". We also need to collect sample RSSI values from various locations within this area. First of all, we start with 4 pegs installed on the four corner of the area. In another word, the pegs are on (0,0),(6,0),(0,6) and (6,6). Afterwards, we randomly leave the transmitter on an intersection then move to another intersection and so on. Note that not all intersection will be collected RSSI value. We continue this for the 6 pegs and 9 pegs by adding 2 pegs on (0, 3),(6,3) and 3 more pegs on (3, 0),(3, 3),(3, 6) in order. Figure 3.1 shows the peg's positions. We found that 9 pegs will give the best reading of RSSI values. As a result, the successive experiment will stay on 9 pegs.

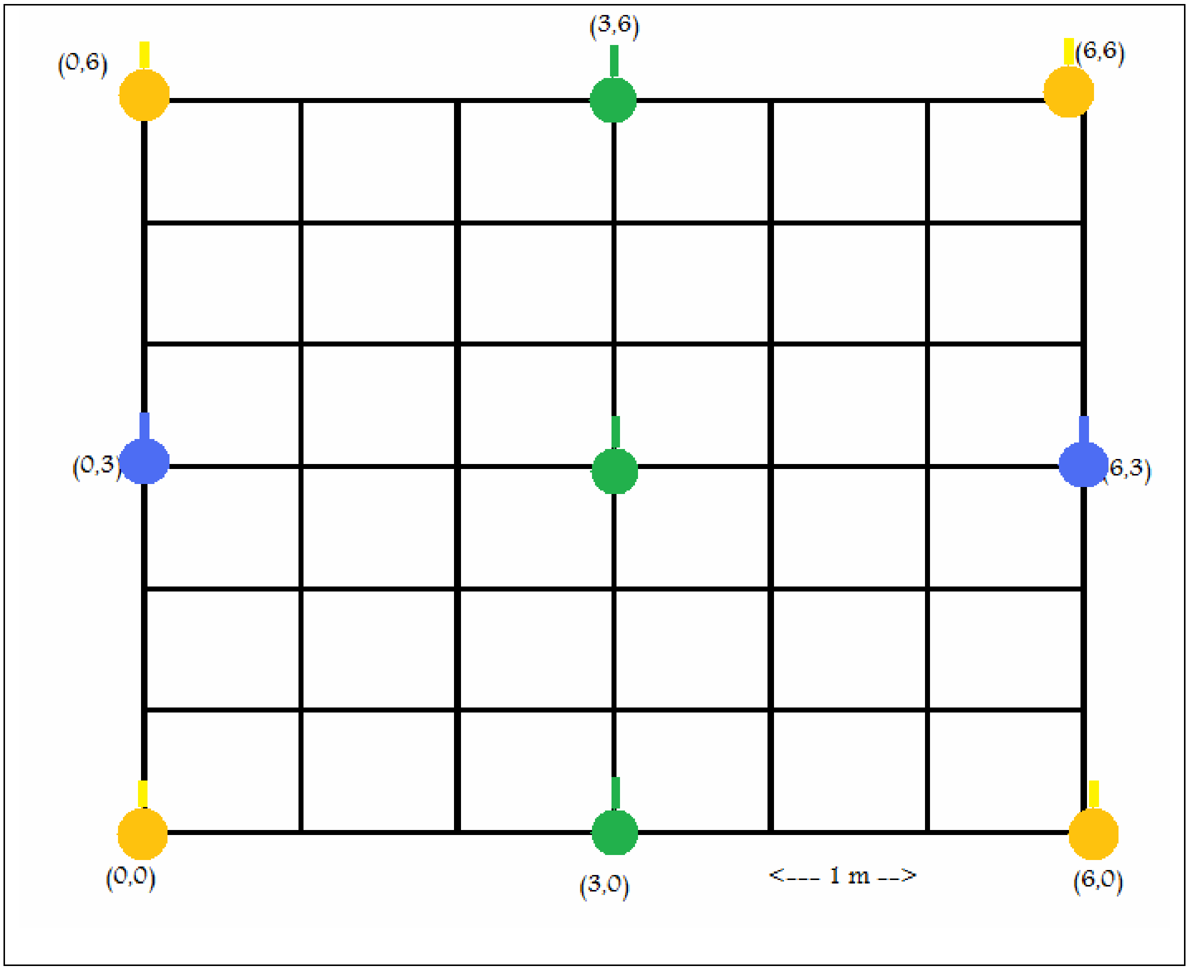


Figure 3.1 Various positions on the installed pegs

Note that since experiment, data collection will take reading from 3 cycles with about 1 minute for each cycle. Therefore, Saverage program will select RSSI data transmitted from node 50 to other node 1-9 from these 3 cycles (one reading) and output the average of RSSI data. In addition, we repeat the process to get 5 reading for a position.

3.4 Measurements from various locations

To localize a transmitter, we must have enough RSSI sample from different locations within the grid. We divide data measurement into two tasks.

Intersection collection

We agree that a transmitter will be moved and stopped on all intersection to let us collect signal. Then we gather data from the transmitter on an intersection start on (1, 0). Next, the transmitter is shifted to the next location (2, 0) for RSSI sample on this location. After that, we move it to (4, 0) and so on. So, we can collect RSSI sample from 40 positions. Note that, the transmitter is not placed at the same points of the pegs.

