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**GSM Mobile Positioning Based on Path Loss Using Hyperbolic Positioning and
Different Interpolation Techniques**

By:

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A THESIS

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ABSTRACT

Location estimation is an essential feature for many location-based services. Different location-based services may have different performance and operation requirements such as accuracy in localization and frequency of location tracking. Time Difference Of Arrival (TDOA), Angle of Arrival (AOA), Time Of Arrival (TOA), Received signal Strength (RSS), Received Signal Strength Indicator (RSSI), Stationary Signal Strength Difference (SSSD) are some methods used for estimating location of MS. Location estimation using RSS is a promising technique since it does not require any modification in the network side and time synchronization information are also not required. In this thesis, RSS received from serving and neighbor Base Station Transceiver (BTS) and known transmitter power are main parameter for estimating distance to Mobile Station (MS) from BTS using Walfisch-Ikegami pathloss model. Distance difference of MS from two BTS is used to draw hyperbola and intersection of two such hyperbola is the location of MS. Estimated distance contains error because of various reason such as error in signal measuring device, error in network parameter and error introduced by pathloss model itself which leads to error in location estimation. Cubic spline interpolation along with weighted least square method is used to minimize such error. With this consideration 69 percentile of estimated location are within 90m whereas only 36 percentile of location estimated using polynomial interpolation are within 90 m. Hence, from result it is found that hyperbolic localization along with spline interpolation and WLS method gives better location estimation than that of polynomial interpolation.

Keywords: Hyperbolic Localization, Interpolation, Weighted Least Square (WLS), Received Signal Strength (RSS), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE).

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LIST OF ABBREVIATIONS

AOA	Angle of Arrival
BSIC	Base Station Identity Code
BTS	Base Transceiver Station
CI	Cell Identity
CRLB	Cramer-Rao Lower Bound
Freq	Frequency
GPS	Global Positioning System
IoT	Internet of Things
Lat	Latitude
LBS	Location Based Service
Long	Longitude
LOS	Line of Sight
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MCT	Machine Type Communication
MMSE	Minimum Mean Square Error
MS	Mobile Station
PL	Path Loss
RF	Radio Frequency
RMSE	Root Mean Square Error
RSS	Receive Signal Strength
SSSD	Stationary Signal Strength Difference
TDOA	Time Difference of Arrival
TEMS	Test Mobile System
TOA	Time of Arrival
TTD	Time Travel Duration
Tx-Rx	Transmitter and receiver
WI	Walfisch-Ikegami
WLS	Weighted Least Square

CHAPTER ONE: INTRODUCTION

1.1. Background

Mobile user location estimation is gaining popularity because of various location-based system application whose applications are: Using LBS for disaster management such as provide positioning, tracking and navigation to people in need such as earthquake victim, consumer needs, health sector, industry, building management, surveillance, enterprise business and a number of various other sectors. It can also benefit many novel systems such as Internet of Things (IoT), smart architectures (such as smart cities, smart buildings, smart grids) and Machine Type Communication (MTC) [1].

With the rapid growth of wireless system, there is a huge demand for accurate and effective positioning methods for the indoor as well as outdoor. Recently, cellular positioning has gain attention with its improved accuracy. Despite the rise of Global Positioning System (GPS) technologies, cellular positioning remains to be significant because it can supplement GPS with the following features: Improved urban canyon coverage, less battery drain, positioning support for non- GPS terminals, GPS assistance data and indoor coverage. Furthermore, the distinctive features of cellular positioning that are missing in GPS, such as personal integrity aspects and potential for the use of cell phone signaling data. The location data almost always include an important personal integrity aspect and the use of cellular positioning can be much less intrusive to personal integrity comparing to GPS positioning. GPS works by receiving signals from satellite. Whereas satellite is power limited system, it transmits a low power to MS and hence GPS signal become weaker inside the building as due to penetration loss and multipath loss. Accurate indoor location is critical in order to assist specially for public safety such as locating emergency call tracking, location base service, requires seamless and ubiquitous positioning technology in order to enable continuity of service inside building [2].

1.2 Problem Statement

Availability, cost, reliability and accuracy of localization are the most important parameters when selecting a localization method and technology. Availability of GPS embedded system is less compared to RF-based methods. Cost of GPS embedded system is more than that of any RF based system. Microwave signal of GPS are greatly

attenuated inside a building hence it is difficult to accurately locate position of the MS inside a building. On the other hand, RF-based methods such as Bluetooth, WIFI, cellular network are popular because of their availability, low cost and low power consumption. In Network-based system signal received from network is used to calculate location of mobile used. Whose power is much higher than that of power received from satellite hence they are best fitted for indoor localization [3]. Low power problem of GPS system is addressed but other significant problem such as RSS value are easily affected by unique characteristic of indoor environment such as multipath fading, penetration loss, shadowing effect are prominent in network-based system. In order to achieve more accurate location estimation those parameters should be taken into consideration [2].

1.3 Research Objectives

Objective of this research is:

1. To estimate location of MS using Received Signal Strength and Hyperbolic localization algorithm.
2. To compare location estimated from polynomial and spline interpolation with weighted least square method.

1.4 Scope of This Work

Based on the objective, the scope of this thesis includes estimation of location of MS inside a building. For this RSS is measured inside a concrete building on ground floor at different location under consideration and distance to MS from BTS is calculated based on pathloss model. Estimated distance contain error which are minimized by using interpolation. Error is forecasted using polynomial and spline interpolation and then that error is adjusted in the estimated distance to get enhance distance. Hyperbolic localization algorithm is used to estimate location of MS. Hyperbolic positioning algorithm is used where any symmetrical impact in Base Transceiver Station (BTS) signal may be discarded while computing distance to MS from BTS. Hence it may have higher accuracy. Finally, location obtained from polynomial and spline interpolation are compared and found that spline interpolation has better estimation than that of polynomial interpolation. Estimated location of MS are validated by plotting the coordinates in the google map.

CHAPTER TWO: LITERATURE STUDY

Increasing demand of location aware computing and context-based information has led to growing interest in the low-cost indoor positioning. Localization algorithm can be classified into range-free and range-based techniques. Range-based techniques involves calculation of distance from transmitter to receiver whereas range-free techniques do not involve calculation of distance between transmitter and receiver but uses timing or angle information to locate user in the network. GPS and cellular-based positioning are an example of range-based localization. Range based problem were studied for many years and many algorithms were proposed to estimate location of MS in NLOS environment. In the field of RADAR and SONAR where the range measurements are obtained form time of arrival (TOA) or time difference of arrival (TDOA). TOA based system requires high precision timing and synchronization components; signal processing technique to combat multipath effect further increase system complexity [4] [5] [6].

2.1 Related Works

To solve localization problem many algorithms are proposed so far among them Circular localization is mostly used because of less computational complexity [7] [8]. Though it is simple but location accuracy of this algorithm is poor compared to hyperbolic localization algorithm [7]. Various approach for range-based and range-free localization are studied such as Time difference of arrival (TDOA), Time of Arrival (TOA), Angle of Arrival (AOA), Received signal strength (RSS), Stationary signal strength difference (SSSD) [3] [2] which have their own pros and cons.

Performance analysis of mobile positioning techniques in GSM network is done in [9]. AOA utilize the Triangulation principle as it uses two known reference points and one unknown point which location is need to find. For finding precise AOA needs a clear LOS signal since AOA is calculated using phase difference between signals from different array antenna otherwise the accuracy is decreased. Indoor signal contains lots of Multipath signal with building loss. It has accuracy of 100 meter to 200 meters and accuracy is decreased with decreasing distance between MS and BTS.

TOA utilizes time taken to reach the signal from BTS to MS is calculated known as time travel duration (TTD). Such duration is then converted into distance using known

velocity of radio wave propagation. Circular positioning is used to find location of MS and its accuracy is 50 m to 200 m [9] .

TDOA utilizes hyperbolic localization to estimate location of MS where distance difference between two BTS from MS is used to draw hyperbola and intersection of two such hyperbola is the location of MS. Its accuracy is 50 m to 125 m [9] but using Maximum likelihood algorithm accuracy is further increased [4] [10].

Fingerprinting utilizes the distant RF patterns (multipath phase and amplitude characteristics) of the radio signals arriving at a receiver antenna from a single caller. The unique characteristics of the signal, including its multipath pattern are analyzed and a “fingerprint” is determined for a defined area. The fingerprint is then compared with a database of previously “fingerprinted” locations, and match is made. By matching the fingerprint of the caller’s signal with the database of known fingerprints, the caller’s geographical location is identified to one of the surveyed areas”. It has been shown that an accuracy of 44m is possible in GSM networks [9].

RSS with circular positioning utilizes RSS to estimate distance between MS to BTS and draw circle with the radius equal to that distance, intersection of three circle is the location of MS. It has accuracy mean error 393 m for 3 BTS and 246 m for 6 BTS [10]. RSS based circular positioning along with interpolation and Walfisch-Ikegami pathloss model further increase accuracy to 22 m [11]. RSS with hyperbolic positioning using Okumara-Hata model for distance estimation, the locations mean error is found to be 345 m with 3BTS and 282m with 6 BTS [7]. Also, Mobile Localization Based on Received Signal Strength and Pearson’s Correlation Coefficient gives location estimation with mean error of 150 m [12]. SSSD with hyperbolic localization using Okumara-Hata model for distance estimation accuracy thus obtain is mean error of 343 meter with 3 BTS and 298 m with 6 BTS [7]. Weighted least squares techniques with RSS and hyperbolic localization gives much accurate result [4]. Circular localization based on TOA and AOA along with Artificial Neural Network (ANN) is proposed in [13] and claims to improve location estimation accuracy under different NLOS environments. ANN is used to overcome the problem of exclusive nonlinear relationships. TDOA and RSSD based hybrid passive source localization is proposed in [14]. TDOA and RSSD based weighted least square (WLS) estimator of passive source localization is presented also maximum likelihood and Cramer-Rao lower bound

(CRLB) for hybrid localization scheme was derived as performance benchmark. Results presents that hybrid algorithm provide better result than TDOA alone.

2.2 Research Gap

Location estimation problem was studied for many years yet exact location of MS was not estimated because of various environmental and computational factors. Environmental factors such as signal received from BTS to MS is affected by multipath fading, absorption loss, shadowing effect, humidity, interference from neighbor BTS signal etc. also computational factor means algorithm used to estimate location of MS could not accurately locate MS location. Proposed algorithm which is future enhancement of [15] where location estimation was done using hyperbolic localization and interpolation and its accuracy is 24 m to 250m however this thesis uses hyperbolic localization using spline interpolation and weighted least square method and location was estimated with error 22m to 173 meter which clearly shows that accuracy was increased by 8% in minimum error and 31% in the maximum error along with increased computational complexity.

