Error corrected location determination in an outdoor wireless environment by using estimation, filtering, prediction and fusion techniques : A wifi application by using terrain based knowledge

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THESE EN COTUTELLE INTERNATIONALE
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(Specialte Informatique et Genie Informatique)

et

de UNIVERSITI Kuala Lumpur, Malaysia
Doctor of Philosphy in Engineering Technology
(Specialite Electrical/Electronic)

par

MUHAMMAD MANSOOR ALAM

Composition du jury

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DECLARATION

I hereby declare that the work have been done by myself and no portion of the work contained in this thesis has been submitted in support of any application for any other degree or qualification of this or any other university or institute of learning, except as stated in Article 16 (Degrees award) of the "Convention of Co-organization of a Joint PhD between The University of La Rochelle (France) and Universiti Kuala Lumpur (Malaysia)".

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Muhammad Mansoor Alam

My Parents,
My Teachers & My Family

Preface

Research work presented in this thesis is executed under the supervision of Institute of Research and Postgraduate Studies (IRPS), Universiti Kuala Lumpur (UniKL), Malaysia and Laboratoire d' Informatique et d' Imagerie Industrielle (L3i), Universite' de La Rochelle, France.

I would like to express special thanks and gratitude towards Dean IRPS, Dr. Mohd Azizan bin Mohd Noor and Director L3i, Prof. Remy Mullot for accepting me as a research student in their prestigious institutes. I also would like to thanks Dean IRPS for providing financial support by accepting my application of Short Term Research Grant (STRG).

I cannot fully express my thanks in words towards my supervisors Dr. Mazliham Mohd Su'ud, Prof. Patrice Boursier and Dr. Shahrulniza Musa for their assistance, guidance and support throughout this research. I am also grateful to Dr. Mazliham of introducing me as a joint PhD student in ULR and of Prof. Patrice of accepting my proposal for supervision. I am also very much honored by the time by time guidence of Prof. Jean-Marc Ogier during his visit of Malaysia.

Not forgetting Pn. Jawahir Che Mustapha, En. Laqman Hakim, En. Yasir Mumtaz Hussain and En Amjad Khan (Fauji) for their support in field testing also Pn. Salina Abu Bakar and En. Abdul Muin bin Abdul Rani for their administrative support.

Last but not least, my deepest gratitude to my wife for her support and also of my daughters as they sacrifice the one of the best part of their life for my education.

APPROVAL SHEET

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LIST OF ABBREVIATIONS

AGPS	Assisted Global Positioning System
AP	Access Point
ASS	Available Signal Strength
AuC	Authentication Centre
BDT	Bayesian Decision Theory
BS	Base Station
BSC	Base Station Controller
BTS	Base Transceiver Station
Cell-ID	Cell Identifier
CERT	Clutter based Error Rate Table
DGPS	Differential Global Positioning System
DR	Dead Reckoning
EIR	Equipment Identifier Register
ERT	Error Rate Table
GMSC	Gateway Mobile Switching Centre
GPS	Global Positioning System
HLR	Home Location Register
ID	Identification
KF	Kalman Filter
k-NN	k Nearest Neighbor

LBS	Location Based Services
Loc M	Location of Mobile Node/Station
LOS	Line of Sight
MANET	Mobile AdHoc Network
MME	Minimum Mean Square Error
MS	Mobile Station
MSC	Mobile Switching Centre
Non-LOS	Non Line of Sight
NSS	Network Subsystem
P2LE	Posterior Probability based Location Estimation
P2P	Point-to-Point
PCLDA	Predicted and Corrected Location Determination Algorithm
PMA	Power Management Algorithm
QOS	Quality of Service
RoC	Region of Confidence
RoI	Region of Interest
RSS	Receive Signal Strength
RSSI	Receive Signal Strength Indicator
Rx	Receive Signal
SELFLOC	Selective Fusion Location Estimation
SIMPLE	Simple Indoor Multi-level Portable Location Engine
SMP	Smallest M-Vertex Polygon

SNR	Signal to Noise Ratio
TDOA	Time Difference of Arrival
TN	Triangulation
TOA	Time of Arrival
Tx	Transmitted Signal
VANET	Vehicular AdHoc Network
VLR	Visitor Location Register
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WSN	Wireless Sensor Network
WWAN	Wireless Wide Area Network

Abstract

Location estimation of wireless nodes has been a very popular research area for the past few years. The research in location estimation is not limited to satellite communication, but also in WLAN, MANET, WSN and Cellular communication. Because of the growth and advancement in cellular communication architecture, the usage of handheld devices has increased rapidly, therefore mobile users originating calls are also increasing. It is estimated that more than 50% emergency calls are originated by mobile phones. Researchers have used different location estimation techniques, such as satellite based, geometrical, statistical and mapping techniques. In order to achieve accuracy, researchers have combined two or more techniques. However the terrain based location estimation is an area which is not considered by researchers extensively.Due to the fact that radio waves behave differently in different atmospheres, the calculation of few parameters is not sufficient to achieve accuracy in different terrains, especially when it is totally based on RSS which is carrying impairments.

Research Area

Problem Statement

This research is focusing on the localization of wireless nodes by using geometrical and statistical techniques with the consideration of impairment/attenuation of terrains. The proposed model is consisting of four steps, which are estimation, filtering, prediction and fusion. A prototype has been built using the WiFi IEEE 802.11x standard. In step one, by using signal to noise ratio, the peninsular Malaysia geographical area is categorized into 13 different terrains/clutters. In step two, point-to-point data points are recorded by using available signal strength and receive signal strength with the consideration of different terrains. **Estimation** of the location is done in step three by using the triangulation

Proposed Architecture

method. The results of estimated locations are further filtered in step four by using average and mean of means. For error correction, **filtering** of the location is also done by using k- nearest neighbor rule. **Prediction** is done in step five by using combined variance which predicts the region of interest. Region of interest helps to eliminate locations outside of the selected area. In step six filtering results are **fused** with prediction in order to achieve accuracy.

Results show that the current research is capable of reducing errors from 18 m to 6 m in highly attenuated terrains and from 3.5 m to 0.5 m in low attenuated terrains.

Résumé

L’estimation de la position des noeuds de communication sans fil est un domaine de recherche très populaire au cours des dernières années. La recherche de l'estimation de l'emplacement n'est pas limitée à la communication par satellite, mais elle concerne aussi les réseaux WLAN, MANET, WSN et la communication cellulaire. En raison de la croissance et de l’évolution des architectures de communication cellulaire, l’utilisation des appareils portables a augmenté rapidement, et les appels provenant d’utilisateurs mobiles ont également rapidement augmenté. On estime que plus de 50% des appels d'urgence sont émis par des téléphones mobiles. Les chercheurs ont utilisé différentes techniques d'estimation de la position, tels que les satellites, les techniques statistiques et la cartographie. Afin d'atteindre une meilleure précision, certains chercheurs ont combiné deux ou plusieurs techniques. Cependant, l'estimation de la position basée sur le terrain est un domaine qui n'a pas été considéré en profondeur par les chercheurs.

Espace de Recherche

Grâce aux ondes radio qui se comportent différemment dans des atmosphères différentes, les calculs à l’aide de quelques paramètres ne sont pas suffisants pour atteindre une précision avec différents terrains, surtout quand il sont totalement basés sur le format RSS, qui entraine des altérations.

Énoncé du Problème

Cette recherche se concentre sur la localisation des noeuds de communication sans fil en utilisant des techniques géométriques et statistiques, et en prenant en compte l’altération et l'atténuation des terrains. Le modèle proposé est constitué de quatre étapes, qui sont l'estimation, le filtrage, la prédiction et la fusion. Un prototype a été construit en utilisant le WiFi IEEE 802.11x standard. Dans la première étape, en utilisant

Architecture Proposée

le rapport signal-bruit de la zone géographique, la péninsule Malaisienne est classée en 13 types de terrains différents.

Dans la deuxième étape, les points de données point-à-point sont enregistrés en utilisant la force du signal disponible et en recevant la puissance du signal en considérant différents types de terrains. L'estimation de la localisation se fait au cours de troisième étape en utilisant la célèbre méthode de triangulation. Les résultats estimés sont encore filtrés dans la quatrième étape en utilisant la moyenne et la moyenne des moyennes. Pour la correction des erreurs, le filtrage de l'emplacement est également fait en utilisant la règle des plus proches voisins. La prédiction est affinée au cours de la cinquième étape en utilisant la variance combinée qui permet de prédire la région considérée. L'utilisation des régions d'intérêt contribue à éliminer les emplacements situés à l'extérieur de la zone sélectionnée. Au cours de la sixième étape, les résultats du filtrage sont fusionnés avec la prédiction afin d'obtenir une meilleure précision.

Les résultats montrent que les recherches effectuées permettent de réduire les erreurs de 18 m à 6 m dans des terrains fortement atténués, et de 3,5 m à 0,5 m dans des terrains faiblement atténués.

Abstrak

Anggaran lokasi nod tanpa wayar adalah penyelidikan yang sangat popular sejak beberapa tahun yang lalu. Penyelidikan dalam anggaran lokasi tidak terhad kepada komunikasi satelit, tetapi juga untuk WLAN, MANET, WSN dan komunikasi selular. Olch kerana pertumbuhan dan kemajuan dalam seni bina komunikasi selular, penggunaan peranti mudahalih telah meningkat dengan pesat. Oleh kerana itu pengguna pengguna juga turut meningkat. Adalah dianggarkan bahawa lebih daripada 50% panggilan kecemasan telefon bimbit. Dibuat melalui para penyelidik telah menggunakan teknik anggaran lokasi yang berbeza, seperti teknik berasaskan satelit, geometri, statistik dan pemetaan. Untuk mencapai ketepatan, para penyelidik telah menggabungkan dua atau lebih teknik. Walau bagaimanapun, lokasi anggaran berdasarkan rupa bumi adalah kajian yang tidak dipertimbangkan oleh penyelidik secara meluas. Oleh kerana gelombang radio berkelakuan berbeza dalam persakitaran yang berlainan, pengiraan parameter sahaja tidak mencukupi untuk mencapai ketepatan dalam rupa bumi yang berbeza terutama apabila ia hanya berdasarkan RSS yang mengandungi ketidaktepatan.

Kawasan Penyelid-ikan

Kenyataan masalah

Kajian ini memberi tumpuan kepada persetempatan nod tanapa wayer dengan menggunakan teknik geometri dan statistik dengan mengambil kira ketidaktepatan/kemerosotan daripada rupa bumi. Model yang dicadangkan terdiri daripada empat langkah, iaitu anggaran, penapisan, ramalan dan gabungan. Prototaip dibina dengan menggunakan standard WiFi IEEE 802.11x. Dalam langkah pertama, dengan menggunakan nisbah isyarat kepada hingar, kawasan geografi Semenanjung

Seni Bina Cadangan

Malaysia dikategorikan kepada 13 rupa bumi berbeza. Dalam dua langkah kedua, titik data yang di ukur dari satu titik-ti-titik yang lain direkodkan dengan menggunakan kekuatan isyarat yang ada dan menerima kekuatan isyarat dengan mengambil kira rupa bumi yang berbeza. Anggaran lokasi dilakukan dalam tiga langkah dengan menggunakan kaedah Triangulasi . Keputusan lokasi anggaran seterusnya ditapis dalam empat langkah dengan menggunakan purata dan purata dari purata. Untuk pembetulan ralat, penapisan lokasi juga dilakukan dengan menggunakan kaedah k-jiran. Peramalan dilakukan dalam lima langkah dengan menggunakan kaedah varian gabungan yang meramalkan kawasan dalam pemerhatian. Wilayah kepentingan membantu untuk menyingkirkan lokasi di luar kawasan yang dipilih. Dalam langkah ke enam hasil penapisan digabungkan dengan ramalan untuk mencapai ketepatan. Keputusan menunjukkan bahawa kajian ini mampu untuk mengurangkan ralat dari 18 m 6 m di rupa bumi yang sangat lemah dan dari 3.5 m hingga 0.5 m di rupa bumi yang rendah dilemahkan.

INTRODUCTION

From the past decade location estimation of wireless nodes is becoming a very popular research area. It is not only limited for path finder or vehicle tracking by using GPS, but is also used in robot tracking [1], VANET [2], Wireless Local Area Network (WLAN) [3], and Wireless Sensor Network (WSN) [4]. Because of the rapid growth in the usage of handheld devices [5] and in the advancement in the mobile communication facilities and architecture, the hand phone originating calls are also increasing rapidly. A recent study shows that almost 50% of emergency calls are originated by the hand phones [6]. Therefore error minimization in location estimation of wireless devices is becoming a big challenge for service providers, crime investigators and disaster management authorities in order to research the receiver [7].

Techniques which are most popularly used for location estimation are geometrical technique, statistical technique, satellite based technique and mapping technique [8, 9]. This research is focused in the terrain based outdoor location determination. In order to achieve accuracy and avoid terrain errors a kalman filter recursive model is followed in this research which uses estimation, filtering, prediction and fusion. Point-to-point data collection is made in every terrain by using WiFi (IEEE 802.11 x) prototype. Based on the P2P data location are estimated by using triangulation method. As data points are recorded at five different timestamps and three triangles are used in order to satisfy triangulation basic rules, therefore fifteen locations are estimation in triangulation process. Averaging and k-NN rule are used to filter the estimated location. Prediction is done by using Region of Interest (RoI), if the filtered value is falling in the RoI then it will be most predicted value for selection. Finally k-NN based filtered results are fused with prediction's RoI to get the accurate value.

This thesis is divided into three sections

I Location Estimation: A Review

II Description of a Terrain Based Location Estimation Based on Geometrical and Statistical Methods

III Application to Real World Location Estimation

A brief description of the section is as under:

I Location Estimation: A Review

Section one consist of two chapters. Chapter 1 is providing a glance view about the research area and chapter 2 is dedicated to literature review. A brief description of chapters is as under:

In **chapter 1**, we are discussing different location estimation techniques, methods and their use in specific architecture (such as WLAN, GSM etc.) as background knowledge for the reader. Problem statement and novelty of current research is also discussed in this chapter.

Chapter 2 is dedicated for literature survey. The research of other scholars is discussed in this chapter. Based on the topic relevancy this chapter is divided into four sections.

1. Location Estimation in Wireless Local Area Network (WLAN)

2. Location Determination in Wireless Metropolitan Area Network (WMAN)
3. Location Estimation in Wireless Wide Area Network (WWAN)
    a. An Application of Global System for Mobile Communication (GSM)
    b. An Application of Global Positioning System (GPS)
4. Terrain /Clutter affects on Wireless Signals

II Description of a Terrain Based Location Estimation Based on Geometrical and Statistical Methods

Chapter 3 is discussing about the Receive Signal Strength (RSS) and Available Signal Strength (ASS). These are the primary parameters used in location estimation of a mobile node. These parameters come with error because of attenuation, atmospheric absorption and other external factors. All the factors indeed lead towards the inaccurate location estimation. Proposed architecture is built by considering the attenuation in clutters/terrains. Thirteen clutters are proposed by considering the attenuation of the field. ERT is constructed based on the data points collected at 10 meter distance in each clutter and with the three zone divisions. Furthermore we collect data points in each clutter at every 2m instead of 10m to reduce error of ERT. Clutter based Enhance Error Rate Table (CERT) is proposed by dividing the data points in eight zones for precise location estimation. Data collected from Agriculture/Field (A/F) clutter is considered as a baseline data because of its low error rate. CERT helps to minimize errors from 3m-18.5m (ERT correction) range to 2.5m-10m (CERT correction) range based on the clutter we are dealing with. In order to get the random distance we use linear interpolation with the CERT results. A C sharp program is built to calculate random distance based on the recorded signal strength. A famous triangulation method is applied on the previously collected data to localize the position of wireless node

Filtering is done in the second section of Chapter 3. Filtering of the estimated results is done by applying geometrical and statistical location estimation techniques in order to calculate the precise location of the mobile node. Based on the triangulation results we average the fifteen calculated location by using timestamp. Average and k-NN rule applied for the precise location filtering of wireless node. Instead of just averaging the fifteen estimated locations we apply the k-NN algorithm to minimize error in the localization of position. Results show that the k-NN can produce from 217% - 289% better results compare to the average method. The purpose of the use of k-NN is to reduce errors in order to achieve estimated position near to accurate.

Combine variance is used to calculate the Region of Interest (RoI) in the prediction section. RoI is the strongest candidate for the filtered location. Finally fusion is done by fusing the results of filtering with prediction.

III Application to Real World Location Determination

Chapter 4 is dedicated to P2P data collection and the cases of ERT and CERT. Modeling interpolated distance is calculated in this chapter. Finally results of interpolated distance error with CERT are compared.

Chapter 5 is based on the estimation and filtering. In estimation triangulation is implementation on collected data points. Filtering is done by using average, mean value of average and the k - nearest neighbor algorithm.

Chapter 6 is dedicated for prediction and correction. For prediction region of interest is calculated and the results of k-NN based filtering is fused with prediction to increase the level of confidence of selected location. Finally by combining the prediction and fusion results PCLDA (Predicted and Corrected Location Determination Algorithm) is established. Timestamp is used for recursive steps in Kalman filter.

Finally, the general conclusion of this work is presented in the Conclusion and Future Directions. We also discuss the limitations, the prespective and the future work that can be carried out in the future based on this work.

LOCATION ESTIMATION: A REVIEW

CHAPTER 1

UNDERSTANDING THE PROBLEM

1.1 Chapter Introduction

Location estimation of wireless nodes is becoming a very popular research area from the past few decades. GPS receiver positioning, vehicle tracking and road navigation systems are few of the popular application areas of localization. But location estimation is not limited with these applications. Researchers also have investigated localization techniques in robot tracking [1], VANET [2], Wireless Local Area Network (WLAN) [3], Wireless Sensor Network (WSN) [4] and cellular networks [7] .

Techniques which are most popularly used for location estimation are geometrical technique, statistical technique, satellite based technique and mapping technique [8, 9]. Each of the above technique has its own advantages and disadvantages. In this chapter we are discussing different location estimation techniques, methods and their usage in specific architectures which are WiFi, GSM, WiMAX and GPS. This chapter provides sufficient knowledge about the topic which will help to understand this research. Problem statement and novelty of current research are also discussed in this chapter.

1.2 Location Estimation

Location estimation, location determination and localization are the terms which are alternatively used for the positioning of a wireless node. Techniques which are used for location estimation are satellite based techniques, geometric techniques, statistical techniques and the mapping based techniques [8, 9]. A brief description of these techniques is:

- **Satellite Based Technique**

  NAVSTAR location estimation is the example of satellite based technique. The Time of Arrival (TOA) and the Time Difference of Arrival (TDOA) are the key factors used in this technique. GPS and Differential GPS are the implementations of Satellite Based Technique [10, 11].

- **Geometrical Technique**

  Receive Signal Strength (RSS) and Available Signal Strength (ASS) [12-14] are used with AOA (Angle of Arrival), TOA and TDOA at different time t_i ($i = 1 \dots n$). Averaging method is used for optimizing the results [15-17].

- **Statistical Technique**

  Statistical tools are used for the optimization of the location. Bayesian decision theory is the most popular technique used by researchers in recent years [13, 14, 18-24].

- **Mapping Based Technique**

  In the mapping based technique, image processing is applied to digitize the image for the location estimation [24].

Classically the above mentioned techniques can be categorized into direct positioning and the two step positioning [9, 25, 26].

In **Direct Positioning** location is totally based upon Receive Signal Strength (RSS). Based on the available signal strength at the mobile node the distance from the base is determined. In **Two Step Positioning** the RSS is used as a parameter in geometrical, statistical, satellite or mapping based techniques for the localization of wireless node.

Figure 1.1 (a) is explaining the concept of direct positioning and figure 1.1 (b) is explaining two step positioning.

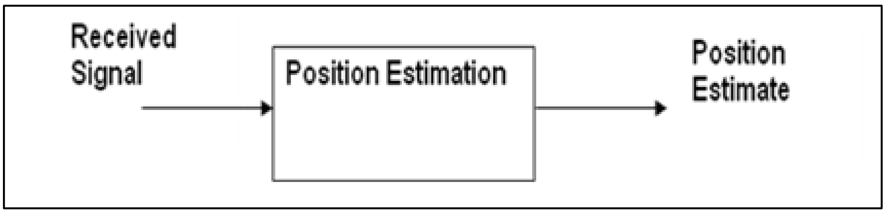


Figure 1.1 a: Architecture of direct positioning [25, 26]

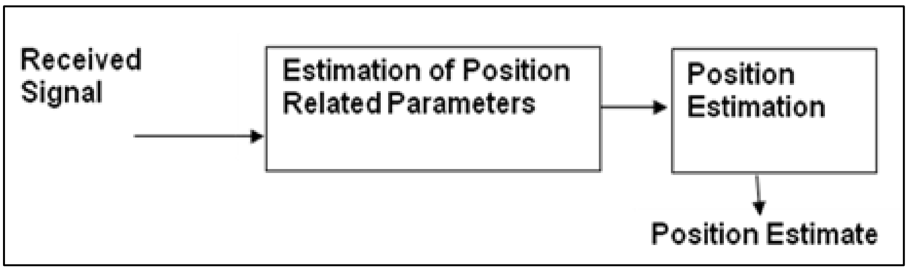


Figure 1.1 b: Architecture of two step positioning [25, 26]

This research is based on the two step positioning approach. Authors have applied the geometric and the statistical location estimation techniques for the positioning of a mobile node. In geometric technique triangulation is the most popular way to map and find out the position of static or dynamic node. Even satellite based technique uses triangulation for the positioning of the GPS receiver.

1.3 Basic Positioning Methods

In above discussed positioning techniques there may be one or more positioning methods are used. Basic positioning methods mentioned by [27-44] are:

i. Dead Reckoning
ii. Proximity Sensing: Signal Signature Tracking
iii. Trilateration: Signal Strength Analysis and TOA
iv. Multilateration: TDOA
v. Triangulation: AOA

1.3.1 Dead Reckoning (DR)

Dead Reckoning [27] is a process of estimating one's current position based upon the previous determined positions, the speed and acceleration, the moving direction, the elapsed time and the traveled distance.

Examples of DR are animal navigation [such as ants, rodents and geese have also been shown to continuously keep track of their locations relative to a starting point and return to it], marine navigation and air navigation.

The disadvantage of DR is that, since new positions are calculated solely from the previously known positions therefore the error in the position grows with time.

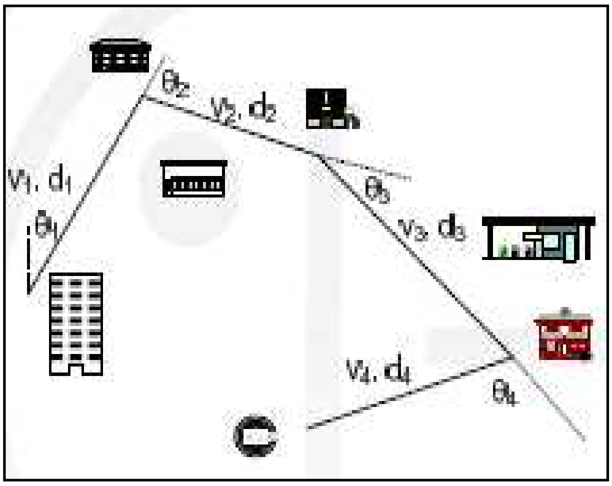


Figure 1.2: Dead Reckoning [27]

Figure 1.2 is explaining the concept of dead reckoning angle, distance and velocity calculation.

1.3.2 Proximity Sensing: Signal Signature Tracking [27, 41-44]

In the proximity sensing, the wireless node position is derived from the base station (BS) coordinates. It is usually determined by tracking signal signatures or cell identity (Cell-ID) of neighboring base station. Every base station has its own signal pattern, which is usually embedded into its pilot with synchronization channels. Tracking of signal signature is basically consists of the signal signature estimation, neighbor list update and the mobile location analysis.

1.3.3 Trilateration

Trilateration is a process to determinate absolute or relative locations of points by using measurement of distance using the geometry of circles, spheres or triangles [45]. Trilateration [27, 41-44] determines the relative positions of object using the knowledge locations of two or more reference points (for example the serving tower or base station) and the measured distance between the mobile and each reference point.

Signal strength and TOA (Time of Arrival) play vital role in the calculation of location by using trilateration method. The distance is proportional to the receive signal strength (RSS)

$$SS_{RX} = P_{TX} - 10\,\alpha \log (d) + X\ (dB) \qquad (1.1)$$

where SS_{RX} is signal at receiver end

P_{TX} is transmitted power

d is distance

α is Angle of Arrival (AOA) and

X (dB) is transmitted signals in decibels

Receive signal (SS_{RX}) calculation is based on the transmitted power (P_{TX}) of the signal from the source, distance (d) from the source to receiver, angle of arrival (α) between source and destination and the transmitted signals (X).

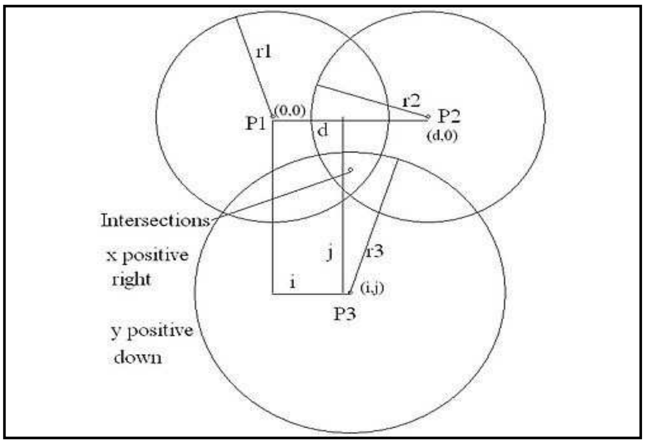


Figure 1.3: Calculation in Trilateration [27]

In figure 1.3 the plane, z=0, showing the three (3) sphere centers, P1, P2, and P3; their x, y coordinates; and the three (3) sphere radius, r1, r2, and r3. The two intersections of the three sphere surfaces are directly in front and directly behind the point designated intersections in the z=0 plane.

1.3.4 Multilateration

Multilateration [27, 41-44] which is also known as hyperbolic lateration usually is the positioning process by estimating the time difference of arrival (TDOA) of a signal. TDOA method is similar to TOA estimation but does not require clock synchronization.

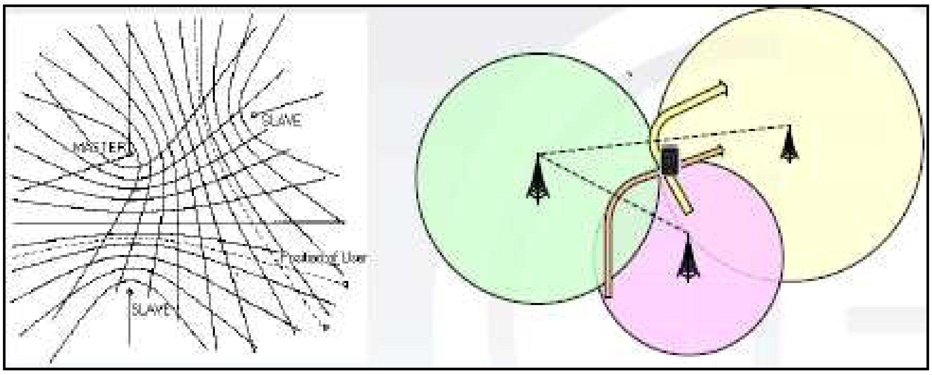


Figure 1.4: Hyperbolic lateration (left part of figure: hyperbolic image of signal) [27]

1.3.5 Triangulation

Triangulation [27, 41- 44] is a process of positioning a wireless node by measuring the Angle of Arrival (AOA) between the wireless node and the Reference Point (RP) and the distance between the wireless node and the RP.

Triangulation is used for many purposes including survey, navigation and astrometry. The AOA is usually determined by using multiple antennas at the base station. Many schemes are developed for estimating AOA such as [27]:

- Maximum output power
- Maximum likelihood estimation
- Subspace-based approaches.

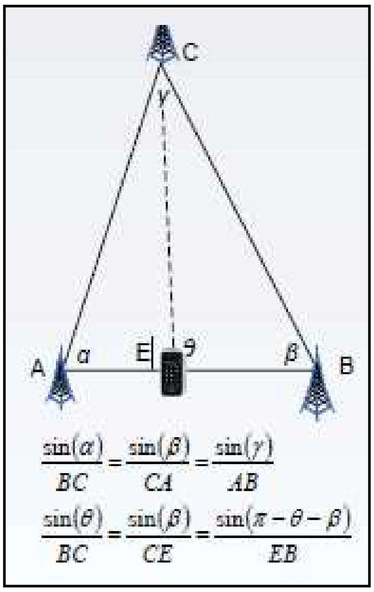


Figure 1.5: The Triangulation (Angles and side measurement) [27]

Figure 1.5 is representing the angles and sides measurement in triangulation method. Cosine formula may also be used for angle calculation.

$$\cos\alpha = (b^2 + c^2 - a^2) / 2bc \quad (1.2)$$

$$\cos\beta = (a^2 + c^2 - b^2) / 2ac \quad (1.3)$$

$$\cos\gamma = (a^2 + b^2 - c^2) / 2bc \quad (1.4)$$

where

a, b , c are sides of triangles

α, β, γ are angles of triangles

1.4 How Triangulation Works for Location Estimation?

Triangulation is a way of determining a location using the location of other [45-49]. In the wireless environment a mobile node can be localized by calculating either the radial distance or the direction by using received signal strength (RSS) from two or three antennas. Triangulation is very popular approach for location estimation of GPS receiver or a satellite phone. It is also sometime used in cellular communication to find out the geographical position of a user [46].

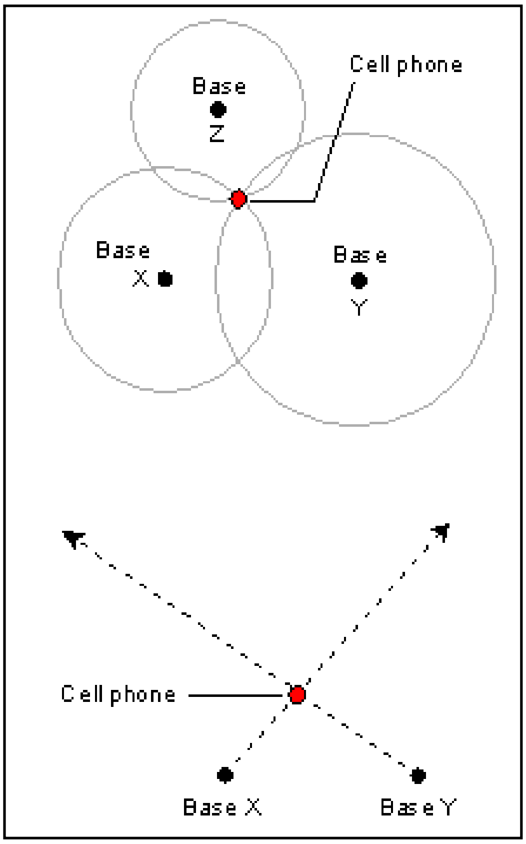


Figure 1.6: Localization by using triangulation method [46].

Figure 1.6 is representing the basic principle of triangulation. Base X, Base Y and Base Z are getting different RSS from the mobile node based on the signal strength to construct a circle. When we combine the results of Base X with Base Y we are still not confident that out of two intersections which of the location of the mobile node is? To solve this problem we need to consider the Base Z. The intersection point of all three antennas is localized as the best possible location of mobile node [46].

1.5 Applications of triangulation method

The following are the commonly used applications of triangulation method:

- **Localization of asteroids in space to figure out its exact location**

  During the movement of space shuttle the localization of asteroids is one of the major concerns for the astronauts for the safe journey. Triangulation is used to find out the moving object and their trajectory in space.

- **Astronaut's movement in space**

  Another application of triangulation in space is astronaut's movement in free space. Moving in space is not as simple as walking in the lawn. With the asteroid's trajectory and location, astronauts need to localize theirselves in order to avoid accidents.

- **Vehicle localization in VANET**

  VANET is one of the popular research areas in wireless environment. But the network becomes worthless if the nodes are not able to establish handshake with each other. Triangulation helps to localize nodes therefore they can discover each other for handshaking.

1.6 Location Estimation of Wireless Node

Location estimation or location determination is a research area which is used to localize the position of a wireless or mobile node. Before discussing the location estimation implementation techniques in different wireless environment, it is essential to know the types of wireless architectures. Wireless location estimation environments can be categorized as mentioned in the table 1.1

Table 1.1: Location Estimation Categories

Category	Example
Wireless Local Area Network (WLAN)	WiFi (IEEE 802.11 standard) etc
Wireless Metropolitan Area Network (WMAN)	WiMAX (IEEE 802.16 standard)
Wireless Wide Area Network (WWAN)	GSM and similar architectures, Satellite Communication etc.

All of the above wireless architectures are using location positioning at some extend. The discussion of each of the category is in the following sub topics.

1.6.1 WLAN: Case Study of the WiFi (IEEE 802.11x)

WiFi provides network connectivity over wireless local area network environment. Access Point (AP) works as a bridge between the wired and the wireless network. The range of the WiFi depends on the equipment and conditions. The range may vary from 150 meters to 400 meters [50].

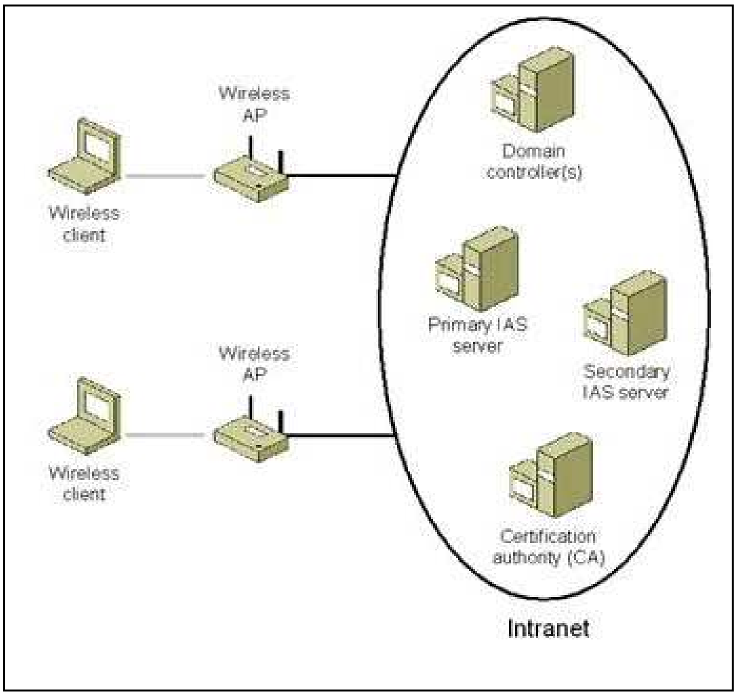


Figure 1.7: WiFi Architecture [50]

Figure 1.7 is representing the WiFi architecture. Frequency of WiFi is not much different from the GSM frequency range. WiFi uses 2.4, 3.6 and 5 GHz unlicensed band for communication [51] where as GSM is operating on 900, 1800, 1900 and 2100 MHz [ref]. Frequency channels of 2.4 GHz is shown in figure 1.8.

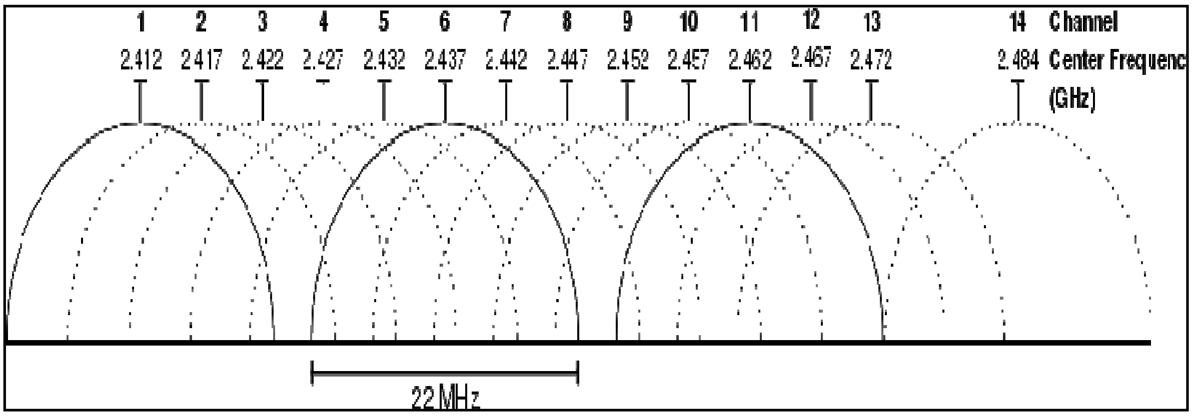


Figure 1.8: Frequency Channels of 2.4 GHz [51].

1.6.1.1 Localization in WiFi

WiFi location estimation is used as a litmus paper test for other types of wireless environments because of its easy installation and cheap cost of hardware. Researchers used triangulation method frequently for location estimation in WiFi architecture [52-58]. Furthermore in order to achieve accuracy researchers also added probabilistic techniques [59-70].

In [16], authors used the triangulation method with the calibration to estimate the position of wireless node in an indoor environment. They did testing with number of walls between the access point and the mobile node in order to minimize the error. The error rate from the mapping of the result was 5.5 meter to 6 meters.

In [17], author proposed a trilateration method to estimate the position of a mobile device and used the weighted mean to minimize the error. Their testing was also based on the indoor WiFi environment.

In [59], authors used probabilistic technique to achieve accuracy in an indoor WiFi environment. Based on the triangulation results they used the Bayesian Decision Theory to achieve high accuracy with low computational requirements.

As mentioned above authors used either triangulation method alone or the triangulation with the combination of geometric or statistical tools to minimize the error rates. In horus system [22, 24], authors used probabilistic technique to minimize error in WiFi location estimation. The horus system error rate is low as compare to other localization techniques but still in the range of three (3) meter.

1.6.2 WMAN: Case Study of the Worldwide Interoperability for Microwave Access (WiMAX)

Unlike WiFi, WiMAX is intended to work outdoor over long distances. WiMAX is actually not eliminating the WiFi technology but the two technologies are complementing each other. WiMAX eliminates the constraints of WiFi such as short range, security problem, mobility and interference. WiMAX can provide two form of services which is Line of Sight (LOS) and Non LOS.

1.6.2.1 LOS (Line of Sight)

In LOS a fixed antenna points straight to the WiMAX tower from the rooftop or a pole. The LOS established connection is stronger and stable and can transfer high amount of data with low interference. It uses high frequency ranges reaching a possible 66GHz.

1.6.2.2 Non- LOS (Non Line of Sight)

Non LOS is actually WiFi sort of service where a small antenna which is connected with computer communicates with WiMAX tower and works as a last mile end form the user. Normally uses low frequency ranges from 2 to 11 GHz.

Figure 1.9 is explaining both architecture of WiMAX [71]. The term backhaul is used for the backbone network connection in WiMAX. There are two types of backhaul

- LOS backhaul (connected wirelessly from WiMAX to WiMAX antenna)
- Fixed backhaul (Connected through wired network)

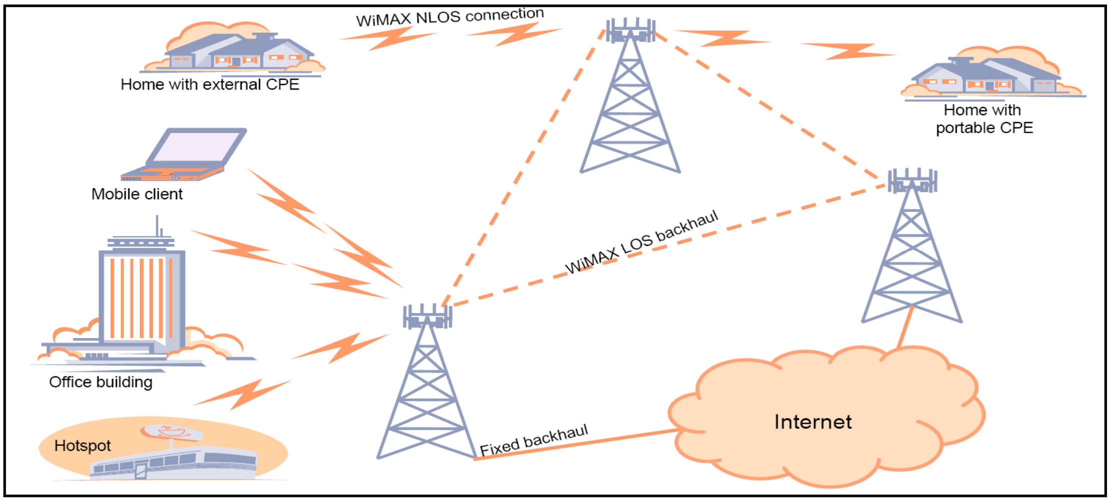


Figure 1.9: WiMAX Architecture [71]

1.6.2.3 Localization in WiMAX

The patent work [72] is focusing to localize the accurate position of wireless nodes in WiMAX architecture. Authors used receive signal strength and referred the location with at least one reference point in order to apply the triangulation method.

1.6.3 WWAN: Case Study of the Global System for Mobile Communication (GSM)

The GSM architecture is quite comprehensive compared with the WiFi and the WiMAX [73]. It comprises of

- **Mobile Station (MS):**

  MS is a device which is most familiar to the users. To initiate or to receive a call user uses it to connect with the Base Station Controller.

- **Base Station Subsystem (BSS):**

  BSS consists of multiple Base Transceiver Station (BTS) and Base Station Controller (BSC). BTS consists of multiple antennas mounted on the top of tower and the routing device which is connected with BSC.

BSC is a master of each location area. It is connected with multiple BTS at the same time. A dedicated path is established by the parabolic antenna to communicate with the Mobile Switching Centre (MSC).

- **Network Subsystem:**

The main part of network subsystem is Mobile Switching Center (MSC) which contains AuC (Authentication Center), EIR (Equipment Identifier Register), HLR (Home Location Register) and VLR (Visitor Location Register). The HLR and VLR only provide support to the network in identifying the user's subscription for roaming and call transfer purposes. VLR and HLR have nothing to do with the location cell phone. Cell Identifier (CI) and Location Area Identifier (LAI) are the two types of information that reside in Base Station Controller (BSC) to identify the location of cell phone. Complete architecture of GSM is presented in figure 1.10

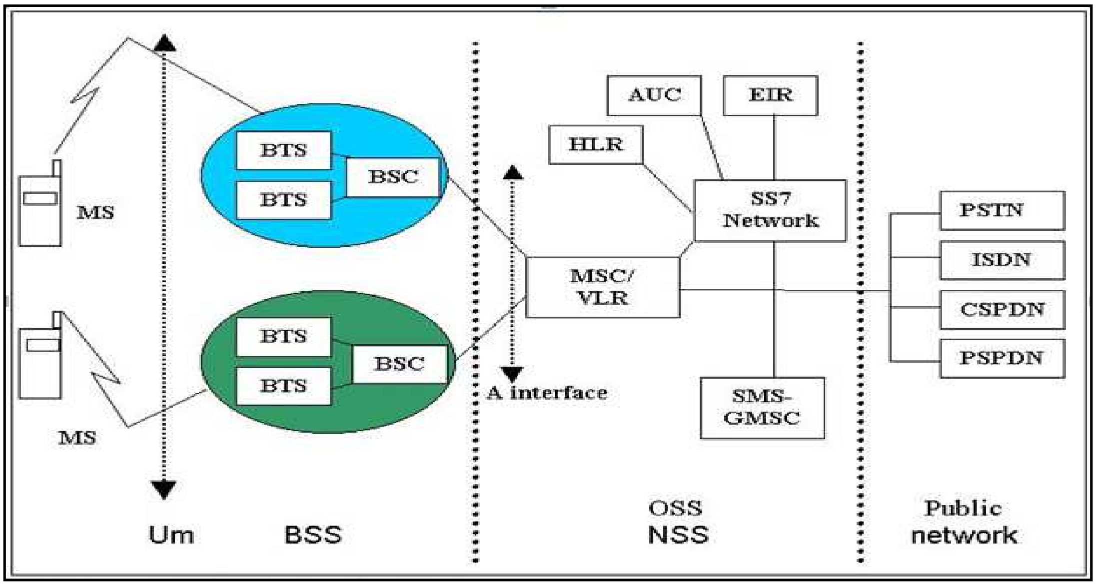


Figure 1.10: Build Blocks of GSM Architecture [74]

1.6.3.1 Localization in GSM

The most visible thing for the user in the GSM network is the tower with antennas which is technically known as BTS (Base Transceiver Station). Each BTS requires at least three (3) quarter wave dipole antennas to cover 360^{o} of angle. Single dipole antenna can cover up to 120^{o} only. The range of each dipole antenna is up to five (5) km, which handshakes with the antenna of other BTS in its direction. This architecture of handshaking helps to maintain connection with network while moving from one cell to another. Figure 1.11 represents the BTS tower with three (3) antennas installed. It also explains the coverage area of each antenna.

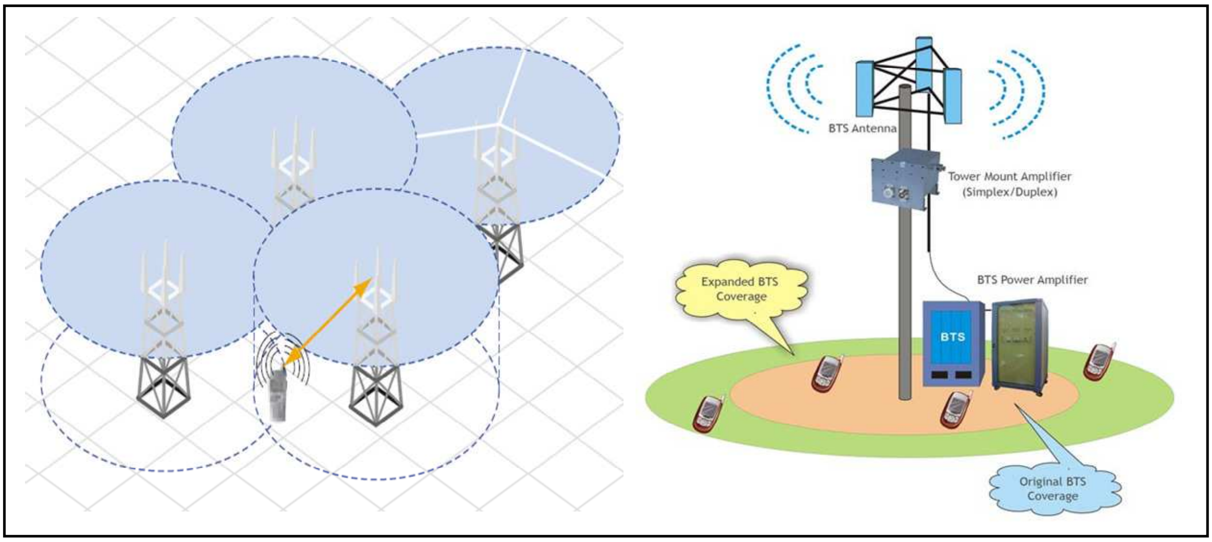


Figure 1.11: Localization in GSM [75].

In the left part of figure 1.11 a cell phone is receiving signals from one of the omni-directional antenna. Therefore for the area identification only one third of the whole cell will be focused which is covered by that specific antenna. Figure 1.12 is explaining the concept with the reference of Cell and location area.

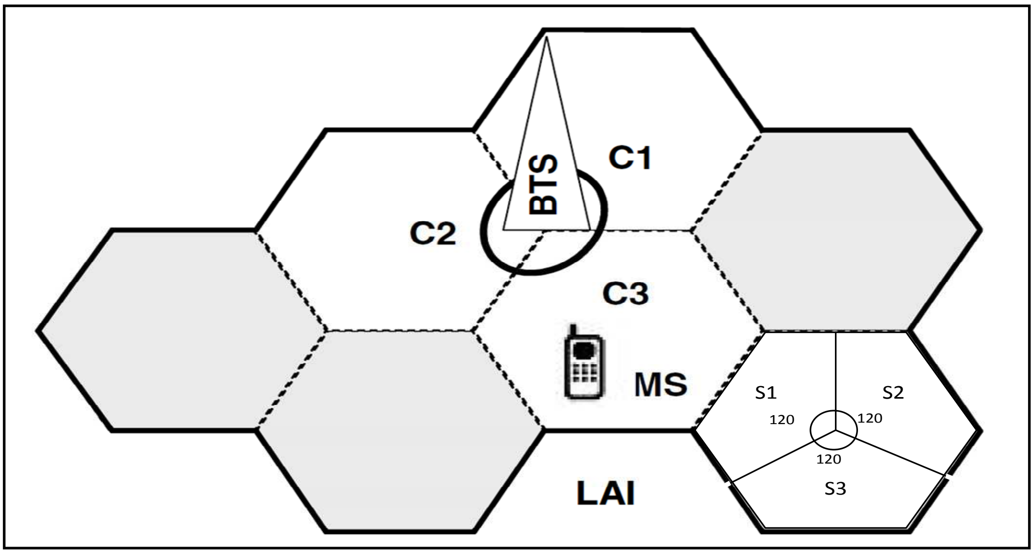


Figure 1.12: Cell-ID location technique [76]

A BTS covers a set of cells (mini, micro, pico cells), each cell is identified by a unique cell ID i.e C1, C2 and C3 as mentioned in the figure above. A mobile node selects a cell and exchanges traffic signaling and data with the linked BTS. These cells are grouped in clusters each of them has assigned a identical LAI.

Location of the cell phone is based on two items, the cell identifier and the location area identifier. The cell identifier is the BTS number and its location whereas the Location Area Identifier is the coverage area of a specific antenna. As the BTS covers five (5) km in diameter which is quite big area therefore antennas coverage area is used to minimize the two third (2/3) BTS coverage area [75]. As the size of clusters under each antenna is big therefore it is impossible to point out the exact location of a cell phone. Neither less with the help of CI and LAI one can point out the region under a specific cell.

1.6.4 WWAN: Case Study of the Global Positioning System (GPS)

GPS positioning is based on trilateration, which is the method of determining a position by measuring the distance to a point of a known coordinates. At a minimum, trilateration requires three (3) ranges of three (3) known points. GPS point positioning, on the other hand, requires four (4) “pseudoranges” to four (4) satellites [77].

The Global Positioning System (GPS) refers to a group of orbiting satellites funded by and controlled by the U. S. Department of Defense (DOD). While there are many thousands of civil users of GPS world-wide, the system was designed for and is operated by the U. S. military. GPS provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute the position, the velocity and the time. Four (4) GPS satellite signals are used to compute the positions in three dimensions and the time offset in the receiver clock. These satellites transmit very low power radio signals that allow anyone with a GPS receiver to determine their location on the Earth’s surface.

There are other satellite positioning systems similar to GPS, launched by European Union (The Galileo: GNSS- Global Navigation Satellite System), Russian (The Glonass) and Chinese (The Compass: Beidou-2)

1.6.4.1 GPS Components

The GPS system consists of three components:

i. Space segment (the satellites)
ii. Control segment (ground stations)
iii. User segment (GPS receiver with user)

The **space segment**, which consists of at least 24 satellites [21 of which are active at any one time with three (3) reserve in case of failure], is the major feature in the system. The satellites are spread so that a GPS receiver on the Earth's surface can receive signals from at least four of the satellites at any one time. GPS nominal constellation with orbital classes is presented in figure 1.13.

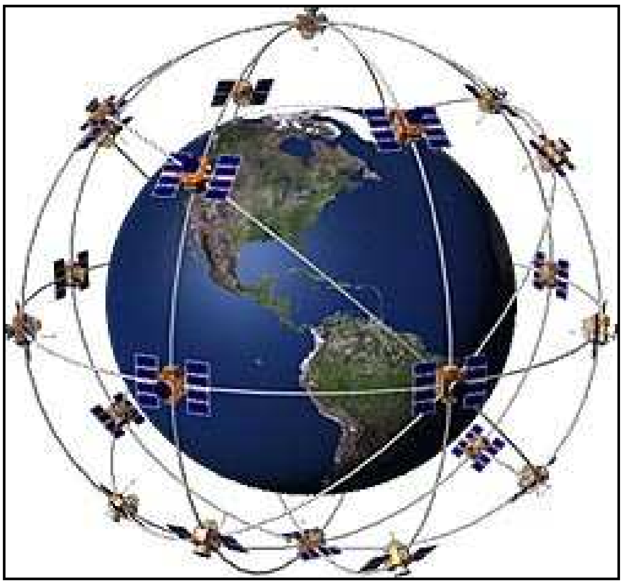


Figure 1.13: GPS Nominal Constellation [27, 78] (24 Orbits in 6 orbital planes; 4 Satellites in each plane; 20,200 km Altitude, 55 Degree Inclination)

The **control segment** controls the GPS satellites by tracking them and providing them with correct orbital and clock data. It also controls the positioning of the satellites, their speed and their distance from the earth's surface. The Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in Colorado. These monitor stations measure signals from the Space Vehicles (SVs) that are incorporated into orbital models for each satellites. The models compute precise orbital data (ephemeris) and SV clock corrections for each satellite. The Master Control station uploads ephemeris and clock data to the SVs. The SVs then send subsets of the orbital ephemeris data to GPS receivers over radio signals. Figure 1.14 is representing the control segments installed allover the world.

Figure 1.14: Global Positioning System (GPS) Master Control and Monitor Station Network [27, 78]

The final segment is the **user segment**, which consists of an end user with a GPS receiver. For its location on the Earth's surface receiver needs to know two elements; firstly where the satellites are located (location) and how far away they are from the receiver (distance). This data is always transmitted and is stored in the memory of the GPS receiver, so that it will know the orbits of the satellites. Precised positioning is possible using GPS receivers at reference a location which provides corrections and relative positioning data for remote receivers (e.g. DGPS implementation). Surveying, geodetic control, and plate tectonic studies are examples.

Time and frequency dissemination, based on the precised clocks on board the SVs and controlled by the monitor stations, is another use for GPS. Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precised time signals or controlled to accurate frequencies by special purpose GPS receivers. Research projects have used GPS signals to measure atmospheric parameters [77-79].

1.6.4.2 Localization in Global Positioning System

The GPS applies the triangulation method to localize the GPS receiver. It requires three satellites to construct three triangles. Time of Arrival (TOA) and Time Difference of Arrival (TDOA) are the parameters used to calculate receiver's location. This information is updated periodically as the satellites move around. If the receiver has the information about both the satellite location and the distance, then it can calculate its position [80]. Although the system is stable and well tested and has a global availability and the GPS receivers are cheap and available for a large number of platforms along with large amount of maps available based on GPS coordinates, the obstruction and signal scattering makes the GPS system is practically nonfunctional in indoor environment. Furthermore it is owned and operated by a single nation that can potentially shut it down without any warning [78].

1.7 Comparison between different techniques based on level of accuracy

Each location estimation type has different accuracy level. The table 1.2 is demonstrating the accuracy level in each of the above discussed techniques and methods.

Table 1.2: Demonstrating accuracy level in different location estimation techniques [27].

Type	Attribute	Network	Handset	Accuracy
Cell ID	Obtain Cell ID based on pilot measurement	All	Both	100- 3km depending on cell size and density
Cell ID +TA	Combines Cell ID with time advance	GSM	Both	Default is 500m. Depends on bandwidth
EFLT	Mobile measure the forward link pilot timing	CDMA	Both	250-350m
AFLT	Mobile measures the forward link pilot timing	CDMA	Upgrade	50-200m
AOA	Network measure the angle of arrival	All	Both	100-200m
U-TDOA	Network measures the timing difference	All	Both	< 50m
EOTD	Mobile measure time difference	GSM	Upgrade	50-200m
GPS/A-GPS	GPS receivers in handsets and/or network	All	Upgrade	5-30m

Figure 1.15 is the graphical representation of the above mentioned technologies in table 1.2 meter scale is based on accuracy and coverage.

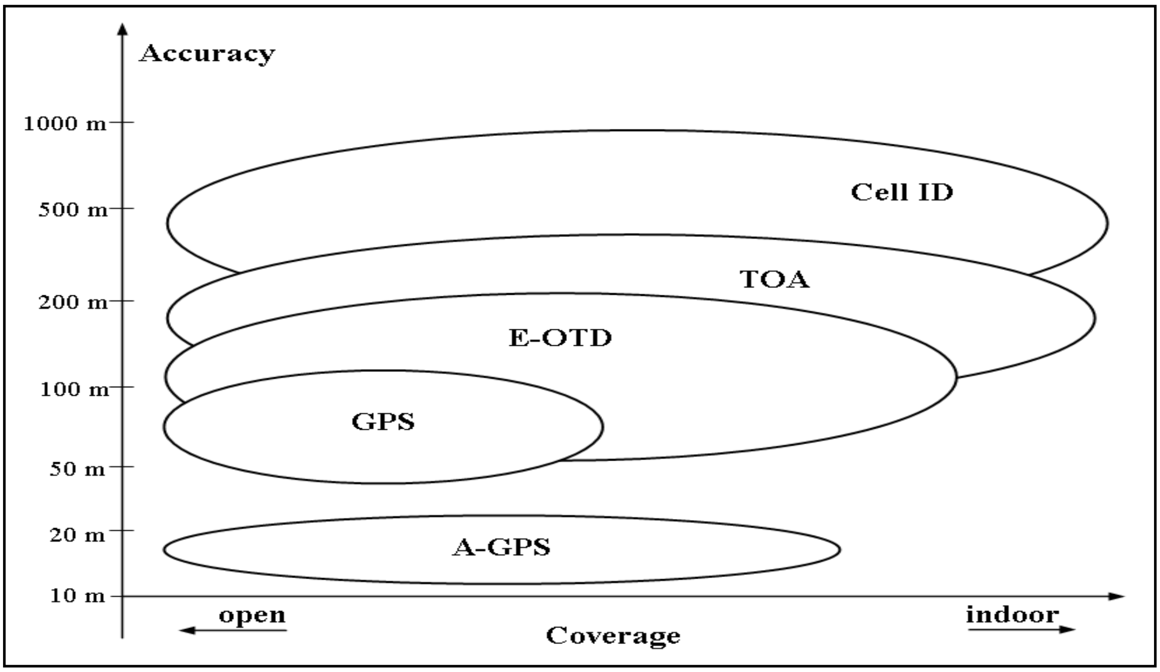


Figure 1.15: Comparison between different localization techniques [76].

