Analysis of WiMAX Positioning Using Received-Signal-Strength Method

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***Abstract*—This paper presents an analysis of WiMAX positioning by using received-signal-strength (RSS) method. A simulator was developed using MATLAB to demonstrate the ability of RSS method for WiMAX positioning. With this simulator, the user can specify their own data or parameters in analyzing and obtaining the target object location. In this study, the analysis was done in three different scenarios that simulate various conditions for WiMAX positioning. Result shows that channel or propagation models are crucial part in the process of analyzing the communication system where it will affect the performance of positioning detection. Selection of perfect model that resemble the real environment will led to better wireless positioning system. By the performance evaluation, the user can plan better simulation system and can create more accurate algorithms for radio positioning.**

***Index Terms*— Lateration, linear least squares, radio positioning, received signal strength, WiMAX.**

I. Introduction

RADIO positioning is one of the important fields in wireless systems. It was used mainly to enable location-based-services (LBS) applications such as turn by turn navigation, tracking, monitoring, emergency services and much more. In radio positioning, many techniques and algorithms can be used to locate our target position or mobile station. The most commonly used techniques are time-of-arrival (TOA), time-difference-of-arrival (TDOA), angle-of-arrival (AOA) or direction-of-arrival (DOA), and received-signal-strength (RSS). Basically, these common techniques will provide distance information between the transmitter and receiver while AOA/DOA will provide information on bearings relative to receiver [1, 2]. With the demand of LBS, nearly each wireless technology had applied positioning technologies to their system and one of them is WiMAX (Worldwide Interoperability for Microwave Access) technology, which will be our focus in this study [3].

WiMAX is a wireless technology that based on WirelessMAN (Metropolitan Area Network) standards under IEEE 802.16 working group. WiMAX technology offers interesting features such as OFDM (Orthogonal Frequency Division Multiplex)-based physical layer, high peak data rates, scalable bandwidth and data rates, robust security, support for mobility and much more [4]. All these great features lead to various studies in various fields for WiMAX technology and one of them is radio positioning. Generally for WiMAX positioning, methods for mobile station estimation that may be used include GPS (Global Positioning System), measurement-report-based techniques, hybrid method and others [5].

In this project, our main goal is to use RSS method instead of TOA or AOA in order to determine the range between base station (BS) to mobile station (MS) and use linear-least-squares (LLS) method to solve the coordinates of target object or MS. RSS technique has the lowest complexity and cost since it is available in most wireless systems and can solve indoor coverage problems encountered by GPS. TOA on the other hand require high precision timing and clock synchronization while AOA require antenna array that will increases the system complexity [6]. The drawback of using RSS technique is their low accuracy compared to TOA and we will try to analyze this problem throughout this study. However, due to its straightforward implementation to the wireless system and other factors, RSS will be our main interest in our study. Practically, RSS information is readily available in nearly every wireless system without system modification or additional hardware.

MATLAB software will be used as a tool to create a Graphical User Interface (GUI) simulator for the analysis and study of this project. In this simulator, user can specify their own parameters such as the location of base station, frequency, gain and other parameters. User may also choose different types of channel or propagation model from free space, shadowing, and ITU WiMAX standards to suit the real measurement campaign. This simulator will evaluate the data and calculate the coordinates, errors, and shows the resulted output.

In summary, our main goal is to utilize the RSS obtained by MS from BS to extract the range information in order for positioning determination. Various algorithms can be used to solve the location problem but in this project linear-least-square method is used to find the coordinates of MS from the lateration technique. Different types of scenarios will be applied using the simulator to illustrate different scenario of wireless conditions and to provide analysis towards the wireless positioning.