2.2 Related Theory

2.2.1 Hata Model

Hata-model is widely used to model path-loss in macro networks operating in the frequency range 150-1500 MHz, and this model is valid for transmitter/base station (BS) heights ranging from 3m to 20m, receiver/mobile-station (MS) antenna heights ranging from 1m to 10m and Tx-Rx distance from 1 km to 20 km. There are three different sub model as for urban, suburban and rural city [7]. Here we consider urban model. The formula for Hata model is given below.

$$L = 69.55 + 26.16 \log(f_c) - 13.82 \log(h_{tx}) - a(h_{rx}) + (44.9 - 6.55 \log(h_{tx})) \log(d) \dots \dots \dots (2.1)$$

where (f_c) is the carrier frequency in MHz, (h_{tx}) and (h_{rx}) are the transmitting and receiving antenna heights in meters, respectively, and d is the TX-RX separation distance in km. $a(h_{rx})$ denotes the mobile antenna correction factor for small and medium sized city as given by

$$a(h_{rx}) = (1.1 \log(f_c) - 0.7)h_{rx} - (1.56 \log(f_c) - 0.8) \dots \dots \dots (2.2)$$

2.2.2 Cost 231 Hata

This model is developed by the European Cooperation in the Field of Scientific and Technical Research (Euro-Cost), COST 231, as extension of Hata model in the upper frequency band in the range $1500 \leq f \leq 2000$ MHz. The application of this model is restricted to large and small cells.

The formula for Hata model is given below.

$$L = 46.3 + 33.9 \log(f_c) - 13.82 \log(h_{tx}) - a(h_{rx}) + (44.9 - 6.55 \log(h_{tx})) \log(d) + CM \dots\dots\dots (2.3)$$

Whereas, the parameters considered here are the same as those defined previously in the subsection on the Hata model for medium-sized and suburban centers with moderate tree density (i.e. $CM = 0$ db) [7].

2.2.3 Walfisch-Ikegami

Cost 231 subgroup develop this model in which street canyon propagation and build obstruction is dealt separately. It is based on measurements performed in the city of Stockholm in case of the line-of-sight and a combination of the Walfisch and Bertoni and Ikegami models in case of the obstructed path situation. The model is applicable to large and small as well as micro cells for frequencies. This model is valid for frequency range of 800Mhz to 2000Mhz, transmitter/base station (BS) heights ranging from 4m to 50m, receiver/mobile-station (MS) antenna heights ranging from 1m to 3m and Tx-Rx distance from 20m to 5 km. The formula for Cost 231 Walfisch-Ikegami model is given below

For line of sight case.

$$L = 42.6 + 26 \log(d) + 20 \log(f_c) \dots\dots\dots (2.4)$$

Where, d is distance between BTS and MS and f_c is transmitting frequency.

For the obstructed case,

$$L = L_f + L_d + L_s \dots\dots\dots (2.5)$$

Where, total loss L is composed by three terms namely, the free-space loss L_f , the roof top-to-street diffraction and scatter loss L_d , and the multi screen loss L_s .

The free-space loss LF is given by

$$L_f = 20 \log(f_c) + 0 \log(d) 32.44 \dots \dots \dots (2.6)$$

The roof top-to-street diffraction and scatter loss LD is given by

$$L_d = -16.9 - 10 \log(r_w) + 10 \log(f_c) + 20 \log(h_B - h_{rx}) L(\phi) \dots \dots \dots (2.7)$$

Where,

r_w is road width in meter, h_B is other building height in meter and $L(\phi)$ in degree is the road orientation with respect to the direct radio path which is different for different angle.

$$L(\phi) = -10 + 0.35\phi \leq \phi < 35^\circ \dots \dots \dots (2.8)$$

$$L(\phi) = 2.5 + 0.075(\phi - 35) 35^\circ \leq \phi < 55^\circ \dots \dots \dots (2.9)$$

$$L(\phi) = 4.0 - 0.114(\phi - 55) 55^\circ \leq \phi < 90^\circ \dots \dots \dots (2.10)$$

The multi-screen diffraction Loss L_s is given by

$$L_s = -18 \log(1 + (h_{tx}) - (h_B) - 9 \log(d_b) + k_a + k_d \log(d) + k_f \log(f_c). (2.11)$$

Where d_b is separation between two building, d is distance between BTS and MS.

The first term after the equal sign is assumed to be zero if $(h_{tx}) - (h_B) \leq 0$ and

$$k_a = 54 \quad \text{for } (h_{tx}) - (h_B) > 0 \dots \dots \dots (2.12)$$

$$k_d = 18 \quad \text{for } (h_{tx}) - (h_B) > 0 \dots \dots \dots (2.13)$$

$$k_f = -4 + 1.5 \left(\frac{f_c}{925} - 1 \right) \text{ for metropolitan centers.} \dots \dots \dots (2.14)$$

2.2.4 Hyperbolic Positioning Algorithm

By comparing the signal power as it is received at a user from 2 BTS, the distance difference can be evaluated. A constant distance difference between two BTSs defines a hyperbola on which the user must lie. The intersection of at least two hyperbola determines the user location. The distance difference defines a set of non-linear equations given as

$$d_{ij} = d_i - d_j \dots \dots \dots (2.15)$$

Where, d_i is the distance of MS from i^{th} BTS,

d_j is the distance of MS from reference BTS,

And all these distance difference can be determined completely from (n-1) distance difference by selecting one reference point.

Hence, we can see that,

$$X_i^2 + Y_i^2 - 2X_i x - 2Y_i y + x^2 + y^2 = d_{ij}^2 + 2d_{ij}d_j + d_j^2 \dots\dots\dots (2.16)$$

Let $d_i^2 = (X_i - x)^2 + (Y_i - y)^2$ be evaluated by mapping a reference point. Setting $i = j$ and subtracting it from (2.16), we have

$$Q_i - Q_j - d_{ij}^2 - 2d_{ij}d_j - 2[X_i - X_j \quad Y_i - Y_j] \begin{bmatrix} x \\ y \end{bmatrix} = 0 \dots\dots\dots (2.17)$$

Where, $Q_i = X_i^2 + Y_i^2$ and $Q_j = X_j^2 + Y_j^2$, d_j is the reference distance from the reference BTS to the mobile user and d_{ij} is evaluated form 2.15. As the j th equation is degenerate, we have $n - 1$ equation. The set of $n - 1$ equation can be written in matrix form as

$$G - 2WP = 0 \dots\dots\dots (2.18)$$

Where,

$$G = \begin{bmatrix} Q_1 - Q_j - d_{1j}^2 - 2d_{1j}d_j \\ \vdots \\ Q_{j-1} - Q_j - d_{j-1j}^2 - 2d_{j-1j}d_j \\ Q_{j+1} - Q_j - d_{j+1j}^2 - 2d_{j+1j}d_j \\ \vdots \\ Q_N - Q_j - d_{Nj}^2 - 2d_{Nj}d_j \end{bmatrix}, W = \begin{bmatrix} X_1 - X_j & Y_1 - Y_j \\ \vdots & \vdots \\ X_{j-1} - X_j & Y_{j-1} - Y_j \\ X_{j+1} - X_j & Y_{j+1} - Y_j \\ \vdots & \vdots \\ X_N - X_j & Y_N - Y_j \end{bmatrix}$$

and $P = [x \quad y]^T$. Afterward, we are able to find the user location provided by the least square procedure. The least square solution of user location is

$$P = \frac{1}{2} (W^T W)^{-1} W^T G \dots\dots\dots (2.19)$$

In this way location of MS is estimated. It is assumed that P and d_j are independent however the known relation existed as $d_j^2 = (X_j - x)^2 + (Y_j - y)^2$. Thus, the relative error existed between the distance of P from reference point and d_j which is calculated as

$$e = (\sqrt{(X_i - x)^2 + (Y_i - y)^2} - d_i)^2 [15].$$

2.2.5 Weighted Hyperbolic Algorithm

The linear problem in 2.19 can be further solved using weighted least square estimator as

$$\hat{P} = \frac{1}{2} (W^T S^{-1} W)^{-1} W^T S^{-1} G \dots\dots\dots (2.20)$$

Where S is where S is the covariance matrix of vector G. Note that the noise affecting the measurement vector G does not have zero mean, so the estimator Equation (2.20) is biased. Assuming that the measurements of the distances d_i to different reference nodes are independent and as X_i and Y_i are constants, the matrix S can be easily calculated as [14].

$$S = \begin{bmatrix} Var(d_1^2) + Var(d_2^2) & Var(d_1^2) & Var(d_1^2) \\ Var(d_1^2) & Var(d_1^2) + Var(d_3^2) & Var(d_1^2) \\ \vdots & \ddots & \vdots \\ Var(d_1^2) & Var(d_1^2) & Var(d_1^2) + Var(d_N^2) \end{bmatrix}$$

2.2.6 Interpolation

It is the process of deriving a simple function from a set of discrete data points so that the function passes through all the given data points (i.e. reproduces the data points exactly) and can be used to estimate data points in-between the given ones. Polynomials are commonly used for interpolation because they are easier to evaluate, differentiate, and integrate - known as polynomial interpolation.

Spline interpolation uses a number of polynomial functions to interpolate a set of data points with each polynomial for two adjacent data points. The Spline method is necessary because often times when the order of the polynomial become large polynomial interpolation shows oscillatory behavior. The most common spline interpolations are linear, quadratic, and cubic splines. Linear interpolation uses lines to connect each pair of consecutive data points resulting in a piecewise interpolation.

CHAPTER THREE: METHODOLOGY

3.1 Research Work Flow

Figure 3.1 shows the intermediate stages that have been followed for the accomplishment of this thesis work.

3.1.1 Study and Selection of Mathematical Principle

Various range based mathematical principles to calculate the position based on geometric principle such as circular, hyperbolic are studied [7] and it is found that performance of hyperbolic localization is better than that of circular localization. This thesis work is performed for indoor mobile user and indoor MS received signal is drastically affected by penetration loss, multipath signal loss and diffraction loss resulting in increased RSS value. If Circular localization is used in then, error will be very high as the circle drawn with radius equal to the distance estimated from observed RSS value inside the building will be larger than that of the signal received just outside the building in open space concluding to intersection of 3 circle at different place from the actual MS location where as Hyperbolic localization uses distance difference to draw hyperbola hence such common error are eliminated resulting in better estimation of MS location. Hence, Hyperbolic localization is used in this research.

3.1.2 Selection of the Pathloss Model and Enhance its Estimated Distance

Accuracy

Empirical pathloss model for urban area are studied and distance estimation is performed taking Hata model, Cost 321 Hata and Walfisch-Ikegami. Pathloss model with minimum RMSE value is selected and, in this study, pathloss of Walfisch-Ikegami has minimum RMSE value and hence it is selected to estimate distance of MS from BTS.

