

ANALYSES OF LOCATION-BASED SERVICES IN
AFRICA AND INVESTIGATING METHODS OF
IMPROVING ITS ACCURACY

Folasade Mojisola Dahunsi

A thesis submitted to the Faculty of Engineering and the Built Environment,
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the degree of Doctor of Philosophy.

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DECLARATION

I declare that this thesis is my own unaided work, except where otherwise acknowledged. It is being submitted for the Degree of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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Folasade Mojisola Dahunsi

Signed thisday of May, 2012

ABSTRACT

The subject area of this thesis analyses the provision of location-based services (LBS) in Africa and seeks methods of improving their positional accuracy. The motivation behind this work is based on the fact that mobile technology is the only modern form of information and communication technology available to most people in Africa. Therefore all services that can be offered on the mobile network should be harnessed and LBS are one of these services. This research work is novel and is the first critical analysis carried out on LBS in Africa; therefore it had to be carried out in phases.

A study was first carried out to analyse the provision of LBS in Africa. It was discovered that Africa definitely lags much of the World in the provision of LBS to its mobile subscribers; only a few LBS are available and these are not adapted to the needs of the African people. A field data empirical investigation was carried out in South Africa to evaluate the performance of LBS provided. Data collected indicated that the LBS provided is not dependable due to the inaccuracy introduced by two major factors - the positioning method and the data content provided.

Analyzing methods to improve the positional accuracy proved quite challenging because Africa being one of the poorest continents has most mobile subscribers using basic mobile phones. Consequently, LBS often cannot be provided in Africa based on the capability of the mobile phones but rather on the capability of the mobile operator's infrastructure. However, provision of LBS using the network-based positioning technologies poses the challenge of dynamically varying error sources which affects its accuracy.

The effect of some error sources on network-based positioning technologies were analysed and a model developed to investigate the feasibility of making the RSS-based geometric positioning technologies error aware. Major consideration is given to the geometry of the BSs whose measurements are used for position estimation.

Results indicated that it is feasible to improve location information in Africa not just by improving the positioning algorithms but also by using improved prediction algorithms, incorporating up-to-date geographical information and hybrid technologies. It was also confirmed that although errors are introduced due to location estimation methods, it is impossible to model the error and make it applicable for all algorithms and all location estimations. This is because the errors are dynamically varying and unpredictable for every measurement.

DEDICATION

To God, my Alpha and Omega

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PUBLISHED WORK

1. Journal Papers

- Dahunsi F.M., Dwolatzky B., “An Empirical investigation of the accuracy of Location Based Services in South Africa,” *Journal of Location Based Services*, DOI 10.1080/17489725.2011.625303, pp. 1- 13, 2011.
- Dahunsi F.M., Dwolatzky B. and Love A., “Effect of Distance on the Accuracy of RSS-Based Geometric Positioning Methods,” *SAIEE Africa Research Journal*, vol. 103, no. 3, 2012.
- Dahunsi F.M. and Dwolatzky B., “Towards the Deployment and Adoption of Location-based Services for Optimal Mobile Communication Operations in Africa,” accepted for publication in *The African Journal of Information Systems*, 2012.

2. Submitted Journal Papers

- Dahunsi F.M., Dwolatzky B., “Investigation of Error-Aware Network-based positioning,” submitted to *Journal of Wireless Communication and Mobile Computing*, 2012.

3. Conference Papers

- Dahunsi F.M., Dwolatzky B., “Statistical Analysis of the Accuracy of Location Measurements Provided for LBS in South Africa,” in *10th International IEEE African Conference (AFRICON)*, Livingstone, Zambia, 13 - 15 September 2011.
- Dahunsi F.M., Dwolatzky and Love A., “Analysis of the impact of some network parameters on the accuracy of RSS-based geometric positioning methods,” in *Southern Africa Telecommunication Networks and Applications Conference (SATNAC)*, East London, South Africa, 5 - 8th September 2011.

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- Dahunsi F. M. and Dwolatzky B., “Improving the QoS of Location Services Using Adaptive and Environment-Aware Positioning,” poster Presentation at SATNAC 2009 *South African Telecommunication Networks and Applications Conference*, Manzini, Swaziland, 31st August - 2nd September, 2009.

LIST OF SYMBOLS

2G	Second Wireless Network Generation
2.5G	An Upgrade of Second Wireless Network Generation
3G	Third Wireless Network Generation
4G	Fourth Wireless Network Generation
3GPP	3G Partnership Project
A-FLT	Advanced Forward Link Trilateration
AGPS	Assisted Global Positioning System
AOA	Angle of Arrival
ARPU	Average Revenue per User
BS	Base Transceiver Station
BSC	Base Station Controller
CDMA	Code Division Multiple Access
Cell-ID	Cell Identification
COG	Centre of Gravity
COT	Centre of Trilateration
EC	European Union Commission
ECEF	Earth-Centered Earth-Fixed
EOTD	Enhanced Observed Time Difference
EIR	Equipment Identity Register
FCC	Federal Communication Commission
GDP	Gross Domestic Product
GIS	Geographical Information System
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communication
HLR	Home Location Register
ICT	Information Communication Technologies
ITU	International Telecommunication Union
LBS	Location-based Services

LMU	Location Management Unit
LOS	Line-of-Sight
LS	Least Squares
MS	Mobile Station
MSC	Mobile Services Switching Centre
NLOS	Non-Line-of-Sight
OTDOA-IPDL	Observed Time Difference of Arrival Idle Period Downlink
PLMN	Public Line Mobile Network
QoS	Quality of Service
R	RAND (Currency)
RMSE	Root Mean Squared Errors
RSS	Received Signal Strength
RxLev	Received Signal Power Level
SMS	Short Message Service
SMLC	Serving Mobile Location Centre
TA	Timing Advance
TDOA	Time Difference of Arrival
TRAU	Transcoding Rate and Adaptation Unit
UMTS	Universal Mobile Telecommunications System

LIST OF NOTATIONS

f_c	transmitting frequency
h_{BS}	base station height
h_{MS}	mobile station height
D	distance between the transmitter(BSs) and receiver(MS)
$a(h_{MS})$	mobile antenna height correction factor for different environments
α	environmental factor
P_{LC}	Okumura Hata urban area prediction path loss model
P_{SU}	Okumura Hata suburban area prediction path loss model
P_{OA}	Okumura Hata open or rural area prediction path loss model
RSS, R	received signal strength
n	number of BSs
N	normalization constant
K	scaling factor
x_{min}, y_{min}	probable area of MS
x_{max}, y_{max}	probable area of MS
x_i, x_{BSi}	x coordinate of BS i
y_i, y_{BSi}	y coordinate of BS i
$\hat{x}_{MS}, \hat{y}_{MS}$	estimated coordinates of MS
x_{MS}, y_{MS}	actual coordinates of MS
x_{BS}, y_{BS}	actual coordinates of BS
$x_{(MBS)i,k}, y_{(MBS)i,k}$	coordinate of the i^{th} model geometry BS in the k^{th} quadrant
χ_k	deviation of the actual BS from the model BS in the x direction in the k^{th} quadrant
γ_k	is the deviation of the actual BS from the model BS in the y direction in the k^{th} quadrant
$x_{(ABS)i}, x_{(ABS)i}$	coordinate of the i^{th} actual BS

CHAPTER ONE

1 INTRODUCTION

1.1 GENERAL BACKGROUND

This thesis has two major areas of interest - analyses of the provision of location-based services (LBS) in Africa and investigating methods of providing accurate LBS in Africa for a more optimal use of the mobile network. The purpose of this chapter is to provide a motivation for the thesis and give a brief overview of ideas the thesis is built on.

1.2 MOTIVATIONS FOR LBS IN AFRICA

Developing countries are caught up in the worldwide mobile technology evolution and Africa is no exception, though a bit slower. Until the year 2000, fifty (50) of the fifty-four African (54) countries had less than 40 percent mobile phone coverage [1]. By 2008, 65 percent of the African population had access to mobile phone coverage even though barely a quarter of the African population have access to electricity. This is shown figuratively in Figure 1.1 [1, 2]. In Africa, mobile technology has not only been accepted, the mobile station(s) (MS) has become the ubiquitous form of communication. The penetration of mobile technology into rural Africa is particularly dramatic where mobile phones are the first contact the populace had with modern telecommunication infrastructure [2].

In Africa especially in rural areas, the mobile network infrastructure is made up of mainly 2G (second wireless network generation) networks. South Africa with the most advanced mobile network in Africa is a good indication of this. VODACOM South Africa with the largest network coverage in the country has about 99.7 percent 2G coverage and 54 percent 3G coverage. With a total urban coverage of 27,272 km²

and total rural coverage of 1,191, 818 km², 2G rural coverage was 81.8 percent while 3G rural coverage was just about 7.3 percent [3]. This might be because a large percentage of users only use voice and short messaging service (SMS) services. Consequently, rolling out more advanced mobile network in most areas do not present economic importance. This might also be due to the low average revenue per user (ARPU) in most areas. Even though the major services presently offered are voice and SMS, the economic benefits currently enjoyed are enormous. Such benefits include communication among social and business networks, job creation and development projects using “m - development” [1, 2, 4].

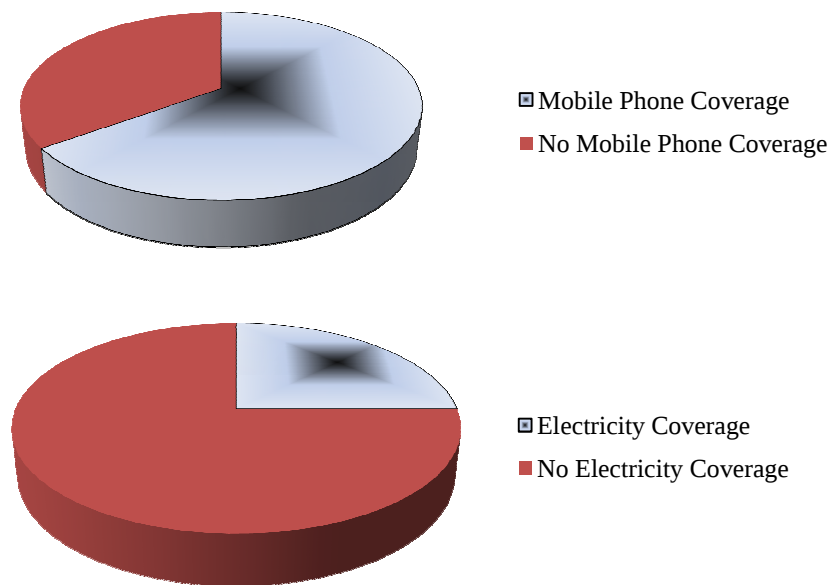


Figure 1.1: Mobile phone coverage and electricity coverage in Africa in the year 2008 [1, 2]

Even with the limitations presented by the mobile infrastructure in Africa, there are many other services which can be introduced in order to optimize the major communication technological penetration available to them: mobile technology. Such new services include mobile money services; location-based content services, menu driven information services et cetera.

1.3 RESEARCH BACKGROUND

LBS enable mobile users to connect to points of interest around a particular geographical location providing personalized real - time services based on location [5, 6, 7, 8, 9, 10]. These services are location information services based on wireless mobile technology and are accessible through mobile stations (mobile phones, Personal Digital Assistants (PDA), et cetera) [9, 10, 11]

Geographical location capability is a feature in the mobile network which makes it successful, attractive and optimized [5, 9, 10]. This is because it gives the mobile users access to location-based services anywhere and at any time. For example it assists in locating friends and family, enhances quicker rescue operations for emergencies, et cetera [7, 8, 9, 10]. Mobile operators also have the opportunity to provide value-added services and generate revenue from services other than voice and data [9, 10, 11].

LBS can therefore give mobile operators the much needed value-added services to increase their ARPU while at the same time optimizing all that the mobile network has to offer to African subscribers. LBS can help reduce the spread of tuberculosis, aid in a wider coverage area for immunization, economic empowerment and more. More examples of LBS which can be introduced in Africa are discussed in detail in Chapter Five, Section 5.7, and page 101 of this thesis.

In 1996, the Federal Communications Commission (FCC) of the United State of America (USA) adopted a report that enforced mobile operators in the USA to provide and deliver wireless emergency service (E911) [11, 12]. The E911 report became a major driver of LBS to enhance effective location based emergency service delivery sent from MS(s) to Public Safety Answering Points (PSAPs) (911 call centres) [12].

According to USA FCC regulations, MS-based positioning technique must provide an accuracy of 50m to 67 percent of calls (150 m for 95 percent of calls) while

network-based E911 service is to provide an accuracy of 100 m to 67 percent of calls (300 m for 85 percent of calls) [11, 12]. The mobile operators in a bid to obey the FCC rules, invested many resources in their mobile network thereby paving the way for commercial LBS as well [10], [11]. The European Union (EU) commission (EC) also issued a directive in 2002 ("Directive 2002/22/EC" 2002) enforcing the Enhanced 112 (E112) a variant of the USA's E911 [13].

1.3.1 Performance Evaluation of LBS

The LBS presently offered by most LBS providers to subscribers often present very limited or no guarantee of service [14] and studies of LBS accuracy presented in [15] reiterate the fact that the quality of service (QoS) of LBS varies. It can vary based on many factors such as: the mobile operator, positioning technique, type of LBS, position of the MS relative to the base station (BS) and geographical location of the MS (rural, suburban or urban), the location information provider et cetera. Mobile operators today try to offer and are required to offer LBS with most of the following characteristics to ensure maximum returns on users' expenses: good location accuracy, quick response time, QoS, high reliability, anywhere service / any location and high flexibility [7].

There are three negotiable QoS parameters of LBS [7]. These are vertical and horizontal accuracy of the geographical location and the response time of providing the location service. Currently, for emergency purposes and most LBS offered, the vertical accuracy is not considered [7]. Vertical accuracy and response time are not requirements for the provision of most LBS. The horizontal accuracy is the major requirement to be met. Therefore, in this thesis, the vertical accuracy and response time will not be considered while horizontal accuracy is referred to as "accuracy".

LBS users depend on the QoS offered to effectively utilize location information provided to them [10, 16]. This is because LBS assist users to perform location dependent tasks for example consider a request made for the location of the nearest hospital. The user is dependent on the QoS offered by the LBS provider to make an

informed decision based on the location information service provided. Therefore a failure in the accuracy of the location information provided translates to a failure in the decision made. This reiterates the importance of good service delivery to LBS users [16]. A reliable and dependable LBS occurs when an LBS is provided in response to an LBS request and, on getting to the user, assists in an informed location-based decision. Accuracy of LBS provided to subscribers is therefore very important.

a. Accuracy

Accuracy is one of the major parameters that determine the QoS of LBS. Though it should also determine if specified LBS can be deployed at a particular location or not, but this is not always the case. The accuracy requirement of LBS differs, e.g. the local weather report does not need as high a level of accuracy as an emergency call or a child tracker as shown in Table 1.1 [7, 10]. The accuracy requirement presented in Table 1.1 is that expected from both developing and developed countries.

There are two major ways in which error or inaccuracy can be introduced into LBS. The first is inaccuracy in estimating the position of a MS by the mobile network operator and the second is the inaccuracy introduced by the location information made available by the data and content provider. Location information and positional accuracy are two very important factors of geographical information made available to users on request. Effective and reliable LBS not only require accurate positioning technology, it also needs dependable and reliable location information [17].

1.3.2 Basic LBS Components

Location-based services have five basic components according to Stienger et al [9], MS(s), communication network, service and application provider, data and content provider and the positioning. Figure 1.2 shows the relationship between the components.

a. Mobile station (MS)

A MS is a device used by a subscriber to access services on the mobile network and it is also used to request for and receive geographical location information for LBS.

Table 1.1: Examples of LBS service and their requirements (adapted from [7], [10])

Service Category	Horizontal Accuracy	Vertical Accuracy	Response Time	Periodic Location Reporting	About the service
Emergency Service (Pull)	Network based: 100 m (67%) 300 m (95%) Mobile station based: 50 m (67%) 150 m (95%)	n/a	<5 sec.	Required Period TBD suggest 1-10 minutes	Activated by pressing the help button and an SOS is sent immediately to the required authorities
Emergency Alert Service (Push)	125 m	n/a	< 5 sec.	Required Period TBD suggest 1-10 minutes	From the emergency mgt team to the users in a particular area to warn them about dangerous situations)
Home-Zone Billing	Depends on billing zone (5 m – 300 m)	n/a	Depends on increments of billing.	Required depends on billing increment and coverage zone	Billing by Mobile operators will be location sensitive.
Fleet Management	125 m - Cell-ID	n/a	5 sec.	Required (1-10 minutes)	Authorization required.
Asset Management	10 m – 125 m	n/a	5 sec.	Required (1-10 minutes)	Authorization required
Person Tracking	10 m - 125 m	n/a	5 sec.	Required (1-10 minutes)	Authorization required
Pet Tracking	10 m – 125 m	n/a	5 sec.	Required (1-10 minutes)	Authorization required, special SIM or USIM might be required.
Routing to Nearest Commercial Enterprise	10 m - 125 m	n/a	5 sec.	Not required	Subscription required
Traffic Congestion Reporting	10m – 40 m	May be required for over-passes	5 sec.	Required (1-2 minutes)	Subscription required
Roadside Assistance	10 m - 125 m	n/a	5 sec.	Not required	Subscription required
Navigation	10 m – 125 m	n/a	5 sec.	Required (1-10 minutes)	Subscription required
City Sightseeing	10 m - 125 m	n/a	5 sec.	Not required	Subscription required
Localized Advertising	125 m – Cell-ID	n/a	Not sensitive (default to 5 sec.)	Not required	Subscription required
Mobile Yellow Pages	125 m – Cell-ID	n/a	5 sec.	Not required	Subscription required

b. Service and application provider

The service and application providers process the service requests of users and offer location information based on user's request.

c. Data and content provider

Location information is stored and maintained by the appropriate authorities for example, governmental or private mapping agencies or business and industry partners. Examples of such information include geographic data and information data of a particular area, state or country. These agencies or organizations maintain the maps by making sure that up-to-date information is stored and made available to service providers when needed.

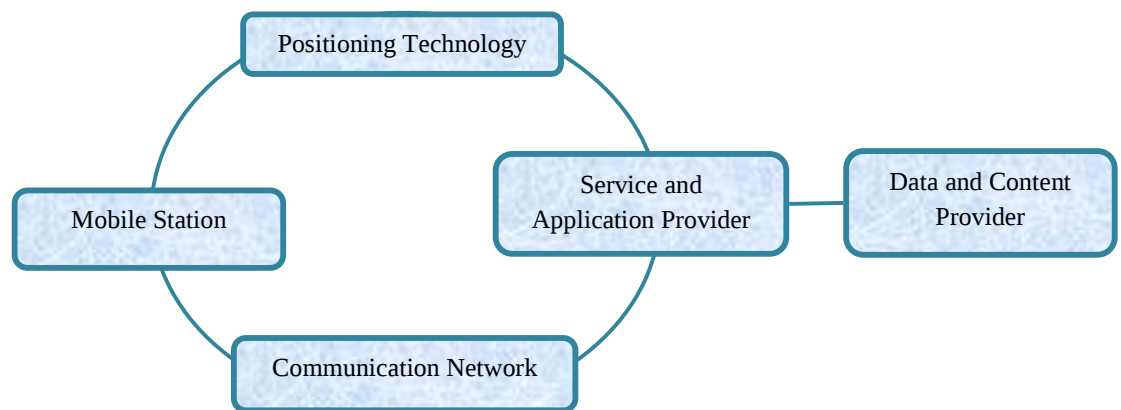


Figure 1.2: Basic LBS components (adapted from [9])

d. Communication network

This is the connection between a MS and mobile network operator. Due to the limitation in the capacity of MSs in Africa most users will have to depend largely on locating their positions based on the infrastructure and technology available on the Global System for Communication (GSM) network.

e. Positioning technology

This uses known measurements from fixed receivers/transmitters to estimate the location of a MS. Positioning techniques can be grouped in different forms such as those based on:

i. Number of measurements

Number of measurements needed for positioning is dependent on the type of technology to be used or needed [18], [15] and it can be:

- o Multilateral with multiple BSs simultaneously taking measurements to locate a MS.
- o Unilateral, where a MS takes measurement from multiple BSs and estimates its position. This is MS assisted positioning.
- o Bilateral with only one BS and the MS for positioning.

ii. Type of Handset

The handset might be modified or remain unmodified for positioning purposes [19]:

- o Modified MS solutions: this technique requires software or/and hardware modification of existing handsets.
- o Unmodified MS solutions: no modification is needed at the MS; modifications are carried out only at the BSs or the switching centre.

iii. Measurement and Estimation

Measurement of data and position estimation can be implemented on the mobile network, on the MS or combination of both [20]:

- o Network-based positioning uses the mobile network and is very important especially when global positioning system (GPS) solutions are not available or applicable [20].
- o MS-based positioning requires a smart phone with built-in GPS module to calculate its own position, and provides relatively higher accuracy when estimating the location of a MS than network-based positioning [21].
- o Hybrid positioning which can be either MS assisted or BS assisted and not strictly based on either the MS or the network and the estimation of the MS position can be carried out on either side.

1.3.3 Positioning of MS with No Built-in GPS Module

The mobile network is not the only feature which has evolved over the years. The MS has also evolved in size, features and capabilities. In late 2007, the mobile phone manufacturing sphere entered into the GPS world and started making mobile phones with built-in GPS modules [22]. This was attributed to the need by the mobile network operators to achieve the mandate created by the USA government for E-911 services [17]. With GPS positioning being more accurate will enable network operators will be able to achieve the E-911 report specification by a milestone. A GPS receiver receives precise orbit and transmit signal information from the GPS satellite and uses these to triangulate the exact position of the user on earth [23]. With a built-in GPS module on a MS, mobile services and accurate LBS services can be offered. Unfortunately, not all mobile subscribers can afford a MS with built-in GPS module therefore most users use a basic MS.

A basic mobile phone has all the capabilities needed for voice communication, SMS and other applications such as FM radio, memory space, organizer, games, low megapixel camera et cetera and they are available for between R70 and R400. The cheapest smart phone with built-in GPS module goes for about R1 500, more than fifteen times the amount for a basic mobile phone [24] (R–RAND is the currency of South Africa). A smart phone can be as expensive as a motorbike depending on its features and capabilities.

Africa is one of the poorest continents in the world with more than 30 percent of the African populace living on less than \$1 per day (R7.5 per day) and more than 40 percent of these people live in rural areas (shown in Appendix A Table A.1, page 202) [25]. Consequently, most mobile subscribers in Africa can only afford and therefore make use of a basic MS [26]. Considering these facts, the positioning technique best suited for the provision of LBS in Africa is the network-based positioning technique which can be provided to a basic MS without the need for an upgrade.

The handset pyramid shown in Figure 1.3 depicts this scenario better. About 75 - 87 percent of subscribers in Africa presently use basic phones and just about 3 - 5 percent use smart phones. The prices in [27] are quite different from what is available in the market in South Africa [24] and it should also be noted that not all smart phones have built-in GPS modules. This further reduces the percentage of users who have smart phones with built-in GPS modules.

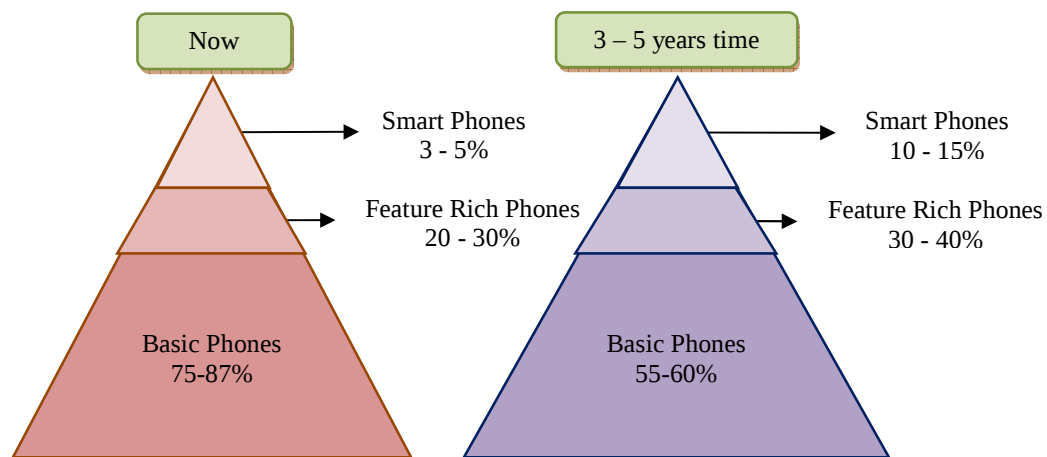


Figure 1.3: The handset pyramid (adapted from [27])

The cost of basic mobile phones is not the only issue to be considered, but also low power consumption and battery life. With only about a quarter of Africa having erratic electricity coverage [1], smart phones are quite difficult to maintain in Africa. In rural and even urban areas in Africa where there is no electricity coverage or erratic supply, MS users might only be able to charge their MS irregularly. Smart phones which are high-end devices consume much more electricity and their batteries drain faster than basic phones. A basic mobile phone has a battery life of about 400 hours while a smart phone battery hour is highly dependent on the type of service it is used for as shown in Table 1.2.

Table 1.2: Average battery life of a typical smart phone (adapted from [28])

Services	Talk time on 3G	Talk time on 2G	GPS services	Stand by time	Media, games, surfing the web
Battery life	5 hours	10 - 15 hours	5 hours	150 hours	< 5 hours

1.3.4 LBS in Africa

Global LBS platform revenue reached about US\$510 million in 2010 and it is expected to reach a record high of about US\$1.8 billion by 2015. Governments across the globe after evaluating the importance of LBS have not only embraced it and they are investing in network-based positioning which can assist in lawful interception of criminals, emergency services and national security purposes. Some governments are also taking the lead in network-based positioning because it is more reliable indoors and in covered areas than GPS [29].