II. Received-Signal-Strength Method

The distance between BS to MS can be obtained by using RSS-based method. In this method, the path loss model is required and can be established from the real measurement or radio propagation models in order to determine the distance. RSS technique has the lowest complexity and cost since it is available in most wireless systems and can solve indoor coverage problems. Practically, RSS information is readily available in nearly every wireless system without system modification or additional hardware. Models that will be used throughout this study for RSS-based positioning are as follows:

A. General Path Loss Model

Free space path loss or propagation is the most well-known and basic model to predict the received signal with LOS where it assuming that there are no obstacles between transmitter (Tx) and receiver (Rx)'s propagation path. The signal propagate is considered passing through the free space usually air without having the effects of reflection, diffraction or others. Equation 1 shows the equation for free space path loss (FSPL) where λ is the signal wavelength in meter and d is the distance from Tx to Rx in meter. By considering a non-isotropic antenna gain transmit of G_t, gain received G_r and power transmitted P_t in watts, the received power at a distance, $P_r(d)$ is expressed in Equation 2 which is also known as Friis equation. Generally for a direct transmission without obstacles, Friis model is sufficient to gives a first-order approximation for link budget.

$$FSPL(db) = 10log_{10}\left(\left(\frac{\lambda}{4\pi d}\right)^2\right) \quad (1)$$

$$P_r(d) = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \quad (2)$$

B. Log-Distance Path Loss

In wireless communication, the average received signal power usually will decreases logarithmically with distance, whether in outdoor or indoor environment. The average large-scale path loss for transmitter-receiver (T-R) separation can be expressed as a function of distance by using a path loss exponent, *n*:

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n \quad (3)$$

$$\overline{PL}(dB) = \overline{PL}(d_0) + 10nlog\left(\frac{d}{d_0}\right) \quad (4)$$

By combining the path loss exponent formula with the free space path loss, we can construct model that is known as the log-distance path loss as in Equation 4. Where n is the path loss exponent, d_0 reference distance, and d is T-R separation distance. Table 1 below list down typical path loss exponents for various mobile radio environments whereby it can vary from 1.6 to 6 depending on the environment [7]. Typically, the reference distance, d_0 is set at 1 km for a cellular system that have large coverage and for indoor, d_0 can be at 100 m.

Table 1: Path loss exponent for different environments

Environment	Path Loss Exponent
Free Space	2
Urban area cellular radio	2.7 – 3.5
Shadowed urban cellular radio	3 – 5
In building line-of-sight	1.6 – 1.8
Obstructed in building	4 – 6
Obstructed in factories	2 – 3

Model as defined in Equation 4 actually does not consider the surrounding effects between T-R channels. Practically, measurements have shown that at any value of d, the path loss $PL(d)$ at a particular location is random and distributed log-normally (normal in dB) about the mean distance-dependent value that is:

$$PL(d)[dB] = \overline{PL}(d_0) + 10nlog\left(\frac{d}{d_0}\right) + X_\sigma \quad (5)$$

where X_σ is a zero-mean Gaussian, distributed random variable (in dB) with standard deviation of σ (in dB). The log-normal distribution describes the random shadowing effects which occur over a large number of measurement locations which have the same T-R separation but different levels of clutter on the propagation path. This phenomenon is referred to as log-normal shadowing and this model is useful when dealing with a more realistic situation.

C. ITU M.1225 Large Scale Path Loss Model

In mobile WiMAX, WiMAX Forum had used ITU M.1225 channel models to testing the interoperability of the equipment in fading environments. ITU M.1225 models specify three different environments that are 1) indoor office environment, 2) indoor to outdoor and pedestrian environment, and 3) vehicular environment [8]. In this project we will use large-scale path loss models that covered pedestrian and vehicular environment for WiMAX channel modeling. Actually, there are also other well-known empirical models such as Okumura, Hata, COST 207 or 231 models but in this project those models doesn't include our experimental operating frequency and specifications. ITU M.1225 large scale path loss is consists of two equations that were produced from empirical data collected at frequency of 2GHz [9]. The path loss equations are as follows for:

i. Pedestrian environment

$$PL(dB) = 40log_{10}R + 30log_{10}(f) + 49 \quad (6)$$

where R is the distance between BS to MS in km and f is the carrier frequency in MHz and should not deviate far from 2GHz.

ii. Vehicular environment

$$PL(dB) = 40(1 - 4 \times 10^{-3}\Delta h_b)log_{10}R - 18log_{10}(\Delta h_b) + 21log_{10}(f) + 80 \quad (7)$$

where R is the distance between BS to MS in km, f is the carrier frequency in MHz and should not deviate far from 2GHz and Δh_b is the BS antenna height in meter (in general 15m and valid between 0 to 50m).

This ITU model is limited for a measurement campaigns that utilized approximately 2GHz carrier frequency and frequency of 1.5 – 2.5 GHz is acceptable. Else, if frequency that being use didn't fall between the ranges, the results will be inaccurate and will affect the link budget design.