Distance estimated form Walfisch Ikegami model is not so accurate hence Polynomial and spline interpolation are used to forecast error and that error is adjusted in the estimated distance to find enhanced estimated distance. Degree of polynomial is taken based on minimum RMSE and MAE value.

3.1.3 Selection of Performance Metric

Location accuracy means difference in the distance between the actual location and calculated location such accuracy is measured in meter. Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) is used as a performance metric. Performance metrics are used here to select pathloss model and degree of polynomial.

3.1.4 Validation.

The result is validated with the data received from TEMS.

TEMS is a handheld tool for verification, maintenance and troubleshooting of mobile networks as well as for basic cell planning task. It collects measurements and event and presents them on device display. It is either can be installed in laptop with a handset or in handset only such as TEMS pocket 14 is installed in Samsung Galaxy S4 to record network parameter in this observation. Data can either be recorded in idle mode (only scan network parameter and record, no need to generate call) or dedicated mode (call is generated to any number and parameters were recorded). Here, while performing this research data were recorded in idle mode and recorded data were signal strength from serving and neighbor BTS and latitude and longitude of handset.

Latitudes and longitudes received from TEMS and calculated latitudes and longitudes are plotted in the Google Map.

Data received from TEMS contains latitude and longitude value up to 6 decimal digits. 1 degree of latitude variation gives location error of 111 km, when data were truncated to 4 decimal digits it is observed that location error was improved by 3 m in average and when data were truncated to 3 decimal digits then location error was improved by 35 m in average.

Geometric Dilution of Precision (GDOP) is calculated to check the precision of data measuring device such as location of MS relative to error introduced by the device i.e. how errors in the measurement will affect the final state estimation. From table 3.1 it is seen that calculated GDOP value lies in the range 2-5 which means GPS accuracy is good and represents a level that marks the minimum appropriate for making accurate decisions. Positional measurements could be used to make reliable in-route navigation suggestions to the user.

$$GDOP = \frac{\Delta(\text{Output location})}{\Delta(\text{Measured Data})}$$

Table 3.1 Calculated GDOP

MS location	Actual lat. of MS [deg]	Actual long. of MS [deg]	Estimated Lat. Of MS [deg]	Estimated long. Of MS [deg]	Lat. of BTS [deg]	long. of BTS[deg]	Delta Output	Delta Measured.	GDOP
Alka	27.674805	85.314870	27.675168	85.314280	27.672110	85.313610	70.717788	22.018628	4
Bigmart	27.677348	85.308705	27.677330	85.308476	27.675080	85.307490	22.633567	10.746322	3
chakupat2	27.681282	85.324975	27.680942	85.323886	27.679610	85.324154	113.697189	52.265670	3
farmarmart	27.678885	85.309365	27.679342	85.309618	27.678500	85.310010	56.609299	24.652728	3
gyanodaya	27.680308	85.305452	27.679853	85.305640	27.674920	85.302570	53.974704	36.695589	2
Jawalakhel	27.672212	85.315197	27.671811	85.315828	27.672110	85.313610	76.512341	64.273828	2
Kandevasthan	27.686480	85.316905	27.687026	85.317612	27.687238	85.317216	92.408148	44.169156	3
ThadoDunga	27.678367	85.306058	27.678038	85.306239	27.674920	85.302570	40.614076	13.898126	3

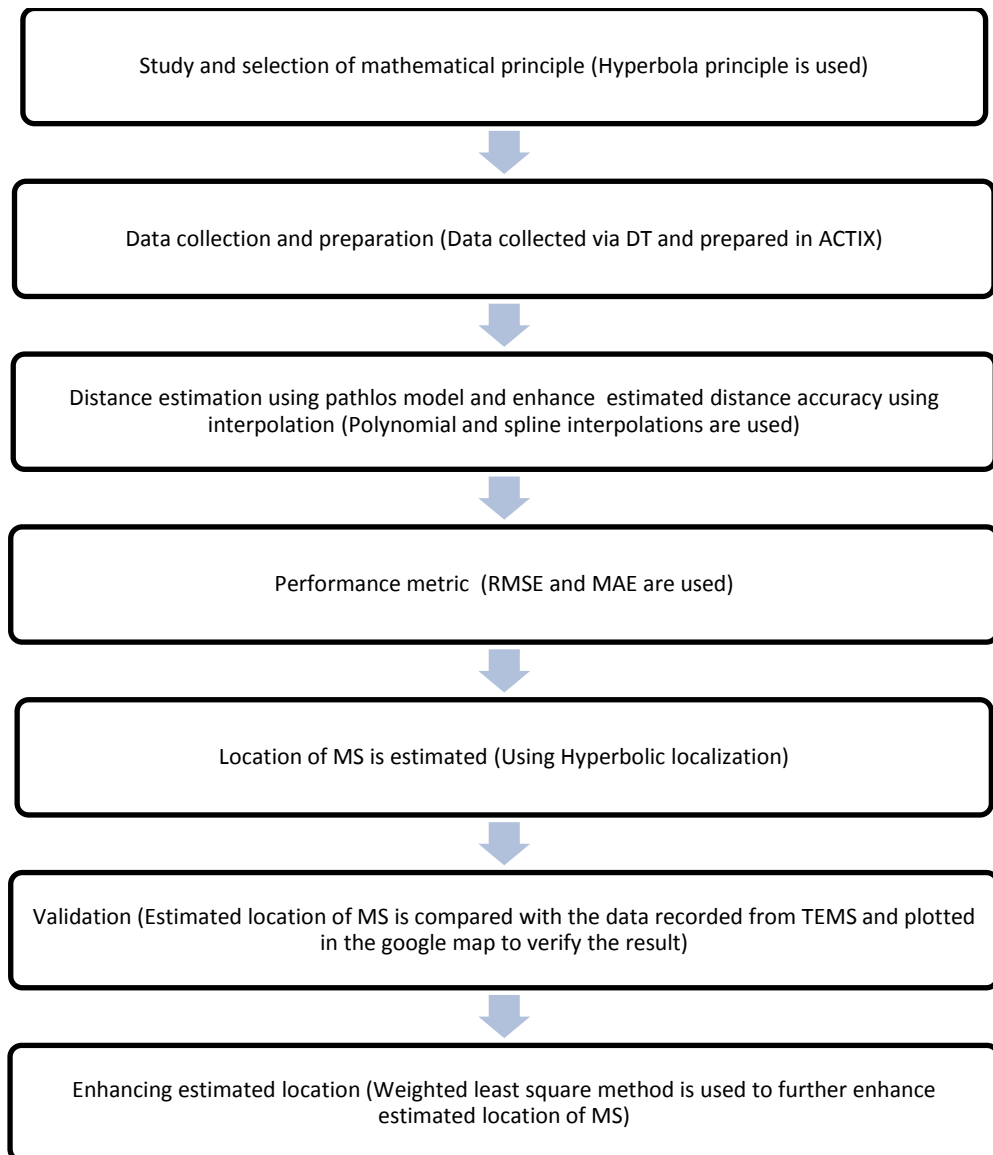


Figure 3.1 A flow chat for methodology

3.2 Tools Used

- a) Pocket TEMS 14 for Drive test.
- b) Actix
- c) Visual basic script.
- d) Google Earth
- e) MapInfo

3.3 Data Collection

Data collection has been performed at 20 locations via drive test at Sanepa, Jhamsikhel, Jawlakhel and Patan area which are covered by 23 BTS of Ncell as shown in fig 3.2. More than 500 samples were taken in each location and RSS for a location is average of those samples taken at interval of 3 to 4 minutes. Since RSS value is fluctuating every second hence for each location RSS value is taken for about 4 minutes and average was taken from those samples. Similarly, for measured MS location also data were taken by walking a diameter of 4m to 5m distance and average of samples were taken to find the exact location. Data were recorded in the radius of 70 m to 800 m distance from the BTS and received data are more accurate in the place with less building which can be seen from estimated distance. Parameters measured from TEMS is given in table 3.2.

Table 3.2 Parameter measured from TEMS

MS location	Site ID	BSIC/CI	RSS [dBm]	lat. of MS [deg]	long. of MS [deg]
Alka	KTM381	7-6,	-65.8	27.674805	85.314870
Alka	KTM361	13611	-56.5	27.674805	85.314870
Alka	KTM541	2-7,	-75.4	27.674805	85.314870
Alka	KTM366	0-3,	-73.7	27.674805	85.314870
Bigmart	KTM362	13623	-63	27.677348	85.308705
Bigmart	KTM341	3-0,	-62	27.677348	85.308705
Bigmart	KTM383	0-6,	-76	27.677348	85.308705

Table 3.3 Data form Cell file

Site ID	Transmit power [dBm]	long. of BTS [deg]	lat. of BTS [deg]	Freq. [MHz]	Antenna height [m]
KTM381	40	85.315705	27.677531	900	21
KTM361	42	85.313610	27.672110	900	45
KTM541	42	85.318760	27.674730	900	31
KTM366	42	85.319000	27.671130	900	23
KTM362	42	85.310010	27.678500	900	29
KTM341	42	85.307490	27.675080	900	22
KTM383	42	85.307557	27.685003	900	19
KTM383	42	85.307557	27.685003	900	19
KTM059	42	85.301470	27.681010	900	24
KTM327	46	85.312156	27.683670	900	27

Table 3.4 Other parameter for calculating distance from pathloss model

Site ID	Other building height [m]	Building separation [m]	Road width [m]	Angle incident [deg]	Height of mobile [m]
KTM381	9	1	11	1	1.2
KTM361	11	3	14	1	1.2
KTM541	19	2	9	1	1.2
KTM366	11	1	11	1	1.2
KTM362	15	1	9	1	1.2
KTM341	10	1	8	1	1.2
KTM383	7	1	12	1	1.2
KTM383	7	1	12	1	1.2
KTM059	12	2	11	1	1.2
KTM327	15	1	12	1	1.2

3.5 Calculation of Path Loss from Three Different Path Loss Models and Selecting One with Least Error.

Measured pathloss (which is RSS + transmission power) is compared with the pathloss calculated from three different pathloss models such as Okumura-Hata model, Cost 231

model and Walfisch-Ikegami model. It is seen that Pathloss calculated form Walfisch-Ikegami is much closer to measured pathloss than that of another model based on RMSE value. RMSE for Walfisch-Ikegami is least (4.58158) compared to other models as shown in the table 3.4. Hence distance is estimated using Walfisch- Ikegami model.