As mentioned above the AGPS/DGPS is the best in terms of accuracy but it is dedicated for DOD and not available for public.

1.8 Signal Distortion in Wireless Networks

Wireless signal propagates in a free space while transmitting from sender to receiver or vice versa. External factors like bright sunlight, heavy rain, humidity factors and others effect on the transmitted signal. As radio waves behave differently in different environments, therefore the calculation of few parameters is not sufficient to achieve accuracy in different terrains especially when it is totally based on RSS which is carrying impairments. Behavior of radio waves can be categorized as the reflection, refraction, diffraction, scattering and absorption based radio waves [81, 82].

It is much more complicated to manage the strength of wireless signal than in a wired network. One factor that affects radion signal strength is ElectroMagnetic Interference (EMI) which is also known as noise. Airlines require to its passengers to shut off all electronic devices in order to the electrical interference form the airplane's navigationals devices and radion systems. Moreover, many type of objects, both stationary and moving, can impact the signal [83,84]. The Signal-to-Noise Ratio (SNR) refers to measure the signal strength with respect to the background noise. If the background noise is highet than the actual signal then the interference can take place [83,84].

Radio waves are directly affected by terrains atmosphere [85]. Signal to Noise ratio (SNR) adds error rate in received signal (Rx). When the transmitted signal (Tx) passes from different terrains then the above mentioned characteristics apply on that Tx. Because of the noise addition the Rx value differs from the Tx value [86]. The difference between the Tx and the Rx values is known as loss. The received signal strength is inversely proportional to loss, if the loss increases the received signal strength decreases. When these errors containing Tx and Rx values are used for the location estimation of a node will add error in the calculated location estimation.

1.9 Terrain/Clutter Characteristics in Wireless Communication

Terrains also play a vital role in the distortion of a radio signal [87]. Researchers used different definitions of terrains/clutters according to their requirements and the projected area [86, 88]. It is recorded that every terrain has different level of impairments other than external effects [87]. In [86] researchers divided the projected geographical area of minipur of rural Indian terrain in eight (8) different terrains. Authors in [88] also used 8 terrains for their research. Their projected area was in the Malaysian peninsula. In [89], authors used urban terrain for the localization of cell phones. They proposed the architecture that enabled the discovery by using builds and landmarks. Each of the above research results show that terrains produce great impact on the signal quality and strength which leads towards the impairments and the attenuation.

1.10 Background of the Problem

As mentioned above location estimation/determination is a well developed research area especially in satellite communication, whereas in WiFi, MANET, VANET, WiMAX and GSM it has few applications. But the main question is the accuracy in localizing the position of the receiving node. Researchers also tried to reduce error in order to increase accuracy by using geometrical and statistical techniques, but still there is a considerable error. As in WiFi the error is up to six (6) meter [16], in GSM the error is one (1) km or more [76] and in GPS the error is from 50 - 100 m [76].

Terrain consideration is another aspect which is required to be considered for location estimation. Studies showed that the terrain characteristics and external effects of terrains play a vital role for signal distortion [81-89].

1.11 Problem Statement

Location Based Services (LBS) are used in almost every type of wireless communication. A few of them are very accurate but they are not available for public e.g DGPS. Also extensive hardware is required for the location estimation of wireless node, whereas precision is still a question in the LBS. From WiFi to GPS every type of localization carries error [16, 76]. Cell ID is only capable to estimate the location with error rate of few kilometers [27, 76]. On the other hand, mobile originating emergency calls are increasing very rapidly [6]. There is a need to explore this research area by considering all means, for example attenuation, hardware constraint, external effects, environment etc. This thesis researches to minimize the error in Location Based Services (LBS) by combining the statistical and geometric location estimation techniques. The knowledge of the terrain is also used to minimize the error.

1.12 Research Objectives

The current research is seeking to meet the following objectives

1. Terrains/Clutters defination based on Signal to Noise Ratio (SNR).
2. Terrains/Clutters based SNR error calculation in each projected area.
3. Error calculation by using geomatric and statistical techniques with terrains/clutter based knowledge.
4. Fusion of geomatric and statistical results for the minimization of errors.

1.13 Proposed Architecture

The proposed model is consisting of the four steps of kalman filtering, which are estimation, filtering, prediction and fusion. A prototype is built by using the WiFi IEEE 802.11x standard. In step one, by using signal to noise ratio the peninsular Malaysia geographical area is categorized into 13 different terrains/clutters. In step two, point-to-point data points are recorded by using available signal strength and receive signal strength with the consideration of different terrains. Estimation of location is done in step three by using triangulation method. The Results of estimated locations are further filtered in step four by using average and mean of means. For error correction filtering of the location is also carry out by using k- nearest neighbor rule. The prediction is done in step five by using combine variance in order to predict the region of interest, which helps to eliminate locations outside of the selected region. In order to achieve accuracy the filtering results are fused with prediction in step six. The results show that this research has reduced errors from 18 m to 6 m in highly attenuated terrains and from 3.5 m to 0.5 m low attenuated terrains. The focus of this research is to minimize errors by considering terrains characteristics and the combination of geometrical and statistical techniques.

1.14 Novelty of this research

From this research the following novelties have been found:

1. Firstly, signal to noise ratio (SNR) is considered to catagorize terrains/clutters. Point-to-Point (P2P) location estimation of wireless node in each terrain is calculated by using Available Signal Strength (ASS) and Receive Signal Strength (RSS) [90-92]. Based on P2P terrain based location estimation, the Error Rate Table (ERT) is developed which helps to minimize P2P location estimation errors [93]. The Clutter based Enhance Error Rate Table (CERT) is further developed by considering zones [94] (CERT- A enhance form of ERT) for error correction in ERT results. Moreover linear interpolation is used, which helps to predict P2P distance at random, based on the recorded signal strength.

2. Filtering of the P2P distance is being done by using the famous triangulation method and the k-Nearest Neighbor [95, 96]. Results show that k-NN produce better results than triangulation.
3. Region of Interest is calculated by using combine variance approach for prediction. By fusing results of estimation, filtering and prediction a Predicted and Corrected Location Determination Algorithm (PCLDA) for error correction is proposed which helps to minimize error in open area [95, 97].

1.15 Chapter Summary

The objective of this chapter is to provide the reader the sufficient knowledge and understanding about the topic. A brief view of location estimation techniques and methods is presented in this chapter. Different applications of WLAN, WMAN and WWAN are also discussed. As attenuation/impairment is also the part of this research, therefore we dedicated a section for the basics of signal distortion and impairments.

Chapter 2

Literature Review

2.1 Chapter Introduction

This chapter is dedicated for literature review. The research of other scholars is discussed in this chapter. This chapter is divided into four sections:

1. Location Estimation in Wireless Local Area Network (WLAN)
2. Location Determination in Wireless Metropolitan Area Network (WMAN)
3. Location Estimation in Wireless Wide Area Network (WWAN)
    a. An Application of Global System for Mobile Communication (GSM)
    b. An Application of Global Positioning System (GPS)
4. Terrain /Clutter affects on Wireless Signals

2.2 Location Estimation in Wireless Local Area Network (WLAN)

In [98], the author proposed and implements GPS free global positioning method for mobile units for indoor wireless environment. He used Bayesian filtering approach for initial measurement. The cell-ID of the serving base station and the predetermined route radio maps are used as parameters. Firstly, the author derived generic recursive Bayesian filter algorithm for prediction and update. Secondly, the positioning algorithm was derived which was used to track the probable position of mobile unit. Finally position tracking algorithm was used for tracking purpose. He repeated the experiment for 100 times and claimed the estimated position tracking error is between 15 and 20m.

In [99], the authors investigated and presented various positioning algorithms. They pointed out that there were two approaches used for the position estimation. Firstly, the “Direct approach” in which position of the mobile node is estimated based on the signal travel between two nodes [100]. Secondly, the two-step positioning that calculates the different position parameters like AOA, TOA, TDOA, ASS, RSS etc and based on these parameters position of the cell phone was estimated. They also pointed out that the geometric and statistical techniques can be used to improve the accuracy.

In [101], the authors used Extended Kalman filter approach in WSN for location estimation. Parameter considered was RSSI, where is

$$RSSI=K/R2 \tag{2.1}$$

K is considered as the measure of confidence level and R is representing the radius of the sensor network communication range. The authors claimed that their method was showing better results when compare with existing methods.

In AVG [102], the authors used Kalman filter very efficiently to control noise and error control. Based on experiments they claimed that their derived approach offered better suppression of vision measurement noise and a better performance in the absence of vision measurements.

In [103], the authors proposed Kalman filter based Location estimation with NLOS mitigation. They fused results of geometric approach with the Kalman filter for location estimation. They suggested that geographical information can be added for better accuracy of mobile location.

In [104], the authors introduced a Bayesian hierarchical modeling approach for location estimation. Instead of locating a single node they simultaneously located a set of wireless nodes. Their work was based on prior knowledge and they constructed the network as used in Boltzmann learning. They demonstrated that their model achieved similar accuracy as previously published models and algorithm.

In Selective Fusion Location Estimation (SELFLOC) technique [105], the authors assigned weight to each location and weighted sum gave the SELFLOC estimation. They calibrated the branch weights during the offline stage using the error feedback. They claimed that the main benefit of the SELFLOC algorithm is the accuracy gained by combining uncorrelated information contributed from multiple branch inputs of heterogeneous source and algorithms. They adopted the Minimum Mean Square Error (MME) [106] for SELFLOC weight calibration. They also applied SELFLOC algorithm with other classical location algorithms to improve accuracy. Classical algorithms they used in their experiments were Triangulation (TN), K-Nearest Neighbor averaging (KNN) and the Smallest M-vertex Polygon (SMP).

In Region of Confidence (RoC) approach [105], the authors attempted to counter aliasing in the signal domain. By using the probabilistic techniques the algorithm first forms a region of confidence within which the true location of a user lies. Then a series of estimates are obtained in a close time intervals either from the same or different classical location algorithms and filtered by using the formed RoC. Through implementation and experiments authors experienced best mean distance error of 1.6m when using SELFLOC weighted localization algorithm. By using RoC with eKNN they experienced that the error was improved from six (6) meters to 4.5 meters.

In [107], the authors used Bayesian sampling approach for the location estimation of indoor wireless devices by using RSSI as main sensing parameter. Their proposed architecture in the paper computes posterior probability of the target location using sequential Monte-Carlo sampling, which is capable of using arbitrary a-priori distribution to compute a posterior probability [107]. Based on the simulation results they believed that the method is less computationally intensive and it is also suited to an indoor wireless environment where other standards may not work.

In [108], the author presented a statistical location estimation technique based on a propagation prediction model. He took signal parameters such as Receive Signal Strength, Angle of Arrival and the propagation delay as random variables. These variables were statistically dependent on the location of receiver, transmitter and the propagation environment. He commented that there are certain types of flexibility in the statistical approaches. This flexibility allows the fusion of different types of measurement results like Receive Signal Strength and the timing advance.

In [16], a low cost solution is specified for the location determination of mobile node by combining the benefits of Triangulation and Calibration methods in a wireless local area network. The authors presented an implementation-based study that demonstrated the strong relationship between the two of the location determination methods and their performance. The main objective of their work was to provide a method in which no dedicated hardware is required. Only wireless LAN card was required and could be placed in any suitable location. The significance of their result lied in allowing a network designer to make a suitable tradeoff between QoS of location determination and other application protocols while choosing a network topology. The combination of these two methods reduced the error rate of locating a mobile node to a great extent. The results were being plotted on a given map using both algorithms.

WLAN location determination systems usually work in two phases: an offline training phase and an online location determination phase. During the offline phase, the system tabulates the signal strength received from the access points at selected locations in the area of interest, resulting in a so-called radio map. During the location determination phase, the system uses the signal strength samples received from the access points to “search” the radio map in order to estimate the user location. Radio-map based techniques can be categorized into two broad categories: deterministic techniques and probabilistic techniques. Deterministic techniques [17, 109] represent the signal strength of an access point at a location by a scalar value. For example, in the Radar system [17] nearest neighborhood techniques were used to infer the user location. On the other hand, probabilistic techniques [20-24, 101-108, 110] store information about the signal strength distributions from the access points in the radio map and used probabilistic techniques to estimate the user location. For example, the Nibble system [111] used a Bayesian Network approach to estimate the user location.

The Horus system [22, 24], was a probabilistic technique that tried to satisfy two goals: high accuracy and low computational requirements. It identified different causes for the wireless channel variations and addressed them to achieve its high accuracy by using location-clustering techniques which reduces the computational requirements of the algorithm. The lightweight Horus algorithm allowed it to be implemented in energy-constrained devices.

In [112], the author presented a trilateration approach for locating a wireless device in indoor environment based on the signal strength received from the access points at known locations. This approach mainly consists of two phases. First, the calculation of distance from RSSI values of various access points as received by the mobile device. Second, determination of the most probable location of wireless device using coordinates of various known or fixed access points and calculated distances of the device from those access points. The proposed algorithm provided a solution for location tracking of mobile devices in indoor environment where the configuration of access points like transmit power etc., was not fixed and the movements in environment affecting attenuation of signal was so unpredictable that any mathematical modeling of indoor RF signal propagation was infeasible.

The SIMPLE (Simple Indoor Multi-level Portable Location Engine) [113], is a wireless location prototype run on an IPAQ PDA equipped with an 802.11b wireless LAN interface and provided a handheld location system in conjunction with a number of access points. This work was based on [24] and [114]. The system had been particularly developed to work within a museum or heritage scenario that spaned multiple locations and may enable metropolitan wide location services. SIMPLE enabled a wireless enable PDA or a cellular phone with WLAN functionality to download a wireless database and map and determined their location based on received signal strength indicator (RSSI) information. A number of techniques had been combined within SIMPLE to enable the PDA to function as an autonomous device with minimal interaction to the service provider infrastructure. The system worked in two phases: offline and online. The offline phase involved building a radio map and the preprocessing of signal strength distributions. A radio map stored distributions of RSSI values from detectable access points (APs). In the online phase, a user's location was estimated using a 'live' sample, or an observation of RSSI values, which was compared to data collected in the radio map.

Results showed that a wireless LAN could indeed be exploited to identify device position using RSSI techniques. Testing had shown that SIMPLE could achieve an average accuracy of just over 4 meters while incurring only a moderate training cost. SIMPLE determine a location within 8 meters 90% of the time, which may be sufficient to provide positional information for enhanced user and location-based experience. In order to realize this, the next step was to integrate SIMPLE into a LBS middleware, which provided the necessary functionality to provision services.

2.3 Location Determination in Wireless Metropolitan Area Network (WMAN)

In [115], authors utilised some of the WiMax offered features for enhancing the location accuracy in location services. The authors used adaptive modulation and coding (AMC), beamforming and relay station (RS) for localization of WiMax node. Simulation results showed that in term of location accuracy, the proposed solution adheres to federal communications commission (FCC) requirements.

The patent work [72] is focusing to localize the accurate position of wireless nodes in WiMAX architecture. Authors used receive signal strength and referred the location with at least one reference point in order to apply the triangulation method. The architecture included the receiver, a message containing location data for a serving base station and atleast one neighbor base station and means for calculating a location of the mobile station using location data at serving base ststion.

2.4 Location Estimation in Wireless Wide Area Network (WWAN)

Based on the application division WWAN localization can be catagorize into Global System for Mobile Communication and the Global Positioning System.

2.4.1 Location Estimation in Global System for Mobile Communication (GSM)

There are several location estimation systems for wide-area cellular based networks [116]. The technological alternatives for locating cellular phone users involve measuring the signal attenuation, the angle of arrival (AOA) and/or the time difference of arrival (TDOA). While these systems have been found to be promising in outdoor environments, their effectiveness in indoor environments is limited by the multiple reflections suffered by the RF signals, and the unavailability of off-the-shelf and cheap hardware to provide fine-grain time synchronization [117].

In [118], the authors described another method for ubiquitous computing (ubicomp) device positioning: using radio beacons "in the wild" (PlaceLab, [119]). Beacons in the wild refer to fixed private omnidirectional short-range radio sources with unique IDs that include IEEE 802.11 (WiFi), Bluetooth, and GSM transmitters. The approximate location of these transmitters was mapped by volunteers wandering around with GPS units and receivers which log the user's location at the time they were able to receive a signal and this was recorded as the location of the beacon. This map was then distributed with the location determining applications that currently run on laptops, PDAs and certain Nokia mobile telephones. User application was then able to triangulate their location by measuring the strength of all of the beacons "visible" at a given time and comparing this to the apparent positions of the beacons. In contrast with the poor coverage of GPS location determination, GSM beacon triangulation gave nearly 100% coverage in urban areas. While Bluetooth and WiFi beacons have a range of between 10 and 100 meters respectively, GSM transmitters could have a range of thousands of meters. This means that the wardriving technique could give very inaccurate beacon location information for GSM beacons.

GSM network operators and third parties currently sell location based services using the inverse of the PlaceLab method described by [118]. They calculated the position by triangulating the phone location relative to the cell towers which were able to see the phone. A wide range of services are available including interfaces for parents to track their children and business to track their mobile sales force in order to deploy the appropriate person for a given task [120].

Pin-Point [121] was a distributed algorithm that enabled a set of *n* nodes to determine the RF propagation delays between every pair of nodes, from which the inter-node distances and the spatial topology could be readily determined. PinPoint did not require any calibration of the area of interest and thus is rapidly deployable. Unlike existing TOA techniques, PinPoint did not require an infrastructure of accurate clocks (e.g., GPS) nor did it incur the message exchanges of “echoing” techniques. PinPoint could work with nodes having inexpensive crystal oscillator clocks, and incurs a “constant number” of message exchanges per node to determine the location of *n* nodes. Each node’s clock was assumed to run reliably but asynchronously with respect to the other nodes, i.e., they could run at slightly different rates because of hardware (oscillator) inaccuracies. PinPoint provided a mathematical way to compensate for these clock differences in order to arrive at a very precise timestamp recovery that in turn leads to a precise distance determination. Moreover, each node was able to determine the clock characteristics of other nodes in its neighborhood allowing network synchronization. The authors presented a prototype implementation for Pin-Point and discussed the practical issues in implementing the mathematical framework and how

PinPoint handled the different sources of error affecting its accuracy. Evaluation of the prototype in typical indoor and outdoor environments gave an average accuracy of four to six feet.

In [122], the authors characterized the accuracy of three published positioning algorithms: a simple centroid algorithm that did not model radio propagation, fingerprinting, and Monte Carlo localization with a Gaussian Processes signal propagation model. This paper examined the feasibility of a client-side, beacon-based GSM location system and the methods from the WiFi literature could be retargeted to GSM phones in a metropolitan setting.

In [123], Alex Varshavsky and other argued that for emerging location enhanced applications, client-based GSM localization could provide an adequate solution both in terms of coverage and accuracy in a device that people already carry. To dispel the notion that location systems using GSM phones were inherently less accurate than systems built for WiFi devices. They commented that by using GSM it was feasible to detect places people go in their everyday lives with 2-5 meters median error and room-level localization for indoors and 70-200 meters median error for outdoors.

In [124], the authors used the rectangulation method to estimate the location of cell phone. They also proposed extra hardware named RP's (reference point) at the edge of each cell, means we require six extra antennas (RP's) with each BTS to calculate the location of mobile phone. They considered RSSI value for the calculation of coordinates. Main difference between their researches with the other researchers in this field is that, they used lower RSSI and higher RSSI value. By using these values they claimed that the location could be much more précised as compared with the old research. Secondly they used rectangulation method to calculate the location of mobile nodes, as used in GPS by the other researchers.

In [125], Veljo and his colleagues established indoor GSM environment and examined the effectiveness of GSM fingerprinting as an indoor localization technique. They claimed that this combination was new in terms of indoor localization, radio fingerprinting and usage of GSM for localization. They also executed the experimental work to check the signal stability in GSM and compared it with 802.11 standard.

2.4.2 Location Estimation in Global Positioning System (GPS)

In [126] author considerably simplified the approach of GPS location, in the scenario that each satellite is sending out signals with the following content: "Hello Mr. I am satellite A, my position is B and this information was sent at time T_0". In addition to its own configuration each satellite was also sending information about the location of other satellites in the near orbits. These orbital data (ephemeris and almanac data) were stored for the future configurations location estimation and calculations. To calculate its position on the earth each GPS receiver compared the time when the signal was sent by the satellite with the time T_0 and the time T_1 the signal was received by the receiver [127]. From this time difference the GPS receiver could calculate its distance from the satellite.

Same function was repeated by the GPS receiver with other satellites on the basis of the results position of the GPS receiver could be calculated by using the trilateration means the method that calculates the distance from three (3) points. Therefore at least three satellites were required to calculate the precise location of the GPS receiver on the earth. The calculation of a position from three (3) satellite signals is called 2D-position fix (two-dimensional position determination). It is only two dimensional because the receiver had to assume that it was located on the earth surface (on a plane two-dimensional surface). By means of four or more satellites, an absolute position in a three dimensional space could be determined. A 3D-position fix also gave the height above the earth surface as a result. The basic formula behind all the technique is not new for all which is:

$$\text{Distance} = \text{Time} * \text{Velocity} \qquad (2.2)$$

2.5 Terrain /Clutter affects on Wireless Signals

In [86], the authors divide the projected geographical area in eight terrains/clutters for the deployment of the GSM network architecture in a specific Indian terrain. Categorization of available terrains were low density urban, village/low density vegetation, medium density vegetation, high density vegetation, agriculture, open/quasi open area, water bodies and river/sea. Authors introduced the concept of clutter loss which they named as CL. Based on the Receive Signal Strength (RSS) measurement they proposed a tower location prediction for the region. Based on the path losses simulation results, they concluded that the proposed tower prediction method would better work in the remote Indian area of Manipur.

In [128], the authors considered terrains/clutters impairments for the purpose of power management of mobile nodes. They proposed Power Management Algorithm (PMA) based on the clutter based location estimation. Authors considered clutters/terrains impairment knowledge to decide that how much power could be required for the cell phone in order to maintain communication. In the first phase they proposed eight clutters then they used Google earth facility for the mapping of the clutters. Finally based on the clutters knowledge they proposed power management algorithm for efficient use of the mobile phone battery power. The simulation showed that the PMA could save battery power up to 40% if clutter knowledge was used.

In [129], the authors studied the forest terrain. They studied the propagation losses which were due to antenna height, antenna gain, depolarization, humidity effect and few other factors. They discussed that the propagation losses could increase or decrease due to the above in forest terrain. They also discussed that the external effects such as rain could cause unexpected losses in the communication links.

2.6 Chapter Summary

This chapter discusses about the research executed from scholars in the same field of this research area. As this work is based on location based services therefore we try to briefly discuss all types of location estimation. We discuss the literature of localization in different wireless environments. Meanwhile the terrain/clutter based radio propagation effects are also discussed in the same field of research.

DESCRIPTION OF A TERRAIN BASED LOCATION DETERMINATION BASED ON GEOMETRICAL AND STATISTICAL METHODS

CHAPTER 3

LOCATION ESTIMATION, FILTERING, PREDICTION AND FUSION BY USING TERRAINS/CLUTTERS CONSIDERATIONS

3.1 Chapter Introduction

Transmitted signal and the received signal are the two key parameters used to calculate available signal strength and receive signal strength. These ASS and RSS are used to calculate the point-to-point distance between the transmitting antenna and the receiving node. This P2P calculated distance is not sufficient to localize the wireless node, because it does not tell about the angle of arrival. The calculated distance can be anywhere in the 360^{o} of the transmitting antenna's diameter. Therefore location estimation is required to localize the position of wireless node.

This chapter is divided into six (6) sections: section one (1) is explaining the terrain characteristics and the division. Section two (2) is discussing the **point-to-point** (P2P) location calculation by using ASS and RSS. Error Rate Table (ERT) and Clutter

Based Enhance Error Rate Table (CERT) for P2P error correction are also discussed in this section. Section three (3) is dedicated for **estimation**. Famous triangulation method is applied on P2P data to calculate estimation position of wireless node. **Filtering** is discussed in section four (4), which is used for error correction in estimation results. Averaging, mean of averaging and k-nearest neighbor rule (k-NN) are applied for filtering.

Prediction is a process to calculate confidence level of an event to be selected. Location prediction performed on the estimated location to select the best possible value/region out of estimated position. Combine Variance approach is used in section five (5) to calculate Region of Interest (RoI) with upper and lower limits. RoI increases the level of confidence if the estimated location is falling inside the RoI.

Fusion of the prediction results with filtering (both averaging and k-Nearest Neighbor rule) is done in section six (6) and Predicted and Corrected Location Determination Algorithm (PCLDA) is developed to achieve the accurate/ near to accurate position of wireless node.

3.2 Terrain/Clutter Characteristics

It is much more complicated to manage the strength of wireless signal than in a wired network. One factor that affects radio signal strength is ElectroMagnetic Interference (EMI) which is also known as noise. Airlines require to its passengers to shut off all electronic devices in order to the electrical interference form the airplane's navigationals devices and radion systems. Moreover, many type of objects, both stationary and moving, can impact the signal [83]. The Signal-to-Noise Ratio (SNR) refers to measure the signal strength with respect to the background noise. If the background noise is highest than the actual signal then the interference can take place [83].

The terrain based location estimation is a research area which is not considered by researchers extensively. Radio waves behave differently in different terrains and atmosphere. Therefore the calculation of few parameters is not sufficient to achieve accuracy in different terrains especially when it is totally based on RSS which is carrying impairments. Behavior of radio waves can be categorized as [9, 10]:

- Reflection
- Refraction
- Diffraction
- Scattering
- Absorption

Radio waves are directly infected by terrains atmosphere [11]. Signal to Noise Ratio (SNR) adds error rate in receive signal (Rx). When the transmit signal (Tx) passes from different terrains then the above mentioned behaviors apply on that Tx. Because of the noise addition the Rx value differs from the Tx value [12]. The difference between the Tx and the Rx values is known as loss. The receive signal strength is inversely proportional to loss, if the loss increases the receive signal strength decreases. For location estimation researchers use this receive signal as a primary value for parameters calculation. If we do not consider the terrain error rate then it will not give us accurate position of a wireless node. Every terrain has different error rate because of its specific environment.

3.2.1 Terrain/Clutter Division

Based on the SNR we divide terrains in 13 different categories under four environmental groups which are:

3.2.1.1 Urban Terrains/Clutters

- Low Dense Urban (LDU)

  The edge of the city areas, where SNR is relatively low.

- Medium Dense Urban (MDU)

  Medium populated city areas, where high rise buildings are not available to increase SNR.

- High Dense Urban (HDU)

  Thickly populated and congested city area with high rise buildings, where signals are distorted due to high SNR.

3.2.1.2 Rural Terrains/Clutters

- Low Dense Rural (LDR)

  The edge of rural areas with the lowest distortion of signals.

- Medium Dense Rural (MDR)

  Rural area with average distortion or SNR.

- High Dense Rural (HDR)

  Highly populated rural area with high SNR.

3.2.1.3 Plantation Terrains/Clutters

- Agriculture/Field (A/F)

Most ideal terrain with lowest SNR. A/F includes agriculture fields and grounds with no problem of LOS.

- Low Forest/ Plantation (LF/P)

  Forest with average number of trees. We did our testing in the low forest where the number of trees where 170-180 per hector.

- Dense Forest (DF)

  Includes typical tropical area rain forest like Malaysian forest.

3.2.1.4 Highways & Water Bodies Terrains/Clutters

- Highway/Motorway (H/M)

  Road with heavy traffic.

- River/Lake (R/L)

  Water reservoirs, lakes, rivers and water bodies etc.

- Sea

  Sea shore falls under the definition of sea.

We propose desert as a 13th category in the terrain division but has not been considered in this research due to the unavailability of desert in Malaysian peninsula.

We use WiFi (IEEE 802.11 b/g standard) to perform testing. A C# program is used to calculate the receive signal strength at the mobile node. Three AP's are used in order to satisfy the triangulation implemented in GPS. Based on the above terrain divisions we repeat our testing in all defined terrains. Test results are included in table

5.1- 5.4. All testing is repeated five times at every single spot of a selected terrain to avoid unnecessary errors such as external affects.

3.3 Point-to-Point (P2P) Location Calculation: Terrain Consideration

In phase one (1) of P2P location calculation point-to-point signal calculation is recorded from antenna to mobile node. Phase 2 leads towards the manual measurement. Agri/Field (A/F) is considered as a baseline terrain because of its low attenuated property. Each experiment is repeated five times in order to achieve accuracy. Tables (5.1 to 5.4) are representing the recorded P2P values in each terrain at 10 meter distance.

3.3.1 Error Rate Table (ERT)

The focus of Error Rate Table is to analyze the data taken from the experimental work done in different terrains. We propose twelve terrains under four environmental groups. Distance mentioned in tables is in meters. We calculate RSS from under 1 m to 150 m. Signal strength is represented in percent (%), which is showing the RSS values at different distances. According to our experiment A/F is the lowest noise area which is also mentioned in [84, 125], therefore we compare receive data of other terrains with A/F for the Error Rate Table (ERT). Overlapping of two or more high impairment terrains can increase error rate. We repeat our experiment 5 times (t_0 to t_4) on every single point of each terrain and take the mean value.

3.3.2 Clutter based Enhance Error Rate Table (CERT)

The focus of Clutter based Enhance Error Rate Table is to refine the ERT results. We repeat the test in every single clutter at the average distance of 2 meters from 0 meter to 150 meters. Signal strength is represented in percentage (%) which depicts the change in Rx value from Tx value at different points. We repeat our experiment 5 times ($t_0 – t_4$) at every n-2 points.

We construct a Clutter based Enhance Error Rate Table (CERT) with the division of eight zones by using collected data points. These zones helps to reduce error in the clutter we are dealing and ensure to precisely calculate the position of a wireless node. Table 5.6 is representing the collected data points with the division of clutter groups and the distance interval at 2 meters.

3.3.3 Linear Interpolation

Interpolation is a method which is used to define a function under the two set of values [130]. Two set of points in a plane represent a straight line. But to read variation in readings we need interpolation. There are different types of interpolation like Linear, Cosine, Cubic, Hermite, 3D linear, 3D cubic, 3D Hermite, Trilinear interpolation etc. Linear interpolation is the simplest form to get the intermediate values between two data points [131]. Formula which is used to calculate linear interpolated points is as under

$$P(x) = \sum_{k} \left(\prod_{j \neq k} \frac{x - xj}{xk - xj} \right) \qquad (3.1)$$

3.3.3.1 Modeling Interpolated Distance Error

By using the concept of linear interpolation signal strength to distance converter program is developed by using the data points calculated in CERT. The purpose of the signal strength to distance converter is to calculate the distance at random by using the recorded signal strength. Program helps to avoid manual measurements. Although the results of program leads an element of error, but this error is catered by using modeling interpolated distance error.

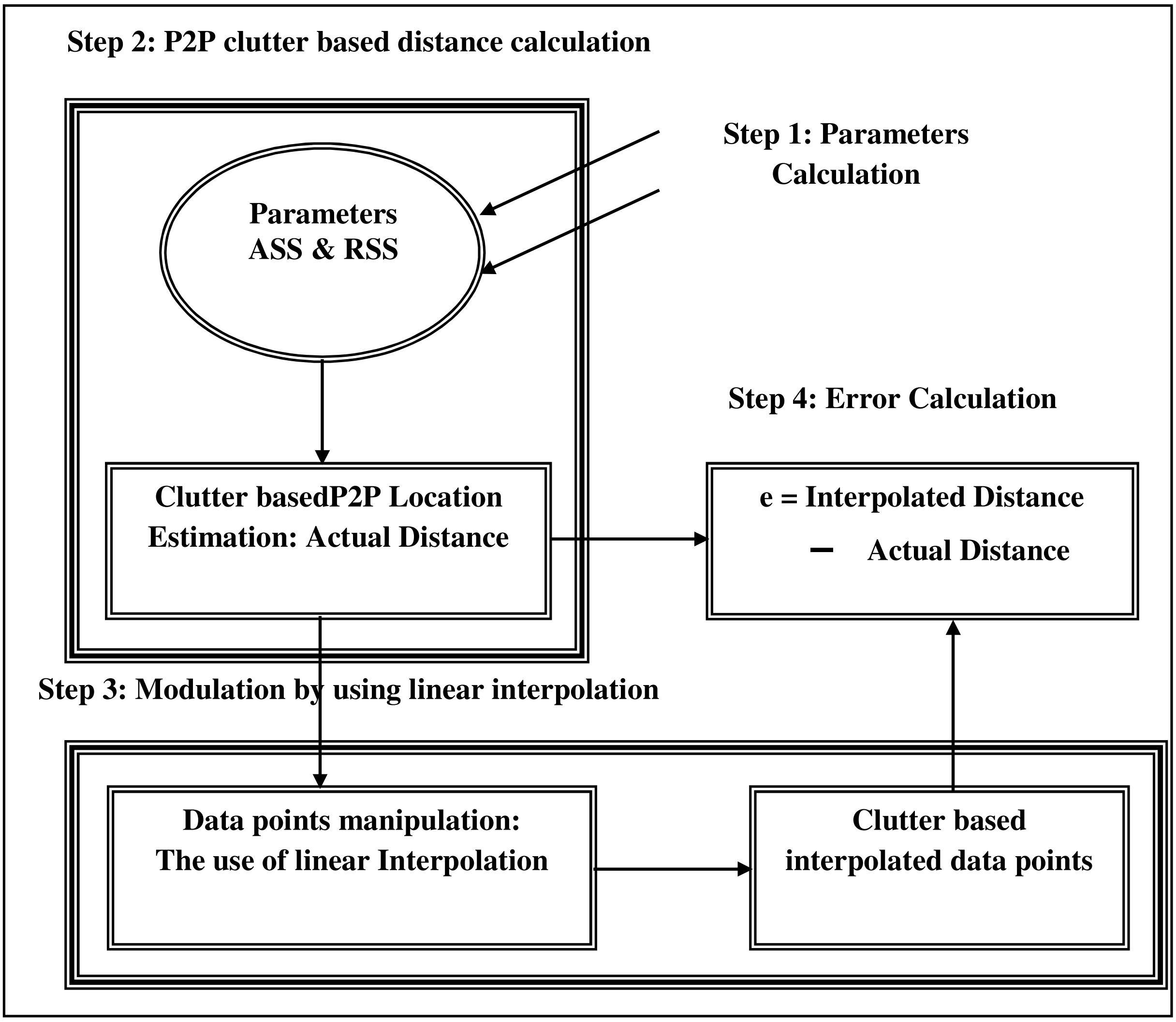


Figure 3.1: Tracking architecture of modulated interpolation location estimation and error.

Figure 3.1 is the tracking architecture for the modulated interpolation location estimation and distance error. It is representing the overall flow model used form point-to-point calculation to modelling of data by using linear interpolation and the error calculation. In step 1 we calculate the ASS and RSS based on terrain. In step 2 we calculate P2P distance by using the parameters of step 1. Step 3 is the implementation of linear interpolation in order to calculate the random clutter based distance based on the signal strength. Step 4 is the error calculation and its comparison with the actual data.

3.4 Location Estimation

The purpose of estimation is to localize the position of the wireless node by using AOA. P2P data points only help to calculate the distance between the transmitter and the receiver, but do not tell about the direction of the receiving (wireless) node. Triangulation is a one of among the location estimation techniques, which is used to estimate the position based on the available distance.

3.4.1 Triangulation

Geometrical technique is the most popular technique for locating a position of wireless nodes [12 - 24]. It is very hard to find location estimation without the geometrical technique. From GPS/DGPS [27, 124] to WLAN [52 - 70] this geometric technique is rigorously used by the researchers. In location estimation RSS is the parameter which is used for geometrical technique.

Triangulation is one famous method of geometrical technique for location estimation. By constructing three triangles we can have GPS like scenario which leads towards the accurate position. If we build triangulation method by considering clutters/terrains atmospheric characteristics then the results will be more accurate because of the atmospheric considerations.

We use triangulation method to estimate position in different terrains. The combination of RSS and ASS is used to avoid terrain attenuation and better location. We repeat our experiment 5 times on each node and construct three triangles. As a result we calculate fifteen location of a wireless node.

3.4.2 Triangulation Implementation with three antennas for location estimation

Based on the data points calculated in P2P the AOA is calculated and a triangle is constructed as shown in figure 3.1. For error correction three (3) antennas are used which provides overlapping coverage feature. In this condition three (3) triangles will be constructed i.e. ∆ABM, ∆ACM and ∆BCM as shown in the figure 3.1 [16], [17].

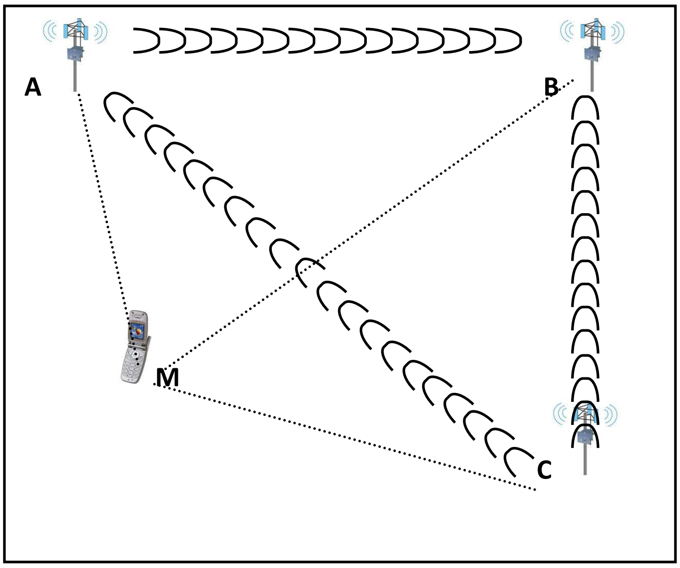


Figure 3.2: Mobile node (M) is receiving signals from antennas

where

A, B, C are antennas (transmitters)

M is a wireless node (receiver)

By using the ASS and the RSS, the distance between points AB, AM and AC is calculated.

where

ASS is Actual Signal Strength at A and B at t_0

RSS is Receive Signal Strength from A, B and M at time t_0.

As the location and the distance between points A, B and C are known, by using the ASS and the RSS, the distance between points AB, AM and BM is calculated.

$$D_{(AB)t0} = (ASS_{(A)t0+}ASS_{(B)t0}) \ / \ 2 - (RSS_{(A)t0} + RSS_{(B)t0}) \ / \ 2 \qquad (3.2)$$

$$D_{(AM)t0} = ASS_{(A)t0} - RSS_{(M)t0} \qquad (3.3)$$

$$D_{(BM)t0} = ASS_{(B)t0} - RSS_{(M)t0} \qquad (3.4)$$

where

$D_{(AB)}$ is distance between point A and B.

$D_{(AM)}$ is distance between point A and M

$D_{(BM)}$ is distance between point B and M

As the location of points A, B and C are known and now also the distance between A, B and M is calculated, so by using the simple trigonometry formula angles α, β and 𝛾 are calculated.

By using basic trigonometric f*ormula for angle calculation with three known sides,*

$$Cos\alpha = (b^2 + c^2 - a^2) / \ 2bc$$

$$Cos\beta = (a^2 + c^2 - b^2) / \ 2ac$$

$$Cos\gamma = (a^2 + b^2 - c^2) / \ 2bc$$

$$Cos\alpha = [\{D_{(AM)t0}\}^2 + \{D_{(AB)t0}\}^2 - \{D_{(BM)t0}\}^2] / 2 D_{(AM)t0} D_{(AB)t0} \quad (3.5)$$

$$Cos\beta = [\{D_{(BM)t0}\}^2 + \{D_{(AB)t0}\}^2 - \{D_{(AM)t0}\}^2] / 2 D_{(BM)t0} D_{(AB)t0} \quad (3.6)$$

$$Cos\gamma = [\{D_{(BM)t0}\}^2 + \{D_{(AM)t0}\}^2 - \{D_{(AB)t0}\}^2] / 2 D_{(BM)t0} D_{(AM)t0} \quad (3.7)$$

By using the distance between AB, AM and BM and the angles α and β a triangle is plotted to estimate the location of M (Loc M) at time t_0 by using ΔABM, as shown in figure 3.3

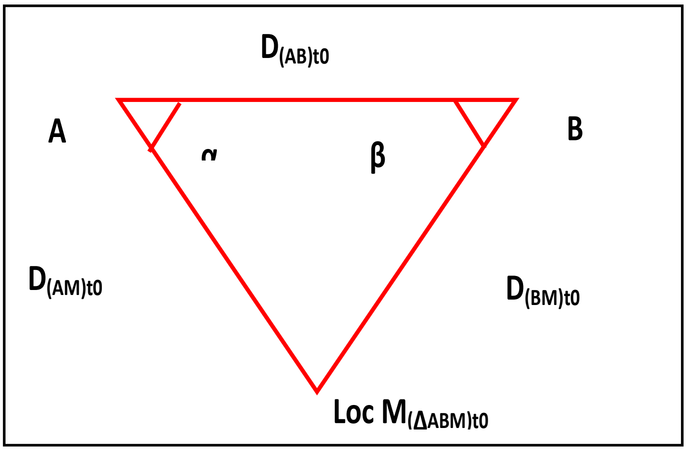


Figure 3.3: Mapping of M by using distances AB, AM and BM and the angles α and β

Similarly by using triangles ΔACM and ΔBCM two other locations of M are calculated as shown in figure 3.4.

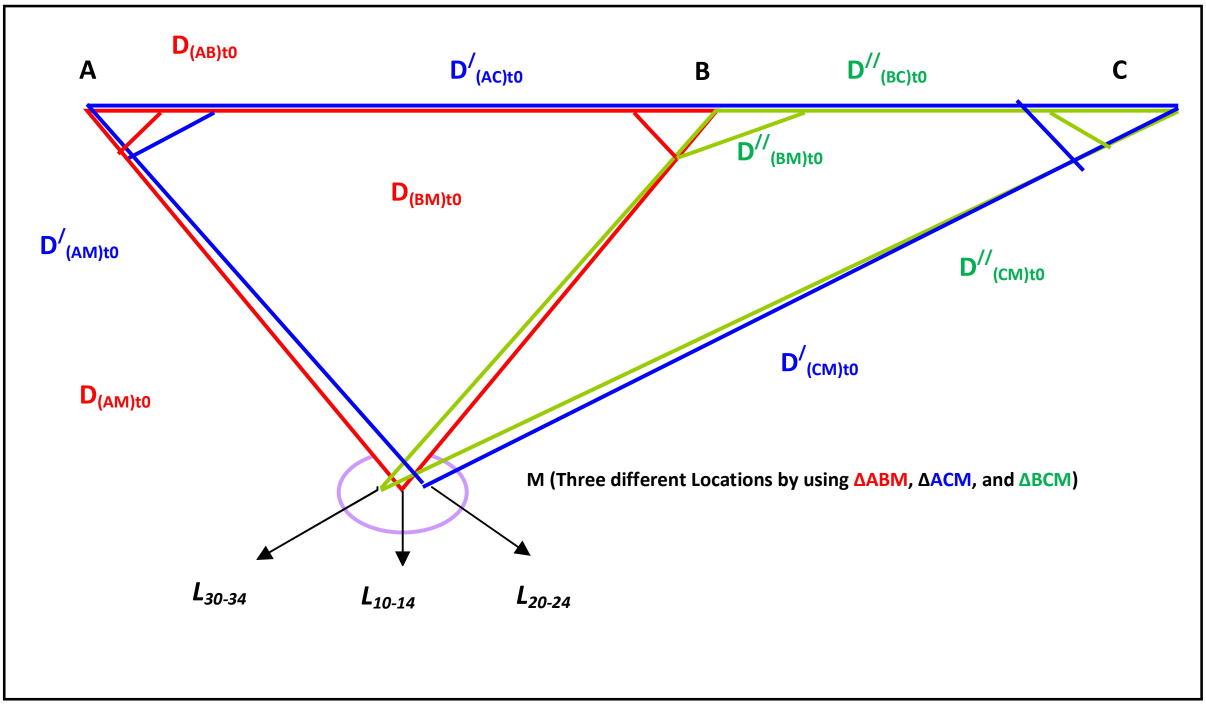


Figure 3.4: Location estimation of Mobile by using three triangles, where D is the distance calculated by ∆ABM, $D^{/}$ is calculated by ∆ACM and $D^{//}$ is calculated ∆BCM.

3.5 Location Filtering

Although location estimation by using triangulation provides a location which is refined compared with P2P location calculation. But for accuracy it is required to filter it. Averaging and mean of averaging method is used first to filter the estimated location. Furthermore k-NN rule is applied on estimated position to calculate best possible results. Averaging and k-NN results are compared to calculate the error.

3.5.1 Average Based Filtering

As the experiment is repeated 5 times for every triangle (as shown in figure 3.3), therefore 15 different locations are calculated which are from L_{10-14} ,L_{20-24} and L_{30-34}.

As we have five (5) different locations from ΔABM at t_0 to t_4, averaging is applied on timestamp to filter one location of ΔABM.

$$Loc\ M_{\Delta ABM} = [Loc\ M_{(\Delta ABM)t0} + Loc\ M_{(\Delta ABM)t1} + Loc\ M_{(\Delta ABM)t2} + Loc\ M_{(\Delta ABM)t3} + Loc\ M_{(\Delta ABM)t4}]\ /5 \quad (3.8)$$

$$Loc\ M_{\Delta ACM} = [Loc\ M_{(\Delta ACM)t0} + Loc\ M_{(\Delta ACM)t1} + Loc\ M_{(\Delta ACM)t2} + Loc\ M_{(\Delta ACM)t3} + Loc\ M_{(\Delta ACM)t4}]\ /\ 5 \quad (3.9)$$

$$Loc\ M_{\Delta BCM} = [Loc\ M_{(\Delta BCM)t0} + Loc\ M_{(\Delta BCM)t1} + Loc\ M_{(\Delta BCM)t2} + Loc\ M_{(\Delta BCM)t3} + Loc\ M_{(\Delta BCM)t4}]\ /\ 5 \quad (3.10)$$

3.5.1.1 Mean of Means

Finally to calculate a single filtered location mean is calculated from averages calculated in 3.8, 3.9 and 3.10.

$$Loc\ M = [Loc\ M_{\Delta ABM} + Loc\ M_{\Delta ACM} + Loc\ M_{\Delta BCM}]\ /\ 3 \quad (3.11)$$

We use simple and cost effective averaging method to calculate single location out of fifteen different locations.

3.5.2 k-Nearest Neighbor Algorithm

The k-Nearest Neighbor algorithm (k-NN) is one of the easiest and simplest machine learning algorithms [132] as by considering the nearest neighbor it calculates weighted mean. On the other hand it is also known as “lazy algorithm” as it is slow, and “eager algorithm” [133] as it uses all data elements for training this characteristic of k-NN help in this research to produce accuracy. Its selection criteria are based on closest set of data from the point of focus. The value of k varies based on the set of data elements available for training. Each data elements behave as a central point until frequency of occurrence is obtained for all data set. Weights are further multiply with frequency to calculate weighted mean. Weighted mean leads towards the estimated position from the data set.

$$\text{K-weighted mean} = [\sum fw / \sum f] + 1 \qquad (3.12)$$

where

f is frequency of occurrence and

w is the weight of each data element.

We use k-NN because it considers all data sets which help to calculate the precise location of a mobile node. This nature of k-NN helps to minimize error in location prediction of a mobile node. We use three triangulated location with five different times which is as follow

$$(t_0 - t_4) \times (L_1, L_2, L_3) = 15$$

(L_{10}, L_{11}, L_{12}, L_{13}, L_{14},

L_{20}, L_{21}, L_{22}, L_{23}, L_{24},

L_{30}, L_{31}, L_{32}, L_{33}, L_{34})

where in L_{10}

1 is representing the location of triangle ABM and

0 is representing the location at t_0 timestamp

All 15 locations are used by the k-NN rule to estimate the best possible location. Result comparison shows that k-NN is producing 217% - 289% better results from famous triangulation based averaging method if we also consider clutter information.Tracking architecture of k-NN Algorithm is presented in figure 3.5

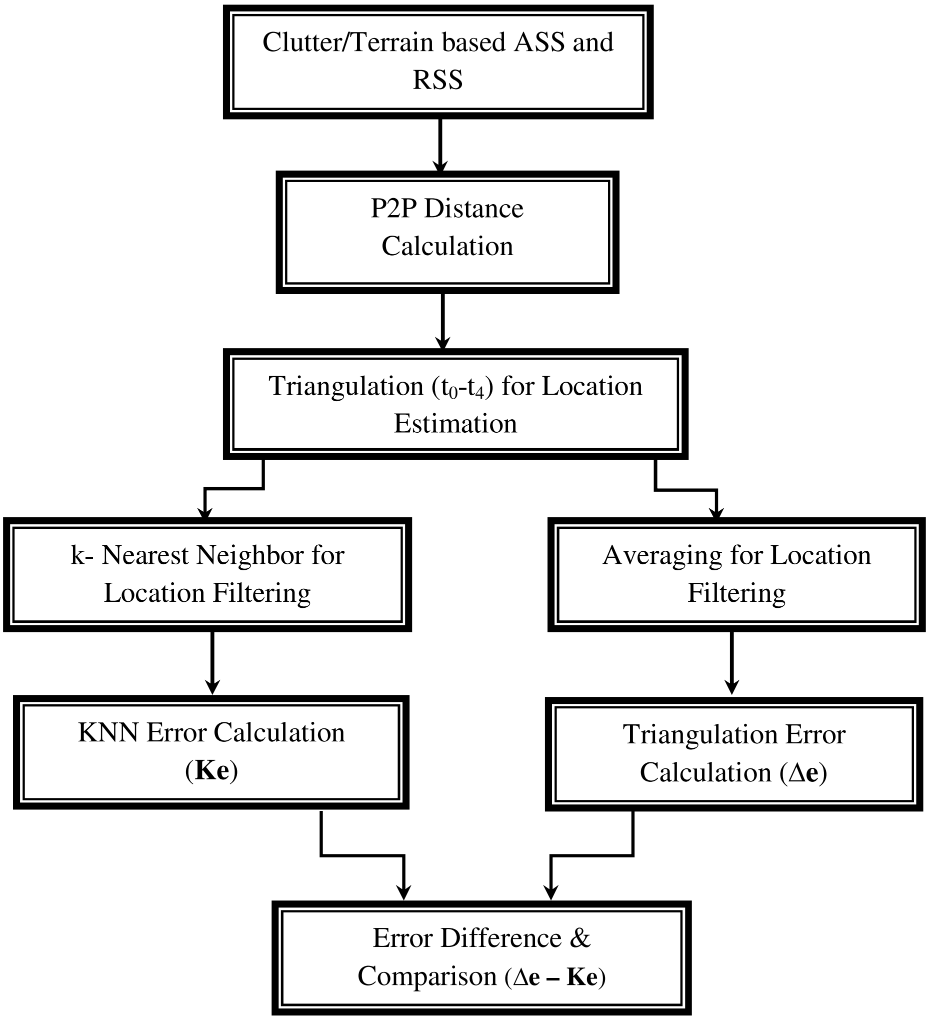


Figure 3.5: Tracking Architecture of k- NN implementation for precise location estimation

Fig 3.5 is presenting the step by step procedure for location estimation of a mobile node by using the k-nearest neighbor algorithm.

3.6 Location Prediction

Location prediction is done by using combine variance approach which helps to calculate Region of interest.

3.6.1 Variance For Minimize Location Estimation Predicted Area

Although average and k-NN based filtering calculate the filtered position of a wireless nodes, but it comes with error because it is just to calculate mean value. Combine variance is used to calculate RoI which helps to predict that if the estimated average location is falling inside the region of interest then its confidence level will be high.

$$\sigma^2 = \frac{\sum (X - \overline{X})^2}{N}$$

Basic formula of variance

Variance Calculation at time t_0 to t_4 of ∆ABM

$$\sigma^2_{(Loc\ M)\ \Delta ABM} = \Sigma\ (L_{n(\Delta ABM)} - Loc\ M_{\Delta ABM})^2\ /\ N \quad (3.13)$$

where

n= 1, 2, 3,4,5 and

N= 5

Similarly variation of location is recorded by calculating variance at t_1 to t_4 of ∆ACM and ∆BCM

$$\sigma^2_{(Loc\ M)\ \Delta ACM} = \Sigma\ (L_{n(\Delta ACM)} - Loc\ M_{\Delta ACM})^2\ /\ N \quad (3.14)$$

and

$$\sigma^2_{(Loc\ M)\ \Delta BCM} = \Sigma\ (L_{n(\Delta BCM)} - Loc\ M_{\Delta BCM})^2\ /\ N \quad (3.15)$$

Figure 3.6 is representing the variation in locations at different timestamps. By calculating the variance of Loc M_0 to Loc M_4 (at ∆ABM), variance of Loc M_0 to Loc M_4 (at ∆ACM) and variance of Loc M_0 to Loc M_4 (at ∆BCM) following scenario is recorded.

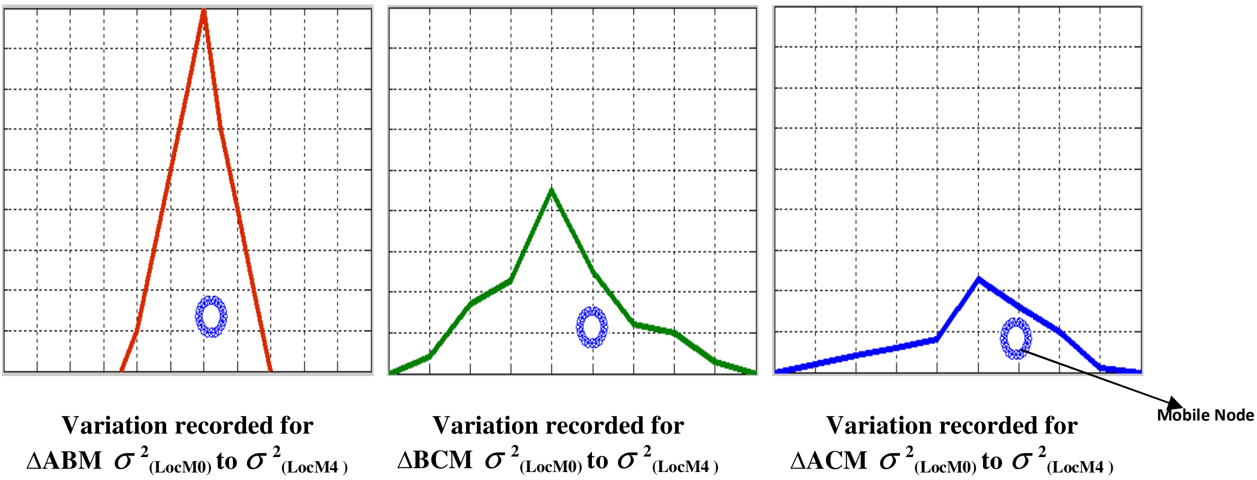


Figure 3.6: Variation in location of M by using ∆ABM, ∆ACM, ∆BCM

Figure 3.6 is representing the variations of location by using three different triangles. Although the location of mobile node is falling inside the Region of Interest (RoI) but still it is only pointing out only the region of high availability and unable to predict the actual position.

3.6.2 Combine Variance for precision in Location Estimation

By combining the variances [134, 135] of 3.13, 3.14, and 3.15 we get combine variation area for the location prediction. This overlapping variant area is considered as a most powerful candidate for the location of mobile node. Combine variance calculation is as under:

$$1/\sigma^2 = 1/\sigma^2_{(Loc\ M)\ \Delta ABM} + 1/\sigma^2_{(Loc\ M)\ \Delta ACM} + 1/\sigma^2_{(Loc\ M)\ \Delta BCM} \quad (3.16)$$

Figure 3.7 is explaining the RoI calculated by using combine variance

$$\text{Let } S = 1/\sigma^2 \quad (3.17)$$

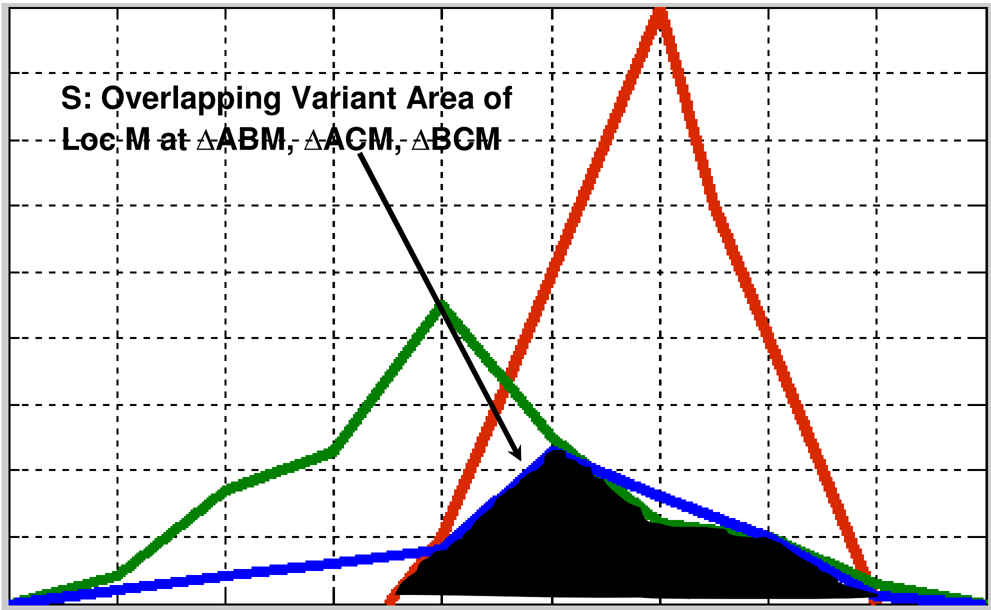


Figure 3.7: Overlapping variant area by combining variances

Figure 3.7 is the combine variance representation, which is combining the overlapping variance area. The shaded portion is representing the overlapping variant area. If the selected value is falling in the RoI then its chances to be accurate will be higher. We use combine variance approach for prediction to minimize the region of interest. Although the Region of Interest (RoI) helps to minimize the predict area but it does not support to pinpoint actual position.