III. Positioning Technique Using Lateration

Lateration is the most common method to derive the location of target objects. It refers to a technique where multiple range measurements between known reference points such as base stations to a mobile station points are performed to calculate the coordinates [10]. If *n* denotes the number of BS of 3, the lateration is known as trilateration. Assume that *i* is number of known coordinates base stations. When the number of stations increases, the coordinates of target MS will be reduces as illustrated in Figure 1 where the position of MS can be anywhere in the radius and by after increasing the *i* to 3, the point had been reduced until one point. The calculation of the MS is based on the Pythagoras theorem. Let (X_i, Y_i) are known coordinates of *i*th base stations and (x, y) represents the target location, hence the equation is:

$$r_i = \sqrt{(X_i - x)^2 + (Y_i - y)^2} \quad (8)$$

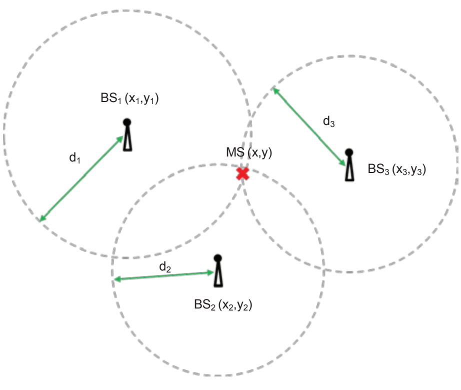

Figure 1: Multilateration with three base stations as the reference point to determine the mobile station.

By referring to Figure 1, assume that the position of MS is located at $X = [x, y]^T$ and base stations, BS_i, is located at $X_i = [x_i, y_i]^T$. Using Pythagorean Theorem, the distance between BS_i to MS is:

$$d_i^{\ 2} = (x_i - x)^2 + (y_i - y)^2 \quad (9)$$

Next, the above equation can be subtracting with the distance equation for BS_1 as in Equation 10 and can be expressed as in equation x with matrix notation as in Equation 11:

$$d_i^{\ 2} - d_1^{\ 2} = x_i^{\ 2} + y_i^{\ 2} - x_1^{\ 2} - y_1^{\ 2} - 2x(x_i - x_1) - 2y(y_i - y_1) \quad (10)$$

$$HX = B \quad (11)$$

where

$$H = \begin{bmatrix} x_2 - x_1 & y_2 - y_1 \\ x_3 - x_1 & y_3 - y_1 \\ \vdots & \vdots \\ x_n - x_1 & y_n - y_1 \end{bmatrix}$$

and

$$B = \frac{1}{2}\begin{bmatrix} (d_1^{\ 2} - d_2^{\ 2}) + (x_2^{\ 2} + y_2^{\ 2}) - (x_1^{\ 2} + y_1^{\ 2}) \\ (d_1^{\ 2} - d_3^{\ 2}) + (x_3^{\ 2} + y_3^{\ 2}) - (x_1^{\ 2} + y_1^{\ 2}) \\ \vdots \\ (d_1^{\ 2} - d_n^{\ 2}) + (x_n^{\ 2} + y_n^{\ 2}) - (x_1^{\ 2} + y_1^{\ 2}) \end{bmatrix}$$

Using the least square method, the above matrix can be solve by multiply with inverse H in the both side and solve for the *X* as in Equation 12 that represent the coordinate of MS in longitude and latitude of *x* and *y* [11] .

$$H^T HX = H^T B$$

$$X = (H^T H)^{-1} H^T B \quad (12)$$

IV. Positioning Accuracy Evaluation

Accuracy of the positioning system depends on several factors such as the radio ranging measurement accuracy, the algorithm used to process the measurements and the geometry of the nodes in the system. A lot of accuracy evaluation techniques can be used to measure the accuracy of various algorithms and positioning systems such as Cramer-Rao lower bound (CRLB), Geometric Dilution of Precision (GDOP) and root mean square error (RMSE).The CRLB benchmarks the location accuracy of any unbiased estimators. GDOP describes the geometric impact of node configuration towards accuracy. By given specific location, RMSE can be used to measure the accuracy [121].