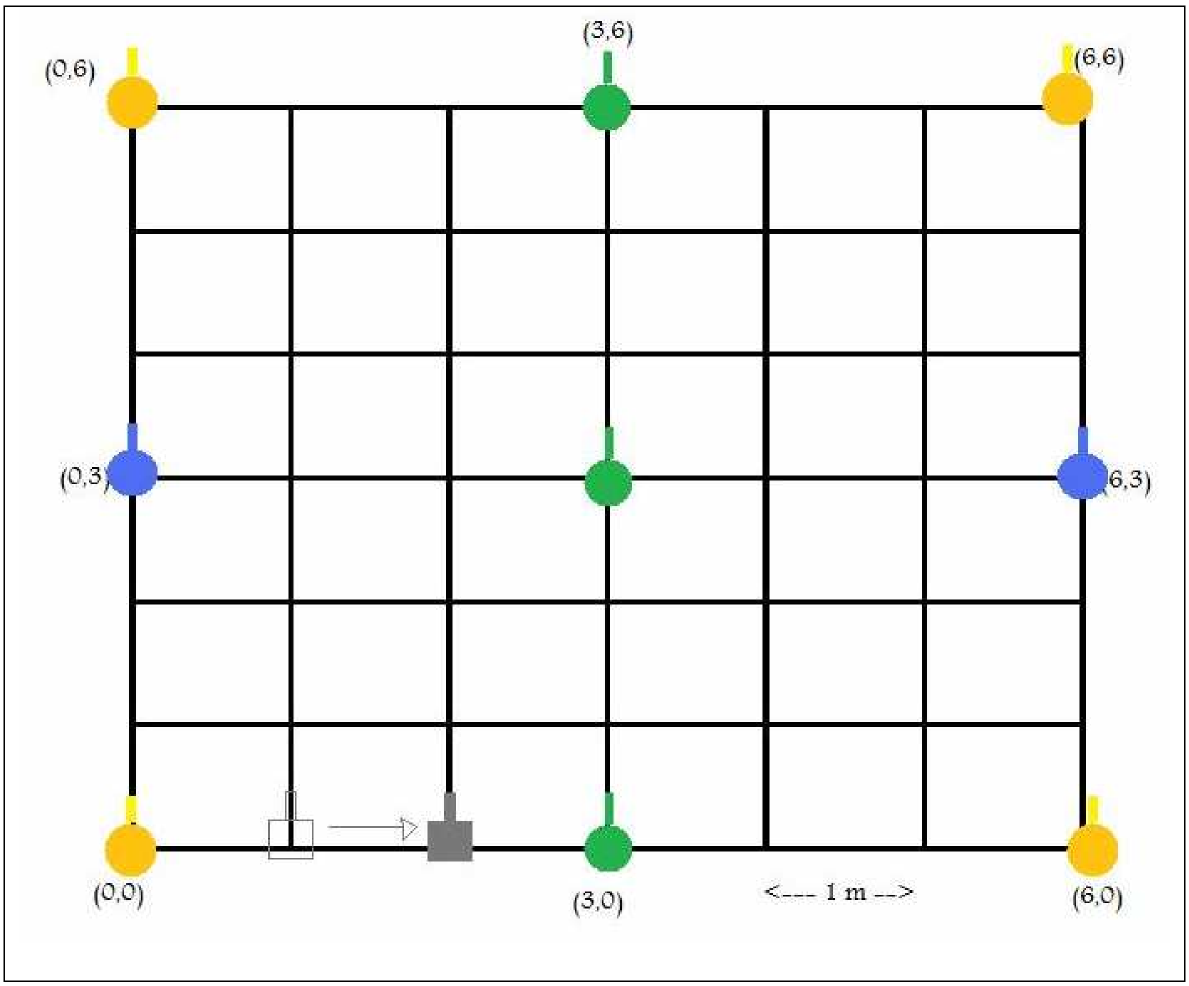


Figure 3.2 The transmitter moving on the intersection

Center of square collection

This task is the same as the previous collection but putting the transmitter on the center of every square instead. In other words, the transmitter will move on (0.5, 0.5), (1.5, 0.5), and so on with a total of 36 points (squares).