LBS currently rolled out in South Africa are compatible with a basic MS. These LBS are quite affordable when weighed against the importance of LBS. Presently, in South Africa; the subscription fee for basic LBS is about R13/month. Operational details of four (4) basic LBS that might interest most mobile subscribers are shown in Table 1.3 [30].

VODACOM and MTN offers emergency pull LBS to certain accuracy as Look4Help and MTN2myAid services respectively. Once the LBS request is made, a distress SMS is sent to emergency contacts specified by the registered user indicating the approximate location of the distress caller. They also offer person tracking/locator service of a mobile phone user to certain accuracy with the consent of the mobile phone users. This service is offered by VODACOM as Look4me and by MTN as WhereRU.

The network providers specify that accuracy provided for location-based services offered is dependent on cell coverage and density of cells in an area. For example, accuracy provided at built-up areas is better than that provided in rural areas.

Though those presented are not popular location applications in South Africa, the most popular is Foursquare, a location-based social networking website for smart phones users. Others include Facebook Places, Gowalla and Google Latitude and these support smart phones and computers [31] .

Table 1.3: Cost of some LBS offered in South Africa (adapted from [32, 33, 34, 35])

LBS	Cost (content)	Bearer
MTN 2MyAid		
Monthly Subscription	R12.49	
Add someone to locate (SMS)	Free	R0.86
To locate someone via SMS	R2.00 per received SMS	R0.86
To locate someone via USSD	R2.00 per location request	21c per unit of 20sec
MTN WhereRU		
Monthly Subscription	R12.49	
Activate an alert using USSD	R2.00	21c per unit of 20sec
VODACOM Look 4 me		
Monthly Subscription	R12.49	
Add someone to locate (SMS)	Free	R0.05
To locate someone via SMS	R1.84 per received SMS	R0.50
To locate someone via USSD	R1.84 per location request	20c per unit of 20sec
VODACOM Look 4 help		
Monthly Subscription	R12.70	
Activate an alert using USSD	R1.84	20c per unit of 20sec

1.3.5 Network-based Positioning technology

All measurements and calculations needed for MS location estimation takes place in the mobile network and hence no extra capability is needed by the MS. Some advantages of network-based positioning techniques include [6, 15]:

- o Measurements needed for network-based positioning can be obtained over the air in GSM networks.
- o Requires no hardware and minimal software modifications to the mobile network.
- o Available underground, in car parks and urban canyons.
- o Available everywhere there is mobile network coverage.
- o Old and new mobile phones can be used to access LBS effectively.

Disadvantages of network-based positioning are:

- o Relatively low accuracy levels when compared to GPS positioning techniques.

- o The accuracy obtained is highly dependent on dynamically varying factors such as network density, propagation channel, cell size, geometry of the network and wireless environment.

To ensure QoS delivery to MSs with no built-in GPS module, the positioning accuracy offered by network-based positioning methods needs to be improved. This can be achieved based on the awareness that the accuracy of LBS offered is usually dependent on the amount mobile network operators and mobile users are willing to invest [10].

1.4 RESEARCH OBJECTIVE AND SCOPE

The goal of the research performed in the frame of this thesis was to study LBS in Africa, propose some LBS adapted to African needs, suggest and investigate appropriate techniques for providing satisfactory accuracy and dependability to location information users.

This research also studied the feasibility of improving the location accuracy of a basic MS on GSM infrastructure by making the positioning algorithm aware of error sources around it. This will then assist in improving the accuracy of location information provided to users. The thesis objectives and scope are examined in greater detail in Chapter 3 once the relevant literature has been reviewed in Chapter 2.

1.5 THESIS ORGANIZATION

To achieve the stated objectives, the layout of the thesis is as follows:

Chapter One: Introduction

This chapter contextualises the study presented in this thesis.

Chapter Two: General Literature Review

Relevant literatures are reviewed about Global System for Communications (GSM), LBS, LBS data and content issues and network-based positioning techniques.

Chapter Three: Literature Review on network-based positioning techniques

Various positioning estimation algorithms applied in the network-based positioning techniques of interest are reviewed;

Chapter Four: Research Questions

Describes and explains the research motivation, research question, methodology and contribution to knowledge;

Chapter Five: Critical Evaluation of LBS in Africa

Presents a critical evaluation of LBS in Africa and methods of LBS adaptation and deployment in Africa;

Chapter Six: Critical Analyses of the Dependability of LBS in Africa

Critical analyses of the dependability of LBS in Africa and key parameters affecting LBS accuracy in Africa are presented.

Chapter Seven: Analysing Error Introduced To Network-Based Positioning and LBS

An investigative analysis of sources of error in network-based positioning methods was carried out and the effect of geometry on received signal strength (RSS) based positioning technique was established through statistical analyses.

Chapter Eight: Geometry-aware Network-based Positioning

Some methods that can be employed to effectively predict the accuracy of Cell-ID positioning technique were proposed. The neural network-based geometry-aware model that was built to analyse the feasibility of improving the accuracy of predictions from geometric RSS-based positioning methods is presented; and

Chapter Nine: Future Work, Recommendation and Conclusion

Future work, recommendations and a conclusion is presented.

CHAPTER TWO

2 GENERAL LITERATURE REVIEW

2.1 INTRODUCTION

This chapter gives a review of relevant literature. It begins with a review of GSM technology: its inception, structure of the air interface, its logical and physical channels and its architecture. There are many services on the GSM network that can be offered such as voice, data and other value-added services such as LBS.

LBS are important services which can revolutionize the way things are carried out in Africa. The importance of LBS and their variations is reviewed later in this chapter. Thereafter, the types of positioning techniques are reviewed with special emphasis on network-based positioning.

2.2 GSM NETWORK

A brief introduction on GSM is given to help understand positioning in GSM networks better, a brief introduction is given to GSM and the organization of the GSM air interface.

2.2.1 Evolution of GSM

The main governing body of the European telecommunication standardization organization, known as CEPT (Conférence Européenne des Postes et Télécommunications), created the Groupe Spécial Mobile (GSM) committee in 1982 and the acronym GSM was used for the first time. GSM was tasked with defining a new standard for mobile communications to operate in the 900 MHz band and a digital technology was decided on. CEPT later evolved to the European Telecommunications Standards Institute (ETSI) and in 1988, GSM became a Technical Committee under ETSI [36, 37].

In 1988 the initial draft of the GSM specifications became available and the Phase 1 of the system specification was launched. In 1991 the acronym GSM was changed to Global System for Communications and also in the same year, Digital Mobile System 1800 (DCS 1800), was derived. The DCS 1800 was adopted in the United States and was called Personal Communication System 1900 (PCS 1900) because it adopted the 1900 MHz band. By 1992 GSM had attracted worldwide interest and became a major commercial success [36, 37].

Phase 2 of the GSM specification was launched in June 1993 and phases 2+ also evolved. GSM Phase 1 system specification handled the common services (e.g. call forwarding and call barring), while phase 2 handled other services such as supplementary services and facsimile. Phase 2+ handled newer features such as half-rate speech coder and reliability [36].

2.2.2 GSM Network Architecture

A GSM network comprises several components as shown in a simplified block diagram structure in Figure 2.1: the mobile station (MS), base transceiver station (BS), the base station controller (BSC), transcoding rate and adaption unit (TRAU), the mobile services switching centre (MSC), home location register (HLR), visitor location register (VLR), and equipment identity register (EIR). Together these components make up the GSM public land mobile network (PLMN) [6, 36, 37]. There are three additional components which are added for positioning in GSM networks, which are called Serving Mobile Location Centre (SMLC), Location Measurement Unit (LMU) and the cell broadcast centre (CBC) [6] which is expanded upon later in the Chapter.

a. The mobile station (MS)

A subscriber uses a MS to make measurements of downlink signals in a GSM network. It can also make location measurements which can be used by different location methods though the location method to be used determines the location measurement to be made. A MS may also contain positioning

applications for MS - based or MS assisted positioning. The subscriber identity module (SIM) and the mobile equipment (ME) are the two functional modules of a MS. The SIM is a database that is specific to a particular subscriber and communicates directly with the VLR and indirectly with the HLR. The mobile equipment (ME) is the mobile station without the SIM card [6, 36, 37].

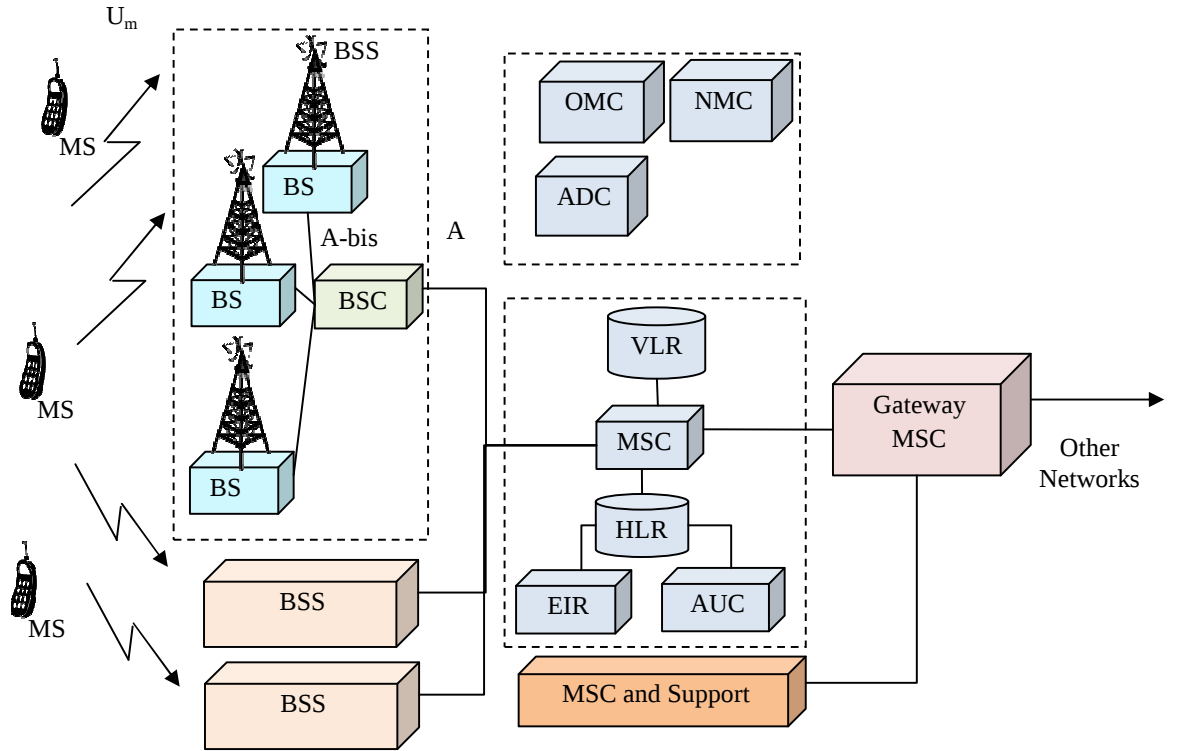


Figure 2.1: GSM network architecture (adapted from [35], [36])

b. The base station subsystem

The base station subsystem comprises of the BS, the BSC and the TRAU. A MS communicates with the base station subsystem (BSS) through a base transceiver station (BS) via the radio interface, U_m . A BS can be considered as a complex radio modem which handles connectivity and all the transmission and reception functions relating to the GSM radio interface between the GSM network and the MS. It also provides connectivity between the GSM network and the MS and plays a minor role in radio resource allocation. Coverage cells

in GSM networks are formed by the BSs and it determines the cell coverage area and capacity. The BS is connected to the BSC via the Abis interface. The TRAU compresses and decompresses speech between the MSC and the TRAU and is typically located between the BSC and the MSC [6, 36, 37].

c. The mobile services switching centre

The BSS is connected to the mobile services switching centre (MSC) which manages the routing of calls to and from MSs and additional functionality of coping with mobility of subscribers. An MSC area is a network covered by a particular MSC that manages its associated BSSs. It possesses large switching capability and a typical MSC controls tens of BSCs and has the capacity to handle several tens of thousands of subscribers. The capacity of the MSC varies with different manufacturers. The A-interface connects the MSC to the BSS, B-interface connects it to the VLR, C-interface to the HLR and E-interface connects different MSCs. A single MSC then serves as the gateway MSC (GMSC) between the PLMN and external networks [6, 36, 37].

d. The GSM network databases

The GSM network databases are the home location register (HLR), authentication centre (AuC) and the visitor location register (VLR). The HLR is a database for a large number of subscribers with information specific to each subscriber such as services they have access to and the location (MSC area) where the subscriber is currently registered. Every GSM subscriber will have an entry in the HLR of their home network and each PLMN has an HLR. The AuC though closely related to the HLR is used to store only information related to the security features of GSM's, i.e. user authentication and radio path encryption.

A VLR is a database with information relating to subscribers that are currently within an MSC area(s) it is associated with i.e. visiting the VLR area. A VLR can be associated with one or more MSCs. It provides a local copy of the

subscriber's information and eliminates the need to continually access the HLR to retrieve subscriber information. This is very important for roaming subscribers. The interface between different VLRs is called the G-interface and between the HLR and the VLR is called the D-interface [6, 36, 37].

e. Management of the GSM network

The network management system of the GSM telecommunications network are the operations and maintenance centre (OMC), the network management centre (NMC) and the administration centre (ADC). The network operator controls the network using the OMC and it's typically each OMC controls a subsystem e.g. the BSS. The NMC manages the entire network and the ADC takes care of the administration of the network [36, 37].

2.2.3 Structure of GSM Air-Interface

This subsection describe the structure of the GSM air-interface and it gives a brief overview of modulation and multiple access schemes, frames, synchronization for both uplink and downlink communication and the physical and logical channels used on the GSM network.

a. Modulation and multiple access schemes

GSM uses the Gaussian Minimum Shift Keying (GMSK) modulation technique. GMSK as the name suggests is based on a simpler modulation scheme known as Minimum Shift Keying (MSK) which belongs to the group of frequency modulation (FM) techniques. The information is carried in the form of phase variation. A logical '0' will cause the carrier phase to decrease by 90° over a bit period and a logical '1' will cause the carrier phase to increase by 90° over the same period. The modulated F_m output signal depends on the input signal F_l , where F_m is switched between two frequencies $(F_T + F_l)$ and $(F_T - F_l)$. The relative bandwidth of the Gaussian filter is the determining factor of the modulated spectrum; a bigger filter translates to a broader modulated spectrum. An advantage of GMSK in comparison with other schemes is that it comes with

a narrow transmission frequency spectrum of 200 kHz. It thereby causes only slight neighbour channel interference and theoretically contains no amplitude modulation (AM) portion [36, 37].

Though GSM operates in a range of frequencies the principle of design and operation are the same for all of the frequency ranges. GSM utilizes a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) for separating and controlling the air-interface into channels. This means that each time slot on each frequency is assigned to a single user. The available spectrum is partitioned into slots of 200 KHz each [36, 37].

b. Frame hierarchy and frame numbers

Every TDMA frame is assigned a fixed number and it repeats itself after a time period of 3 hours, 28 minutes, 53 seconds and 760 milliseconds [37] which is also called the hyperframe. Other hierarchical structures that lie between the hyperframe and the basic TDMA frame are the multiframe which consists of 26 or 51 TDMA frames and superframe with 26 or 51 multiframes. 26 or 51 multiframes makes up a superframe, and 2,048 superframes constitute a hyperframe. The fixed numbers assigned to each TDMA frame is used for data encryption and for synchronization during positioning [36, 37].

Eight time slots (TS) are mapped into each frequency and these eight bursts, numbered 0 through 7, constitutes a TDMA frame. Each duplex carrier supports a number of timeslots with duration of $15/26$ ms ($\approx 576.9\mu\text{s}$) and carries 156.25 bits. Therefore a TDMA frame repeats every $60/13$ ms (≈ 4.615 ms) and has a data transmission rate of 270.83 kbps. The timeslots and the frame duration are deduced from the fact that 26 TDMA frames are transmitted in 120ms. These particular numbers are important in designing the GSM's frame structure [36, 37].

c. Frame burst

In TDMA transmission energy is emitted in a pulse manner rather than continuous. MS and BSs send bursts periodically and a GSM burst with the duration of a time slot (577 μ s) on a certain carrier realizes a physical burst that transmits either user data or signalling data. The physical burst needs extra bits for administrative purposes which reduce the space available for the payload and signalling [36, 37].

The BS uses the format and length of the access burst to calculate the actual propagation delay between a MS and a BS called the offset time. This closed loop timing advance mechanism is activated when there is an established link between the MS and the BS which is used by the MS to transmit within the required time period. This information also allows for the calculation of the distance between a MS and a BS [36, 37].

One major drawback of positioning in GSM networks is the lack of time synchronization between BSs. The downlink structure of the TDMA frame and the time slots for each BS is according to its internal clock. The BS clock is usually realized by Oven-Controlled Crystal Oscillators OCXO and suffers from a frequency offset of between 10^{-8} and 10^{-10} , which in the worst case approximately corresponds to a phase deviation of 1 ms per day. This makes it impossible to realize accurate positioning with time measurements on the GSM network as it is [6]. Figure 2.2 shows the summary of the different types of GSM frame burst.

d. Synchronization between uplink and downlink and timing advance

Guard times are used to separate neighbouring time slots to avoid interference between them. Therefore it was necessary to establish an agreement for a MS to send its data three time-slots after receiving data from the BS. This helps prevent collision of data from other MSs provided the burst from the MS is in a well-defined time frame. The synchronized time between sending and

receiving of data is also used by a MS to perform various measurements on the quality of the signal received from the BS and the neighbour cells [6, 36, 37].

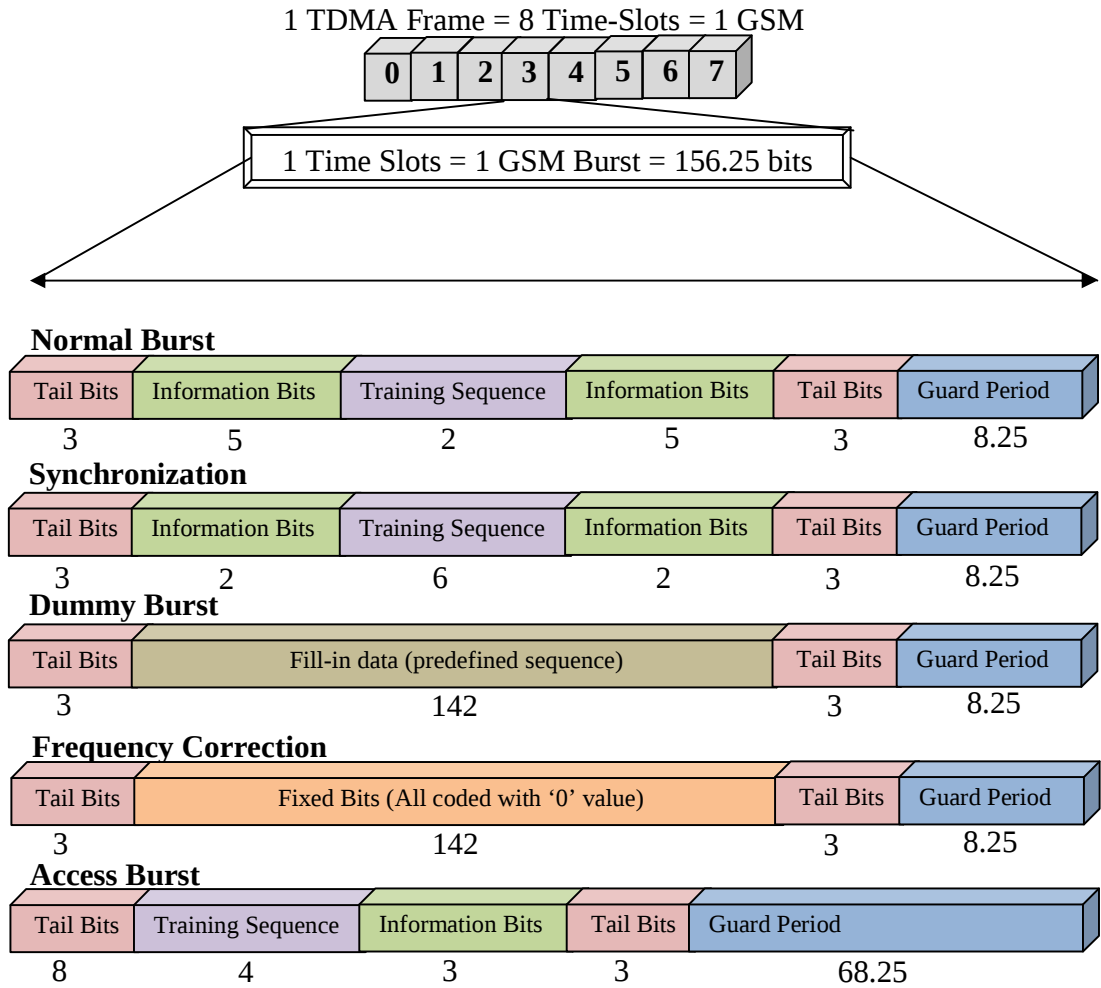


Figure 2.2: GSM frame burst (adapted from [36, 37])

The TA information makes a MS further from the BS to send its burst earlier. Therefore, the sent burst always arrives at the BS exactly within the correct timeslot. TA parameter is transmitted as a six-bit number of any value between 0 and 63 providing 64 timing advance steps. Step 0 means no TA takes place. Each corresponds to a period of one bit which is $3.69\mu\text{s}$ and

therefore the maximum TA will correspond to 63 bit periods ($3 \times 3.69\mu\text{s} \approx 63$ bit periods). The GSM radii is designed for cell radii of up to 35 km, each TA step corresponds to 553.46 m ($35 \text{ km} / 63 \approx 553.46 \text{ m}$) [6, 36, 37].

The TA value gives a rough estimate of the distance between a BS and a MS, which is very useful for positioning. It is important to note that TA represents twice the propagation delay ($PD = 2TA$) and it is only available for MS in busy mode, as it is calculated by the serving BS. Therefore it is not possible to get TA from another BS except through forced handover to three or more other BSs.

2.2.4 Physical and Logical Channels

Uplink and downlink communication between a MS and a BS is carried out on a specific pair of radio frequency (RF) carriers within a given time slot in each consecutive TDMA frame. Each time slot and carrier frequency realizes a physical channel that transmits either user or signalling data. The transmission of user and signalling data are mapped onto physical channels after being carefully arranged on logical channels which is quite a complex matter. Logical channels carry specific information which carries out specific tasks and this can be deduced from their names.

One RF channel will support eight physical channels in time slots zero through to seven. There are basically three types of logical channels: traffic channels, broadcast channels and control channels. Traffic channels require the fastest data rate in comparison to others and they are mapped onto a single physical channel. Multiple signalling or control signals share the same time slot according to well-defined patterns [36, 37].

2.2.5 Services Offered on GSM Networks

The GSM was designed to be interoperable with integrated services digital network (ISDN) and therefore services provided are a subset of the standard ISDN services. While intended primarily for voice communication, however they also support fax

and email services at low data transmission rate of between 8 and 9kbps. The three basic services offered on a GSM network are teleservices, bearer services and supplementary services [37]. Selected detailed services offered on GSM network are shown in Figure 2.3.

Voice calls are the most basic service supported by GSM. It also supports data services such as facsimile, e-mail messaging, web browsing and basic multimedia. Supplementary services enhance that basic teleservices are offered and these includes call conferencing, call waiting, call hold, call barring, number identification, advice of charge, closed user groups and unstructured supplementary services.

LBS are network enabling technology and they function independent of other services provided on the GSM network; though subscriber requests and location information delivered uses these services. LBS can be requested by sending a request by USSD or the internet. Location information can be delivered to the subscriber through SMS, MMS, USSD, WAP, e-mail or on the internet, depending on the subscriber's profile and MS capabilities.



Figure 2.3: Selectively detailed services offered on GSM network

2.2.6 GSM Network Positioning Architecture

There are three major additional components that enhance positioning on the GSM architecture - the location measurement unit (LMU), the serving mobile location

centre (SMLC) and the cell broadcast centre (CBC) [6]. The structure of the GSM positioning architecture is shown figuratively in Figure 2.4.

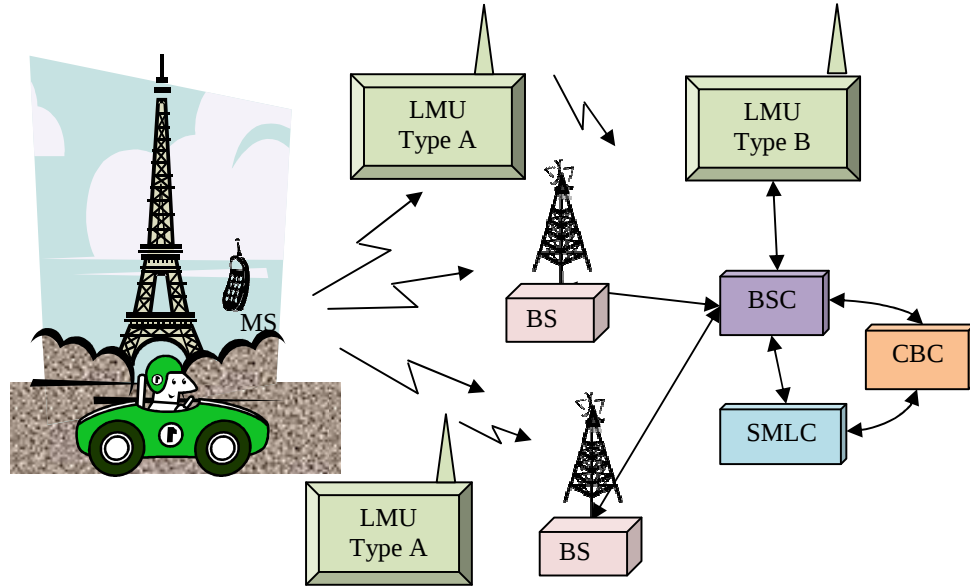


Figure 2.4: Structure of the GSM network positioning architecture

The LMU is used to perform time measurements for time-based positioning algorithms and there are two types. LMU Type A gets access to the network through the air interface while LMU Type B is connected over a wired link to the access network. The LMU is not a necessary component for other positioning techniques which are not based on time measurements.