Table 3.5 Comparison of pathloss model

Site ID	Measur ed PL [dBm]	Hata PL [dBm]	Cost 231 Hata PL [dBm]	Walfisc h-ikegami PL [dBm]	error Hata [dBm]	error Cost 231 [dBm]	error Walfisch -Ikegami [dBm]
KTM381	106	111	107	105	-5.298	-0.882	0.934
KTM361	99	108	103	94	-9.590	-4.228	4.204
KTM541	117	112	108	113	5.049	9.223	3.924
KTM366	116	120	118	117	-4.474	-2.144	-1.173
KTM362	105	101	94	101	3.796	10.833	4.482
KTM341	104	109	104	105	-5.038	-0.132	-1.353
KTM383	118	128	127	119	-9.509	-8.668	-0.513
KTM383	97	112	108	103	-15.331	-11.225	-5.722
KTM059	108	117	114	112	-9.330	-6.348	-4.234
KTM327	119	120	118	120	-1.087	1.161	-1.288
RMSE					7.645	7.231	4.582

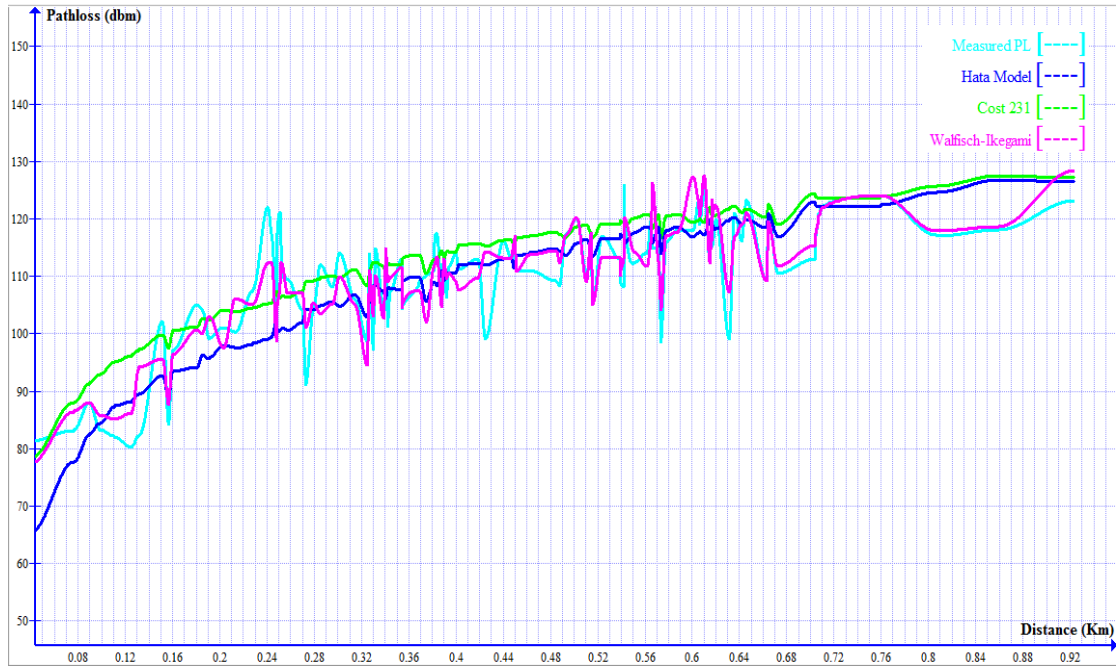


Figure 3.3 Comparison of Pathloss model

Table 3.6 Distance calculated using Walfish- Ikegami pathloss model

Site ID	Transmit power [dBm]	RSS [dBm]	Measured PL [dBm]	Walfisch-Ikegami PL [dBm]	Distance estimate using Walfish-Ikegami [Km]
KTM381	40	-66	106	105	0.3327
KTM361	42	-57	99	94	0.4189
KTM541	42	-75	117	113	0.4865
KTM366	42	-74	116	117	0.5375
KTM362	42	-63	105	101	0.2383
KTM341	42	-62	104	105	0.2575
KTM383	42	-76	118	119	0.8333
KTM383	42	-55	97	103	0.2334
KTM059	42	-66	108	112	0.3775
KTM327	46	-73	119	120	0.5610

3.6 Error Prediction Using Polynomial Interpolation and Spline Interpolation

Error is calculated by taking difference between actual distance and estimated distance by Walfisch-Ikegami model. Actual distance is calculated from the latitude and longitude of MS and BTS obtained from TEMS. Distance calculation formula from latitude and longitude is given by

$$d = \cos^{-1}(\sin(lat1) * \sin(lat2) + \cos(lat1) * \cos(lat2) * \cos(long1 - lng2)) * 6373554 \text{ m} \dots\dots\dots (3.1)$$

Error of distance estimation from Walfisch-Ikegami is then used as one of the parameters for polynomial interpolation to forecast error. Newton dividend difference formula is used to calculate coefficient of polynomial equation used for error forecast and error is predicted for different degree of polynomial. Predicted error is then added to the distance estimated by Walfisch-Ikegami pathloss model to find enhanced estimated distance and again error is calculated with actual distance. Similarly, the process is repeated for each degree of polynomial interpolation.

For polynomial interpolation: From the table 3.9 it can be seen that RMSE for 8th degree is least than other degree but MAE and MAPE value is least for 11th and 12th degree of polynomial moreover RMSE value of 11th degree polynomial is less than that of 12th degree hence 11th degree of polynomial is selected for error forecast.

For Spline interpolation: For this first of all data is arranged in ascending order and taking data from first, last and varying middle data cubic spline interpolation is implemented and forecasted value with minimum error is taken into consideration.

Table 3.7 Error prediction using polynomial interpolation

Tx-Rx Actual Distance [Km]	Distance estimate using Walfish-Ikigami [Km]	error in m	Error predicted by 11degree interpolation [Km]	New enhanced distance estimated [Km]	Error between actual and enhanced distance [Km]
0.040	0.051	0.011	-0.006	0.045	0.005
0.077	0.063	0.014	0.003	0.066	0.011

Tx-Rx Actual Distance [Km]	Distance estimate using Walfish-Ikigami [Km]	error in m	Error predicted by 11degree interpolation [Km]	New enhanced distance estimated [Km]	Error between actual and enhanced distance [Km]
0.131	0.064	0.067	0.004	0.068	0.063
0.099	0.085	0.014	0.012	0.097	0.002
0.126	0.088	0.038	0.014	0.101	0.025
0.090	0.090	0.000	0.015	0.105	0.015
0.111	0.094	0.017	0.017	0.111	0.000
0.157	0.125	0.032	0.034	0.159	0.002
0.213	0.148	0.065	0.040	0.189	0.024
0.273	0.149	0.124	0.041	0.190	0.083

Table 3.8 Selection of degree of polynomial to predict error

Minimum value	Performance Metric	3	6	8	9	10	11	12
100.95	RMSE	102.85	101.79	100.95	101.56	101.12	101.07	101.24
204.60	MAPE	214.25	223.09	213.74	217.09	216.47	204.60	204.98
75.02	MAE	78.13	78.88	77.69	78.16	76.12	75.09	75.02
Minimum value	Performance Metric	14	16	19	21	24	28	32
100.95	RMSE	158.66	104.88	117.35	111.75	273.29	113.50	483.33
204.60	MAPE	239.68	218.85	253.19	215.57	339.28	230.87	553.80
75.02	MAE	100.13	79.79	88.50	82.61	138.66	83.92	257.83

Table 3.9: Error prediction using Spline interpolation

Distance estimate using Walfish-Ikigami [Km]	Tx-Rx Actual Distance [Km]	Error [Km]	Error predicted by Spline interpolation [Km]	Enhanced estimated distance [Km]	Error between actual and estimated distance [Km]
0.06283	0.07668	0.01385	0.00512	0.06794	0.00873
0.09011	0.08977	0.00034	0.02156	0.11167	0.0219
0.08459	0.09858	0.01398	0.01848	0.10307	0.0045
0.09406	0.1112	0.01714	0.02368	0.11775	0.00654
0.08753	0.12601	0.03848	0.02013	0.10766	0.01835
0.06446	0.13136	0.0669	0.00304	0.0675	0.06386
0.22532	0.15218	0.07314	-0.1088	0.11647	0.03571
0.12494	0.15683	0.03188	0.03881	0.16375	0.00692
0.16847	0.15989	0.00858	-0.0542	0.11424	0.04565
0.23829	0.18161	0.05668	-0.0534	0.1849	0.00329

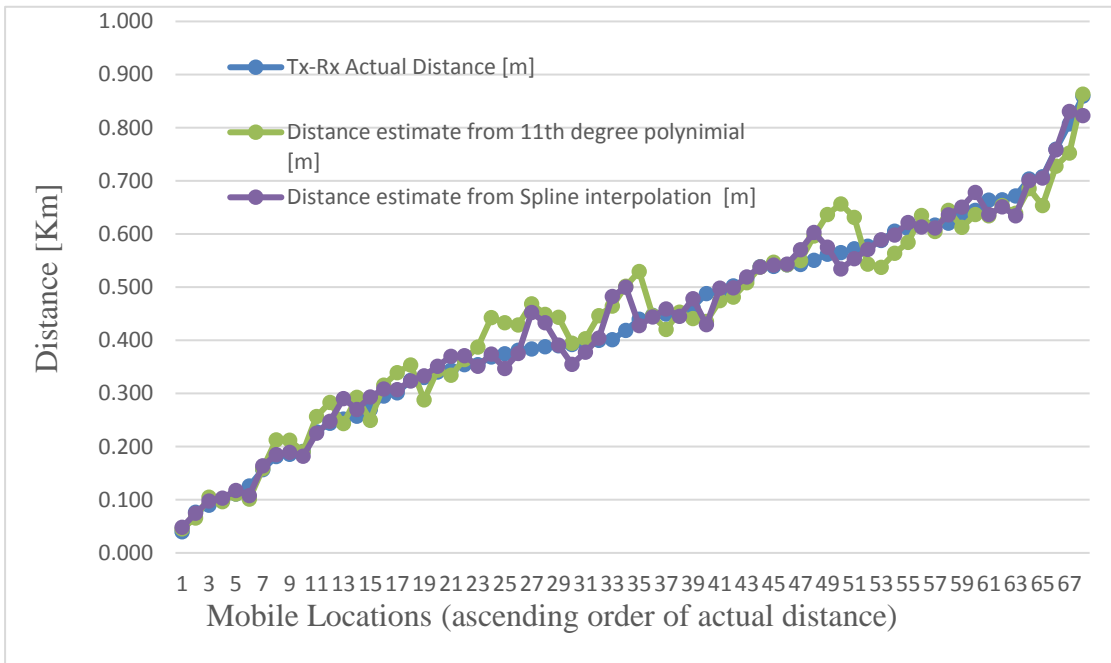


Figure 3.4: Comparison of estimated distance using polynomial interpolation and spline interpolation with actual distance

3.7 Estimating MS Location Using Hyperbolic Localization Algorithm

Location of MS is estimated using algorithm described in the literature (2.19).

Estimated location using hyperbolic localization is compared with four different scenario and found that spline interpolation with weighted least square method have most accurate estimation but still there is error ranging from 22 m to 173 meter which is not as good as GPS data in open space which has accuracy of 5m.