A. Root Mean Square Error

Mean square error (MSE) or (RMSE) is often used to measure the accuracy of the location estimates of specific positioning algorithms and systems. MSE is the square of the distance between the true coordinates of MS with the estimated MS [13]. The equation for MSE and RMSE was derived in Equation 13 and 14:

$$MSE = \varepsilon = E[(x_r - x_e)^2 + (y_r - y_e)^2] \quad (13)$$

$$RMSE = \sqrt{\varepsilon} \quad (14)$$

Where x_r, y_r denotes real coordinates of mobile station while x_e, y_e denotes the estimated coordinates of mobile station.

V. Results And Discussions

The theoretical formula of RSS-based positioning system was written in MATLAB and simulator was built in order to analyze the output data. Figure 2 shows the main GUI for WiMAX positioning system.

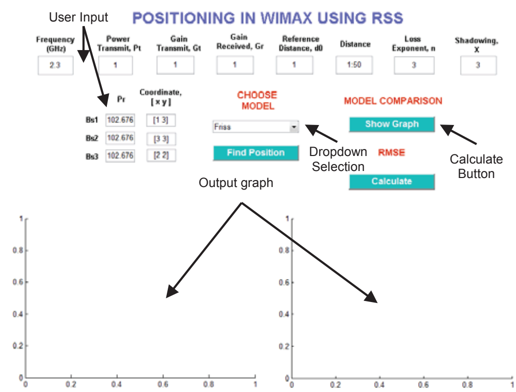

Figure 2: Project main GUI

The parameters specified in this project are as in the Table 2 below:

Table 2: Parameters used in the analysis

Parameter	Value
Frequency	2.3 GHz
Wavelength, λ	0.13 meter
Power transmit, Pt	1 dB
Gain transmit, Gt	1 dB
Gain received, Gr	1dB
Reference distance, d0	1 km
Path loss exponent, n	3
Shadowing, X	3 dB

In RSS-based method, the propagation path loss or channel was used to determine the distance between MS to BS. Figure 3 shows the resulted path loss of various models with the range of 1 to 50 km from BS to MS. As we can observe, the free space model produces the lowest total path loss because it neglected the effects of reflection, diffraction and scattering and assuming LOS propagation. The attenuation of Friis model is slightly above the free space. This due to the fact that the difference between Friis and free space is it include transmit power, transmitting and receiving gain. Log-distance path loss shadowing produces unpredictable received signal since it assume a shadowing effects.

The ITU M.1225 large scale path loss was modeled based on measured data collected in the 2GHz through curve-fitting methods. It is considered as empirical model and usually this type of model contribute to higher attenuation or path loss because it represents worst-case environments that the mobile can operate.

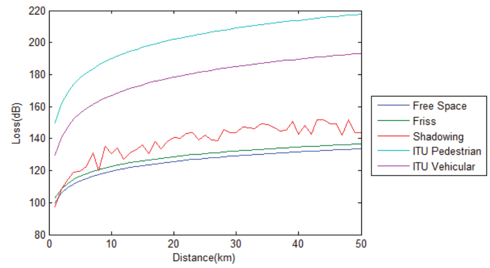

Figure 3: Path loss of different type of models

From the results, we can observed that although the properties of transmission such as frequency, power transmit, gain transmit/receive and distances are the same, different models will produce different output. The reason for this is that different type of terrains and environments will produce different path loss/attenuation. Hence, to have an accurate analysis of the wave propagation loss, we must choose the correct type of models that suit our planning environment for radio transmission. From this result, we can conclude that to be able to have higher accuracy of mobile positioning detection, the selection of the best model that suit the real environment is crucial to have precise distances measurement.

A. Scenario 1

Scenario 1 will assume that MS will receive same power level from all three base stations. We had specified the received power of MS from all three base stations are the same at 102.676 dB. From this received power signal data, we can obtain the distance from the BSs to MS by reversing the path loss models equation. The BS_1, BS_2 and BS_3 is located at coordinate of (1, 3), (3, 3) and (2, 2) respectively as in Figure 4. The calculation to determine the range of BSs to MS for path loss model is as follows:

a. Range of MS for Friis model

$$d = 10^{\left(\frac{PL-Pt-Gt-Gr}{20}\right)} \times \frac{\lambda}{4\pi d}$$

$$d = 10^{\left(\frac{102.676-1-1-1}{20}\right)} \times \frac{0.13}{4k \times \pi} = 1\ km$$