The SMLC controls all other positioning processes such as allocation of resources, evaluating measurements and estimating the position of a MS. The other additional component, the CBC is used to broadcast positioning assistance to a MS from the network. It is used by Enhanced Observed Time Difference (E-OTD) and AGPS for MS-based positioning techniques [6].

2.3 LOCATION-BASED SERVICES

LBS are one of the supplementary services offered on GSM mobile networks. It is an electronic service which enables personalized services to mobile subscribers based on

their current geographical location [38, 39]. Some mobile users have embraced LBS because of the important and significant relationship between mobility, geographical location and location dependent services. There are many attractive location information services offered on the GSM network, for example: locating a child, fleet management, locating the cheapest restaurant around, shortest route, emergency calls etc.

2.3.1 Importance of LBS

a. The short-term reason for LBS

i. Emergency services

As the number of mobile network users grows more and more emergency calls are made wirelessly. There are over one million emergency calls made yearly in Europe in which the location is unknown to the caller and in some of these emergency calls wrong or inaccurate location information are given [40]. This wastes valuable time and hinders prompt dispatch of emergency services. Often there may also be a very high number of calls referring to the same incident, e.g. in traffic accidents, causing unnecessary dispatches and at the same time congestion to the mobile network. Therefore, even without authoritative requirements, automatic location estimation of the mobile station and its user is an important task to perform in case of an emergency.

Emergency location and other public safety related services can be regarded as the most important of the location-based applications. In network-based location techniques, subscriber location can be obtained independent of MS operation. Typically, the positioning process depends on the operational status of a MS (idle/connected/off). All location techniques require the MS to be turned on and many need the MS to be connected actively to at least a serving BS [40].

b. Medium-term reasons for LBS

The medium-term reasons for creating location-sensitive technologies are to provide:

i. Value-added services

Currently, the mobile phone has become a popular device among mobile users due to its small, handy and versatile nature. The popularity of MS and the number of users are continuously increasing and at the same time MS manufacturers and service providers are striving to introduce new features and services to their users [41].

LBS provide new opportunities for network operators and application and content providers to provide innovative value-added services and creation of new revenue sources [38]. Due to large revenue expected from LBS in the near future it has gained considerable attention from both academia and industry [39]. It also opened a new market for developers, mobile network operators and service providers to develop and deploy value-added services [41].

ii. Application/ commercial value

LBS allows for efficient planning and use of resources. It enables mobile users for example to get access to local traffic information and detailed directions to places of interest. Police and rescue teams will be able to quickly and precisely locate people who are lost or injured but cannot give their precise location. Companies might use geographical location based applications to track personnel, vehicles, and other assets [42, 43]. LBS provide many new business opportunities for mobile operators, application and content providers and other third party partners [38].

iii. Law enforcement

Location information can be used to locate subscribers who have broken the law and are being investigated by the Police or the Secret Service. Location

information also assists in other location related investigations carried out by law enforcement persons.

iv. Statistical information

The number of persons in a particular cell in a mobile network can be gleaned from the network and the information can be used by the transport industry, population control agency and other related agencies.

c. Long-term reason for LBS

Knowledge of the spatial distribution of mobile callers assist in planning, design and optimization of resources in the mobile network [42]. Also, fast moving MS can be assigned to larger cell, thus handover between cells can be reduced considerably [43, 44]. A large number of handovers always consumes a lot of network resources and failures of handovers would lead to call-drops and data loss. Faulty registration of MS(s) caused by multipath reflections of radio signal into far cells instead of nearby cells can also be prevented [44].

2.3.2 Types of LBS

According to the International Telecommunication Union (ITU), LBS can be classified as pull and push services [45]. For broader analyses of LBS applications consult [46].

a. Pull services

With pull services, the request for LBS is initiated by the user and location information is sent based on user interaction and request [9]. Examples of push services include information, functional, interactive, emergency and mobility services as presented by [9, 10]:

- **Information service**

This provides information about objects or places of interest close to or at the user's location. Examples include locating current position, nearest Police station, city guides and mobile yellow pages.

- ***Functional service***

These LBS are provided directly to subscribers and they include ordering a taxi or an ambulance based on their location.

- ***Emergency service***

The LBS provide information about the user location to rescue services or related services in case of an emergency.

- ***Interactive service***

Provides interactive service between mobile users or between mobile users and an object based in their location. It does not require a connection to the internet. Examples include gaming, dating and chatting.

- ***Mobility service***

This service provides information on navigation such as getting from one place to another, shortest route and route alternative.

b. Push services

Location information is pushed by the service providers to the end users not based on request but rather the location of the user. Such services are activated when the mobile user gets to a particular location or area and it might also be time dependent. Sometimes user needs and preferences have to be sensed by the push system [9]. Some examples are presented below [9, 10]:

- ***Information Service***

This provides information about events or things happening at the present location of LBS subscriber. Examples include advertisements on entering a shopping mall and advertising a petrol station in an area the user just entered.

- ***Emergency service***

Emergency alert services are sent to subscribers within specific geographical locations or cell in the mobile network. Currently, there are no legal or administrative requirements needed for this service worldwide.

- ***Tracking service***

An end user with tracking capabilities is able to track another end user, but consent is needed for this service to be provided. Examples include person tracking, fleet management and asset management.

- ***Location sensitive billings***

Users are charged tariffs based on the location they are or where they might have been close to. Examples include Pay as you Drive car insurance and road toll [47].

2.3.3 Interoperability of LBS

Interoperability between different components is necessary for the provision of LBS to mobile users. The LBS supply chain presented at this subsection explains information transfer between components concerned while the mobile originating location request procedure gives the procedural approach to the provision of LBS.

a. LBS Supply Chain

This identifies the different parties participating in the provision of LBS based on a request by the user. Although it is not an LBS standard it has been generally accepted and used by the concerning parties [6]. Figure 2.5 shows the LBS supply chain with the relevant location information transfer between them, presented after [6] and [48].

- ***MS***

A MS connected to the mobile network already registered for LBS and which can be used to request LBS and accept location information.

- ***Location provider***

It triggers and controls the process of positioning on behalf of the LBS provider. This service is also referred to as location service (LCS). The Location provider sends location information, which contains a MS's estimated location, MS identifier, quality of data and other location related information.

Table 2.1 shows some elements of location data information made available to the LBS user.

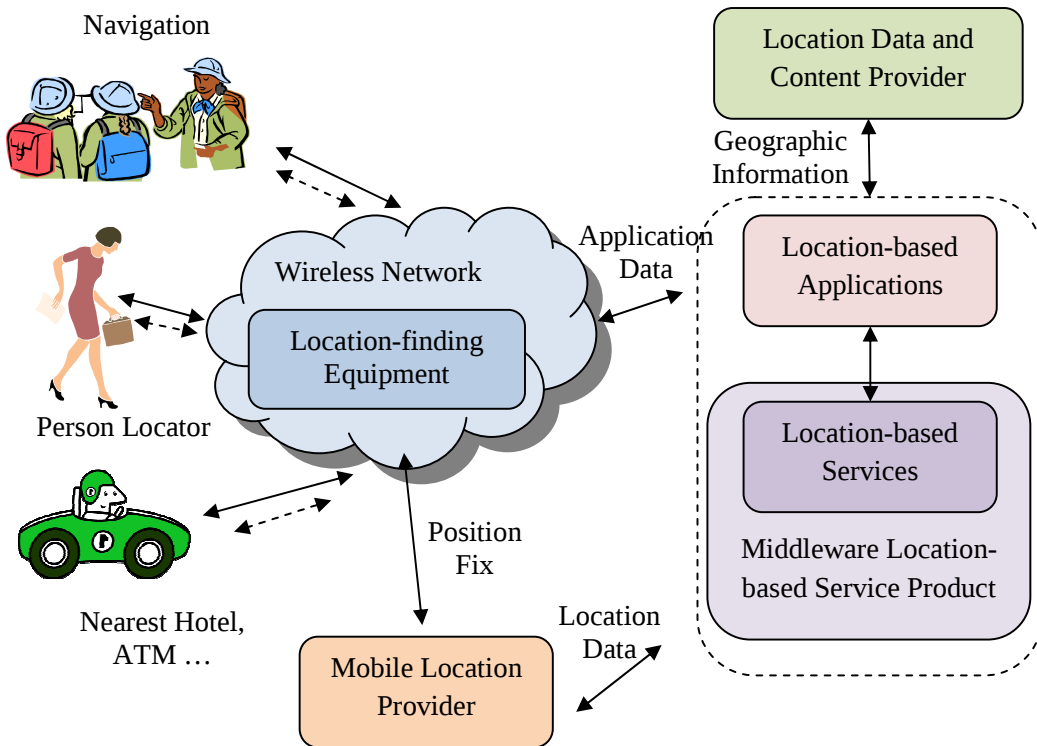


Figure 2.5: LBS requests ([6, 48])

- **Position originator**

The mobile network operator is the position originator for network-based positioning methods and it estimates the position fix of the LBS subscriber. The position fix is the bare coordinate of the target.

- **LBS provider**

Spatial analyses and query are performed here on the location data and the data is combined with other necessary and understandable geographical content. The output resulting application data is transferred to the LBS user.

- **Content provider**

The content provider maintains a spatial database and most content providers also have GIS. This geographical information is delivered on request to the LBS provider and onward to the MS.

- **LBS user**

The LBS user uses the location information to make relevant decision and choices.

Table 2.1: Elements of location data [6]

Element	Description
Location	Represents the target's location, but not necessarily in the original format resulting from positioning.
Type of Location	Indicates whether the location is the current, initial, or last known location.
Format of representation	Specifies the spatial reference system the location is based on.
Quality	Contains quality parameters such as accuracy of location and the time when it has been generated.
Identity	Specifies the target's identity and the identity type.
Direction	Denotes the direction of the target's motion.
Speed	Denotes the speed of the target's motion.

b. Mobile originating location request procedure

The location request originates from the subscriber's MS. The location preparation procedure then performs authentication checks, network resources reservation, privacy policy checks and determining the positioning technique to use based on user preferences and MS features. This is handled in steps 1-5 of the procedure shown in Figure 2.6. The MS sends LBS request to the mobile network (1), which is forwarded to the MSC (2).

A service acceptance is sent to the MS thereby indicating the MSC acknowledgement of the request (3). If MS is in idle state, authentication and ciphering is carried out before sending the accepted message. The MS then invokes the LCS (4) and specifies the type required. This invocation contains

some necessary parameters, for example the MS features, user preference and QoS required [6].

The MSC then checks if the subscriber has permission for all or some of the parameters. If the location request is accepted by MSC, it proceeds by checking if the MS is idle or connected to a serving BS. If idle, the MS is then paged to make it active and messaging for positioning accepted (5) – (7).

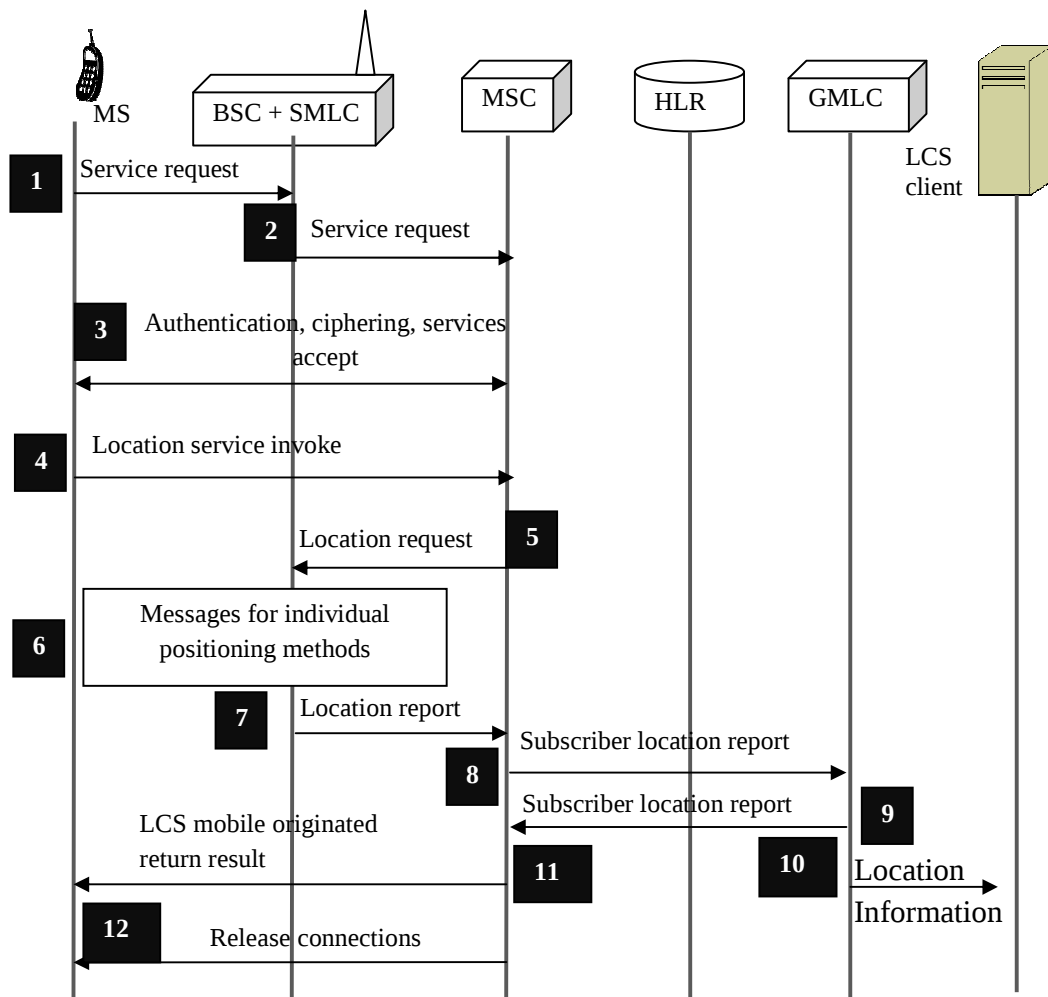


Figure 2.6: Mobile originating location request procedure [6]

After positioning, the position fix is sent to the gateway mobile location centre (GMLC), where it is translated to the required reference system and forwarded

to the LCS server (10). The LCS server then gives the final location data to the MS to be used by the subscriber (11) and all the connections are released for another process (12) [6].

2.3.4 Context in LBS

Dey [49] defines context as “any information that can be used to characterize the situation of an entity”. The entity in this case is LBS and it is user characterized in a geographical location. There are many contexts in which to characterize LBS and some of these are presented after Nivala [50] and shown in Figure 2.7:

- **LBS user:** specifies the profile of the LBS subscriber.

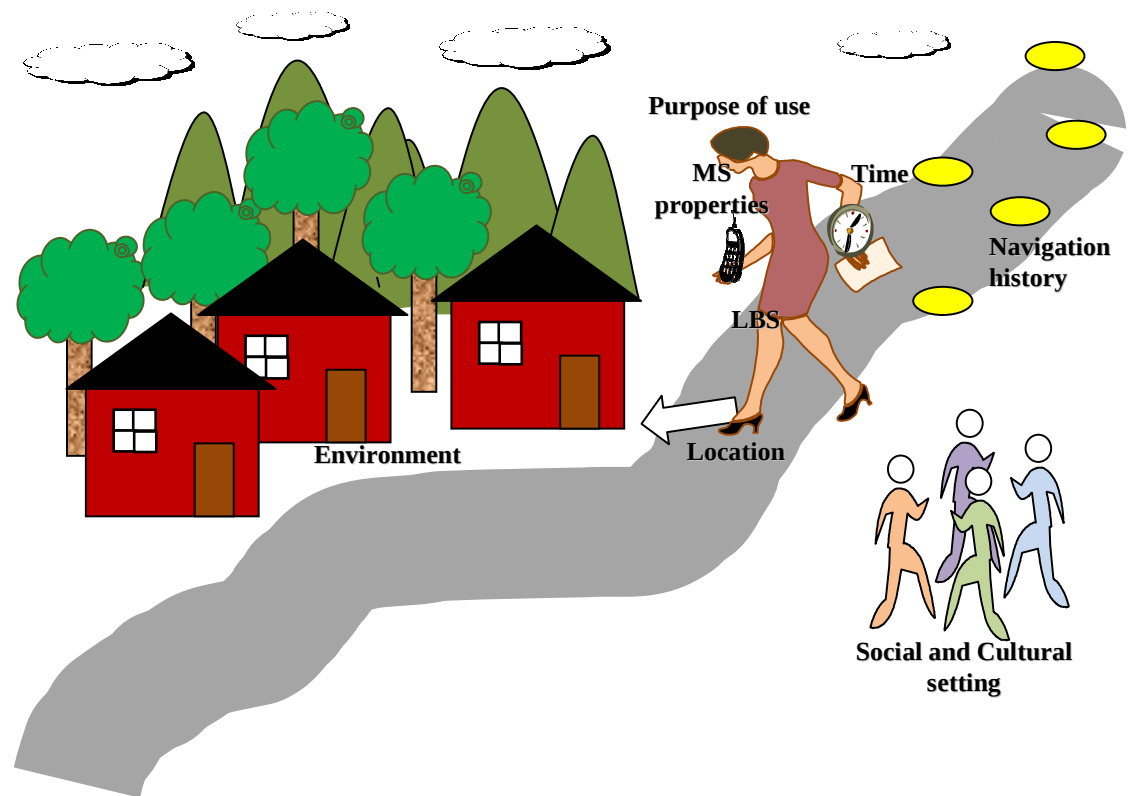


Figure 2.7: Different types of context in LBS (adapted from [9]).

- **Location:** the location the LBS subscriber when requesting for/about LBS.
- **Time:** gives the time LBS request was made by the LBS subscriber.
- **Orientation:** specifies the orientation or direction the LBS subscriber is heading or coming from.
- **Navigation history:** gives where the LBS user has been and what they have seen and done.
- **Purpose of use:** this is determined by the purpose of the location information.
- **Social and cultural setting:** this is characterized by the social relationships or groups the LBS subscriber belongs to.
- **Environment:** specifies the characteristic of the physical environment.
- **MS Properties:** specifies type and capabilities of MS used for LBS request.

2.4 DATA FOR LBS

The information provided by the data and content provider for location-based services needs to be fine grained and up-to-date to ensure the provision of accurate and reliable services. Even though data collection and gathering techniques are getting sophisticated, there are still challenges in the data content delivered to LBS users such as integrity, dependability, reliability and fitness-of-purpose of the data.

Most data have a finite shelf life and they can become too out-of-date and unusable. This is a huge challenge in developed countries as cited by [47] and a bigger challenge in developing countries where new buildings and infrastructure are built more frequently.

2.4.1 Types of data

There are many types of data that can be considered for LBS depending on the context they are used in. Some of these are presented here after Brimicombe and Li [47]:

- **Base mapping:** this includes road and railway networks, building outlines, elevation data and administrative boundaries.

- ***Points-of-interest:*** addressable and non-addressable prominent places and landmarks.
- ***Services-of-interest:*** includes geocoded yellow pages.
- ***Events-of-interest:*** from sickness outbreaks, weather forecast, traffic news, to events such as festivals and violence.
- ***Navigation data:*** known public routes, intersections and road features.
- ***Imagery:*** satellite, aerial and terrestrial imagery, geographical pictures and images for visualization from light detection and ranging devices (LiDAR).
- ***Multimedia clips:*** includes commentaries on features of interest relating to a particular location data. Webcams and closed circuit television (CCTV) can also be used for video clips and these are typically about 1 MB a minute file size. Also included is visual reality visualization relating to the location data of interest.

2.4.2 Data collection technologies

The data presented above can be collected in various ways. Some of these are presented here after [47].

- ***GPS and Inertial Navigation System (INS)***

These allow users to track their positions based on known coordinates. GPS is based on a constellation of 24 satellites orbiting the earth at an altitude of about 20,200 km. Most forms of measurement and mapping is derived from the GPS. The initial navigation system (INS) is a different technology from GPS and it uses three sets of gyroscopes and accelerometers carefully calibrated inside a vehicle.

- ***Remote sensing***

Data is acquired about objects without direct contact with them. Examples of devices used for remote sensing includes camera (static and moving), light detection and ranging device (LiDAR) et cetera.

- **Ground survey**

This is the measured distances between objects including the direction of line and angle of inclination between them.

- **Others**

There are other methods in which data can be collected such as the use of close circuit television (CCTV), web crawlers, wireless network and MS.

2.4.3 Data quality issues

Uncertainty of location information is a central issue in geographical information science (GIScience). This is because compilation of data set for location information is expensive, time consuming and requires expertise [47]. For example if two GIS layers are used for positioning and they are each about 70 percent correct, (0.7×0.7), this will result in a data set which is only about 49 percent correct (0.49).

2.5 LOCATING THE USER

2.5.1 Introduction

This is one of the basic components (as previously mentioned in Chapter One) for the provision of LBS. Positioning techniques utilize known measurements to determine the position of a MS. Basic principles for calculating a MS's position are [10, 18]:

- o The position of the fixed station relative to the user.
- o Signal propagation and signal strength relative to the user.
- o Distance to the fixed station which can be obtained from the signal propagation relative to the user.

There are several ways of differentiating methods of positioning MS outdoors as shown in Figure 2.8. Using network-based techniques, all measurements and calculations needed for positioning take place in the mobile network [6, 51]. Examples include Cell Identification (Cell-ID) and Angle of Arrival (AoA) which can be applied to GSM and Universal Mobile Telecommunications System (UMTS) networks, Enhanced Observed Time Difference (E-OTD) and Uplink Time

Difference of Arrival (U-TDoA) for GSM networks and Observed Time Difference of Arrival (O-TDoA) for only UMTS networks. Enhanced and Advanced Forward Link Trilateration (E-FLT and A-FLT) can be used for Code Division Multiple Access (CDMA) networks. There is also the fusion of two or more methods which are called hybrid location methods. Examples include Cell ID + Timing Advance (TA) or Received Signal Strength (RSS), Assisted GPS (AGPS) [6, 51] et cetera.

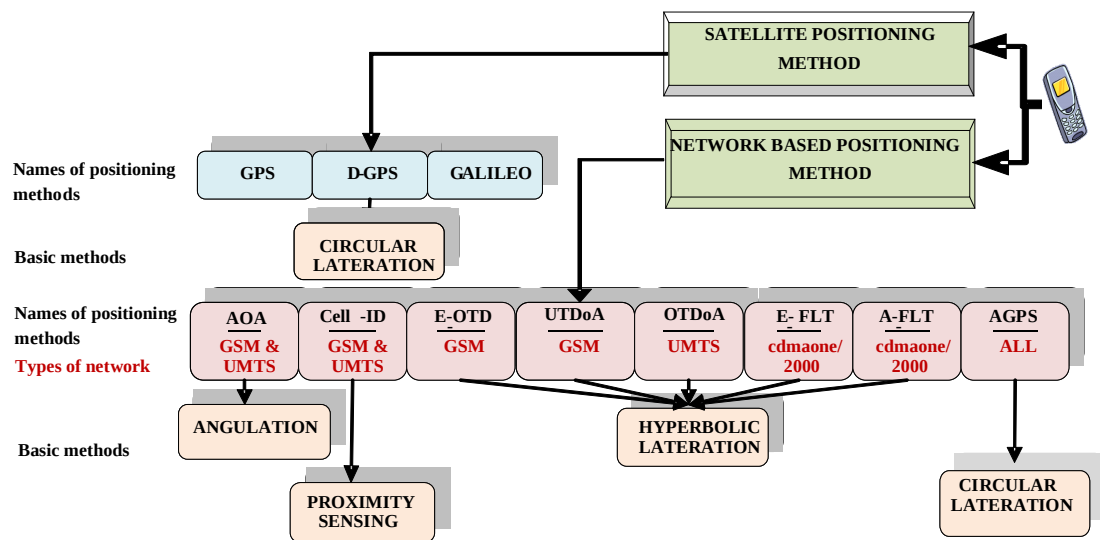


Figure 2.8: Overview of satellite and mobile network positioning

One of the methods of estimating a MS's position is based on where measurement and position estimates are calculated and they can be either MS-based, network-based [6] or a hybrid of both. For the former, all measurements and calculations needed for position estimation takes place in the MS. Examples include GPS, Differential GPS (D-GPS) and Galileo.

2.5.2 Network-Based Positioning Techniques

Network-based positioning is the most applicable technique for locating MS in Africa as stated previously in Chapter One. With no required modification on the MS and little modification carried out on the mobile network, the services can be made available at relatively low cost. Network-based technologies rely mostly on the

existing network infrastructure and are relatively less complex [6, 10, 52]. The BSs measure necessary signals originating from a MS and uses the measurement to estimate the location of a MS. Measurements available for the implementation of network-based location estimation based on GSM standards are Cell Identification (Cell-ID), Timing Advance (TA), and strength of signals received by the handset (RXLEVs or RSS) [53].