Table 3.10 Location estimation of MS using hyperbolic localization

MS location	lat. of MS TEMS [deg]	long. of MS TEMS [deg]	Estimated lat. Of MS using walfisch Ikegami [deg]	Estimated long. Of MS using walfisch Ikegami [deg]	Estimated lat. Of MS using 11th degree Interpolation [deg]	Estimated long. Of MS using 11th degree Interpolation [deg]	Estimated lat. Of MS using Spline Interpolation [deg]	Estimated long. Of MS using Spline Interpolation [deg]	Estimated lat. Of MS Spline Interpolation with WLS [deg]	Estimated long. Of MS Spline Interpolation with WLS [deg]
Alka	27.674805	85.314870	27.674340	85.314686	27.674405	85.315008	27.675168	85.314280	27.675103	85.314425
Bigmart	27.677348	85.308705	27.677444	85.307711	27.678767	85.306275	27.677330	85.308476	27.677330	85.308476
Chakupat patan	27.678358	85.323358	27.679104	85.324931	27.678145	85.326177	27.678743	85.325267	27.678599	85.325307
Chakupat2	27.681282	85.324975	27.681861	85.324478	27.681511	85.323834	27.680942	85.323886	27.681737	85.323983
Farmar-mart	27.678885	85.309365	27.680440	85.308541	27.680608	85.307688	27.679342	85.309618	27.679342	85.309618
Gyanodaya	27.680308	85.305452	27.679259	85.305504	27.679306	85.306259	27.679853	85.305640	27.679831	85.305752
Jawalakhel	27.672212	85.315197	27.671889	85.315606	27.672101	85.315332	27.671811	85.315828	27.672337	85.315688
Kandevasthan	27.686480	85.316905	27.685860	85.319242	27.686119	85.319167	27.687026	85.317612	27.687026	85.317612
ThadoDunga	27.678367	85.306058	27.678854	85.304339	27.678233	85.305898	27.678038	85.306239	27.678038	85.306239

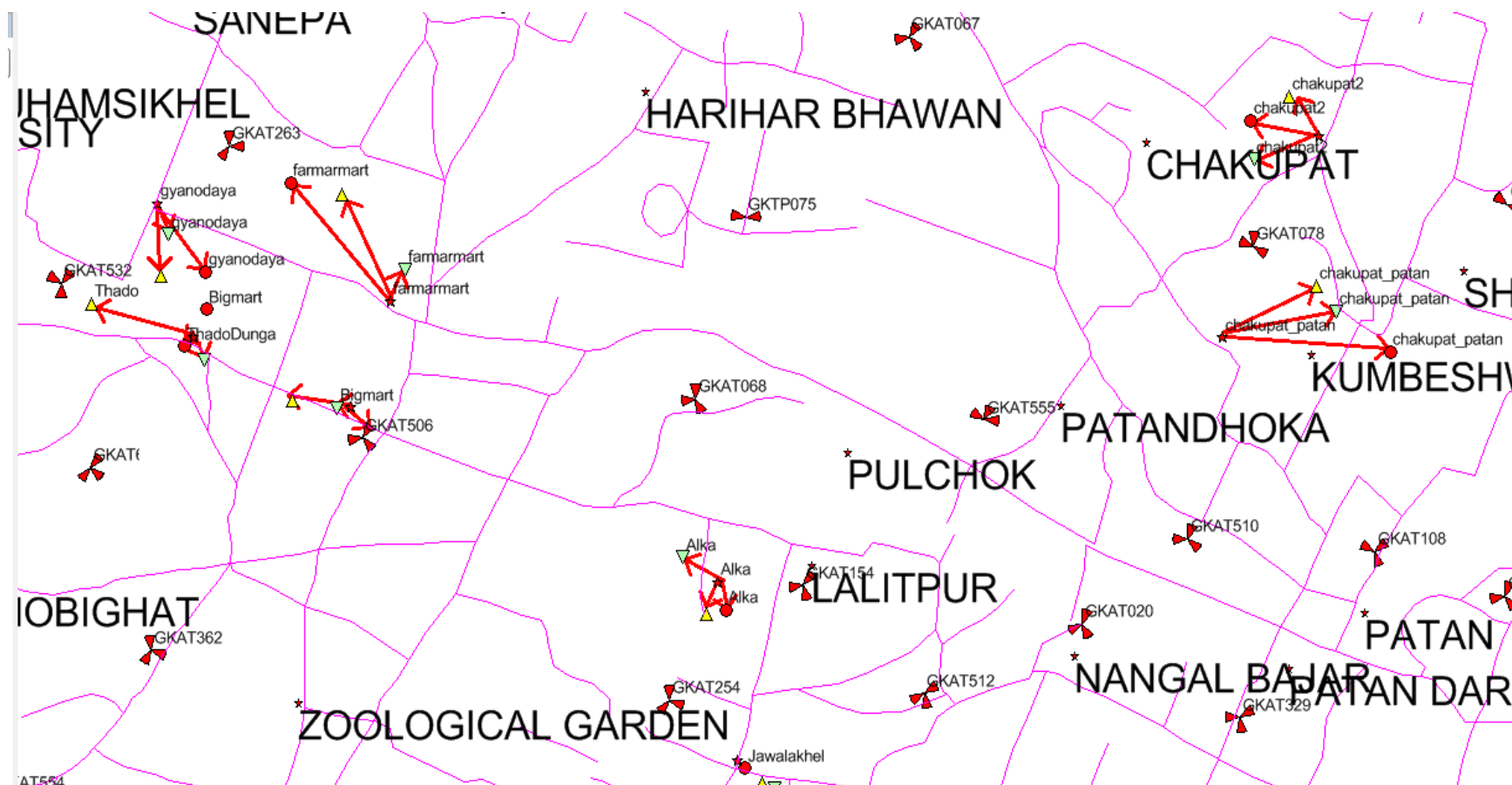


Figure 3.5 Actual and estimated location plotted in MapInfo.

CHAPTER FOUR: RESULT AND DISCUSSION

RSS is measured to estimate location of MS in cellular network. Maximum value of RSS recorded was -38.1 dBm and minimum RSS recorded was -81.3 dBm. Acceptable range of RSS for secure connection is -86dBm to -100 dBm whereas strong signal with good data speed is obtained at RSS value of -70 dBm to -85dBm. Walfisch-Ikegami model was used to estimate distance from the recorded RSS level. Walfisch-Ikegami model has linear relationship with measured pathloss throughout the distance 70 m to 800 m. Among three pathloss model used for distance estimation Walfisch-Ikegami have lowest RMSE value (3.75949) hence it is selected to estimate distance between MS and BTS.

Distance estimated from WI model contains error while compared with actual distance hence interpolation is performed based on actual distance and error and error is forecasted for WI estimated distance. Such forecasted error is then adjusted with WI estimated distance to obtain enhance distance which then used to calculate location of MS using Hyperbolic localization. RSS from minimum 3 BTS and RSS from maximum 5 BTS were taken to locate MS in cellular network. To draw hyperbola distance difference of MS from BTS is taken into consideration and RSS with highest value is taken as reference BTS. Comparison of location error while changing reference BTS is shown in table 4.1. And result shows that location error is minimum when RSS from BTS with highest value is taken as reference BTS. Location of MS is calculated for four different scenario such as: WI model alone, WI with 11th degree interpolation, WI with spline interpolation and WI with spline interpolation and WLS. WLS does not show much variation in location estimation while taking only 3 BTS however the result is much improved when more than 3 BTS are taken into consideration for estimating location of MS as shown in table

This thesis result shows that 69 percentile of estimated location are within 90m using spline interpolation whereas only 36 percentile of location are estimated are within 90 m using polynomial interpolation. Location error of 53 m at minimum and maximum error 250m using estimated distance from Walfisch-Ikegami pathloss model, 18 m to 286 m while using estimated distance from 11th degree of polynomial interpolation and 22 m to 177 m from spline interpolation. Minimum location error from spline interpolation is not less than that of polynomial interpolation but MAE of spline

interpolation (76.738) is much better than that of Polynomial interpolation (153.703). Though WLS method does not decrease minimum distance error but overall MAE of the system is decreased (73.901) using spline interpolation with WLS.

From the result it can be clearly seen that location accuracy is increased while using hyperbolic localization along with WLS and spline interpolation than that of hyperbolic localization with spline interpolation and hyperbolic localization with polynomial interpolation.

Table 4.11 Comparison of location error while changing reference BTS

MS location	RSS [dBm]	Distance estimate from Spline Interpolation [m]	Reference BTS without highest RSS value	Reference BTS with highest RSS value
			Location error	
Alka	-66	327	92	55
Alka	-57	290		
Alka	-75	471		
Alka	-74	571		

Table 4.2 Comparison of location error with respect to number of BTS in case of WLS algorithm.

MS location	RSS [dBm]	With WLS	Without WLS
		Location error	
Gyanodaya	-72	174	177
Gyanodaya	-75		
Gyanodaya	-72		
Gyanodaya	-77		
Gyanodaya	-63		
Gyanodaya	-78	22	22
Bigmart	-63		
Bigmart	-62		
Bigmart	-76		

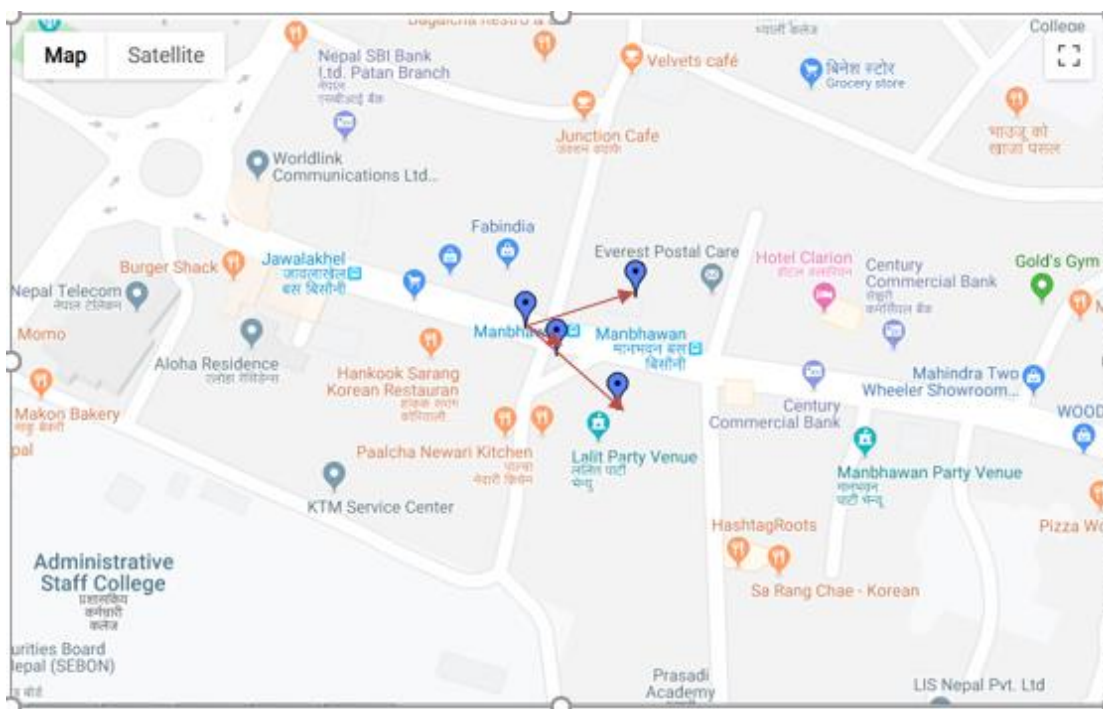


Figure 4. 1 Actual and estimated location of MS shown in Google Map

Table 4.3 Comparison of location estimation distance error

MS location	Location error using Walfisch-Ikegami	Location error using 11th degree polynomial interpolation	Location error using Spline interpolation	Location error using Spline interpolation and WLS
Alka	54	46	70	54
Bigmart	98	286	22	22
Chakupat_patan	175	278	177	173
Chakupat2	80	115	113	110
Farmarmart	191	253	56	56
Gyanodaya	116	136	53	60
Jawalakhel	53	18	62	53
Kandevasthan	240	226	92	92
ThadoDunga	177	21	40	40