3.7 Fusion

The purpose of fusion is to combine the filtering results with prediction to increase or decrease the level of confidence of selected location. Based on the fusion results a Predicted and Corrected Location Determination Algorithm (PCLDA) is proposed for the minimization of errors in the selected locations.

3.7.1 Predicted and Corrected Location Determination Algorithm (PCLDA)

In this section by combining the filtering results with prediction the PCLA is proposed for error minimization. Algorithm is catering all four steps of location correction which are estimation, filtering, prediction and fusion. Kalman filtering recursive approach is used for correction.

3.7.1.2 The Algorithm

```
1.  Terrain selection
2.  Signal capturing
3.  P2P distance calculation
4.  Terrain error correction: CERT
5.  estimation: W
6.  filtering: X
7.  prediction: Y
8.  fusion: Z           ( Z = X + Y )
9.      if  Loc M € Z          }
10.             select: Loc M  }   Prediction
11.     timestamp:             }
```

```
12.     else
13.           goto 1
14.   estimation: W
15.   filtering: X
16.   prediction: Y              } Correction
17.   fusion: Z
18.     if      X + 1= X; Loc M € Z
19.      break loop:
20.      else
21.    goto 2
```

Above algorithm is based on the prediction and the correction rule of the Kalman filter. From line number 5 to line number 8 all four steps are involved for error corrected location. Based on the fusion results if the selected location is falling in the RoI then the location will be confirmed otherwise the control will be transferred to line number 1. If the location is selected then after the defined timestamp the correction procedure will start again which again consist of all four steps after that the control will be transferred to line number 2 for better prediction. If the corrected value is similar to previous filtered location and the value is falling in the RoI again, then the loop will break and the filtered value will be confirmed. Figure 3.6 is representing the tracking architecture of the algorithm.

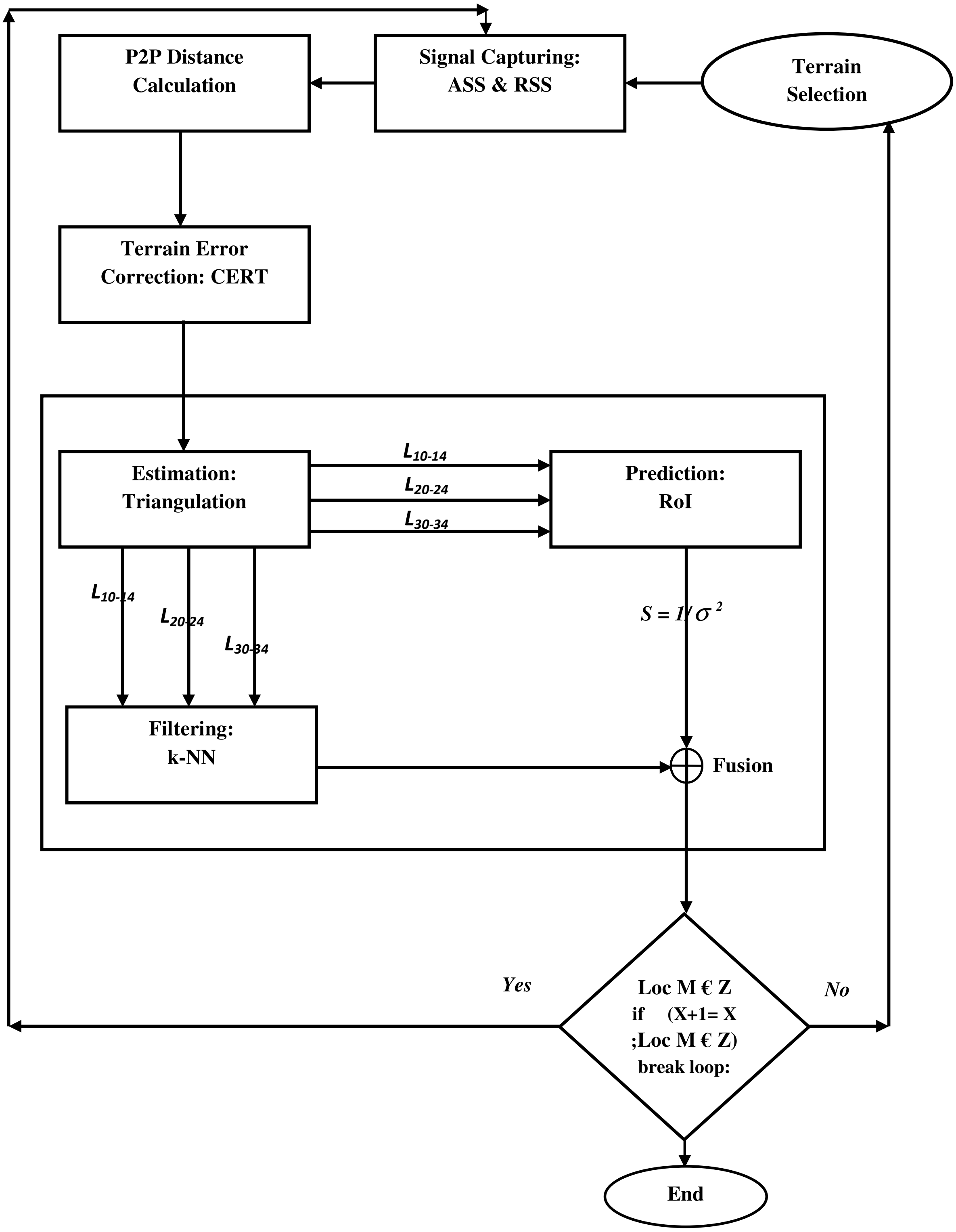


Figure 3.8: Tracking architecture of PCLDA

Figure 3.8 is explaining the overall architecture of PCLDA which is using recursive approach to predict and correct the estimated position.

3.8 Chapter Summary

This chapter describes the overall architecture of this research. After the terrain definition P2P data points are collected. ERT and CERT are used to avoid terrain error. Famous triangulation method is used for location estimation from the calculated data points. As multiple triangles estimate multiple locations therefore averaging and k-NN are used for filtering. To predict best location combined variance approach is used to calculate RoI. Finally Filtering results are fused with prediction results to localize the best possible position of wireless node. PCLDA is produced in the end by using Kalman filtering predicted and corrected approach to combine estimation, filtering, prediction and correction.

APPLICATION TO REAL WORLD

LOCATION DETERMINATION

CHAPTER 4

POINT- TO - POINT TERRAIN BASED DATA COLLECTION

4.1 Chapter Introduction

Point –to-Point terrain based data collection is done in this chapter by using Wifi prototype. ERT is then developed to reduce terrain errors. CERT which is an enhanced model of ERT is further proposed for terrain based error minimization. Finally we use linear interpolation to calculate distance of random signal strength.

4.2 Data Collection

WiFi (IEEE 802.11x standard) is used to perform testing. A C# program is used to calculate the receive signal strength at the wireless node. Three AP's are used in order to satisfy the triangulation implemented in GPS. Based on the terrain divisions describe in chapter 3 we select regions to perform testing. Test results are included in table 4.1- 4.4. All testing is repeated five times at every single spot of a selected terrain to avoid unnecessary errors such as external affects. Following are the plates 4.1 - 4.12 where actual testing of all above mentioned terrains is performed.

Plate 4.1: Testing site of Low Dense Urban (LDU) Terrain.

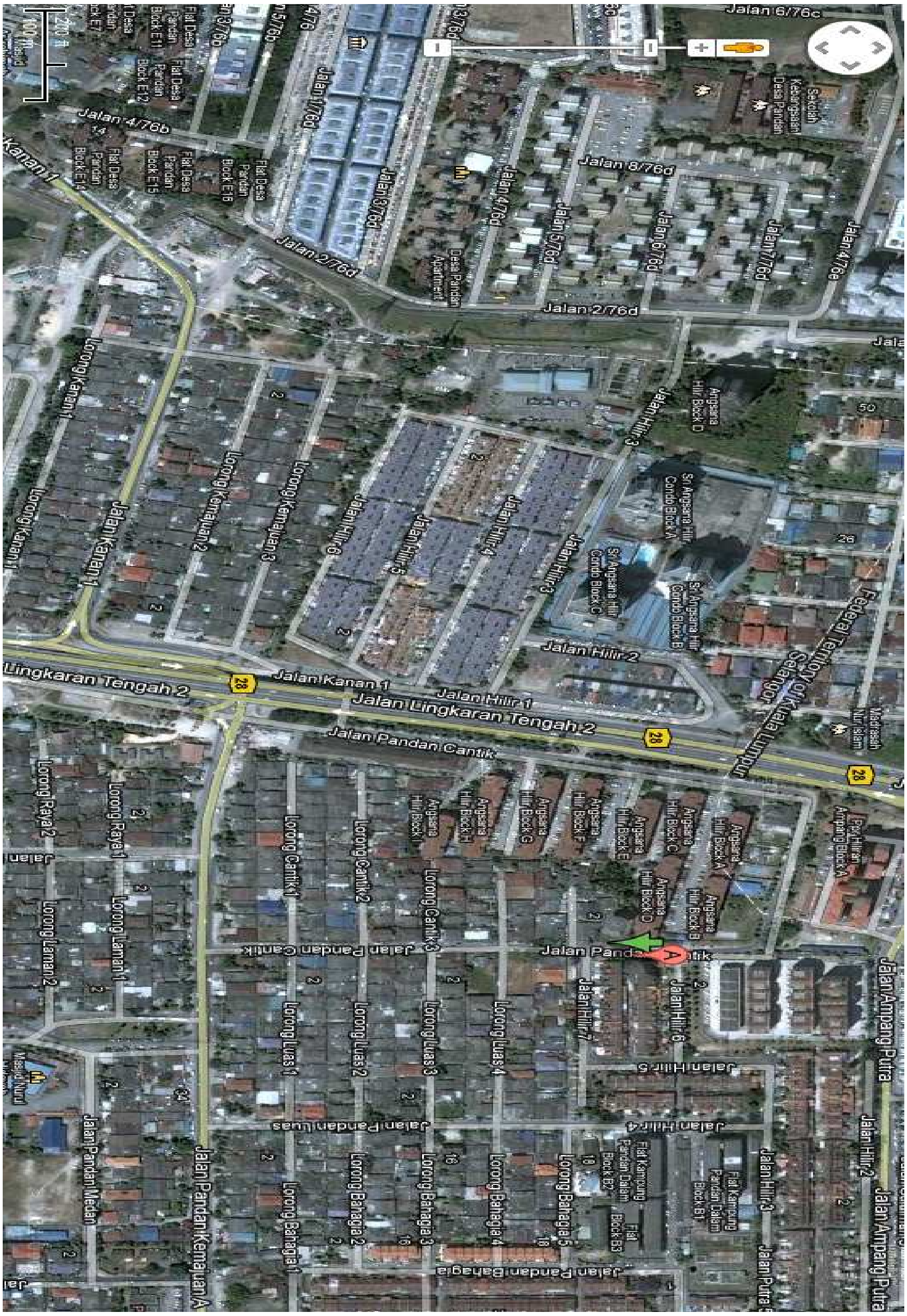


Plate 4.2: Testing site of Medium Dense Urban (MDU) Terrain.

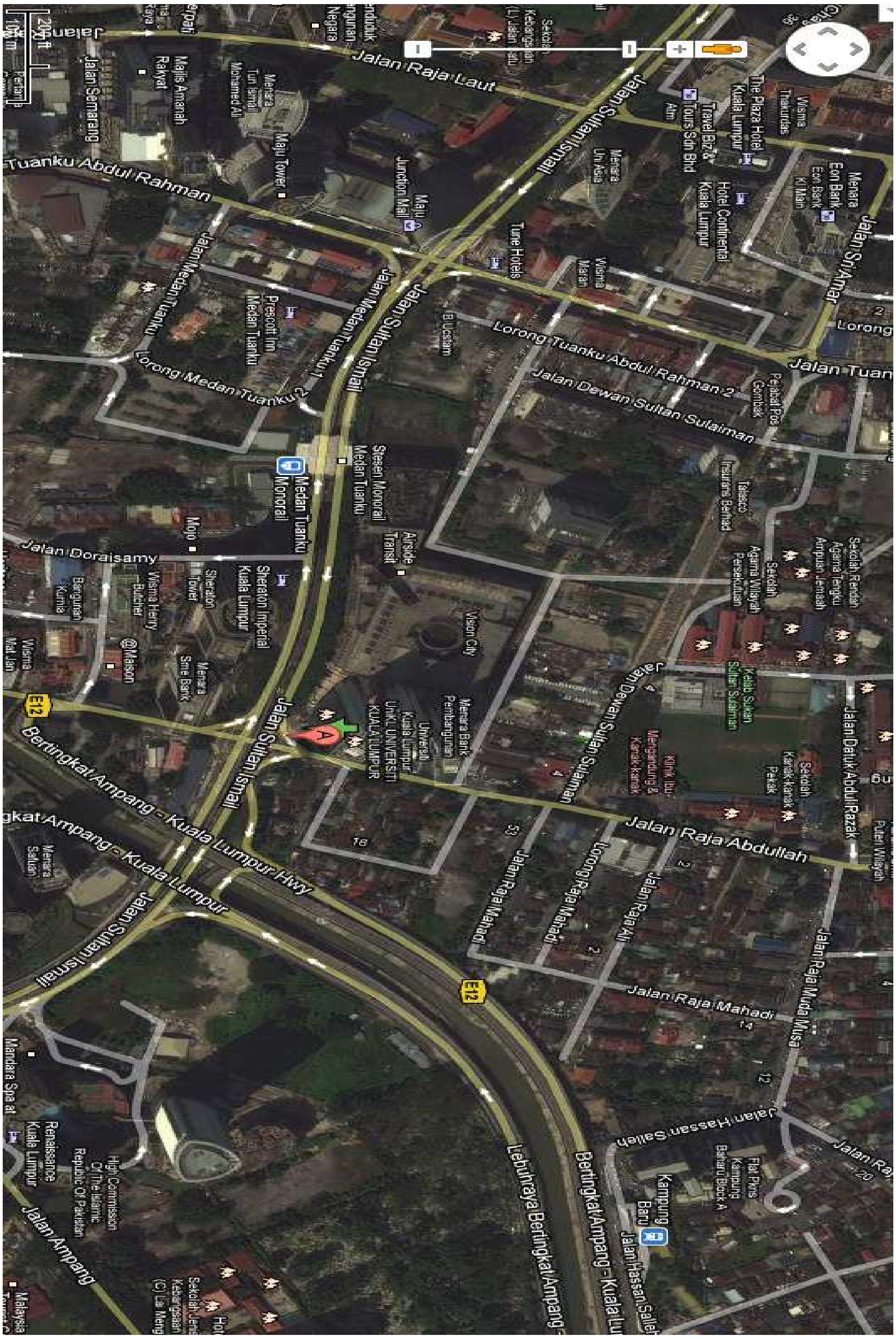


Plate 4.3: Testing site of High Dense Urban (HDU) Terrain.

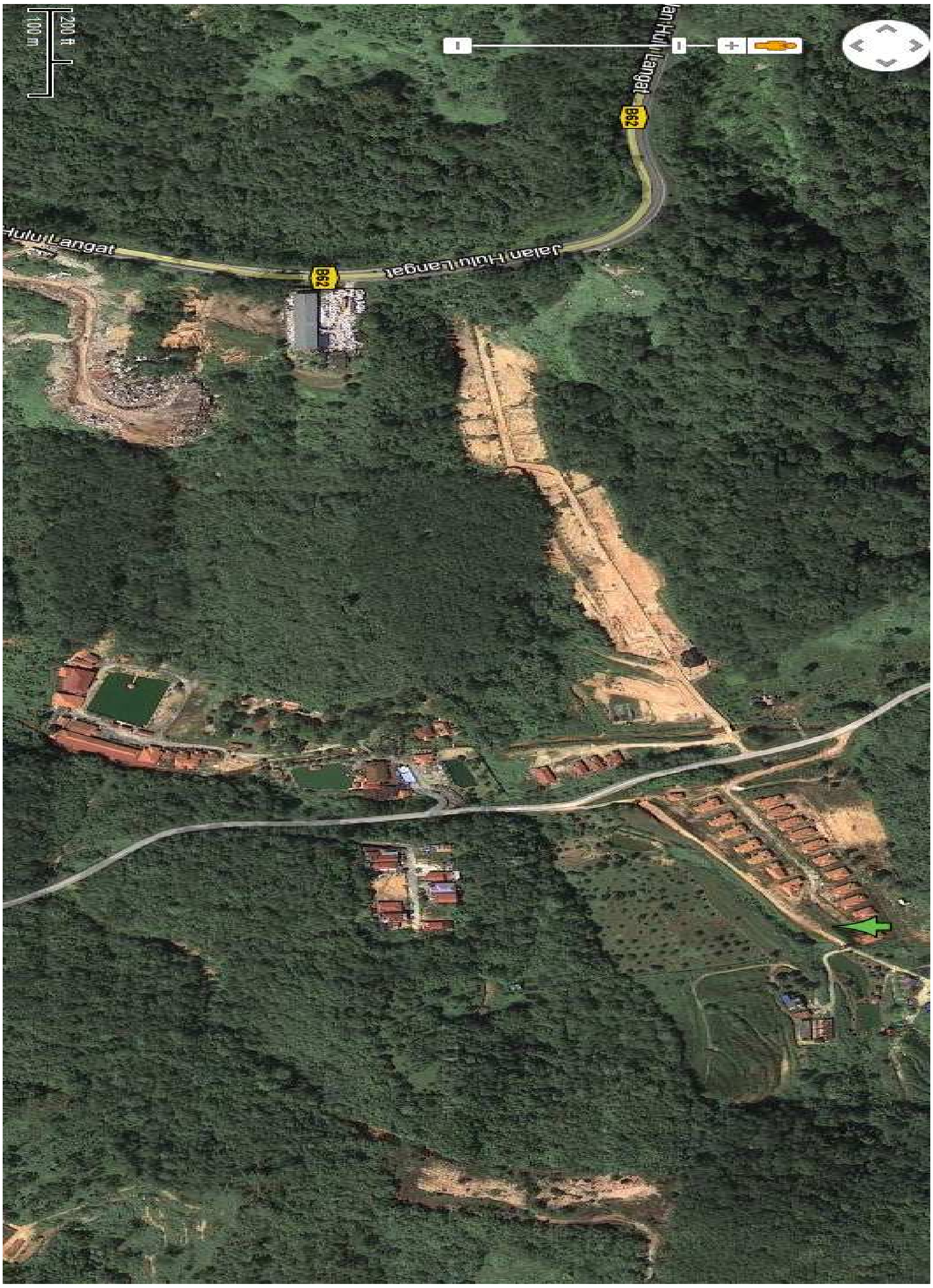


Plate 4.4: Testing site of Low Dense Rural (LDR) Terrain.

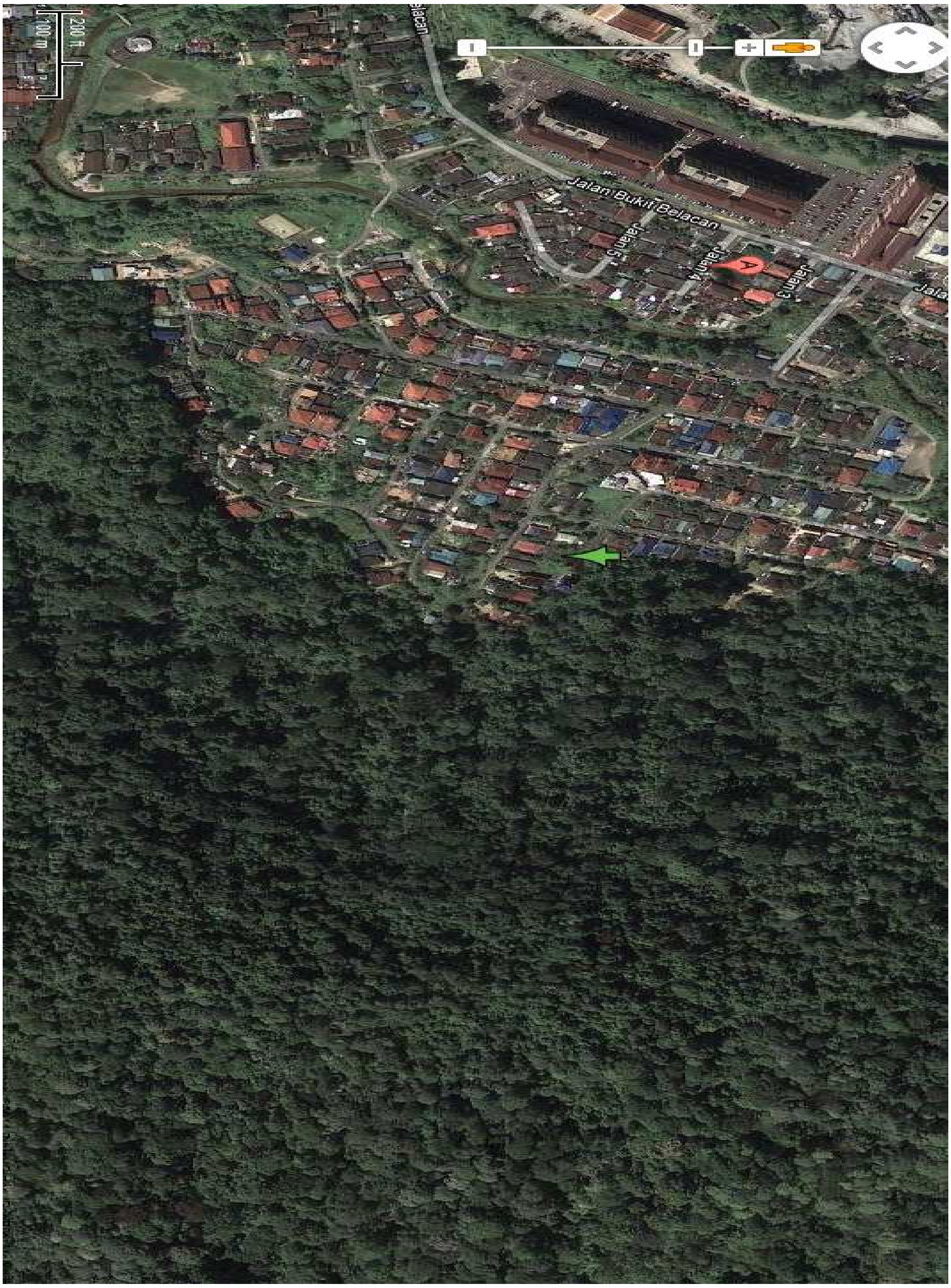


Plate 4.5: Testing site of Medium Dense Rural (MDR) Terrain.

Plate 4.6: Testing site of High Dense Rural (HDR) Terrain.

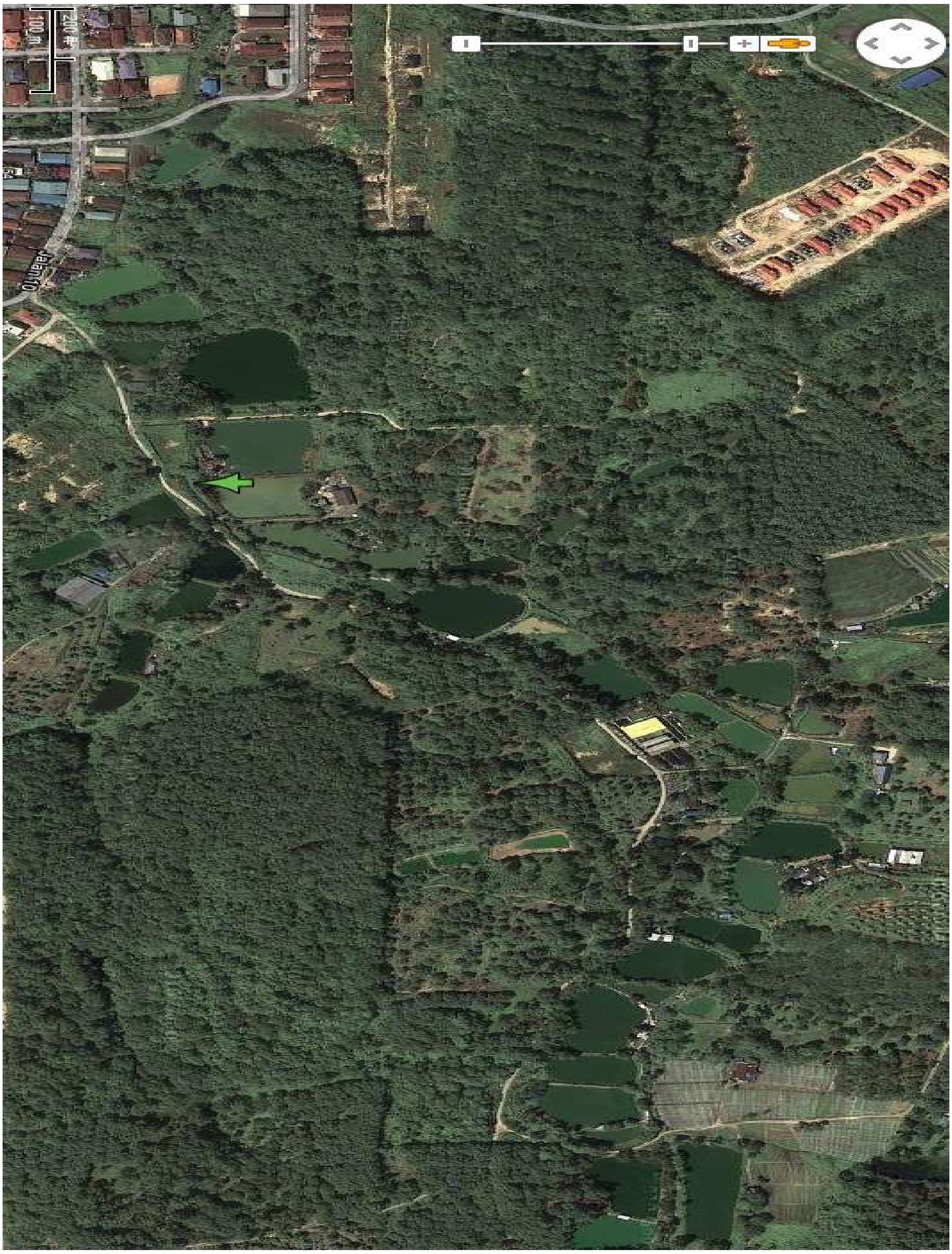


Plate 4.7: Testing site of Agriculture/Field (A/F) Terrain.

Plate 4.8: Testing site of Low Forest/ Plantation (LF/P) Terrain.

Plate 4.9: Testing site of Dense Forest (DF) Terrain(border/near border of DF)

Plate 4.10: Testing site of River/ Lake (R/L) Terrain.

Plate 4.11: Testing site of Sea Terrain.

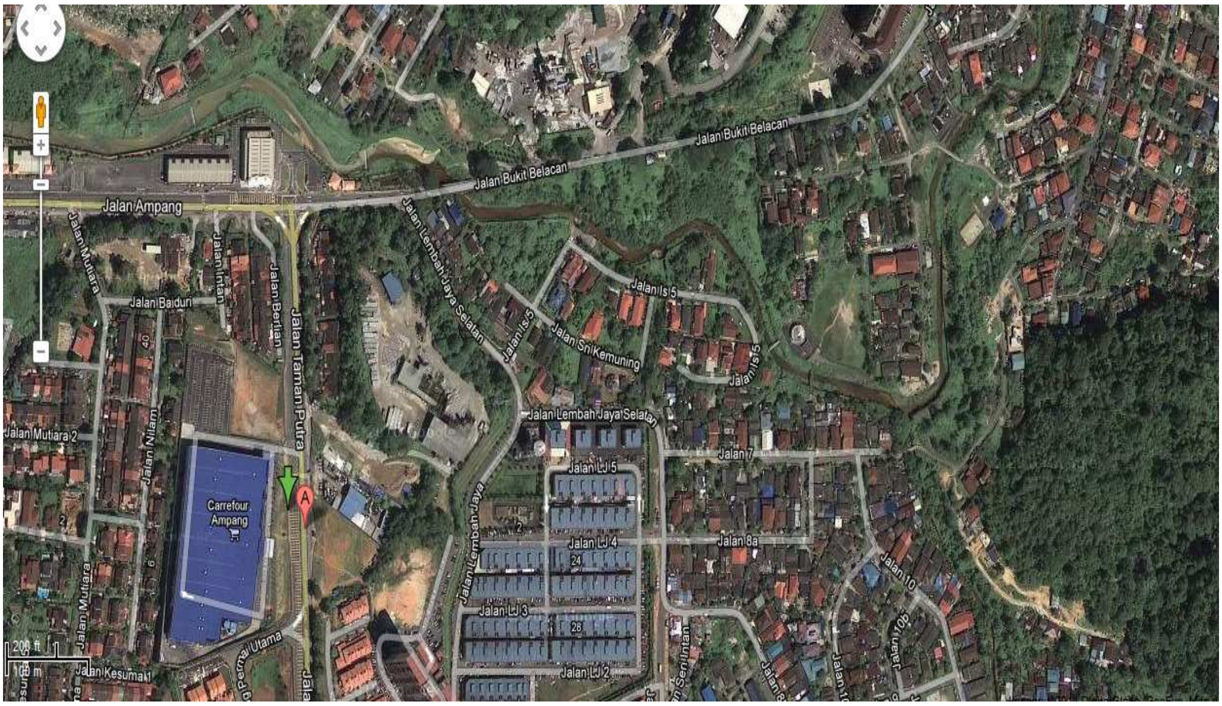


Plate 4.12: Testing site of Highway/Motorway (H/M) Terrain

4.3 Point-to-Point location estimation: Terrain Consideration

All above terrains/clutters are considered for testing in this research. I phase 1, point-to-point signal calculation is recorded from antenna to mobile node. Phase 2 leads towards the manual measurement. Agri/Field (A/F) is considered as a baseline terrain because of its low attenuated property. Each experiment is repeated five times in order to achieve accuracy. Tables 4.1 to 4.4 are representing the recorded P2P values in each terrain at 10 meter distance.

Table 4.1: Point-to-Point RSS calculation for Urban terrains/clutters

Distance (d) (in meters)	**Urban Terrains/Clutters (Signal Strength in %)**		
	Low Dense Urban(LDU)	**Medium Dense Urban(MDU)**	**High Dense Urban(HDU)**
10 (t_0- t_4)	100	100	96
20	82	78	78
30	66	64	62
40	60	56	52
50	52	50	46
60	46	44	40
70	38	36	32
80	34	30	26
90	30	28	20

Distance (d) (in meters)	Urban Terrains/Clutters (Signal Strength in %)		
	Low Dense Urban(LDU)	Medium Dense Urban(MDU)	High Dense Urban(HDU)
100	22	20	16
110	18	16	12
120	6	4	2
130	2	0	0
140	0	0	0
150	0	0	0

Towns/City ends = LDU, City ends/mild populated areas = MDU, Thickly populated city/Town centers = HDU.

Table 4.2: Point-to-Point RSS calculation for Rural Terrains/Clutters

Distance (d) (in meters)	Rural Terrains/Clutters (Signal Strength in %)		
	Low Dense Rural(LDR)	Medium Dense Rural(MDR)	High Dense Rural(HDR)
10 (t_0- t_4)	100	100	100
20	84	82	80
30	70	68	66
40	62	60	58
50	56	52	52
60	50	48	46

Distance (d) (in meters)	Rural Terrains/Clutters (Signal Strength in %)		
	Low Dense Rural(LDR)	Medium Dense Rural(MDR)	High Dense Rural(HDR)
70	42	40	38
80	38	36	34
90	34	32	30
100	30	26	22
110	24	22	18
120	14	10	6
130	6	2	0
140	0	0	0
150	0	0	0

Village and town area is considered under the definition of rural terrains/Clutters.
Low, Medium and High dense rural areas are decided on the population in the specific area.

Table 4.3: Point-to-Point RSS calculation for Plantation Terrains/ Clutters

Distance (d) (in meters)	Plantation Terrains/Clutters (Signal Strength in %)		
	Agriculture/ Field (A/F)	Low Forest/ Plantation (LF/P)	Dense Forest (DF)
10 (t_0- t_4)	100	100	92
20	88	86	76

Distance (d) (in meters)	Plantation Terrains/Clutters (Signal Strength in %)		
	Agriculture/ Field (A/F)	Low Forest/ Plantation (LF/P)	Dense Forest (DF)
30	72	64	58
40	66	58	44
50	58	52	40
60	52	46	36
70	46	40	34
80	42	34	26
90	38	28	14
100	34	20	8
110	30	10	4
120	26	6	2
130	20	2	0
140	12	0	0
150	2	0	0

LF/P refers to 160 to 170 trees per hector. DF is the typical tropical region forest.
A/F refers to the plain fields of low vegetation areas.

Table 4.4: Point-to-Point RSS calculation for Highway & Water bodies Terrains/Clutters

Distance (d) (in meters)	**Highway & Water Bodies Terrains/Clutters (Signal Strength in %)**		
	River/Lake (R/L)	**Sea**	**Highway/ Motorway (H/M)**
10 (t_0- t_4)	100	92	96
20	86	74	80
30	66	58	62
40	58	44	54
50	50	40	48
60	46	36	42
70	40	32	34
80	32	26	28
90	28	22	26
100	20	18	18
110	8	12	14
120	2	8	4
130	0	4	0
140	0	2	0
150	0	0	0

LF/P noise is also added in R/L which leads to early dead signals as compare to sea.

Figure 4.1 is representing the line graph of all terrains receive signal strength against distance (0 m-150 m). The top most line is representing A/F which contains less impairment. Whereas sharp curves at the bottom are representing Sea and DF which carry more noise in their environment.

As the distances increasing the gap between the A/F and other terrains is also increasing. To cater this problem we divide the distance in 3 zones. Fig. 4.1 is also representing all three zones based on distance. Zone 1 boundaries are from $0 < d < 30$, zone 2 boundaries are $30 \leq d < 120$ and zone 3 limits from $120 \leq d < 150$.

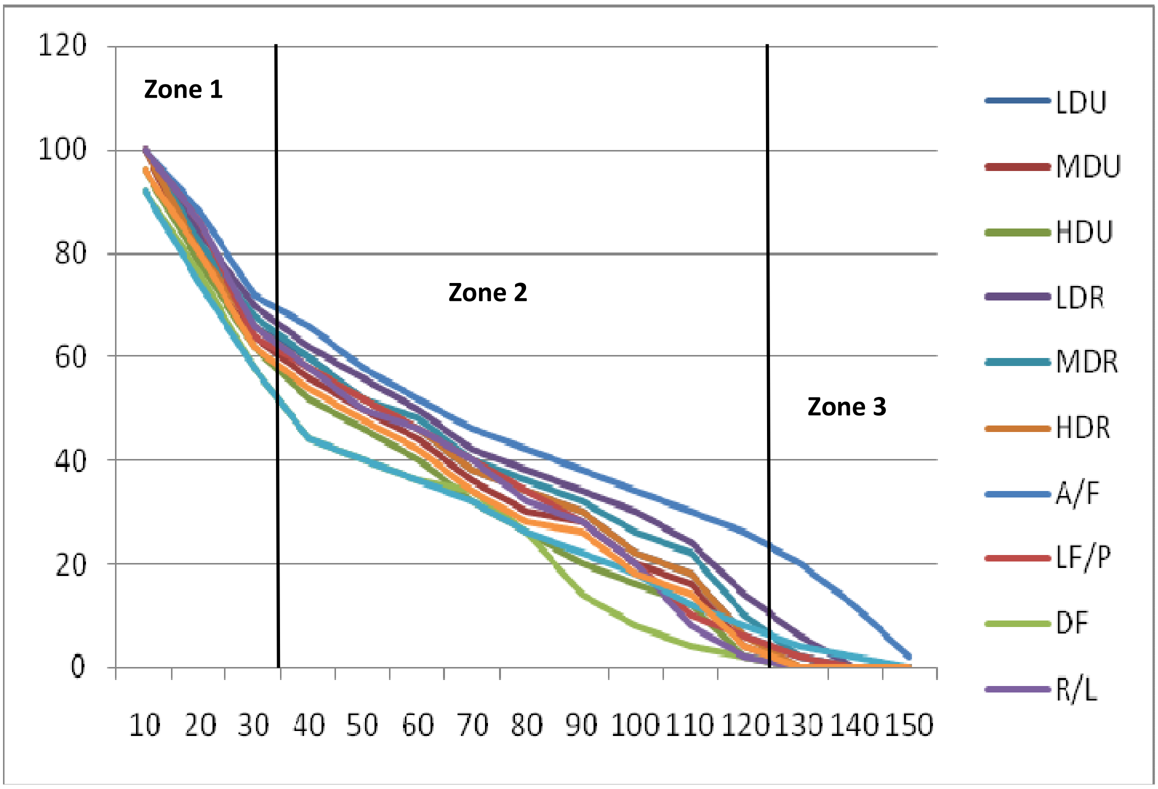


Figure 4.1: Representation of data taken form twelve terrains (signal strength against distance).

4.4 Error Rate Table (ERT)

The focus of Error Rate Table is to analyze the data taken from the experimental work done in different terrains. We propose twelve terrains under four environmental groups. Distance mentioned in tables is in meters. We calculate RSS from under 1 m to 150 m. Signal strength is represented in percent (%), which is showing the RSS values at different distances. According to our experiment A/F is the lowest noise area which is also mentioned in [84, 125]. Therefore we compare receive data of other terrains with A/F for the Error Rate Table (ERT). We use WiFi (IEEE 802.11 b/g) standard for prototype. Overlapping of two or more high impairment terrains can increase error rate. We repeat our experiment 5 times (t_0 to t_4) on every single point of each terrain and take the mean value.

The zone division is based on the sharp or inconsistent signal loss. Error rate table (table 4.5) is also based on these zones. For example we are measuring location of a wireless node in MDR. If the calculated distance is 80 m, then as an error we be will subtracted 6.25 m. Therefore the actual distance considering the terrain noise will be 73.75 m.

Table 4.5: Terrain based Error Rate Table (ERT)

Terrains/ Clutters	**Error Rate Calculation (in meters)**		
	$0 < d < 30$	**$30 \leq d < 120$**	**$120 \leq d < 150$**
LDU	6 m	8.25 m	17.5 m
MDU	9 m	10.75 m	18 m

Terrains/ Clutters	Error Rate Calculation (in meters)		
	0 < d < 30	30 ≤ d < 120	120 ≤ d < 150
HDU	10 m	15.25 m	18.5 m
LDR	3 m	3.75 m	12.5 m
MDR	5 m	6.25 m	14.5 m
HDR	9 m	8.5 m	17.5 m
A/F	0	0	0
LF/P	5 m	9.75 m	16.5 m
DF	13 m	18 m	18 m
R/L	4 m	10.5 m	18 m
Sea	14 m	17 m	14.5 m
H/M	9 m	12.75 m	18 m

Error Rate table (error distance in meters) of three categories of terrains.

As mentioned in ERT, A/F is used as a baseline data for all other terrains because of its less impairment. As ERT and figure 4.1 explaining that every terrain has continuous increase in error as the distance increases. By subtracting the ERT values in the calculated values we can get the precision in the location estimation.

4.5 Clutter based Enhance Error Rate Table (CERT)

The focus of Clutter based Enhance Error Rate Table is to analyze the data points taken from the experimental work. We repeat the test in every single clutter (except desert) at the average distance of 2 meters from 0 meter to 150 meters. C sharp program is used to calculate RSS (Rx), and ASS (Tx) values. Signal strength is represented in percentage (%) which depicts the change in Rx value from Tx value at different points. As Agriculture/Field is the low noise clutter [84, 91, 125], therefore we select it as a baseline to compare the attenuation of other clutters. We repeat our experiment 5 times ($t_0 – t_4$) at every n-2 points. Although the data collection procedure is repeated to achieve accuracy but overlapping of two or more clutters and the external factors like heavy rain, bright sunlight may cause in the increase of SNR. These factors may lead to change in the Rx value unpredictably.

We construct a Clutter based Enhance Error Rate Table (CERT) with the division of eight zones by using collected data points. These zones helps to reduce error in the clutter we are dealing and ensure to precisely calculate the position of a wireless node. Table 4.6 is representing the collected data points with the division of clutter groups and the distance interval at 2 meters. All collected data points are in percentage (%) and representing the RSS (The Rx) Value.

Table 4.6: Clutter Based RSS readings at 2 meters interval

Distance in meters (t_0-t_4)	**Urban Clutters/Terrains**			**Rural Clutters/Terrains**			**Plantation Clutters/Terrains**			**Highway & Water Bodies Clutters/ Terrains**		
	LDU	**MDU**	**HDU**	**LDR**	**MDR**	**HDR**	**A/F**	**LF/P**	**DF**	**R/L**	**SEA**	**H/M**
10	**100.**	**100.0**	**96.00**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**92.00**	**100.0**	**92.00**	**96.00**
12	96.2	94.96	92.24	96.64	96.08	95.52	97.92	97.84	88.96	97.68	88.24	92.96
14	92.5	90.24	88.56	93.36	92.32	91.28	95.68	95.36	85.84	95.12	84.56	89.84
16	88.9	85.84	84.96	90.16	88.72	87.28	93.28	92.56	82.64	92.32	80.96	86.64
18	85.4	81.76	81.44	87.04	85.28	83.52	90.72	89.44	79.36	89.28	77.44	83.36

Distance in meters (t_0-t_4)	Urban Clutters/Terrains			Rural Clutters/Terrains			Plantation Clutters/Terrains			Highway & Water Bodies Clutters/ Terrains		
	LDU	MDU	HDU	LDR	MDR	HDR	A/F	LF/P	DF	R/L	SEA	H/M
20	**82.0**	**78.00**	**78.00**	**84.00**	**82.00**	**80.00**	**88.00**	**86.00**	**76.00**	**86.00**	**74.00**	**80.00**
22	78.6	74.56	74.64	81.04	78.88	76.72	85.12	82.24	72.56	82.48	70.64	76.56
24	75.3	71.44	71.36	78.16	75.92	73.68	82.08	78.16	69.04	78.72	67.36	73.04
26	72.1	68.64	68.16	75.36	73.12	70.88	78.88	73.76	65.44	74.72	64.16	69.44
28	69.0	66.16	65.04	72.64	70.48	68.32	75.52	69.04	61.76	70.48	64.04	65.76
30	**66.0**	**64.00**	**62.00**	**70.00**	**68.00**	**66.00**	**72.00**	**64.00**	**58.00**	**66.00**	**58.00**	**62.00**
32	64.3	62.33	61.62	69.21	66.67	65.04	71.30	62.62	50.06	64.65	51.07	60.33
34	62.9	60.67	59.55	68.25	65.75	64.47	70.47	61.41	46.26	63.25	47.40	58.67
36	61.8	59.04	56.89	66.01	63.22	62.99	68.57	60.27	44.72	61.66	45.57	57.04
38	60.8	57.48	54.27	63.10	61.95	60.35	67.28	59.14	44.22	59.89	44.62	55.48
40	**60.0**	**56.00**	**52.00**	**62.00**	**60.00**	**58.00**	**66.00**	**58.00**	**44.00**	**58.00**	**44.00**	**54.00**
42	57.5	54.62	50.19	60.02	56.86	56.12	63.92	56.83	43.68	56.10	43.40	52.62
44	55.5	53.35	48.82	58.58	54.66	54.69	62.12	55.64	43.09	54.28	42.70	51.35
46	54.0	52.18	47.73	57.54	53.27	53.63	60.57	54.43	42.22	52.64	41.87	50.18
48	52.9	51.07	46.84	56.74	52.47	52.78	59.22	53.22	41.15	51.20	40.95	49.07
50	**52.0**	**50.00**	**46.00**	**56.00**	**52.00**	**52.00**	**58.00**	**52.00**	**40.00**	**50.00**	**40.00**	**48.00**
52	51.0	48.93	45.10	55.19	51.61	51.16	56.84	50.79	38.88	49.01	39.07	46.93
54	50.0	47.83	44.07	54.21	51.10	50.16	55.58	49.58	37.88	48.18	38.20	45.83
56	48.9	46.65	42.88	53.01	50.36	48.96	54.49	48.38	37.06	47.45	37.40	44.65
58	47.5	45.38	41.51	51.59	49.32	47.57	53.27	47.19	36.44	46.75	36.68	43.38
60	**46.0**	**44.00**	**40.00**	**50.00**	**48.00**	**46.00**	**52.00**	**46.00**	**36.00**	**46.00**	**36.00**	**42.00**
62	44.3	42.51	38.39	48.30	46.45	44.32	50.72	44.81	35.68	45.14	35.33	40.51
64	42.6	40.94	36.73	46.57	44.78	42.61	49.45	43.62	35.42	44.13	34.63	38.94
66	40.9	39.29	35.08	44.90	43.07	40.94	48.22	42.42	35.11	42.93	33.86	37.29
68	39.4	37.63	33.49	43.36	41.45	39.38	47.06	41.21	34.66	41.54	32.99	35.63

Distance in meters (t_0-t_4)	**Urban Clutters/Terrains**			**Rural Clutters/Terrains**			**Plantation Clutters/Terrains**			**Highway & Water Bodies Clutters/ Terrains**		
	LDU	**MDU**	**HDU**	**LDR**	**MDR**	**HDR**	**A/F**	**LF/P**	**DF**	**R/L**	**SEA**	**H/M**
70	**38.0**	**36.00**	**32.00**	**42.00**	**40.00**	**38.00**	**46.00**	**40.00**	**34.00**	**40.00**	**32.00**	**34.00**
72	36.8	34.45	30.62	40.86	38.77	36.83	45.04	38.79	33.05	38.35	30.90	32.45
74	35.8	33.04	29.35	39.93	37.80	35.87	44.18	37.58	31.76	36.64	29.71	31.04
76	35.0	31.81	28.18	39.18	37.05	35.12	43.40	36.38	30.16	34.97	28.46	29.81
78	34.5	30.79	27.08	38.56	36.48	34.52	42.69	35.18	28.22	33.40	27.21	28.79
80	**34.0**	**30.00**	**26.00**	**38.00**	**36.00**	**34.00**	**42.00**	**34.00**	**26.00**	**32.00**	**26.00**	**28.00**
82	33.5	29.42	24.91	37.43	35.52	33.49	41.31	32.83	23.59	30.82	24.90	27.42
84	32.9	29.02	23.76	36.77	34.95	32.90	40.58	31.65	21.07	29.87	23.94	27.02
86	32.1	28.72	22.56	35.99	34.20	32.16	39.79	30.47	18.56	29.14	23.14	26.72
88	31.2	28.42	21.29	35.06	33.22	31.20	38.92	29.26	16.17	28.55	22.51	26.42
90	**30.0**	**28.00**	**20.00**	**34.00**	**32.00**	**30.00**	**38.00**	**28.00**	**14.00**	**28.00**	**22.00**	**26.00**
92	28.5	27.32	18.75	32.88	30.61	28.56	37.05	26.66	12.13	27.33	21.54	25.32
94	26.8	26.26	17.63	31.80	29.15	26.94	36.11	25.22	10.61	26.36	21.03	24.26
96	25.1	24.70	16.75	30.88	27.77	25.21	35.25	23.64	9.45	24.91	20.35	22.70
98	23.4	22.60	16.18	30.26	26.67	23.52	34.53	21.91	8.61	22.81	19.37	20.60
100	**22.0**	**20.00**	**16.00**	**30.00**	**26.00**	**22.00**	**34.00**	**20.00**	**8.00**	**20.00**	**18.00**	**18.00**
102	20.8	19.11	15.21	29.09	25.33	20.77	33.66	17.94	7.51	16.54	16.24	17.41
104	20.1	18.35	14.07	28.30	24.93	19.92	32.42	15.77	6.98	12.72	14.22	16.05
106	19.6	17.43	12.98	27.11	23.95	19.39	32.07	13.60	6.28	9.19	12.30	15.43
108	19.2	16.89	12.43	25.55	22.87	18.94	31.16	11.59	5.29	7.03	11.17	14.67
110	**18.0**	**16.00**	**12.00**	**24.00**	**22.00**	**18.00**	**30.00**	**10.00**	**4.00**	**8.00**	**12.00**	**14.00**
112	14.4	12.77	8.94	21.71	19.58	15.32	29.36	9.36	3.83	6.38	11.43	11.49
114	11.6	9.98	6.49	19.59	17.10	12.73	28.64	8.61	3.49	4.99	10.69	9.23
116	9.30	7.62	4.57	17.63	14.63	10.28	27.84	7.78	3.05	3.81	9.85	7.23
118	7.46	5.63	3.10	15.77	12.25	8.03	26.96	6.90	2.53	2.82	8.93	5.49

Distance in meters (t_0-t_4)	Urban Clutters/Terrains			Rural Clutters/Terrains			Plantation Clutters/Terrains			Highway & Water Bodies Clutters/ Terrains		
	LDU	**MDU**	**HDU**	**LDR**	**MDR**	**HDR**	**A/F**	**LF/P**	**DF**	**R/L**	**SEA**	**H/M**
120	**6.00**	**4.00**	**2.00**	**14.00**	**10.00**	**6.00**	**26.00**	**6.00**	**2.00**	**2.00**	**8.00**	**4.00**
122	4.84	2.69	1.21	12.30	7.93	4.23	24.96	5.11	1.48	1.34	7.08	2.76
124	3.91	1.66	0.67	10.65	6.07	2.75	23.84	4.24	1.00	0.83	6.20	1.75
126	3.16	0.90	0.31	9.09	4.46	1.55	22.64	3.43	0.58	0.45	5.38	0.96
128	2.53	0.35	0.11	7.50	3.10	0.63	21.36	2.68	0.25	0.18	4.65	0.39
130	**2.00**	**0.00**	**0.00**	**6.00**	**2.00**	**0.00**	**20.00**	**2.00**	**0.00**	**0.00**	**4.00**	**0.00**
132	1.53	0.00	0.00	4.57	1.16	0.00	18.56	1.41	0.00	0.00	3.45	0.00
134	1.09	0.00	0.00	3.23	0.57	0.00	17.04	0.92	0.00	0.00	2.98	0.00
136	0.69	0.00	0.00	1.99	0.20	0.00	15.44	0.52	0.00	0.00	2.60	0.00
138	0.33	0.00	0.00	0.91	0.03	0.00	13.76	0.21	0.00	0.00	2.28	0.00
140	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**12.00**	**0.00**	**0.00**	**0.00**	**2.00**	**0.00**
142	0.00	0.00	0.00	0.00	0.00	0.00	10.16	0.00	0.00	0.00	1.73	0.00
144	0.00	0.00	0.00	0.00	0.00	0.00	8.24	0.00	0.00	0.00	1.45	0.00
146	0.00	0.00	0.00	0.00	0.00	0.00	6.24	0.00	0.00	0.00	1.09	0.00
148	0.00	0.00	0.00	0.00	0.00	0.00	4.16	0.00	0.00	0.00	0.63	0.00
150	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**2.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

External affects like humidity, heavy rain and bright sunlight are not considered in this specific research. All clutters are considered in the tropical region of Malaysian peninsula.

Figure 4.2 is representing the line graph of all clutters. Graph is constructed with RSS in percentage against the distance from 0 meter – 150 meters at a regular interval of 2 meters. The sharp curve is representing the Dense Forest (DF) and the Sea clutters which means that these two clutters have more atmospheric attenuation as compare to other clutters. As the distance increases the gap (error rate) between clutters is also increasing. To solve this problem we divide the distance in eight zones. Zone 3, 5 and 7 are catering the attenuation problem faced in DF and Sea clutters. Zone 1 and 8 dealing with all clutters, whereas zone 2, 4 and 6 are dealing with other nine zones except DF and Sea with the reference of A/F. Table 4.7 is representing the zone division with respect to clutters/terrains with range.

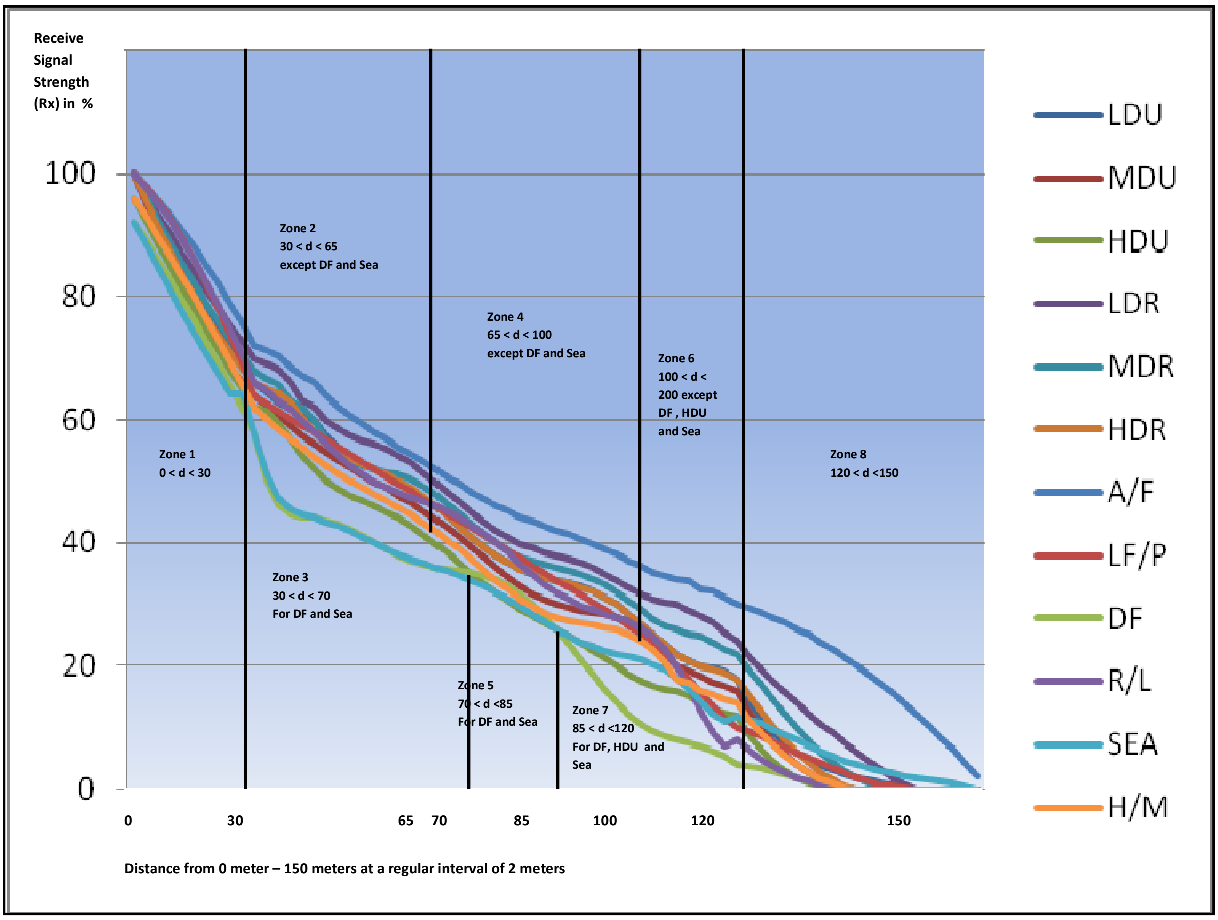


Figure 4.2: Representation of data taken form twelve clutters (signal strength against distance), with eight zone division.

Table 4.7: Zone division table

Zones	Zones Range Division	
	Range	**Clutter**
Zone 1	0 < d < 30	All
Zone 2	30 < d < 65	except DF and Sea
Zone 3	30 < d < 70	DF and Sea
Zone 4	65 < d < 100	except DF and Sea
Zone 5	70 < d <85	DF and Sea
Zone 6	100 < d <120	except DF, HDU and Sea
Zone 7	85 < d <120	DF, HDU and Sea
Zone 8	120 < d <150	All

DF and Sea are the clutters of high attenuation. In zone 7 HDU is also added in high attenuated clutters because of its behavior

Table 4.7 is constructed to cater the impairments in DF, HDU and Sea as they are not linear with other clutters data. The zone division is based on inconsistent or sharp signal loss. Based on the data points and the zone table CERT is developed with helps to minimize the error rate when dealing with different clutters. CERT values are calculated by averaging the data collected in each clutter with the reference of zones. HDU is the attenuated only if distance increases therefore in zone 7 we add HDU with Sea and D/F to overcome its attenuated problem.

Table 4.8: Clutter Based Enhance Error Rate Table (CERT)

Clutters/ Terrains	**Error Rate Calculation (in meters)**							
	Z 1	**Z 2**	**Z 3**	**Z 4**	**Z 5**	**Z 6**	**Z 7**	**Z 8**
LDU	5.5m	5m	--	4.5 m	--	5 m	--	5 m
MDU	7.5 m	6m	--	6 m	--	6.5 m	--	6.5 m
HDU	8 m	8m	--	7.5 m	--	--	9 m	9.5 m
LDR	3 m	2.5 m	--	2.5 m	--	3 m	--	3 m
MDR	5 m	3.5 m	--	4m	--	4.5 m	--	4.5 m
HDR	7 m	6.25m	--	6.5 m	--	6.25 m	--	7 m
A/F	0	0	0	0	0	0	0	0
LF/P	5 m	4.5 m	--	5 m	--	5.25 m	--	4.5 m
DF	8.5 m	--	9.5 m	--	10 m	--	9.5 m	9.5 m
R/L	4 m	4 m	--	5.5 m	--	6.25 m	--	5 m
Sea	9 m	--	10 m	--	10 m	--	9.5 m	10 m
H/M	9 m	7.5 m	--	8 m	--	8.25 m	--	8.5 m

Z = Zone

Values of the table 4.8 are required to add in the calculated location to get the precise location of a wireless node. For example the calculated distance in H/M is 90 meters. First of all we have to refer the zone table (Table 4.7). Calculated value falls under zone four therefore we will subtract 8 m in calculated value (refer CERT). The error corrected value will be 82 m instead of 90 m.