The Network-based technologies approved by the 3rd Generation Partnership Project (3GPP) are Cell-ID + TA, U-TDoA, E-OTD and satellite-based GPS technologies [7]. E-OTD and U-TDoA technologies utilize time measurements for positioning of a MS and therefore require installation of location measurement unit (LMU), a new network element. The former method requires LMU installed at every BS while the latter requires its installation for every 2 - 5 BSs. MS(s) using E-OTD does not require software modification while MS(s) being positioned using U-TDoA requires software modifications. Due to the non-synchronization of BSs on GSM networks, location measurement unit (LMU) determines the time offsets of measurements to be used for position estimation.

However, all network-based technologies require a new modification to the network in the form of the serving mobile location centre (SMLC). The SMLC manages the coordination and scheduling of resources for MS location estimation and it is responsible for the final location estimation and accuracy [7, 53].

The network-based solutions applicable to developing countries are the ones that require minimal hardware modification and software modifications to the network. This leaves just the Cell-ID and TA technology to be used in Africa. This is the reason why RSS-based positioning technique was also investigated in this thesis. This might make more options available to developing countries in providing accurate and reliable LBS.

RSS-based methods are not specified by the 3GPP because RSS-based measurements are generally very inaccurate compared with time measurements and therefore all

technologies approved by the 3GPP apart from Cell-ID are based on time measurements [7]. The variant introduced by RSS can be as much as 30-40dB especially in built up areas [54]. However, considering rural environments especially in Africa where at least 50 percent of the people live in rural areas and where multipath is considerably lower, RSS-based methods are applicable.

Technologies reviewed in chapter three are Cell-ID, TA, RSS-based and a hybrid of these.

Though the network-based positioning method is the most applicable in developing countries, it offers minimal accuracy and predictability. Tremendous challenges are faced in designing fast, robust, have high accuracy, minimal cost and with minimum delay network-based positioning techniques. Cell-ID technology's accuracy is mainly dependent on the cell size of the serving BS, TA technology's accuracy is dependent on about 553.46m radius around the serving BS (as explained in Section 2.2.3 (d) and page 21) and RSS-based technology is also highly dependent on the multipath and error introduced by the wireless environment.

2.5.3 Accuracy challenges of network-based positioning technology

Dependence on mobile location providers to improve the accuracy of network-based positioning in developing countries is quite challenging. At present, LBS research is mainly focused on the needs of developed countries where smart phones with built-in GPS module are more prevalent and network infrastructure better established.

The relationships between radio environment, geographical features, positioning systems and the accuracy of network-based positioning are also quite complex. Mobile operators and the safety community involved in LBS have expressed a desire to take these factors into consideration to provide more accurate location service but “unfortunately there is currently little factual information from which to establish or evaluate weighing factors” of these dynamically varying parameters [12]. The dynamically varying error sources of network-based positioning techniques can be

classified into three major groups according to [10, 15, 55]: errors due to computation and measurement, geometric features of the network and the wireless environment.

a. Computation and measurement

The measurements in the field are not error-free and therefore the estimation techniques must take into account measurement noise. The simplest solution to reduce the challenges posed by measurement error is by using more base stations' measurements [15]. Computation and measurement error sources can be introduced by clocks, software limitation and hardware limitation [6], [15] .

b. Geometrical features

Different types of network geometries pose different challenges in mobile positioning, especially with positioning using more than three BSs. Thus, it is not feasible to employ a universal positioning algorithm for varying geometries and to expect the same accuracy [56]. Geometric error sources include: dilution of precision (DOP), base station (BS) coordinates, BS geometry, BS cell size [6, 15].

c. Wireless environment/ harsh environments

A major accuracy challenge is positioning in harsh environments, such as dense urban environments, complex buildings, and other areas where multipath propagation usually exists. Due to non-line-of-sight (NLOS), the first signal arriving at the receiver might suffer stronger attenuation than later arrivals and a wrong time of arrival might be estimated. The resulting estimated location by the estimation algorithm might provide biased estimation. Other sources of error include signal attenuation, noise and interference, fading et cetera [38, 51, 57]. Unfortunately, whichever method is used, the rough wireless environment imposes big challenges for precise estimation of these parameters at multiple base stations (BS) which resulting in large errors in the estimation of mobile location.

2.5.4 Challenges of the Wireless Environment

Although in most cases, line-of-sight (LOS) propagation is expected between a transmitter and receiver this is not so especially in urban areas where there are so many natural and artificial obstructions such as buildings, mountains and foliage. In real communication channels, electromagnetic (EM) waves get to the receiver from the transmitter via different methods such as reflection, refraction and diffraction. The EM waves arriving via several paths simultaneously form a complicated interference picture of the received radio signal forming a multipath situation [58, 59, 60]. This causes the strength of electromagnetic wave transmitted to decrease as the distance between the MS and the BS increases.

The path loss also fluctuates randomly due to the mobility of a MS over irregular terrain, and/or among buildings during communication with the BS. The propagation channel is also affected by noise generated within the transmitter and receiver such as thermal noise in passive and active elements of the electronic devices, and from external sources such as cosmic radiation, man-made noise and atmospheric effects. The speed of motion and frequency of transmission also causes the signal to fade [58, 59, 60].

These different noise sources in the wireless channel are classified as additive noise and multiplicative noise. Additive noise is generated within each element used for communication while multiplicative noise is caused by various processes inside the propagation channel. It firstly depends mainly on the directional characteristics of the transmitter and receiver antennas and the distance between them. Secondly, it depends on the multipath experience of the electromagnetic wave when transmitted between a MS and a BS [58].

Three basic types of interference introduced by the wireless environment are presented here - fading, multipath and path loss.

a. Fading

Fading is the temporal variation of signal amplitude caused by movement of the receiver/transmitter in a multipath propagation environment or movements of scatterers. Fading can be in the space-domain, time-domain and frequency-domain [58, 60]. Fading can also be categorised as slow fading, fast fading or random fading.

Slow fading, also known as “shadowing effect” is a large-scale fading in the space domain or slow fading in the time domain. It is caused by diffraction from the obstructions placed along the radio link surrounding transmitting and receiving antennas. Fast fading is the short-scale signal variation in the space domain or fast variation in the time domain caused by mutual interference of the wave components in the multi-ray field [58, 60].

Random fading which is temporal is associated with a shift of frequency radiated by the stationary transmitter. In fact, the time variations, or dynamic changes of the propagation path lengths, are related to the Doppler Effect, which is due to relative movements between a stationary base station (BS) and a moving subscriber (MS) [58, 60].

b. Multipath

Radio signals reaching the receiving antenna arrive by two or more paths. This is due to reflection, diffraction and refraction from surrounding objects and water bodies. Multipath fading is highly dependent on frequency therefore it can be mitigated using frequency hopping. GSM systems allow for frequency hopping and all GSM MSs can hop, but usually, only cells located in severe fading areas are designated as hopping cells [36].

c. Path loss

The effectiveness of the propagation channel in different environments can be determined by the path loss. Path loss can be defined as a large-scale smooth decrease in signal strength of the EM wave with distance between the

transmitter and the receiver. Path loss is caused by the spreading of EM wave radiated outward in space by the transmitter and obstructed by man-made and natural obstacles in its path. The spatial variations of the EM wave due to path loss are large while the temporal variations are slow [58, 60].

2.5.5 Propagation Models

Propagation models are empirical mathematical models for characterising radio wave propagation based on its frequency, environment, distance, BS and MS parameters and other factors. There are various approaches to obtaining the average received signal strength as a function of location. Often, the higher the accuracy required the more complex the propagation model. There is always a trade-off between the accuracy of the propagation model and its complexity. The accuracy of the propagation model is measured by the mean and the standard deviation of the error term. A most suitable propagation model will be one with zero mean error and a very small standard deviation [61].

The various approaches for getting a propagation model are [61]:

- o propagation models found in literature, Okumura-Hata's model, Egli's model, Lee's model, et cetera;
- o terrain-based computational model;
- o measurement-based model; and
- o hybrid model. The propagation models found in literature and the terrain based model can be tuned to obtain better accuracy. The measurement model and the propagation model can also be tuned to obtain better results or a combination of all three methods.

a. Okumura-Hata model

The Okumura-Hata model is an empirical model used by mobile network operators in South Africa because of its applicability to the South African environment. The Okumura model is based solely on measurements made in Tokyo in the 1960s for frequencies between 200 – 1920 MHz. The actual path

loss predictions are made based on graphs of the measurement analyses and correction factors applied to some parameters [62]. Okumura model is comparatively difficult to use and it was modified to the Okumura-Hata model. Hata developed a useful model for path loss as a function of BS height, MS height, carrier frequency and the type of environment (urban, suburban or rural) based on measurements and analyses (graphical information) from the Okumura model. Hence it is called the Okumura-Hata model and it is one of the most widely used prediction models. The model has been validated for frequencies between 150 and 1500 MHz, mobile station antenna heights between 1 - 10 m and base station antenna heights of 30 - 200 m and separation distances from 1 - 20 km. The basic prediction formula is based on flat urban terrain but additional correction factors make them applicable to other geographical areas such as rural and suburban areas [62, 63].

The influence of irregular terrain is defined by terrain correction factors given by prediction curves. For suburban and open areas, correction formulae can be produced with the help of measurement data. Since the environmental definition is not clear, it is not certain how to select correction formulae in an actual application. In the Okumura-Hata model, the effects of buildings are more significant in small area propagation environments. The environmental features such as the information about buildings, fields and roads between the transmitter and the receiver should be considered for accurate prediction. For these reasons, environment estimation is very crucial in order to select the correct propagation model and to calculate the distance between BS and mobile station [63].

Urban areas are built-up cities or large towns with tall and large buildings, or larger villages with closely built houses and tall thickly grown trees and vegetation. The open-area model represents locations with open space, no tall trees or buildings in the path, and the land cleared for 300 – 400 m ahead (i.e., farmland). The suburban area model represents a village or a highway scattered

with trees and houses, some obstacles near the mobile but not very congested [62].

The baseline model - urban prediction for path loss (PL_U):

$$PL_U \text{ (dB)} = 69.55 + 26.16 \times \log_{10}(f_c) - 13.82 \times \log_{10}h_{BS} - a(h_{MS}) \quad \dots 2.1$$

$$+ (44.9 - 6.55 \times \log_{10} h_{BS}) \times \log_{10}(d)$$

Where f_c is the transmitting frequency in MHz, h_{BS} is the base station height above the terrain in meters, h_{MS} is the antenna height above the terrain in meters, d is the distance between the transmitter (BSs) and receiver (MS) in kilometres, $a(h_{MS})$ is the mobile antenna height correction factor for different environments.

These ranges of parameters are valid over these ranges in Okumura-Hata's model:

$$150 \leq f_c \leq 1500, f_c \text{ in MHz}$$

$$30 \leq h_{BS} \leq 200, h_{BS} \text{ in m}$$

$$1 \leq h_{MS} \leq 10, h_{MS} \text{ in m}$$

$$1 \leq d \leq 20, d \text{ in km}$$

Mobile antenna height correction factor for a small or medium-sized city:

$$a(h_{MS}) = (1.1 \times \log_{10}(f_c) - 0.7) h_M - (1.56 \times \log_{10}(f_c) - 0.8) \text{ dB} \quad \dots 2.2$$

Where $1 \leq h_{MS} \leq 10\text{m}$

and for large cities;

$$a(h_{MS}) = 8.29 (\log_{10}(1.54h_{MS}))^2 - 1.1, \text{ if } 150 \leq f_c \leq 200\text{MHz} \quad \dots 2.3$$

$$a(h_{MS}) = 3.2 (\log_{10}(11.75h_{MS}))^2 - 4.97, 200 \leq f_c \leq 1500\text{MHz}$$

when the mobile station height is 1.5m, $a(h_{MS}) = 0 \text{ dB}$ regardless of the frequency.

For environments other than Urban, corrective formulas must be applied. Path loss in large cities and urban environments (PL_{LC}) is given as;

$$PL_{LC} = PL_U \text{ (dB)} - a(h_{MS}) \quad \dots 2.4$$

Suburban area prediction for path loss (PL_{SU}) is formulated as;

$$PL_{SU} = PL_U - a(h_{MS}) - 2(\log(f_c/28))^2 - 5.4 \quad \dots 2.5$$

Open or rural areas prediction for path loss (PL_{OA}) is given as:

$$PL_{OA} = PL_U - a(h_{MS}) - 4.78 \times (\log_{10}(f_c))^2 + 18.33 \times \log_{10}(f_c) - K \quad \dots 2.6$$

K ranges from 35.95 (countryside) to 40.94 (desert) [59].

The Hata model does not go beyond 1500 MHz while Okumura provides support for up to 1920 MHz. The Hata model also does not provide path specific correction factors unlike the Okumura model. For distances greater than 1 km, the Hata model reasonably approximates the Okumura model. However, due to the distance, the Okumura model alone is better for small mobile cell and higher frequency mobile systems including indoor application [59].

2.6 CONCLUSION

A review of GSM networks was given, particularly in relation to positioning on GSM networks. The types, importance, interoperability and context of LBS were reviewed giving an appropriate background on LBS. The types and quality of data required for the provision of LBS was also presented.

The estimation of the location of a MS is an important aspect of the provision of LBS. A background of this was also presented including the various challenges encountered and error introducing factors which mitigates the accuracy of a MS location estimate and ultimately the accuracy of the LBS provided to the subscriber.

The next chapter presents network-based positioning techniques which are the most applicable positioning methods for the provision of LBS to basic MSs.

CHAPTER THREE

3 LITERATURE REVIEW ON NETWORK - BASED POSITIONING TECHNIQUES

3.1 INTRODUCTION

This chapter gives emphasis to geometric network-based positioning techniques based on cell identification (Cell-ID), timing advance (TA), and received signal strength (RSS) measurements. Critical reviews of technologies used throughout this thesis will then be presented.

Two-dimensional location estimation is considered through out this thesis, the analyses and methods presented can be extended to three-dimensional location estimations.

3.2 NETWORK-BASED POSITIONING: MEASUREMENT AND IMPLEMENTATION

Cell-ID, TA and RSS are measurements available on the GSM standards for network-based MS position estimation with minimal additional hardware and software modifications [53]. In this section, the positioning techniques and positioning algorithms that make use of such measurements are reviewed.

3.2.1 Cell-ID Positioning

When a subscribed MS is turned on it is always connected to a serving BS with known coverage size and position. Any MS thus connected to a particular serving BS can be located based on the known coordinate of the BS and its coverage area.

a. Measuring cell size

The large macrocell, the small macrocell and the microcell are used in GSM networks while the picocell and nanocell are used indoors. The macrocell are mainly used in rural areas to cover large areas with fairly even terrain and good

line of sight (LOS) and it can be up to 35 km between a BS and a MS. The small macrocell and microcell are used in urban areas where there are tall buildings, multipath, diffraction and refraction [64].

b. Cell-ID based position estimation

All BSs are assigned cell identities to uniquely locate them and these groups of cells are grouped into clusters forming a location area (LAC) [37]. The Cell-ID based algorithm uses the Cell-ID of the serving BS (BS assumed to be with the strongest signal and handling communication to the MS) to estimate an approximate location of the MS [11, 53, 64]. The BS always broadcasts information about itself such as its cell identity and its LAC and MSs within its cell coverage receives the broadcasted message. Hence it is aware of the cell identity. The information is then converted to geographic position by using the coordinates of the BS stored in the network operator's database.

Cell-ID is a common and the most basic positioning method used in GSM networks and often, it is the first positioning method used to offer LBS. The position of the MS is estimated in relation to its serving BS coordinates as shown in Figure 3.1. It requires no major hardware upgrades, minor software upgrades, is relatively cheaper to deploy and the technology is supported by all MSs (legacy and new handsets and also roaming subscribers) [64, 65].

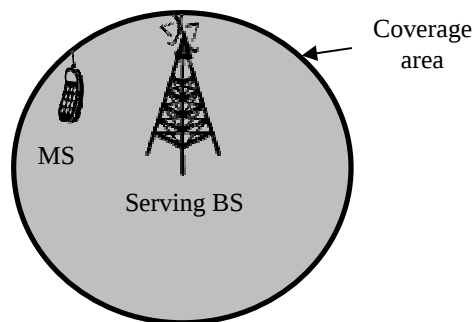


Figure 3.1: Cell-ID positioning

Cell-ID works well in all areas with signal coverage which includes indoors and it provides a low cost, plug and play and easy to deploy location information solution [66, 53].

3.2.2 TA Positioning

GSM networks have no dedicated pilot signals from BSs for positioning instead they have time slots and TDMA frames serves as timing measurements. TA measurement is often not used by itself to position a MS. It assists other positioning methods and often used as a fall-back procedure [7].

a. TA measurement model

TA parameter gives a rough estimate of the distance between a BS and a MS, which is very useful for positioning. TA information ensures that the MS furthest from the BS send its burst earlier and it's twice the propagation delay ($PD = 2TA$). The burst therefore always arrive at the BS within the correct timeslot. TA parameter is transmitted as a six-bit number as mentioned previously in Chapter 2.2.3(d), page 21 providing 64 timing advance steps; it can be any value between 0 and 63. Step 0 means no TA takes place. Each step corresponds to a period of one bit which is $3.69\mu s$ and therefore the maximum TA will correspond to 63 bit periods ($3 \times 3.69 \mu s \approx 63$ bit periods). The GSM is designed for cell radii of up to 35 km and each TA step corresponds to 553.46 m ($35 \text{ km} / 63 \approx 553.46 \text{ m}$).

TA is calculated at the serving BS during the MS's dedicated or busy mode. To obtain TA information from a MS when in idle mode, the MSC has to establish a dedicated connection unnoticeable to the user [37, 53]. It is therefore not possible to get TA from other neighbouring BSs except through forced handover.

The distance (d) between a MS and a BS can be described by Equation 3.1 and shown in Figure 3.2 [67]:

$$553.46 \text{ m} \times [TA - (1/2)] \leq d \leq 553.46 \text{ m} \times [TA + ((1) / (2))] \quad \dots 3.1$$

when $0 < TA < 64$

$$0 \leq d \leq 225 \text{ m when } TA = 0$$

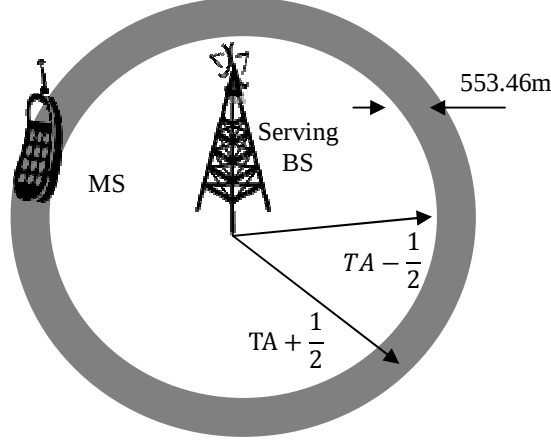


Figure 3.2: The outer and inner rings within which the MS should be located

b. TA-based position estimation

There are many methods of estimating a MS location using TA information and some of these are discussed below. The first three methods were presented by Simic and Pejovic [68].

i. The method of squares

This method uses squares to estimate the likely region of a MS's position. Assuming that the coordinates of the i_{th} BS are $[x_{BSi}, y_{BSi}]^T$, coordinates of the MS are $[x_{MS}, y_{MS}]^T$ and the TA parameter resolution quantum is $TA_{step} = 553.46$ m, the idea proposed is defined by Equations 3.2 - 3.5.

Defining some parameters, let

$$\begin{aligned} x_{i(min)} &= x_{BSi} - (TA_i + 1) \times TA_{step} \\ x_{i(max)} &= x_{BSi} + (TA_i + 1) \times TA_{step} \\ y_{i(min)} &= y_{BSi} - (TA_i + 1) \times TA_{step} \\ y_{i(max)} &= y_{BSi} + (TA_i + 1) \times TA_{step} \end{aligned} \quad \dots 3.2$$

The square region in which the annulus is contained can then be defined as;

$$\begin{aligned} x_{i(\min)} &\leq x_{MS} \leq x_{i(\max)} \\ y_{i(\min)} &\leq y_{MS} \leq y_{i(\max)} \end{aligned} \quad 3.3$$

Assuming uniform probability density function within the rectangular region, the expectation of the random variable (MS coordinate) can be obtained as;

$$\begin{aligned} x_{EMS} &= 1/2 (x_{\min} + x_{\max}) \\ y_{EMS} &= 1/2 (y_{\min} + y_{\max}) \end{aligned} \quad \dots 3.4$$

Error of the localization process is defined by Equation 3.5.

$$\varepsilon = \sqrt{(x_{EMS} - x_{MS})^2 + (y_{EMS} - y_{MS})^2} \quad \dots 3.5$$

ii. The method of circles

Assumes that the TA parameter is assigned according to the round trip time of the signal the MS must be located within a circular region around the BS. The MS is located within the radius of two circles defined by the propagation distance for the signal. The indirect wave propagation effect is greatly reduced in circular annuli method as compared to the annuli method.

The indirect wave propagation effect is greatly reduced in square annuli method as compared to the annuli method.

When $0 < TA < 64$:

$$553.46m \times [TA - (1/2)] \leq d \leq 553.46m \times [TA + (1/2)] \quad \dots 3.6$$

And when $TA = 0$:

$$0 \leq d \leq 225m \quad \dots 3.7$$

iii. *The method of Annuli*

The method of annuli further reduces the probable area of MS localization and it makes the circular annuli and square annuli method more precise. It involves changing the rectangular region or circular region specified by Equation 3.8 into grid form of $n_x \times n_y$ elements. Let us assume that $\Delta x = \Delta y$. The grid elements are defined by:

$$\begin{aligned} n_x &= \text{int}((x_{\max} - x_{\min})/\Delta x) + 1 \\ n_y &= \text{int}((y_{\max} - y_{\min})/\Delta y) + 1 \end{aligned} \quad \dots 3.8$$

Representing the grid elements by their centre points in order to determine their distances:

$$\begin{aligned} x_p &= x_{\min} + (p - (1/2))\Delta x \\ y_r &= y_{\min} + (r - (1/2))\Delta x \end{aligned} \quad \dots 3.9$$

For $p = 1, 2, \dots, n_x$ and for $r = 1, 2, \dots, n_y$ respectively.

Matrix A is an $n_x \times n_y$ containing flags indicating if a MS is located in the grid element or not. Distance between the BS and a grid element is given by:

$$d_{p,r,i} = \sqrt{(x_p - x_{BSi})^2 + (y_r - y_{BSi})^2} \quad \dots 3.10$$

If $d_{p,r,i} < TA \times TA_{\text{step}}$ or $d_{p,r,i} > (TA + 1) \times TA_{\text{step}}$, the corresponding elements in the matrix A is set to zero.

iv. *Trilateration using TA*

Time of Arrival (TOA) can be estimated from the TA information even though the BSs might not be synchronized. The MS can be located even more accurately by using TA to at least three BSs as shown in Figure 3.3.

Ideally, only the serving cell can measure TA. To obtain TA information from the neighbour BSs when the MS is in idle mode there has to be a “forced handover”. This is the establishment of a dedicated connection between the

MS and the neighbour BSs unnoticeable to the subscriber [69, 70]. The network forces the MS to make a handover attempt from the serving BS to two or more neighbour BSs. The neighbour BS then measures the TA and rejects the handover request [70].

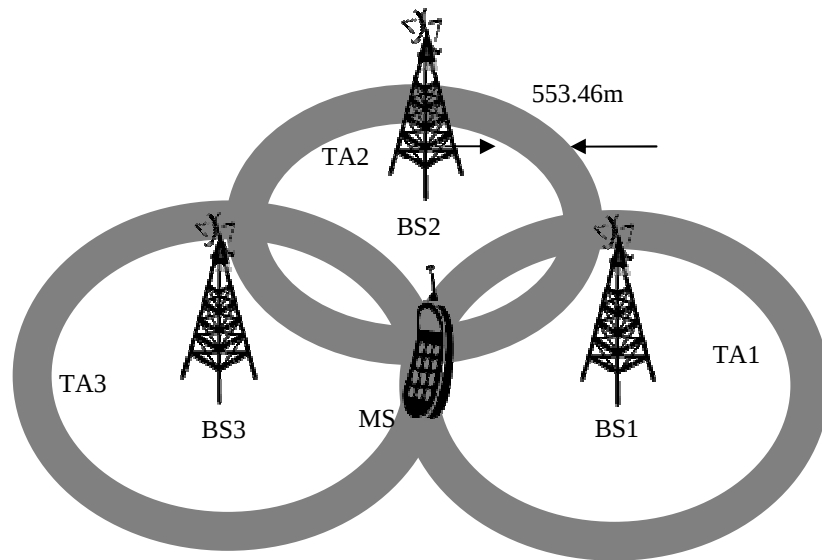


Figure 3.3: Positioning using TA information in a basic trilateration scheme

The retrieved TA information from three BS can then be used in a trilateration scheme to calculate the position of the MS. Each BS is used as two circle centre with the inner and outer radius of the TA. With three BS, there is an intersection of the circles as shown in Figure 3.3 and the possible location of the MS can be estimated with improved accuracy [69, 70].