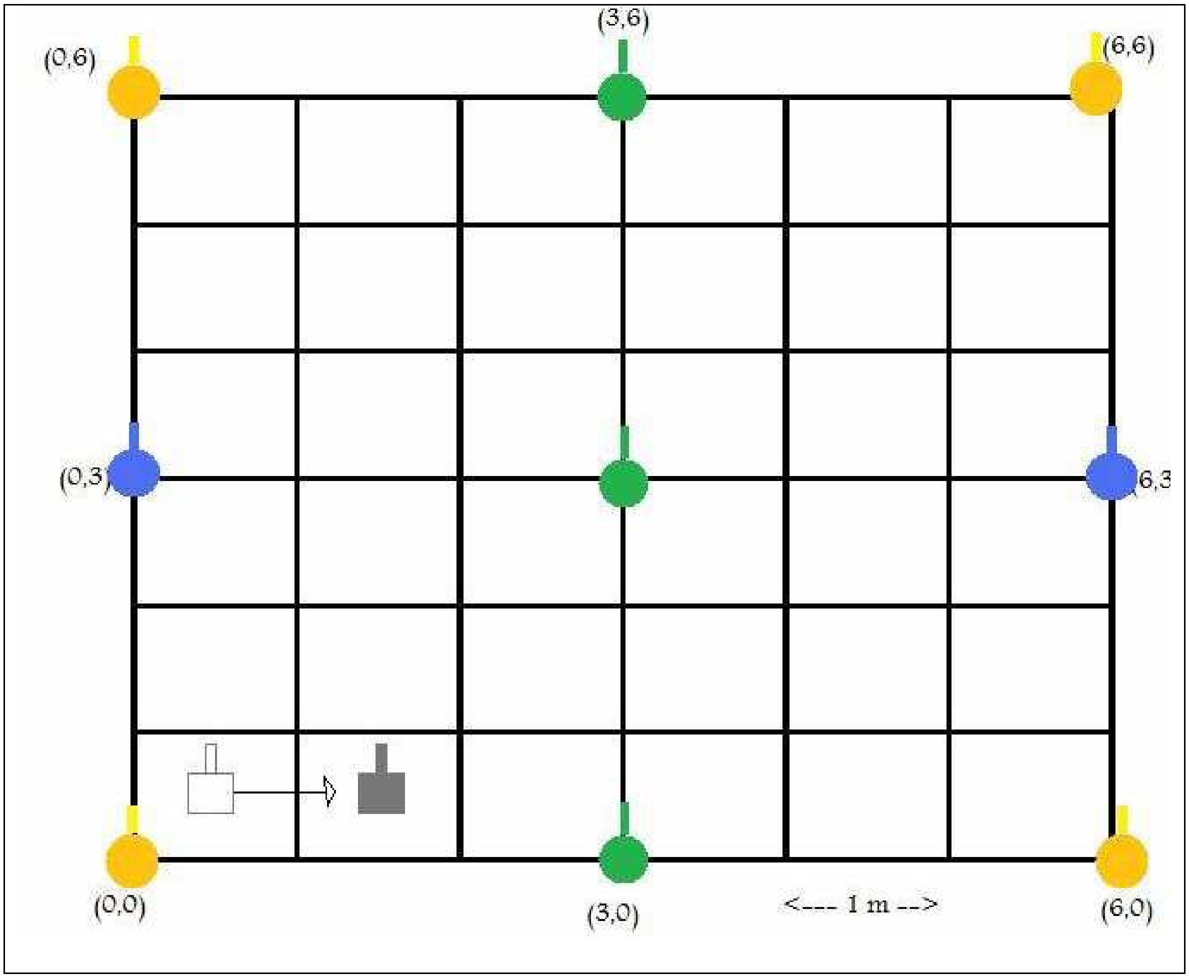


Figure 3.3 The transmitter moving on the center

3.5 Experimental result

The sample of the result in Table 3.1 is from the reference point 1. The Position on the first two column indicate x,y co-ordinates of the transmitter's position consecutively. The Order column shows the sequences of which position the transmitter are placed on orderly. Using Eq.(1) to convert RSSI to received signal strength (Rx) dBm, Path Loss will be calculated from the different between Rx and Tx (-15 dBm). If Path loss is over than Tx power (-15) the ‘0’ value will be placed to indicate errors. The distance on the table is the Euclidean distance between receivers and a transmitter. All of the RSSI values collected from the experiments can be found on the Appendix 1.

Positions			Distance(m)	log d	RSSI	Rx power (dBm)	Path loss	Fit Y	ry^2	rx^2	Log(d Est.)	d Estimate R1
5	6	85	5.147815	0.711623	74	-37	22	5.60079	268.9341	4668.995	69.04167	1.1E+69
5	6	81	5.147815	0.711623	80.75	-33.625	18.625	5.60079	169.6301	2944.966	54.97917	9.53E+54
5	6	120	6.519202	0.814194	82	-33	18	5.625407	153.1306	2658.517	52.375	2.37E+52
5	6	152	5.522681	0.74215	82	-33	18	5.608116	153.5588	2665.951	52.375	2.37E+52
5	6	151	5.522681	0.74215	83.66667	-32.1667	17.16667	5.608116	133.6001	2319.446	48.90278	7.99E+48
4	6	115	5.700877	0.755942	87	-30.5	15.5	5.611426	97.7839	1697.637	41.95833	9.09E+41
4	6	326	5	0.69897	87	-30.5	15.5	5.597753	98.0545	1702.335	41.95833	9.09E+41
4	6	353	7.071068	0.849485	87.2	-30.4	15.4	5.633876	95.37717	1655.854	41.54167	3.48E+41
4	6	175	7.106335	0.851646	88	-30	15	5.634395	87.71456	1522.822	39.875	7.5E+39
4	6	303	4.472136	0.650515	88	-30	15	5.586124	88.62107	1538.56	39.875	7.5E+39
2	6	333	5.09902	0.707487	88.66667	-29.6667	14.66667	5.599797	82.20813	1427.224	38.48611	3.06E+38
2	6	62	2.54951	0.406457	89	-29.5	14.5	5.52755	80.50487	1397.654	37.79167	6.19E+37
2	6	40	2.12132	0.326606	90.6	-28.7	13.7	5.508386	67.10255	1164.975	34.45833	2.87E+34
1	6	174	7.106335	0.851646	91	-28.5	13.5	5.634395	61.86774	1074.093	33.625	4.22E+33
2	6	265	5.385165	0.731199	91	-28.5	13.5	5.605488	62.32332	1082.002	33.625	4.22E+33
2	6	33	5.0990	0.707	91	-	13.5	5.599	62.41	1083.	33.62	4.22E

		2	2	487		28.5		797	321	563	5	+33
		15	5.5226	0.742				5.608	54.63	948.6	31.54	3.48E
1	6	3	81	15	92	-28	13	116	995	102	167	+31
		17	7.1063	0.851				5.634	54.25	941.8	31.54	3.48E
1	6	2	35	646	92	-28	13	395	214	774	167	+31
						-						
		30	4.4721	0.650	92.42	27.7	12.78	5.586	51.83	899.8	30.64	4.45E
1	6	2	36	515	857	857	571	124	411	977	881	+30
						-						
		19		0.301	92.66	27.6	12.66	5.502	51.32	891.1	30.15	1.42E
1	6	0	2	03	667	667	667	247	89	268	278	+30
		23	6.0827	0.784		-		5.618	47.35	822.2	29.45	2.87E
6	5	4	63	101	93	27.5	12.5	184	939	116	833	+29
		32		0.698		-		5.597	47.64	827.1	29.45	2.87E
6	5	7	5	97	93	27.5	12.5	753	102	01	833	+29
		19		0.602		-		5.574	42.58	739.2	27.79	6.19E
6	5	1	4	06	93.8	27.1	12.1	494	222	747	167	+27
						-						
		18		0.301	93.83	27.0	12.08	5.502	43.31	751.9	27.72	5.28E
6	5	8	2	03	333	833	333	247	07	218	222	+27
			2.1213	0.326				5.508	42.14	731.6	27.37	2.37E
5	5	37	2	606	94	-27	12	386	106	156	5	+27
		15	5.5226	0.742				5.608	40.85	709.3	27.37	2.37E
5	5	4	81	15	94	-27	12	116	618	087	5	+27
		33	5.0990	0.707				5.599	40.96	711.1	27.37	2.37E
6	5	5	2	487	94	-27	12	797	26	563	5	+27
						-						
		15	5.7008	0.755	94.83	26.5	11.58	5.611	35.66	619.1	25.63	4.35E
5	5	9	77	942	333	833	333	426	368	611	889	+25
		17	7.1063	0.851				5.634	28.78	499.8	23.20	1.62E
4	5	3	35	646	96	-26	11	395	972	215	833	+23
		33	5.0990	0.707				5.599	29.16	506.2	23.20	1.62E
4	5	4	2	487	96	-26	11	797	219	881	833	+23
		33	5.3851	0.731				5.605	29.10	505.2	23.20	1.62E
5	5	8	65	199	96	-26	11	488	076	216	833	+23