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this thesis RSS is used to calculate distance between MS to BTS and that distance difference is then used to estimate location of MS using hyperbolic localization. Though there are various range-based algorithm are available for location estimation but RSS is found to be more realistic in term of implementation. Despite of low complexity and easy implementation, RSS based system have high bias error which may be because of error while recording data, error introduced by device and finally error in distance estimation using RSS value. Using hyperbolic localization mitigate common error while measuring RSS value from different BTS.

Results clearly shows that location accuracy is increased while using hyperbolic localization along with WLS and spline interpolation than that of hyperbolic localization with spline interpolation and hyperbolic localization with polynomial interpolation. However, error is prominent in the final result as well. Reason for such error may be because of measurement error i.e. device used for recording RSS and other information could not record accurately, empirical pathloss model which could not accurately estimate reference distance also interpolation could not predict such non-linear error hence that error get propagated in the final result.

5.2 Recommendations

Following steps can be performed which probably could reduce error and locate MS more accurately than this:

1. Device with more precision can be used to record data.
2. Recording more data at a location so that while taking average more accurate result can be obtained.
3. Precisely selecting parameter for pathloss model which then used to estimate distance.
4. Using neural network algorithm to minimize error for distance estimation as well as in the final result.

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APPENDIX A: PARAMETER MEASURED FORM TEMS

MS location	Site ID	BSIC/CI	RSS [dBm]	lat. of MS [deg]	long. of MS [deg]
Alka	KTM381	7-6,	-65.8	27.674805	85.314870
Alka	KTM361	13611	-56.5	27.674805	85.314870
Alka	KTM541	2-7,	-75.4	27.674805	85.314870
Alka	KTM366	0-3,	-73.7	27.674805	85.314870
Bigmart	KTM362	13623	-63	27.677348	85.308705
Bigmart	KTM341	3-0,	-62	27.677348	85.308705
Bigmart	KTM383	0-6,	-76	27.677348	85.308705
CG	KTM383	13833	-55	27.682290	85.306203
CG	KTM059	1-6,	-66	27.682290	85.306203
CG	KTM327	0-2,	-73	27.682290	85.306203
chakupat_patan	KTM334	13342	-55	27.678358	85.323358
chakupat_patan	KTM380	2-2,	-78	27.678358	85.323358
chakupat_patan	KTM359	1-5,	-72	27.678358	85.323358
chakupat_patan	KTM379	2-4,	-73	27.678358	85.323358
chakupat2	KTM334	13341	-59	27.681282	85.324975
chakupat2	KTM392	2-7,	-73	27.681282	85.324975
chakupat2	KTM380	2-2,	-74	27.681282	85.324975
chakupat2	KTM379	2-4,	-70	27.681282	85.324975
Farmer-mart	KTM362	13623	-41	27.678885	85.309365
Farmer-mart	KTM341	3-0	-69	27.678885	85.309365
Farmer-mart	KTM383	0-6	-71	27.678885	85.309365
Friend-Colony	KTM327	13272	-53	27.682863	85.313865
Friend-Colony	KTM379	2-4,	-68	27.682863	85.313865
Friend-Colony	KTM362	7-3,	-73	27.682863	85.313865
Gabahal	KTM541	15412	-65.4	27.674293	85.321015
Gabahal	KTM346	13463	-67.9	27.674293	85.321015
Gabahal	KTM381	7-6,	-81	27.674293	85.321015
Gabahal	KTM542	1-4,	-81.3	27.674293	85.321015

MS location	Site ID	BSIC/CI	RSS [dBm]	lat. of MS [deg]	long. of MS [deg]
Gusingal	KTM354	13543	-60	27.687848	85.308560
Gusingal	KTM382	7-5,	-66	27.687848	85.308560
Gusingal	KTM383	0-7,	-73	27.687848	85.308560
Gyanodaya	KTM059	1-6	-72	27.680308	85.305452
Gyanodaya	KTM362	7-6	-75	27.680308	85.305452
Gyanodaya	KTM383	0-6	-72	27.680308	85.305452
Gyanodaya	KTM341	2-7	-77	27.680308	85.305452
Gyanodaya	KTM358	13581	-63	27.680308	85.305452
Gyanodaya	KTM327	0-2	-78	27.680308	85.305452
HasapataGanesh	KTM362	13623	-62	27.680903	85.310378
HasapataGanesh	KTM327	0-2,	-67	27.680903	85.310378
HasapataGanesh	KTM341	3-0,	-79	27.680903	85.310378
Ikhache	KTM359	1-2,	-72	27.679663	85.328732
Ikhache	KTM334	13341	-69	27.679663	85.328732
Jawalakhel	KTM361	13612	-41.8	27.672212	85.315197
Jawalakhel	KTM366	0-3,	-69.3	27.672212	85.315197
Jawalakhel	KTM541	2-7,	-70.2	27.672212	85.315197
Jawalakhel	KTM375	0-0,	-71	27.672212	85.315197
Kandevasthan	KTM356	13562	-46	27.686480	85.316905
Kandevasthan	KTM379	2-3,	-69	27.686480	85.316905
Kandevasthan	KTM392	1-1,	-74	27.686480	85.316905
Kishnagali	KTM381	7-4,	-69	27.680450	85.317480
Kishnagali	KTM379	13793	-65	27.680450	85.317480
Kishnagali	KTM380	2-2,	-81	27.680450	85.317480
Kishnagali	KTM334	2-5,	-79	27.680450	85.317480
Kishnagali	KTM359	1-5,	-81	27.680450	85.317480
Kumaripati-kumari	KTM366	13662	-40.1	27.670683	85.320233
Kumaripati-kumari	KTM368	0-7,	-62	27.670683	85.320233
Kumaripati-kumari	KTM361	0-1,	-68.4	27.670683	85.320233
Lagankhel	KTM368	13683	-38.1	27.669565	85.322010

MS location	Site ID	BSIC/CI	RSS [dBm]	lat. of MS [deg]	long. of MS [deg]
Lagankhel	KTM366	1-3,	-64.9	27.669565	85.322010
Lagankhel	KTM542	1-4,	-57	27.669565	85.322010
Lagankhel	KTM375	0-0,	-66.1	27.669565	85.322010
Lagankhel	KTM374	0-1,	-57	27.669565	85.322010
Manbhawan	KTM366	13663	-67.8	27.672798	85.317330
Manbhawan	KTM541	2-7,	-67.5	27.672798	85.317330
Manbhawan	KTM361	0-1,	-68	27.672798	85.317330
Manbhawan	KTM381	7-6,	-72	27.672798	85.317330
Mart	KTM356	1-2,	-62	27.685725	85.318005
Mart	KTM379	13791	-49	27.685725	85.318005
Mart	KTM327	0-0,	-74	27.685725	85.318005
Patan	KTM380	2-2,	-73	27.678608	85.320875
Patan	KTM334	13343	-59	27.678608	85.320875
Patan	KTM381	7-4,	-77	27.678608	85.320875
Patan	KTM379	2-4,	-73	27.678608	85.320875
Pulchowk	KTM381	13812	-43.2	27.676742	85.316158
Pulchowk	KTM541	2-7,	-70.6	27.676742	85.316158
Pulchowk	KTM361	3-4,	-56.2	27.676742	85.316158
spid4	KTM379	13792	-58	27.681452	85.320127
spid4	KTM334	2-5,	-71	27.681452	85.320127
spid4	KTM380	2-2,	-71	27.681452	85.320127
spid4	KTM381	7-4,	-75	27.681452	85.320127
sports	KTM362	13622	-39	27.678588	85.310405
sports	KTM341	3-0	-67	27.678588	85.310405
St.Maryschool	KTM362	7-3,	-79	27.676707	85.311558
St.Maryschool	KTM381	13813	-73	27.676707	85.311558
St.Maryschool	KTM341	3-0,	-74	27.676707	85.311558
Summit	KTM356	13563	-62	27.686832	85.313648
Summit	KTM327	0-2,	-65	27.686832	85.313648
Summit	KTM354	1-3,	-78	27.686832	85.313648

MS location	Site ID	BSIC/CI	RSS [dBm]	lat. of MS [deg]	long. of MS [deg]
ThadoDunga	KTM362	7-6,	-72	27.678367	85.306058
ThadoDunga	KTM341	2-7,	-64	27.678367	85.306058
ThadoDunga	KTM358	13581	-59	27.678367	85.306058
un	KTM381	7-4,	-72	27.680085	85.315885
un	KTM379	13793	-68	27.680085	85.315885
un	KTM327	0-0,	-80	27.680085	85.315885
un	KTM362	7-3,	-81	27.680085	85.315885
un	KTM356	2-0,	-75	27.680085	85.315885