3.2.3 RSS-based Positioning

A basic MS has the capacity to receive signal strength from six BSs and the capacity to measure the strength of individual signal received. RSS measured is directly proportional to distance between a MS and BS and thus positioning can be carried out using RSS. An RSS-based positioning technique is relatively less complex and cost effective as the RSS measurements are readily available in GSM systems. It is a general positioning method which can be applied to any MS. It does not rely on the

assumption of LOS propagation and turns the multipath phenomenon to surprisingly good use [41].

a. RSS measurements

RSS is a signal parameter in that the power or energy of a signal travelling between a BS and a MS contains information related to the distance between them. There is a mathematical relationship between the RSS and the path loss model to estimate the distance [71, 72]. It is assumed that an error free case is considered where a reliable NLOS detection algorithm had been used to eliminate measurement with large errors [71]. Averaging of the RSS over a sufficiently long interval to eliminate the effects of shadowing and multipath fading is also assumed [72].

Consider two dimensional positioning where the true location of the MS = $[x_{MS}, y_{MS}]^T$ and the coordinates of the i^{th} BS = $[x_{BSi}, y_{BSi}]^T$, $i = 1, 2, \dots, n$. Where n is the total number of receiving BSs with adequate receive signal level quality between 29 dBm and -114 dBm according to GSM specifications [71].

The distance between the MS and i^{th} BS, denoted by d_i is given by

$$d_i = \sqrt{(x_{MS} - x_{BSi})^2 + (y_{MS} - y_{BSi})^2} \quad \dots 3.11$$

where $i = 1, 2, \dots, n$, number of hearable transmitters

b. RSS-based position estimation

RSS-based location estimation methods are classified into statistical and geometric techniques as shown in Figure 3.4. The former approach uses probabilistic information and it is better applied to over-determined systems with little or no measurement error [51, 73]. The latter relies on deterministic information and geometric interpretations of measurement which are then used to estimate a MS's position. This approach also gives a better result when there are no measurement errors [51].

This research investigates only the geometric methods of position estimation because most measurements expected have error and they are not over-determined. The geometric techniques are further divided into two - the empirical method and propagation model-based method. The former technique is based on digital maps of a specific area and this requires extensive on-site measurements and calibrations. The latter technique utilizes the relationship between RSS and distance.

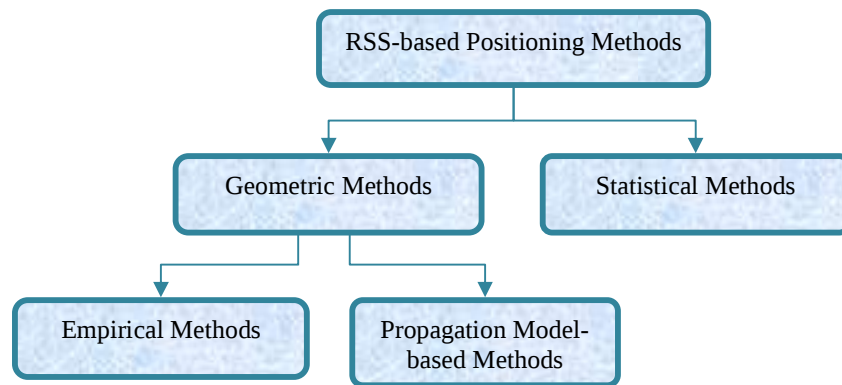


Figure 3.4: Types of RSS-based positioning methods

i. Empirical method

The empirical method also known as “fingerprinting” appears in literature under many names such as: “database correlation”, “pattern matching” and “map-based”. The fingerprinting method is based on the assumption that there is a one-to-one mapping between RSS measurements and a specific location [74, 75]. This method consists of two phases; training and positioning.

The training phase is carried out by fingerprint filtering and fingerprint matching. It involves the building of the fingerprint database by using measurements of RSS from specified points. From the measurements, characteristics features of the reference point or grid point are determined and recorded in a database. Building the fingerprint database or the training phase is comparatively simple though labour intensive. Measurements are collected

from the interested coverage area using a grid space of about 50m. The signal information samples are stored in the database and are called fingerprints. Another alternative is to use standard commercial network planning tools to artificially generate the desired mapping [74, 76].

The positioning phase is carried out by fingerprint matching and location estimation algorithms. The former matches the signal information of the request fingerprint received by the MS to the reference signal stored in the database. This mapping is passed to the fingerprint matching algorithm which estimates the location of the MS [41].

ii. Signal propagation model-based method

The RSS method also makes use of a propagation path loss model which relates the RSS measurement for each BS at a MS and the relative position of the transmitting and receiving elements with distance [77, 78]. RSS measurements from different BSs measured at the MS at corresponding times can be used to obtain the distance and the speed of the MS of interest which can then be used to calculate the position of the MS [79].

This approach employs RSS from a serving BS and at least two or more strong neighbour BSs measured and converted to distances by using basic propagation models. The position of the MS is then determined using standard geometric techniques [76]. The signal received or rather the level of attenuation of the signal is directly proportional to the distance between the BS from which the signal is transmitted and the MS of interest. Attenuation levels or the propagation path losses from multiple BS are modelled through basic propagation models which best suit the environment of interest [62, 76].

This research narrows down further to investigate signal propagation model-based techniques rather than empirical techniques. Empirical methods are expensive because they require extensive measurements, a lot of man-power hours, professional expertise and scheduled updating of the database. In a

developing continent, infrastructures are built-up and demolished frequently therefore scheduled up-dates are more frequent and if they are not carried out as often as necessary the out-dated database becomes very inaccurate.

Four methods based on signal propagation models are investigated in this thesis and used for major analyses carried out. This is because one of the major factors to be studied is the effect of geometry in predicting the accuracy of the positioning algorithm. For this study, the known distances of three or more BSs to the MS are utilized for position estimation and the feasibility of incorporating the geometry in predicting the accuracy of position estimates investigated [56].

c. Geometric RSS-based position estimation

The flow of RSS measurement interpretation and location estimation using geometric methods is presented in Figure 3.5. The geometrical techniques considered are Centre of Gravity (COG), Centre of Trilateration (COT), Trilateration (TRI) and Least Squares (LS). It should be noted that these basic methods were chosen to investigate the feasibility of improving the predictability of geometrical positioning methods. The same methods of investigation can be applied to more sophisticated and complex algorithms.

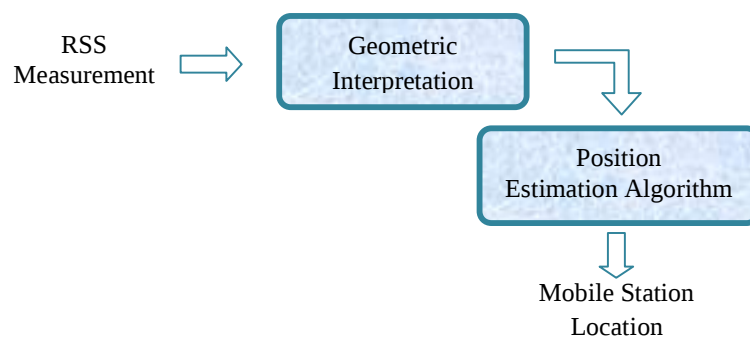


Figure 3.5: Geometric approach to location estimation

i. Centre of Gravity (COG)

Zhou et al in 2003 [73, 80] proposed the algorithm COG to locate the position of a MS as the weighted mean of the locations of the serving BS and the neighboring BSs. The COG assumes that the relation between RSS and distance between a MS and a BS is based on an inverse square law and also considered interference and distortion introduced by buildings. The relationship was as $R \propto d^{-\alpha}$, where α is an environmental factor, R is the received signal strength and d is the distance between a MS and a BS.

Considering that the MS can receive adequate RSS from n BSs the COG approach defined the location estimation formula as [80],

$$\begin{aligned}x_{MS} &= (x_1 R_1^{-\alpha} + x_2 R_2^{-\alpha} + x_3 R_3^{-\alpha} + \dots + x_i R_i^{-\alpha}) / (R_1^{-\alpha} + R_2^{-\alpha} + R_3^{-\alpha} + \dots + R_i^{-\alpha}) \\y_{MS} &= (y_1 R_1^{-\alpha} + y_2 R_2^{-\alpha} + y_3 R_3^{-\alpha} + \dots + y_i R_i^{-\alpha}) / (R_1^{-\alpha} + R_2^{-\alpha} + R_3^{-\alpha} + \dots + R_i^{-\alpha})\end{aligned}$$

... 3.12

where $[x_{MS}, y_{MS}]^T$ is the estimated location of the MS. $[x_1, y_1]^T, [x_2, y_2]^T, \dots, [x_i, y_i]^T$ are the locations of n serving BSs. The neighbouring BSs: $R_1, R_2, \dots, R_i$ are corresponding RSS received by the MS for each transmitting BS.

It was proved that the COG approach has an outstanding performance in urban areas because of the proximity of a MS to the BSs. However, the COG method can only estimate a mobile device inside the convex hull of the BS involved because it is the weighted mean of the BSs locations [80]. It has a restrictive coverage area determined by the polygon area formed by the outer positions of the BSs regardless of the position of a MS inside or outside the convex hull.

ii. Circular Trilateration (COT)

Zhou et al also proposed the COT approach which is accomplished by the construction of three circles with the RSS parameter and the known coordinates of the transmitting BSs. The intersection of circles is used to

estimate the location of the MS. It assumes that the distance relationship between a MS and a BS and the RSS is based on an inverse square law that is $(N + R)^{-\alpha} \propto d$ where α is an environmental factor, N is the normalization constant, R is the received signal strength and d is the distance between the MS and the BSs. By using this relationship, three circles can be constructed using the COT approach [73, 80]:

$$\begin{aligned}(x_{MS} - x_1)^2 + (y_{MS} - y_1)^2 &= \left(k^2/R_1^\alpha\right) \\(x_{MS} - x_2)^2 + (y_{MS} - y_2)^2 &= \left(k^2/R_2^\alpha\right) \\(x_{MS} - x_3)^2 + (y_{MS} - y_3)^2 &= \left(k^2/R_3^\alpha\right)\end{aligned} \quad \dots 3.13$$

Where, R_1 , R_2 and R_3 are the received signal strength from three (3) transmitting BSs with the geographic locations at $[x_1, y_1]^T$, $[x_2, y_2]^T$ and $[x_3, y_3]^T$ respectively, where k is the common scaling factor. The MS is then estimated as the intersection point of the three circles. COT is not highly reliable because it does not always provide estimates because of signal fading introduced by the wireless environment. COT eliminates the convex hull problem which was evident with COG.

iii. *Trilateration (TRI)*

Assumes availability of three or more BSs which a MS can communicate with and receive an acceptable level of signal strength. Considering that the unknown true position of the MS be $[x_{MS}, y_{MS}]^T$ and the BSs with known coordinates $[x_i, y_i]^T$, for $i = 1, 2, \dots, n$, where n is the number of BSs under consideration.

Given the distance measurement of each BS to the receiving MS, the BS is located at the centre of the distance radius and the MS can be located somewhere on the circle. In most cases, two circles will cross at two points producing two solutions. A third circle produced by the third base station

normally resolves the ambiguity of the solution to be adopted as shown in Figure 3.6.

Suppose there are three BSs with known locations $[x_i, y_i]^T$, $1 \leq i \leq 3$, and the unknown location of the target is denoted $[x_{MS}, y_{MS}]^T$ [81]. The distance measured from the MS to BS_i is defined as;

$$\hat{d}_i = d_i + \varepsilon_i, i = 1,2,3 \quad \dots 3.14$$

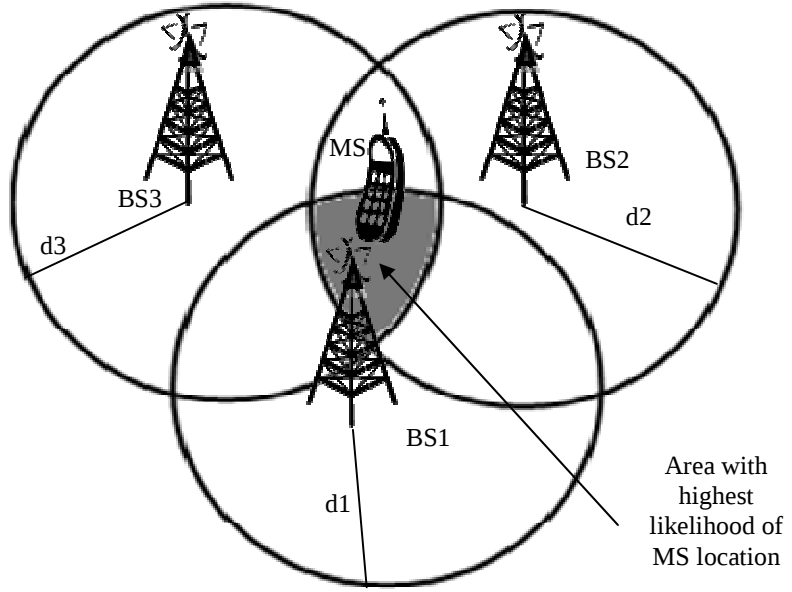


Figure 3.6: Two dimensional positioning using range based measurements

Where ε_i is the distance measurement error and

$$d_i = \sqrt{(x_{MS} - x_{BSi})^2 + (y_{MS} - y_{BSi})^2} \quad \dots 3.15$$

When there are three unknown location parameters using the three distance measurements $\hat{d}_1, \hat{d}_2, \hat{d}_3$ from three BSs and their known locations, the unknown location parameters $[\hat{x}_{MS}, \hat{y}_{MS}]^T$ representing the calculated MS position can be determined using trilateration.

For $i = 1,2$

$$\hat{y}_{MS} = -(x_2 - x_1/y_2 - y_1)\hat{x}_{MS} + (\hat{d}_1^2 - \hat{d}_2^2 + x_2^2 + y_2^2 - (x_1^2 + y_1^2))/2(y_2 - y_1)$$

... 3.16

For $i = 2, 3$

$$\hat{y}_{MS} = -(x_2 - x_3/y_2 - y_3)\hat{x}_{MS} + (\hat{d}_3^2 - \hat{d}_2^2 + x_2^2 + y_2^2 - (x_3^2 + y_3^2))/2(y_2 - y_3)$$

... 3.17

Defining some parameters:

$$\xi_{i,1} = x_i^2 + y_i^2 - (x_1^2 + y_1^2)$$

... 3.18

$$x_{i,j} = x_i - x_j$$

... 3.19

$$y_{i,j} = y_i - y_j$$

... 3.20

Where s_{12} and s_{13} is given as:

$$s_{1,2} = 1/2 \left[(\hat{d}_1^2 - \hat{d}_2^2) + \xi_{2,1} \right]$$

... 3.21

$$s_{1,3} = 1/2 \left[(\hat{d}_1^2 - \hat{d}_3^2) + \xi_{3,1} \right]$$

... 3.22

Equations 3.16 and 3.17 can be rearranged to get:

$$\hat{y}_{MS} = (x_{3,1}s_{1,2} - x_{2,1}s_{1,3}/x_{3,1}y_{2,1} - x_{2,1}y_{3,1})$$

... 3.23

$$\hat{x}_{MS} = (y_{2,1}s_{1,3} - y_{3,1}s_{1,2}/x_{3,1}y_{2,1} - x_{2,1}y_{3,1})$$

... 3.24

Reliability of producing a unique estimate is dependent on the fact that the MS and the BSs under consideration should not lie in a straight line. The coverage area is also dependent on the geometry of the BSs and position of the MS. The accuracy of this method is highly dependent on the propagation path loss model used because of environment specific challenges of the wireless environment. This method is highly applicable to both developing and developed countries.

iv. **Linearization based Least Square method (LS)**

This is an extension of the trilateration method and it is applicable when the number of independent equations is greater than the number of unknown

parameters i.e. when there are measurements from more than three BSs. The LS method can be applied to optimize the redundant measurements to obtain improved location estimates [81].

Consider a network in which there are n BSs whose coordinates are known $[x_{BSi}, y_{BSi}]^T$, $i = 1, 2, \dots, n$ and the coordinates of the MS are denoted by $[x_{MS}, y_{MS}]^T$. When a distance measurement is made to the BS, there are n measurement equations:

$$\hat{d}_i = d_i + \varepsilon_i, i = 1, 2, \dots, n \quad \dots 3.25$$

Where ε_i is the distance measurement error and the distance between the MS and i^{th} BS is:

$$d_i = \sqrt{(x_{MS} - x_i)^2 + (y_{MS} - y_i)^2} \quad \dots 3.26$$

A new equation was introduced to linearise the distance measurement equations. Squaring both sides of the equation produces:

$$\begin{aligned} (\hat{d}_i - \varepsilon_i)^2 &= \sqrt{(x_{MS} - x_i)^2 + (y_{MS} - y_i)^2} \\ (x_{MS}^2 + y_{MS}^2) - (2x_{MS}x_i + 2y_{MS}y_i) &= (\hat{d}_i - \varepsilon_i)^2 - (x_i^2 + y_i^2) \end{aligned} \quad \dots 3.27$$

By defining parameters P and P_i as;

$$P = \sqrt{x_{MS}^2 + y_{MS}^2} \quad \dots 3.28$$

$$P_i = \sqrt{x_i^2 + y_i^2} \quad \dots 3.29$$

Equation 3.27 becomes

$$P^2 - (2x_{MS}x_i + 2y_{MS}y_i) = \hat{d}_i^2 - P_i^2 + \varepsilon_i^2 - 2\hat{d}_i\varepsilon_i \quad \dots 3.30$$

Equation 3.30 can be written in compact form as

$$\mathbf{h} = \mathbf{G}\boldsymbol{\theta} + \mathbf{N} \quad \dots 3.31$$

Where,

$$\boldsymbol{\theta} = [x_m \ y_m \ p^2]^T \quad \dots 3.32$$

$$\mathbf{h} = \begin{bmatrix} \hat{d}_1^2 - p_1^2 \\ \hat{d}_2^2 - p_2^2 \\ \vdots \\ \hat{d}_n^2 - p_n^2 \end{bmatrix} \quad \dots 3.33$$

$$\mathbf{G} = \begin{bmatrix} -2x_1 & -2y_1 & 1 \\ -2x_2 & -2y_2 & 1 \\ \vdots & \vdots & \vdots \\ -2x_n & -2y_n & 1 \end{bmatrix} \quad \dots 3.34$$

$$\mathbf{N} = \begin{bmatrix} \epsilon_1^2 - 2\hat{d}_1 \epsilon_1 & \epsilon_2^2 - 2\hat{d}_2 \epsilon_2 & \dots & \epsilon_n^2 - 2\hat{d}_n \epsilon_n \end{bmatrix} \quad \dots 3.35$$

The least squares solution of Equation 3.27 is given by:

$$\hat{\boldsymbol{\theta}} = \mathbf{G}^{-1} \mathbf{h} \quad \dots 3.36$$

3.2.4 Hybrid Positioning

This is a combination of two or all of Cell-ID, TA and RSS measurements for positioning. It can be in the form of Cell-ID and TA, Cell-ID and RSS and Cell-ID, TA and RSS as shown in Figures 3.7 - 3.10.

3.3 EVALUATION OF CELL-ID, TA AND RSS-BASED NETWORK-BASED POSITIONING TECHNIQUES

3.3.1 Evaluation criteria

Four criteria are used to impartially evaluate and compare Cell-ID, TA and RSS-based network-based positioning methods to further assess their usability in Africa. The criteria to be used are as defined by [82] and they are coverage area, accuracy in positioning, reliability and applicability.

a. Coverage area

The coverage area and capacity for running LBS should be large enough to handle user demands. The coverage area is a parameter that had been estimated

before positioning starts to eliminate non-availability of the LBS to certain users or certain areas.

b. Accurate Positioning

Accuracy is defined by how close the actual location of a MS is to the estimated location. The accuracy needed for positioning should be dependent on the LBS required. Some services require very high accuracy e.g. emergency positioning, while some require relatively low accuracy e.g. a location based advertisement.

c. Reliability

Reliability is the ratio of accurate and reliable positioning attempts out of all attempts made. It is an important criterion because positioning methods should give high reliability, especially when used for emergencies and asset tracking service.

d. Applicability

The ability to apply a proposed technology is a very important evaluation criterion of positioning methods which had not been considered adequately in relation to developing countries. The physical limitations and requirements associated with the successful implementation of positioning methods in developing countries are mainly network dependency and the amount users can afford to spend on such services.

3.3.2 Critical Evaluation of Cell-ID Positioning

a. Coverage area

Cell-ID has a wide coverage area both indoors and outdoors and it is defined by the size of the mobile network a MS is subscribed to. It requires minor hardware and software upgrades, relatively cheaper to deploy and available to all MSs [65].

b. Accurate Positioning

Cell-ID can be very inaccurate where BSs is sparsely spaced or when the serving BS has a large coverage area. Firstly, the accuracy of Cell-ID is relatively unpredictable and can be anywhere within the coverage radius of the BS which can be from a few meters to kilometres. It is difficult to render accurate services. Secondly, it requires knowledge of the location of the base stations and deployment by a third party software becomes problematic because the mobile network operator is in full control of the services and no access can be granted without permission [66].

Cell-ID also works under the assumption that a MS is always connected to the nearest BS and the serving BS's coordinates is used to estimate the location of a MS. This might not always be correct due to many factors such as multipath, number of users in the area, antenna sensitivity et cetera [83].

Accuracy ranges from about 100 m to a couple of kilometres depending on the characteristics of the area covered by the mobile network, size of the cell (macrocell, microcell, picocell or nanocell), type of cell (omnidirectional or sectored) and some other factors. The accuracy can be up to 250 m for an urban area as shown in Table 3.1 and about 35 km in rural areas where there are larger distances between a MS and the serving BS [64]. The measurement only puts the user within a coverage area.

Table 3.1: Accuracy of Cell-ID positioning [64]

	Rural	Suburban	Urban	Indoor
Accuracy	1 km - 35 km Typically 15 km	1 km - 10 km Typically 5 km	500 m - 5 km for macrocells 50 m - 500 m for microcells	10 m – 50 m for pico cells

The accuracy of Cell-ID technique improves with sectorized BSs also known as enhanced Cell-ID. A sectored cell uses several BSs co-located at a single site with each antenna covering only an area of 120 to 180 degrees. A three antenna cell for example gives sector coverage of 120 degree by each cell.

Cell-ID positioning is shown in Figure 3.7. To locate a MS in a sector cell, the antenna azimuth and the size of the cell are taken into consideration and mathematical algorithms are used to calculate the MS position [53]. The accuracy will thus be ± 60 degree unlike if the MS is registered with an omnidirectional cell. [65].

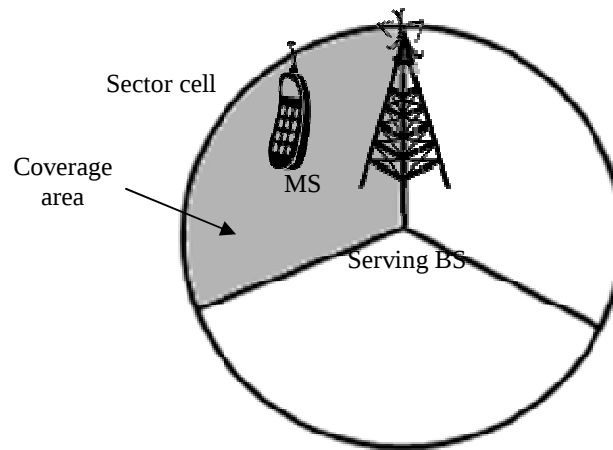


Figure 3.7: Enhanced Cell-ID positioning

c. Reliability

Cell-ID positioning is very reliable because the mobile network is always on and a MS once subscribed and turned on connects to the network. The reliability of positioning reduces with an increase in network. When the traffic to the closest cell is high, a MS tend to connect with any other cell it can receive adequate signal from.

3.3.3 Critical Evaluation of TA-based Positioning

a. Coverage area

The coverage area is defined by the size of the mobile network a MS is subscribed it has coverage both indoors and outdoors.

b. Accurate Positioning

TA information has a coverage radius of about 553.46m (form of a doughnut ring) and the accuracy of TA positioning is directly proportional to this. The TA information is estimated from the signal strength between a MS at a BS and it is therefore also dependent on multipath and other propagation channel challenges.

c. Reliability

TA-based positioning is very reliable and is similar to that obtainable for Cell-ID positioning.

d. Applicability

TA-based positioning is very applicable for all GSM networks tbut for trilateration using TA a forced handover is needed for practical implementation. Forced handover comes with its own challenges. Firstly, more traffic is used up for positioning which might have been available to other users and this is an issue not justified by the field trial objectives [70]. Secondly, extra software modifications are carried out at the BS. Thirdly, no communication can take place while the MS is being located.

3.3.4 Critical Evaluation of RSS-based Positioning

a. Coverage area

The coverage area of the RSS-based propagation model technique is dependent on the ability of a MS to receive adequate signals from three or more BSs. The coverage area of the fingerprinting technique is defined by the size and the coverage of the fingerprint database.

b. Accurate Positioning

The accuracy of location estimation using RSS-based propagation model technique is directly dependent on the suitability of the propagation model to the particular environment to which it is applied. The use of generic

propagation models will result in inaccurate distance calculation which will increase the inaccuracy of the location technique. However, the use of a propagation model which best fits the environment becomes inaccurate with time because of changes in the propagation environment. The best propagation model applied to a specific environment is one that is dynamically derived and can be arrived at with as little measurement and information as possible [43].

Fingerprinting technology is the most accurate of the RSS-based methods. Its accuracy is however dependent on the precision of the fingerprint data collected. The finer the grid space the better the mapping and the accuracy that is obtained from the mapping [74]. It is therefore very important to adapt the grid to be used to the need of the environment concerned and typically, the intervals are often selected in order of tens of meters. The measurement from each grid should represent the signal propagation profile of a small area for better accuracy [15, 74].

c. Reliability

RSS-based propagation model technique is also quite reliable and gives an estimate of a MS location provided there are measurements from three or more BSs. Possibility of obtaining estimation also reduces when the BSs considered are all on a straight line. The fingerprinting method is more reliable and always gives an estimate of the location.

d. Applicability

Propagation and statistical RSS-based models are more applicable in developing countries because a best fit propagation model is cheaper to develop and less man-power intensive. However, in rural areas the ability for a MS to receive radio signal from three or more BSs is quite difficult.