Table 3.1 Sample data from reference point 1

3.6 Path loss exponent from measurements and distance estimation

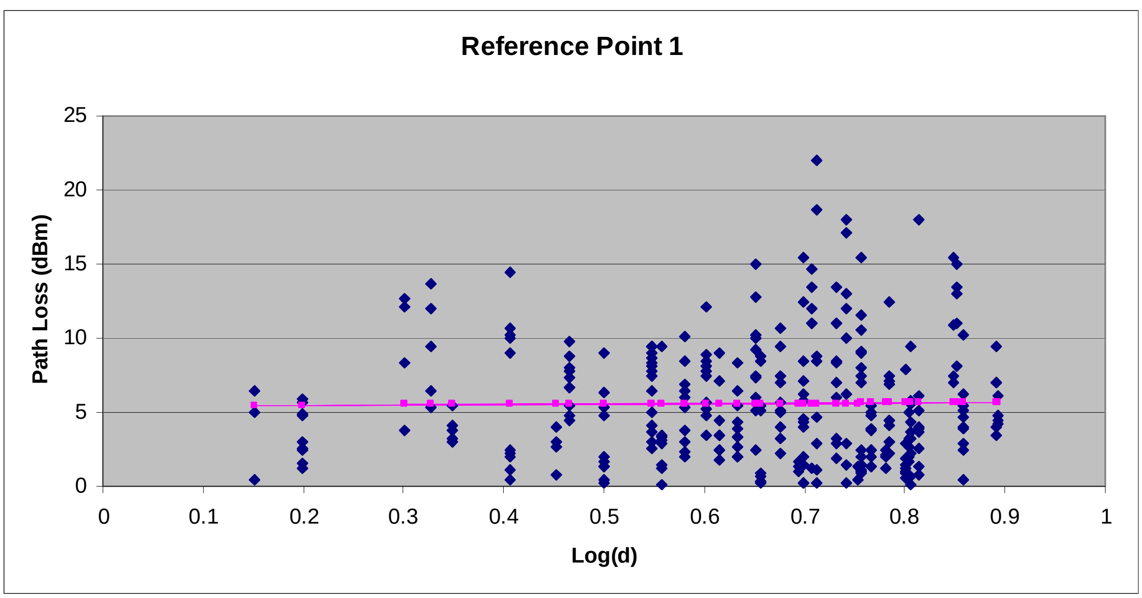
As mentioned in 2.8, best fit line will be plotted from the scatter graph of received signal strength against a range of distances. Fit y values in Table 3.1 is the result from y=ax+b where LINEST will give the results of slope (a) and intercept (b). x in the equation is Log(distance). Fit y values specify the path loss prediction but we need to predict the distance instead. We have to invert the linear equation to x=(y/a)-b. Note that x in the equation is Log(distance) so the equation should be rewritten to:

Predicted Distance = $10^{(y/a)-b}$ ---------------------- Eq.(8)
Where:
y= path loss (dBm) from measurements

The estimated distances are in the “d Estimate R1” column. Let’s take a look in each reference point.

Reference Point 1:

-Best Fit Line and the scatter graph

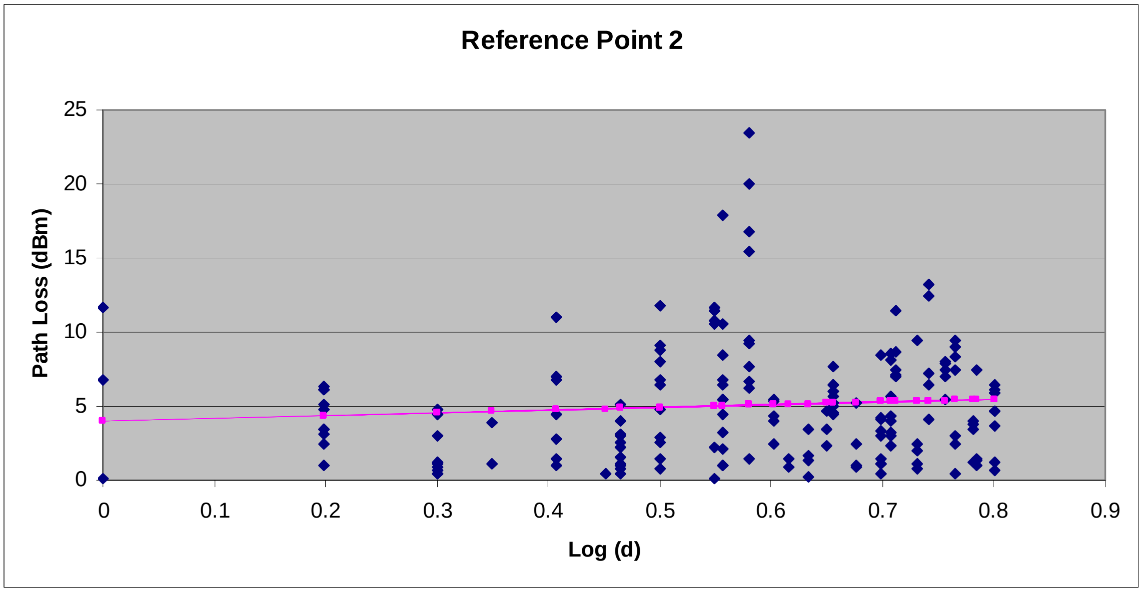


-Linear Equation and path loss exponent

y=0.24x+5.43; Path loss exponent = 0.24

Reference Point 2:

-Best Fit Line and the scatter graph

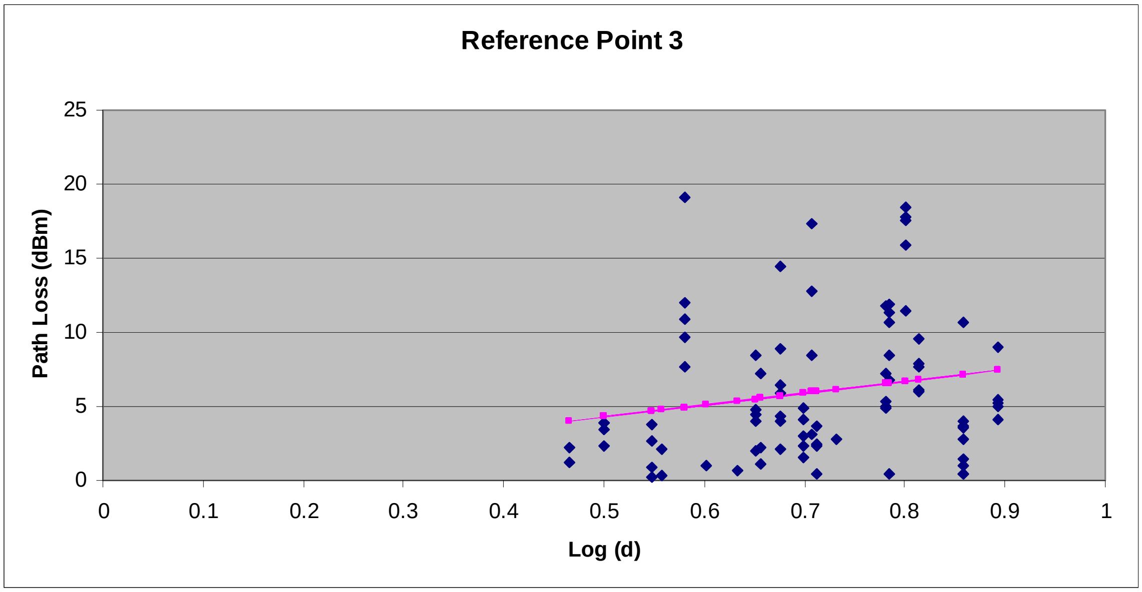


-Linear Equation and path loss exponent

y=1.85x+3.99; Path loss exponent = 1.85

Reference Point 3:

-Best Fit Line and the scatter graph

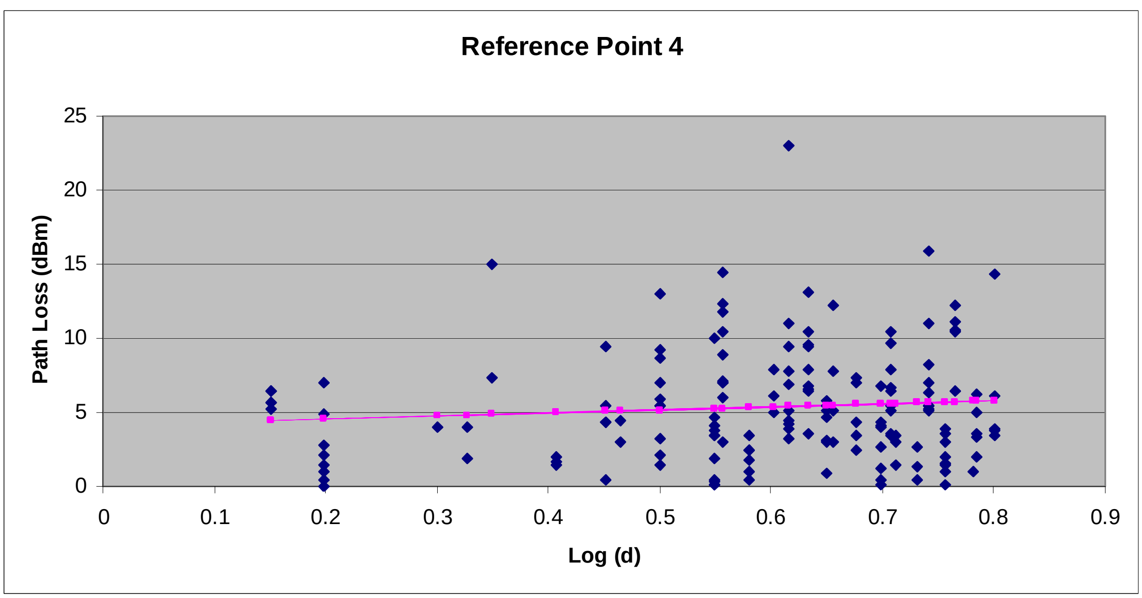


-Linear Equation and path loss exponent

y=8.02x+0.28; Path loss exponent = 8.02

Reference Point 4:

-Best Fit Line and the scatter graph

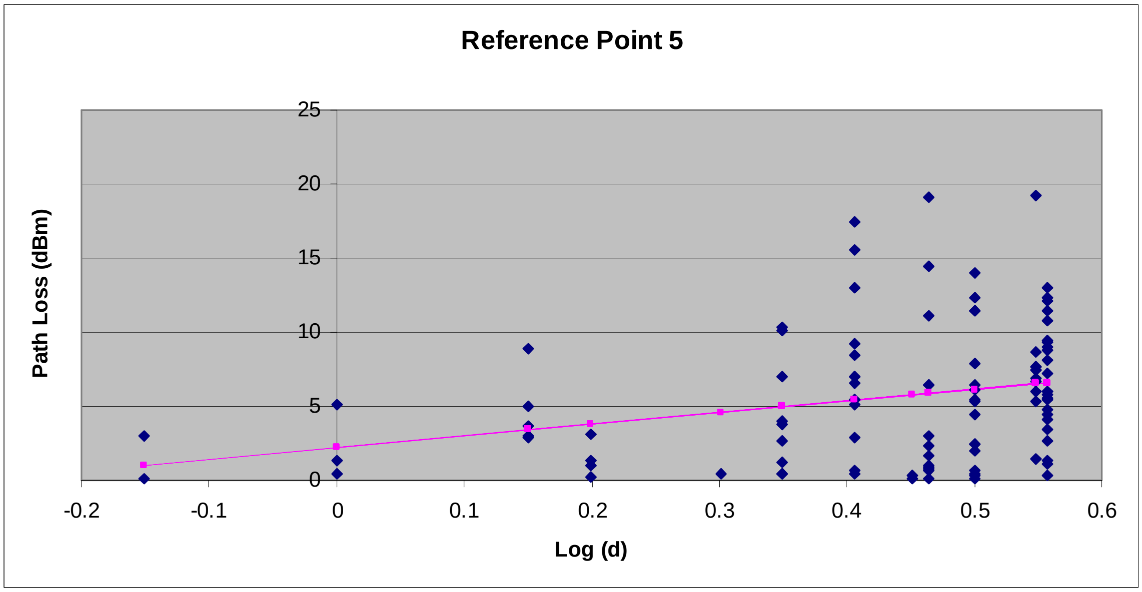


-Linear Equation and path loss exponent

y=2.06 x+4.13; Path loss exponent = 2.06

Reference Point 5:

-Best Fit Line and the scatter graph

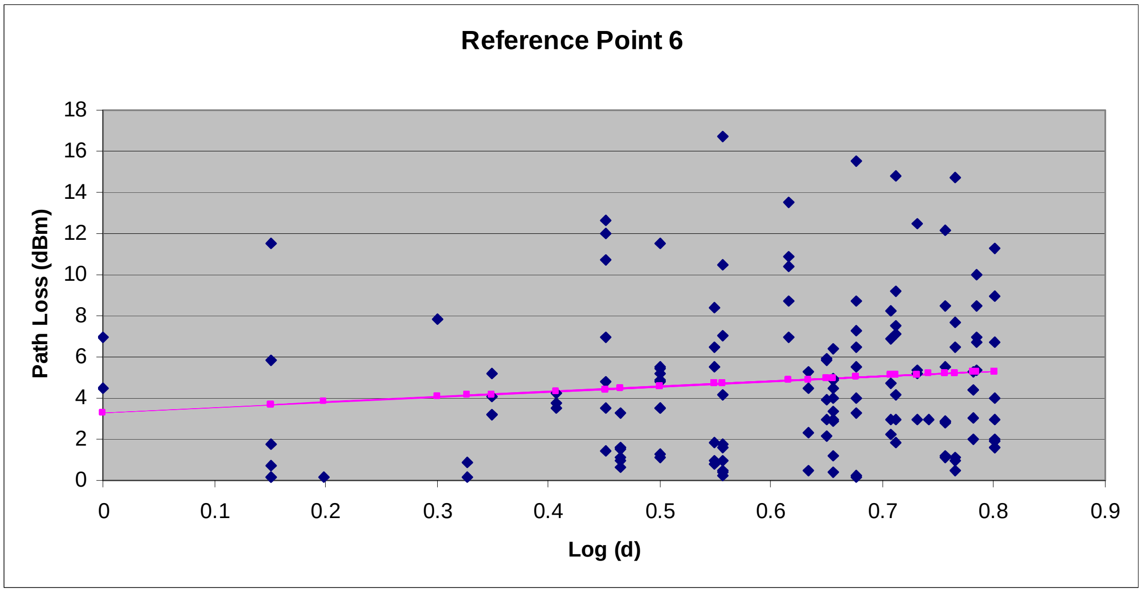


-Linear Equation and path loss exponent

y=7.87x+2.22; Path loss exponent = 7.87

Reference Point 6:

-Best Fit Line and the scatter graph

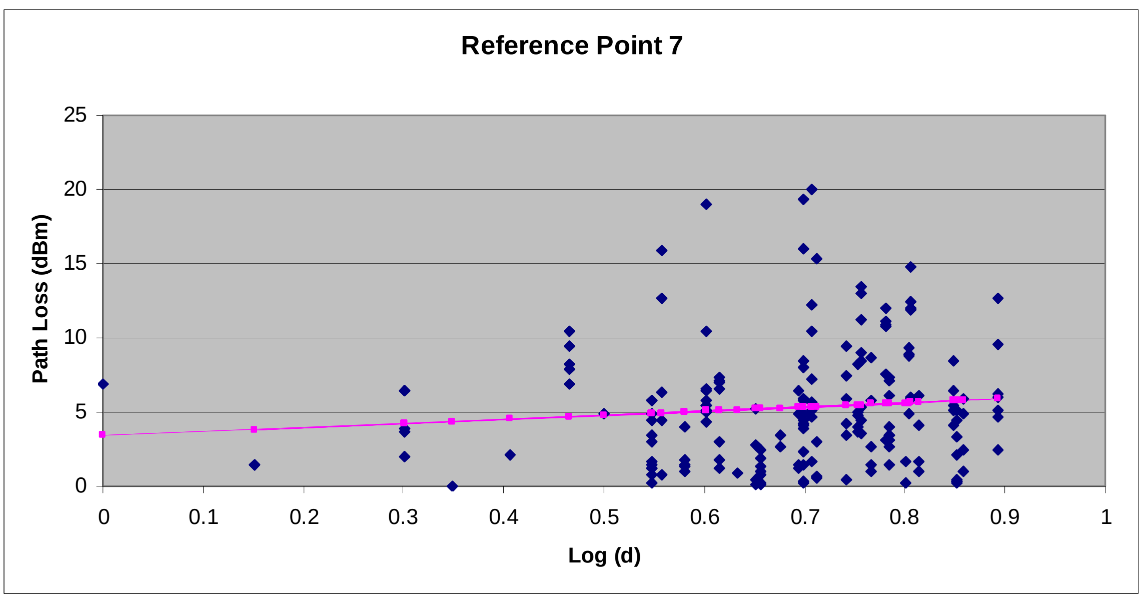


-Linear Equation and path loss exponent

y=2.52x+3.30; Path loss exponent = 2.52

Reference Point 7:

-Best Fit Line and the scatter graph

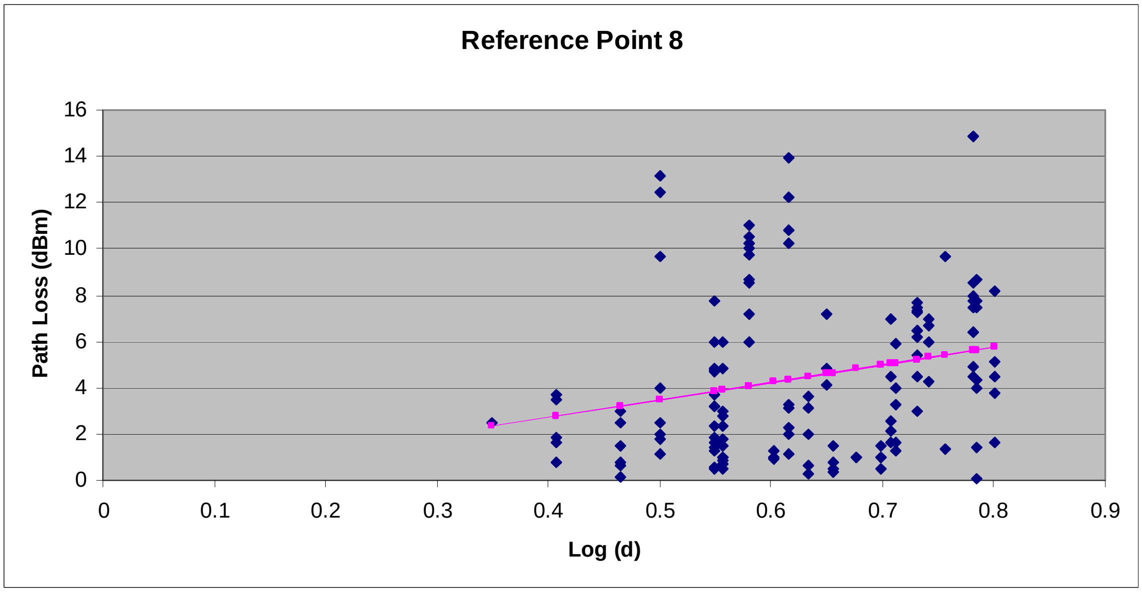


-Linear Equation and path loss exponent

y=2.75x+3.40; Path loss exponent = 2.75

Reference Point 8:

-Best Fit Line and the scatter graph

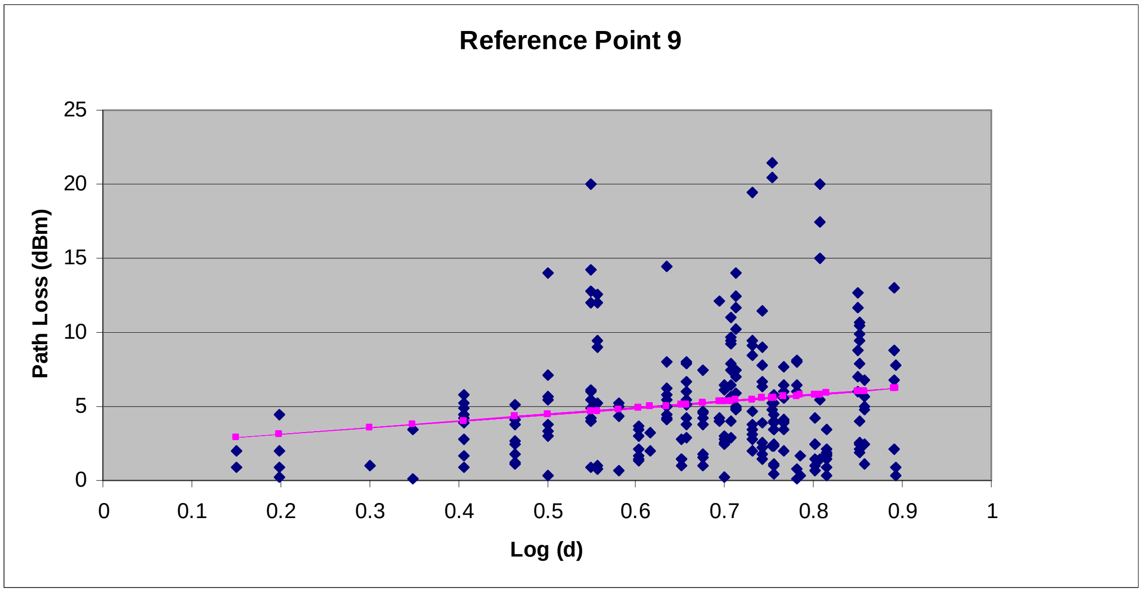


-Linear Equation and path loss exponent

y=7.56x-0.31; Path loss exponent = 7.56

Reference Point 9:

-Best Fit Line and the scatter graph



-Linear Equation and path loss exponent

y=4.48x+2.21; Path loss exponent = 4.48

3.7 Comparisons on the standard-based and the measurement-based distance prediction

As stated in Chapter 2, the comparison will base on the better result of localization evaluated from the standard-based and the measurement-based distance estimation.

3.7.1 The result of r-a from the measurement-based

Let r be a predicted distance, a is the actual distance. Table 3.2 illustrates some result of r-a on the measurement-based.

		Order	Ref 1	Ref 2	Ref 3	Ref 4	Ref 5	Ref 6	Ref 7	Ref 8	Ref 9
Positions			r-a	r-a	r-a	r-a	r-a	r-a	r-a	r-a	r-a
0.5	0.5	1	0	0	0	0	0	0	-5.43448	8.591832	2.535012
0.5	0.5	2	0	0	0	0	-2.72548	0	0	-1.71396	-6.82092
0.5	0.5	3	0	0	0	0	0	0	0	94.67169	21.05028
0.5	0.5	4	0	0	0	0	0	0	0	94.67169	21.05028
0.5	0.5	5	0	0	0	0	-2.72548	0	0	4.749653	248.3646
1.5	0.5	6	-1.58114	0	0	0	0	0	62.19106	0	-4.59703
1.5	0.5	7	-1.57967	0	-2.76719	0	0	0	-3.18899	0	-5.9456
1.5	0.5	8	-1.58114	0	-3.23779	0	0	-4.38757	-4.53496	-4.03023	-6.12836
1.5	0.5	9	-1.58114	0	0	0	0	0	0	0	-5.89879
1.5	0.5	10	-1.57704	0	2.869677	0	0	-4.886	0	15.389	-6.26451
2.5	0.5	11	-2.54951	0	0	-3.52468	-1.33828	0	27.16414	0	-4.57856
2.5	0.5	12	-2.54951	0	0	0	0	0	647.9684	0	-5.54123
2.5	0.5	13	-2.54951	0	0	-2.56851	0	0	464.6401	3.74415	0
2.5	0.5	14	-2.54951	0	0	-3.45512	0	0	1334.477	2.934949	-6.02636
2.5	0.5	15	-2.54951	0	0	-3.04102	0	0	527.6284	1.311022	-5.74979

Table 3.2 r-a on measurement-based

As we discussed in Chapter 2, the r-a is the radius of a circle. As well, the circle is the approximate area that the transmitter may locate. We ignore the circle area which is larger than $36m^2$ which is the area of localization. Thus, r-a is greater than 3.39 will be ignore too. All acceptable r-a implied successful localization for each reference points are shown in Fig 3.4.