b. Range of MS for Log-distance path loss

$$d = d_0 \times 10^{((PL-FSPL-X)/10n)}$$

$$d = 1k \times 10^{((102.676-99.67-3)/30)} = 1\ km$$

c. Range of MS for ITU Pedestrian environment

$$d = 10^{((PL-30log(f_c)-49)/40)}$$

$$d = 10^{((102.676-30log(2300)-49)/40)} = 0.066\ km$$

d. Range of MS for ITU Vehicular environment

$$d = 10^{((PL-18log(h_b)-21log(f_c)-80)/40\times(1-4e-3\times h_b)}$$

$$d = 10^{((102.676-18log(15)-21log(2300)-80)/40\times(1-4e-3\times 15)}$$

$$= 0.766\ km$$

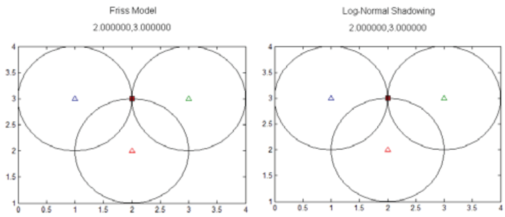

Figure 4: Friss model (left) and Log-Distance path loss (right) for Scenario 1

Since we had set the received power are equal, the range between MS to all three BS will be the same at 1 km radius. In Figure 4 and 5, all the base station produce same circular size and lateration techniques were performed to find the MS coordinates. By solving the matrix using linear least square, the MS coordinates that was obtained for all the models are the same that position at x, y = (2, 3).

In Figure 4, we can observe that the lateration process was perfectly done with the interception between the BSs range precisely determined at coordinate of (2, 3). This is because the power received by MS is the same from all three BS and the range is appropriately covering the MS position. As in Figure 5, the circular lateration does not intercept between each station due to high propagation loss in both ITU pedestrian and vehicular model. However, the simulator still manages to find the coordinates with the exact position mainly because of the same received power obtained from the BSs and also the usage of direct LLS algorithm.

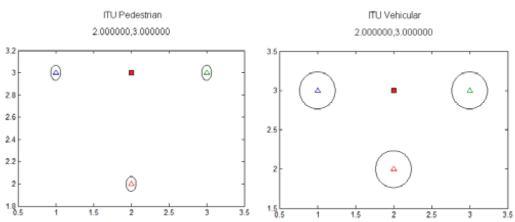

Figure 5: ITU Pedestrian model (left) and ITU Vehicular (right) for Scenario 1

To evaluate the performance of the positioning system, RMSE was adapted and as in Figure 6, there is no error produces because the system predicts the MS position accurately. The main reason for this is because the MS received same power level from the entire BS and hence with this direct power level and range between MS and BS, LLS algorithm can be calculated more accurately without error. The error only will occur when the measured coordinate does not match the exact or real coordinate.

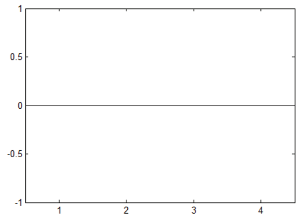

Figure 6: Root mean square error compared to Friss model for Scenario 1

B. *Scenario 2*

In Scenario 2, the MS will receive different power from different BS where MS will receive 100 dB from BS_1, 103 dB from BS_2 and 102 dB from BS_3. The coordinate of base stations are the same as the previous where BS1, BS2, and BS2 is located at (1, 3), (3, 3) (2, 2) respectively. The results of this simulation are shown in Figure 7 and 8. Below the title of the graph is the resulted measured coordinates of MS obtained from the lateration and RSS-based technique. Table 3 below shows the overall measured coordinates:

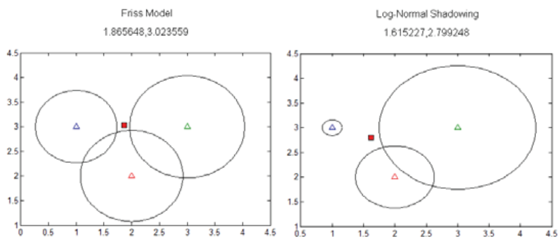

Figure 7: Friss model (left) and Log-Distance path loss (right) for Scenario 2

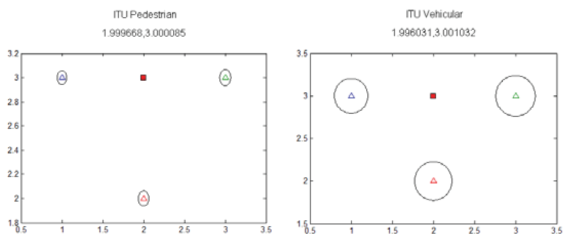

Figure 8: ITU Pedestrian model (left) and ITU Vehicular (right) for Scenario 2

Table 3: Measured coordinates for Scenario 2

Model	Coordinates
Friss model	1.865648, 3.023559
Log-distance shadowing	1.615227, 2.799248
ITU Pedestrian	1.999668, 3.000085
ITU Vehicular	1.996031, 3.001032

When we vary the power received from different base stations, the resulted MS coordinates are different with the results in Scenario 1. Although the coordinates of base station between Scenario 1 and 2 are the same, the power received had affected the lateration process and calculation of LLS algorithm. Here, LLS algorithm function as the main solver of MS coordinates. LLS are basic and straightforward algorithm and there are many other algorithms that can be used to serve the same functionality such as NLS, CRLB and GDOP.

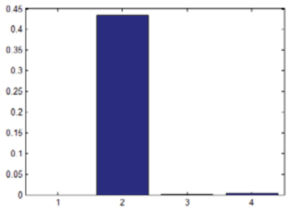

Figure 9: Root mean square error compared to Friss model coordinates for Scenario 2

In Figure 9, the bar graph represents the root mean square error from the simulation. This error was obtained by comparing the measured coordinate of MS with the true coordinate of MS. Here, the Friss model's MS position was chosen as a true coordinate. Starting from left, bar number 1 is Friss model, 2 is Log-distance path loss shadowing, 3 is ITU pedestrian and 4 is ITU vehicular. From the bar graph, when comparing to the Friss model that act as true location, the log-distance shadowing model produce higher error with RMSE of 0.43km while the ITU method were slightly deviate from the true coordinates. As in our previous discussion, log-distance shadowing model is random and unpredictable as shown in Figure 3. Thus, the power received is unstable and affect the calculation of positioning.

C. *Scenario 3*

In Scenario 3, we had specified the MS received power from BS_1 and BS_2 with 100 dB and BS_3 with 200 dB. The aim for this setup is to show that the positioning algorithm will not work under unsupported received power. For instance, log-distance model as shown in Figure 3 only have a path loss from 100 to 140 dB and here we had specified the received power to be more than that range with 200 dB. This lead to unpredictable results as showed in Figure 10 where the simulator cannot determine the location of MS. Moreover the RMSE for this simulation is far beyond the expected results as in Figure 11. In other words, the system needs to be able to distinguish the real received power with unwanted power and befitting the propagation model parameter. This also shows that if we choose wrong propagation model for RSS-based positioning, we will not be able to detect the MS location precisely whereby it will produce higher error and inaccurate position.

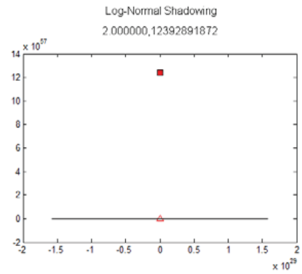

Figure 10: Positioning results for Scenario 3

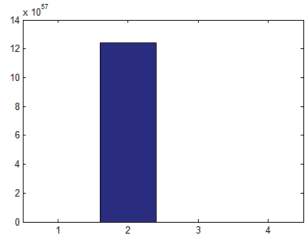

Figure 11: RMSE for Scenario 3

D. *Discussions*

In the previous simulation results, we had demonstrated the functional working simulator to determine the position of MS in WiMAX technology. In obtaining the distances between BS and MS, we had used standard path loss propagation model as well as WiMAX propagation model defined by ITU to manipulate the received-signal-strength data. To sum up, our WiMAX positioning simulator are able to determine the coordinate of MS using the RSS and lateration techniques, choose and compare the propagation models that we want to analyze and show the performance of the positioning estimation based on RMSE methods.