The major disadvantages of fingerprinting techniques are that they are labour intensive and implementation is demanding. Extensive and accurate measurement is required for the creation of the database which needs to be

updated with time due to varying propagation characteristics of the wireless environment [15]. The fingerprinting method is as reliable as the order/size of the grid space and the age of the fingerprinting database, due to constant changes in the wireless environment. The destruction or erection of a single structure can greatly affect the accuracy of the fingerprinting database which will in turn affect the accuracy of positioning of the MS. It is a good method for both mobile and stationary users but gives better accuracy for stationary users. It is highly applicable in developed countries where most of the structures are developed and there is sophisticated equipment to update the fingerprint database. For developing countries, however, it is not highly applicable due to new developments taking place frequently and lack of adequate equipment and man power to update the database when required.

3.3.5 Critical Evaluation of Hybrid Positioning

Accuracy can also be improved using Cell-ID in combination with other network-based location measurements such as TA and RSS. These provide an attractive alternative as they utilize only network information and require minimal hardware and software installations at the BSs. This is advantageous in terms of cost, coverage and accuracy [84] .

a. Cell-ID and TA

The cell within which a MS is located is first confirmed then its accuracy further increased to a distance or space of 553.46m between the two rings formed by the TA. For a sectorized antenna, the user location is defined by a fraction of “doughnut” shaped curve as shown in Figure 3.8.

The accuracy of this method depends largely on the assigned TA value whose accuracy is dependent on the wireless environment in which the MS is located. The TA parameter from a single BS, multiple BSs and just a single BS and the Cell-ID applied to MS location estimation evaluation against said criteria is discussed in Table 3.2.

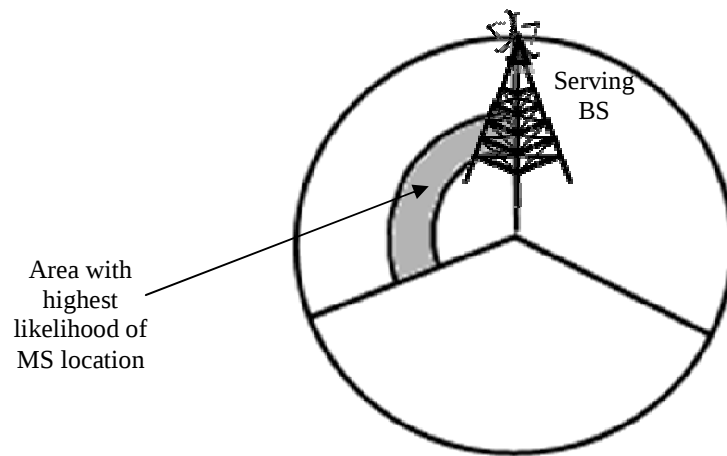


Figure 3.8: Cell-ID with TA positioning

Table 3.2: Cell-ID + TA methods with some evaluation criteria

Timing Advance + Cell-ID			
	TA from single BS	TA from multiple BSs	TA + Cell-ID
Evaluation Criteria	Coverage Area	Coverage area is as large as the mobile network	Coverage area is dependent on the number of BSs TA information can be received from.
	Accuracy	Coverage area is as large as the mobile network	
	Indirect wave propagation effect is greatly reduced in square annuli method as compared to the annuli method.	It has a higher accuracy in comparison with only the use of conventional TA methods.	This technique overcomes some of the major flaws inherent in Cell- ID only. Better in suburban areas.
Applicability	Provides the easiest computation of the MS coordinate limits. Applicable in developed and developing countries	The disadvantage of this method is that forced handover is needed for practical implementation. More applicable in developed and not applicable in developing countries.	Highly applicable in developing countries. Has an impressive trade-off between increased precision and implementation costs therefore highly applicable in developing countries.

b. Cell-ID + RSS

The RSS from three or more BSs and Cell-ID from the serving BS are the measurements applied for MS positioning. This is shown in Figure 3.9 and evaluation against said criteria is discussed in Table 3.3.

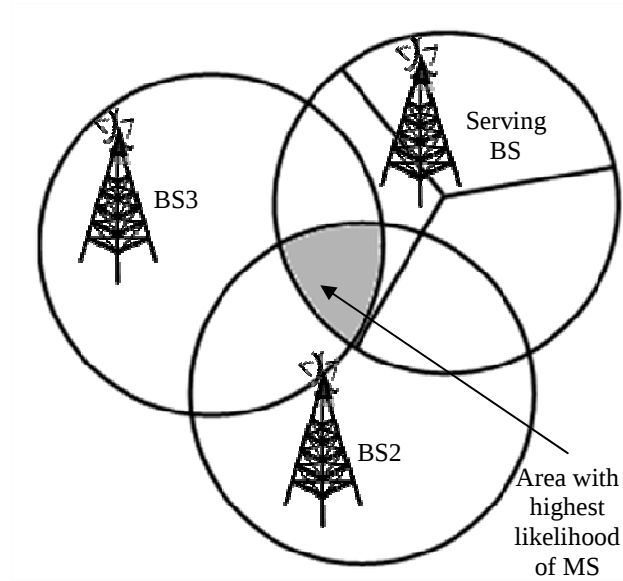


Figure 3.9: Cell-ID with RSS-based positioning

Table 3.3: Cell-ID + RSS methods with some evaluation criteria

Evaluation Criteria	RSS + Cell-ID		
	RSS		RSS + Cell-ID
	Coverage Area	Coverage area is as large as the mobile network	Coverage area is dependent on the number of BSs RSS information can be received from and coverage area of the serving BS.
	Reliability	High dependence of RSS-based method on highly variable factors makes it not very reliable.	Increases with the number of BS used and statistical estimation gives better reliability than geometric estimation.
	Accuracy	Accuracy of the RSS-based method is highly dependent on the network density, the propagation conditions and the geometry of the network.	Accuracy increases with the number on RSS measurements
	Applicability	Applicable in developed and developing countries.	Applicable in developed and developing countries.

c. Cell-ID + RSS +TA

Figure 3.10 shows graphically how Cell-ID +RSS +TA position estimation is carried out while Table 3.4 discusses the evaluation against aforementioned criteria - when RSS from three or more BSs, TA and Cell-ID from the serving BS parameters are used for MS location estimation.

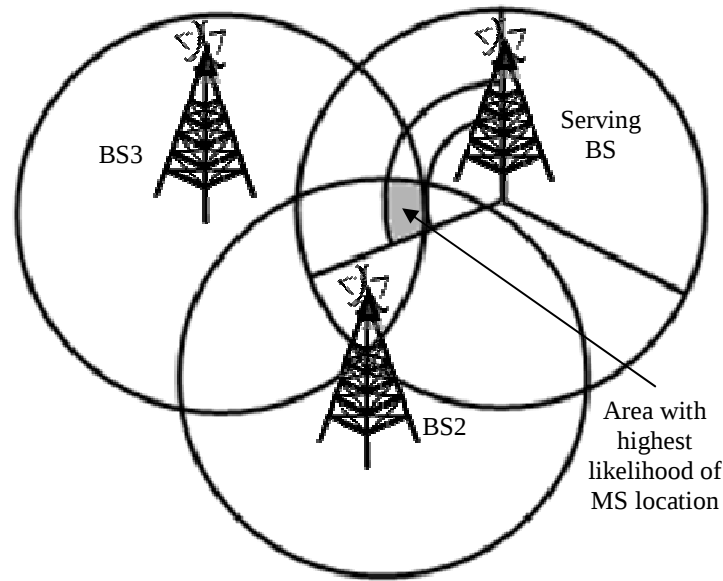


Figure 3.10: Cell-ID, TA with RSS-based positioning

Table 3.4: Cell-ID, TA + RSS methods with some evaluation criteria

Evaluation Criteria	Received Signal Strength + Timing Advance + Cell-ID	
	Coverage Area	The coverage area is as large as the mobile network
	Reliability	This is more reliable because it combines the strong points of all the parameters available and it always gives a location estimate
	Accuracy	Accuracy scales according to the cell size, network density, the propagation conditions and the geometry of the network. Gives better accuracy in densely populated area with smaller cells.
	Applicability	Applicable in developed and developing countries.

3.3.6 Conclusion on Critical Evaluation of CELL-ID, TA and RSS-based

Network-Based Positioning Techniques

Four criteria were used to compare Cell-ID, TA and RSS network-based positioning methods. Based on these criteria, it can be concluded that the techniques all have similar coverage areas and their accuracy is dependent on various factors. Cell-ID accuracy depends more on the cell size, TA on the distance between the MS and BS and also environmental interferences while RSS depends more on environmental interferences.

Cell-ID and TA are more reliable than RSS and they give an estimate once the MS is connected to a BS whereas RSS requires the MS to be connected adequately to at least 3 BSs. It might not be possible to have good connections to at least 3 BSs in some remote/rural areas where there are mainly macro-cells and they are placed far in between.

All positioning methods considered are applicable in Africa wherever there is network coverage, though Cell-ID and TA techniques might be more applicable in some remote/rural areas. A hybrid of these techniques will definitely provide for a more accurate and applicable service.

3.4 CONTEXT IN POSITIONING TECHNIQUES

Context-aware positioning makes position fix available to location services based on the characteristics of parameters used for positioning. The information that can be used to characterize the situation of the positioning devices includes the user's environment, the time of day, mobility of the user, type of LBS request, positioning technology and geometry of BSs. Some of these characteristics were investigated in literature and are stated here.

3.4.1 Error-Aware Positioning

It has been previously established that there are many types of error introduced to network-based positioning (Chapter Two, Section 2.5.3, page 40). Error-aware positioning takes into consideration the error that might be introduced during MS location estimation by error parameters. Errors introduced are mainly dependent on the wireless environment where the positioning is carried out, the geometry of the BSs used for positioning and computational and measurement error introduced. The error introduced is variable and dynamically changing, and no previous work has been carried out on error-aware positioning.

3.4.2 Adaptive Positioning

Filjar et al proposed [14] the adaptive selection of positioning sensors based on a group of position estimation algorithms and some parameters such as user profile and service profile. This proposed method makes the positioning algorithm aware of the user preference and service profile which is indicative of the amount the user is able and willing to pay for the service. There are three major concepts under consideration:

- o User profile,
- o LBS profile, and
- o Two or more positioning algorithms.

Unfortunately, in Africa, the basic service profile for LBS is what most users will prefer due to the price. From the analyses of measurement data collected and investigations carried out and presented in the Chapters Five and Six of this thesis, the positioning technique used by most mobile network operators in Africa is enhanced Cell-ID and Cell-ID. There is therefore there is not much opportunity for adaptive positioning as previously envisaged at the beginning of this research.

3.4.3 Computation and Measurement

A model cannot usually be developed for computation and error measurement. Instead these are estimated and mitigated against using tuning and other software methods before positioning. Three major concepts are of important consideration:

- o Computational error,
- o Measurement error, and
- o Positioning algorithm.

3.4.4 Wireless Environment-Aware Positioning

Turkyilmaz et al. [38] proposed an environment-aware RSS-based positioning algorithm based on the relationship between the radio propagation characteristics and environment. Data was collected from various locations at Istanbul. An artificial

neural network was then developed to identify the environment characteristics of the site where the MS is so that the most suitable channel model is used for position estimation. A 10.75 percent improvement in error was recorded.

This method is labour intensive and will require technical professionals collecting data for every environment that has to be covered. Instead of this method, Fingerprinting is a better option. Fingerprinting uses similar methods to build the database and gives a better network-based positioning accuracy. Some other factors that affect RSS-based positioning such as the geometry of the BSs used for positioning, was not investigated. Two major contexts were considered:

- o The environment where measurement data is collected for positioning, and
- o The positioning algorithm.

3.4.5 Geometry-Aware Positioning

The geometry of the network is an important metric which should be considered when position estimation is carried out using measurements from three or more BSs. Geometric dilution of precision (GDOP) is a metric which describes the effect geometry has on the relationship between measurement error and resultant position error [85, 86]. GDOP is defined in [87] as “the ratio of the accuracy of a position fix to the statistical accuracy of the ranging measurements”.

The geometry-aware positioning method can be established on two major contexts:

- o Geometry of the BSs where measurement data is collected.
- o Positioning algorithm that needs two or more BSs for positioning.

Figure 3.11 (a and b) shows a change in the BS geometry where the MS's location is constant while Figure 3.11 (c and d) shows the same BSs geometry but a change in the position of the MS.

3.4.6 Hybrid Positioning

When the three measurements aforementioned are used together for positioning, a better accuracy is obtained for the MS's location but all three cannot be used for positioning in all situations. For example using RSS measurements in urban areas will introduce a large error in positioning measurements and using cell-ID in an area with macro cells will also hamper accuracy. The hybrid method therefore becomes very useful [14]. When using a hybrid method, the positioning algorithms complement each other and provide a better position estimation. This method considered two major contexts:

- o Measurement data collected for different positioning algorithm, and
- o Two or more positioning algorithms.

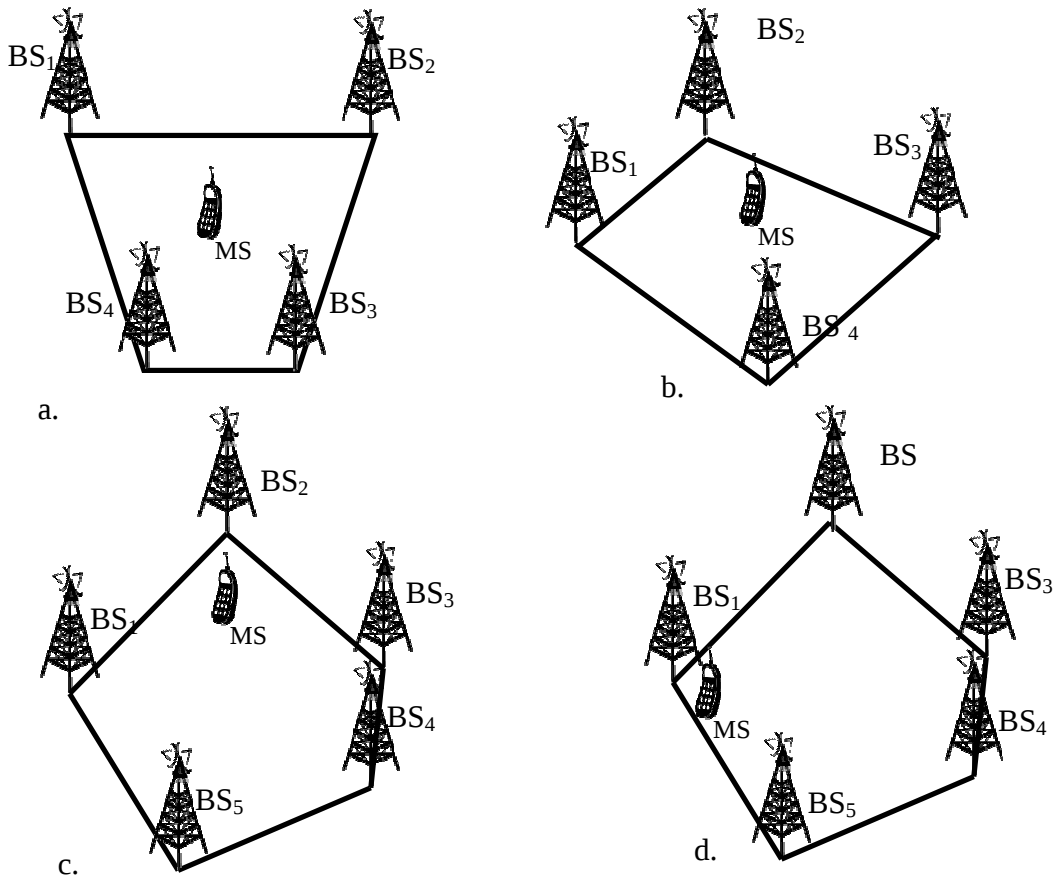


Figure 3.11 Different network geometries

3.5 CONCLUSION

Three basic network-based positioning techniques can be employed with no modification required to the MS and minimal modification to the mobile network. The Cell-ID, TA and RSS based positioning methods were reviewed and a critical evaluation of each one of them presented.

There are many sources of error encountered during network-based position estimation - measurement error mitigation, environment-aware mitigation method, multipath and others appear in published literature. Adaptive positioning was also investigated on by [14] to reduce positioning error by making the position algorithm aware of user preference. However, there has not been published work on geometry-aware RSS-based positioning.

The next chapter presents the research questions drawn from the review carried out and the methods utilized to answer the questions.

CHAPTER FOUR

4 RESEARCH QUESTIONS

4.1 INTRODUCTION

This chapter presents motivation for this research, research questions, methodology and the contribution of this research to knowledge.

4.2 RESEARCH MOTIVATION

This research is motivated by the fact that mobile subscribers in Africa need all the services the mobile phone coverage has and which the mobile network operators can offer. As previously stated, mobile communication is more accessible than electricity to the people in Africa and hence needs to be optimized for technological advancement. LBS are services that can be offered on the mobile network which can make a huge difference in the lives of Africans.

To use LBS it has to be dependable, accurate and reliable to be used effectively. This research is also motivated by the need of the African continent for accurate LBS that are adapted to its needs. Such LBS has to be network-based and accessible to all MSs (legacy and modern) and supported on the GSM mobile network.

This research focuses on improving the accuracy of LBS provided, by making it geometry - aware and bearing in mind that network-based positioning technique is highly dependent on the dynamically varying error sources,.

4.3 RESEARCH QUESTIONS

The purpose of this research is to study LBS in Africa and investigate the feasibility of improving the accuracy of network-based position estimation of an MS by using geometry-aware models for the dynamically varying error sources. This may ensure the provision of dependable and reliable LBS to MS users in Africa. Before the research question is stated, an explanation of some keywords is provided.

a. Error-aware positioning

The accuracy of LBS is dependent on accuracy degrading error sources which might be reduced by defining error models for the positioning methods [6, 15]. The error model can be used to predict a relatively more accurate positioning of a MS based on the particular wireless geometry and environment. Error-aware positioning also takes into consideration the error that might be introduced during measurement and computation.

b. Geometry-aware positioning

Geometry in this thesis is used in the context defined by [88], which states that “Geometry is the study of figures in a space of a given number of dimensions and of a given type”. Geometry-aware positioning takes into consideration the geometry of the BSs in the mobile network used for positioning and also the location of the MS relative to the BSs under consideration. Geometry-aware positioning is an important consideration when measurements from more than one BS are used to estimate the location of the MS.

c. Dependable LBS

LBS assist users to perform location-based task, for example a request made for the nearest hospital. The user is dependent on the QoS offered by the LBS to effectively utilize location information provided to make an informed decision [16].

d. Reliable LBS

An LBS user gets reliable service when the mobile location provider is able to provide location information in response to an LBS request.

e. Accurate LBS

The importance of accuracy has previously being explained in Chapter One Section 1.3.1 and page 4. A failure in the accuracy of the location information also translates to a failure in the decision made based on the LBS information provided. As the LBS user will not be able to depend on the location

information provided for an informed decision. This reiterates the importance of good service delivery to LBS users [16].

There are many error sources and considering all of them is beyond the scope of a single thesis. This research work will therefore only be considering geometry-aware positioning applied to geometric RSS-based positioning methods.

There are two questions to be answered by this thesis and these are:

1. *What is the status of LBS in Africa?*
2. *Is it possible to provide dependable, reliable and accurate LBS in Africa by making network-based positioning techniques geometry-aware?*

These two questions further broken down into the following sub-questions:

- i. What is the status of LBS in Africa?
- ii. To what measurable extent are the LBS in Africa dependable, reliable and accurate and how can they be improved?
- iii. What are the major sources of error in network-based positioning technology?
- iv. How will the parameters be harmonised and a model developed to make the positioning algorithm geometry-aware? Will location estimation be carried out with adequate considerations given to the geometry of the mobile network?
- v. Is the model feasible and robust enough to tackle the nonlinearities and uncertainties of its dynamically varying parameters?

4.4 METHODOLOGY

4.4.1 Brief Background of Research Methodologies

Research is a systematic process of using tools and techniques to collect and analyze information (data) in order to discover new knowledge or expand and verify the existing one. There are four types of research when viewed from the objectives of the research: descriptive, correlational, explanatory and exploratory research [89]. From

the viewpoint of the strategies of inquiry for obtaining data, they can be quantitative, qualitative and mixed strategies. Quantitative strategy (structured approach) explores and determines the extent of a problem, relationship, issue or phenomenon and this includes survey research and experimental research. While qualitative strategies (unstructured approach) investigate exploratory studies of the nature of a problem, relationship, issue or phenomenon. Some quantitative research experiments includes survey and experimental research while qualitative research procedures can be ethnography, grounded theory, case studies, phenomenological and narrative research [90].

Some of these methods were applied during the investigation analysis carried out in this thesis. Some sub questions need to be addressed before the major question can be analysed. This research was therefore carried out in phases and different methodologies were used for each phase.

4.4.2 Phase 1

This phase answers the first research question and first sub-question: what is the status of LBS in Africa? This research had to be carried out from the ground up, by first covering the basics of LBS in Africa. The research was carried out using the mixed strategy with a combination of quantitative and qualitative research strategies.

Six countries were investigated and data collected on them through academic literature available from different sources. The six countries include: United States of America (USA) and United Kingdom (UK) with already established LBS and four African countries -South Africa, Nigeria, Kenya and Egypt, four African countries. A reference framework was developed and used to access the state of LBS in Africa and the potential services that can be offered. This was to establish the importance of LBS in the much needed improvement in the way of life of the African populace and thereby bridging the digital divide.

The full version of the methodology and results from this investigation are presented in Chapter Five.

4.4.3 Phase 2

To answer the second sub-question (To what measurable extent are the LBS in Africa dependable, reliable and accurate and how can they be improved?) LBS measurement data was collected from South Africa, the only country in Africa with fully deployed LBS. These results are presented in Chapter Six of this thesis. A quantitative research strategy was employed in this phase of the research. A field study was performed outside the laboratory by the author and LBS data collected.

An empirical investigation was carried out on the LBS data using a reference model, ArcGIS, Statistical Package for Social Sciences (SPSS) and Gauteng map collected from the Gauteng City-Region Observatory (GCRO). The research investigates the accuracy, dependability and reliability of LBS in Africa and the results will assist in making an informed choice of techniques to be employed to ensure QoS.

4.4.4 Phase 3

Research sub question three “What are the major error source of network-based positioning technology?” was investigated in this phase. Here, a quantitative research approach was used and two types of field data were utilized. The first was LBS data collected by the author during field experiment and the second was drive test data collected from a mobile operator in South Africa. Major factors affecting the accuracy of the positioning technique used were investigated using similar components to those used in phase 3; a reference model, ArcGIS, SPSS, and Gauteng map provided by GCRO.

RSS-based positioning depends on most of the factors analyzed using the LBS data collected but it also depends largely on the position of three or more BSs for its position estimation. Consequently, an investigative analysis was carried out to determine the effect of geometry on the accuracy of RSS-based positioning technique.

Results and critical discussion of the results obtained are presented in Chapter Seven.

4.4.5 Phase 4

This phase answers research sub-questions four and five:

How will the parameters be harmonised and a model developed to make the positioning algorithm geometry-aware? In effect, location estimation carried out with adequate considerations given to the geometry of the mobile network.

Is a model feasible and robust enough to tackle the nonlinearities and uncertainties of its dynamically varying parameters?

Experimental simulation was used to analyse the feasibility of how the introduction of error models to Cell-ID, TA and RSS-based positioning methods might affect the quality of LBS provided to subscribers. Results and critical discussion of the results obtained are presented in Chapter Eight.

4.5 CONTRIBUTION TO KNOWLEDGE

The following contributions to knowledge have been made:

- o A comprehensive analysis of the potentials and challenges of LBS in Africa.
- o An empirical analysis of the dependability, reliability and accuracy of LBS in Africa.
- o A comprehensive analysis of some error parameters affecting network-based positioning technique accuracy.
- o Methods of improving the accuracy of LBS in Africa.
- o A geometry-aware model RSS-based positioning technique for GSM networks was developed.
- o Feasibility of a geometry-aware network-based positioning to improve LBS accuracy is presented.

4.6 SCOPE OF THESIS AND ASSUMPTIONS

The scope of this research is network-based positioning technique in an existing GSM network infrastructure for a MS with basic features. It is assumed that the radio propagation models used by the mobile network operator are accurate enough to be used for the analyses in the experimental areas. This research is also limited only to LBS applicable outdoors only. In this thesis, “outdoor” LBS will simply be referred to as LBS.

CHAPTER FIVE

5 CRITICAL EVALUATION OF LBS IN AFRICA

5.1 INTRODUCTION

LBS in USA represented 15 percent of revenue made from downloadable applications in Q2 of 2007 (second quarter of 2007) [91] and it is surprisingly almost non-existent in Africa. Even though the characteristics of each country and continent for the successful implementation of LBS are significantly different, LBS can help improve the lives of people in Africa. LBS applications that can be offered in Africa are numerous based on the needs of the people and the infrastructure available. Therefore, the African continent needs to address the provision of LBS to her people particularly those living in rural areas, low income earners in slums and settlements and also to urban and suburban dwellers. There is no known written research into LBS in Africa especially analyzing its deployment and adaption to an African setting. Therefore an investigative research into the growth and deployment of LBS in Africa is presented in this chapter.