4.6 Linear Interpolation

Interpolation is a method which is used to define a function under the two set of values [130]. Two set of points in a plane represent a straight line. But to read variation in readings we need interpolation. There are different types of interpolation like Linear, Cosine, Cubic, Hermite, 3D linear, 3D cubic, 3D Hermite, Trilinear interpolation etc. Linear interpolation is the simplest form to get the intermediate values between two data points [131]. Formula which is used to calculate linear interpolated points is as under

$$P(x) = \sum_{k} \left(\prod_{j \neq k} \frac{x - xj}{xk - xj} \right) \qquad (4.1)$$

4.6.1 Modeling of interpolated Distance Error

Previously we calculated distance based on signal strength by using regular interval of 10m (from 10m – 150m). We proposed an Error Rate Table (ERT) [91] and CERT [92] which help to improve location by considering the terrain impairments. But it does not cater the problem if the distance varies from the regular interval. In modeling of interpolated distance error we use linear interpolation and combine it with ERT to minimize the distance error in order to achieve precise location. Finally we have compared actual results with interpolated data points to check accuracy in the mechanism.

4.6.2 Experimental Work and Data Analysis

We apply linear interpolation on the collected data points at the regular interval of 10 meter (from 10 m to 150 m). We consider Line of Sight (LOS) as a mandatory element for data collection in all clutters/terrains otherwise distortion may leads towards the unreliable results. C-sharp program is used to modulate the random data points from the fixed data set. Calculated interpolated variable distance is presented in table 4.9. A sample size of four is used in linear interpolation. Furthermore all terrains/clutters are divided into six zones in order to achieve accuracy and reduce error. In table 4.9 error (e) is calculated which is a difference between the interpolated and the actual location distance. All experiments are executed in tropical Malaysian weather. Figure 4.3 is a screen shot of signal strength to distance converter software which is using linear interpolation. We need to select a terrain/clutter from it which we a dealing with.

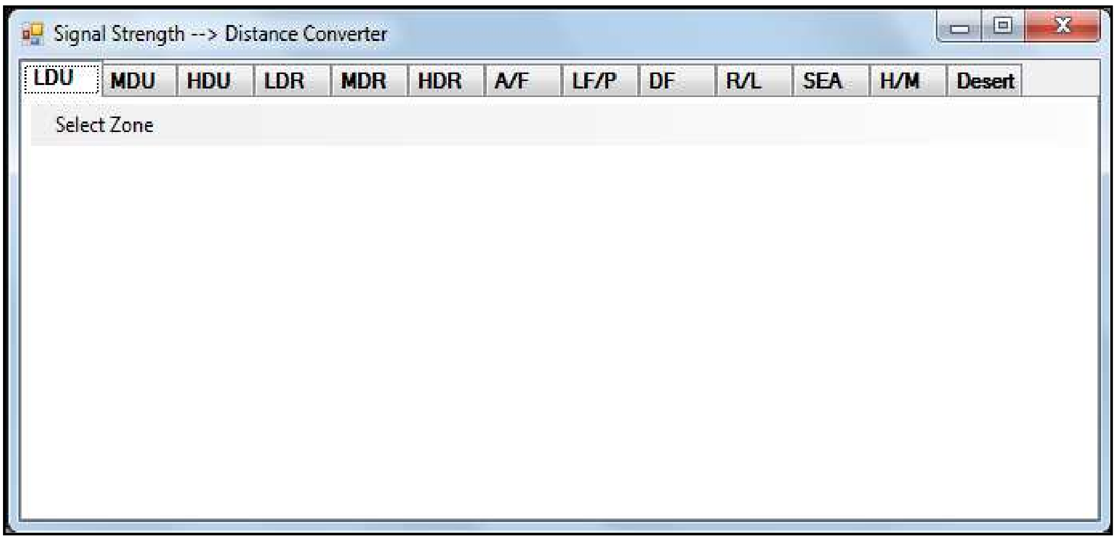


Figure 4.3: Signal strength to distance convertor. Tabs are representing each clutter type.

Figure 4.4 is explaining zone division. The zone division is based on the impairment/attenuation of each clutter. Zone division also mentions the signal strength. We need to select a zone according to the recorded signal strength. For example in figure 4.4, zone 3 of MDU is from 50% to 36% (signal strength) whereas in zone 3 of HDU it is from 46% to 32% (refer figure 4.5).

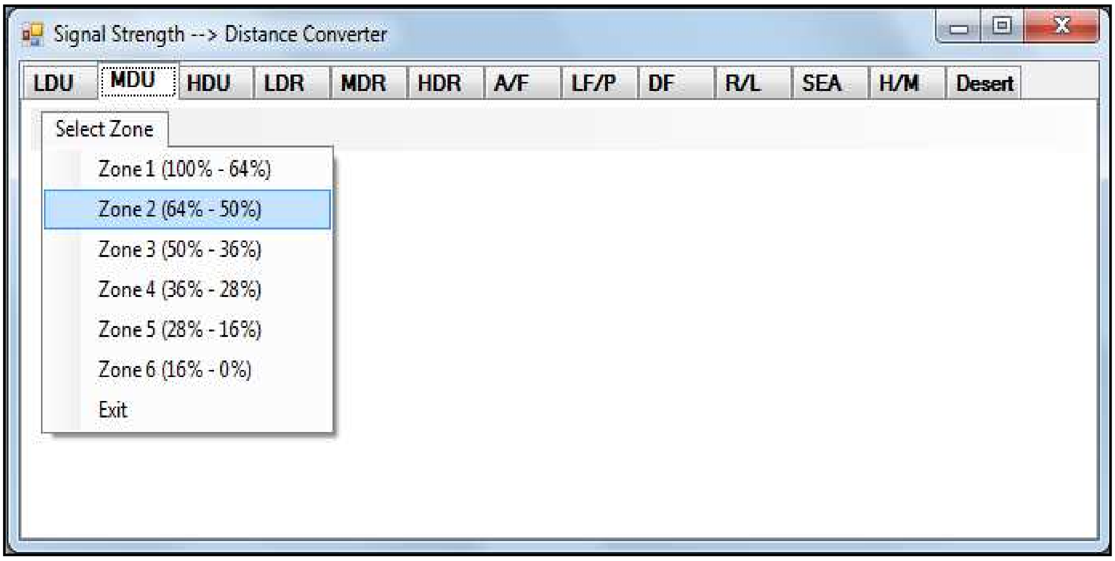


Figure 4.4: Zone selection procedure in each clutter. Zone can be selected based on your device receive signal strength.

After the clutter and the zone selection based on the signal strength we need to enter the signal strength which will calculate the distance of our device with the antenna. The calculated distance in HDU is 58.48218 m at 41% signal strength whereas actual distance is 57.955m at the same signal strength. The error value (e) is 0.52714 m

$$e = \text{Interpolated distance} - \text{actual distance} \quad (4.2)$$

In the above example the accuracy error is approx ½ m only (towards the antenna) in the highly attenuated clutter of HDU. Zones division of clutters helps to minimize error as representing in table 4.9.

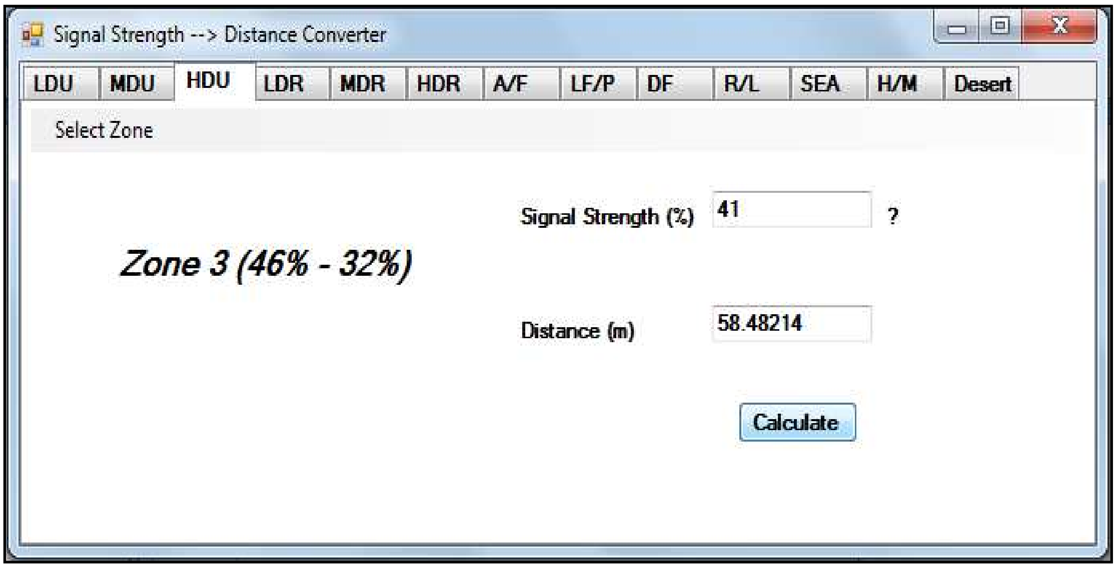


Figure 4.5: Distance calculation based on the device signal strength.

Data points are not collected from the clutter type desert because of the unavailability of desert in the peninsular Malaysian.

4.7 Results Comparison

We take sample size of four from each clutter and measure actual distance on specific signal strength. We calculate interpolated distance based on categorization of zones. Finally we compare the actual distance with interpolated distance to calculate error (e). Negative values in error representing the actual position is after the interpolated position (with the reference of antenna) whereas positive value representing that actual position is before the interpolated distance (towards antenna).

Table 4.9: Error calculation between actual distance and the interpolated distance on the sample size of 4

Modeling Interpolated Distance & Error				
Recorded Signal Strength (in %)	**Clutter/ Terrain Type**	**Interpolated Distance (I) (in meters)**	**Actual Distance (A) (in meters)**	**Error(e) (in meters)**
93	LDU	13.7316	13.80	-0.0684
54	LDU	47.8571	46.00	1.8571
39	LDU	68.9583	67.85	1.1083
20	LDU	104.5833	103.95	0.6333
92	MDU	12.8283	13.215	-0.3867
51	MDU	48.1845	47.9455	0.239
37	MDU	68.9583	67.9555	1.0028
17	MDU	107.1875	107.8333	-0.6458
90	HDU	13.1863	13.0325	0.1538
47	HDU	48.125	47.8555	0.2695
33	HDU	68.9583	67.5950	1.3633
13	HDU	107.50	105.9580	1.542
91	LDR	15.4375	15.5455	-0.108
57	LDR	48.1845	46.9540	1.2305
43	LDR	68.9583	67.8455	1.1128
25	LDR	108.75	107.7555	0.9945

Modeling Interpolated Distance & Error				
Recorded Signal Strength (in %)	**Clutter/ Terrain Type**	**Interpolated Distance (I) (in meters)**	**Actual Distance (A) (in meters)**	**Error(e) (in meters)**
94	MDR	12.9762	13.1010	-0.1248
53	MDR	48.75	47.6855	1.0645
41	MDR	69.4792	69.2520	0.2272
23	MDR	107.25	107.8450	-0.595
96	HDR	11.5966	11.8565	-0.2599
55	HDR	44.7321	43.9530	0.7791
39	HDR	68.9583	69.2525	-0.2942
19	HDR	107.1875	107.9545	-0.767
93	A/F	16.0938	16.4540	-0.3602
59	A/F	48.9583	48.6540	0.3043
47	A/F	68.3333	68.1245	0.2088
31	A/F	107.5	108.2450	-0.745
94	LF/P	14.6320	14.9550	-0.323
53	LF/P	48.3333	48.3545	-0.0212
41	LF/P	68.3333	68.1235	0.2098
11	LF/P	109.125	108.8080	0.317
93	DF	9.3403	9.5450	-0.2047

Modeling Interpolated Distance & Error				
Recorded Signal Strength (in %)	**Clutter/ Terrain Type**	**Interpolated Distance (I) (in meters)**	**Actual Distance (A) (in meters)**	**Error(e) (in meters)**
44	DF	44.6032	40.00	4.6032
35	DF	64.5833	66.1255	-1.5422
9	DF	97.9167	96.7545	1.1622
91	R/L	16.7122	17.2415	-0.5293
51	R/L	48.75	48.3520	0.398
41	R/L	68.75	68.3450	0.405
10	R/L	108.75	105.3555	3.3945
95	SEA	8.4620	7.4545	1.0075
41	SEA	47.2024	47.8545	-0.6521
33	SEA	67.5	67.9595	-0.4595
13	SEA	108.75	105.7545	2.9955
90	H/M	13.8726	13.8540	0.0186
49	H/M	48.1845	47.9555	0.229
35	H/M	68.9583	67.9545	1.0038
15	H/M	107.1875	107.0545	0.133

Figure 4.6 is representing the comparison between actual distance and the interpolated distance in LDU (figure 4.6a) and DF (figure 4.6b). As DF is highly

attenuated clutter because of the vegetation therefore the error rate in few zones is high. Similarly the error is high in other highly attenuated clutters like HDR, SEA, R/L and H/M (refer figure 4.7 and 4.8).

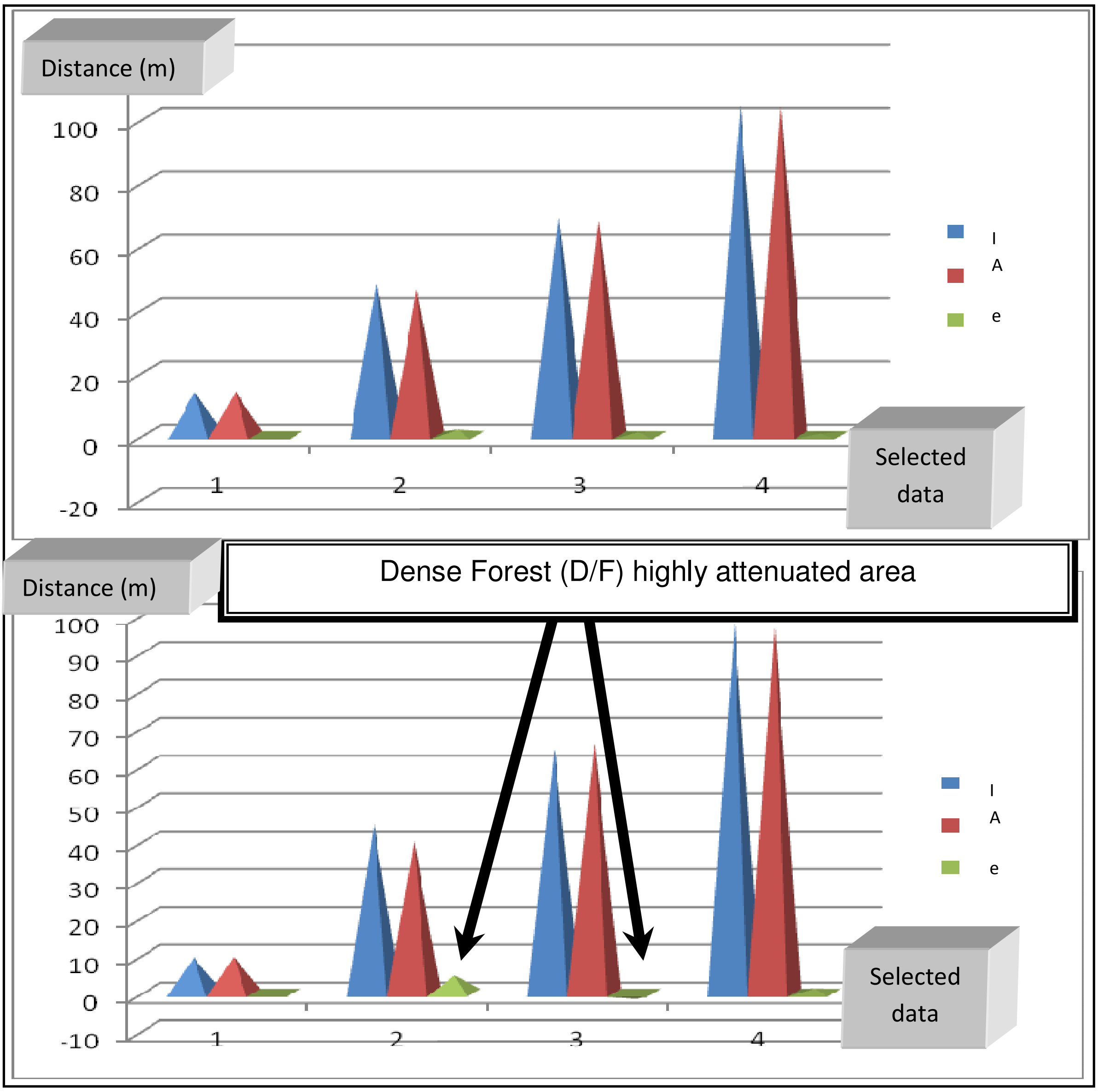


Figure 4.6: Comparison between interpolated distance (I), actual distance (A) and error (e). Figure 4.6a is representing LDU comparison and figure 4.6 b is representing DF.

Figure 4.7 is representing the interpolated distance, actual distance and the interpolated error calculated in table 4.9.

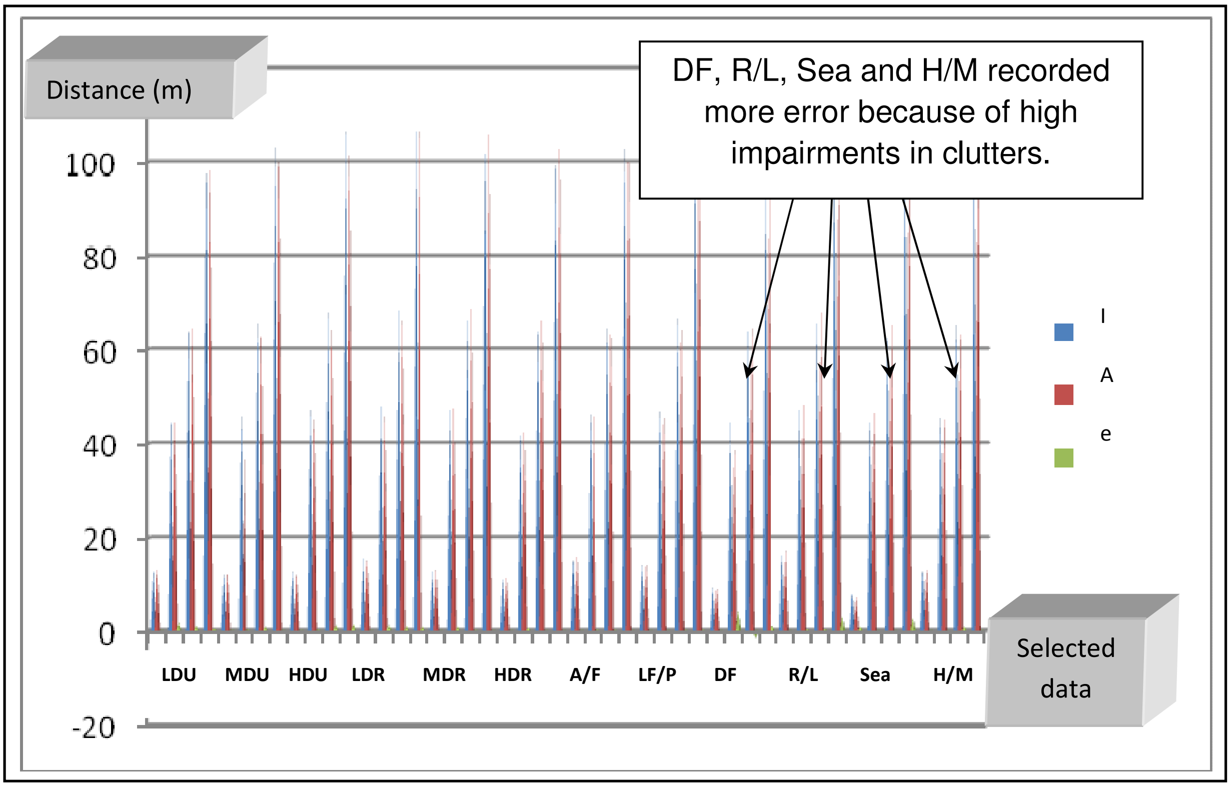
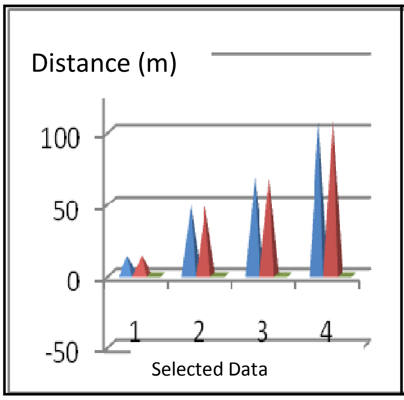


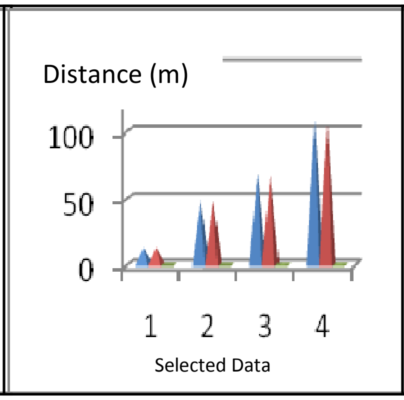
Figure 4.7: Graphical representation of table 3.9 data points. Only highly affected clutters have high error rate but still it is approx with the average error of 1.5 m.

Modelling shows that the interpolated distance calculation has accuracy of about 0.5 m when the clutter impairments are considered. In some cases even it is less than 0.2 m (either -ve or +ve value) only. Figure 3.9 is representing the comparison between the interpolated distances, actual distances and the error rate in all terrains. Error is high only in highly attenuated area such as D/F, R/L, SEA, and HDR.

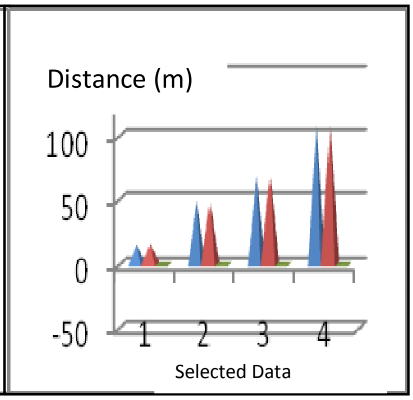
MDU



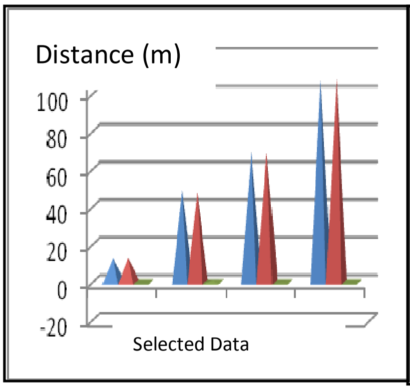
HDU



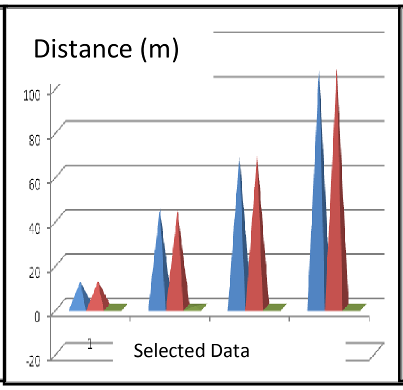
LDR



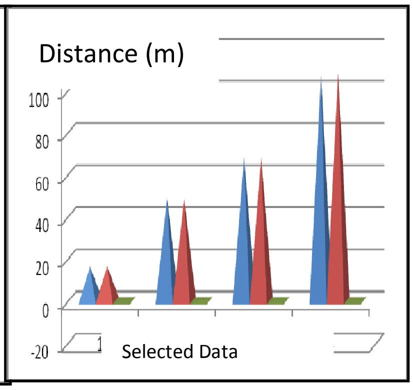
MDR



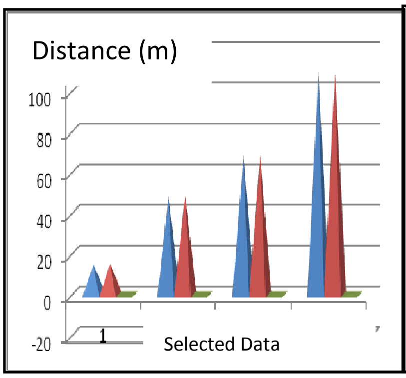
HDR



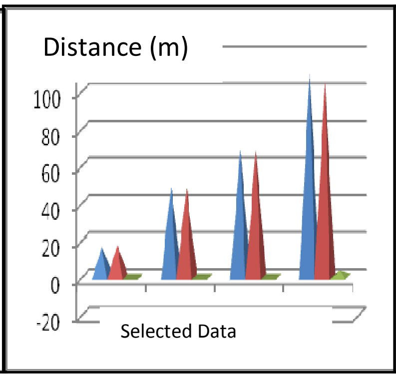
A/F



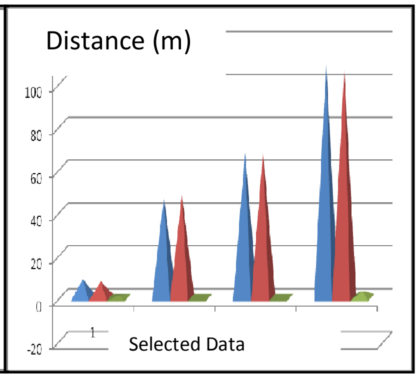
LF/P



R/L



SEA



H/M

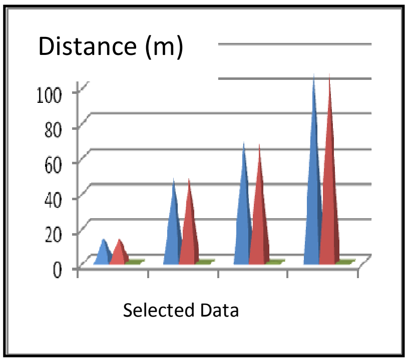


Figure 4.8: Comparison between the interpolated and the actual distance.

4.8 Chapter Summary

In this chapter, terrain based noise (impairment) has been measured. We divide the geographical area in 13 terrains/clutters. By using WiFi (IEEE 802.11 b/g) based prototype we calculate the ASS based RSS values with the common interval of 10 m in different terrains. By comparing the error rates of different terrains an error rate table (ERT) is established with three zone division. By referring the ERT we can minimize the error from 3 m to 18.5 m based on the terrain we are dealing with.

We then present the CERT which is the enhance form of ERT. ERT helps to minimize errors from 3m-18.5m range whereas CERT ensures 2.5m-10m range based on the clutter we are dealing with. In the calculated value of a mobile node we have to add the error corrected value from the CERT. This addition helps to precisely calculate the location of a mobile node by avoiding the clutter attenuations.

Terrains/clutters based interpolated distance error helps to calculate random distance corrected location and minimize error. Although in clutters with high impairments sometimes it gives error of 3.5 meters but in average the error is 0.5 meter or even lesser depends on the clutter we are dealing with. This research helps to study and understand clutters behavior and to calculate interpolated distance with minimal error.

CHAPTER 5

LOCATION ESTIMATION AND FILTERING

5.1 Chapter Introduction

Based on the Point-to-Point data collection of previous chapter, estimation and filtering is performed in this chapter. Estimation is done by using triangulation method, whereas filtering is done by using average method and the k-nearest neighbor rule. The result comparison shows that k-NN has less error compare with filtering by using average method.

5.2 Location Estimation and Filtering

Tables 5.1 to 5.12 are representing the estimation results, which is done by using triangulation method. Filtering results are also displayed in tables 5.1 to 5.12 by using average ($\bar{Y}$). Finally last column is calculating error of average in each terrain. Selected case is based on the zones ranging from 40 to 60 meters. Figure 5.1 to figure 5.12 representing the error of average method.

5.3 Experimental Results of Triangulation (Estimation) and Average (Filtering)

5.3.1 Terrain Type: Low Dense Rural

Table 5.1 is representing the estimation and filtering results by using LDR terrain. Estimation errors after triangulation are mentioned in last column of table.

Table 5.1: Estimation and Filtering in Low Dense Rural terrain type

Terrain Type	**Triangulation Location (w.r.t α, β, γ) in meters**	**$\bar{Y}$ (Mean)**	**Error of each estimated location**
Actual location of wireless node in LDR with respect from antenna A is 58.70 m			
LDR (ΔABM, t_0)	57	57.38	1.7
LDR (ΔABM, t_1)	57.4		1.3
LDR (ΔABM, t_2)	58.1		0.6
LDR (ΔABM, t_3)	57.3		1.4
LDR (ΔABM, t_4)	57.1		1.6
LDR (ΔACM, t_0)	56.8	56.94	1.9
LDR (ΔACM, t_1)	57.1		1.6
LDR (ΔACM, t_2)	57.3		1.4
LDR (ΔACM, t_3)	57		1.7
LDR (ΔACM, t_4)	56.5		2.2
LDR (ΔBCM, t_0)	56.7	57.02	2
LDR (ΔBCM, t_1)	57.2		1.5
LDR (ΔBCM, t_2)	57.7		1
LDR (ΔBCM, t_3)	56.9		1.8
LDR (ΔBCM, t_4)	56.6		2.1
Location M (LDR)		**57.11**	

Distance of wireless node from antenna A is 58.70 meters whereas filtered location by using average and mean of means is 57.11 meters. The error in distance is 1.59 meters. Figure 5.1 is representing the LDR error graphically.

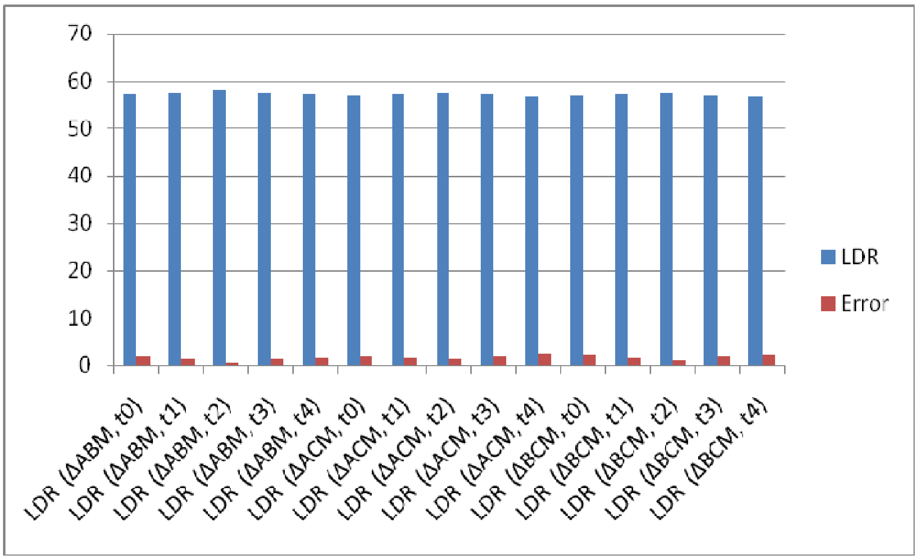


Figure 5.1: LDR terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

Figure 5.1 is a graphical representation of error estimation column in table 5.1.

5.3.2 Terrain Type: Medium Dense Rural

Table 5.2: Estimation and Filtering in Medium Dense Rural terrain type

Terrain Type	**Triangulation Location (w.r.t α, β, γ) in meters**	**$\bar{Y}$ (Mean)**	**Error of each estimated location**
Actual location of wireless node in MDR with respect from antenna A is 56.90 m			
MDR (ΔABM, t_0)	54	54.76	2.9
MDR (ΔABM, t_1)	54.6		2.3
MDR (ΔABM, t_2)	54.7		2.2
MDR (ΔABM, t_3)	55.6		1.3
MDR (ΔABM, t_4)	54.9		2
MDR (ΔACM, t_0)	55.4	54.76	1.5
MDR (ΔACM, t_1)	53.9		3
MDR (ΔACM, t_2)	55.2		1.7
MDR (ΔACM, t_3)	55.1		1.8
MDR (ΔACM, t_4)	54.2		2.7

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
MDR (ΔBCM, t_0)	54.6	55.12	2.3
MDR (ΔBCM, t_1)	55.1		1.8
MDR (ΔBCM, t_2)	55.4		1.5
MDR (ΔBCM, t_3)	55.6		1.3
MDR (ΔBCM, t_4)	54.9		2
Location M (MDR)		**54.88**	

In selected case of MDR actual distance of wireless node from antenna A is 56.90 meters whereas filtered location by using average and mean of means is 54.88 meters. The error in distance is 2.02 meters. Figure 5 2 is representing the MDR error graphically.

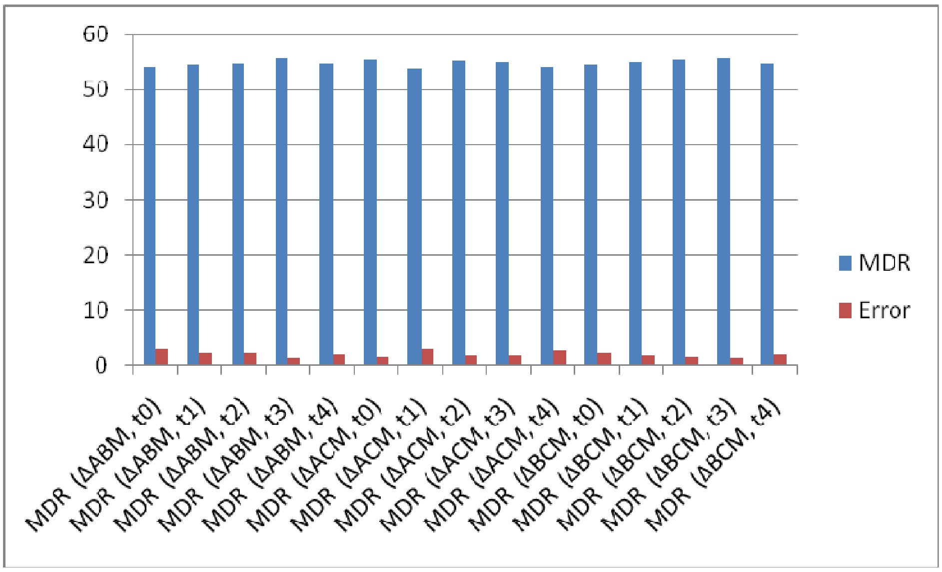


Figure 5.2: MDR terrain error by using triangle ABM, ACM & BCM (from $t_0 – t_4$)

5.3.3 Terrain Type: High Dense Rural

Table 5.3: Estimation and Filtering in High Dense Rural terrain type

Terrain Type	**Triangulation Location (w.r.t α, β, γ) in meters**	**$\bar{Y}$ (Mean)**	**Error of each estimated location**
Actual location of wireless node in HDR with respect from antenna A is 61.0 m			
HDR (ΔABM, t_0)	58.2	58.18	2.8
HDR (ΔABM, t_1)	57.8		3.2
HDR (ΔABM, t_2)	58.6		2.4
HDR (ΔABM, t_3)	58.6		2.4
HDR (ΔABM, t_4)	57.7		3.3
HDR (ΔACM, t_0)	57.9	58.28	3.1
HDR (ΔACM, t_1)	58.6		2.4
HDR (ΔACM, t_2)	58.8		2.2
HDR (ΔACM, t_3)	58.0		3
HDR (ΔACM, t_4)	58.1		2.9
HDR (ΔBCM, t_0)	57.4	57.84	3.6
HDR (ΔBCM, t_1)	57.6		3.4
HDR (ΔBCM, t_2)	57.7		3.3
HDR (ΔBCM, t_3)	58.3		2.7
HDR (ΔBCM, t_4)	58.2		2.8
Location M (HDR)		**58.11**	

In selected case of HDR actual distance of wireless node from antenna A is 61.0 meters whereas filtered location by using average and mean of means is 58.11 meters. The error in distance is 2.89 meters. Figure 5.3 is representing the HDR error graphically.

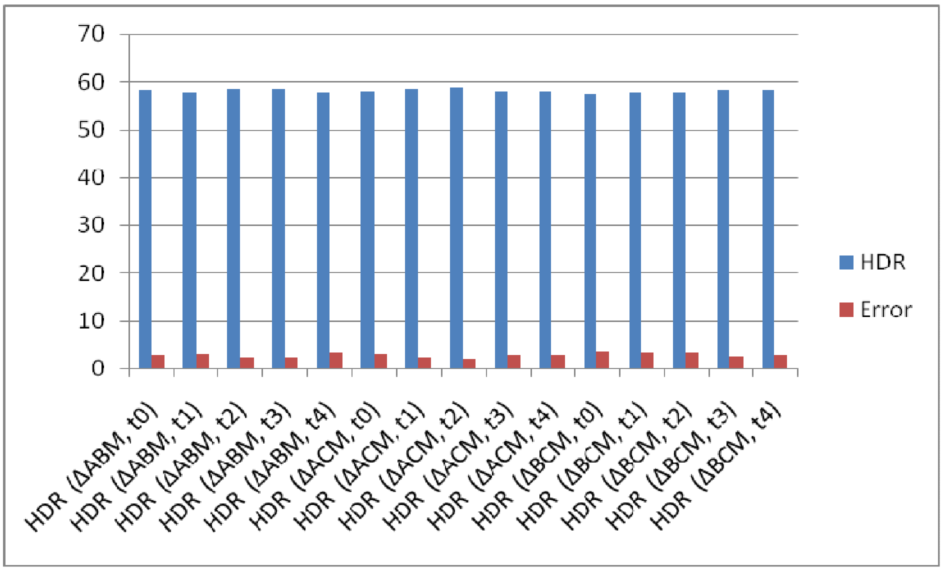


Figure 5.3: HDR terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.4 Terrain Type: Low Dense Urban

Table 5.4: Estimation and Filtering in Low Dense Urban terrain type

Terrain Type	**Triangulation Location (w.r.t α, β, γ) in meters**	**$\bar{Y}$ (Mean)**	**Error of each estimated location**
Actual location of Mobile node in LDU with respect from antenna A is 56.90 m			
LDU (ΔABM, t_0)	55	55.08	1.9
LDU (ΔABM, t_1)	54.6		2.3
LDU (ΔABM, t_2)	55.7		1.2
LDU (ΔABM, t_3)	54.2		2.7
LDU (ΔABM, t_4)	55.9		1
LDU (ΔACM, t_0)	54.6	54.72	2.3
LDU (ΔACM, t_1)	53.8		3.1
LDU (ΔACM, t_2)	55.8		1.1
LDU (ΔACM, t_3)	55.3		1.6
LDU (ΔACM, t_4)	54.1		2.8
LDU (ΔBCM, t_0)	55.8	55.06	1.1
LDU (ΔBCM, t_1)	54.6		2.3

LDU (ΔBCM, t_2)	55.6		1.3
LDU (ΔBCM, t_3)	54.9		2
LDU (ΔBCM, t_4)	54.4		2.5
Location M (LDU)		**54.95**	

In selected case of LDU actual distance of wireless node from antenna A is 56.90 meters whereas filtered location by using average and mean of means is 54.95 meters. The error in distance is 1.95 meters. Figure 5.4 is representing the LDU error graphically.

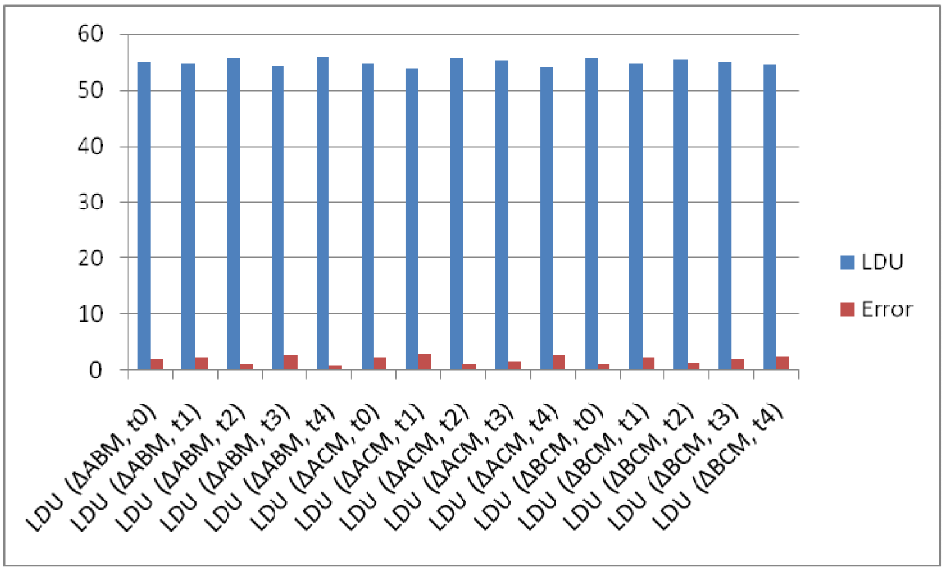


Figure 5.4: LDU terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.5 Terrain Type: Medium Dense Urban

Table 5.5: Estimation and Filtering in Medium Dense Urban terrain type

Terrain Type	**Triangulation Location (w.r.t α, β, γ) in meters**	**$\bar{Y}$ (Mean)**	**Error of each estimated location**
Actual location of wireless node in MDU with respect from antenna A is 54.80 m			
MDU (ΔABM, t_0)	52.1	52.88	2.7

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
MDU (ΔABM, t_1)	53.2		1.6
MDU (ΔABM, t_2)	52.6		2.2
MDU (ΔABM, t_3)	52.9		1.9
MDU (ΔABM, t_4)	53.6		1.2
MDU (ΔACM, t_0)	52.4	52.46	2.4
MDU (ΔACM, t_1)	51.8		3
MDU (ΔACM, t_2)	52.8		2
MDU (ΔACM, t_3)	53.6		1.2
MDU (ΔACM, t_4)	51.7		3.1
MDU (ΔBCM, t_0)	52.4	52.54	2.4
MDU (ΔBCM, t_1)	53.6		1.2
MDU (ΔBCM, t_2)	51.2		3.6
MDU (ΔBCM, t_3)	52.4		2.4
MDU (ΔBCM, t_4)	53.1		1.7
Location M (MDU)		**52.63**	

In selected case of MDU actual distance of wireless node from antenna A is 54.80 meters whereas filtered location by using average and mean of means is 52.63 meters. The error in distance is 2.17meters. Figure 5.5 is representing the MDU error graphically.

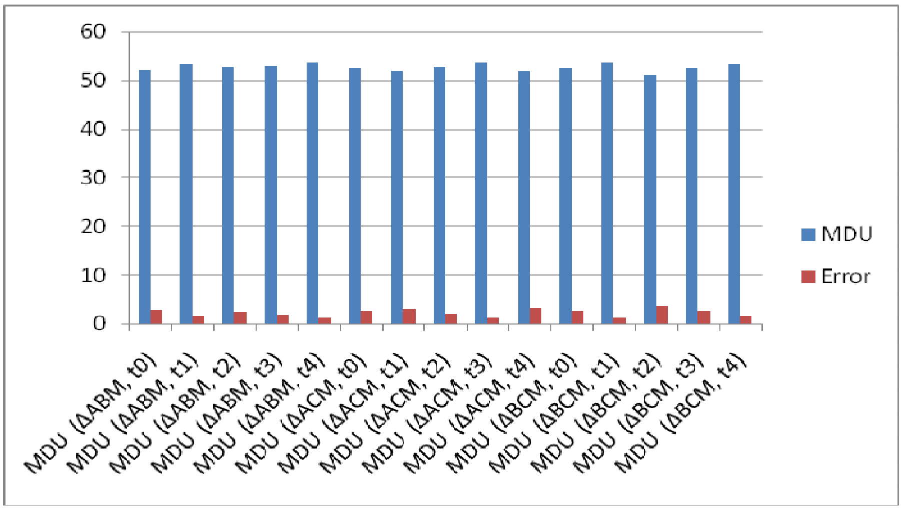


Figure 5.5: MDU terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.6 Terrain Type: High Dense Urban

Table 5.6: Estimation and Filtering in High Dense Urban terrain type

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
Actual location of wireless node in HDU with respect from antenna A is 58.9 m			
HDU (ΔABM, t_0)	56.9	55.62	2
HDU (ΔABM, t_1)	54.9		4
HDU (ΔABM, t_2)	55.8		3.1
HDU (ΔABM, t_3)	54.8		4.1
HDU (ΔABM, t_4)	55.7		3.2
HDU (ΔACM, t_0)	54.7	55.32	4.2
HDU (ΔACM, t_1)	55.8		3.1
HDU (ΔACM, t_2)	56.8		2.1
HDU (ΔACM, t_3)	55.3		3.6
HDU (ΔACM, t_4)	54.0		4.9
HDU (ΔBCM, t_0)	55.8	55.86	3.1
HDU (ΔBCM, t_1)	56.6		2.3
HDU (ΔBCM, t_2)	54.6		4.3
HDU (ΔBCM, t_3)	55.9		3
HDU (ΔBCM, t_4)	56.4		2.5
Location M (HDU)		**55.60**	

In selected case of HDU actual distance of wireless node from antenna A is 58.90 meters whereas filtered location by using average and mean of means is 55.60 meters. The error in distance is 3.30 meters. Figure 5.6 is representing the HDU error graphically.

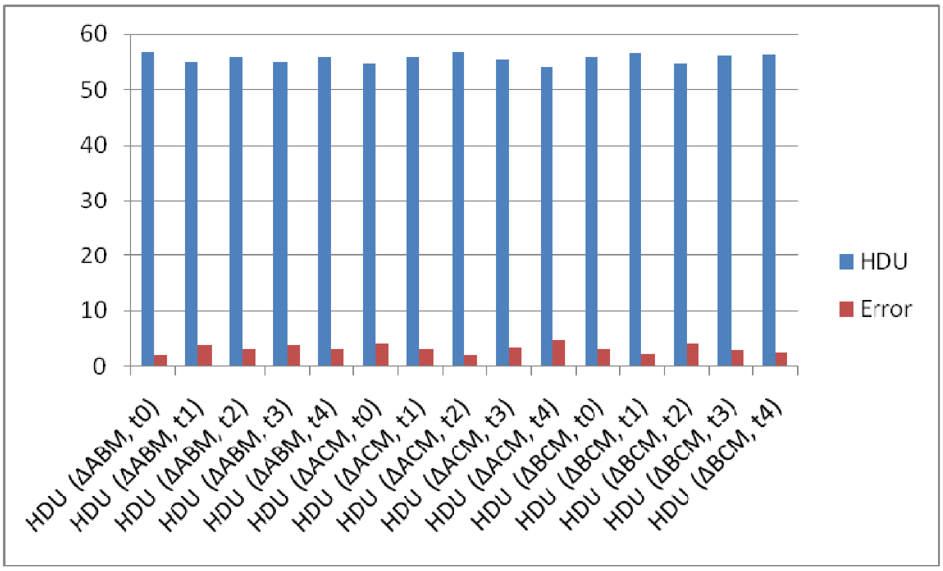


Figure 5.6: HDU terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.7 Terrain Type: Agriculture/Field

Table 5.7: Estimation and Filtering in Agriculture/Field terrain type

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
Actual location of wireless node in A/F with respect from antenna A is 59.60 m			
A/F (ΔABM, t_0)	57.4	58.28	2.2
A/F (ΔABM, t_1)	58.6		1
A/F (ΔABM, t_2)	59.8		-0.2
A/F (ΔABM, t_3)	57.7		1.9
A/F (ΔABM, t_4)	57.9		1.7
A/F (ΔACM, t_0)	58.6	58.56	1
A/F (ΔACM, t_1)	59.2		0.4
A/F (ΔACM, t_2)	58.4		1.2
A/F (ΔACM, t_3)	57.3		2.3
A/F (ΔACM, t_4)	59.3		0.3
A/F (ΔBCM, t_0)	58.8	58.9	0.8
A/F (ΔBCM, t_1)	59.4		0.2
A/F (ΔBCM, t_2)	57.8		1.8
A/F (ΔBCM, t_3)	58.9		0.7

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
A/F (ΔBCM, t_4)	59.6		0
Location M (A/F)		**58.58**	

In selected case of A/F actual distance of wireless node from antenna A is 59.60 meters whereas filtered location by using average and mean of means is 58.58 meters. The error in distance is 1.02 meters. Figure 5.7 is representing the A/F error graphically.

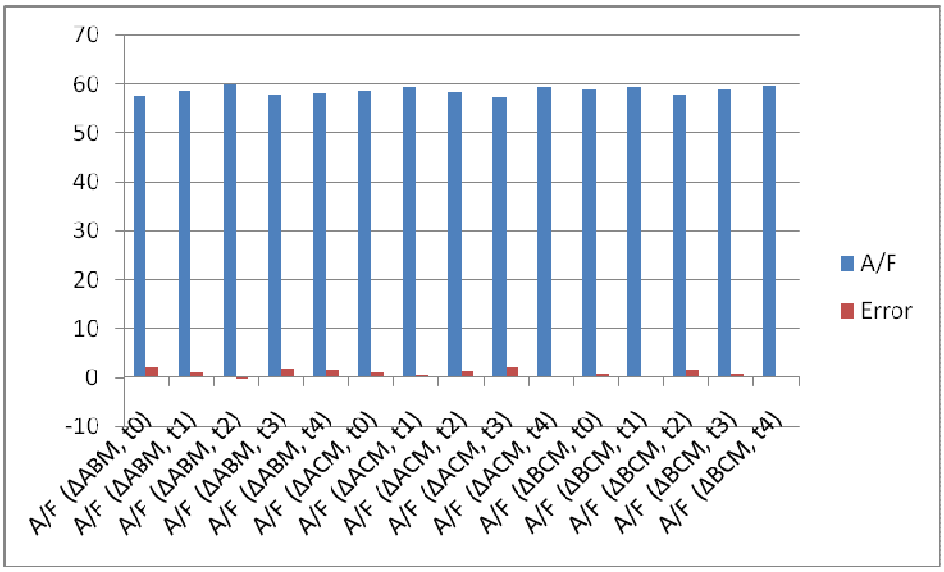


Figure 5.7: A/F terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.8 Terrain Type: Low Forest / Plantation

Table 5.8: Estimation and Filtering in Low Forest / Plantation terrain type

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
Actual location of wireless node in LF/P with respect from antenna A is 56.80 m			
LF/P (ΔABM, t_0)	54.6	55.1	2.2
LF/P (ΔABM, t_1)	55.4		1.4

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	Error of each estimated location
LF/P (ΔABM, t_2)	54.8		2
LF/P (ΔABM, t_3)	54.8		2
LF/P (ΔABM, t_4)	55.9		0.9
LF/P (ΔACM, t_0)	53.7	54.68	3.1
LF/P (ΔACM, t_1)	55.7		1.1
LF/P (ΔACM, t_2)	55.8		1
LF/P (ΔACM, t_3)	54.4		2.4
LF/P (ΔACM, t_4)	53.8		3
LF/P (ΔBCM, t_0)	55.6	54.8	1.2
LF/P (ΔBCM, t_1)	54.2		2.6
LF/P (ΔBCM, t_2)	54.7		2.1
LF/P (ΔBCM, t_3)	55.7		1.1
LF/P (ΔBCM, t_4)	53.8		3
Location M (LF/P)		**54.86**	

In selected case of LF/P actual distance of wireless node from antenna A is 56.80 meters whereas filtered location by using average and mean of means is 54.86 meters. The error in distance is 1.94 meters. Figure 5.8 is representing the LF/P error graphically.

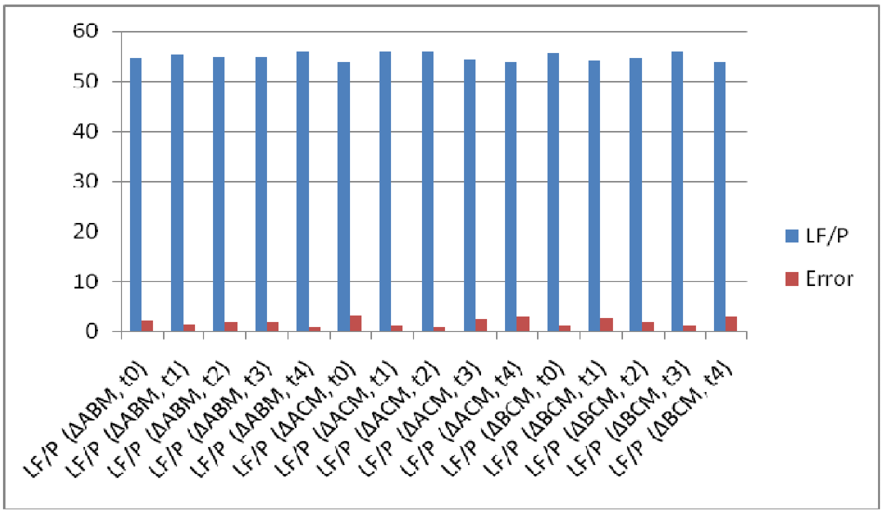


Figure 5.8: LF/P terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.9 Terrain Type: Dense Forest

Table 5.9: Filtering and Estimation in Dense Forest terrain type

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
Actual location of wireless node in DF with respect from antenna A is 60.20 m			
DF (ΔABM, t_0)	55.8	56.54	4.4
DF (ΔABM, t_1)	56.9		3.3
DF (ΔABM, t_2)	57.6		2.6
DF (ΔABM, t_3)	55.6		4.6
DF (ΔABM, t_4)	56.8		3.4
DF (ΔACM, t_0)	55.6	56.50	4.6
DF (ΔACM, t_1)	55.9		4.3
DF (ΔACM, t_2)	56.7		3.5
DF (ΔACM, t_3)	57.7		2.5
DF (ΔACM, t_4)	56.6		3.6
DF (ΔBCM, t_0)	55.6	56.80	4.6
DF (ΔBCM, t_1)	56.5		3.7
DF (ΔBCM, t_2)	57.6		2.6
DF (ΔBCM, t_3)	56.5		3.7
DF (ΔBCM, t_4)	57.8		2.4
Location M (DF)		**56.61**	

In selected case of DF actual distance of wireless node from antenna A is 60.20 meters whereas filtered location by using average and mean of means is 56.61 meters. The error in distance is 3.59 meters. Figure 5.9 is representing the DF error graphically.

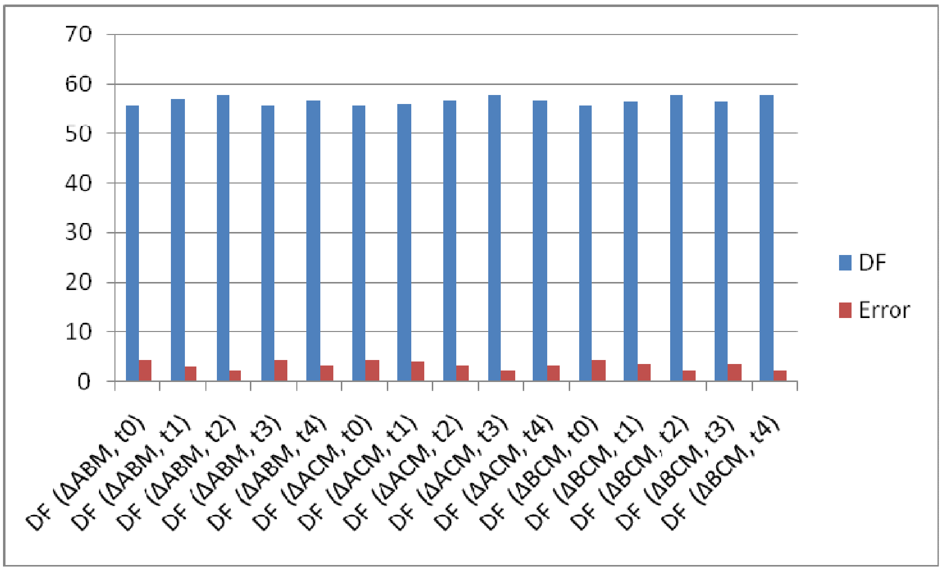


Figure 5.9: DF terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.10 Terrain Type: River/Lake

Table 5.10: Filtering and Estimation River/Lake in terrain type

Terrain Type	**Triangulation Location (w.r.t α, β, γ) in meters**	**$\bar{Y}$ (Mean)**	**Error of each estimated location**
Actual location of wireless node in R/L with respect from antenna A is 55.10 m			
R/L (ΔABM, t_0)	51.2	51.88	3.9
R/L (ΔABM, t_1)	50.3		4.8
R/L (ΔABM, t_2)	53.6		1.5
R/L (ΔABM, t_3)	51.8		3.3
R/L (ΔABM, t_4)	52.5		2.6
R/L (ΔACM, t_0)	53.5	52.18	1.6
R/L (ΔACM, t_1)	52.3		2.8
R/L (ΔACM, t_2)	53.4		1.7
R/L (ΔACM, t_3)	51.2		3.9
R/L (ΔACM, t_4)	50.5		4.6
R/L (ΔBCM, t_0)	52.6	52.16	2.5
R/L (ΔBCM, t_1)	52.9		2.2

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
R/L (ΔBCM, t_2)	53.8		1.3
R/L (ΔBCM, t_3)	51.1		4
R/L (ΔBCM, t_4)	50.4		4.7
Location M (R/L)		**52.07**	

In selected case of R/L actual distance of wireless node from antenna A is 55.10 meters whereas filtered location by using average and mean of means is 52.07 meters. The error in distance is 3.03 meters. Figure 5.10 is representing the R/L error graphically.