APPENDIX B: PARAMETER USED FORM CELL-FILE

Site ID	Transmit power [dBm]	long. of BTS [deg]	lat. of BTS [deg]	Freq. [MHz]	Antenna Height [m]	Other building Height [m]
KTM381	40	85.315705	27.677531	900	21	9
KTM361	42	85.313610	27.672110	900	45	11
KTM541	42	85.318760	27.674730	900	31	19
KTM366	42	85.319000	27.671130	900	23	11
KTM362	42	85.310010	27.678500	900	29	15
KTM341	42	85.307490	27.675080	900	22	10
KTM383	42	85.307557	27.685003	900	19	7
KTM383	42	85.307557	27.685003	900	19	7
KTM059	42	85.301470	27.681010	900	24	12
KTM327	46	85.312156	27.683670	900	27	15
KTM334	42	85.324154	27.679610	900	22	10
KTM380	44	85.321905	27.676616	900	32	20
KTM359	42	85.326309	27.677662	900	26	14
KTM379	42	85.319280	27.683550	900	20	8
KTM334	42	85.324154	27.679610	900	22	10
KTM392	42	85.323200	27.685010	900	27	15
KTM380	44	85.321905	27.676616	900	32	20
KTM379	42	85.319280	27.683550	900	20	8
KTM362	42	85.310010	27.678500	900	29	15
KTM341	42	85.307490	27.675080	900	22	10
KTM383	42	85.307557	27.685003	900	19	7
KTM327	46	85.312156	27.683670	900	27	15
KTM379	42	85.319280	27.683550	900	20	8
KTM362	42	85.310010	27.678500	900	29	17
KTM541	42	85.318760	27.674730	900	31	19
KTM346	42	85.323570	27.674360	900	27	15
KTM381	40	85.315705	27.677531	900	21	9
KTM542	42	85.326130	27.670680	900	24	15
KTM354	42	85.309230	27.689080	900	21	9
KTM382	42	85.305950	27.689150	900	21	9
KTM383	42	85.307557	27.685003	900	19	10
KTM059	42	85.301470	27.681010	900	24	12
KTM362	42	85.310010	27.678500	900	29	15
KTM383	42	85.307557	27.685003	900	19	7
KTM341	42	85.307490	27.675080	900	22	10

Site ID	Transmit power [dBm]	long. of BTS [deg]	lat. of BTS [deg]	Freq. [MHz]	Antenna Height [m]	Other building Height [m]
KTM358	46	85.302570	27.674920	900	34	11
KTM327	46	85.312156	27.683670	900	27	15
KTM362	42	85.310010	27.678500	900	29	15
KTM327	46	85.312156	27.683670	900	27	15
KTM341	42	85.307490	27.675080	900	22	10
KTM359	42	85.326309	27.677662	900	26	14
KTM334	42	85.324154	27.679610	900	22	10
KTM383	42	85.307557	27.685003	900	19	7
KTM327	46	85.312156	27.683670	900	27	15
KTM382	42	85.305950	27.689150	900	21	9
KTM059	42	85.301470	27.681010	900	24	12
KTM361	42	85.313610	27.672110	900	45	11
KTM366	42	85.319000	27.671130	900	23	11
KTM541	42	85.318760	27.674730	900	31	19
KTM375	42	85.316960	27.667630	900	23	11
KTM356	42	85.317216	27.687238	900	22	10
KTM379	42	85.319280	27.683550	900	20	8
KTM392	42	85.323200	27.685010	900	27	18
KTM381	40	85.315705	27.677531	900	21	9
KTM379	42	85.319280	27.683550	900	20	8
KTM380	44	85.321905	27.676616	900	32	20
KTM334	42	85.324154	27.679610	900	22	10
KTM359	42	85.326309	27.677662	900	26	14
KTM366	42	85.319000	27.671130	900	23	11
KTM368	42	85.323190	27.669130	900	25	10
KTM361	42	85.313610	27.672110	900	45	11
KTM368	42	85.323190	27.669130	900	25	10
KTM366	42	85.319000	27.671130	900	23	11
KTM542	42	85.326130	27.670680	900	24	15
KTM375	42	85.316960	27.667630	900	23	11
KTM374	42	85.318830	27.664640	900	23	8
KTM362	42	85.310010	27.678500	900	29	17
KTM341	42	85.307490	27.675080	900	22	10
KTM366	42	85.319000	27.671130	900	23	11
KTM541	42	85.318760	27.674730	900	31	19
KTM361	42	85.313610	27.672110	900	45	11
KTM381	40	85.315705	27.677531	900	21	9

Site ID	Transmit power [dBm]	long. of BTS [deg]	lat. of BTS [deg]	Freq. [MHz]	Antenna Height [m]	Other building Height [m]
KTM356	42	85.317216	27.687238	900	22	10
KTM379	42	85.319280	27.683550	900	20	8
KTM327	46	85.312156	27.683670	900	27	15
KTM380	44	85.321905	27.676616	900	32	20
KTM334	42	85.324154	27.679610	900	22	10
KTM381	40	85.315705	27.677531	900	21	9
KTM379	42	85.319280	27.683550	900	20	8
KTM381	40	85.315705	27.677531	900	21	9
KTM541	42	85.318760	27.674730	900	31	22
KTM361	42	85.313610	27.672110	900	45	11
KTM379	42	85.319280	27.683550	900	20	8
KTM334	42	85.324154	27.679610	900	22	10
KTM380	44	85.321905	27.676616	900	32	20
KTM381	40	85.315705	27.677531	900	21	9
KTM362	42	85.310010	27.678500	900	29	17
KTM341	42	85.307490	27.675080	900	22	10
KTM362	42	85.310010	27.678500	900	29	17
KTM381	40	85.315705	27.677531	900	21	9
KTM341	42	85.307490	27.675080	900	22	10
KTM356	42	85.317216	27.687238	900	22	8
KTM327	46	85.312156	27.683670	900	27	15
KTM354	42	85.309230	27.689080	900	21	12
KTM362	42	85.310010	27.678500	900	29	15
KTM341	42	85.307490	27.675080	900	22	10
KTM358	46	85.302570	27.674920	900	34	11
KTM381	40	85.315705	27.677531	900	21	9
KTM379	42	85.319280	27.683550	900	20	8
KTM327	46	85.312156	27.683670	900	27	15
KTM362	42	85.310010	27.678500	900	29	17
KTM356	42	85.317216	27.687238	900	22	8

APPENDIX C: COMPARISON OF PATHLOSS MODEL

Site ID	Measured PL [dBm]	Hata PL [dBm]	Cost231-Hata PL [dBm]	Walfisch-Ikegami PL [dBm]	error Hata [dBm]	error Cost231 [dBm]	error Walfisch-Ikegami [dBm]
KTM381	106	111	107	105	-5.298	-0.882	0.934
KTM361	99	108	103	94	-9.590	-4.228	4.204
KTM541	117	112	108	113	5.049	9.223	3.924
KTM366	116	120	118	117	-4.474	-2.144	-1.173
KTM362	105	101	94	101	3.796	10.833	4.482
KTM341	104	109	104	105	-5.038	-0.132	-1.353
KTM383	118	128	127	119	-9.509	-8.668	-0.513
KTM383	97	112	108	103	15.331	-11.225	-5.722
KTM059	108	117	114	112	-9.330	-6.348	-4.234
KTM327	119	120	118	120	-1.087	1.161	-1.288
KTM334	97	100	93	96	-3.282	3.631	0.863
KTM380	122	105	99	112	16.866	22.961	9.780
KTM359	114	109	105	110	4.552	9.439	4.167
KTM379	115	124	123	116	-9.056	-7.511	-0.651
KTM334	101	104	98	97	-3.019	3.037	3.639
KTM392	115	115	112	117	-0.494	2.899	-2.137
KTM380	118	119	117	127	-1.035	1.355	-9.295
KTM379	112	122	120	112	-9.935	-7.924	-0.052
KTM362	83	88	78	86	-4.976	5.454	-3.287
KTM341	111	117	114	114	-5.925	-2.826	-2.653
KTM383	113	124	123	115	11.341	-9.818	-2.217
KTM327	99	102	96	103	-3.251	3.444	-3.971
KTM379	110	120	117	110	-9.844	-7.372	0.133
KTM362	115	120	118	123	-4.957	-2.729	-8.498
KTM541	107	104	98	105	2.986	9.258	2.511
KTM346	110	107	101	112	3.366	8.993	-2.403
KTM381	121	122	120	116	-1.175	0.753	4.519
KTM542	123	122	120	121	1.621	3.569	2.278
KTM354	102	100	93	96	2.322	9.304	6.477
KTM382	108	110	105	105	-2.109	2.529	2.788

Site ID	Measured PL [dBm]	Hata PL [dBm]	Cost231-Hata PL [dBm]	Walfisch-Ikegami PL [dBm]	error Hata [dBm]	error Cost231 [dBm]	error Walfisch-Ikegami [dBm]
KTM383	115	112	108	110	2.590	6.680	4.764
KTM059	114	114	111	109	-0.245	3.470	5.035
KTM362	117	117	113	117	0.497	3.610	0.023
KTM383	114	121	118	112	-6.777	-4.487	2.491
KTM341	119	121	119	117	-2.424	-0.356	1.995
KTM358	109	120	118	109	11.209	-9.190	-0.044
KTM327	124	124	122	124	0.445	1.828	0.002
KTM362	104	107	102	107	-3.285	2.192	-3.060
KTM327	113	112	107	111	1.206	5.522	1.583
KTM341	121	124	122	121	-2.615	-1.049	0.307
KTM359	114	111	106	111	3.290	7.867	2.821
KTM334	111	117	113	111	-5.553	-2.369	0.448
KTM383	82	95	87	85	13.070	-5.250	-2.763
KTM327	115	118	115	118	-2.542	0.340	-2.566
KTM382	120	120	118	116	-0.333	2.009	4.068
KTM059	121	122	120	120	-0.675	1.273	1.452
KTM361	84	97	89	88	13.521	-4.901	-3.751
KTM366	111	114	110	111	-2.901	0.824	0.735
KTM541	112	115	111	116	-2.568	0.970	-3.891
KTM375	113	119	117	113	-6.100	-3.519	-0.030
KTM356	88	91	82	88	-3.231	5.756	0.062
KTM379	111	115	112	107	-4.183	-0.686	3.669
KTM392	116	121	119	119	-4.956	-2.925	-2.923
KTM381	109	114	110	108	-4.620	-0.770	1.490
KTM379	107	115	111	104	-7.645	-4.029	2.563
KTM380	125	119	117	128	5.735	8.064	-2.544
KTM334	121	123	121	120	-1.621	0.173	1.353
KTM359	123	127	126	128	-3.804	-3.179	-5.342
KTM366	82	97	89	94	14.965	-7.234	-11.749