Academic research was carried out by the author on two developed countries with already established LBS namely the United States of America (USA) and the United Kingdom (UK). LBS in the developed countries were then compared to those obtainable from an African setting with the view to developing a roadmap for LBS deployment and/or adoption in Africa. Four African countries were investigated namely South Africa, Nigeria, Kenya and Egypt. The primary objective of this chapter is to examine the challenges posed in deploying LBS in Africa by analyzing other developed countries and looking at the peculiarities of the African mobile technology environment. Other issues considered include user satisfaction and profitability of mobile operators and their third party partners.

The investigative research was carried out using a reference model and results presented indicate that Africa is indeed ready for LBS. It will enhance the lives of

many living in Africa as mobile technology has become the major means of information and communication to the African populace.

5.2 RELATED WORK

From the research conducted and presented in Latif et al and by Indicus, it was suggested that Africa is not the only continent with a need to explore the full potential of LBS [92, 93]. Latif et al proposed some location-based services which can be deployed in Pakistan such as e-marketing, parental eye, cellular cab services, location based voting, et cetera. The researchers did not access the infrastructural facilities available and a roadmap to the successful implementation of LBS in Pakistan. The services suggested would only serve urban subscribers adequately [92].

The Indicus white paper gave a detailed roadmap to a proposed deployment of mobile LBS in India. It gave the challenges envisaged and the way forward in the implementation of LBS in India. Current LBS provided in India are fleet management, person locator, mobile yellow pages and tourist information. It also suggested some LBS which might be adapted for use in India [94] such as emergency LBS, LBS navigation, weather alerts, person location based search, location based gaming and other types of location information.

Petrova and Wang compared LBS in developed countries with LBS with New Zealand by using an LBS reference model. They claim that though New Zealand is a developed country it does not enjoy the full potential of LBS like some other developed countries such as the United States, Japan and Europe. They suggested that the possible boosters of LBS could be public safety demand which will lead to legislative laws guiding the provision of LBS as implemented in the US and industry's demand for navigation and routing.

5.3 METHODOLOGY

Data collection was carried out through a survey of literature from different sources such as journal papers, conferences, mobile network operator's reports, newspaper

articles, online publications and others. Data was collected for the aforementioned countries and areas. For the purpose of this research, a reference framework was adapted from [95] to analyze the adoption and deployment of LBS in Africa.

Data collected was analyzed in five stages. At first, for each region considered; the type of LBS deployed and location technologies used were examined. Secondly, the advancement of GIS and GPS were analyzed in these regions. Thirdly, the mobile network market which includes the mobile operators and government regulations were considered. Fourthly, the ARPU, GDP per capita and Gini coefficient of the countries under consideration is presented. Fifth, the outcomes of the findings were used to compare the case of Africa to the other regions. Finally, deployment and adoption of LBS in Africa was analyzed.

5.4 REFERENCE MODEL

The author adapted and extended an earlier developed mobile commerce reference model given by [95] to assist in data gathering and the data analyses carried out. There are five important factors that influence the development of new LBS applications. These are infrastructure, interface, business, customer satisfaction and experience, and the customer's bargaining power. The infrastructure includes the mobile/communication network and the MS. The positioning process is carried out by algorithms and applications to request and deliver the LBS request. Geographical information systems (GIS) are used to provide data and content. A feedback is received by the mobile network operator from the subscriber through the average revenue per user (ARPU). Figure 5.1 is the graphical representation of the reference model.

a. Infrastructure layer

The mobile network is a communication path. It transfers user data and service requests from MS to the service provider and gets the requested information back to the MS. Today, most smart phones are designed to meet the needs of developed countries. Africa home to the poorest citizens in the world has most

subscribers using MS with restricted capabilities [93]. It is predicted that Africa and the Middle East region will have the largest amount of mobile phone shipments with 166 million low cost phones sold by 2014, representing 24 percent of all sales for the year [93].

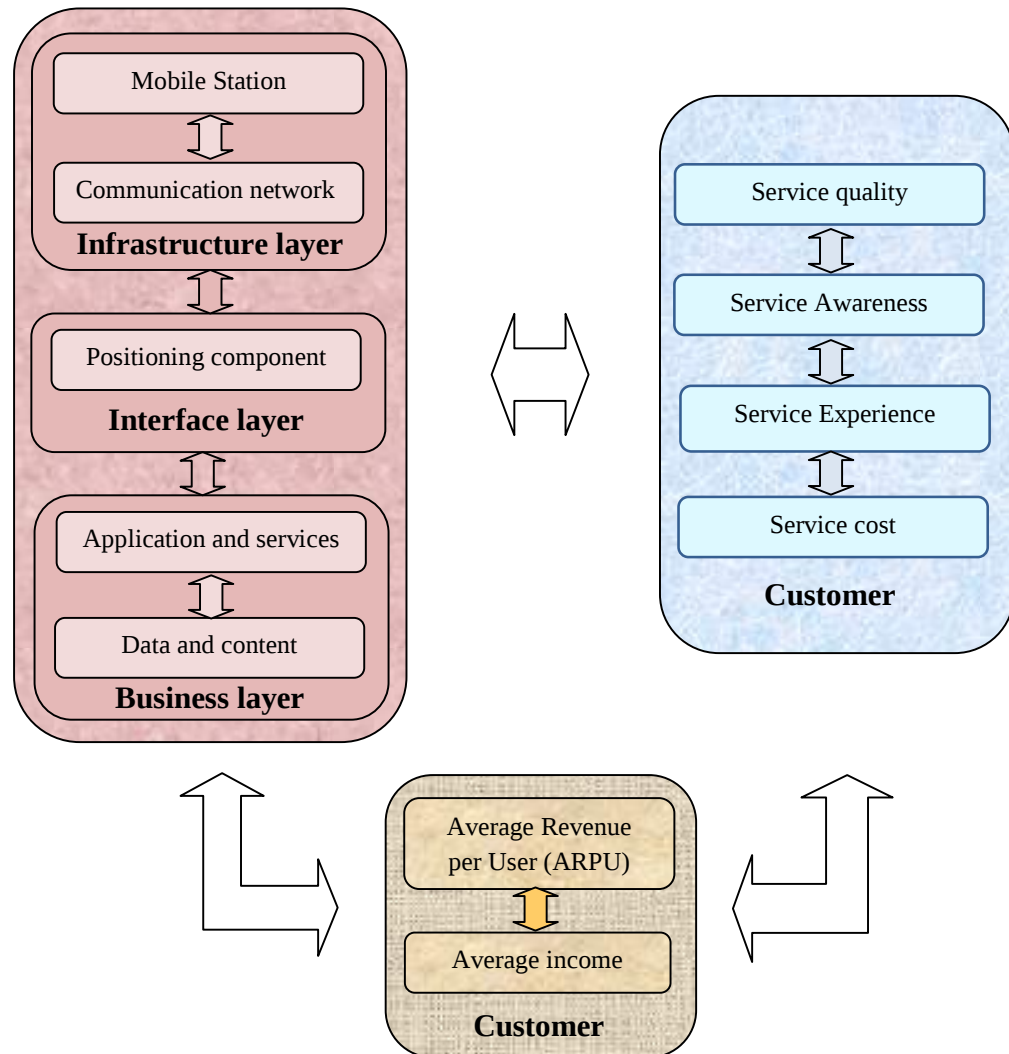


Figure 5.1: LBS reference framework (adapted from [95])

b. Interface layer

The interface layer comprises the positioning component which is used to estimate the location of the MS. Locating the MS is of utmost importance for LBS. Methods of locating the MS can be grouped into three as previously

highlighted - handset based, network-based and a hybrid of both. Most network-based methods are used for MS with basic features, where all measurements and calculations needed for positioning take place in an already existing mobile network [6, 9].

c. Business layer

There are many LBS offered by mobile service vendors in developed countries which include locating a friend, locating a point of interest et cetera. Real world features such as roads, points of interest and companies are represented in databases and these locations information are linked to location coordinates. Consequently, a request is made to a spatial database about a specific location by the software application for the retrieval of location information. All these various aspects are handled at the business layer by mobile service vendors and third party partners.

d. Customer Satisfaction and Experience

The ability to provide good service to the customer is a major corner stone in any service-oriented organization. Unfortunately, LBS developed and adapted to developed countries are transferred to Africa without undertaking adequate research and tailoring the services to the needs and preferences of the continent [93]. This has led to customer dissatisfaction and an inability to optimize the opportunities for services presented by MSs.

e. Customer Bargaining Power

The inclusion of the customer bargaining power in the LBS mobile commerce reference model is one of the important contributions of this research work. It is a major addition to the model presented by Petrova and Wang in [95] which did not consider the effect the customer bargaining power has on customer experience and profitability of mobile operators and their third party partners. The customer bargaining power of the developing and developed countries is compared using GDP per capita, Gini coefficient and ARPU.

Gross Domestic Product (GDP) is a basic measure of a country's economic output, while GDP per capita is the GDP divided by the population of the people in the country by mid- year [96]. Individual purchasing power (GDP-per-capita) is a means to compare the strength of consumers. A country with higher GDP per capita has customers who have higher income and better purchasing power than another with lower GDP per capita. The GDP per capita is taken as the average income of the country [96].

The Gini coefficient is also an important economic indicator which measures the degree of inequality in the distribution of family income among an entire population or country [97]. A high Gini coefficient indicates that more of the income is distributed amongst a small group in the population and a low Gini coefficient indicates that the income is equally distributed among the majority of the people.

The amount mobile operators are ready to invest in research, development of services, applications, infrastructure and their deployment is dependent on the average income of the community of interest. This will in turn give an estimate of the expected average revenue per user (ARPU). ARPU in a mobile network is used to express the income generated by a typical subscriber on the mobile network [98]. ARPU is dependent on the amount an average subscriber earns and the amount the user is willing to pay for the services offered. The customer bargaining power has a direct effect on all the other layers such as the infrastructure layer, interface layer, business layer and definitely the customer's satisfaction and experience.

GDP per capita, Gini coefficient and ARPU are metrics of customer's bargaining power employed in this Chapter but they have various limitations. Some limitations of GDP per capita are that the methods of computed economic statistics vary by country, it excludes informal income and the exchange rate used for computation is rarely stable. Gini coefficient cannot be used when the

distribution is negative and tangible information is lost when absolute national and personal income is considered. ARPU is also not without some limitations as for example subscribers having multiple accounts and generally the metric is skewed to and by certain services. These metrics used are however widely used and accepted metrics and hence appropriate for the investigation carried out in this Chapter.

5.5 CASE STUDY OF DEVELOPED COUNTRIES

5.5.1 Customer Purchasing Power

GDP per capita of the USA and the UK, as given by Central Intelligence agency (CIA) by Q1 2011, are \$47,400 and \$35,100 respectively [97]. The ARPU of AT & T the largest mobile operator in the USA and Orange in the UK is \$61.89 for Q1 2010 [99] and \$31.87 for Q4 2010 [100] respectively. The ARPU presented for the UK and the USA was determined based on the mobile operator with the largest market share; that is the AT&T.

5.5.2 Infrastructure

In Europe, GSM is a unified technology. This is not the case with the USA, where there are both CDMA and GSM networks [95].

5.5.3 LBS Deployment

The main driver of LBS is the requirement by FCC for locating Emergency 911 callers using MSs within a specified accuracy in the USA [101].

Among the top five wireless operators in the USA are Cingular, American Telephone and Telegraph Wireless Service (AT&T WS), T-Mobile, Sprint-Nextel and Verizon. Cingular, AT&T WS and T-Mobile are based on GSM infrastructure while Sprint-Nextel and Verizon operators have CDMA infrastructure [95, 101]. The GSM infrastructure can easily locate both legacy MS and those with built-in GPS module while for the CDMA network it is more technically effective to locate only MSs with built-in GPS.

Cingular AT&T WS, and T-Mobile adopted a network-based solution U-TDOA [101]. Other mobile operators with CDMA technology adopted AGPS, a handset-based solution. U-TDOA technology requires an upgrade of the mobile network while the later requires an upgrade to the MS. The U-TDOA and the AGPS are the only ones which have met the performance requirement for emergency services location U-TDOA supports all kinds of mobile phones [13, 101].

Various types of LBS such as emergency, navigation, information and tracking location-based services are offered in the USA by mobile operators and other third party business partners (shown in Table B.1 in Appendix B, page 104). These LBS are monitored by regulatory bodies and they should therefore meet the specifications of the FCC in both accuracy and reliability.

Enhanced 112 (E112) a variant of E911 in the USA was initiated by the EU commission as a directive in 2002 ("Directive 2002/22/EC" 2002) with the aim of providing emergency services to MS users. In Europe, GSM is a unified technology and as a result, it was easier to work on a technology for E-112 and enhance LBS deployment. The technologies proposed Cell-ID, Cell ID + TA, E - OTD, U-TDOA and AGPS, were all considered suitable for E112. The most probable ones due to accuracy are U-TDOA and AGPS [13]. Various types of LBS such as emergency, navigation, information and tracking location-based services are also offered in the UK (shown in Table B.2 in Appendix B, page 205).

5.5.4 Data and Content of LBS

There are many GIS companies already operational in developed countries especially in the USA and the UK. They will therefore have well managed up-to-date maps and spatial information available on most parts of the country. The data and content made available to LBS subscribers is reliable and up-to-date. LBS vendors employ qualified and trained personnel and therefore services and applications well suited to the needs of subscribers are developed and deployed. This will effectively meet the expected requirements for LBS accuracy.

5.5.5 Regulatory Body

The FCC regulates E-911 in the USA and E-112 was commissioned by the European Commission. Both are well established regulatory bodies. The European Commission did not specify an implementation deadline or accuracy [101, 102]. The accuracy specified by E-911 has been previously presented in Chapter One, Section 1.3, and page 4.

5.6 CASE STUDY OF DEVELOPING COUNTRIES IN AFRICA

5.6.1 Customer Bargaining Power

GDP per capita of South Africa, Nigeria, Kenya and Egypt as provided by CIA for Q1 2011 are \$10,700, \$4,400, \$1,600 and \$6,200 respectively [97]. As can be seen in Figure 5.2, the GDP per capita of the USA is about 30 times more than that of Kenya. The ARPU of the largest mobile operators were also considered. In South Africa it was \$19 for Q1 2010 [103] \$11 for Q4 2010 in Nigeria [104], \$7 in Kenya for Q4 2010 [105] and in Egypt it was \$5.16 for Q3 2010 [106].

Figure 5.2 and Figure 5.3 show a strong correlation between the GDP per capita and the ARPU of the countries considered, except for Egypt which offers the cheapest mobile services in the world. The exchange rate of the Egyptian pound to the dollar is also affected by the turmoil that recently took place in the country [107]. This implies that a country that earns more will pay more or spend more on mobile applications and services.

According to the “World Fact Book” produced by the CIA, the Gini coefficient of USA, UK, South Africa, Egypt, Nigeria and Kenya are 45 percent, 34 percent, 57.8 percent, 34.4 percent, 43.7 percent and 42.5 percent respectively [97]. The Gini coefficient from the Human Development Report produced by the United Nations Development Programme is slightly different due to the method of data collection and analyses and they are given as 40.8 percent, 38 percent, 65 percent, 32.1 percent,

42.9 percent and 47.7 percent respectively [108]. These are shown graphically in Figure 5.4.

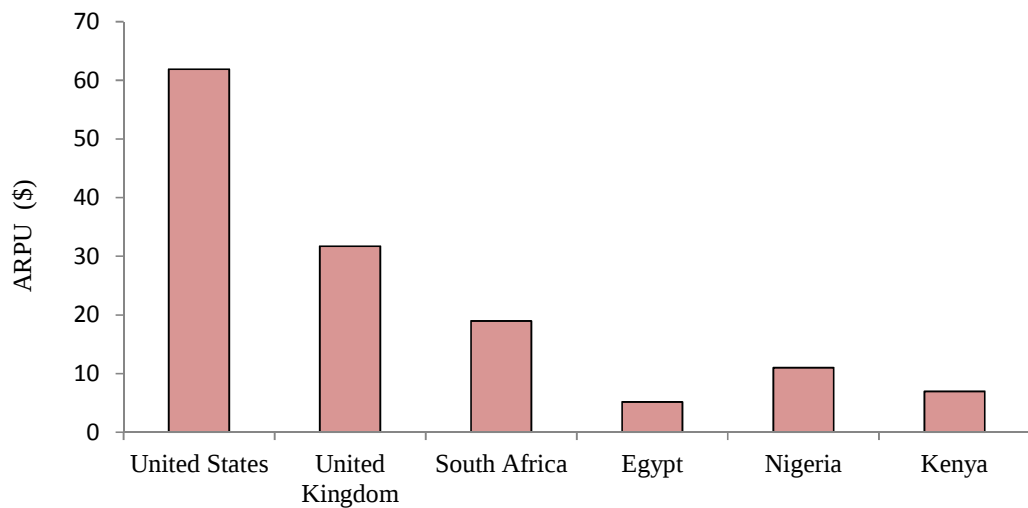


Figure 5.2: ARPUs of countries under investigation in study

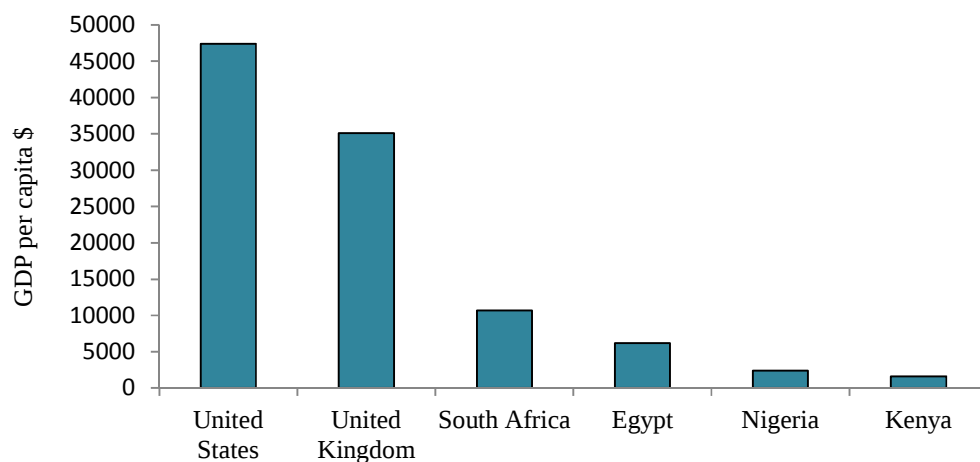


Figure 5.3: GDP per capita of countries under investigation in study

Though income distribution inequality affects all countries, the worst affected are countries with low GDP per capita such as the African countries considered. Although the income in these countries is minimal it is unequally distributed and in the hands of a few of the entire population. Thereby further reducing the purchasing

power of a majority of subscribers. From Figure 5.4, South Africa has the worst Gini index with a large amount of its family income taken by a small group of people and Egypt has the best distribution according to the Gini coefficient.

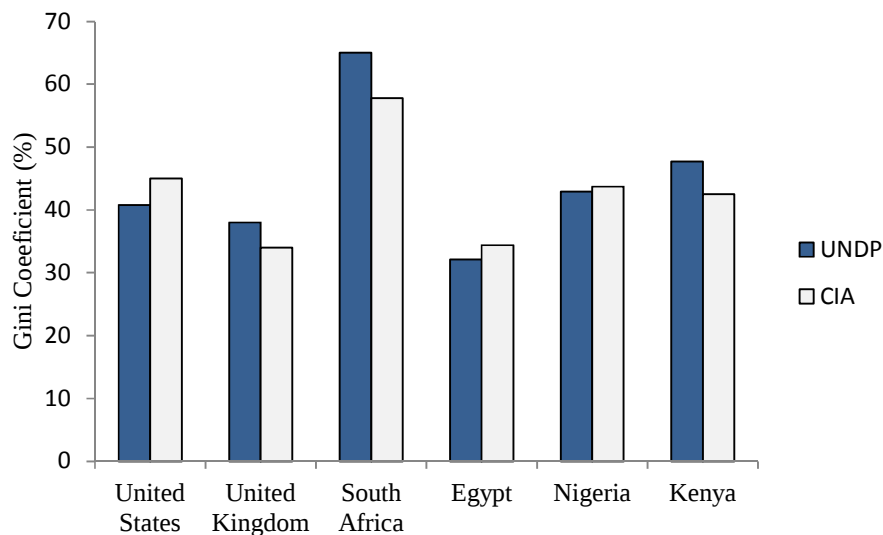


Figure 5.4: *Gini coefficient of countries under investigation in study*

5.6.2 Infrastructure

South Africa has a population of about 50 million people and a mobile network penetration rate of 93 percent [109]. The South African mobile market started in mid-1994 and by 2008 had about 45 million subscribers, or a 92 percent penetration rate. It was predicted that by the end of July 2009 there would be about 54 million mobile subscribers in South Africa which is about 13 percent of the estimated 415 million mobile subscribers in Africa.

South Africa operates with a more advanced technology than other African countries. The mobile operators include Vodacom with about 26.3 million subscribers at 1Q 2010 [110], MTN with about 18.8 million subscribers at 3Q 2011 [111] and Cell C with about 8.2 million subscribers [112]. Virgin Mobile is a mobile virtual network operator using the Cell C network while Red Bull Mobile and 8.ta are roaming virtual mobile network operators using Cell C and MTN respectively for coverage across

South Africa. All the mobile networks operate GSM, General Packet Radio Service (GPRS) and Enhanced Data Rates for GSM Evolution (EDGE) technologies. Vodacom and MTN both operate the UMTS technology. All mobile operators plan to roll out a higher package, High-Speed Packet Access Evolution (HSPA+) in the nearest future.

Kenya has 19.4 million subscribers in total and a 51 percent penetration rate [113]. The mobile operators are Safaricom, Airtel, Orange Kenya and Yu- Essar Telecom Kenya with Safaricom being the largest subscriber base with about 18.1 million mobile subscribers 3Q11 [114]. All mobile operators use GSM technology.

Egypt has about 66.3 million subscribers in total, or a 93.2 percent penetration rate by the end of 2010. Egypt is the second largest market in Africa with approximately 13 percent of the total mobile subscriber market [115]. The mobile operators are Mobinil, Vodafone and Etisalat with 30.4 million, 31.8 million and 13.28 million subscribers respectively. All the networks operate with both the GSM and UMTS technology [114].

Nigeria has a population of about 153.2 million people with about 90 million active mobile line subscribers or a mobile line penetration rate of 60 percent penetration rate. Nigeria is the largest single mobile market in Africa having grown from a no mobile phone country in early 1999 to 59 mobile subscribers per 100 inhabitants in 2010, an enormous growth over about 10 years of mobile technology in the country. The country has over 120 million connected mobile subscribers [116].

The GSM mobile operators in the country include MTN, GloMobile, Airtel-Zain, Etisalat, Mtel with about 40.54 million, 19.49 million, 15.97 million, 7.8 million and 0.2 million. The CDMA mobile operators have about 10% penetration and the CDMA operators are Multilinks-Telkom, Starcomms, Reliance telecoms, Intercellular Nigeria and Visafone [117].

5.6.3 LBS Deployment

VODACOM and MTN are the only South African mobile operators presently offering LBS as at the time of writing this thesis and they make use of enhanced Cell-ID method for locating the MS. Notwithstanding that they have the most advanced technology in Africa, they make use of the most basic positioning method to estimate the position of a MS for most commercial LBS.

VODACOM offers the following network-based LBS; Emergency call (911Alert), Distress call (Look4Help), Person tracking (Look4Me), Points of interest (Look4it) and MTN offers Emergency call (911Alert), Distress call (MTN2myAid) and Person tracking (WhereRU). Asset tracking is offered by MTN and VODACOM in conjunction with asset tracking companies. Cell C offers only emergency calls (911Alert). VODACOM introduced a new trial of a location-based advertising service called the grid to be launched soon [118]. Look4Me for Business, Cellfind Assets, Cellfind Messaging Portal, 911 Alert, Look4Music and miTraffic are other types of LBS offered through third party business partner CELLFIND [119]. South Africa LBS market forecasts an increase in the LBS market to rise to \$33.8 million in 2013 [118].

Safaricom and Airtel- Zain are the only operators offering LBS in Kenya. Safaricom engages commercially in vehicle tracking and Airtel-Zain provides Emergency calls. Table 5.1 summarizes the LBS offered in the aforementioned developing countries.

5.6.4 Data and Content of LBS

South Africa is the most developed country in Africa and was the pilot for many technologies already existing in Europe and the USA. ESRI, a major GIS company, has a subsidiary in South Africa and South Africa therefore has relatively up to date maps and spatial information. Data and content availability is more commendable than in other African countries and there are more qualified and trained personnel to develop and manage LBS.

Until April 2009, Egypt had a ban on GPS and all GPS products. MS entering the country with a built-in GPS module had to be disabled before they could be sold [120]. This might have a positive impact on the growth of LBS in this country.

Table 5.1: Location-based services in 4 African countries

Country	Company	Penetration Rate	Services
Egypt	Mobinil,	58.85% penetration rate (05/2008)	-
	Vodafone		-
	Etisalat		-
Kenya	Safaricom	51.2% penetration rate (06/2010)	Vehicle tracking
	Airtel-Zain		Emergency calls
	Orange Kenya		-
	Yu- Essar Telecom Kenya		-
Nigeria	MTN	59.90% penetration rate (10/2010)	-
	GoMobile		-
	Airtel-Zain		-
	Starcomms		Person tracking
	Mtel		-
	Etisalat		-
	Multilinks-Telkom		-
	Visafone		-
South Africa	Vodacom	92.15% penetration rate	Emergency calls
			Distress calls
			Person tracking
			Points of interest
			Asset tracking
	MTN		Emergency calls
			Distress calls
	Cell C		Emergency calls
	8.ta		rMVNO ¹
	Virgin Mobile		MVNO ¹
	Red Bull Mobile		rMVNO ¹

LBS were introduced in Nigeria in the year 2010 by Starcomms which uses a CDMA network and covers less than 5% mobile penetration. The LBS launched called

¹ (Roaming) Mobile Virtual Network Operator

StarTrack allows subscribers to locate family and friends [121]. At the time of this research, all the other mobile operators were yet to launch any other LBS. With most subscribers on GSM networks, StarTrack on CDMA network is available to very few percentage of the population.