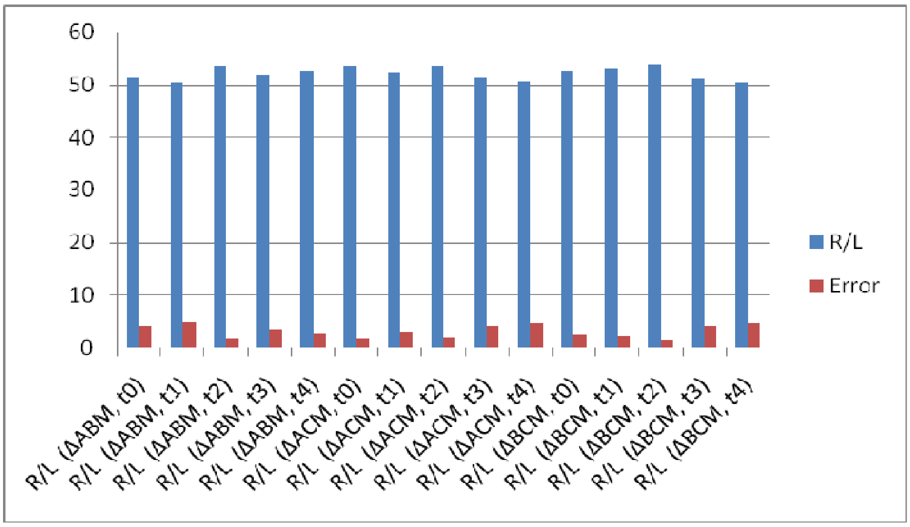


Figure 5.10: R/L terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.11 Terrain Type: Sea

Table 5.11: Estimation and Filtering in Sea terrain type

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	Error of each estimated location
Actual location of wireless node in Sea with respect from antenna A is 59.40 m			

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	Error of each estimated location
Sea (ΔABM, t_0)	55.6	56.0	3.8
Sea (ΔABM, t_1)	55.4		4
Sea (ΔABM, t_2)	54.9		4.5
Sea (ΔABM, t_3)	56.9		2.5
Sea (ΔABM, t_4)	57.2		2.2
Sea (ΔACM, t_0)	54.2	54.94	5.2
Sea (ΔACM, t_1)	55.8		3.6
Sea (ΔACM, t_2)	56.5		2.9
Sea (ΔACM, t_3)	54.4		5
Sea (ΔACM, t_4)	53.8		5.6
Sea (ΔBCM, t_0)	55.7	55.22	3.7
Sea (ΔBCM, t_1)	54.2		5.2
Sea (ΔBCM, t_2)	56.7		2.7
Sea (ΔBCM, t_3)	55.8		3.6
Sea (ΔBCM, t_4)	53.7		5.7
Location M (Sea)		**55.39**	

In selected case of Sea actual distance of wireless node from antenna A is 59.40 meters whereas filtered location by using average and mean of means is 55.39 meters. The error in distance is 4.01 meters. Figure 5.11 is representing the Sea error graphically.

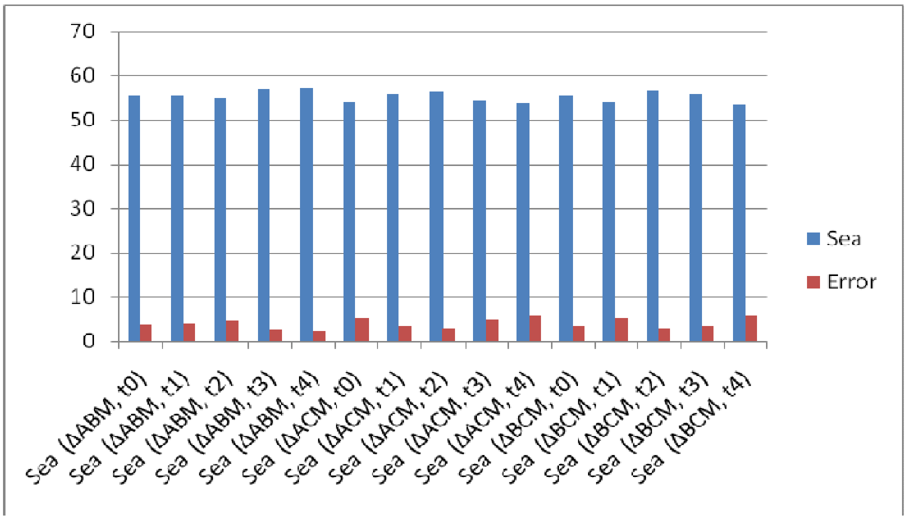


Figure 5.11: Sea terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.12 Terrain Type: Highway/Motorway

Table 5.12: Estimation and Filtering in Highway/Motorway terrain type

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	Error of each estimated location
Actual location of wireless node in H/M with respect from antenna A is 61.20 m			
H/M (ΔABM, t_0)	57.6	58.26	3.6
H/M (ΔABM, t_1)	58.4		2.8
H/M (ΔABM, t_2)	59.8		1.4
H/M (ΔABM, t_3)	56.9		4.3
H/M (ΔABM, t_4)	58.6		2.6
H/M (ΔACM, t_0)	57.8	58.02	3.4
H/M (ΔACM, t_1)	58.7		2.5
H/M (ΔACM, t_2)	59.8		1.4
H/M (ΔACM, t_3)	56.6		4.6
H/M (ΔACM, t_4)	57.2		4
H/M (ΔBCM, t_0)	58.6	58.24	2.6
H/M (ΔBCM, t_1)	59.4		1.8
H/M (ΔBCM, t_2)	58.7		2.5
H/M (ΔBCM, t_3)	57.7		3.5
H/M (ΔBCM, t_4)	56.8		4.4
Location M (H/M)		**58.17**	

In selected case of H/M actual distance of wireless node from antenna A is 61.20 meters whereas filtered location by using average and mean of means is 58.17 meters. The error in distance is 3.03 meters. Figure 5.12 is representing the H/M error graphically.

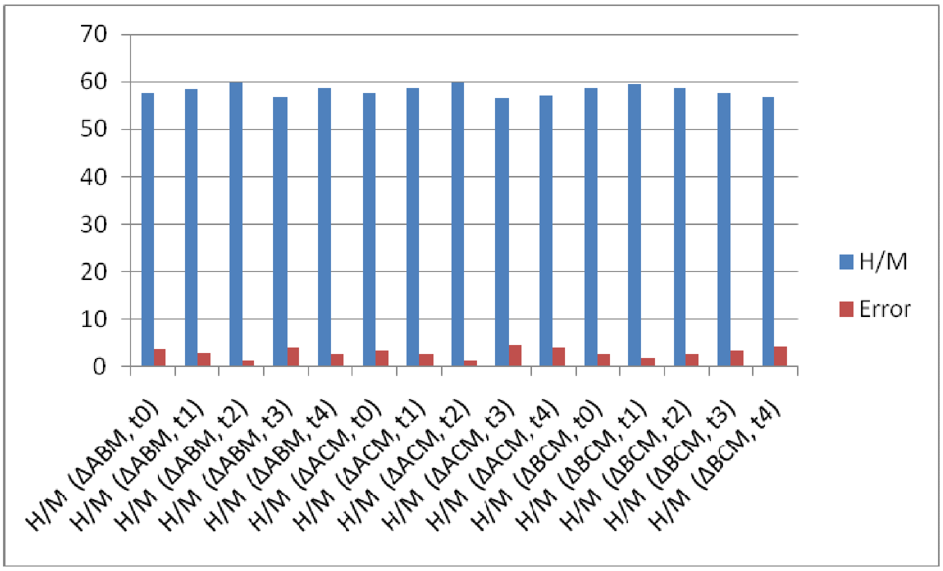


Figure 5.12: H/M terrain error by using triangle ABM, ACM & BCM (from $t_0 - t_4$)

5.3.13 Filtering (by using average) Location Comparison with Actual Location

Table 5.13 is the comparison between the selected cases filtered locations by using average technique with the actual location

Table 5.13: Comparison of average based filtering and actual distance

Terrain Type	Actual Location (in meters)	Filtered Location (in meters)	Error (in meters)
LDR	58.7	57.11	1.59
MDR	56.9	54.88	2.02
HDR	61	58.11	2.89
LDU	56.9	54.95	1.95
MDU	54.8	52.63	2.17

Terrain Type	Actual Location (in meters)	Filtered Location (in meters)	Error (in meters)
HDU	58.9	55.6	3.3
A/F	59.6	58.58	1.02
LF/P	56.8	54.86	1.94
DF	60.2	56.61	3.59
R/L	55.1	52.07	3.03
SEA	59.4	55.39	4.01
H/M	61.2	58.17	3.03

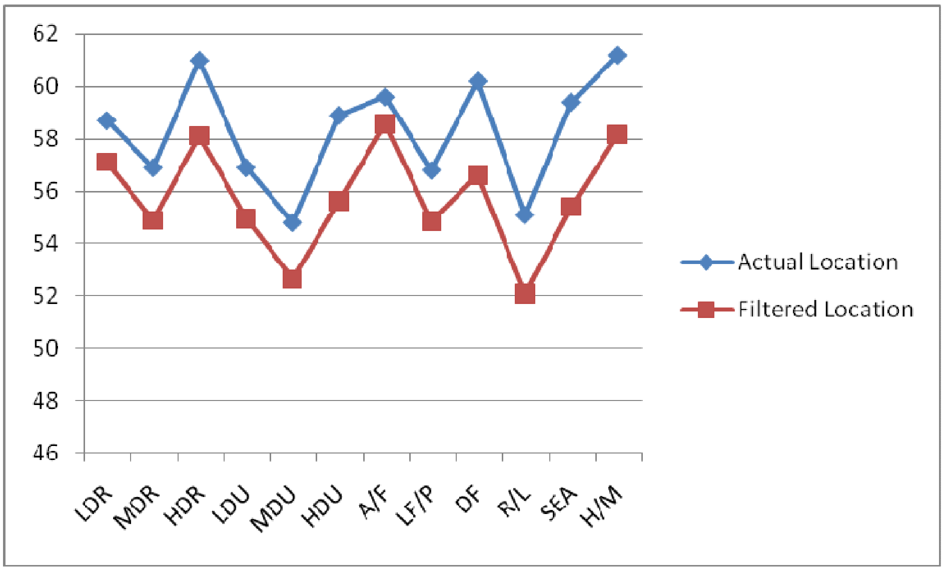


Figure 5.13: Average based filtering Error

In figure 5.13 blue line is representing the actual positions in each terrain whereas red line is representing the filtered location by using average method. Table and figure 5.13 explaining that the error in high attenuated terrain is much higher as compared with attenuated terrains.

5.4 The k-NN Rule for Filtering: Experimental Work and Test Results

Refer back the terrain based Point-to-Point distance calculation in chapter 4 and the estimation of fifteen locations by using triangulation. k-NN rule is applied on the above to calculate best estimated point out of 15 locations. Figure 5.14 is representing the implementation of k-NN bv using triangulation estimated position in Agriculture/ Field (A/F) terrain.

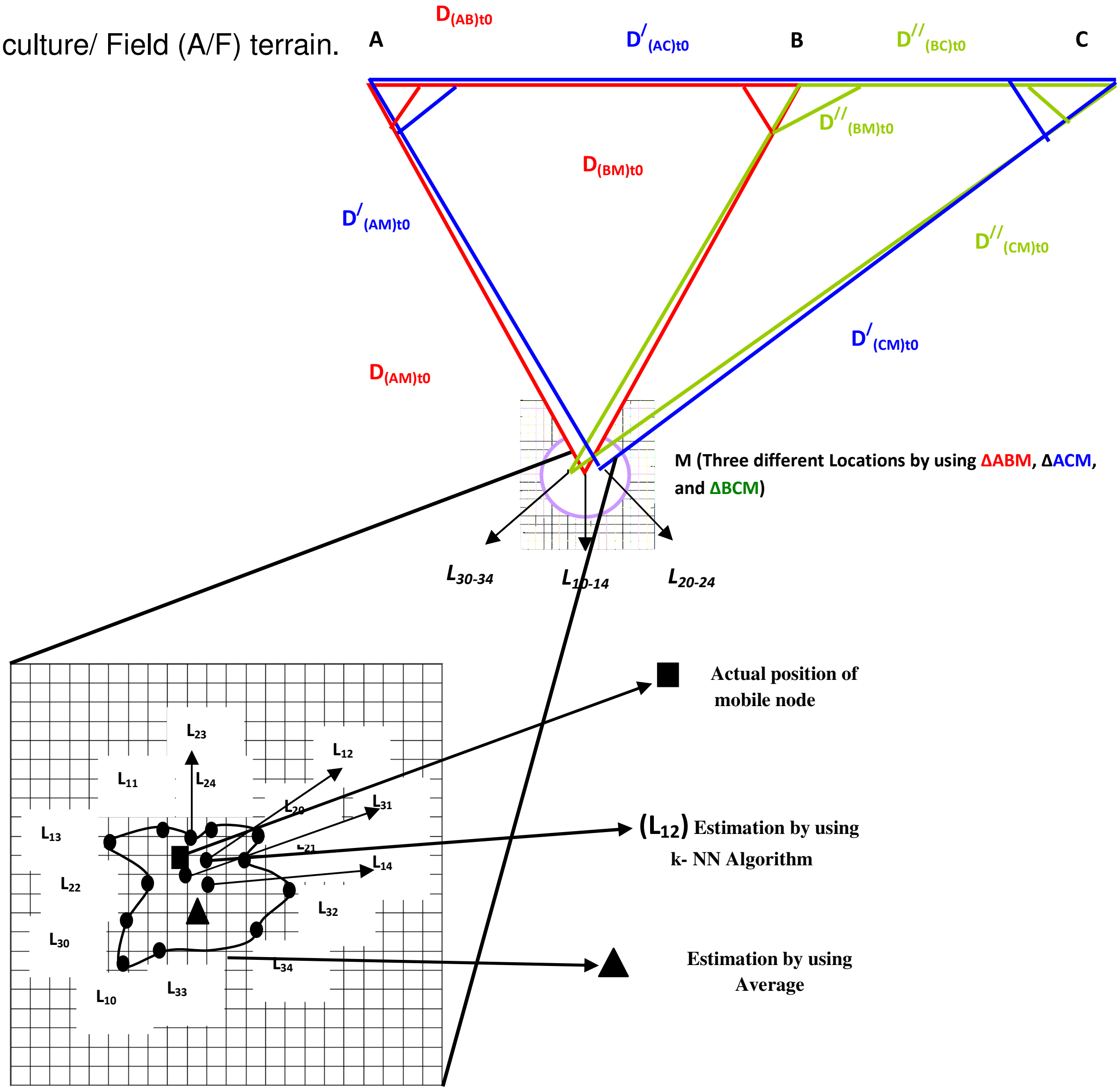


Figure 5.14: k-NN implementation on triangulated estimated positions.

5.4.1 Calculation for k-NN

Table 5.14: k-NN repeated neighbor calculation

Estimated Location	K^{th} nearest Neighbor (where K= 5)	Frequency of Occurrence
L_{10} (t_0-t_4)	L_{33}, L_{11}, L_{32}, L_{14}, L_{31}	2
L_{11}	L_{32}, L_{33}, L_{14}, L_{34}, L_{31}	6
L_{12}	L_{31}, L_{24}, L_{22}, L_{14}, L_{23}	9
L_{13}	L_{30}, L_{32}, L_{12}, L_{14}, L_{31}	3
L_{14}	L_{11}, L_{31}, L_{32}, L_{33}, L_{34}	10
L_{20}	L_{22}, L_{23}, L_{24}, L_{12}, L_{31}	4
L_{21}	L_{23}, L_{24}, L_{34}, L_{31}, L_{20}	4
L_{22}	L_{20}, L_{12}, L_{31}, L_{23}, L_{24}	5
L_{23}	L_{24}, L_{21}, L_{20}, L_{12}, L_{31}	7
L_{24}	L_{31}, L_{12}, L_{22}, L_{23}, L_{21}	7
L_{30}	L_{13}, L_{32}, L_{22}, L_{12}, L_{14}	3
L_{31}	L_{14}, L_{12}, L_{24}, L_{11}, L_{23}	14
L_{32}	L_{13}, L_{30}, L_{31}, L_{14}, L_{12}	6
L_{33}	L_{11}, L_{14}, L_{34}, L_{10}, L_{31}	5
L_{34}	L_{21}, L_{33}, L_{11}, L_{14}, L_{31}	5

Respective frequencies of each location are as under

F_2 (L_{10})

F_3 (L_{13}, L_{30})

F_4 (L_{20}, L_{21})

F_5 (L_{22}, L_{33}, L_{34})

F_6 (L_{11}, L_{32})

F_7 (L_{23}, L_{24})

F_9 (L_{12})

F_{10} (L_{14})

F_{14} (L_{31})

By multiply calculated frequencies with weights we get the following

K Weighted Mean = [(2 x 1) + (3 x 2) + (4 x 2) + (5 x 3) + (6 x 2) + (7 x 2) + (9 x 1) + (10 x 1) + (14 x 1)] /15 + 1

K Weighted Mean = **7**

As the frequency of occurrence of L_{12}, L_{14}, L_{23}, L_{24}, L_{31} are greater than or equal to 7 therefore all five locations are selected as a best possible location.

Table 5.15: k –NN repeated neighbor calculation for single neighbor

Estimated Location	**K^{th} nearest Neighbor (where K= 2)**	**Frequency of Occurrence**
L_{12}	L_{31}, L_{24}	5
L_{14}	L_{31}, L_{12}	2
L_{23}	L_{24}, L_{12}	2
L_{24}	L_{12}, L_{23}	3
L_{31}	L_{14}, L_{12}	3

Frequencies of occurrence are

F_2 (L_{14}, L_{23})

F_3 (L_{24}, L_{31})

F_5 (L_{12})

As KWM = 4 is calculated, therefore locations having frequency of occurrence of 4 and above will be selected. In the table above only **L_{12}** is a calculated location with frequency of occurrence of 5. **By using k-NN algorithm L_{12} is the best estimated position for the Location prediction.** k-NN implantation of other clutters/terrains is as under.

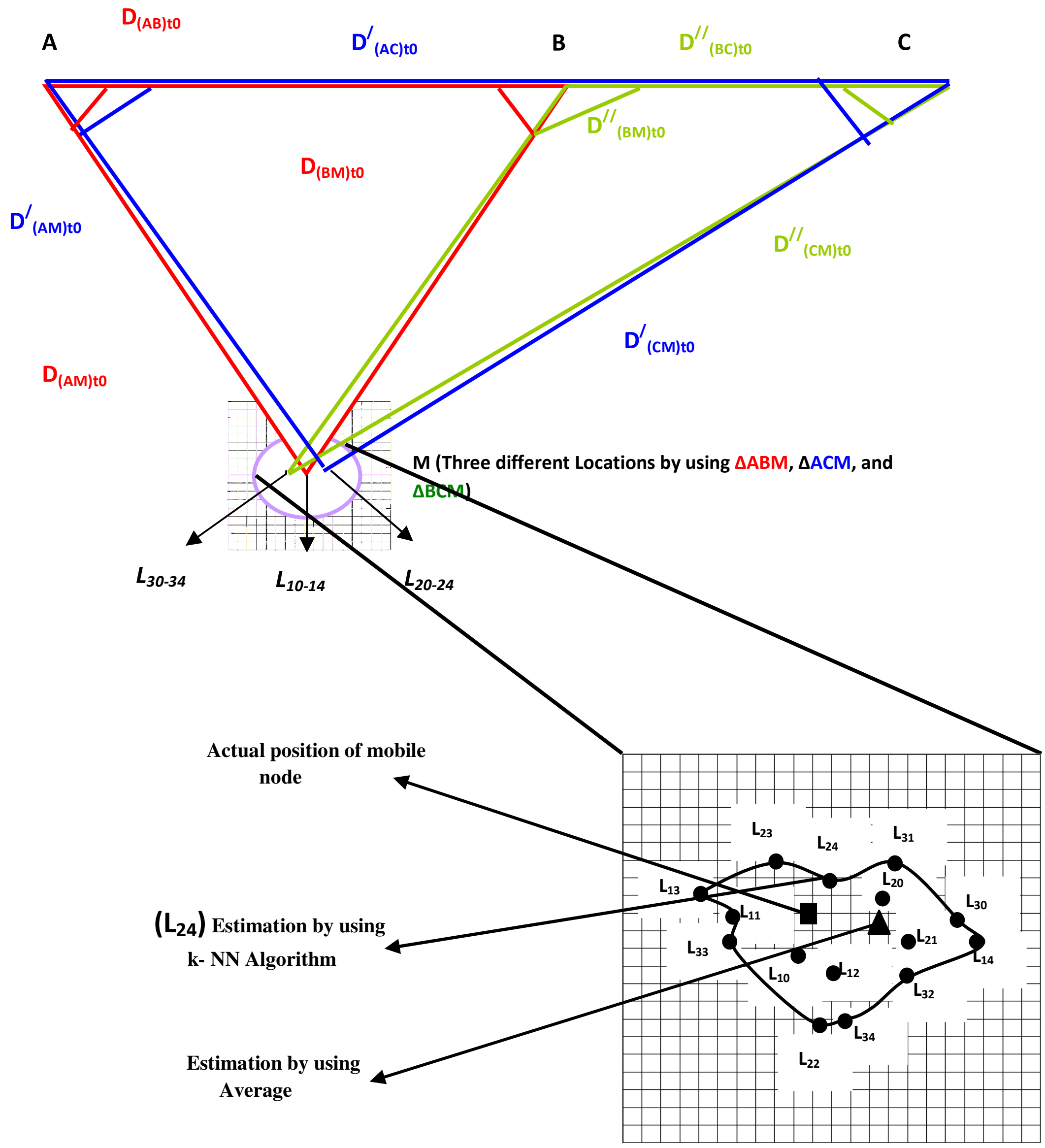


Figure 5.15: Terrain Type: LDR , Selected location: L_{24}

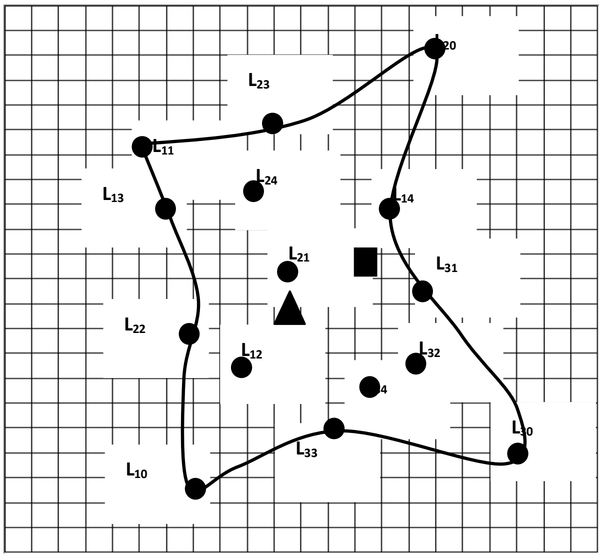


Figure 5.16: Footprint of terrain type MDR, k-NN selected location: L_{31}

Figure 5.16 is a footprint of terrain type of MDR. As MDR is high attenuation terrain as compare to LDR therefore the footprint is relatively bigger which also contain more error. Similarly the footprint of terrain type HDR is bigger than MDR terrain type. The relative error of k-NN location in HDR is approximately 1meter which is more than MDR and LDR errors of triangulation.

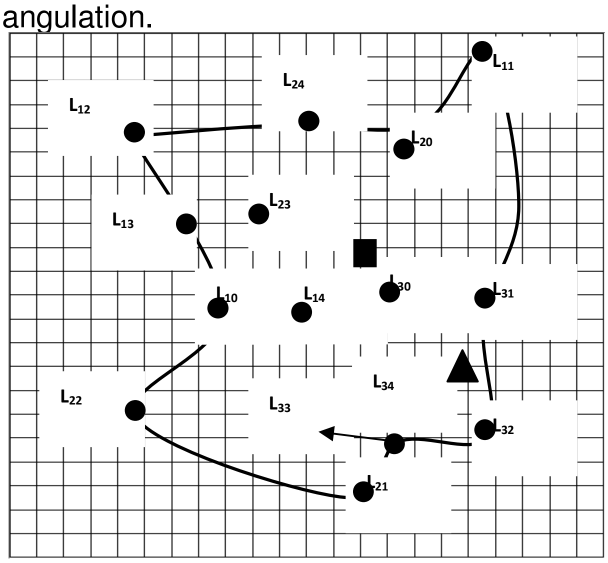


Figure 5.17: Footprint of terrain type HDR , k-NN selected location: L_{14}

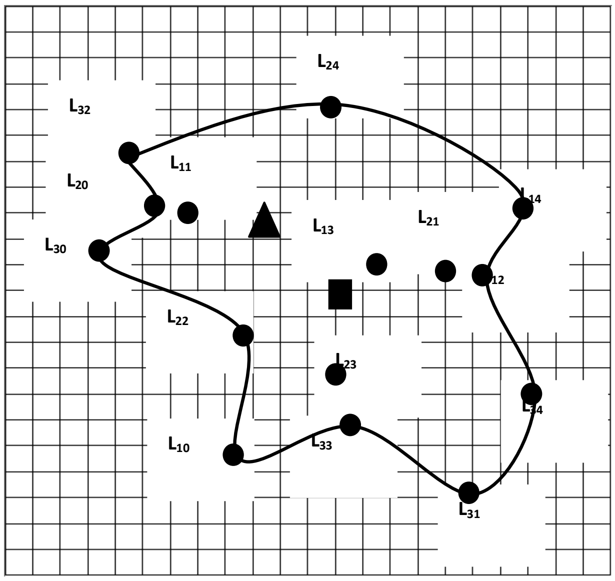


Figure 5.18: Footprint of terrain type LDU , k-NN selected location: L_{13}

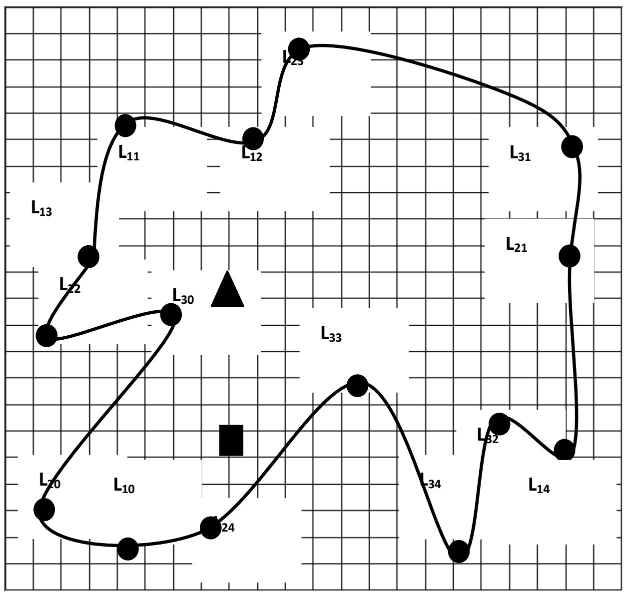


Figure 5.19: Footprint of terrain type MDU , k-NN selected location: L_{24}

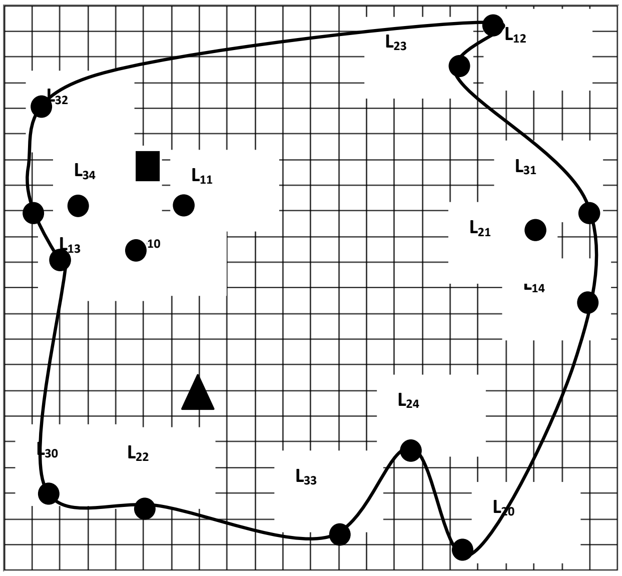


Figure 5.20: Footprint of terrain type HDU , k-NN selected location: L_{10}

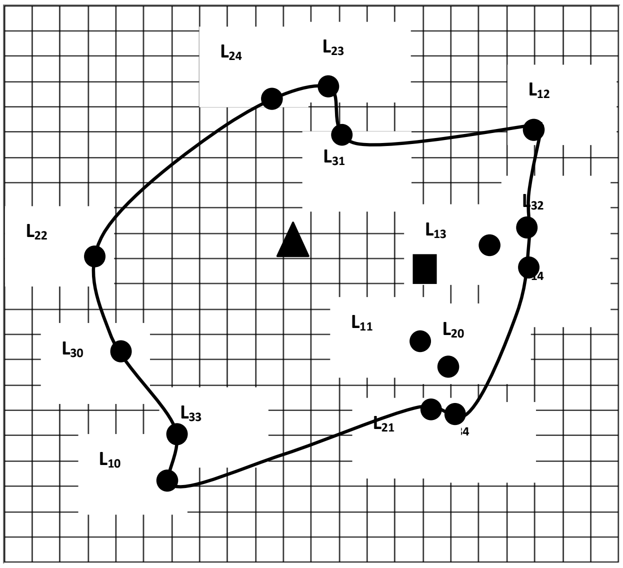


Figure 5.21: Footprint of terrain type LF/P , k-NN selected location: L_{13}

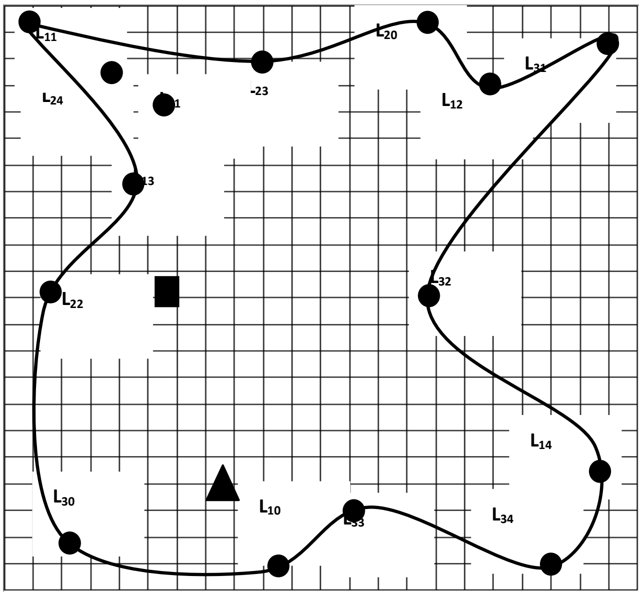


Figure 5.22: Footprint of terrain type DF, k-NN selected location: L_{22}

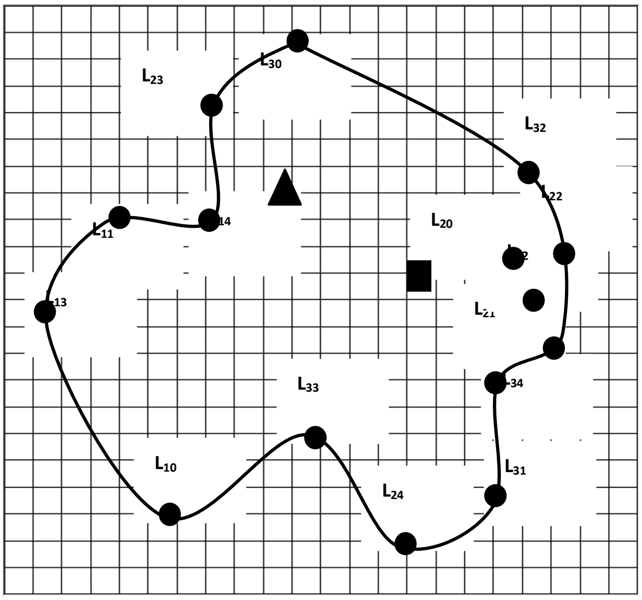


Figure 5.23: Footprint of terrain type R/L, k-NN selected location: L_{12}

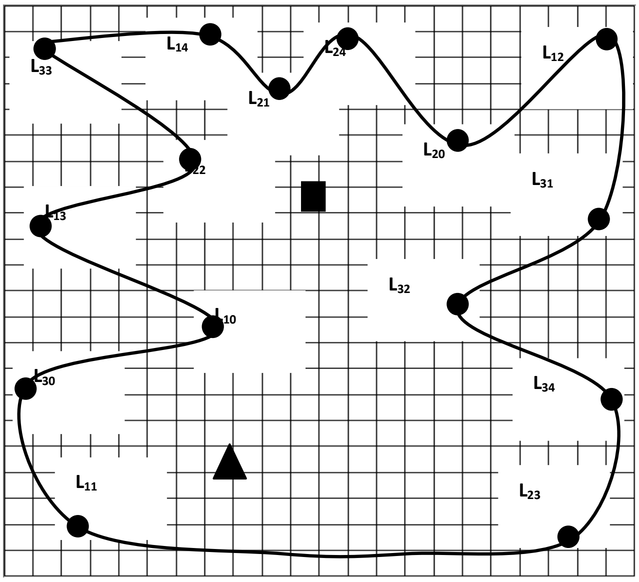


Figure 5.24: Footprint of terrain type SEA, k-NN selected location: L_{21}

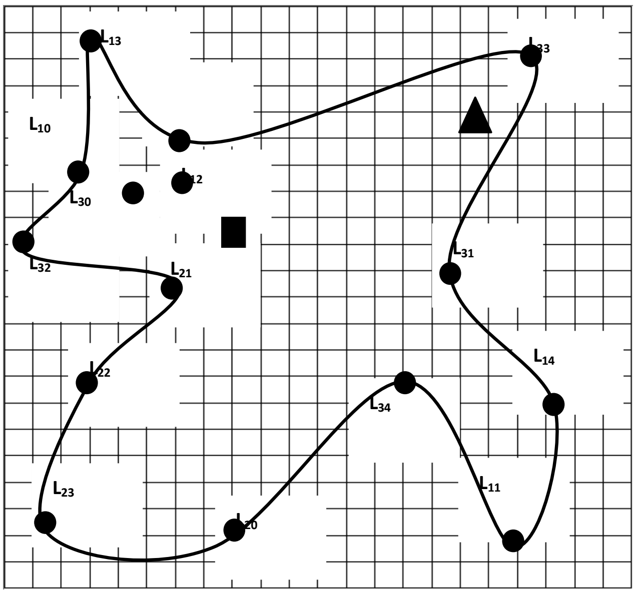


Figure 5.25: Footprint of terrain type H/M, k-NN selected location: L_{30}

From Figure 5.14 to Figure 5.25, triangle is representing filtered location by using average method and square is representing the actual position of a mobile node. k-NN results in all available clutters are mentioned at the bottom with the clutter type. Highly attenuated clutters such as High Dense Urban (HDU), Dense Forest (DF), Sea and Highway/Motorway (H/M) still have more errors because of atmospheric impairments but results are still improved from 217% - 289% from triangulation location estimation.

5.4.2 k-NN Based Filtering Comparison with Average Based Filtering and with Actual Location

Test results show that implementation of k-NN rule produce better results as compared with average based filtering. Table 5.16 depicts the comparison between the actual locations, k-NN based locations and average based locations. Errors of average and k-NN are also shown below.

Table 5.16: k-NN comparison with actual location and filtered location with average

Terrain Type	Actual Location (w.r.t antenna A)	Filtering by using average	Filtering by using k-NN	Average Error (∆e)	KNN Error (Ke)	∆e - Ke
LDR	58.7	57.11	58.1	1.59	0.6	0.99
MDR	56.9	54.88	56.1	2.02	0.8	1.22
HDR	61	58.11	60	2.89	1.0	1.89

Terrain Type	Actual Location (w.r.t antenna A)	Filtering by using average	Filtering by using k-NN	Average Error (∆e)	KNN Error (Ke)	∆e - Ke
LDU	56.9	54.95	56.2	1.95	0.7	1.25
MDU	54.8	52.63	53.8	2.17	1.0	1.17
HDU	58.9	55.6	57.6	3.3	1.3	2
A/F	59.6	58.58	59.2	1.02	0.4	0.62
LF/P	56.8	54.86	56	1.94	0.8	1.14
DF	60.2	56.61	58.9	3.59	1.3	2.29
R/L	55.1	52.07	53.9	3.03	1.2	1.83
Sea	59.4	55.39	57.8	4.01	1.6	2.41
H/M	61.2	58.17	59.9	3.03	1.3	1.73

Although High Dense Urban (HDU), Dense Forest (DF), Sea and Highway/Motorway (H/M) still have more errors (up to 4 m in average based and up to 1.6 m in k-NN based locations) because of atmospheric impairments but in k-NN results are improved from 217% - 289% from average based location filtering. Fig 5.26 is presenting the location difference between the actual, k-NN based and average based locations.

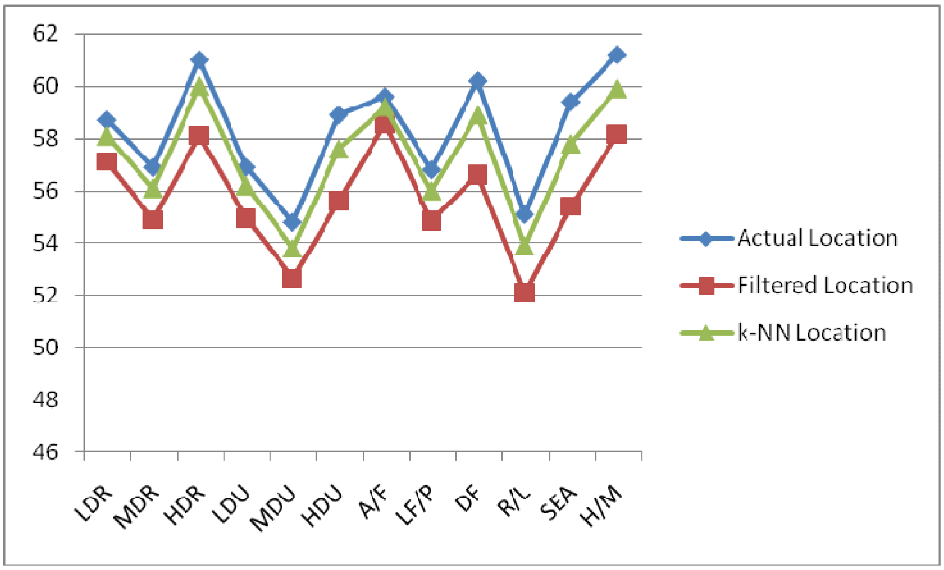


Figure 5.26: Comparison between actual, k-NN based and average based locations

Figure 5.27 is demonstrating the error comparison between the k-NN based locations and average based locations.

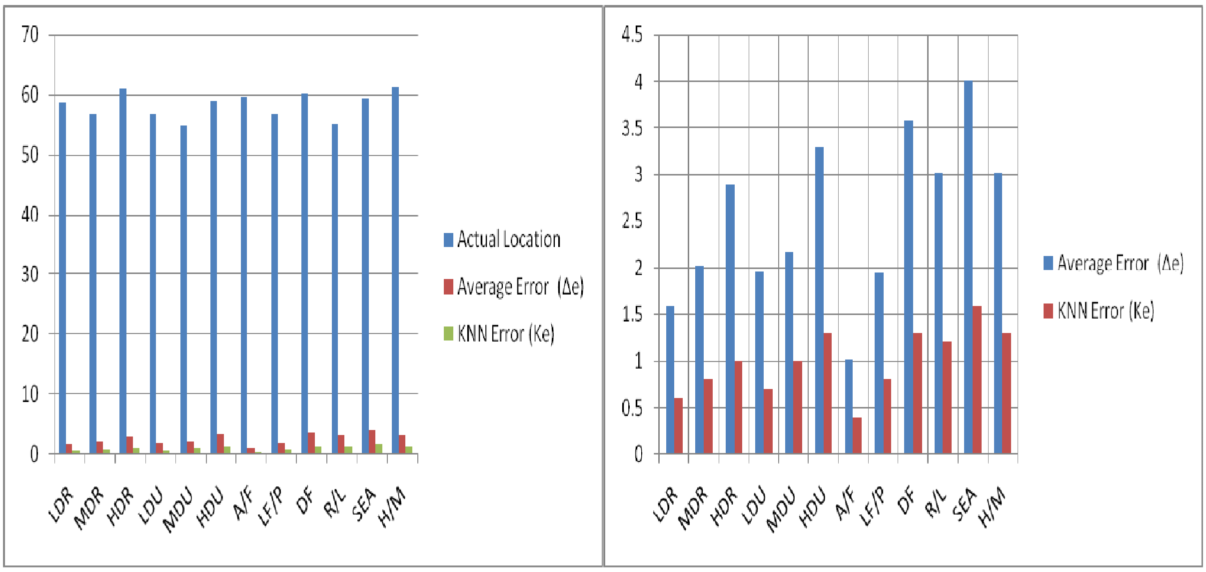


Figure 5.27: Error comparison between k-NN error and average error in each terrain

Scale is representing error in meters against each terrain. Only terrains with high impairments have error of more than one meter. Whereas in low attenuated terrains the error is as low as less than 0.5 meter. Although k-NN produces better result compare with average method, but it still have some errors as recorded in table 5.16. It is also recorded that clutters with high impairments have more error as compare to less attenuated clutters.

5.5 Chapter Summary

In this chapter P2P data points are used which were calculated in previous chapter for location estimation and location filtering. For estimation triangulation is used, as data points were recorded at five different timestamps and three antennas were used to construct three triangles therefore fifteen different locations are estimated after triangulation.

Filtering is firstly done by using average and mean of means method but it is recorded that in open area and especially in highly attenuated terrains average method is unable to produce good results. Secondly k-NN rule is used to filter estimated positions. Results show that the k-NN based filtering improves from 217% to 289% as compared to average method depending on the terrain.

CHAPTER 6

LOCATION PREDICTION AND FUSION

6.1 Chapter Introduction

Based on the test results of estimation and filtering last two steps which are the prediction and the fusion are discussed in this chapter. Prediction is done by calculating Region of Interest (RoI). Estimated fifteen locations are used to calculate RoI. Fusion is done by combining the filtering and prediction's RoI. If the filtered location falls under RoI the confidence level will be higher for that specific location.

6.2 Prediction by using Combine Variance RoI

Combine variance is used to calculate RoI. First the variation of each triangle is recorded, then based on the average location lower and upper limits are calculated which define the boundaries of region of interest. Table 6.1 to 6.12 is calculating RoI of each terrain.

6.2.1 Terrain Type: Low Dense Rural

Table 6.1: Region of Interest calculation in terrain type Low Dense Rural

Terrain Type	**Triangulation Location (w.r.t α, β, γ) in meters**	**$\bar{Y}$ (Mean)**	**σ^2 (Var)**	**Loc M - σ^2**	**Loc M + σ^2**
Actual location of wireless node in LDR with respect from antenna A is 58.70 m					
LDR (ΔABM, t_0)	57	57.38	0.1496	56.8504	57.1496
LDR (ΔABM, t_1)	57.4			57.2504	57.5496
LDR (ΔABM, t_2)	58.1			57.9504	**58.2496**
LDR (ΔABM, t_3)	57.3			57.1504	57.4496
LDR (ΔABM, t_4)	57.1			56.9504	57.2496
LDR (ΔACM, t_0)	56.8	56.94	0.0744	56.7256	56.8744
LDR (ΔACM, t_1)	57.1			57.0256	57.1744
LDR (ΔACM, t_2)	57.3			57.2256	57.3744
LDR (ΔACM, t_3)	57			56.9256	57.0744
LDR (ΔACM, t_4)	56.5			**56.4256**	56.5744
LDR (ΔBCM, t_0)	56.7	57.02	0.1576	56.5424	56.8576
LDR (ΔBCM, t_1)	57.2			57.0424	57.3576
LDR (ΔBCM, t_2)	57.7			57.5424	57.8576
LDR (ΔBCM, t_3)	56.9			56.7424	57.0576
LDR (ΔBCM, t_4)	56.6			56.4424	56.7576
Location M (LDR)		**57.11**			

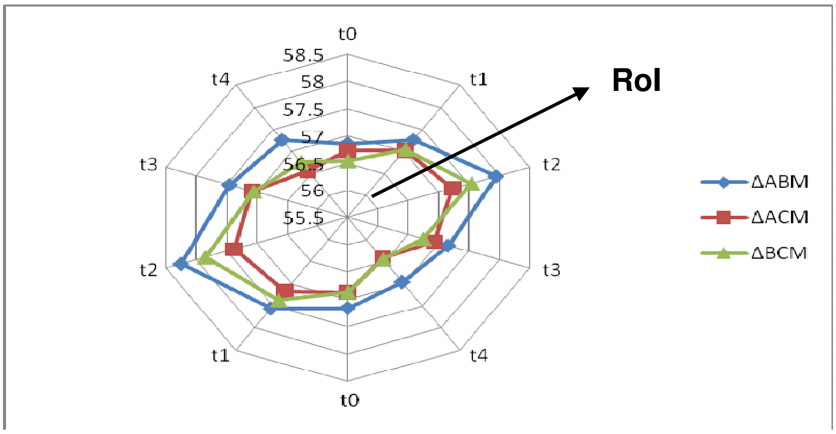


Figure 6.1: RoI in LDR

6.2.2 Terrain Type: Medium Dense Rural

Table 6.2: Region of Interest calculation in terrain type Medium Dense Rural

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in MDR with respect from antenna A is 56.90 m					
MDR (ΔABM, t_0)	54	54.76	0.2664	53.7336	54.2664
MDR (ΔABM, t_1)	54.6			54.3336	54.8664
MDR (ΔABM, t_2)	54.7			54.4336	54.9664
MDR (ΔABM, t_3)	55.6			55.3336	**55.8664**
MDR (ΔABM, t_4)	54.9			54.6336	55.1664
MDR (ΔACM, t_0)	55.4	54.76	0.3544	55.0456	55.7544
MDR (ΔACM, t_1)	53.9			**53.5456**	54.2544
MDR (ΔACM, t_2)	55.2			54.8456	55.5544
MDR (ΔACM, t_3)	55.1			54.7456	55.4544
MDR (ΔACM, t_4)	54.2			53.8456	54.5544
MDR (ΔBCM, t_0)	54.6	55.12	0.1256	54.4744	54.7256
MDR (ΔBCM, t_1)	55.1			54.9744	55.2256
MDR (ΔBCM, t_2)	55.4			55.2744	55.5256
MDR (ΔBCM, t_3)	55.6			55.4744	55.7256
MDR (ΔBCM, t_4)	54.9			54.7744	55.0256
Location M (MDR)		**54.88**			

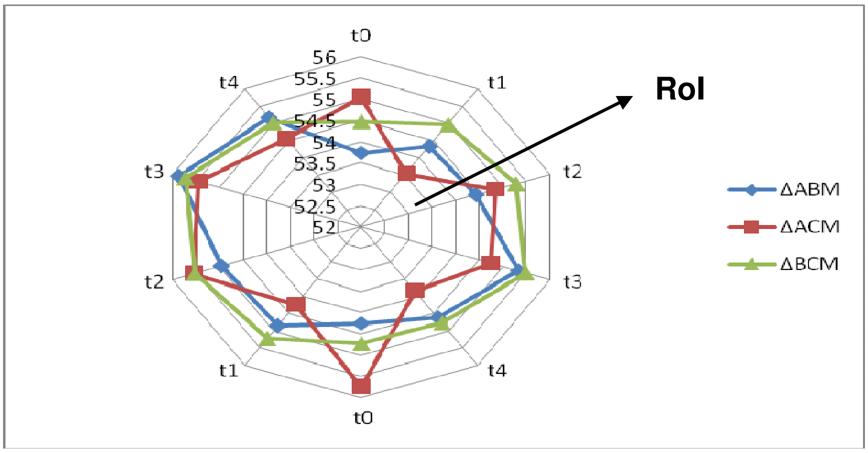


Figure 6.2: RoI in MDR

6.2.3 Terrain Type: High Dense Rural

Table 6.3: Region of interest calculation in terrain type High Dense Rural

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in HDR with respect from antenna A is 61.0 m					
HDR (ΔABM, t_0)	58.2	58.18	0.1456	58.0544	58.3456
HDR (ΔABM, t_1)	57.8			57.6544	57.9456
HDR (ΔABM, t_2)	58.6			58.4544	58.7456
HDR (ΔABM, t_3)	58.6			58.4544	58.7456
HDR (ΔABM, t_4)	57.7			57.5544	57.8456
HDR (ΔACM, t_0)	57.9	58.28	0.1256	57.7744	58.0256
HDR (ΔACM, t_1)	58.6			58.4744	58.7256
HDR (ΔACM, t_2)	58.8			58.6744	**58.9256**
HDR (ΔACM, t_3)	58.0			57.8744	58.1256
HDR (ΔACM, t_4)	58.1			57.9744	58.2256
HDR (ΔBCM, t_0)	57.4	57.84	0.1224	**57.2776**	57.5224
HDR (ΔBCM, t_1)	57.6			57.4776	57.7224
HDR (ΔBCM, t_2)	57.7			57.5776	57.8224
HDR (ΔBCM, t_3)	58.3			58.1776	58.4224
HDR (ΔBCM, t_4)	58.2			58.0776	58.3224
Location M (HDR)		**58.11**			

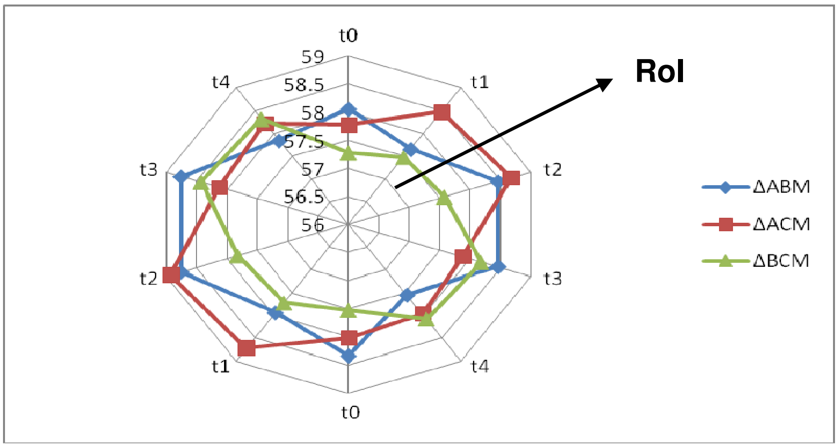


Figure 6.3: RoI in HDR

6.2.4 Terrain Type: Low Dense Urban

Table 6.4: Region of Interest calculation in terrain type Low Dense Urban

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of Mobile node in LDU with respect from antenna A is 56.90 m					
LDU (ΔABM, t_0)	55	55.08	0.4136	54.5864	55.4136
LDU (ΔABM, t_1)	54.6			54.1864	55.0136
LDU (ΔABM, t_2)	55.7			55.2864	56.1136
LDU (ΔABM, t_3)	54.2			53.7864	54.6136
LDU (ΔABM, t_4)	55.9			55.4864	56.3136
LDU (ΔACM, t_0)	54.6	54.72	0.5496	54.0504	55.1496
LDU (ΔACM, t_1)	53.8			**53.2504**	54.3496
LDU (ΔACM, t_2)	55.8			55.2504	**56.3496**
LDU (ΔACM, t_3)	55.3			54.7504	55.8496
LDU (ΔACM, t_4)	54.1			53.5504	54.6496
LDU (ΔBCM, t_0)	55.8	55.06	0.3024	55.4976	56.1024
LDU (ΔBCM, t_1)	54.6			54.2976	54.9024
LDU (ΔBCM, t_2)	55.6			55.2976	55.9024
LDU (ΔBCM, t_3)	54.9			54.5976	55.2024
LDU (ΔBCM, t_4)	54.4			54.0976	54.7024
Location M (LDU)		**54.95**			

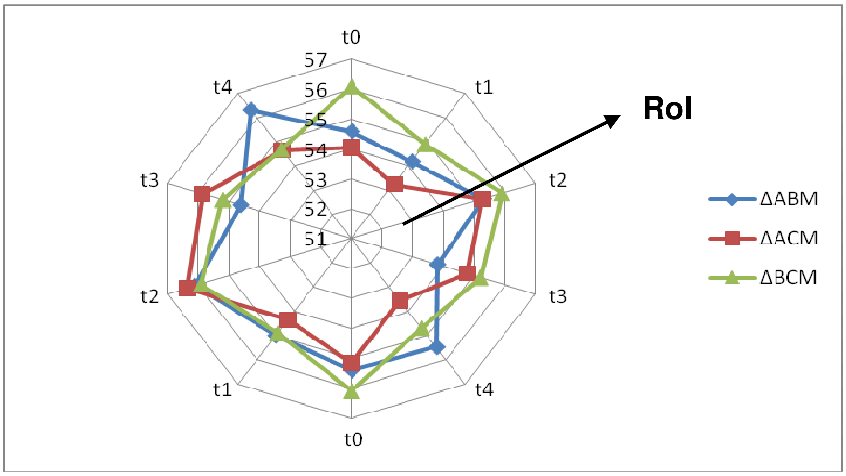


Figure 6.4: RoI in LDU

6.2.5 Terrain Type: Medium Dense Urban

Table 6.5: Region of interest calculation in terrain type Medium Dense Urban

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in MDU with respect from antenna A is 54.80 m					
MDU (ΔABM, t_0)	52.1	52.88	0.2616	51.8384	52.3616
MDU (ΔABM, t_1)	53.2			52.9384	53.4616
MDU (ΔABM, t_2)	52.6			52.3384	52.8616
MDU (ΔABM, t_3)	52.9			52.6384	53.1616
MDU (ΔABM, t_4)	53.6			53.3384	53.8616
MDU (ΔACM, t_0)	52.4	52.46	0.4864	51.9136	52.8864
MDU (ΔACM, t_1)	51.8			51.3136	52.2864
MDU (ΔACM, t_2)	52.8			52.3136	53.2864
MDU (ΔACM, t_3)	53.6			53.1136	54.0864
MDU (ΔACM, t_4)	51.7			51.2136	52.1864
MDU (ΔBCM, t_0)	52.4	52.54	0.6544	51.7456	53.0544
MDU (ΔBCM, t_1)	53.6			52.9456	**54.2544**
MDU (ΔBCM, t_2)	51.2			**50.5456**	51.8544
MDU (ΔBCM, t_3)	52.4			51.7456	53.0544
MDU (ΔBCM, t_4)	53.1			52.4456	53.7544
Location M (MDU)		**52.63**			

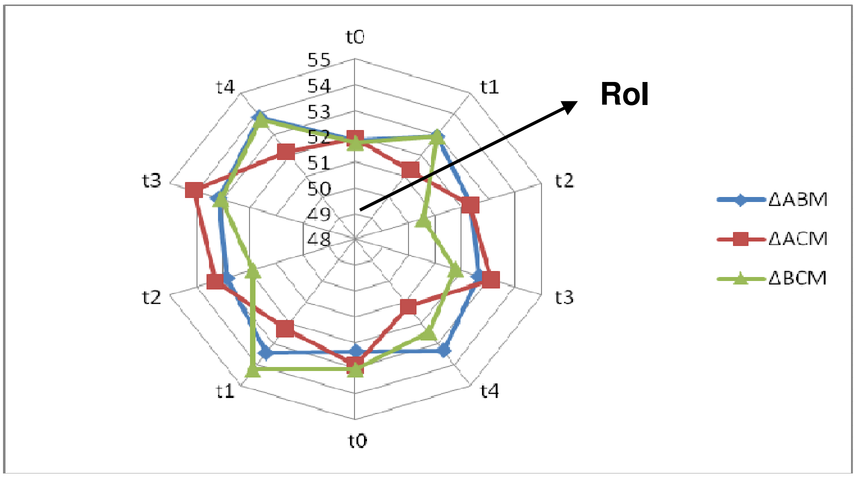


Figure 6.5: RoI in MDU

6.2.6 Terrain Type: High Dense Urban

Table 6.6: Region of Interest calculation in terrain type High Dense Urban

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	$\bar{Y}$ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in HDU with respect from antenna A is 58.9 m					
HDU (ΔABM, t_0)	56.9	55.62	0.5736	56.3264	57.4736
HDU (ΔABM, t_1)	54.9			54.3264	55.4736
HDU (ΔABM, t_2)	55.8			55.2264	56.3736
HDU (ΔABM, t_3)	54.8			54.2264	55.3736
HDU (ΔABM, t_4)	55.7			55.1264	56.2736
HDU (ΔACM, t_0)	54.7	55.32	0.9096	53.7904	55.6096
HDU (ΔACM, t_1)	55.8			54.8904	56.7096
HDU (ΔACM, t_2)	56.8			55.8904	**57.7096**
HDU (ΔACM, t_3)	55.3			54.3904	56.2096
HDU (ΔACM, t_4)	54.0			**53.0904**	54.9096
HDU (ΔBCM, t_0)	55.8	55.86	0.4864	55.3136	56.2864
HDU (ΔBCM, t_1)	56.6			56.1136	57.0864
HDU (ΔBCM, t_2)	54.6			54.1136	55.0864
HDU (ΔBCM, t_3)	55.9			55.4136	56.3864
HDU (ΔBCM, t_4)	56.4			55.9136	56.8864
Location M (HDU)		**55.60**			

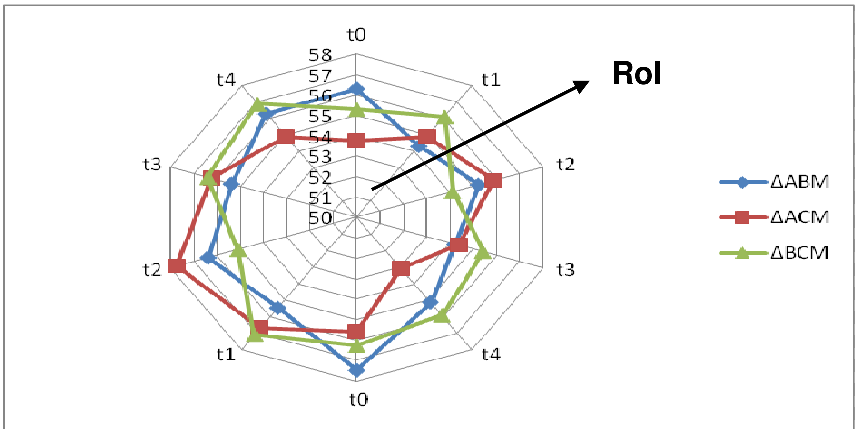


Figure 6.6: RoI in HDU

6.2.7 Terrain Type: Agriculture/Field

Table 6.7: Region of Interest calculation in terrain type Agriculture/Field

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in A/F with respect from antenna A is 59.60 m					
A/F (ΔABM, t_0)	57.4	58.28	0.7336	**56.6664**	58.1336
A/F (ΔABM, t_1)	58.6			57.8664	59.3336
A/F (ΔABM, t_2)	59.8			59.0664	**60.5336**
A/F (ΔABM, t_3)	57.7			56.9664	58.4336
A/F (ΔABM, t_4)	57.9			57.1664	58.6336
A/F (ΔACM, t_0)	58.6	58.56	0.5144	58.0856	59.1144
A/F (ΔACM, t_1)	59.2			58.6856	59.7144
A/F (ΔACM, t_2)	58.4			57.8856	58.9144
A/F (ΔACM, t_3)	57.3			56.7856	57.8144
A/F (ΔACM, t_4)	59.3			58.7856	59.8144
A/F (ΔBCM, t_0)	58.8	58.9	0.3920	58.408	59.192
A/F (ΔBCM, t_1)	59.4			59.008	59.792
A/F (ΔBCM, t_2)	57.8			57.408	58.192
A/F (ΔBCM, t_3)	58.9			58.508	59.292
A/F (ΔBCM, t_4)	59.6			59.208	59.992
Location M (A/F)		**58.58**			