Site ID	Measured PL [dBm]	Hata PL [dBm]	Cost231-Hata PL [dBm]	Walfisch-Ikegami PL [dBm]	error Hata [dBm]	error Cost231 [dBm]	error Walfisch-Ikegami [dBm]
KTM368	104	111	107	102	-7.446	-3.062	1.578
KTM361	110	119	117	112	-8.442	-6.337	-1.155
KTM368	80	96	88	86	-16.007	-7.911	-6.014
KTM366	107	112	108	110	-5.192	-0.975	-2.821
KTM542	99	115	112	114	-16.171	-12.676	-15.126
KTM375	108	119	117	113	-11.075	-8.518	-5.011
KTM374	99	122	120	107	-22.581	-20.579	-8.129
KTM362	100	104	97	106	-3.663	2.743	-5.969
KTM341	118	121	118	118	-2.699	-0.464	0.375
KTM366	110	107	102	103	2.814	8.224	6.855
KTM541	110	106	100	107	3.252	9.033	2.625
KTM361	110	110	105	102	-0.207	4.514	8.077
KTM381	112	120	117	114	-7.918	-5.483	-2.114
KTM356	104	103	96	100	1.388	7.766	4.084
KTM379	91	109	104	101	-18.078	-13.238	-9.953
KTM327	120	120	118	122	-0.432	1.730	-2.418
KTM380	117	105	99	112	11.691	17.740	4.590
KTM334	101	112	108	109	-11.201	-7.020	-7.681
KTM381	117	119	117	113	-2.124	0.489	3.718
KTM379	115	121	119	112	-5.779	-3.513	2.772
KTM381	83	93	84	86	-9.644	-1.126	-2.525
KTM541	113	111	106	115	2.067	6.721	-2.313
KTM361	98	117	114	104	-18.308	-15.493	-5.485
KTM379	100	108	102	98	-7.575	-2.404	1.565

Site ID	Measured PL [dBm]	Hata PL [dBm]	Cost231-Hata PL [dBm]	Walfisch-Ikegami PL [dBm]	error Hata [dBm]	error Cost231 [dBm]	error Walfisch-Ikegami [dBm]
KTM334	113	116	113	113	-3.396	-0.176	-0.097
KTM380	115	118	115	126	-3.122	-0.489	-11.305
KTM381	115	122	120	116	-6.704	-4.670	-0.987
KTM362	81	78	65	77	2.944	15.919	3.963
KTM341	109	118	115	114	-8.678	-5.752	-5.446
KTM362	121	106	100	109	14.815	20.575	12.318
KTM381	113	116	112	110	-2.616	0.786	3.397
KTM341	116	116	113	113	-0.157	3.118	3.155
KTM356	104	113	109	104	-8.770	-4.719	-0.161
KTM327	111	113	109	112	-1.931	2.101	-0.685
KTM354	120	118	116	120	1.528	4.288	-0.108
KTM362	114	113	109	113	1.079	5.111	0.877
KTM341	106	114	111	110	-8.350	-4.661	-3.560
KTM358	105	116	113	105	-11.374	-8.310	0.135
KTM381	112	110	105	103	2.456	7.221	8.763
KTM379	110	119	116	109	-8.984	-6.323	1.031
KTM327	126	118	116	120	7.633	10.310	5.791
KTM362	123	120	117	123	3.327	5.626	-0.194
KTM356	117	126	125	118	-8.667	-7.571	-0.734

APPENDIX D: LOCATION ESTIMATION USING SPLINE INTERPOLATION

MS location	Tx-Rx Actual Distance [Km]	lat. of MS [deg]	long. of MS [deg]	long. of BTS [deg]	lat. of BTS [deg]	Distance estimate from Spline interpolation [m]	Lat. /lon. of MS	Location Error
Alka	0.324690	27.674805	85.314870	85.313610	27.672110	323.605313		
Alka	0.314408	27.674805	85.314870	85.315705	27.677531	290.451767	85.314268	71
Alka	0.383566	27.674805	85.314870	85.318760	27.674730	471.232352	27.675158	
Alka	0.577156	27.674805	85.314870	85.319000	27.671130	571.045330		
Bigmart	0.279464	27.677348	85.308705	85.307490	27.675080	250.574452		
Bigmart	0.181613	27.677348	85.308705	85.310010	27.678500	184.900524	85.308476	23
Bigmart	0.859555	27.677348	85.308705	85.307557	27.685003	852.628715	27.677330	

Chakupat patan	0.159888	27.678358	85.323358	85.324154	27.679610	114.242196		
Chakupat patan	0.241122	27.678358	85.323358	85.321905	27.676616	415.982000	85.324792	177
Chakupat patan	0.301018	27.678358	85.323358	85.326309	27.677662	307.333340	27.679321	
Chakupat patan	0.703984	27.678358	85.323358	85.319280	27.683550	672.103151		
Chakupat	0.202918	27.681282	85.324975	85.324154	27.679610	195.805201		
Chakupat	0.450390	27.681282	85.324975	85.323200	27.685010	462.612207	85.323886	114
Chakupat	0.601093	27.681282	85.324975	85.321905	27.676616	474.854449	27.680942	
Chakupat	0.615543	27.681282	85.324975	85.319280	27.683550	622.202407		
Farmarmart	0.076676	27.678885	85.309365	85.310010	27.678500	67.943608		
Farmarmart	0.462123	27.678885	85.309365	85.307490	27.675080	425.720034	85.309618	57
Farmarmart	0.703954	27.678885	85.309365	85.307557	27.685003	700.564813	27.679342	

Gyanodaya	0.663665	27.680308	85.305452	85.302570	27.674920	616.521134		
Gyanodaya	0.400186	27.680308	85.305452	85.301470	27.681010	404.087552	85.305640	54
Gyanodaya	0.492366	27.680308	85.305452	85.310010	27.678500	472.072449	27.679853	
Gyanodaya	0.562282	27.680308	85.305452	85.307557	27.685003	575.665909		
Gyanodaya	0.615697	27.680308	85.305452	85.307490	27.675080	663.272782		
Gyanodaya	0.759455	27.680308	85.305452	85.312156	27.683670	759.474012		
Jawalakhel	0.156826	27.672212	85.315197	85.313610	27.672110	163.749869		
Jawalakhel	0.393800	27.672212	85.315197	85.319000	27.671130	377.934919	85.315640	63
Jawalakhel	0.449419	27.672212	85.315197	85.318760	27.674730	435.552787	27.671807	
Jawalakhel	0.538817	27.672212	85.315197	85.316960	27.667630	533.225553		
Kandevasthan	0.089772	27.686480	85.316905	85.317216	27.687238	111.668691		

Kandevasthan	0.401471	27.686480	85.316905	85.319280	27.683550	482.347551	85.317612	92
Kandevasthan	0.641709	27.686480	85.316905	85.323200	27.685010	686.031217	27.687026	
ThadoDunga	0.515214	27.678367	85.306058	85.302570	27.674920	510.554830		
ThadoDunga	0.389824	27.678367	85.306058	85.310010	27.678500	390.963586	85.306239	41
ThadoDunga	0.392130	27.678367	85.306058	85.307490	27.675080	318.650737	27.678038	
Gusingal	0.152179	27.687848	85.308560	85.309230	27.689080	116.470540		
Gusingal	0.295258	27.687848	85.308560	85.305950	27.689150	328.423029	85.309702	216
Gusingal	0.331797	27.687848	85.308560	85.307557	27.685003	437.261162	27.689508	

APPENDIX E: LOCATION ESTIMATION USING SPLINE INTERPOLATION WITH WLS

MS location	Tx-Rx Actual Distance [Km]	lat. of MS [deg]	long. of MS [deg]	long. of BTS [deg]	lat. of BTS [deg]	Distance estimate from Spline interpolation [m]	Lat. /lon. of MS	Location error (m)
Alka	0.324690	27.674805	85.314870	85.313610	27.672110	326.646269		
Alka	0.314408	27.674805	85.314870	85.315705	27.677531	290.451767	85.314425	55
Alka	0.383566	27.674805	85.314870	85.318760	27.674730	471.232352	27.675103	
Alka	0.577156	27.674805	85.314870	85.319000	27.671130	571.045330		
Bigmart	0.279464	27.677348	85.308705	85.307490	27.675080	250.574452		
Bigmart	0.181613	27.677348	85.308705	85.310010	27.678500	184.900524	85.308476	23
Bigmart	0.859555	27.677348	85.308705	85.307557	27.685003	852.628715	27.677330	
Chakupat patan	0.159888	27.678358	85.323358	85.324154	27.679610	114.242196		

Chakupat patan	0.241122	27.678358	85.323358	85.321905	27.676616	415.982000	85.324816	174
Chakupat patan	0.301018	27.678358	85.323358	85.326309	27.677662	307.333340	27.679237	
Chakupat patan	0.703984	27.678358	85.323358	85.319280	27.683550	672.103151		
Chakupat	0.202918	27.681282	85.324975	85.324154	27.679610	195.805201		
Chakupat	0.450390	27.681282	85.324975	85.323200	27.685010	462.612207	85.323983	110
Chakupat	0.601093	27.681282	85.324975	85.321905	27.676616	474.854449	27.681737	
Chakupat	0.615543	27.681282	85.324975	85.319280	27.683550	622.202407		
Farmarmart	0.076676	27.678885	85.309365	85.310010	27.678500	67.943608		
Farmarmart	0.462123	27.678885	85.309365	85.307490	27.675080	425.720034	85.309618	57
Farmarmart	0.703954	27.678885	85.309365	85.307557	27.685003	700.564813	27.679342	
Gyanodaya	0.663665	27.680308	85.305452	85.302570	27.674920	616.521134		
Gyanodaya	0.400186	27.680308	85.305452	85.301470	27.681010	404.087552	85.305752	61

Gyanodaya	0.492366	27.680308	85.305452	85.310010	27.678500	472.072449	27.679831	
Gyanodaya	0.562282	27.680308	85.305452	85.307557	27.685003	575.665909		
Gyanodaya	0.615697	27.680308	85.305452	85.307490	27.675080	663.272782		
Gyanodayas	0.759455	27.680308	85.305452	85.312156	27.683670	759.474012		
Jawalakhel	0.156826	27.672212	85.315197	85.313610	27.672110	163.749869		
Jawalakhel	0.393800	27.672212	85.315197	85.319000	27.671130	377.934919	85.315599	53
Jawalakhel	0.449419	27.672212	85.315197	85.318760	27.674730	435.552787	27.671892	
Jawalakhel	0.538817	27.672212	85.315197	85.316960	27.667630	533.225553		
Kandevasthan	0.089772	27.686480	85.316905	85.317216	27.687238	111.668691		
Kandevasthan	0.401471	27.686480	85.316905	85.319280	27.683550	482.347551	85.317612	92
Kandevasthan	0.641709	27.686480	85.316905	85.323200	27.685010	686.031217	27.687026	
ThadoDunga	0.515214	27.678367	85.306058	85.302570	27.674920	510.554830		

ThadoDunga	0.389824	27.678367	85.306058	85.310010	27.678500	390.963586	85.306239	41
ThadoDunga	0.392130	27.678367	85.306058	85.307490	27.675080	318.650737	27.678038	
Gusingal	0.152179	27.687848	85.308560	85.309230	27.689080	116.470540		
Gusingal	0.295258	27.687848	85.308560	85.305950	27.689150	328.423029	85.309702	216
Gusingal	0.331797	27.687848	85.308560	85.307557	27.685003	437.261162	27.689508	

APPENDIX F: PLOT OF COORDINATES OF ACTUAL AND ESTIMATED LOCATION OF MS