In addition, we have simulated the positioning system under three different scenarios and investigate the channel's behavior under different models. The performance of the positioning system is function of the channel model where, when the channel varies, the performance of these positioning methods is affected. It is critical to understand channel models and statistical behaviors.

VI. Conclusion

In this paper, we had discussed the fundamentals of positioning as well as the techniques and method involves in this field. A MATLAB simulator was built to perform the simulation of radio positioning. We had narrow down the techniques by only using received-signal-strength (RSS) based technique and lateration with linear least square in order to determine our target position and just focus on WiMAX parameters. In RSS method, the strength of the received signal indicates the distance traveled by the signal. A propagation model such as log-distance path loss model was used to extract the RSS data in the wireless system. From the analysis, we can conclude some of the important points related to the positioning.

First, to have an accurate positioning detection, we need to choose the appropriate and suitable propagation model that want to be used. For example, if we want to estimate the location of MS in the pedestrian area, we need to use ITU Pedestrian model as our channel modeling rather than using others because that model was specifically design for that area. So, the accuracy will depend on the environment and model chosen.

Next is that lateration will increase the probability of detection of MS. If the lateration doesn't cover the MS position, a balanced power received among BSs can still allow the algorithm to calculate effectively with low error. The positioning system also needs to be able to distinguish between the wanted and unwanted receive power signals. Usually in multipath area, the MS will receive unpredictable power due to reflection, scattering or others and positioning system need to be able to overcome this problem.

In summation, we had applied the RSS techniques for radio positioning in WiMAX to determine the distance and use lateration in solving the MS position coordinates as well as developing a simulator for this project. Studies and analysis of different path loss propagation models and scenarios also had been done.

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REFERENCES

[1] Kegen Yu, Ian Sharp, Y. Jay Gup, Ground-Based Wireless Positioning, John Wiley & Sons Ltd., 2009.

[2] A. A. M. Isa, G. Markarian, M. S. M. Isa, N. Z. Haron, and M. S. M. Zin, "Hybrid TOA-Based MIMO and DOA-Based Beamforming for Location and Positioning in WiMAX Networks," Journal of Telecommunication, Electronic and Computer Engineering, vol. 4, pp. 11-20, 2012.

[3] A. A. M. Isa, "Enhancing location estimation accuracy in WiMAX networks," in MELECON 2010 - 15th IEEE Mediterranean Electrotechnical Conference, pp. 725-731, 2010.

[4] Jeffrey G. Andrews, Arunabha Ghosh, Rias Muhamed, Fundamentals of WiMAX, Understanding Broadband Wireless Networking, Prentice Hall, 2007.

[5] Muthaiah Venkatchalam, Kamran Etemad, Wayne Ballantyne, Bonnie Chen, "Location Services in WiMAX Networks", IEEE Communication Magazine, October 2009.

[6] Xinrong Li, "RSS-Based Location Estimation with Unknown Pathloss Model," Wireless Communications, IEEE Transactions, vol.5, no.12, pp.3626,3633, December 2006.

[7] Rappaport T.S., Wireless Communications, Principles and Practice, Prentice Hall, Second Edition, 2002.

[8] Burbank, J., Kasch, W., Ward, J. An Introduction to Network Modeling and Simulation for the Practicing Engineer, Wiley-IEEE Press, 2011.

[9] ITU-R M.1225, Guidelines for Evaluation Of Radio Transmission Technologies For IMT-2000.

[10] Axel Kupper, Location-Based Services: Fundamentals and Operations, John Wiley & Sons, 2005.

[11] Joao Figueiras, Simone Frattasi, Mobile Positioning and Tracking, From Conventional to Cooperative Techniques, John Wiley & Sons Ltd, 2010.

[12] Seyed A. (Reza) Zekavat, R. Michael Buehrer, Handbook of Position Location, Theory, Practice, and Advances, Wiley-IEEE Press, 2012.

[13] A.A.M. Isa, G. Markarian, M.S.M. Isa, Z. Zakaria,; M.S.I.M. Zin, Simulation of virtual MIMO base stations for mobile location in IMT Advanced networks," Applied Electromagnetics (APACE), 2012 IEEE Asia-Pacific Conference on , vol., no., pp.176,181, 11-13 Dec. 2012.