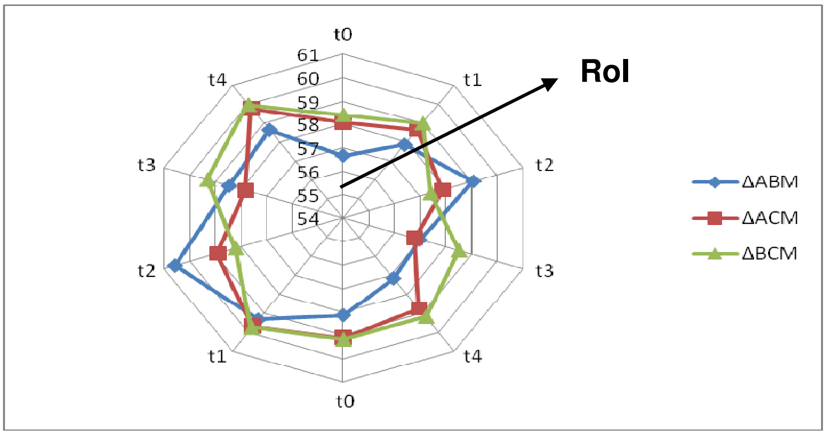


Figure 6.7: RoI in A/F

6.2.8 Terrain Type: Low Forest/ Plantation

Table 6.8: Region of Interest calculation in terrain type Low Forest / Plantation

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in LF/P with respect from antenna A is 56.80 m					
LF/P (ΔABM, t_0)	54.6	55.1	0.2320	54.368	54.832
LF/P (ΔABM, t_1)	55.4			55.168	55.632
LF/P (ΔABM, t_2)	54.8			54.568	55.032
LF/P (ΔABM, t_3)	54.8			54.568	55.032
LF/P (ΔABM, t_4)	55.9			55.668	56.132
LF/P (ΔACM, t_0)	53.7	54.68	0.8216	**52.8784**	54.5216
LF/P (ΔACM, t_1)	55.7			54.8784	56.5216
LF/P (ΔACM, t_2)	55.8			54.9784	**56.6216**
LF/P (ΔACM, t_3)	54.4			53.5784	55.2216
LF/P (ΔACM, t_4)	53.8			52.9784	54.6216
LF/P (ΔBCM, t_0)	55.6	54.8	0.5640	55.036	56.164
LF/P (ΔBCM, t_1)	54.2			53.636	54.764
LF/P (ΔBCM, t_2)	54.7			54.136	55.264
LF/P (ΔBCM, t_3)	55.7			55.136	56.264
LF/P (ΔBCM, t_4)	53.8			53.236	54.364
Location M (LF/P)		**54.86**			

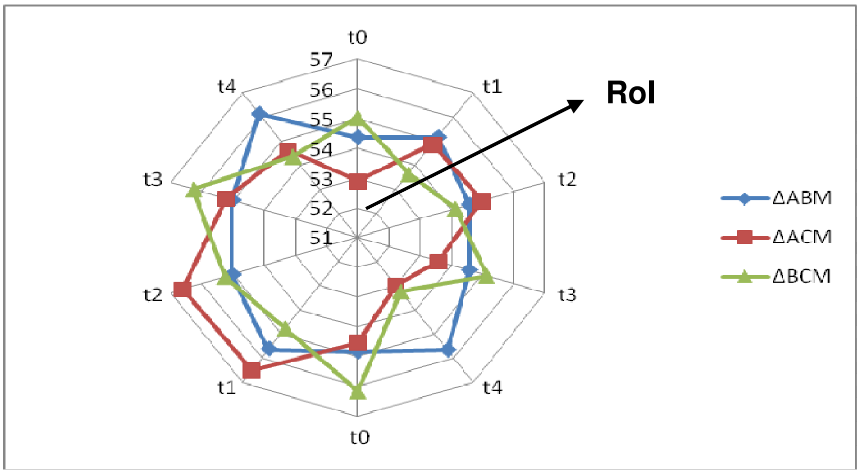


Figure 6.8: RoI in LF/P

6.2.9 Terrain Type: Dense Forest

Table 6.9: Region of Interest calculation in terrain type Dense Forest

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in DF with respect from antenna A is 60.20 m					
DF (ΔABM, t_0)	55.8	56.54	0.5504	55.2496	56.3504
DF (ΔABM, t_1)	56.9			56.3496	57.4504
DF (ΔABM, t_2)	57.6			57.0496	58.1504
DF (ΔABM, t_3)	55.6			55.0496	56.1504
DF (ΔABM, t_4)	56.8			56.2496	57.3504
DF (ΔACM, t_0)	55.6	56.50	0.5320	55.068	56.132
DF (ΔACM, t_1)	55.9			55.368	56.432
DF (ΔACM, t_2)	56.7			56.168	57.232
DF (ΔACM, t_3)	57.7			57.168	58.232
DF (ΔACM, t_4)	56.6			56.068	57.132
DF (ΔBCM, t_0)	55.6	56.80	0.6520	**54.948**	56.252
DF (ΔBCM, t_1)	56.5			55.848	57.152
DF (ΔBCM, t_2)	57.6			56.948	58.252
DF (ΔBCM, t_3)	56.5			55.848	57.152
DF (ΔBCM, t_4)	57.8			57.148	**58.452**
Location M (DF)		**56.61**			

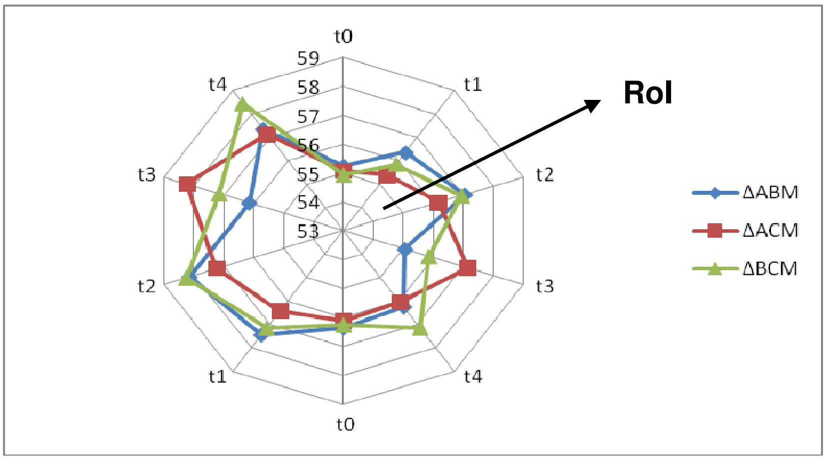


Figure 6.9: RoI in DF

6.2.10 Terrain Type: River/Lake

Table 6.10: Region of Interest calculation in terrain type River/Lake

Terrain Type	**Triangulation Location (w.r.t α, β, γ) in meters**	**$\bar{Y}$ (Mean)**	**σ^2 (Var)**	**Loc M - σ^2**	**Loc M + σ^2**
Actual location of wireless node in R/L with respect from antenna A is 55.10 m					
R/L (ΔABM, t_0)	51.2	51.88	1.2616	49.9384	52.4616
R/L (ΔABM, t_1)	50.3			49.0384	51.5616
R/L (ΔABM, t_2)	53.6			52.3384	54.8616
R/L (ΔABM, t_3)	51.8			50.5384	53.0616
R/L (ΔABM, t_4)	52.5			51.2384	53.7616
R/L (ΔACM, t_0)	53.5	52.18	1.4056	52.0944	54.9056
R/L (ΔACM, t_1)	52.3			50.8944	53.7056
R/L (ΔACM, t_2)	53.4			51.9944	54.8056
R/L (ΔACM, t_3)	51.2			49.7944	52.6056
R/L (ΔACM, t_4)	50.5			49.0944	51.9056
R/L (ΔBCM, t_0)	52.6	52.16	1.5304	51.0696	54.1304
R/L (ΔBCM, t_1)	52.9			51.3696	54.4304
R/L (ΔBCM, t_2)	53.8			52.2696	**55.3304**
R/L (ΔBCM, t_3)	51.1			49.5696	52.6304
R/L (ΔBCM, t_4)	50.4			**48.8696**	51.9304
Location M (R/L)		**52.07**			

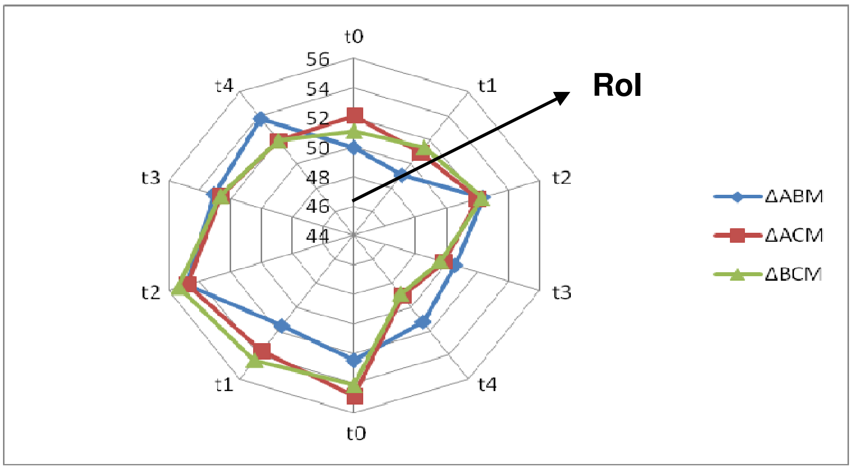


Figure 6.10: RoI in R/L

6.2.11 Terrain Type: Sea

Table 6.11: Region of Interest calculation in terrain type Sea

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in Sea with respect from antenna A is 59.40 m					
Sea (ΔABM, t_0)	55.6	56.0	0.7960	54.804	56.396
Sea (ΔABM, t_1)	55.4			54.604	56.196
Sea (ΔABM, t_2)	54.9			54.104	55.696
Sea (ΔABM, t_3)	56.9			56.104	57.696
Sea (ΔABM, t_4)	57.2			56.404	**57.996**
Sea (ΔACM, t_0)	54.2	54.94	1.0624	53.1376	55.2624
Sea (ΔACM, t_1)	55.8			54.7376	56.8624
Sea (ΔACM, t_2)	56.5			55.4376	57.5624
Sea (ΔACM, t_3)	54.4			53.3376	55.4624
Sea (ΔACM, t_4)	53.8			52.7376	54.8624
Sea (ΔBCM, t_0)	55.7	55.22	1.2216	54.4784	56.9216
Sea (ΔBCM, t_1)	54.2			52.9784	55.4216
Sea (ΔBCM, t_2)	56.7			55.4784	57.9216
Sea (ΔBCM, t_3)	55.8			54.5784	57.0216
Sea (ΔBCM, t_4)	53.7			**52.4784**	54.9216
Location M (Sea)		**55.39**			

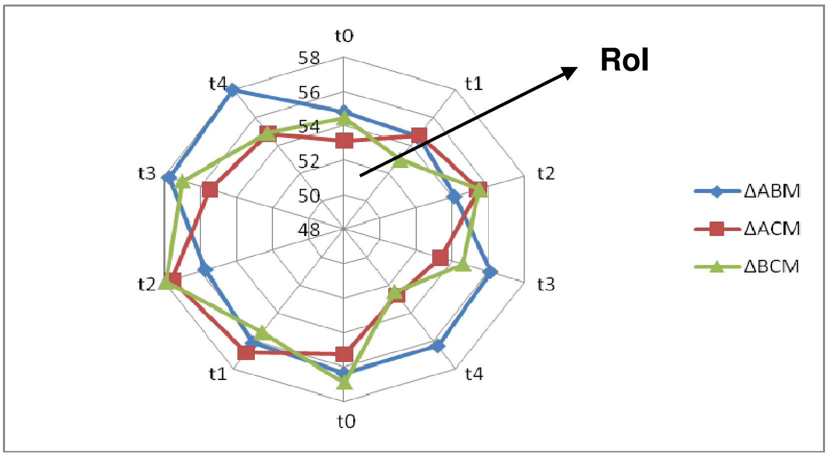


Figure 6.11: RoI in Sea

6.2.12 Terrain Type: Highway/Motorway

Table 6.12: Region of Interest calculation in terrain type Highway/Motorway

Terrain Type	Triangulation Location (w.r.t α, β, γ) in meters	Ȳ (Mean)	σ^2 (Var)	Loc M - σ^2	Loc M + σ^2
Actual location of wireless node in H/M with respect from antenna A is 61.20 m					
H/M (ΔABM, t_0)	57.6	58.26	0.9584	56.6416	58.5584
H/M (ΔABM, t_1)	58.4			57.4416	59.3584
H/M (ΔABM, t_2)	59.8			58.8416	60.7584
H/M (ΔABM, t_3)	56.9			55.9416	57.8584
H/M (ΔABM, t_4)	58.6			57.6416	59.5584
H/M (ΔACM, t_0)	57.8	58.02	1.2736	56.5264	59.0736
H/M (ΔACM, t_1)	58.7			57.4264	59.9736
H/M (ΔACM, t_2)	59.8			58.5264	**61.0736**
H/M (ΔACM, t_3)	56.6			**55.3264**	57.8736
H/M (ΔACM, t_4)	57.2			55.9264	58.4736
H/M (ΔBCM, t_0)	58.6	58.24	0.8104	57.7896	59.4104
H/M (ΔBCM, t_1)	59.4			58.5896	60.2104
H/M (ΔBCM, t_2)	58.7			57.8896	59.5104
H/M (ΔBCM, t_3)	57.7			56.8896	58.5104
H/M (ΔBCM, t_4)	56.8			55.9896	57.6104
Location M (H/M)		**58.17**			

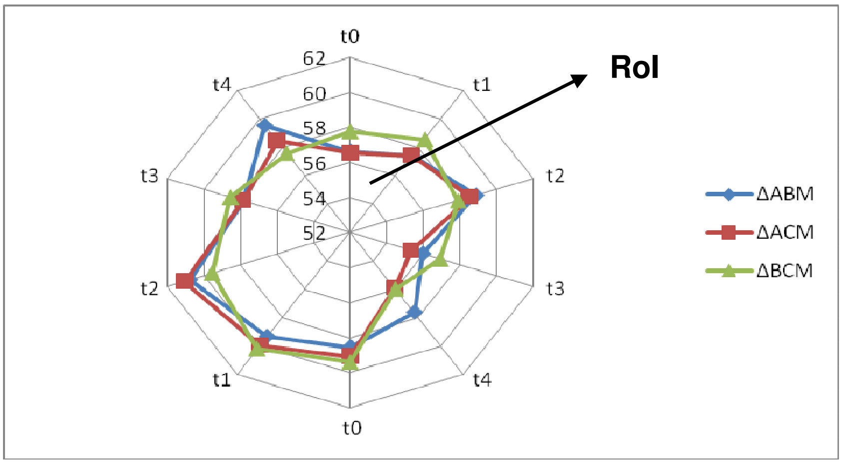


Figure 6.12: RoI in H/M

6.3 Fusion

In this section Predicted and Corrected Location Determination Algorithm (PCLDA) is derived by fusing the results of k-NN based filtering with the prediction's RoI. If the filtered location fall inside the region of interest then the filtered value will be selected and the recursive process will continue to correct the estimated position, otherwise the transfer will go to select the terrain behavior in order to determine the accurate location.

Refer back to tables 6.1 to 6.12, lower and upper limits are calculated for region of interest for each terrain as shown in figure 6.1 to 6.12. In Dense Forest (DF), High Dense Rural (HDR) and Medium Dense Rural (MDR) the filtered location is **not** falling in the RoI, therefore it will reinitiate the process. All other terrains filtered location is falling in the RoI, therefore it will continue the recursive process to correct the location if possible. Table 6.13 is explaining the RoI's lower and upper limits and the filtered values by using k-NN rule.

Table 6.13: Region of Interest and k-NN results fusion

Terrain Type	RoI Lower Limit	RoI Upper Limit	k-NN Calculated Values
LDR	56.4256	58.2496	58.1
MDR	***53.5456***	***55.8664***	***56.1***
HDR	***57.2776***	***58.9256***	***60***
LDU	53.2504	56.3496	56.2
MDU	50.5456	54.2544	53.8

HDU	53.0904	57.7096	57.6
A/F	56.6664	60.5336	59.2
LF/P	52.8784	56.6216	56
DF	***54.948***	***58.452***	***58.9***
R/L	48.8696	55.3304	53.9
Sea	52.4784	57.996	57.8
H/M	55.3264	61.0736	59.9

Refer back to PCLDA (figure 3.8), in DF, MDR and HDR the control will transfer to step two (2) as the filtered location is falling outside the region of interest. In all other terrains the algorithm will continue to correct the filtered location. After second phase calculation if the filtered location is the same and also falling in the RoI then the loop will break and will confirm the location as most predicted location.

6.4 Chapter Summary

In this chapter region of interest is predicted by using the combine variance approach. RoI lower and upper limits are calculated in each terrain. Results of k-NN based filtering are further fused with the prediction's RoI. The RoI helps to increase the level of confidence of the filtered location if falling inside the RoI. Finally correction procedure is applied on the fused value if in the second phase the same value comes and also falling in the RoI the algorithm loop will break and the filtered location will be selected as the most predicted location of wireless node.

CONCLUSION

AND

FUTURE DIRECTIONS

Conclusion

The progress in the development and advancement in wireless communication devices leads towards the increase in their usage rapidly. Because of the wireless devices and technologies popularity, wireless domain is becoming one of the highly focused research area for researchers. In wireless technology location estimation of wireless nodes is a very popular research area for the past few years. The research in location estimation is not limited to satellite communication, but also in WLAN, MANET, WSN and Cellular communication. Researchers have used different location estimation techniques, like satellite based, geometrical, statistical and mapping techniques. In order to achieve accuracy, researchers have combined two or more techniques. However the terrain based location estimation is an area which is not considered by researchers extensively. Due to radio waves behave differently in different atmosphere, the calculation of few parameters is not sufficient to achieve accuracy in different terrains especially when it is totally based on RSS which is carrying impairments.

This research work is on the **calculation of precise outdoor location determination by considering terrains/clutters errors**. Signal to Noise ratio plays a vital role in the distortion of transmitted signal which is a key player in location determination. We categorized terrains into thirteen different categories, terrain categorization is based on the SNR based recorded results. A WiFi based prototype is used to record the data points in all differet terrains. Linear Interpolation is further used to calculate random distance with known signal strength.

We focus in the geometrical and statistical way to localize the wireless node in open environment. The idea was to use two step positioning approach for the localization. Therefore, in step one we gather the data and in step two we use geometric and statistical approaches to localize the wireless node. To deal with the terrain errors after data points collection we constract the clutter based enhance error rate table (CERT) which helps to minimize the point-to-point distance error as showed in [93, 94].

After point-to-point data collection we divide the localization in for phases which are **estimation, filtering, prediction and fusion**. For estimation we use triangulation method which provide us fifteen different location of wireless node in each terrains. For filtering we use average method first which is also used by other researchers and then we have used k-nearest neighbor rule. Results show that k-NN provide better acccuracy compared with average method as shown in [96]. We use combine variance approach to calculate region of interest (RoI) for the prediction of estimated location. Finally we fuse results of k-NN with prediction's RoI to calculate the location of wireless node. Based on the above four steps a predicted and corrected location determination algorithm is proposed which follows the kalman filtering **prediction and correction approach**. If the fuse result falls under the RoI then the algorithm will apply correction measurements to repeat the scenario, otherwise it will start from the step one again.

Scientific and Technological Contributions

Our main scientific and technological contributions in the localization of wireless nodes are:

1. **Terrain/Clutter based Localization**. We categorize terrains based on the recorded data points and SNR. Results show that terrains categorization help to improve accuracy.
2. **Clutter Based Enhance Error Rate Table (The CERT)**. Based on the collected data points, Error Rate Table (ERT) [93] and its advanced form which is Clutter Based Enhance Error Rate Table (CERT) [94] are produced which helps to minimize the terrain based error.
3. **k-nearest neighbor for accuracy**. We use k-NN for filtering which helps to minimize average based filtering results.
4. **Region of Interest (RoI)**. RoI is calculated by using combine variance approach. If the k-NN filtered value fall under the RoI the location will be selected. RoI helps either to increase the level of confidence on the selected location or discart it.

Limitation

In this research we focused on the terrain internal effects only. External effects such as humidity, bright sunlight, heavy rain, multipath distortion are not been considered in this research. Furthermore the overlapping of two or more terrains may produce varing results.

Future Directions

In this research we use geometrical and statistical tools for the minimization of errors in the open area. Artifical Intelligence based techniques may also be used for filtering and prediction of estimated location. As AI based techniques are self learning therefore they may help to minimize error.

Furthermore as mentioned in limitations, external effects considerations may play a vital role for the accuracy in location determination. Study of external effects SNR may also help to get the accurate position.

The overlapping area of terrains increase SNR which introduce distortion and results in an inaccurate prediction. Overlapping terrains consideration may help researchers to pinpoint location of wireless node.

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APPENDIX A: MATHEMATICAL AND STATISTICAL FORMULAS/THEOREMS

A 1: Trilateration

$$SS_{RX} = P_{TX} - 10\ \alpha \log(d) + X\ (db)$$

Where

SS_{RX} is Signal Strength at receiving node

P_{TX} is Transmitted Power

d is distance of receiver from sender

α is Angle of Arrived Signal

X is shifted point at t_1

A 2: Triangulation

Angle calculation of three given sides

$$\text{Cos}\alpha = (b^2 + c^2 - a^2) / 2bc$$

$$\text{Cos}\beta = (a^2 + c^2 - b^2) / 2ac$$

$$\text{Cos}\gamma = (a^2 + b^2 - c^2) / 2abc$$

Where

α, β and γ are angles of arrival

a, b and c are three sides of triangle

A3: Three Distances Known

Seismologists find the epicenter of Earthquakes by a third method of triangulation (actually trilateration). Earthquakes send out two kinds of shockwaves that travel at different speeds. By measuring the time delay between the first shockwave and the second shockwave, they can determine how far away the Earthquake occurred.

Just knowing the distance defines a circle around the station where the measurement took place. The Earthquake could have taken place anywhere along the perimeter of this circle. If two stations in different locations take measurements, it narrows the possible locations down to two -- the points of intersection where the two circles overlap. A third measurement at another station will pinpoint which of the two points is the true epicenter.

Extended to the three-dimensional case, this is how the Global Positioning System works. Every GPS satellite has a high-precision atomic clock in it. By measuring the speed-of-light delay of the transmissions between the GPS and your hand-held receiver (roughly 50 milliseconds), the satellite calculates how far away you are from it. This defines a sphere around the satellite, which is in a known position in orbit around the Earth. The intersection of two spheres is a circle, three narrows it down to two points, and four pinpoints it to a single point in three-dimensional space. Therefore, at least four GPS satellites are necessary to find your location. In practice, one of the two points defined by three satellites is above the satellite orbit, and the GPS system disregards it.

We will only explain the two-dimensional case here, requiring three distance measurements. Given the coordinates (x,y) of the three stations and the distances (r) from the stations to the location you are looking for, you can easily find the equations of the circles defined. For each station:

$$(x-x_n)^2 + (y-y_n)^2 = r_n^2$$

If you know how to solve systems of simultaneous, non-linear equations, more power to you. Just solve the three simultaneous circle equations and get your answer. The rest of us will need a simpler method. If you take two of the three equations for the circles and subtract one from the other, the result will be the equation of the line passing through the two points of intersection of the two circles. The big advantage being that the result is therefore a linear equation, which is much easier to deal with.

Next, subtract any other two of the three circle equations to get a second line equation. The intersection of these two lines is the location you are looking for. Both line equations will pass through two points of intersection between two circles, and one of these points is the point you are looking for. This is where they will cross.

Example: Seismology research station A is located at mile marker (100,100), B at (160,120), and C at (70,150). Analysis of the S and P shockwaves indicates that a particular Earthquake was 50.00 miles from station A, 36.06 miles from station B, and 60.83 miles from station C. Locate the epicenter of the Earthquake.

First find the equations for the three circles, using the distances from the epicenter as the radii.

$$A: (x-100)^2 + (y-100)^2 = 50.00^2$$

$$B: (x-160)^2 + (y-120)^2 = 36.06^2$$

$$C: (x-70)^2 + (y-150)^2 = 60.83^2$$

These équations expand to:

$$A: x^2 - 200x + 10000 + y^2 - 200y + 10000 = 2500$$

$$B: x^2 - 320x + 25600 + y^2 - 240y + 14400 = 1300$$

$$C: x^2 - 140x + 4900 + y^2 - 300y + 22500 = 3700$$

Now subtract two pairs of equations. There are three unique combinations but you only need two. Notice that the x^2 and y^2 terms cancel out, leaving us with linear equations.

$$A - B: 120x - 15600 + 40y - 4400 = 1200 \Rightarrow y = -3x + 530$$

$$B - C: -180x + 20700 + 60y - 8100 = -2400 \Rightarrow y = 3x - 250$$

Finally, find the intersection point between the two linear equations we found. This is our answer.

$$A - B = B - C$$

$$-3x + 530 = 3x - 250$$

$$780 = 6x$$

$$130 = x$$

$$y = 3(130) - 250$$

$$y = 140$$

The epicenter of the Earthquake is (130,140)

A4: Sine and Cosine

This relationship is expressed by the two most fundamental equations of trigonometry:

$$x = r \times \cos\theta;\ y = r \times \sin\theta$$

Or, equivalently:

$$\cos\theta = x/r; \quad \sin\theta = y/r$$

Sin (sine) is the ratio of the vertical side (the side opposite the corner we're looking at) to the hypotenuse. Cos (cosine) is likewise the ratio of the horizontal side (the side adjacent to that corner) to the hypotenuse. Sine and cosine are functions, which is to say that they take one number (an angle in this case, usually expressed in degrees or radians) and spit out another. For certain values of θ, it is easy to figure out what the sine and cosine values are going to be just by thinking about what the angle corresponds to on the circle; the simplest cases are for $\theta = 0°$, which is a line pointing right, giving $\cos\theta = 1$ and sine $\theta = 0$; a line pointing straight up (ie. $\theta = 90°$), which gives us $\cos\theta = 0$ and sine $\theta = 1$, and so on. At 45° the opposite and adjacent sides are the same length, so from Pythagoras' Theorem ($r^2=x^2 + y^2$) they must each be $(\sqrt{2})/2$. For values in between the sine and cosine vary in a smooth curve, so that a plot of sin *x* against *x* is your basic wavy line.

A5: Tangent

The third basic trigonometric function is called the tangent (tan for short), and it is defined as the ratio of the opposite and adjacent sides - that is:

$$\tan \theta = y/x = \sin \theta / \cos \theta$$

So, the three main trig functions express the ratios of the sides of triangles like this:

sin θ = opposite / hypotenuse

cos θ = adjacent / hypotenuse

tan θ = opposite / adjacent

A 6: Location Estimation in Global Positioning System

Localization in GPS is based on TOA and TDOA. Both parameters are associated with the following formula.

Distance = Time * Velocity

A 7: Linear Interpolation

$$P(x) = \sum_{k} \left(\prod_{j \neq k} \frac{x - x_j}{x_k - x_j} \right)$$

A 8: Interpolated Error

Error calculation in distance calculated by using linear interpolation

$$e = \text{Interpolated distance} - \text{actual distance}$$

Where

e is error

Interpolated distance is distance calculated by using linear interpolation

Actual distance is distance calculated by using ASS and RSS calculation

A 9: Calculation of faces of triangle by using RSS and ASS

$$D_{(AB)t0} = (ASS_{(A)t0+}ASS_{(B)t0}) / 2 - (RSS_{(A)t0} + RSS_{(B)t0}) / 2$$

$$D_{(AM)t0} = ASS_{(A)t0} - RSS_{(M)t0}$$

$$D_{(BM)t0} = ASS_{(B)t0} - RSS_{(M)t0}$$

Where

$D_{(AB)}$ is distance between point A and B

$D_{(AM)}$ is distance between point A and M

$D_{(BM)}$ is distance between point B and M

A 10: Averaging

$$Loc\ M_{tk} = [Loc\ M_{(\Delta ABM)tk} + Loc\ M_{(\Delta ACM)tk} + Loc\ M_{(\Delta BCM)tk}] / 3$$

Where

k = 0, 1… n

Loc M is the location of wireless node

Mean of means

Loc M = [Loc M_{tj} + Loc M_{tj+1} + Loc M_{tj+2} + Loc M_{tj+3} **…** + Loc M_{tj+m}] / m

Where

k= 0 & m = 1, 2…n

A 11: Variance

$$\sigma^2 = \frac{\sum (X - \overline{X})^2}{N}$$

$\sigma^2_{(Loc\ M)\ tk} = \Sigma\ (L_{n(tk)} - Loc\ M_{tk})^2\ /\ N$

Where

k = 1,2…m

n, = 1, 2, 3,4 and N= 4

Combine Variance

$1/\sigma^2 = 1/\sigma^{2(LocM)\ t0} + 1/\sigma^{2(Loc\ M)\ t1} + 1/\sigma^{2(Loc\ M)\ t2} + 1/\sigma^{2(Loc\ M)\ t3} + 1/\sigma^{2(Loc\ M)\ t4}$

A 12: k-Nearest Neighbor Algorithm

K-weighted mean = [∑fw/∑f] + 1

Where

w is weight and f is frequency of occurrence

A 13: Angle Calculation by scaling down the recorded data

We scale down the recorded and calculated real time data points to calculate angles. Scaling help to avoid dealing trignomatric formulas of sine, cosine and tangent. Five meters are scale at 1 centimeter.

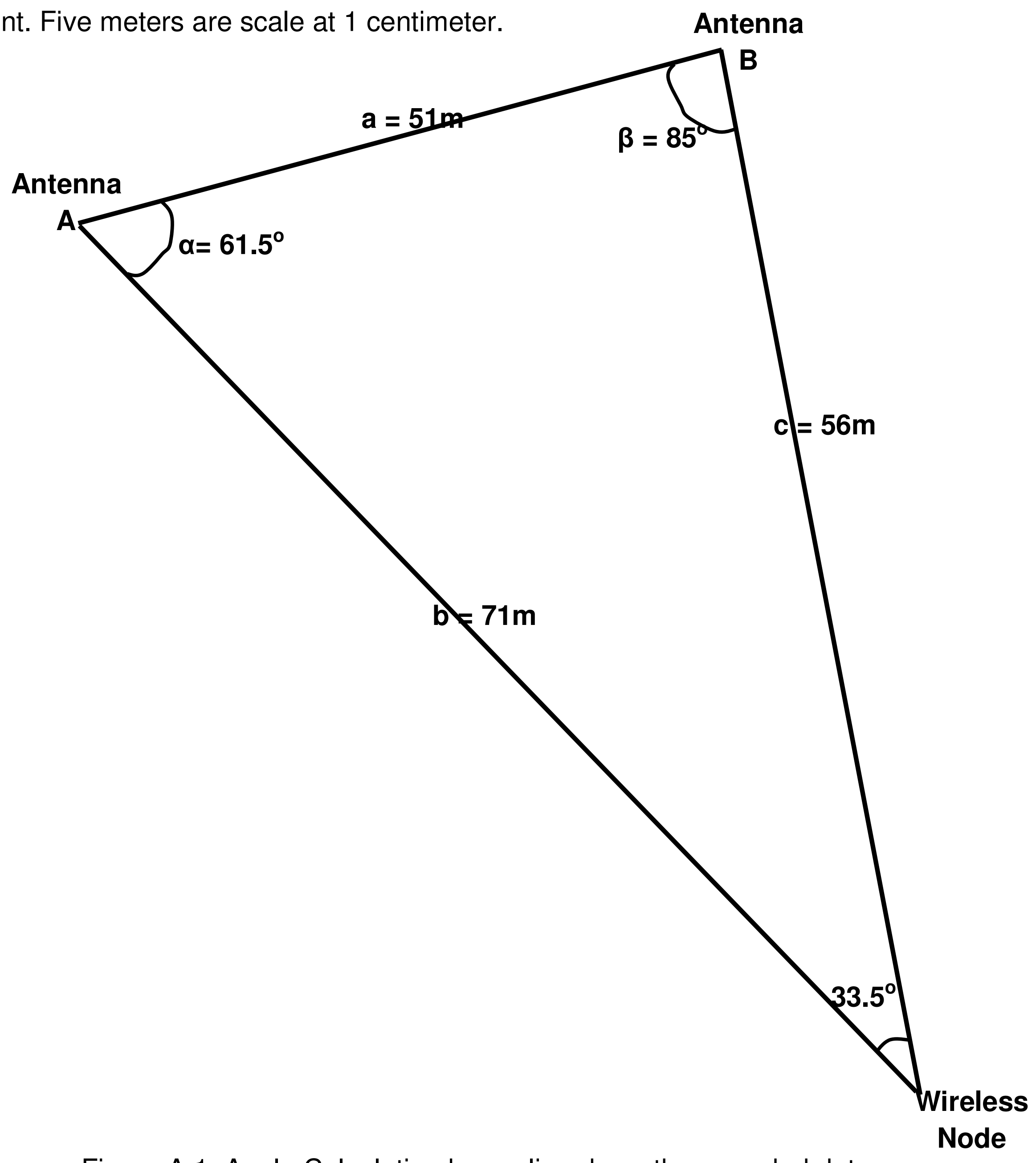


Figure A.1: Angle Calculation by scaling down the recorded data

Case:

Distance from antenna A to antenna B	(a)	= 51 m
Distance from antenna A to wireless node	(b)	= 71 m
Distance from antenna B to wireless node	(c)	= 56 m

By using the above measurements we construct triangle and then calculate the angles α and β which are 61.5^o and 85^o respectively.

APPENDIX B: LIST OF PUBLICATIONS

(During Current Research)

<u>Refereed Journal (ISI and others):</u>

1. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza. M, "k- Nearest Neighbor Algorithm for Improving Accuracy in Clutter Based Location Estimation of Wireless Nodes" Malaysian Journal of Computer Science (MJCS), ISI indexing Journal.
2. **Muhammad.A**, Mazliham.M.S, Shahrulniza.M. "*Power Management of Portable Devices by Using Clutter Based Information*". *IJCSNS, International Journal of Computer Science and Network Security*, VOL.9 No.4, April 2009, pp 237-244. ISSN: 1738-7906.

<u>Book Chapter (</u> **<u>SpringerLink)</u>*****<u>:</u>***

3. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza. M, Jawahir Che Mustapha Yusuf, "Predicted and Corrected Location Estimation of Cellular Nodes Based on the Combination of Kalman Filter and the Bayesian Decision Theory" *Mobilware 2010, 30 June -2 July, Chicago, USA.* Publisher: Springer Link (LNICST).
4. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza.M "Modeling Interpolated Distance Error for Clutter Based Location Estimation of Wireless Nodes" The International Conference on Digital Information and Communication

Technology and its Applications DICTAP 2011 June 21-23, DIJON, France Publisher: SpringerLink (LCNS).

5. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza.M " Location Estimation and Filtering of Wireless Nodes in an Open Environment" , The International Conference on Informatics Engineering and Information Science ICIEIS 2011, November 14-16 2011, Kuala Lumpur Malaysia.

ACM conference proceedings:

6. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza.M " Terrain Clutter Based Location Prediction by using Multi Condition Bayesian Decision Theory", International Conference on Ubiquitous Management and Communication ACM ICUIMC (IMCOM) 2012. Feb 20-22 Kuala Lumpur Malaysia (Submitted).

IEEE proceedings (ISI indexing & Ei Compendex):

7. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza. M, Jawahir Che Mustapha Yusuf, "*Terrain/Clutter Based Error Calculation in Location Estimation of Wireless Nodes by using Receive Signal Strength*" ICCTD 2010, 2nd International Conference on Computer Technology and Development . Cairo, Egypt. November 2-4, 2010 ISBN: 978-1-4244-8844-5
8. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza. M, Jawahir Che Mustapha Yusuf, *"Clutter based Enhance Error Rate Table (CERT) for Error Correction in Location Estimation of Mobile Nodes"* International Conference on

Information and Computer Networks, ICICN 2011, 26-28 January 2011, Guiyang, China.

Other International Proceedings Conferences:

9. **Muhammad. A**, Mazliham M.S, Shahrulniza. M, M.Amir. *"Posterior Probabilities based Location Estimation (P2LE) Algorithm for Locating a Mobile Node in a Disaster Area" MULTICONF-09 pp.217-224, July 13--16 Orlando, Florida. Publisher: American Mathematical Society.*
10. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza. M, Jawahir Che Mustapha @ Yusuf. "*Location Estimation and Power Management of Cellular Nodes for rescue operation" ICET 2009, Dec 08- 10, Kuala Lumpur, Malaysia.*
11. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza. M, Jawahir Che Mustapha @ Yusuf. "*The First Approach towards the Location Estimation of Cellular Nodes by using Movable GSM Antennas" ICET 2009, Dec 08-10, Kuala Lumpur, Malaysia.*
12. **Muhammad. A,** Mazliham M.S, Patrice Boursier, Shahrulniza. M "Modelling Error between Clutter Based Enhance Error Rate Table and Error Rate Table" 3rd Internationl Conference on Engineering Technology ICET 2011, Dec 6-8, Kuala Lumpur Malaysia.

Local Conferences:

13. **Muhammad. A**, Mazliham M.S, Shahrulniza. M, M.Amir. "*Disaster Management: Search and Rescue Operation by using Location Estimation and Power Management of Cellular Nodes" PGC, 30 July 2009, Kuala Lumpur, Malaysia.* ***(Best Paper Award).***
14. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza. M, Jawahir Che Mustapha @ Yusuf. "Comparison between the Clutter Based Enhanced Error Rate Table (CERT) and Error Rate Table (ERT)" 2nd MIIT R&D Colloquium 2010, 13-15 Dec, Kuala Lumpur Malaysia.
15. **Muhammad. A**, Mazliham M.S, Patrice Boursier, Shahrulniza. M, "Error Correction in Location Determination of Wireless Nodes by Modeling Interpolated Distance Error" 3rd MIIT R&D Colloquium 2011, 11-12 July, Kuala Lumpur Malaysia.

Group Publications:

16. Jawahir Che Mustapha @ Yusuf, Patrice Boursier, Mazliham Mohd Su'ud, Tengku Mohd Azahar Tuan Dir , **Muhammad. A** "First Approach to Applying JDL Fusion Model in Natural Disaster Management" *ICET 2009, Dec 08-10, Kuala Lumpur, Malaysia.*
17. Jawahir Che Mustapha@ Yusaf, Muhammad Azmin, **Muhammad.A.** "Developing SDI Community in Malaysia: The Role of Academia" *Map Asia, 18-20 August, 2009, Singapore*.

18. Jawahir Che Mustapha @ Yusuf, Patrice Boursier, Mazliham Mohd Su'ud, Tengku Mohd Azahar Tuan Dir , **Muhammad. A**, "Enriching Ontological Concept for Integrated Information System" MIIT R&D Colloquium 2010, 13-15 Dec, Kuala Lumpur Malaysia.

APPENDIX C: RELATED DEFINITIONS

Attenuation

Signal distortion due to terrain effects or external factors.

Available Signal Strength (ASS)

Signal strength which is available at the transmitter during the beacon frequency or communication with the receiver.

Bayesian Decision Theory

Bayes filters probabilistically estimate a dynamic system's state from noisy observations. The Bayesian approach is an interesting method as it uses the existing knowledge on the information of the likelihood of the validity of the hypothesis prior to the observation of evidence.

Clutter

A geographical area/terrain.

Dead Reckoning (DR)

Dead Reckoning is a process of estimating one's current position based upon previous determined positions, known speed and acceleration, moving direction, elapsed time and traveled distance.

Impairments

See attenuation.

k-Nearest Neighbor Algorithm

The k-Nearest Neighbor algorithm (k-NN) is one of the easiest and simplest machine learning algorithms. On the other hand it is also known as “lazy algorithm” as it is slows and “eager algorithm” as it uses all data elements for training.

Kalman Filter

Kalman filter is a mathematical method which is used to avoid noise, impairments and inaccuracies and to produce results close to the true value. Kalman filter process on the estimated value and correct it. This process is based on the time step. Every time it predicts, estimate and correct and start again in next iteration. This recursive approach helps to calculate the best guess.

Linear Interpolation

Interpolation is a method which is used to define a function under the two set of values. Two set of points in a plane represent a straight line, but to read variation in readings we need interpolation.

Multilateration

Multilateration [6] also know as hyperbolic lateration usually is the positioning process by estimating the time difference of arrival (TDOA) of a signal. TDOA method is similar to TOA estimation but does not need clock synchronization.

Proximity Sensing: Signal Signature Tracking

In the proximity sensing, the wireless node position is derived from the base station (BS) coordinates.

Received Signal (Rx)

Received signal in watts, which is received by the receiver.

Receive Signal Strength (RSS)

Signal Strength which is the receive received from transmitter.

Region of Interest (RoI)

Selected area from the data points after the implementation of combine variance.

Signal to Noise Ratio (SNR)

The ratio between the transmitted signal (Tx) and the distorted signal. Higher SNR leads towards the poor reception.

Transmitted Signal (Tx)

Transmitted Signal in watts, which is transmitted by the sender.

Triangulation

Triangulation is a process of positioning a wireless node by measuring angle of arrival (AOA) between the wireless node and the reference point (RP) and distance between the wireless node and the reference points.

Trilateration

Trilateration is a process of determinating absolute or relative locations of points by using measurement of distance, using the geometry of circles, spheres or triangles.

APPENDIX D: HARDWARE/SOFTWARE USED FOR TESTING

Access points (Three Units)

Level 1 Wireless LAN 108Mbps Wireless Access Point (IEEE 802.11 g). the range or radius coverage for typical WLAN system varies from 100 feet to more than 500 feet. Coverage can be extended, and true freedom of mobility via roaming provided through microcells technology. Long range WLAN can provide services upto 37 km, but LOS antennas are required.

Transmetter Power: 802.11g uses the transmit power of 15 +- 2dBm @ 54Mbps and uses EVM < -24dB.

where 15 dBm = 32 mW

(13 dBm = 20 mW, 14dBm = 25 mW, 16dBm = 40 mW and 17dBm = 50 mW)

Therefore the power in 11g range from

20 mW – 50mW

Figure D.1: A snapshot of Access Point

GPS Receiver (One Unit)

Garmin eTrex® GPS receiver (for coordinates)

Figure D.2: Garmin GPS receiver

Laptop (Servers / Wireless Node) (Four Units)

Dell Inspiron INSP 1440 (for three servers and one mobile node)

Figure D.3: Dell Inspiron

Microsoft Visual Studio 2008

For RSS/ASS signal Calculator and for Interpolated distance Calculator

Figure D.4: Snap Shot of Visual C# 2008

Measuring Tape (Two Unit)

For manual distance measurement

Figure D.5: Measuring Tape

Camping Tent (One Unit)

For shelter incase of rain and bright sunlight

Figure D.6: Camping Tent

Protractor (One Unit)

For angle measurement

Figure D.7: Protractor

APPENDIX E: DATA COLLECTION

E.1: DATA COLLECTION SETUP

Data is collected by using level 1 access points g standard (as transmitting antennas) and wireless LAN card (as a wireless node) installed in laptop. GPS receiver is also used to calculate error measurement.

Table E.1: Measurement Setup parameters

MEASUREMENT TYPE		TRIANGLES	
Actual Measurement	(Δ_{ABM})	(Δ_{ACM})	(Δ_{BCM})
WiFi measurement	($\Delta_{A'B'M}$)	($\Delta_{A'C'M'}$)	($\Delta_{C'B'M'}$)
Combination for both measurement (Actual, WiFi)	Δ_{ABM}, & $\Delta_{A'B'M'}$	Δ_{ACM}, & $\Delta_{A'C'M'}$	Δ_{CBM}, & $\Delta_{C'B'M'}$

To make sure all the triangles fit in the graph paper, the researcher map it to a graph with a scale of 1:5 (1cm = 5m) By plotting all the points in the graph paper, researcher can calculate the error rate by calculating the distance between M and M'. Each error rate (e) will then be multiplied by 5 in order to get the actual error rate (e') in meter (m).

$$e\,(cm) * 5 = e'\,(m) \quad \text{eq E.1}$$

Low Forest/Plantation

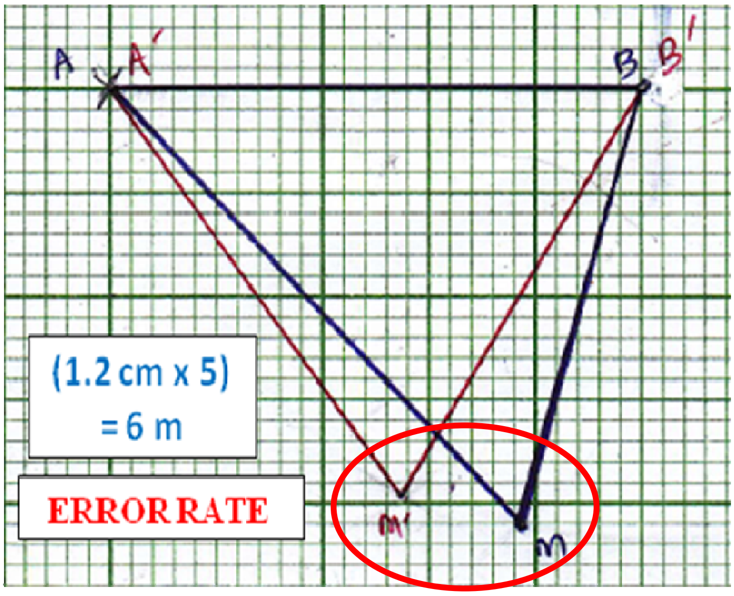


Figure E-1: ∠ABM for Low Forest/Plantation

By refer the triangle from the scan graph paper, for the 1st triangle the error rate between ***ΔABM*** and ***ΔA'B'M'*** is **1.2cm**. Based on the equation, the actual error rate is: **(1.2 cm x 5) = 6 m.**

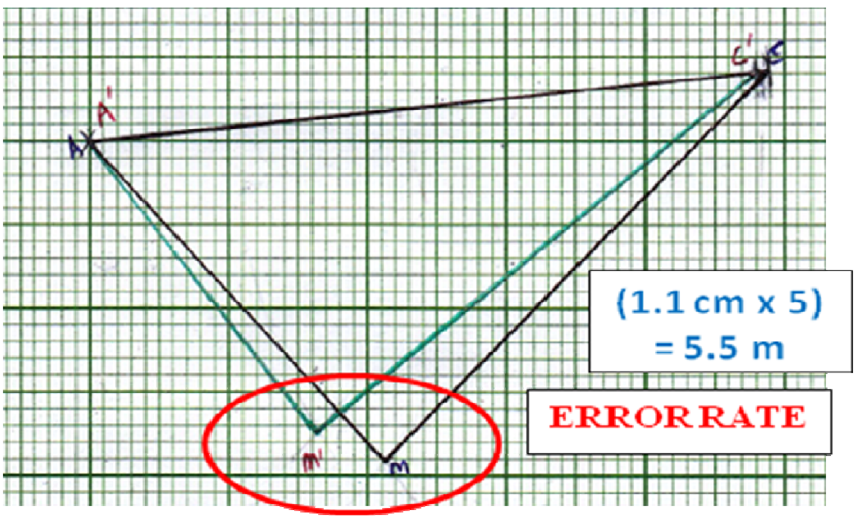


Figure E-2: ∠ACM for Low Forest/Plantation

For the 2nd triangle, the error rate between ***ΔACM*** and ***ΔA'C'M'*** is **1.1cm.** Based on the equation, the actual error rate is: **(1.1 cm x 5) = 5.5 m.**

(3rd triangle)

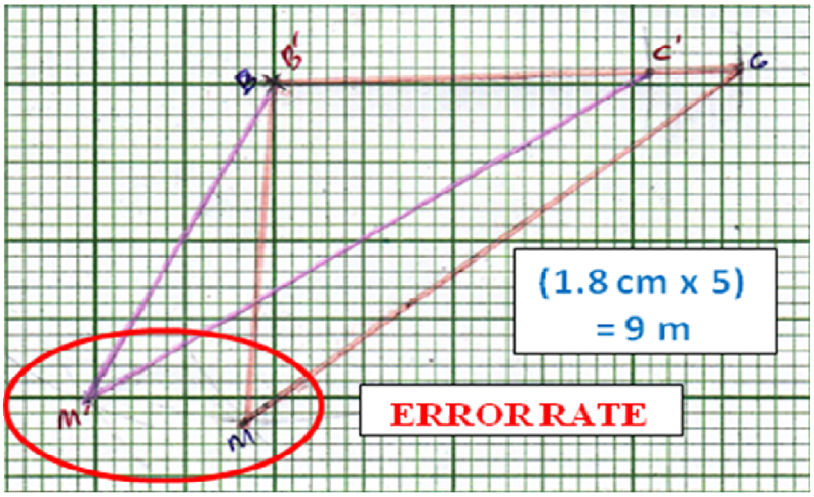


Figure E-3: ∠BCM for Low Forest/Plantation

For the 3rd triangle, the error rate between ***ΔBCM*** and ***ΔB'C'M'*** is **1.8cm**. Based on the equation, the actual error rate is: **(1.8 cm x 5) = 9 m.**

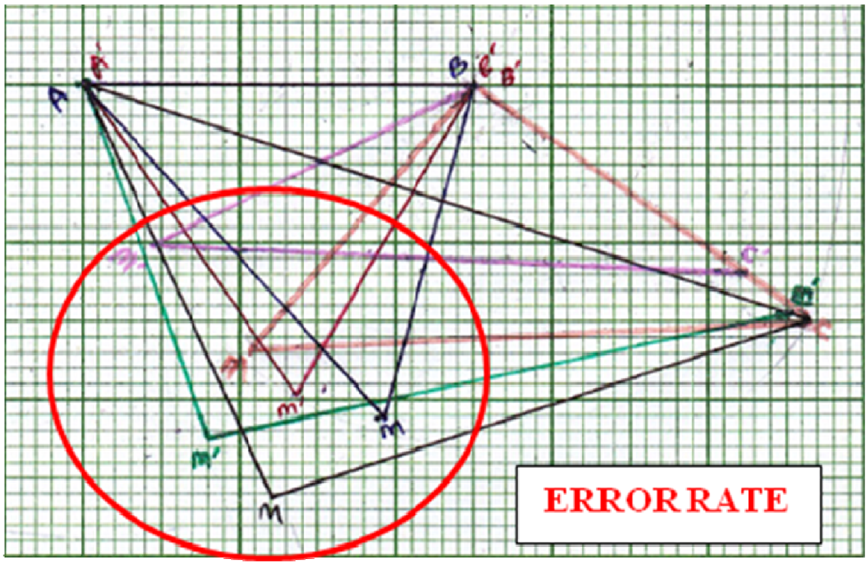


Figure E-4: ∠ABM, ∠ACM and ∠BCM for Low Forest/Plantation

By refer figure above is the combination of the six triangles ((***ΔABM, ΔA'B'M'***), (***ΔACM, ΔA'C'M'***), (***ΔBCM, ΔB'C'M').*** As you can see the point M and M' are dispersed across among each other and it's scattered.

Dense Forest

(1st triangle)

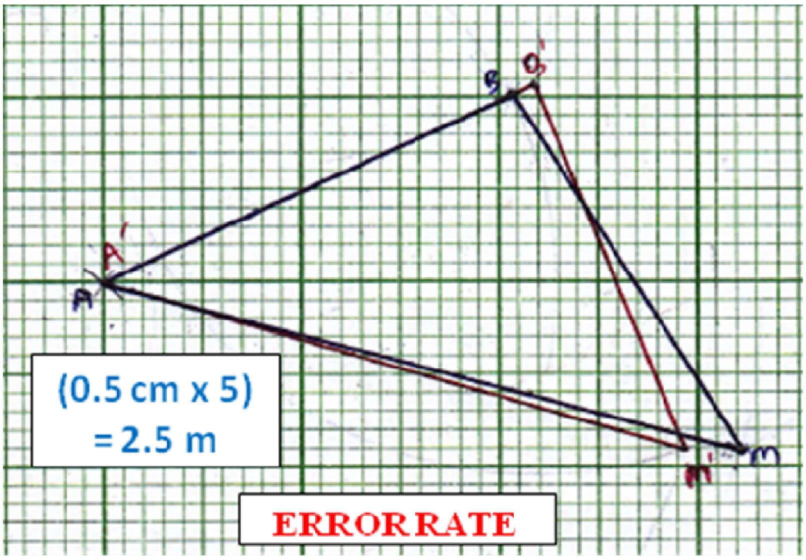


Figure E-5: ∠ABM for Dense Forest

For the 1st triangle, the error rate between ***ΔABM*** and ***ΔA'B'M'*** is **0.5cm**. Based on the equation, the actual error rate is: **(0.5 cm x 5) = 2.5 m**

(2nd Triangle)

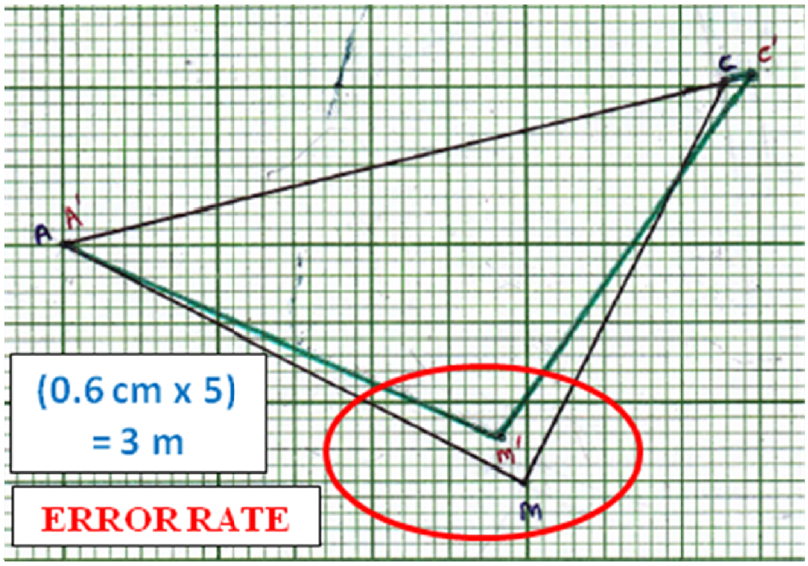


Figure E-6: ∠ACM for Dense Forest

The 2nd triangle, the error rate between ***ΔACM*** and ***ΔA'C'M'*** is **0.6cm**. Based on the equation, the actual error rate is: **(0.6 cm x 5) = 3 m.**

(3rd triangle)

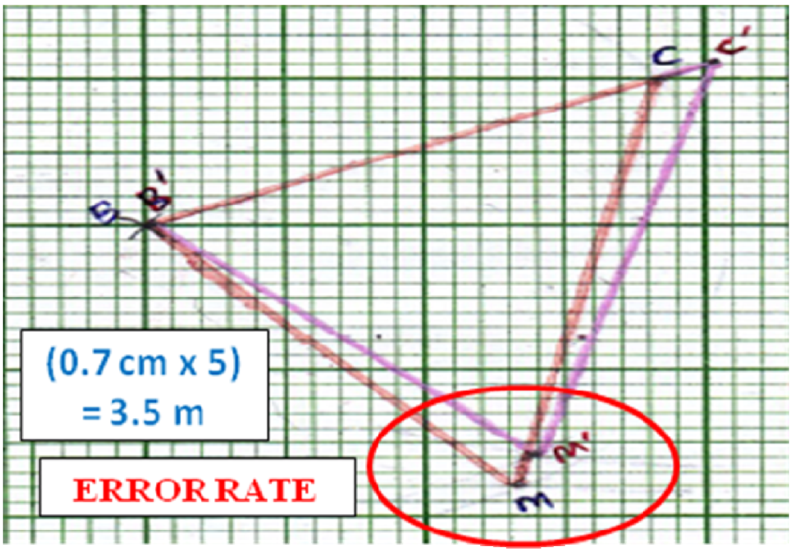


Figure E-7: ∠BCM for Dense Forest

For the 3rd triangle, the error rate between ***ΔBCM*** and ***ΔB'C'M'*** is **0.7cm**. Based on the equation, the actual error rate is: **(0.7 cm x 5) = 3.5 m**

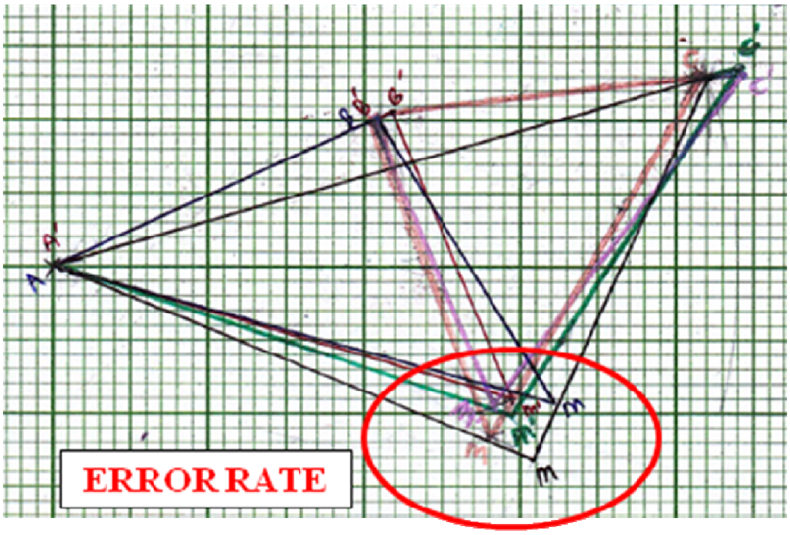


Figure E-8: ∠ABM, ∠ACM and ∠BCM for Dense Forest

Agri/Field

(1st triangle)

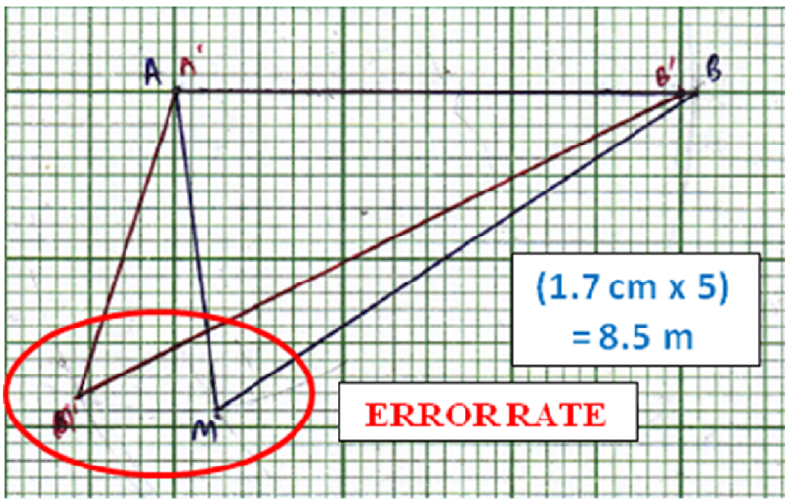


Figure E-9: ∠ABM for Agri/Field

For the 1st triangle, the error rate between ***ΔABM*** and ***ΔA'B'M'*** is **1.7cm.** Based on the equation, the actual error rate is: **(1.7 cm x 5) = 8.5 m.**

(2nd triangle)

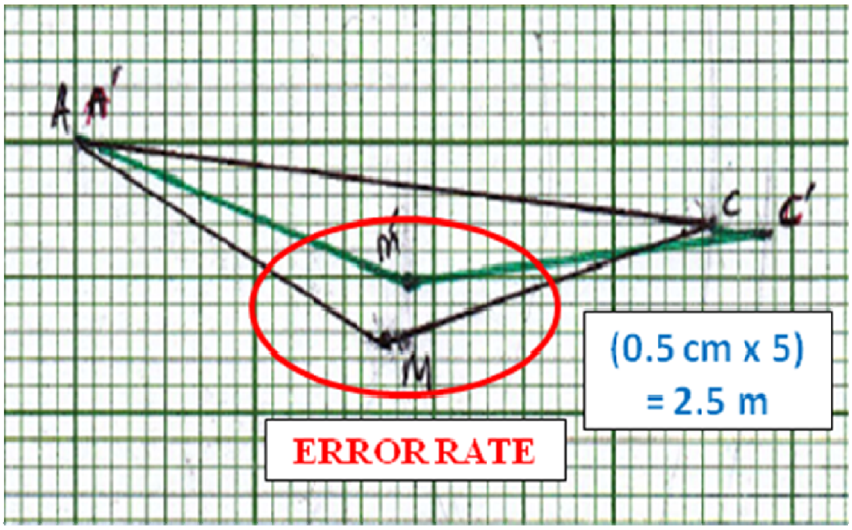


Figure E-10: ∠ACM for Agri/Field

For the 2nd triangle, the error rate between ***ΔACM*** and ***ΔA'C'M'*** is **0.5cm.** Based on the equation, the actual error rate is **(0.5 cm x 5) = 2.5 m**

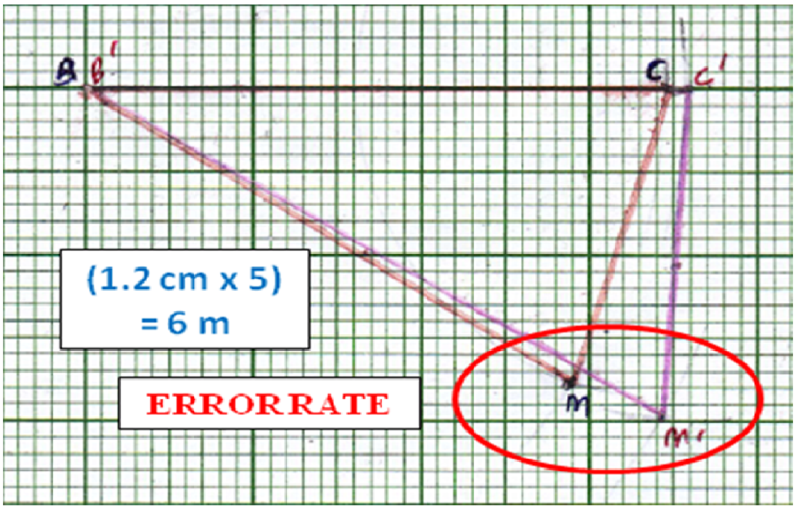


Figure E-11: ∠BCM for Agri/Field

For the 3rd triangle, the error rate between **ΔBCM** and **ΔB'C'M'** is **1.2cm**. Based on the equation, the actual error rate is: **(1.2 cm x 5) = 6 m.**

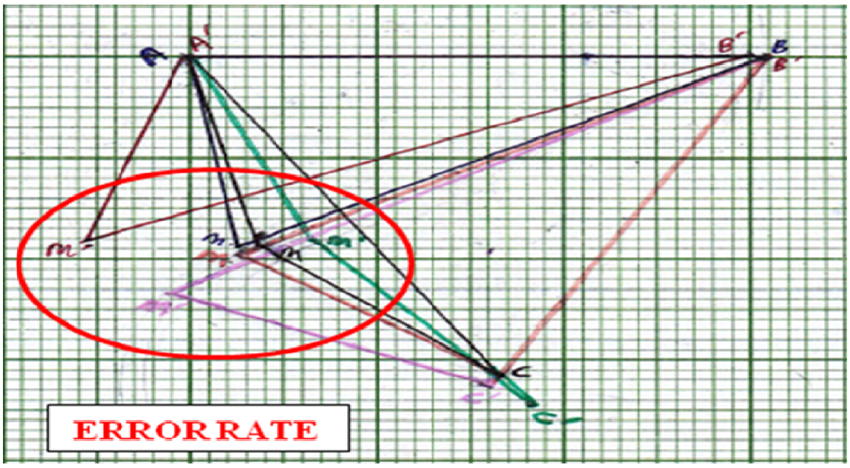


Figure E-12: ∠ABM, ∠ACM and ∠BCM for Agri/Field

Figure above is the combination of the six triangles ((**ΔABM, ΔA'B'M'**), (**ΔACM, ΔA'C'M'**), (**ΔBCM, ΔB'C'M'**). Error rate for this terrain is questionable by refer from table.