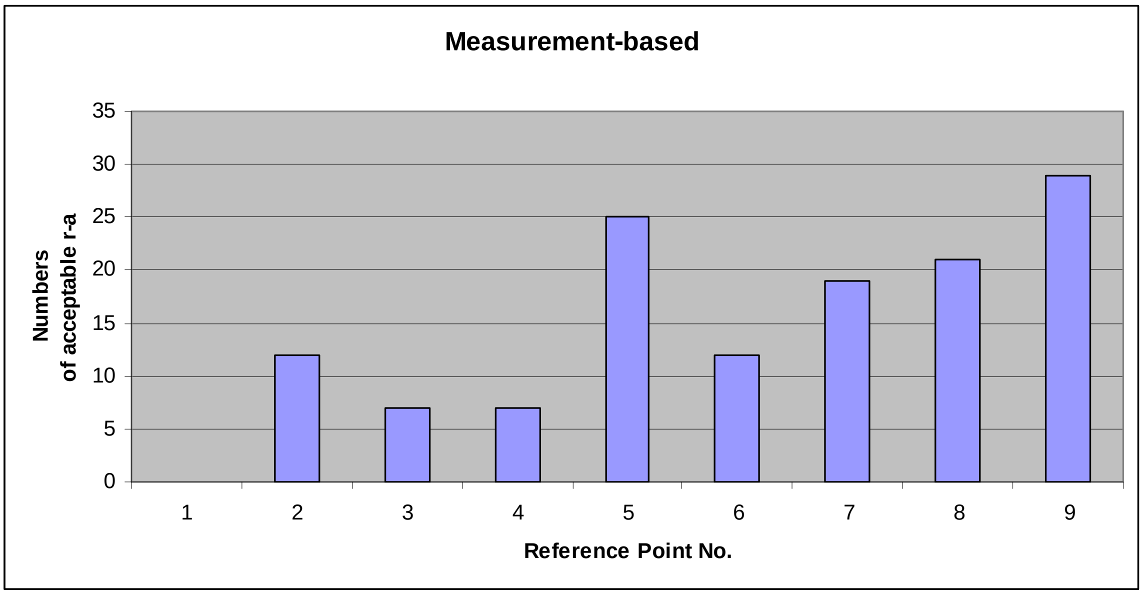


Figure 3.4 Numbers of r-a

It seems reference point 5 and 9 give the best results. Look at the position of ref.5 and ref 9, interestingly we found that both of them locate on the open space which will get less interfered and not as much of problems from multipath propagation.

3.7.2 The result of r-a from the standard-based

-Using COST 231 Model

After applying the estimated distances to Eq.(3), we found that all of r-a are lesser than 0 causing unsuccessful localization. We can conclude that COST 231 Model shouldn't be used in this research topic under the environment expressed in the previous chapter.

-Using The PADE' Model

Refer to Eq.(5) and table 3.3; we replace the reference distance d_0 with the shortest available distance. Then, PL_0 is substituted with path loss at d_0: in this case d_0=1.41, PL_0=2.07.

Position		Order	Ref. 1		Rx power (dBm)	Path loss
0.5	0.5	1	0.707106781	127.9666666	-10.0166667	0
1.5	0.5	37	1	130.9000002	-8.5499999	0
2.5	0.5	41	1	125.1698412	-11.4150794	0
3.5	0.5	42	1.414213562	113.86	-17.07	2.07
4.5	0.5	2	1.58113883	111.4238094	-18.2880953	3.2880953
5.5	0.5	7	1.58113883	112.5718182	-17.7140909	2.7140909
0.5	1.5	38	2	103.3166666	-22.3416667	7.3416667
1.5	1.5	48	2	122.16	-12.92	0
2.5	1.5	8	2.121320344	99.2066666	-24.3966667	9.3966667
3.5	1.5	43	2.236067977	122.4	-12.8	0
4.5	1.5	49	2.236067977	110.1154546	-18.9422727	3.9422727
5.5	1.5	3	2.549509757	114.65	-16.675	1.675

Table 3.3 Path loss on reference point 1

We can predict the distance by Eq.(5) invert: Estimated distance = $10^{((PL - PL0)/15.9+\log(d0))}$

The results are acceptable because not all of r-a < 0.

Table 3.4 shows some of the result

		Order	Reference Point 1			
Positions			Distance(m)	Path loss	Th.Est.d	r-a
0.5	0.5	1	0.707107	0	0	0
0.5	0.5	2	0.707107	0	0	0
0.5	0.5	3	0.707107	0	0	0
0.5	0.5	4	0.707107	0	0	0
0.5	0.5	5	0.707107	0	0	0
1.5	0.5	6	1.581139	3	1.617856	0.036718
1.5	0.5	7	1.581139	4.75	2.084505	0.503366
1.5	0.5	8	1.581139	2.583334	1.523121	-0.05802
1.5	0.5	9	1.581139	1.25	1.255675	-0.32546
1.5	0.5	10	1.581139	4.857143	2.1171	0.535961
2.5	0.5	11	2.54951	2.5	1.504851	-1.04466
2.5	0.5	12	2.54951	0.5	1.126438	-1.42307
2.5	0.5	13	2.54951	1.125	1.233149	-1.31636
2.5	0.5	14	2.54951	2.25	1.451343	-1.09817
2.5	0.5	15	2.54951	2	1.399738	-1.14977
3.5	0.5	16	3.535534	9.4	4.087481	0.551947
3.5	0.5	17	3.535534	8.166667	3.418909	-0.11662
3.5	0.5	18	3.535534	5	2.161355	-1.37418
3.5	0.5	19	3.535534	6.5	2.685751	-0.84978
3.5	0.5	20	3.535534	7.75	3.218712	-0.31682
4.5	0.5	21	4.527693	5.5	2.323661	-2.20403
4.5	0.5	22	4.527693	0.2	1.078548	-3.44914
4.5	0.5	23	4.527693	5.125	2.200836	-2.32686
4.5	0.5	24	4.527693	0.833334	1.182147	-3.34555
4.5	0.5	25	4.527693	0.625	1.147014	-3.38068
5.5	0.5	26	5.522681	0.25	1.086386	-4.43629

Table 3.4 r-a from The PADE' Model

3.8 Comparison on localization results

To compare the two equations (the one from the PADE' model and the one from measurements), we do the following:

- For each measurement where we get a consistent prediction (at least 3 of the a's are less than the r's)

- find the largest (r-a) if it’s over than 3.39 pick the second largest and if the second largest is still greater than 3.39 we will assume error and ignore the r-a from this prediction
- use the area of a circle of radius (r-a) as an estimate of the area of intersection
- divide by the number of consistent predictions to get the average area of uncertainty for a consistent prediction
- calculate the standard deviation of the areas

The result from the measurements:

We get 34 times of successful localization with the average area of 12.26 m^2 and the standard deviation of 10.32.

The result from the PADE’ model:

Even though, the r-a look good for each of the reference point but finally the success rate on localization are only 7 times. This shows that localization from r-a prediction based on result from the PADE’ model is inconsistent. The PADE’ model‘s average area (15.90 m^2) is greater than average area from the measurements.

Chapter 4: Conclusion

This project has presented the path loss exponent from measurements which can be used for further research in localization. The comparisons demonstrate the path loss exponent from this project give improvement on accuracy in distance prediction from other two standard-based models. Furthermore, we have proposed the possible alternative technique for localization which requires only two reference points. With the limit of data quality we have from the experiment, the successful rate of localization is still low but at least we prove that it’s possible to implement this technique for localization. Therefore, more RSSI values need to be collected to advance the data quality.

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Appendix 1

All data including C-code contain in a DVD