Highway/Motorway

(1st triangle)

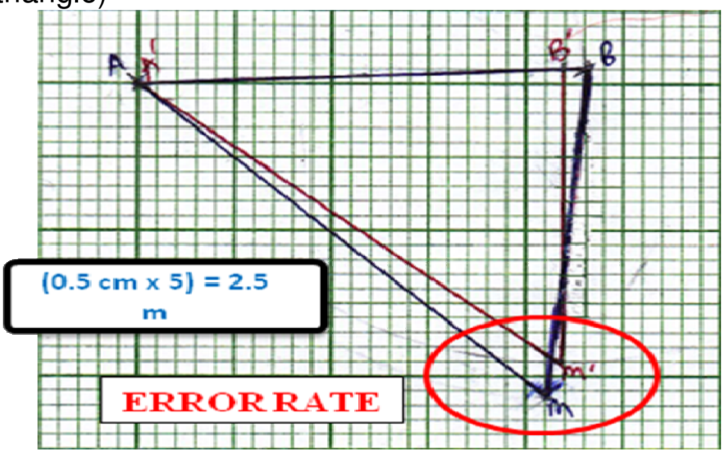


Figure E-13: ∠ABM for Highway/Motorway

For the 1st triangle, the error rate between **Δ*ABM*** and **Δ*A'B'M'*** is **0.5cm**. Based on the equation, the actual error rate is: **(0.5 cm x 5) = 2.5m**

(2nd triangle)

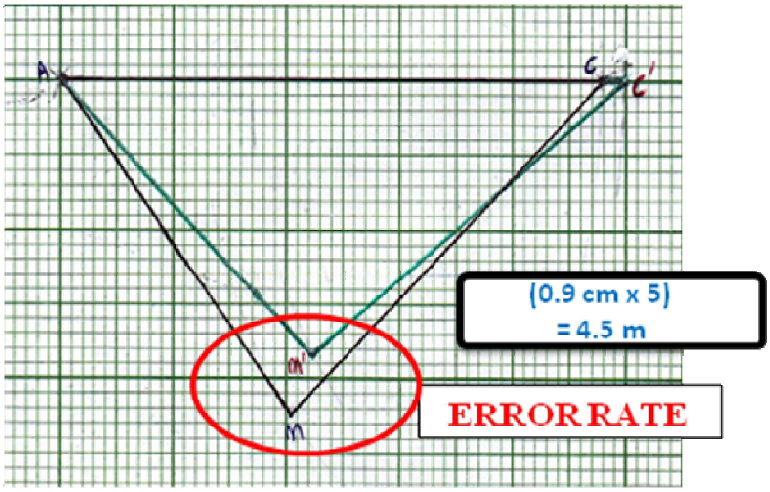


Figure E-14: ∠ACM for Highway/Motorway

For the 2nd triangle, the error rate between **Δ*ACM*** and **Δ*A'C'M'*** is **0.9cm**. Based on the equation, the actual error rate is: **(0.9 cm x 5) = 4.5 m**

(3rd triangle)

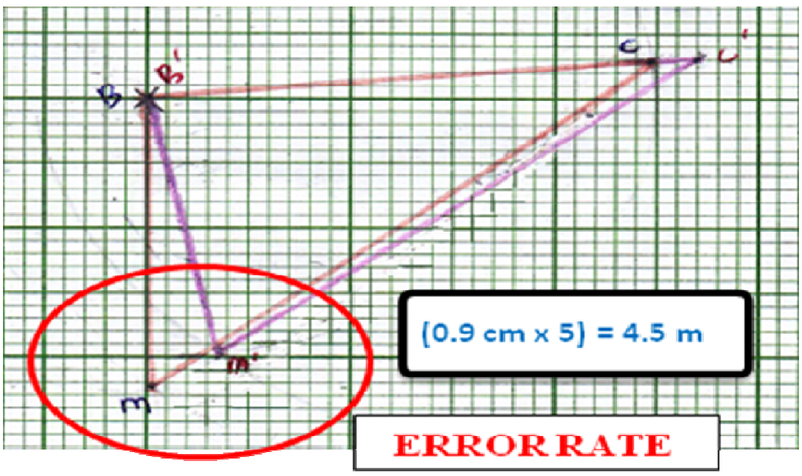


Figure E-15: ∠BCM for Highway/Motorway

For the 3rd triangle, the error rate between ***ΔBCM*** and ***ΔB'C'M'*** is 0.9cm. Based on the equation, the actual error rate is: **(0.9 cm x 5) = 4.5 m.**

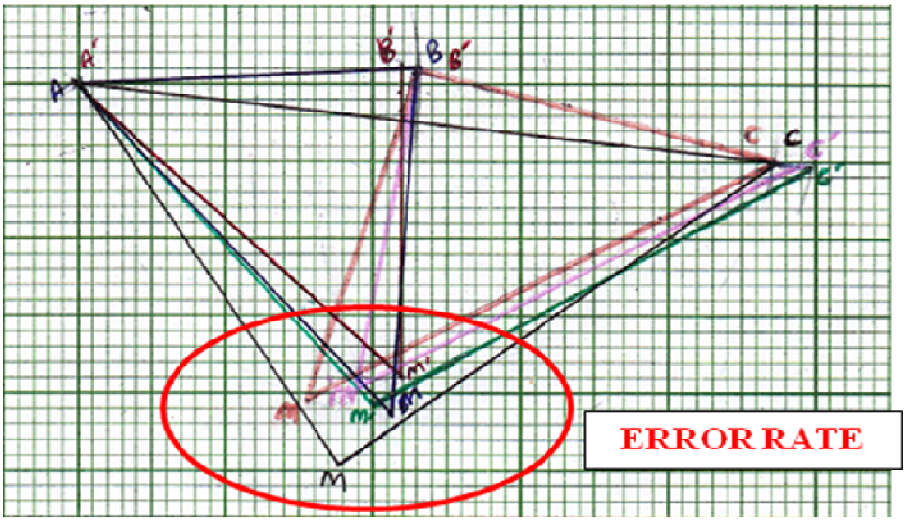


Figure E-16: ∠ABM, ∠ACMand ∠BCM for Highway/Motorway

Lake

(1st triangle)

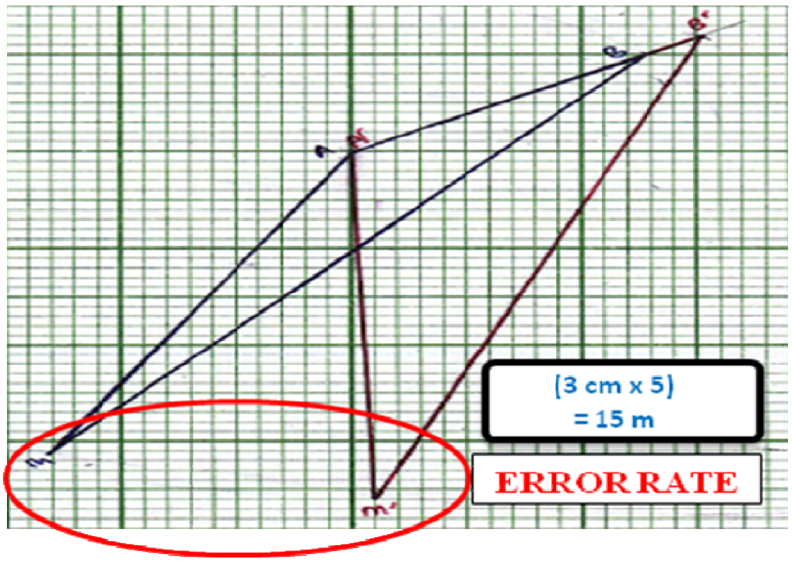


Figure E-17: ∠ABM for Lake

The 1st triangle, the error rate between ***ΔABM*** and ***ΔA'B'M'*** is **3cm**. Based on the equation, the actual error rate is: **(3cm x 5) = 15 m.**

(2nd triangle)

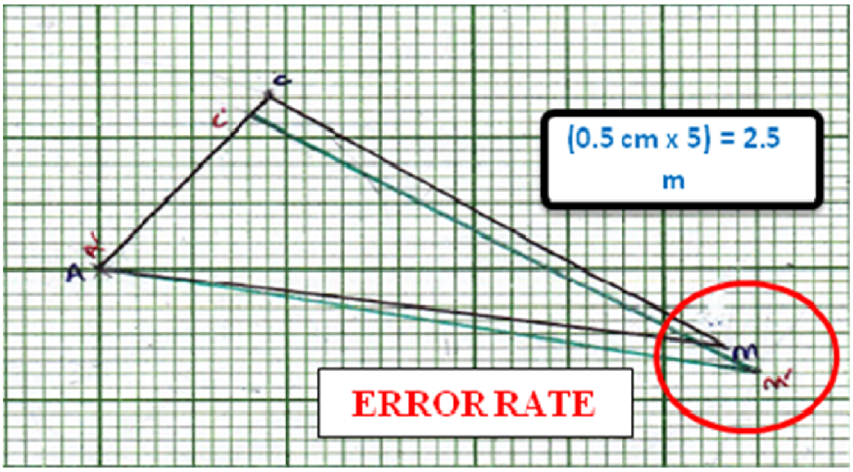


Figure E-18: ∠ACM for Lake

For the 2nd triangle, the error rate between ***ΔACM*** and ***ΔA'C'M'*** is 0.6cm. Based on the equation, the actual error rate is **(0.5 cm x 5) = 2.5 m.**

(3rd triangle)

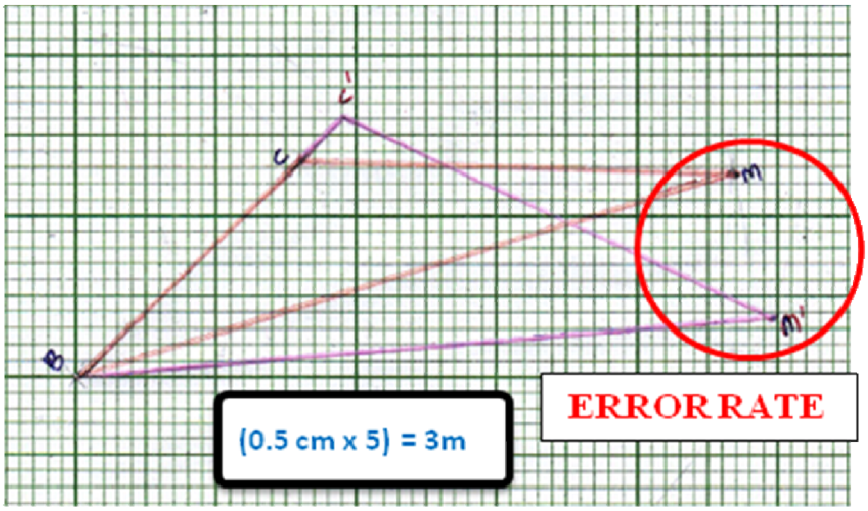


Figure E-19: ∠ABM for Lake

For the 3rd triangle, the error rate between ***ΔBCM*** and ***ΔB'C'M'*** is **0.5cm**. Based on the equation, the actual error rate is: **(0.5 cm x 5) = 3 m.**

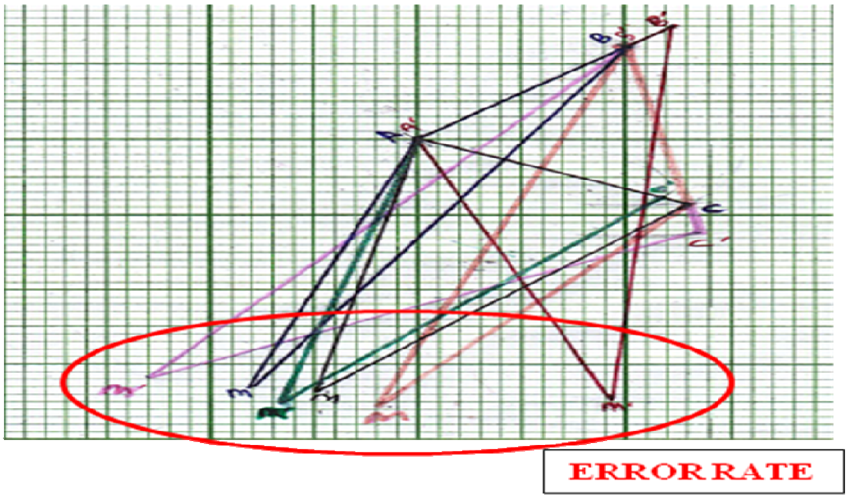


Figure E-20: ∠ABM, ∠ACM and ∠BCM for Lake

Figure above is the combination of the six triangles ((***ΔABM, ΔA'B'M'***), (***ΔACM, ΔA'C'M'***), (***ΔBCM, ΔB'C'M'***). 1st triangle give total huge amount of error rate, 15 meters.

River

(1st triangle)

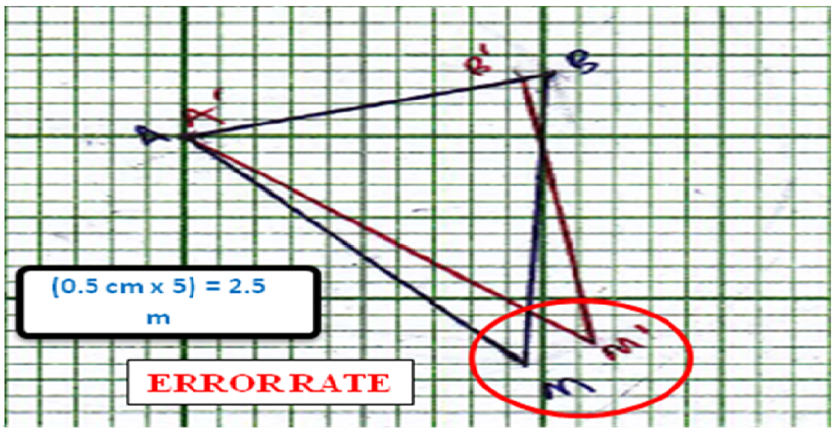


Figure E-21: ∠ABM for River

For the 1st triangle, the error rate between ***ΔABM*** and ***ΔA'B'M'*** is **0.5cm**. Based on the equation, the actual error rate is **(0.5 cm x 5) = 2.5 m.**

(2nd triangle)

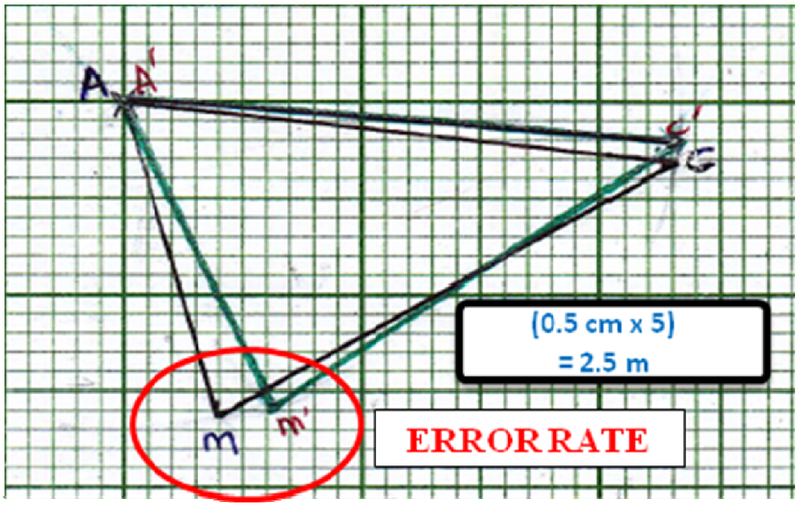


Figure E-22: ∠ACM for River

For the 2nd triangle, the error rate between ***ΔACM*** and ***ΔA'C'M'*** is **0.5m.** Based on the equation, the actual error rate is: **(0.5 cm x 5) = 2.5 m.**

(3rd triangle)

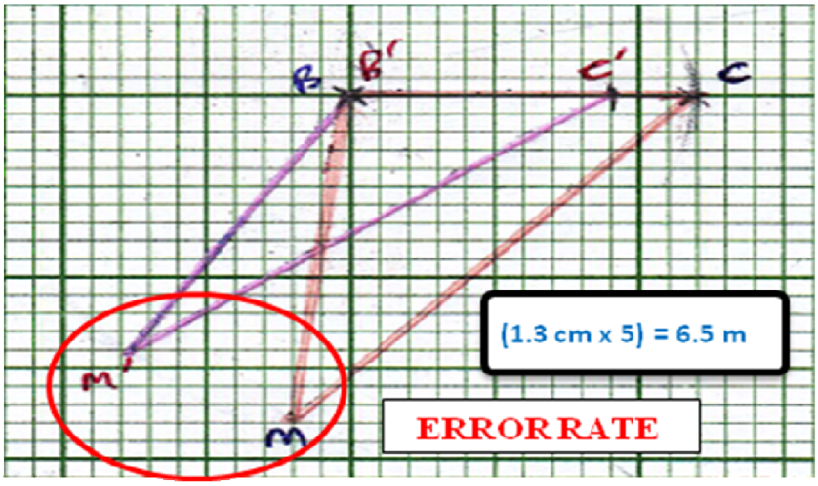


Figure E-23: ∠ACM for River

For the 3rd triangle, the error rate between ***⊿BCM*** and ***⊿B'C'M'*** is **1.3 cm**. Based on the equation, the actual error rate is **(1.3 cm x 5) = 6.5 m.**

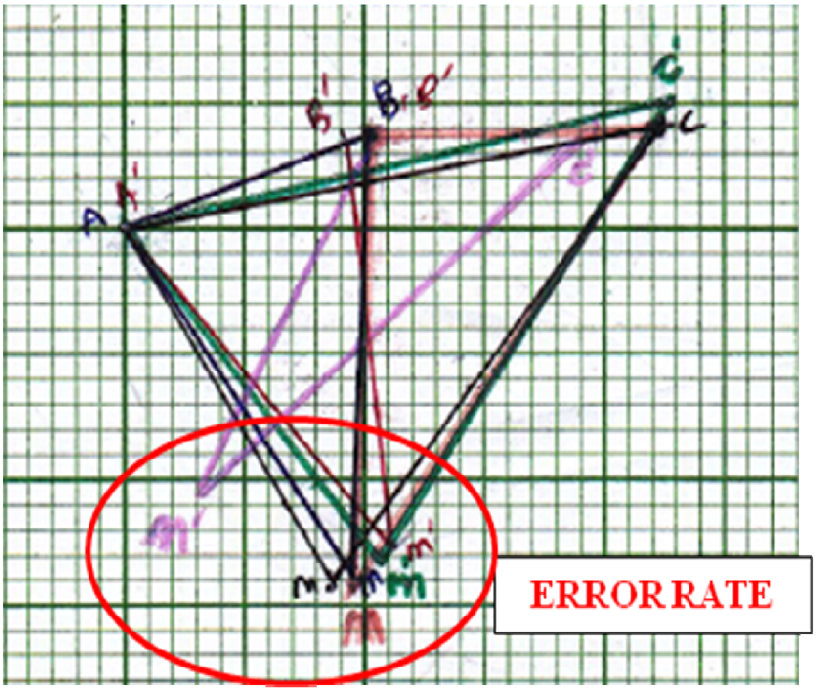


Figure E-24: ∠ABM, ∠ACM and ∠BCM for River

Figure above is the combination of the six triangles ((***⊿ABM, ⊿A'B'M'***), (***⊿ACM, ⊿A'C'M'***), (***⊿BCM, ⊿B'C'M'***). The error is disorderly after all triangles have combined together.

Low Dense Rural

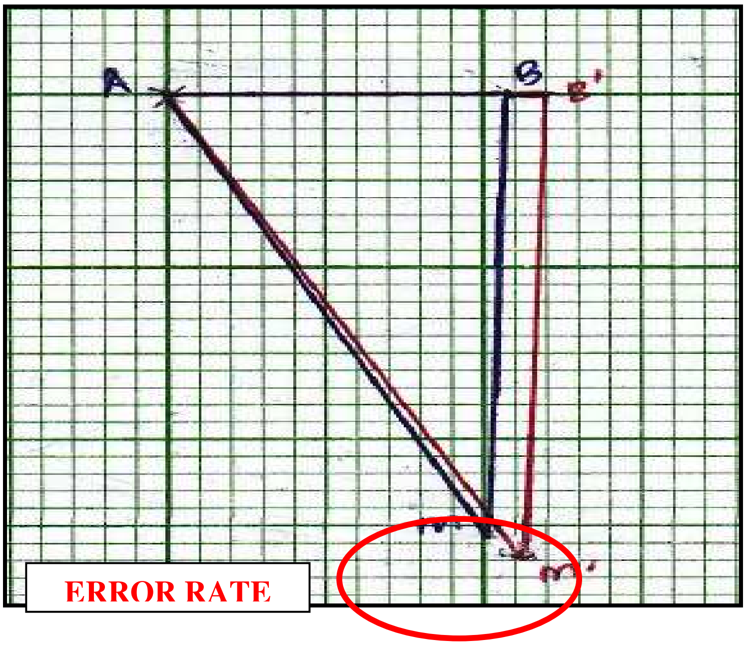


Figure E-25: ∠ABM for Low Dense Rural

For the 1st triangle, the error rate between ***∠ABM*** and ***∠A'B'M'*** is 0.3cm. Based on the equation, the actual error rate is: **(0.3 cm x 5) = 1.5 m**

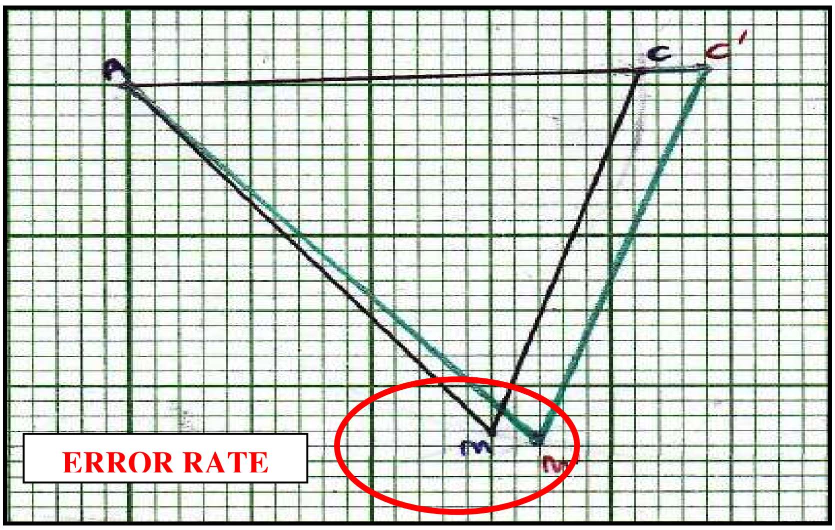


Figure E-26: ∠ACM for Low Dense Rural

For the 2nd triangle, the error rate between ∠***ACM*** and ∠***A'C'M'*** is 0.6cm. Based on the equation, the actual error rate is: **(0.4 cm x 5) = 2 m**

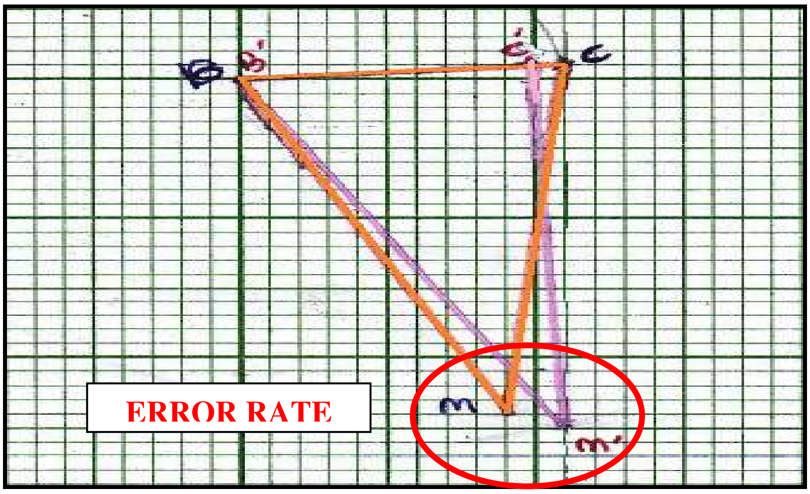


Figure E-27: ∠BCM for Low Dense Rural

For the 3rd triangle, the error rate between ∠***BCM*** and ∠***B'C'M'*** is 0.8cm. Based on the equation, the actual error rate is: **(0.4cm x 5) = 2 m**

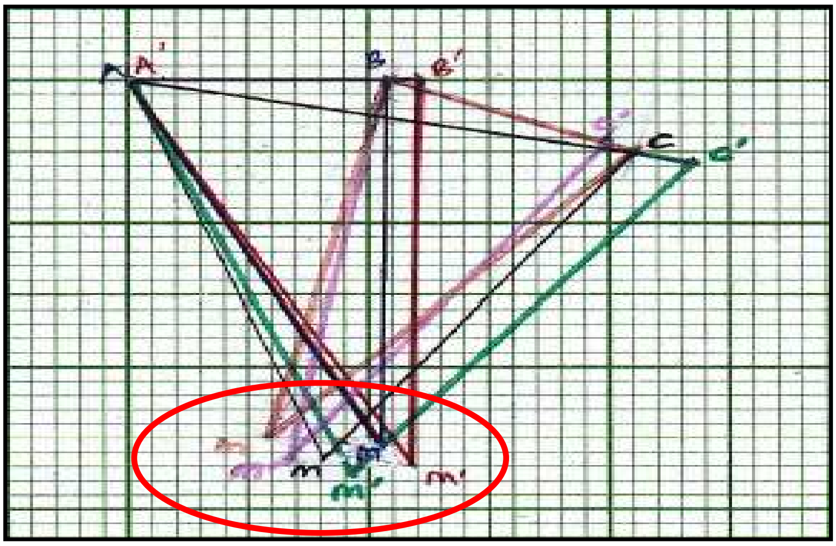


Figure E-28: ((∠ABM, ∠A'B'M'), (∠ACM, ∠A'C'M'), (∠BCM, ∠B'C'M')) for Low Dense Rural

High Dense Rural

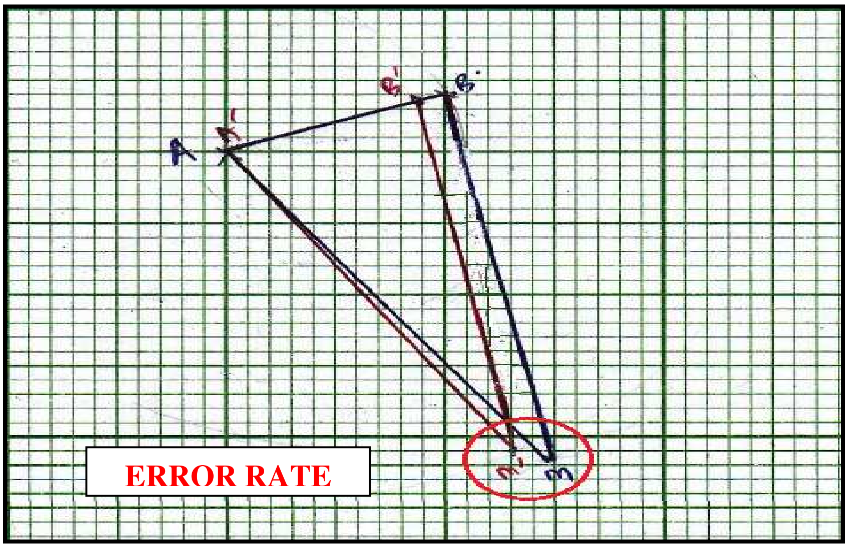


Figure E-29: ∠ABM for High Dense Rural

For the 1st triangle, the error rate between ***∠ABM*** and ***∠A'B'M'*** is 0.4cm. Based on the equation, the actual error rate is: **(0.4 cm x 5) = 2 m**

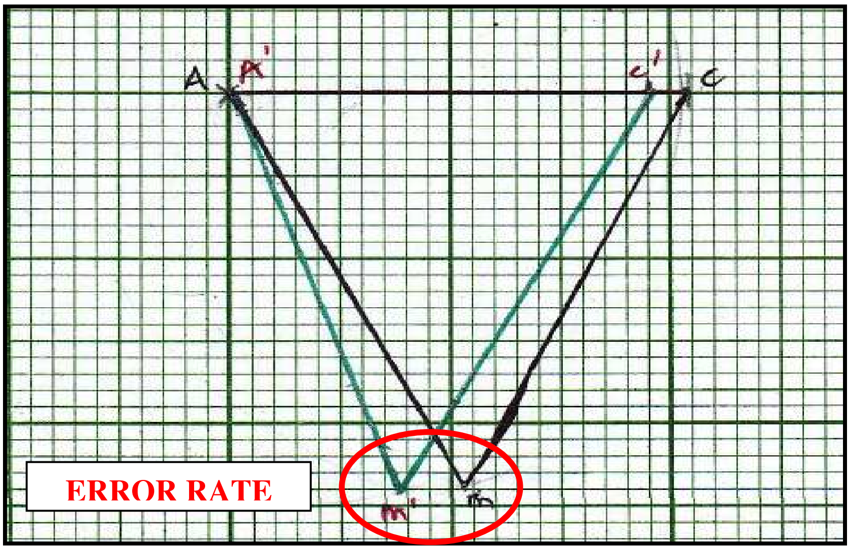


Figure E-30: ∠ACM for High Dense Rural

For the 2nd triangle, the error rate between ***∠ACM*** and ***∠A'C'M'*** is 0.6cm. Based on the equation, the actual error rate is: **(0.6 cm x 5) = 3 m.**

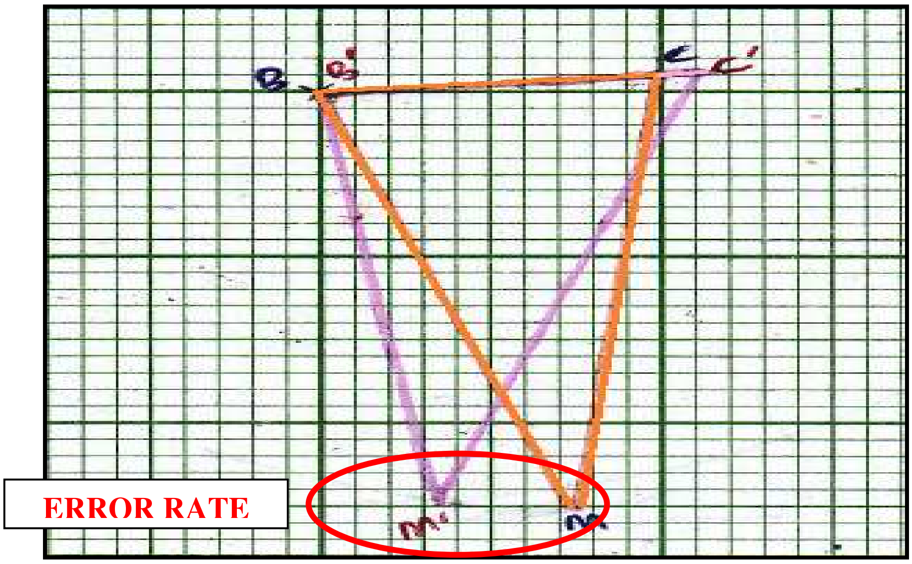


Figure E-31: ∠BCM for High Dense Rural

For the 3rd triangle, the error rate between ***∠BCM*** and ***∠B'C'M'*** is 0.8cm. Based on the equation, the actual error rate is: **(0.8 cm x 5) = 3 m**

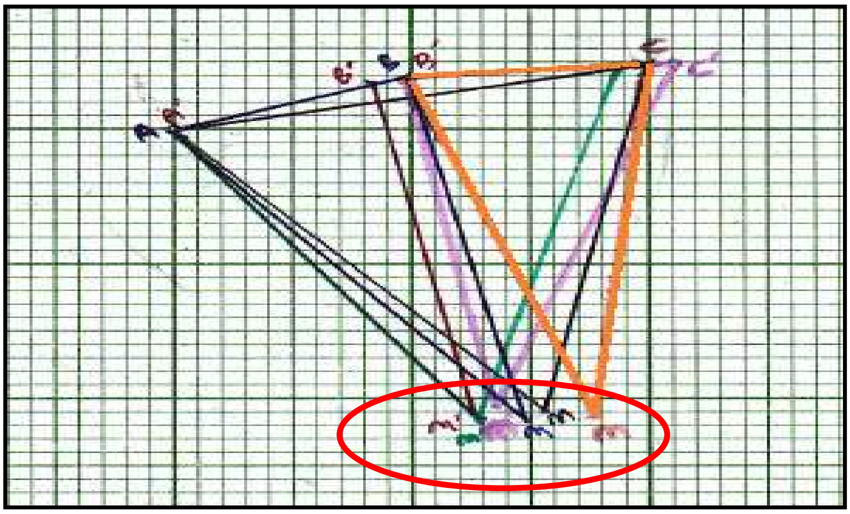


Figure E-32: ((∠ABM, ∠A'B'M'), (∠ACM, ∠A'C'M'), (∠BCM, ∠B'C'M')) for High Dense Rural

Medium Dense Urban

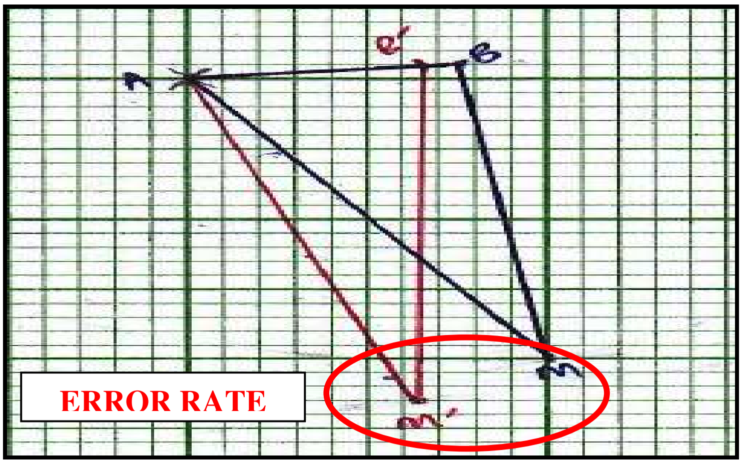


Figure E-33: ∠ABM for Medium Dense Urban

For the 1st triangle, the error rate between ***∠ABM*** and ***∠A'B'M'*** is 0.3cm. Based on the equation, the actual error rate is: **(1 cm x 5) = 5 m**

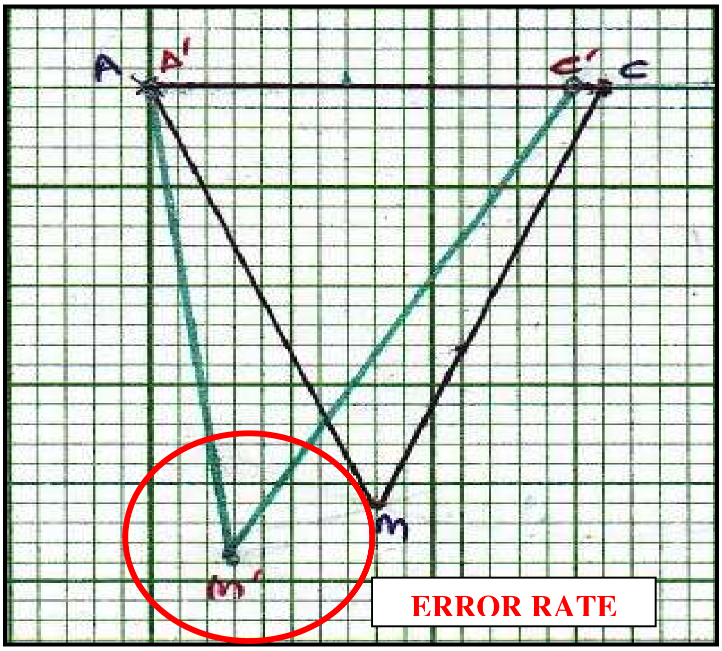


Figure E-34: ∠ACM for Low Dense Rural

For the 2nd triangle, the error rate between **∠ACM** and **∠A'C'M'** is 0.6cm. Based on the equation, the actual error rate is: **(1.2 cm x 5) = 6 m**

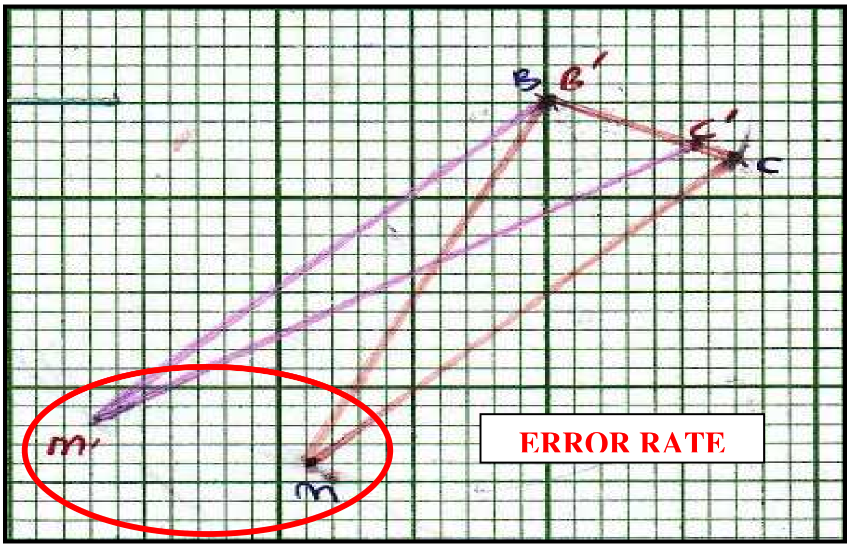


Figure E-35: ∠BCM for Medium Dense Urban

For the 3rd triangle, the error rate between **∠BCM** and **∠B'C'M'** is 0.8cm. Based on the equation, the actual error rate is: **(1.7 cm x 5) = 8.5 m**

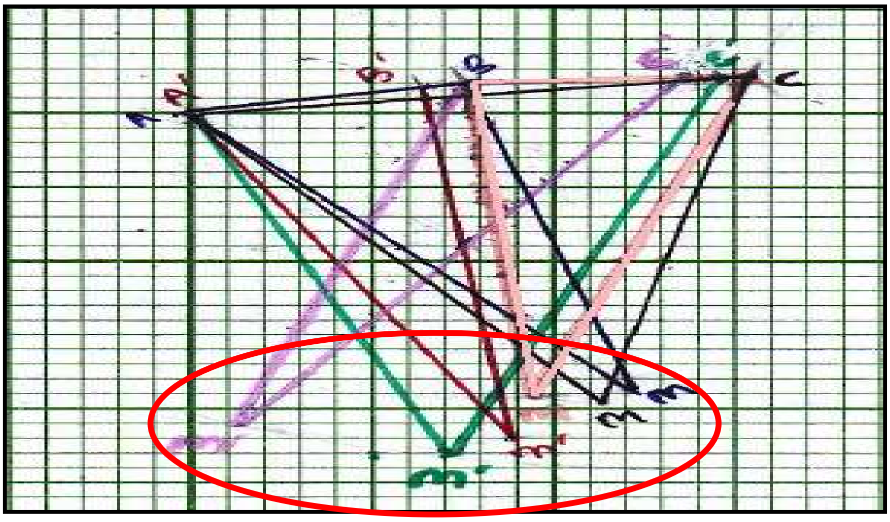


Figure E-36: ((∠ABM, ∠A'B'M'), (∠ACM, ∠A'C'M'), (∠BCM, ∠B'C'M')) for Medium Dense Urban

High Dense Urban

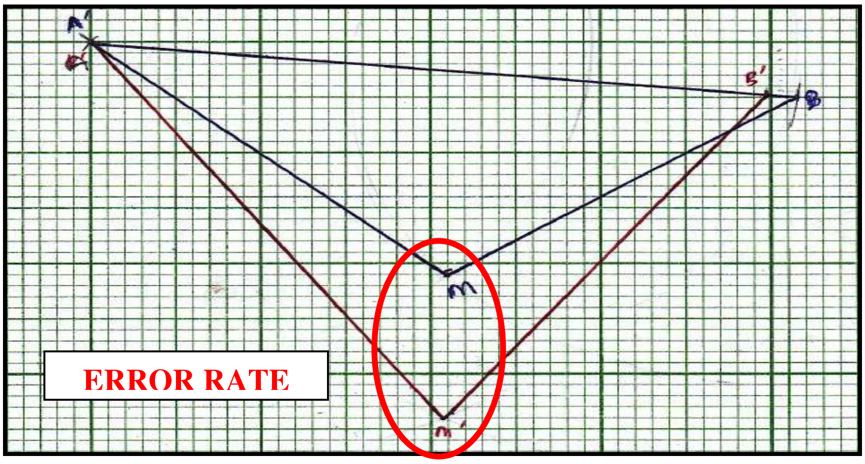


Figure E-37: ∠ABM for High Dense Urban

For the 1st triangle, the error rate between ***∆ABM*** and ***∠A'B'M'*** is 0.3cm.
Based on the equation, the actual error rate is: **(2.5 cm x 5) = 12.5 m**

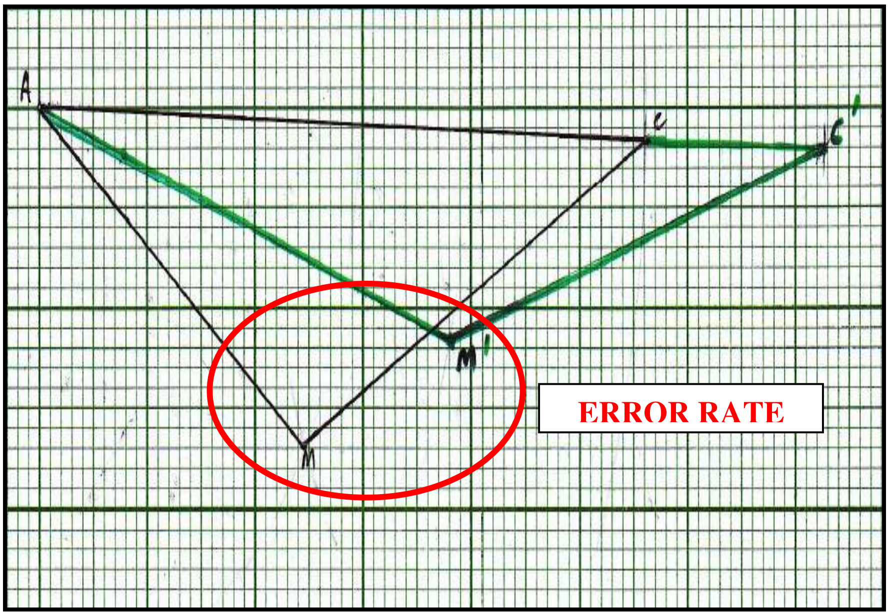


Figure E-38: ∠ACM for High Dense Urban

For the 2nd triangle, the error rate between ∠***ACM*** and ∠***A'C'M'*** is 0.6cm. Based on the equation, the actual error rate is: **(3 cm x 5) = 15 m**

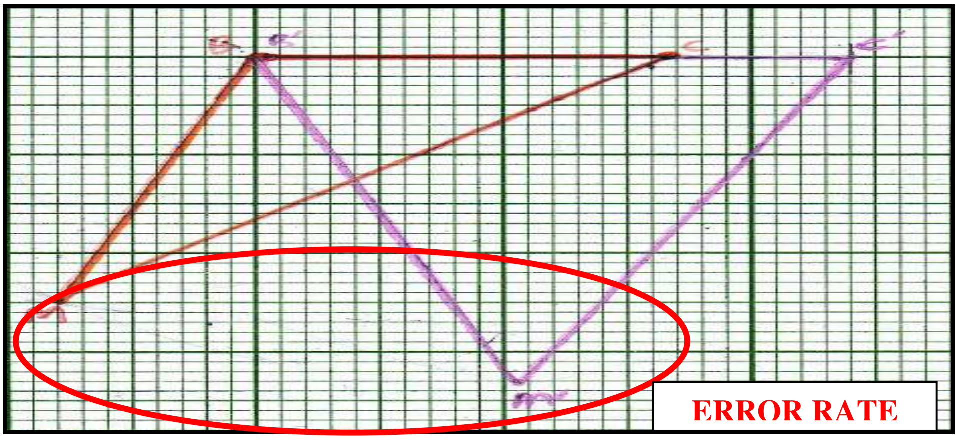


Figure E-39: ∠BCM for High Dense Urban

For the 3rd triangle, the error rate between ∠***BCM*** and ∠***B'C'M'*** is 0.8cm. Based on the equation, the actual error rate is: **(4.1 cm x 5) = 20.5 m**

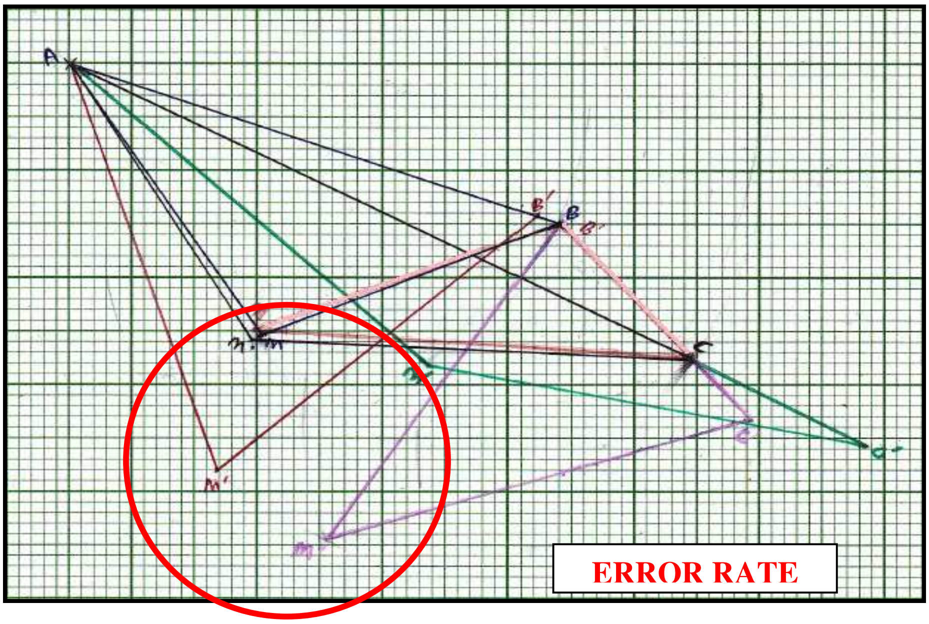
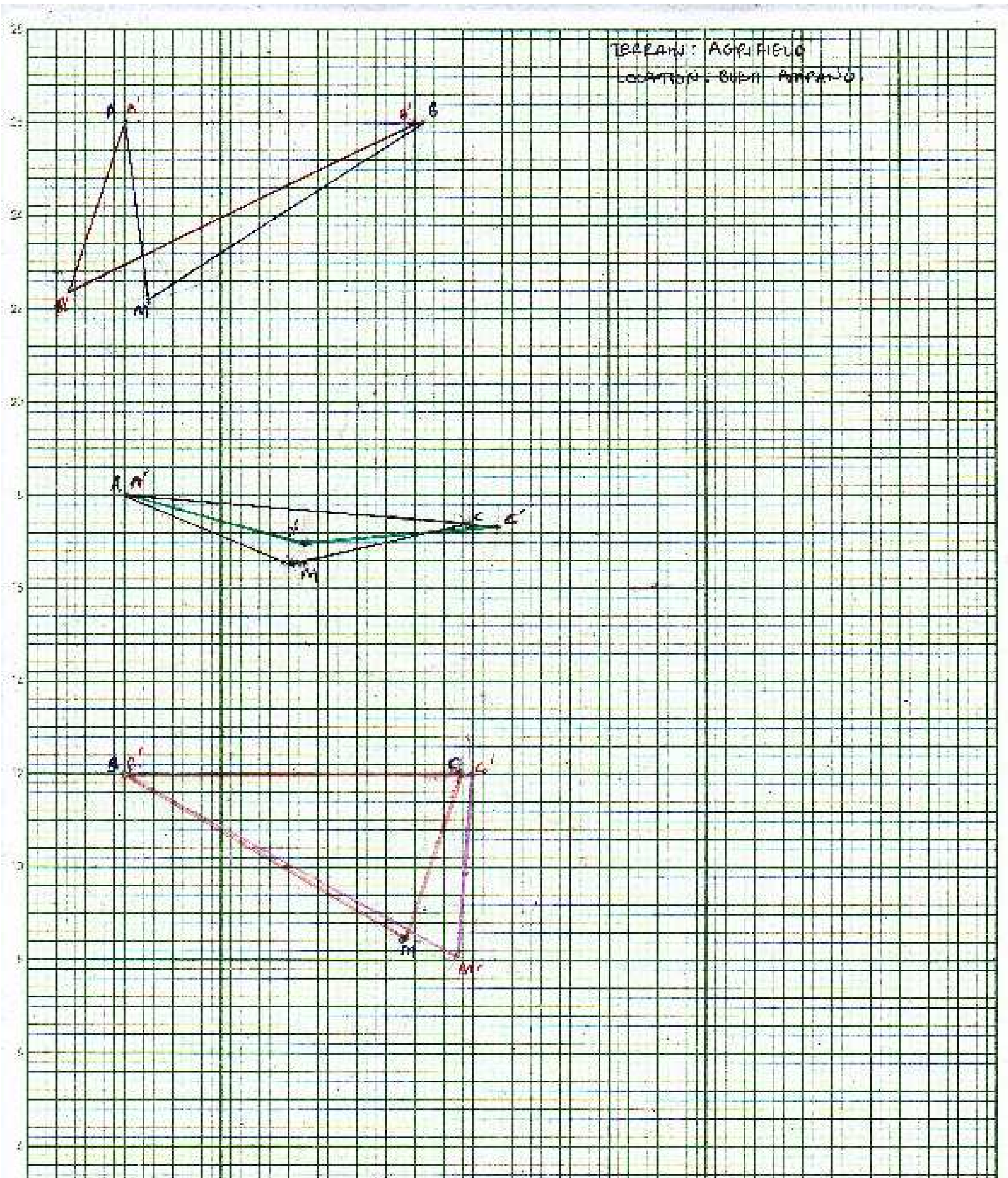
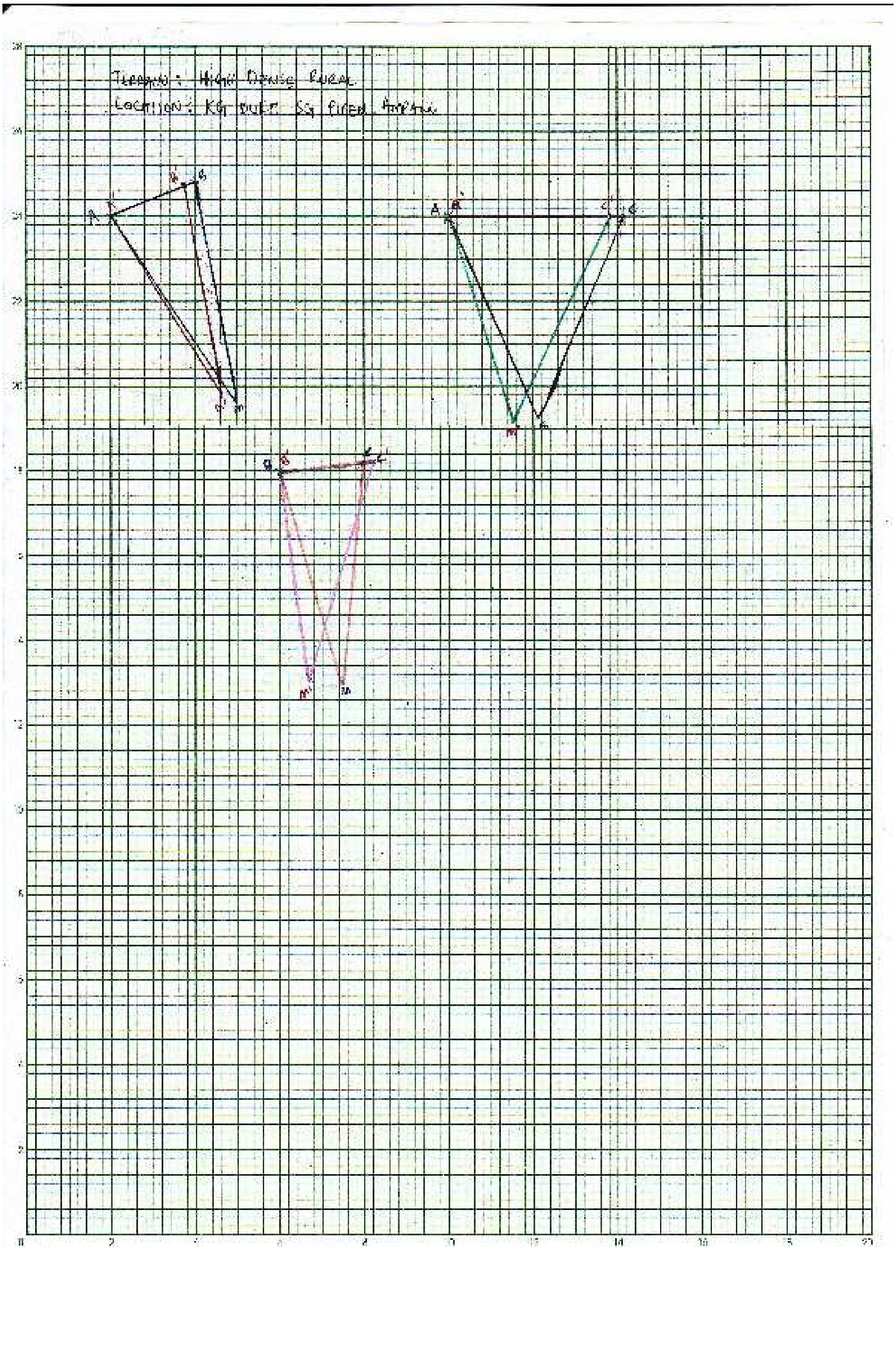
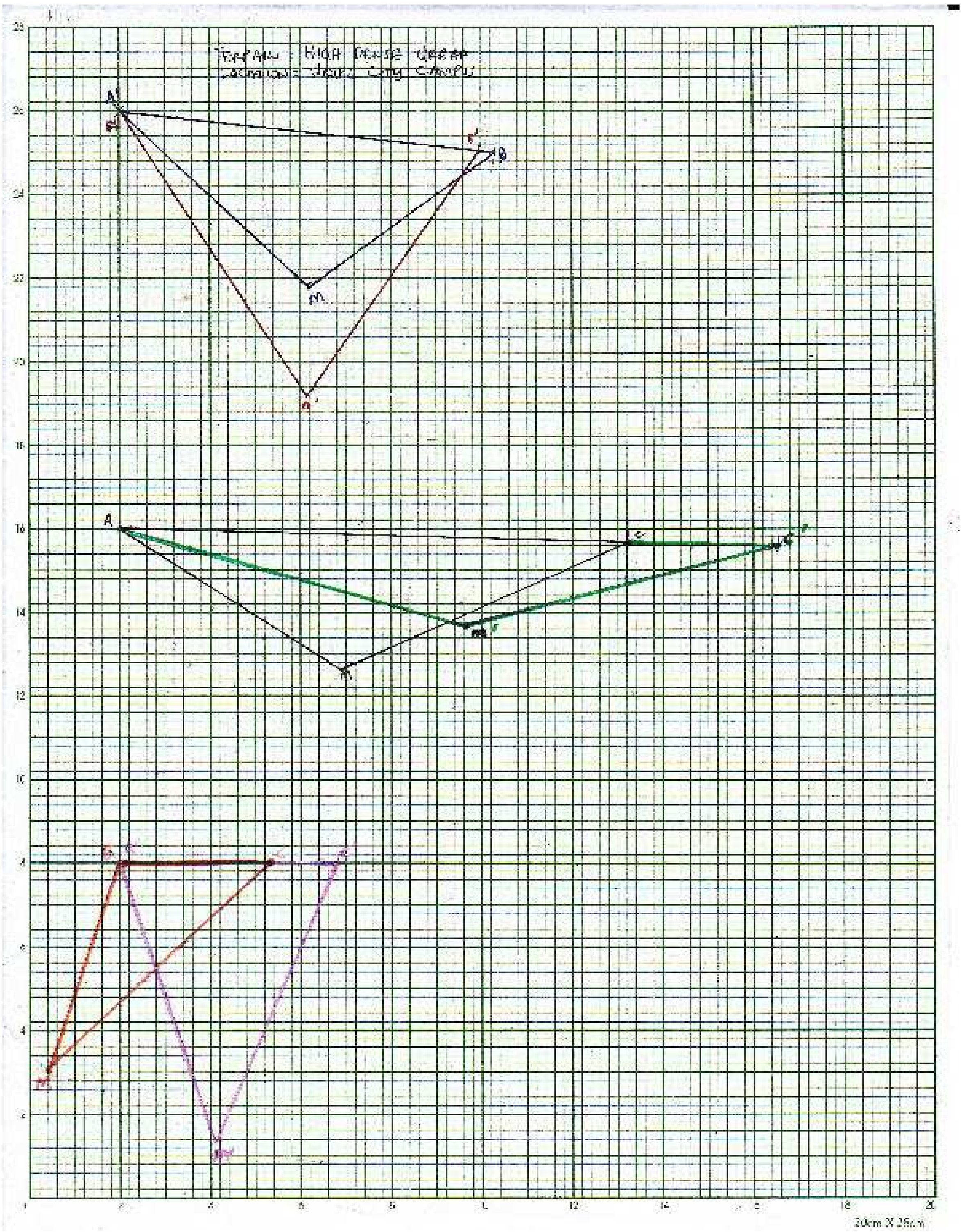


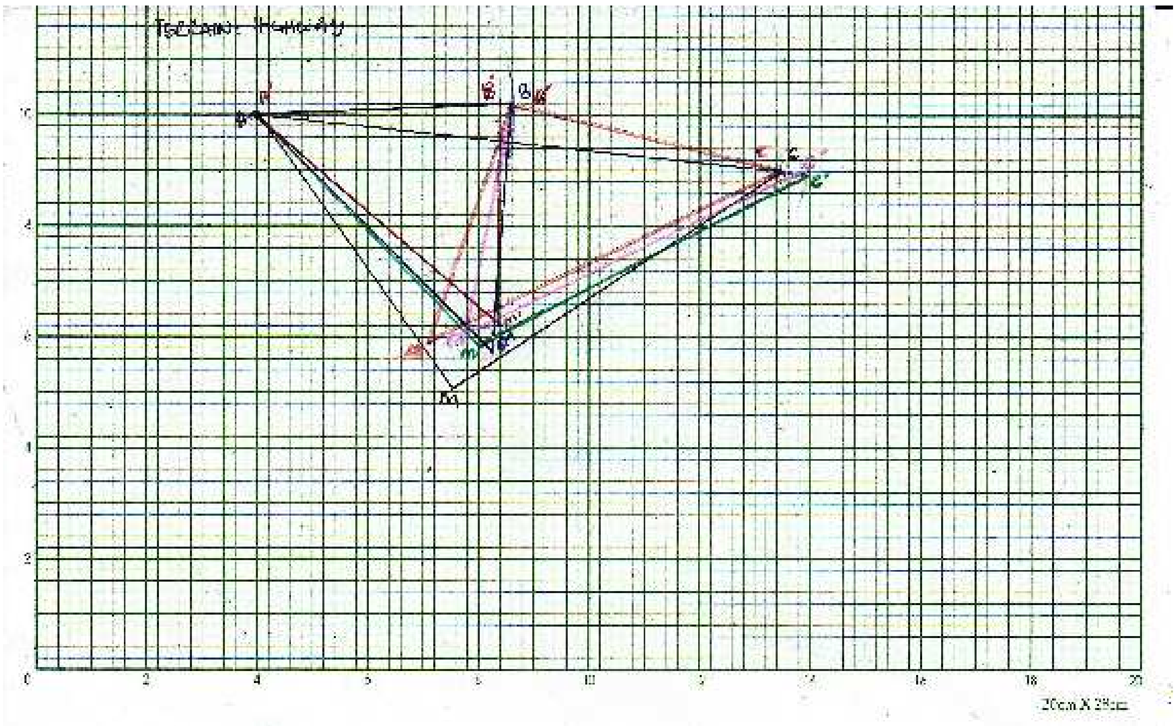
Figure E-40: ((∠ABM, ∠A'B'M'), (∠ACM, ∠A'C'M'), (∠BCM, ∠B'C'M')) for High Dense Urban

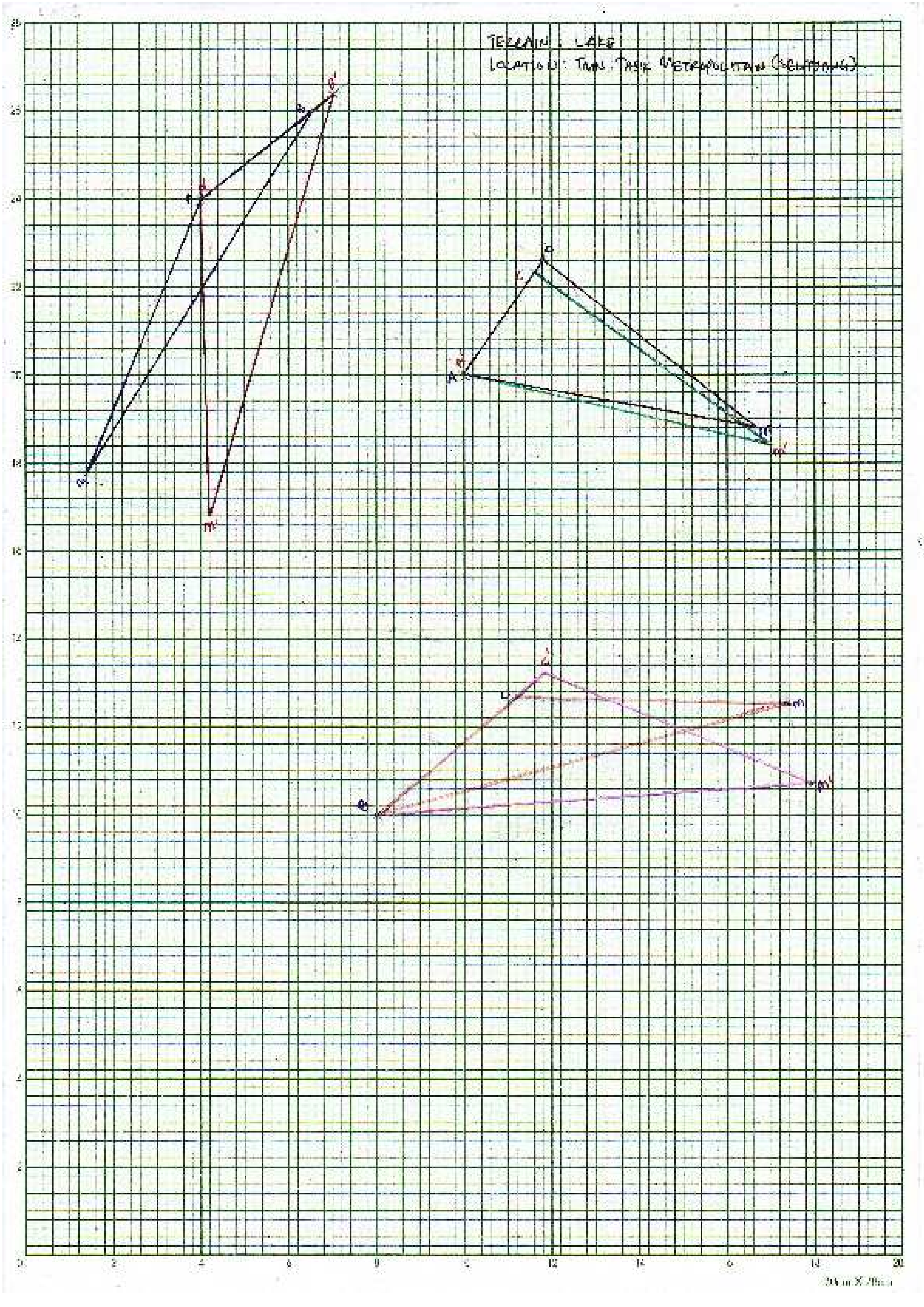
E.2: GRAPH PAPERS

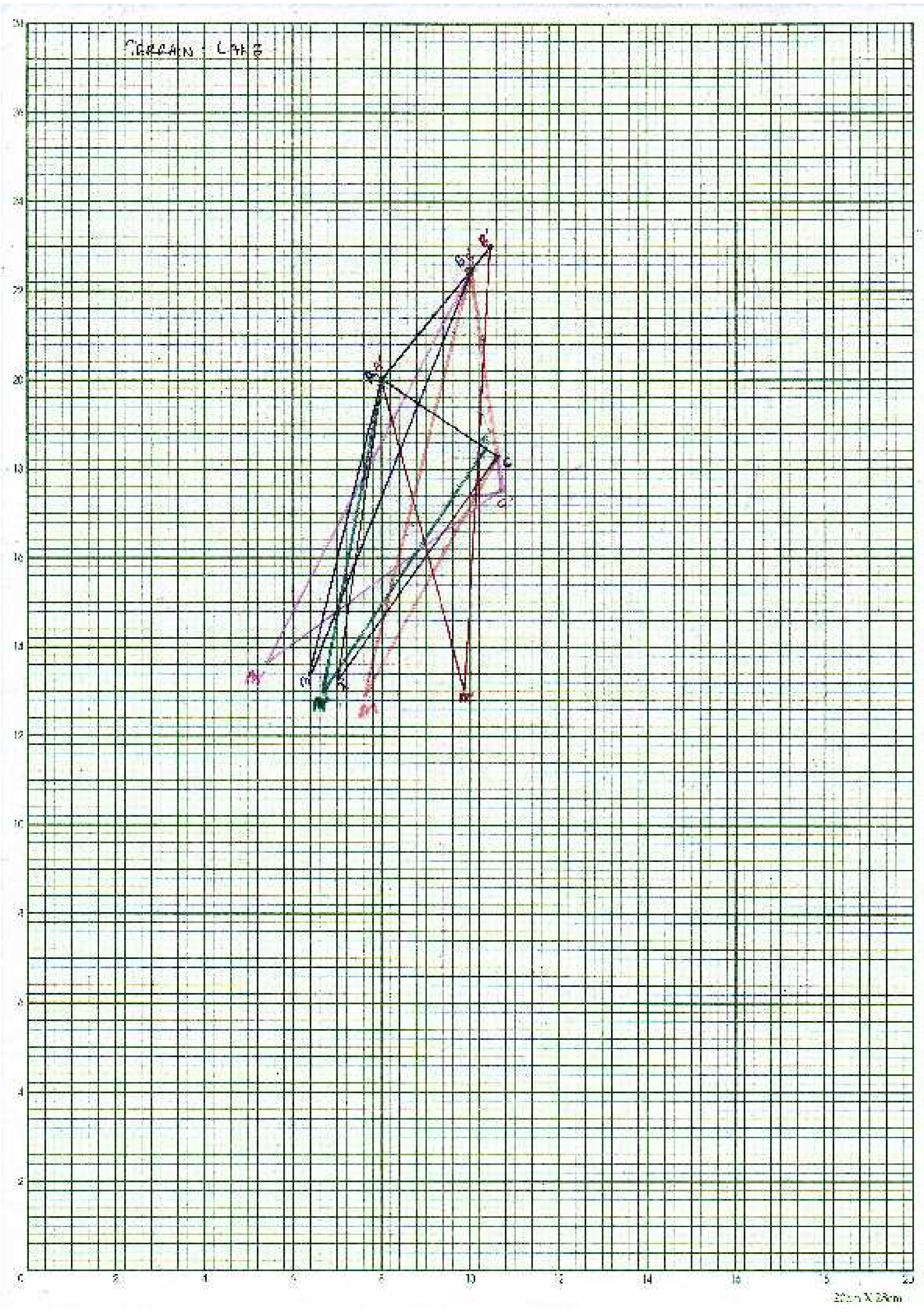


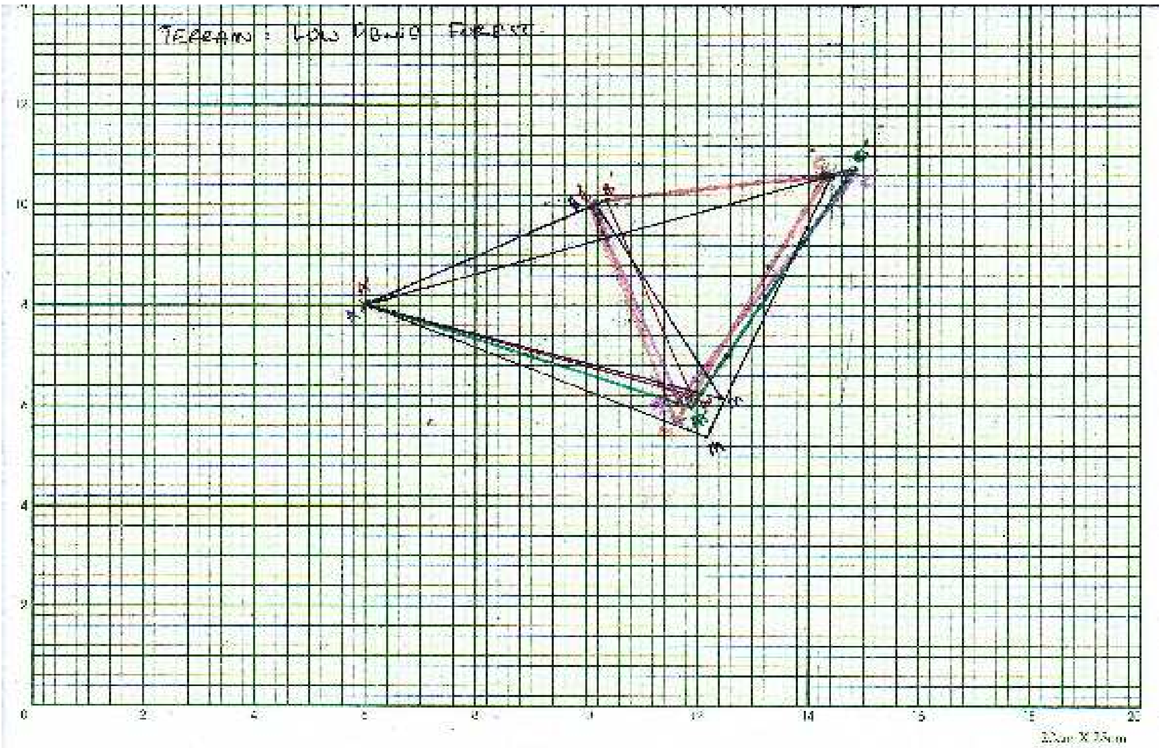

TERRAIN : HIGH DENSE RURAL
LOCATION :

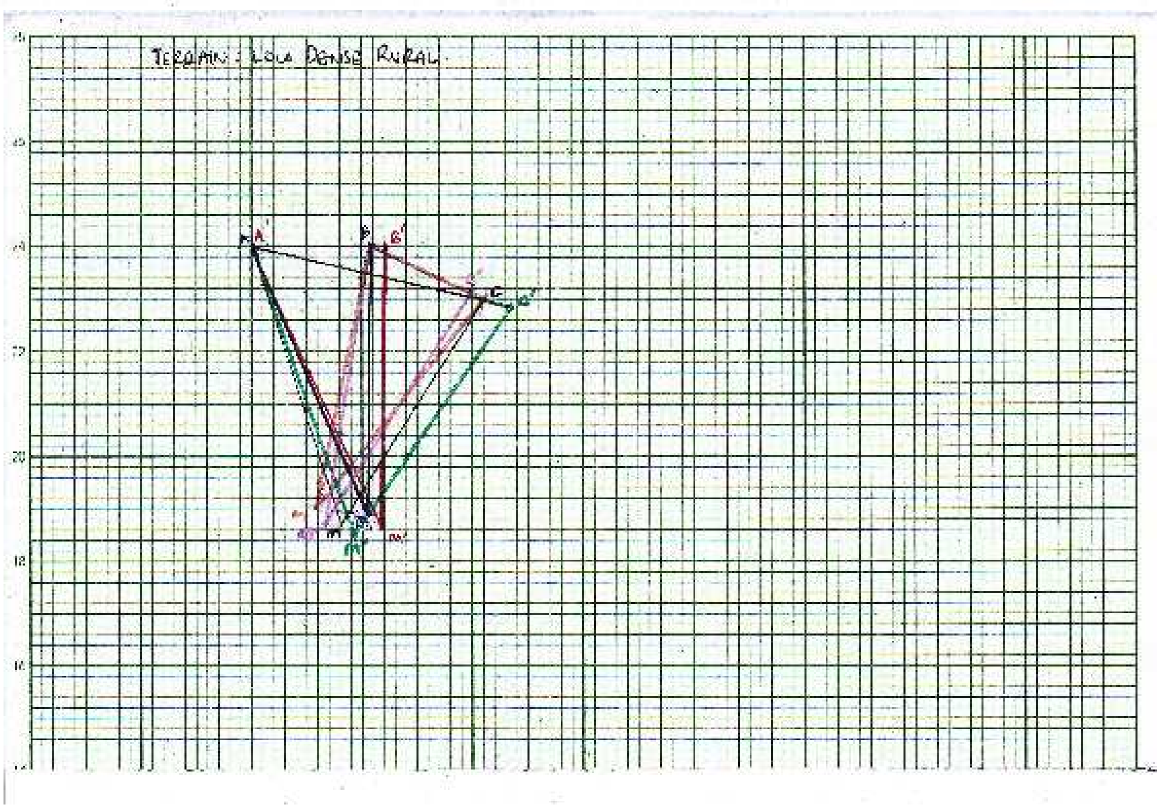


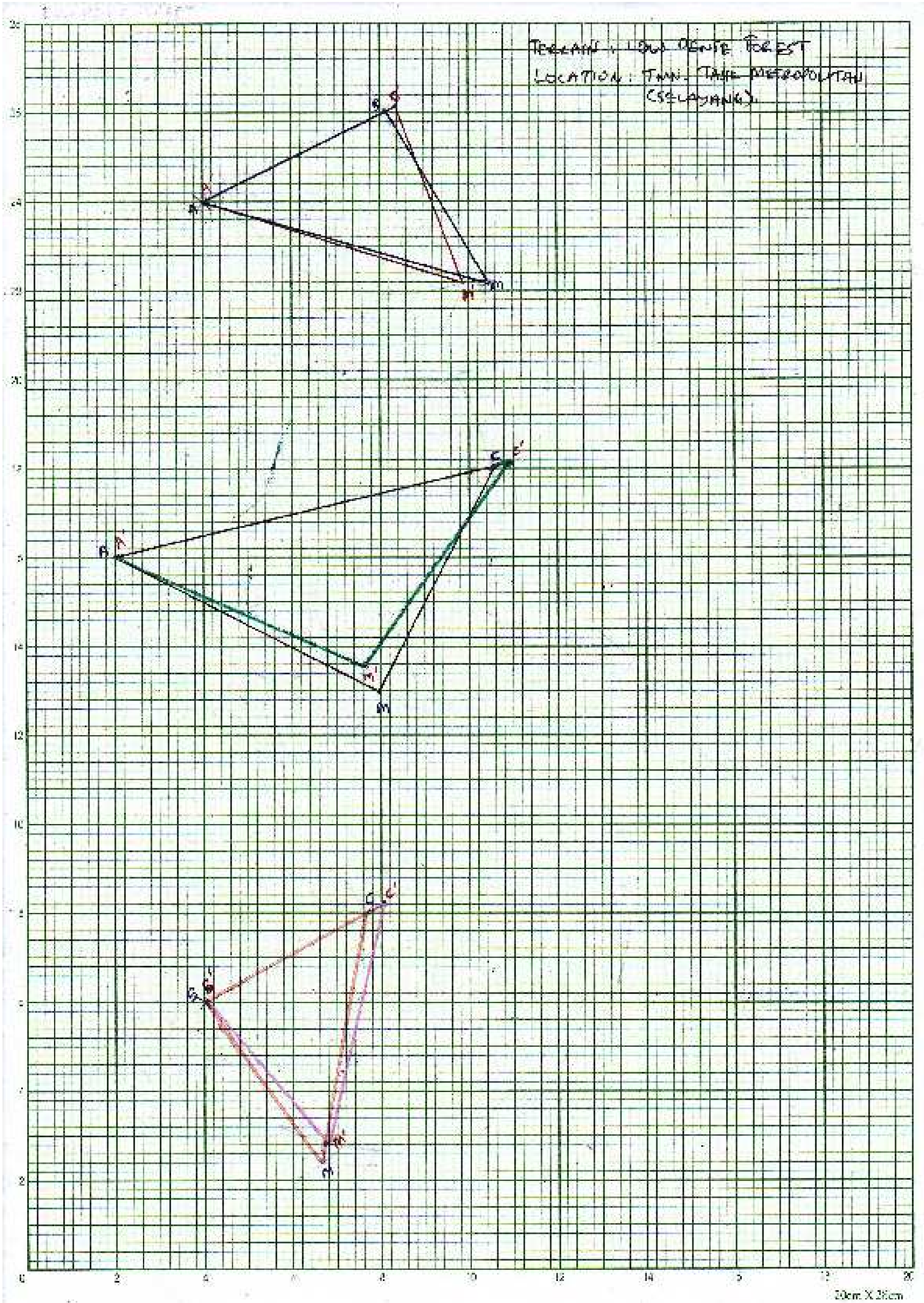


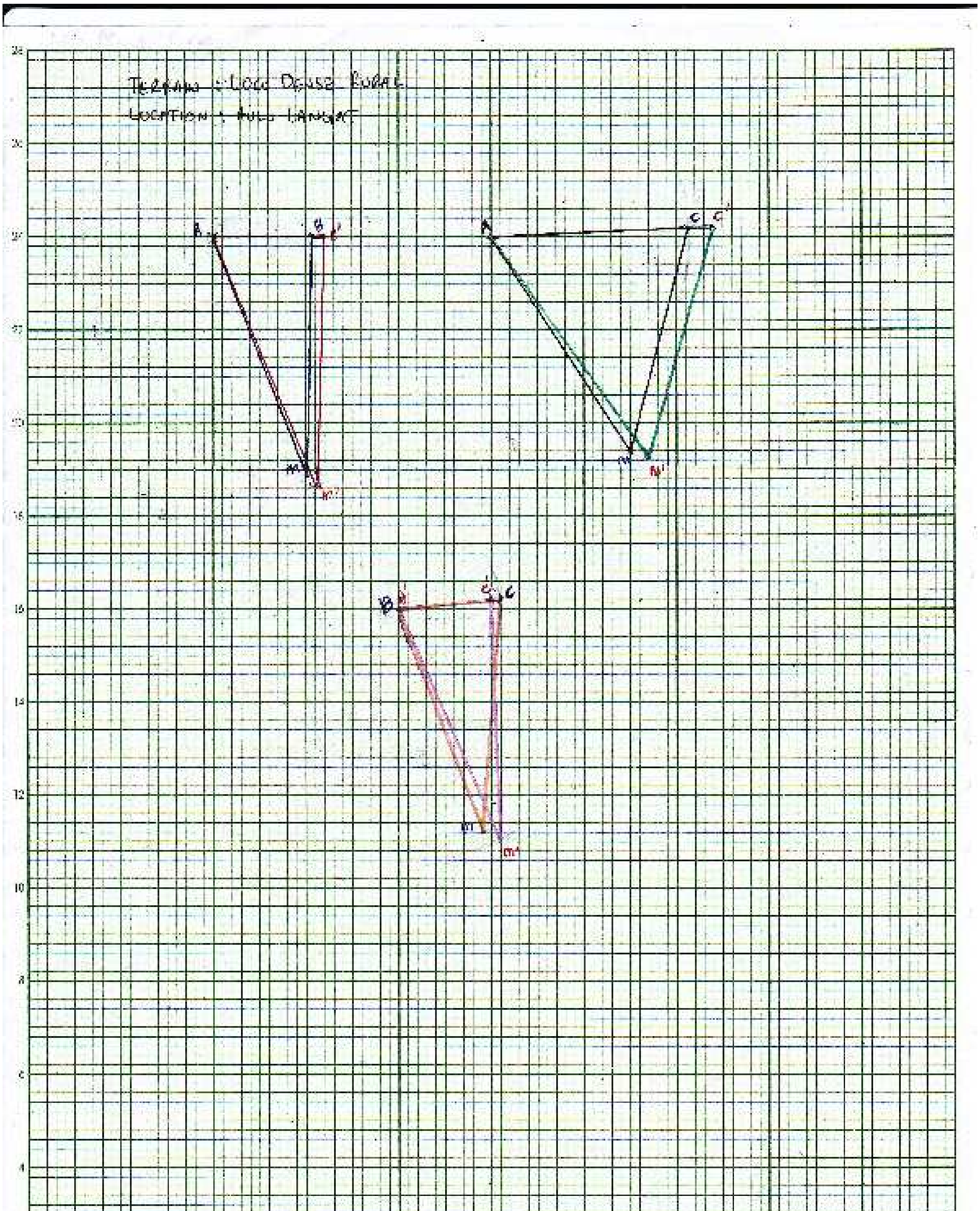

TERRAIN : LAKE
LOCATION : TMN. TASIK METROPOLITAN

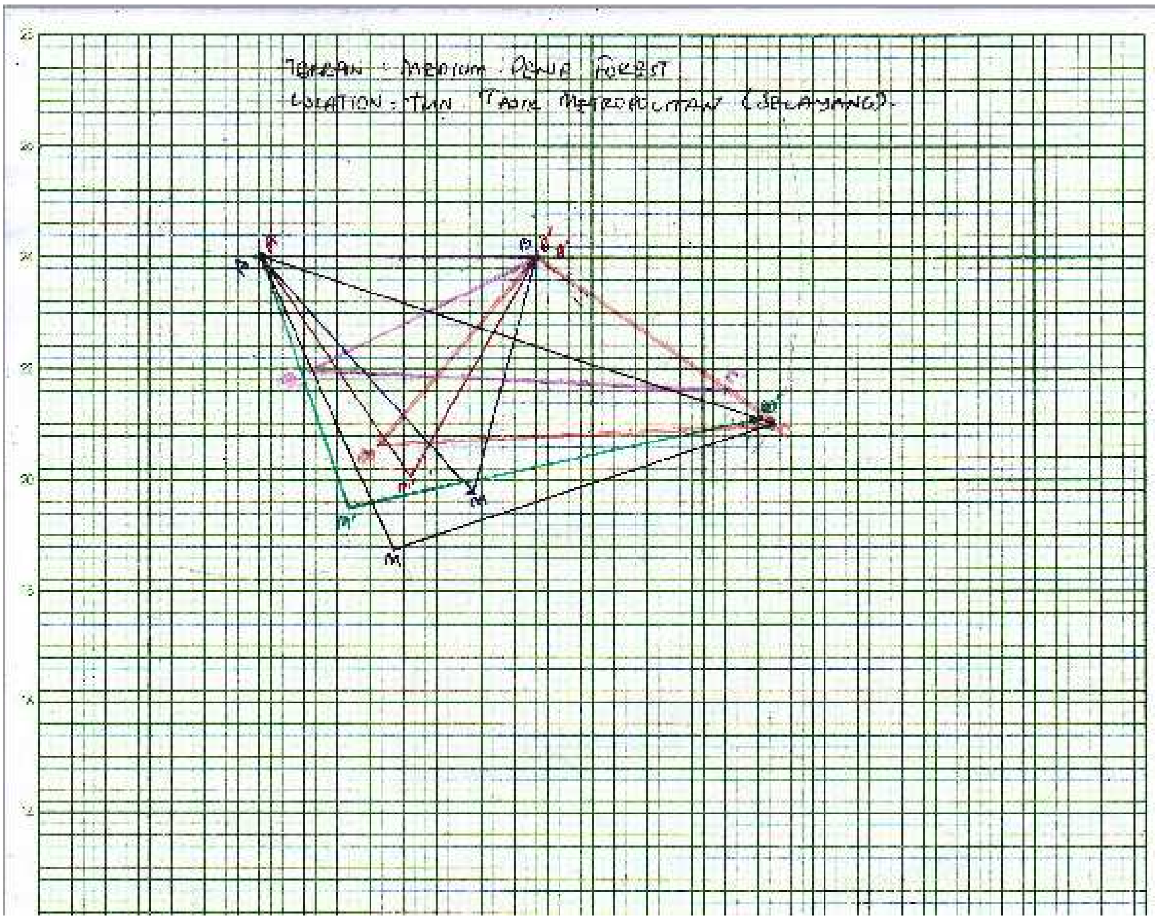


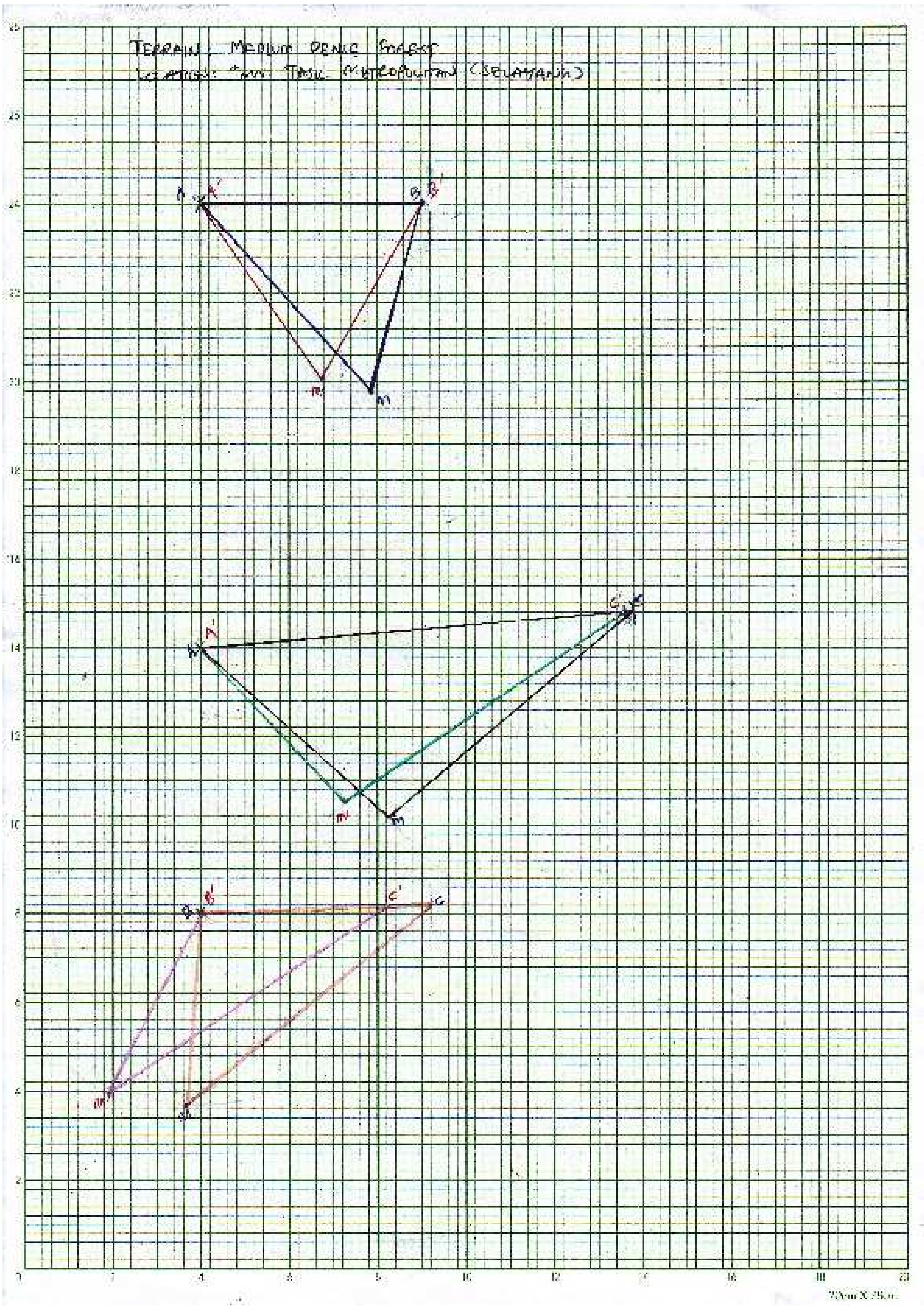

TERRAIN : LOW DENSE FOREST

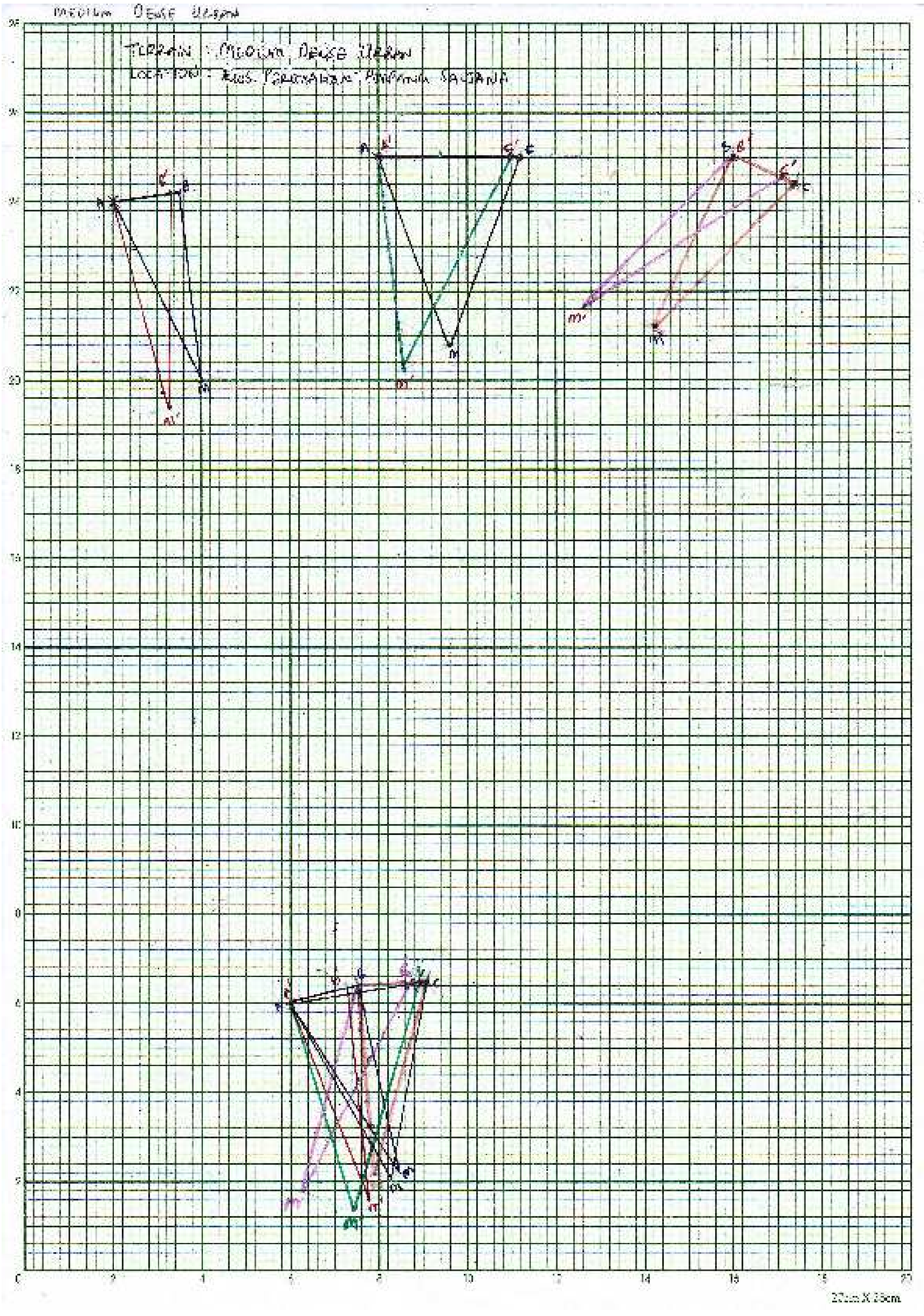

TERRAIN : LOW DENSE RURAL

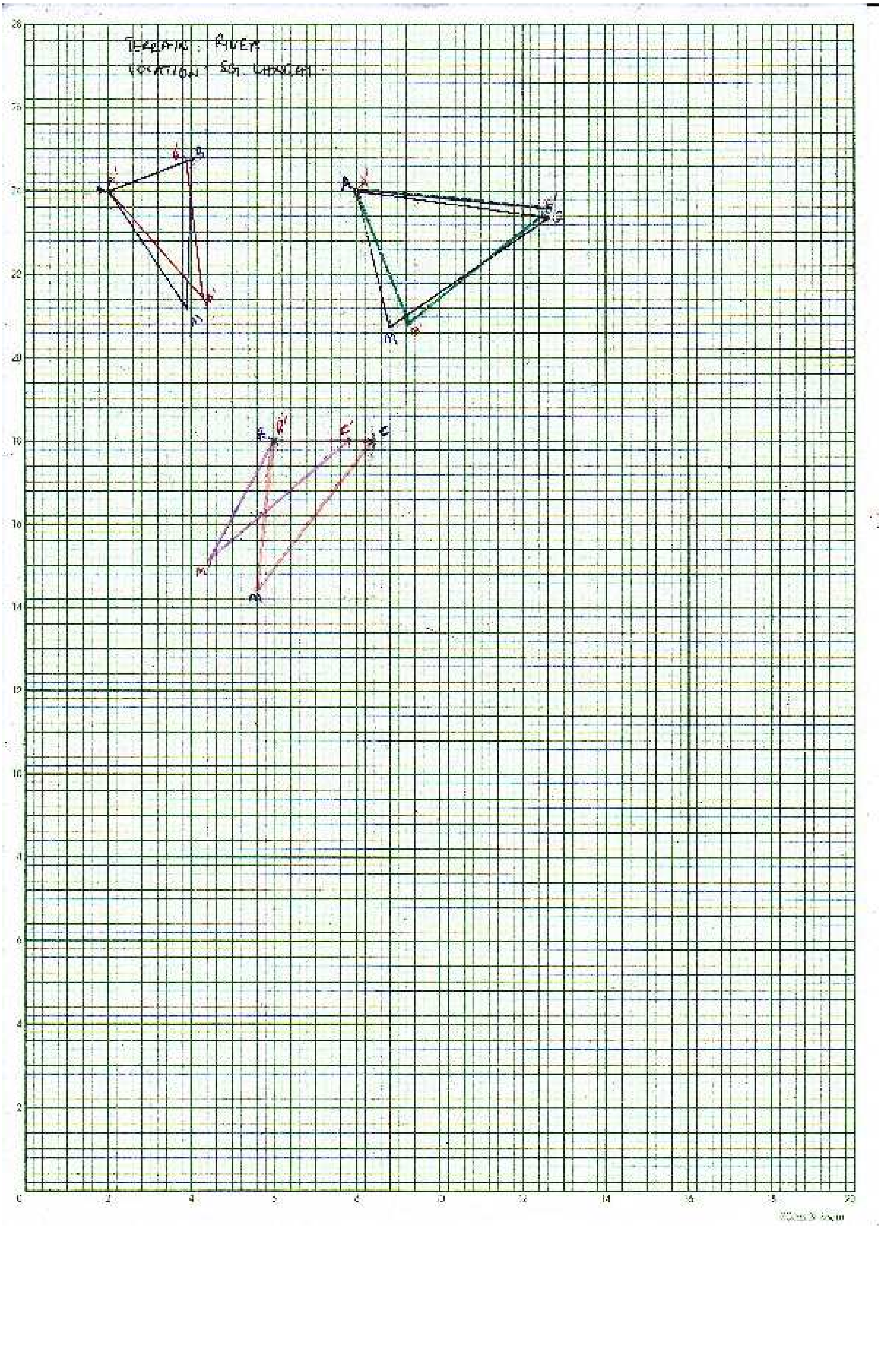

TERRAIN : LOW DENSE FOREST
LOCATION : TMN. TASIK METROPOLITAN (SELAYANG).
20cm X 28cm


TERRAIN : LOW DENSE RURAL
LOCATION : HULU LANGAT

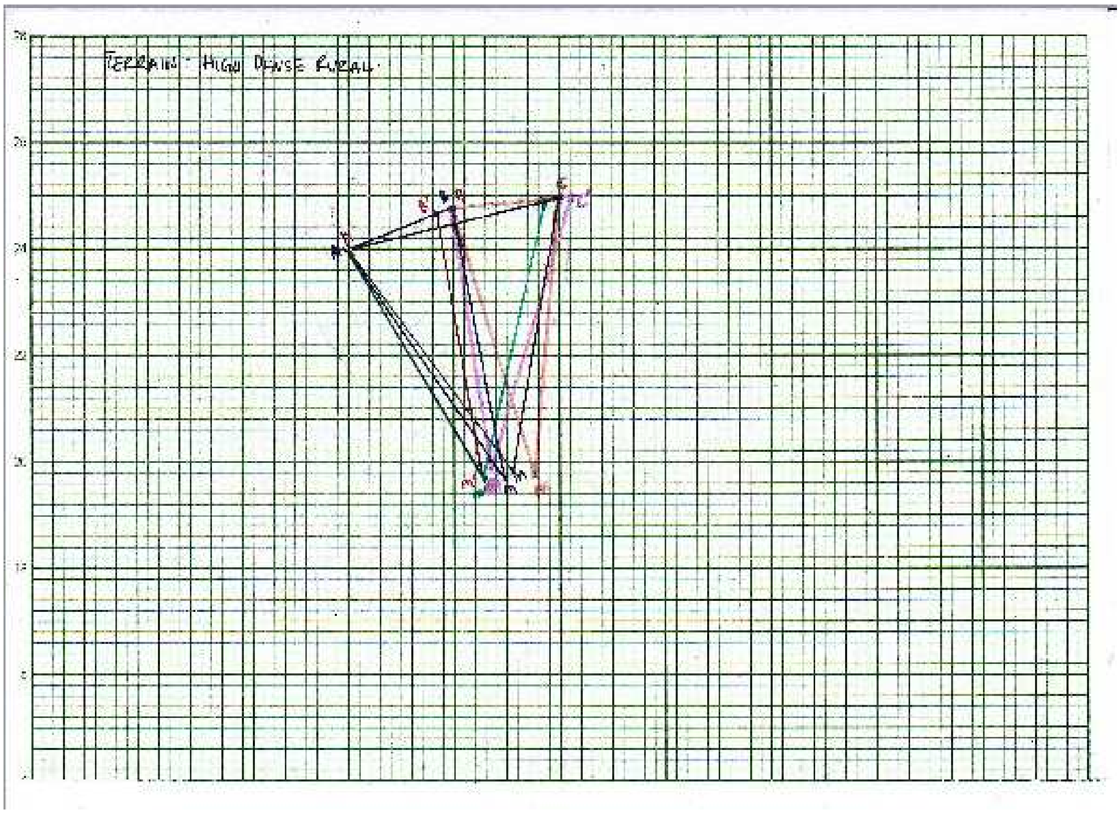

TERRAIN : MEDIUM DENSE FOREST
LOCATION : TMN TASIK METROPOLITAN (SELAYANG)

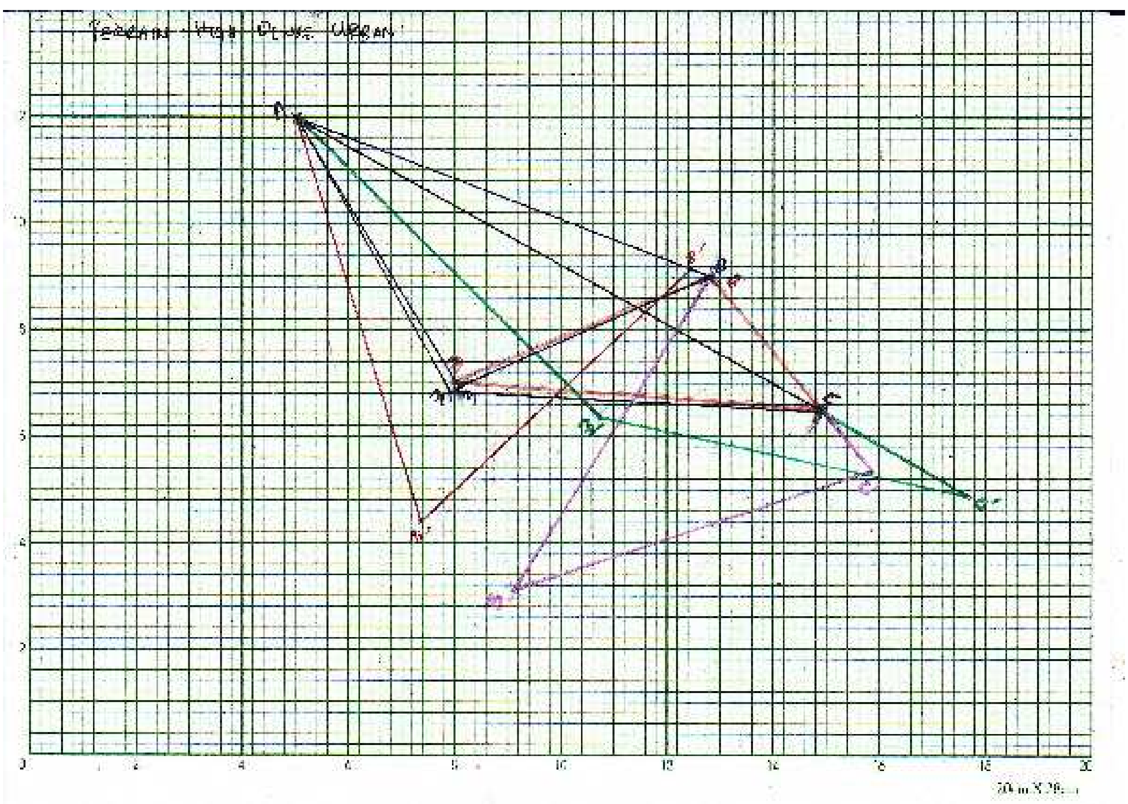


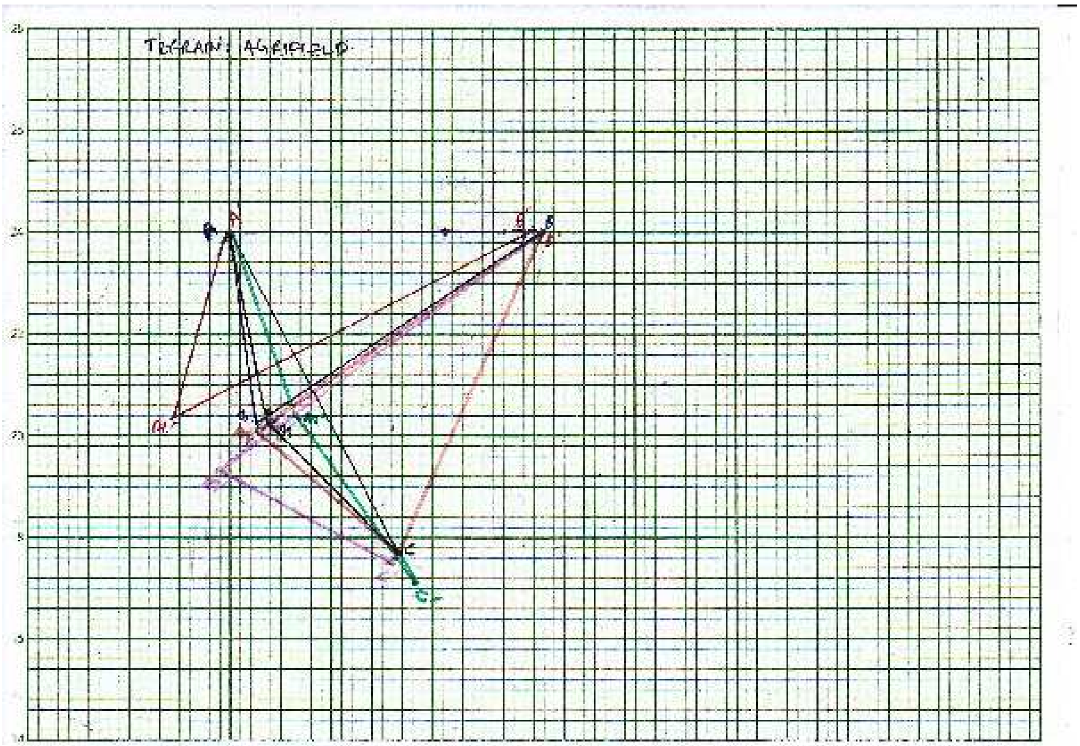

MEDIUM DENSE URBAN
TERRAIN : MEDIUM DENSE URBAN

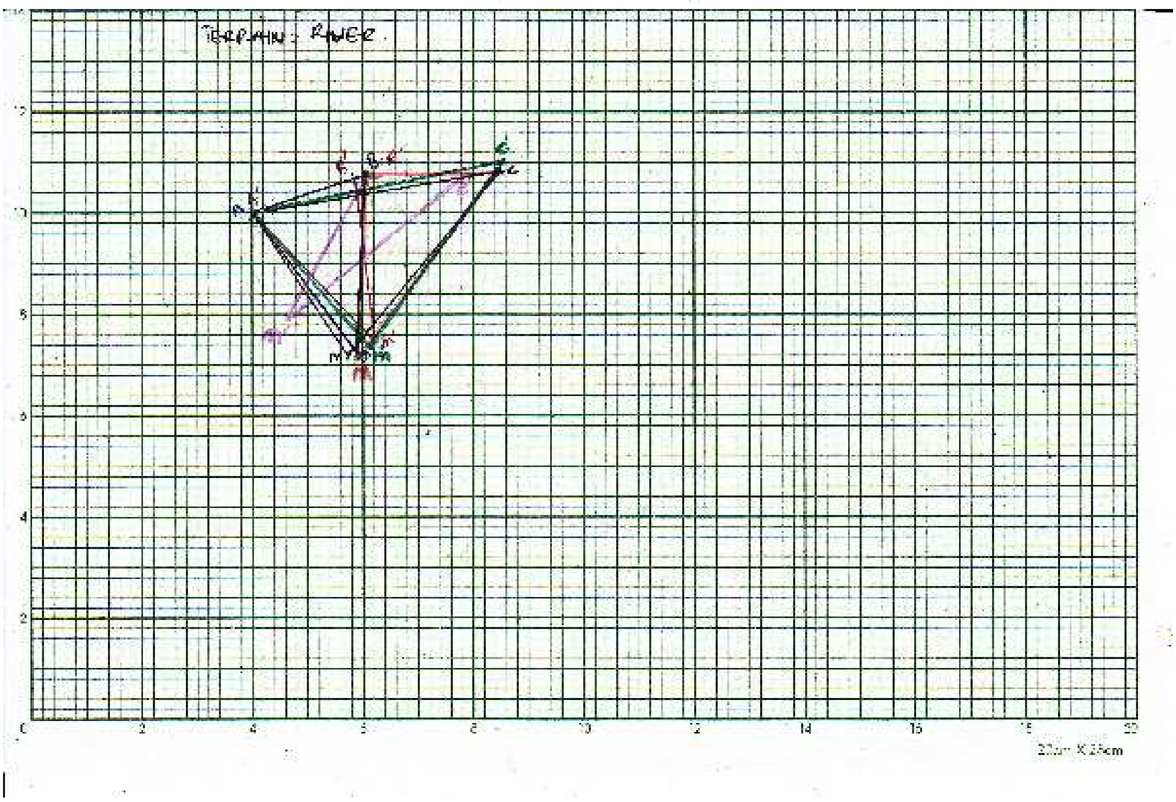


TERRAIN : RIVER
LOCATION : SG. LANGGAM


TERRAIN: HIGH DENSE RURAL


TERRAIN: HIGH DENSE URBAN


TERRAIN: AGRIFIELD


TERRAIN: RIVER
20cm X 25cm

E.3 TESTING PICTURES

Agri/Field

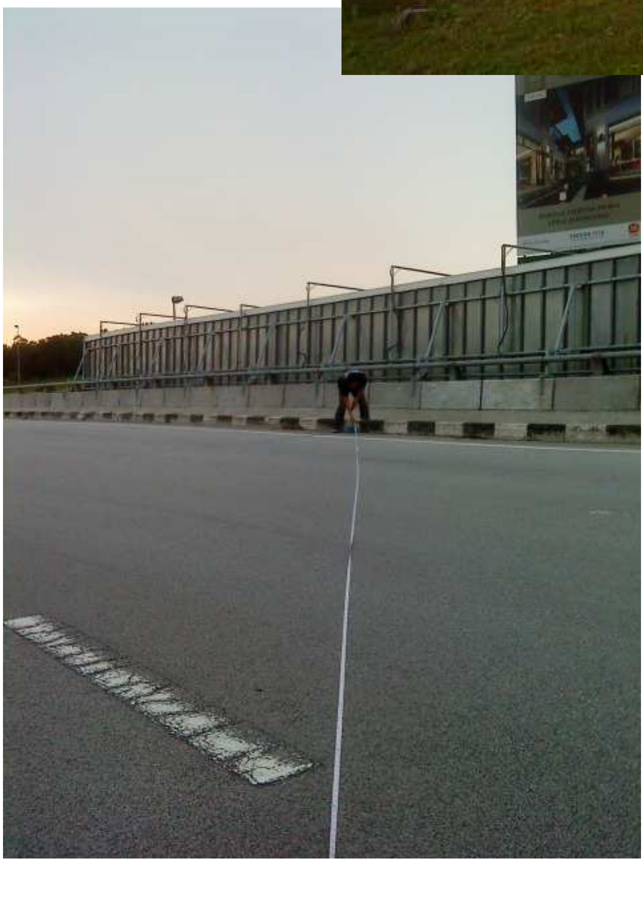
Low Forest

Dense Forest

Sea

River/Lake

Highway/Motorway



Low Dense Rural

High Dense Rural

High Dense Urban

Medium Dense Urban