5.6.5 Regulatory Body

At present, as far as the author can ascertain there is no legislation regarding emergency LBS or other LBS in any African country.

5.7 THE WAY FORWARD TO DEVELOPMENT AND DEPLOYMENT OF LBS IN AFRICA

All over the world, many LBS have been successfully launched and in order to find new opportunities, mobile services providers are looking more closely into Africa. Unfortunately, this is not proving successful. These companies try to push existing products and services deployed in developed countries into the African market, instead of adapting the services and products to the needs and culture of the people [93, 122].

Location information allows subscribers to access information that is pertinent to the location of the requesting user. Subscribers may initiate service requests on demand, or automatically when triggering conditions are met; for example, entering a particular BS cell and when a specific hot spot in the area is approached. There are many types of LBS, and many have been discussed previously in chapter two. Some of the LBS discussed here are applicable both in developing and developed countries and others are more suitable to the needs of Africa.

5.7.1 Critical LBS Needs

These LBS will attend to the short term or critical needs of subscribers.

a. People tracking

Friends and family are the most important assets of man. The LBS helps to pinpoint the geographical location of friends and family especially when they

go missing, or for child tracking purposes. People tracking can also be of importance in fighting the spread of diseases and epidemics in Africa, such as tuberculosis.

African countries face formidable challenges in public health such as the rapid spread of HIV/AIDS, persistence of malaria and related killer diseases such as tuberculosis. Presently Africa is facing the worst tuberculosis epidemic since the advent of the antibiotic era. This is driven by a generalized human immunodeficiency virus (HIV) epidemic, compounded by weak health care systems and the situation has gradually worsened [123]. More than two-thirds of the population in twenty-five of the most affected African countries live in rural areas. Rural people are more prone to the disease because they are less likely to protect themselves and do not have adequate access to health services and information [124]. With LBS, location specific information can be obtained, and the location and treatment of patients to assist the management of these health challenges might be made easier.

Maintaining patients on pulmonary tuberculosis (TB) treatment is also critical to ensure its cure and the prevention of drug-resistant strains of tuberculosis. A contributing factor to high treatment interruption rate is the limited capability of the TB clinics to locate patients who interrupt their treatment as cited in [125]. LBS can be used to trace and locate patients to ensure completion of TB treatment.

b. Health information services

There is a huge brain drain of health professionals in the rural areas to the urban areas [126]. There is therefore a need to make effective and adequate use of the services available. LBS can be used to provide information services to mobile subscribers such as nearby hospitals with health care workers and health care centers with the required medication and health providers. Community health

education days and immunization days' reminders can also be broadcast to the people in a particular location.

c. Cell broadcast

The network automatically broadcasts information to mobile phones in a geographical area. The information can be sent to all mobile phones in the area or to a specific group/community. Health information, weather alerts and other important information can be sent to the people in the coverage area. In most African countries security officials do not always have the capacity to respond to and help victims of attack. People therefore resort to depending upon each other in a community and even employing security personnel if applicable. When there is an incident of robbery or assault, an emergency number can be sent to the police and selected members of a registered community or geographical area, e.g. the Community Policing Forum (CPF).

d. Security alerts

Robbery, murder, rape and other forms of assault are prevalent in particular areas and locations. Warning information might be sent to all persons approaching, or already in the location, to make them aware of the dangers of that particular location and precautions to be taken. This can also be enforced on beaches and unsafe natural habitats. Africa is a continent with many indigenous beliefs, culture and traditions. There are some rural and urban areas in Africa where visitors are not welcome at particular times of the year, on particular days and in particular hours. This is because some traditional rituals are being performed which might be harmful or embarrassing to visitors.

e. Emergency service and alert

Emergency calls and emergency alerts are probably the most important feature offered by LBS, especially in situations where the caller cannot indicate his/her location due to a medical condition or unawareness of his/her location. Emergency alerts are very useful when natural disasters occur, such as flooding,

disease epidemics and fire outbreak which could claim lives and destroy homes. Africa is known for the slow response of emergency personnel. The mobile phones of passengers in any means of transportation can also be automatically linked to emergency alerts.

f. Commodity availability information

Poverty in Africa is predominantly in rural areas with more than 70 per cent of the continent's poor people living in such areas. These rural dwellers still depend on agriculture for food and livelihood even though development assistance to agriculture is decreasing [127]. The availability of LBS in rural areas will enhance the advertisement of commodities available in a particular environment or community and the location of such commodities or agricultural produce. This will improve people's access to commodities or agricultural produce before it perishes due to the unavailability of adequate storage and preservation facilities in rural areas.

g. Route/ security information

Hijacking and accidents on African roads is always a possibility, this LBS service can give security and traffic information about a route to ensure safety and timely passage.

h. Hotspots alert

Africa has experienced and is still experiencing a lot of man-made disasters. Examples include xenophobic attacks in South Africa, religious crises in Northern Nigeria, ethnic cleansing in Sudan and genocide in Rwanda. An effective warning system can be developed which sends out emergency alerts on natural or man-made disasters. This will give information about what is happening and the best way to get to safety. Hotspot alerts locate crisis areas and provide information about the nearest safe spot i.e. Police station, nearest military barrack and directions on how to get there safely. Disaster zones can also be mapped out quicker in the event of fires, outbreak of diseases et cetera.

i. Weather alert

There have been many cases of flooding, drought and destruction of lives and properties due to lack of adequate weather warning. Weather alerts can be sent which might help people adequately prepare for such events thereby saving life and property.

5.7.2 Additional LBS Needs

These LBS applications are suggested for additional LBS needs of subscribers.

a. Directions/Navigation

This application guides a mobile phone user to his/her destination by providing navigational or directional information, linked to a geospatial information system. This service can also be provided to villagers travelling out of their zones for the first time.

b. Traffic monitoring and management

The infrastructure in most urban areas of Africa cannot cater for the population of people living in these urban areas. Traffic management can be a lot easier with traffic information sent for different routes. Traffic management can also assist in decongesting roads and providing alternate routes.

c. City guides

Tourism is an important alternative source of foreign exchange to the continent. A guide should provide information about points of interest such as historical sites, tourist attractions, restaurants, police stations, et cetera.

d. Location based voting

Electoral processes in many parts of Africa have been characterized by electoral crises - Zimbabwe, Nigeria, Democratic Republic of Congo and Kenya are a few examples of this [128] . Location based voting will help monitor the movement of voters and the movement of election materials from

different locations which might assist in authenticating the fairness of the elections.

e. Personnel and workforce management

The workforce and personnel management LBS can be used to track employees and ensure that work-plans are completed. It could also offer the ability to enforce penalties to defaulters. This can be used by both private and government sectors. It could also be used to communicate with field workers to improve their productivity in the field.

f. Route planning, fleet and asset management

This is very important to companies with fleet vehicles that have scheduled deliveries. Routes are carefully planned to deliver the goods no matter the eventualities. Asset management needed in rural communities may range from perishable agricultural goods to cultural artefacts and vehicles and goods in urban areas. These LBS should be able to provide location and a timestamp of the fleet/asset when registered to ensure safety and prompt delivery.

5.8 CHALLENGES ENVISAGED

a. Data and content

A good addressing system and adequate geocoding for Africa is important for the deployment of LBS due to the use of geographical information system used to map real points of interest and streets to geographical coordinates. Considering the fact that Africa is a developing continent and the spatial database might not be well populated, low in accuracy and not up-to-dated due that are not numbered and streets that do not have correct signage. This is a major challenge inferred from the results of LBS provision analyses carried out by the author and presented in Chapter five of this thesis. Africa needs to invest more in geographical information systems.

b. Services and Application

Most of the services currently rolled out in Africa were brought in from developed countries and have therefore not been adapted to the needs of African users [93]. This might be due to the unavailability of trained local staff and personnel to develop the services and applications. Acceptance by most subscribers of such services is slow if not impossible because the needs of the intended subscribers might not be met.

c. Quality of service

Cell density affects most network-based positioning methods. The present challenges with voice services such as high drop call rates in some areas in Africa might translate into reliability challenges with LBS.

d. Regulatory body

There is presently no regulatory body looking into LBS services in Africa. The QoS provided cannot be assured without good regulation in place.

e. LBS Infrastructure

Many location estimation devices such as LMU and smart devices are not readily available in developing countries because of the huge investment involved. At 2Q of 2010 according to the report by [129] the cost of upgrading a BS with a LMU is about R 40 000 – R 53 000 at the conversion rate of 1 British Pound to 13.2 South African Rand. Smart devices are also not a viable option as presented in Chapter 1. Some location estimation technologies using these devices therefore have low applicability in Africa and it is important to explore other methods to further enhance the accuracy of network-based location estimation techniques.

f. Accurate positioning

The most applicable positioning methods in Africa are those that need little modification to the mobile network and no modification to the MS for its implementation. These can be summarized as network-based positioning

techniques. They are generally dependent on many factors such as cell size, multipath, propagation channel, wireless environment and geometry of BSs.

Error models, multipath propagation models and NLOS propagation models are highly dependent on the geometry of BSs and the wireless environment [125]. Consequently, various location estimation algorithms are affected in varying ways by different geometry and wireless environments especially in network-based positioning [56].

Different methods should be adapted to different areas depending on the topography of the area and geometry of the network. There should be no one general solution for all the areas.

5.9 CONCLUSION

This chapter presents a novel investigative research about LBS in Africa. The contribution to knowledge presented in this chapter includes the extension of an LBS reference model to incorporate customer satisfaction, comparing LBS in Africa with developed countries, the adaptation of some LBS to the African setting and highlighting the challenges that might be encountered with deploying LBS in Africa.

It can be concluded from the analyses and evaluation presented that Africa needs LBS adapted to its needs. LBS which are reliable, dependable and their location information can be used for the required purpose. Consequently, there is a need to provide accurate location information (data content) which is highly dependent on accurate network-based positioning techniques.

This chapter answers the first research question and first sub-question with the aim of analysing the status of LBS in Africa in order to firstly ascertain the state of LBS in Africa compared to the world and also to present the different ways location information can enhance the way of life of people living on the continent.

The next chapter presents more analyses on the accuracy and dependability of location based on empirical analyses performed on some LBS data collected in South Africa.

CHAPTER SIX

6 DEPENDABILITY OF LBS IN AFRICA

6.1 INTRODUCTION

The previous chapter reiterates the need for LBS in Africa and highlighted some challenges that might be encountered. This chapter continues with the study of LBS already deployed in Africa with specific investigation into South Africa, the pilot country for LBS deployment in Africa. South Africa has the most advanced mobile communication infrastructure in Africa and it is not surprising that it is also the first country in the continent to roll out LBS to its subscribers.

This chapter investigates the dependability of location information currently provided to LBS users. This is achieved by investigating using empirical analyses the difference between predicted and provided accuracy to LBS users. The empirical investigation was carried out on some parameters affecting accuracy provided and accuracy predicted.

Summarizing, it was established that the predicted accuracy and provided accuracy are quite different and the accuracy defining parameter also affects them in varying degrees. Location information provided by the LBS user, may therefore lead to faulty decision making by the subscriber.

6.2 RELATED WORK

The experimental work presented in this thesis is on network-based positioning methods and no work was presented on experimental work carried out on advanced positioning methods. Spirito, Poykko and Knuuttila collected CI, TA and RSS measurements based on GSM network from the city center and suburban area in Tallinn, Estonia. Based on their analysis, Cell-ID accuracy was between 500m and

1.1 km in the city and suburban areas respectively while Cell-ID + TA + RSS's accuracy was 300m and 800m respectively [53].

In 2004 Trevisani and Vitaletti worked on the experimental study of Cell-ID location technique, collecting data from 2 major cities in the world the New York area in the US and the Rome area in Italy. Data was collected in three distinct contexts - urban, suburban and highway. Based on their analysis, Italy and the USA had estimated accuracy of between 500 m and 1 km and between 800 m and 3 km respectively in urban areas. The study evaluated the ability of inexpensive Cell-ID location technique and its suitability for providing LBS. They discovered that Cell-ID is not satisfactory for a general solution in the provision of LBS but can be effectively used for LBS requiring low accuracy [52].

Lin, Lui and Wu investigated the accuracy of Cell-ID + TA in Kaohsiung, Taiwan by using TA measurements from three or more BSs. They avoided the use of forced handover by using a single TA parameter from the serving BS and two or more simulated TA parameters of some neighbor BSs calculated by the serving BS. The basic Cell-ID + TA provided accuracies of between 200m and 800m which improved to between 100m and 300m when the Cell-ID + simulate TA method was implemented. It was observed that the accuracy degraded with increase in subscriber density [130].

Mohr, Edwards and McCarthy also presented an empirical study of the accuracy of LBS in the UK. It presented that most operators in the UK use sectorized Cell-ID + TA for the provision of LBS. The average accuracy provided across all networks was about 266m [131].

Accuracy of LBS made available to smart phones was also empirically investigated by [132] and they discovered that smart phones have varying degrees of accuracy of location information provided. It concluded that Cell-ID though largely available is less accurate than the positioning obtained from geographical positioning system (GPS) positioning.

6.3 METHODOLOGY

The author carried out empirical research on measurement data from a field test to analyse the dependability of LBS in South Africa. The analyses and results presented are part of this research work. Two types of LBS emergency location service and person location service were each registered with two mobile location providers. Six LBS requests were made, four within the location provider's network and two across networks. All measured data were collected at stationary positions. LBS requests were sent from 60 geographical location points but only 51 geographical location points were used for this research due to measurement error. Over one thousand LBS requests were made and 938 location responses were received from the Mobile location providers. From some analyses carried out on the accuracy provided and questions to some staff of the mobile operators, it was concluded that enhanced Cell-ID positioning technique is the method used by the mobile operator.

It should be noted that data collected and analyzed is used for the empirical investigation presented in this Chapter and in some part Chapter Seven of this thesis. Some part of this chapter had been presented in [133, 134].

6.3.1 Reference Model

This research uses the reference model shown in Figure 6.1 to assist in data gathering and empirical investigation. There are many factors that influence the accuracy of the LBS provided using network-based positioning techniques, but only four of them are investigated and presented. These are the mobile network, geographical location, area from where LBS request is made and the density of cell.

a. Mobile network

The mobile network is made up of cells and these are served by BSs. In most cases for network-based positioning, the coverage area of the cell determines the coverage area of the positioning technique applied in the cell. Mobile operators have different mobile networks (i.e. arrangement of cell) which are dependent on the availability of location for the BS, coverage area of each cell

and the number of people to be served [135, 136]. LBS measurements were collected from two mobile location operators offering LBS services to subscribers using a basic MS.

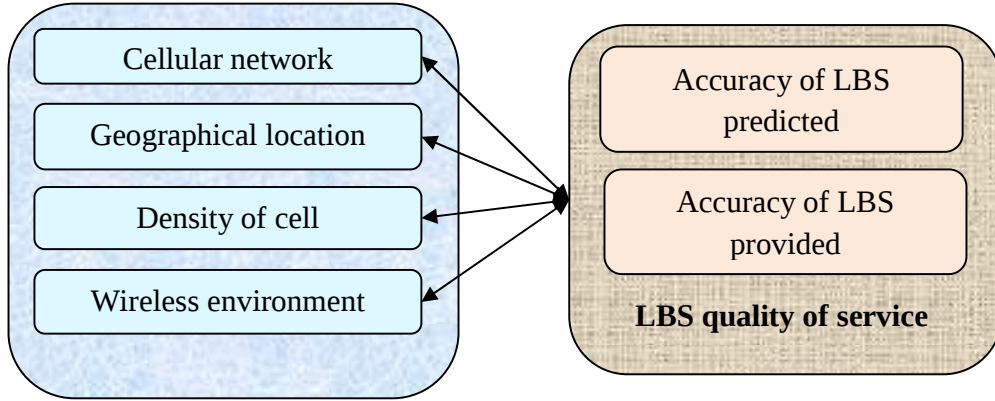


Figure 6.1: Reference model

b. Geographical location

The geographical location is also an important factor to be analysed because the geographical location where the LBS request is made affects its accuracy [52]. The actual/true locations of the geographical locations were collected using AGPS and it was also used to locate points of interest during data collection. All data was collected at a stationary position. Gauteng City-Region Observatory (GCRO) made available geospatial data of the Gauteng province. This was used with the GIS for map matching to establish the true/actual position of the MS during data collection and to check for errors which may have been introduced during data collection [137].

c. Density of cell

Density of the cell refers to the number of subscribers in a single cell and using the same BS at the same time. It has been proved that the cell density affects the accuracy of some network-based methods, therefore its effect was also investigated [65]. The evening/night data collection corresponds to peak periods recorded by mobile operators to ensure that the readings fall in the peak

period and the other collection period represents the off-peak. Thus, data was collected twice a day and over five days from the geographical locations. The first period was between 7:30 and 11:00 in the morning and the second between 15:30 and 21:00 in the late evening.

d. Wireless environment

The terrain, density of buildings and height of building generally have effects on network-based positioning techniques [52]. In this research, LBS requests were made from three different areas which are described as an urban area (Johannesburg CBD), a densely populated suburban area (Soweto) and a relatively more sparsely populated suburban area with very little trees/ shrubs (Sandton). Soweto is a low cost housing area while Sandton is a high cost housing area. Maps of the test areas showing a full description of the test areas and geographical location points considered are presented in Appendix C shown in Figures C1, C2 and C3, page 206.

e. Measure of quality of service (QoS)

Horizontal accuracy was used as the measure of QoS in the analyses presented and it is referred to as “accuracy”. Maps showing places, sub places, major and minor roads of Gauteng were obtained from the Gauteng City-Region Observatory (GCRO) as previously mentioned, and these were imported into ArcGIS 9.2 for geographical analyses [137]. ArcGIS 9.2 was used to estimate the distance between the geographical locations as provided by the GPS and as given by the mobile location provider.

The location estimated by the LBS provider was given relative to the closest road to the BS where the LBS request was made. Accuracy predicted by the mobile location provider was estimated based on the cell size and was made available by the LBS provider when delivering the location information.

The first accuracy provided was calculated by the distance between the true location of the MS to the road estimated by location providers as the crow flies.

It is called “lower bound accuracy”. “Upper bound accuracy” was estimated when the length of the road specified by the location provider was considered. Upper bound accuracy is given by lower bound accuracy in addition to the length of the road specified. This is because the LBS user can be located at any point on the road specified. If the road is 1 km long then the upper bound accuracy is given by lower bound accuracy ± 1 km. Lengths of the roads were also extracted using Geographical Information System (GIS) from geospatial data collected from Gauteng City-Region Observatory (GCRO) [137] and they were very useful for calculating upper bound accuracy. Table 6.1 defines the variables for collected data.

Table 6.1: Variables used for collected data

Variable	Variable name	More information
Time of day	Morning Evening	Morning Night/Evening
Environment	Soweto -A Sandton -B Johannesburg CBD - C	There are three main types of environment
LBS Provider	LBS Provider 1 LBS Provider 2	There were two LBS providers
LBS request	LBS1, LBS2, LBS3, LBS4, LBS4, LBS5 and LBS6	LBS1 = Povider1’s response to distress request from a MS on its network LBS2 = Povider1’s response to person location request from a MS on its network LBS3 = Povider1’s response to location request from a MS on Povider2’s network. LBS4 = Povider1’s response to location request from another MS on Povider2’s network. LBS5 = Povider2’s distress request from a MS on its network. LBS6 = Povider2’s person location request from a MS on its network.
Accuracy One	Predicted accuracy	Accuracy predicted
Accuracy Two	Lower bound accuracy	Accuracy provided to nearest point on the specified road
Accuracy Three	Upper bound accuracy	Accuracy provided to nearest point on the road + length of specified road

6.3.2 Data analyses

Over one thousand LBS requests were made and 938 location responses were received from the mobile location providers. An average of 93.8 percent reliability and success rate was recorded. 11.3 percent, 42.2 percent and 46.5 percent of data was collected from the Johannesburg CBD, Soweto and Sandton respectively. About 94 percent success rate was achieved which makes the LBS services surveyed quite reliable.

The Statistical Package for Social Sciences (SPSS) software was used for the manipulation and statistical analyses of data collected. There were four independent variables (time of day, type of environment, LBS provider and LBS request) and three dependent variables (predicted accuracy, lower bound accuracy and upper bound accuracy). The analyses carried out for this chapter includes descriptive, parametric, paired sample t-test, ANOVA (ANalysis of Variance), MANOVA (Multiple ANalysis of Variance) and effect size statistical analysis. T-tests were used to compare the mean score in continuous variables.

MANOVA (Multiple ANalysis of Variance) statistical analysis is an extension of analysis of variance for use with more than one dependent variable. These variables should be related in some way, or there should be some reason for considering them together because MANOVA compares the groups. MANOVA is based on separate one-way ANOVAs of dependent variable. This type of analysis is used instead of several ANOVAs to reduce the risk of Type 1 error which gives a false output of finding a significant result when in fact there isn't one [138, 139]. All the variables considered are related to the independent variables.

Eta-Squared analysis was used to estimate the effect size, being one of the most popular in statistical analysis. Eta-Squared can be defined as the proportion of variance or strength of influence associated with or accounted for by the independent variable in ANOVA and MANOVA studies. Cohen (cited in [139]) classified effect sizes into three - small (below 0.01), medium (0.06), and large (above 0.14) [139].

6.3.3 Interpretation of Statistical Analyses

Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted. The descriptive statistics for the analyses was also cross-checked to confirm that correct information was analyzed.

6.4 INVESTIGATING THE DEPENDABILITY OF LOCATION INFORMATION

For Figures 6.2 - 6.4, the A, B, and C notations on their x-axis represents Soweto, Sandton and Johannesburg CBD environments respectively. For instance, A_1 represents the first geographical location where data was collected in the Soweto environment.

6.4.1 Investigating the Accuracy of Location Information

A paired-sample t-test was conducted to evaluate the difference in accuracy predicted and accuracy provided for survey data. It was discovered that there was a statistically significant decrease in predicted accuracy ($M = 720.76$, $SD = 433.09$) to lower bound accuracy ($M = 586.02$, $SD = 702.63$). Eta-Squared statistic (0.04) indicated a small effect size. This indicated that the difference between predicted accuracy and lower bound accuracy is statistically small. However considering predicted accuracy and upper bound accuracy, there was a statistically significant decrease in the accuracy from predicted accuracy to upper bound accuracy. Eta-Squared statistic (0.28) indicated a large effect size.

The descriptive statistics and relationship between the accuracy variables are summarized in Table 6.2 and 6.3. The statistical difference between predicted accuracy and upper bound accuracy is statistically large and this is because the lengths of the roads indicated in the predicted accuracy given to the subscribers were significantly long.

Table 6.2 Descriptive statistics of accuracy variables (meters)

	Mean	Standard Deviation	Minimum	Maximum	Average
Predicted accuracy	720.98	433.28	196.77	1310.78	666.01
Lower bound accuracy	586.02	702.63	75.77	1323.635	535.81
Upper bound accuracy	2165.47	2286.98	933	4411.28	2017.12

Table 6.3 Summary of the ANOVA analyses between the accuracy variables

Predicted accuracy to	F	Sig.	Partial Eta Squared
Lower bound accuracy	5.967	.0005	0.04
Upper bound accuracy	-19.248	.0005	0.28

The mean of lower bound accuracy is less than predicted accuracy but the standard deviation is much greater. This revealed that there is a significant variance in the values of lower bound accuracy. Lower bound accuracy provided by the location providers gives a better picture of predicted accuracy but the correct accuracy provided, which is upper bound accuracy was significantly different from predicted accuracy. The mean of predicted accuracy was about 721, lower bound accuracy was 586 and upper bound accuracy was 2166. Upper bound accuracy is about three times more than predicted accuracy. This implies that actual accuracy provided by the location provider is 3 times more than the predicted accuracy as observed from the statistics analyses results in the previous paragraph.

6.4.2 Investigating Accuracy of Location Information Based On Some Accuracy Defining Parameters

a. Location and environment

A multivariate analysis of variance was conducted to explore the impact of environment on the accuracies predicted and provided as measured by data collected. From the analyses, there was a statistically significant difference between predicted accuracy, lower bound accuracy and upper bound accuracy as shown in Table 6.4. Figure 6.2 summarizes the mean accuracy provided at the geographical locations where data were collected.

Table 6.4 Summary of the MANOVA analyses between the accuracy variables

Source	Variable	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Environment	Predicted accuracy	35032752.199	2	17516376.099	116.324	.0001	.200
	Lower bound accuracy	10034381.679	2	5017190.839	10.370	.0001	.022
	Upper bound accuracy	66739944.578	2	33369972.289	6.455	.0020	.014
Location	Predicted accuracy	50788454.847	50	1015769.097	7.207	.0001	.289
	Lower bound accuracy	76637034.289	50	1532740.686	3.525	.0001	.166
	Upper bound accuracy	775691770.592	50	15513835.412	3.337	.0001	.159
Time of day	Predicted accuracy	1371.640	1	1371.640	.009	.923	.000
	Lower bound accuracy	2222538.358	1	2222538.358	5.162	.023	.006
	Upper bound accuracy	586872.623	1	586872.623	.132	.716	.000

The analyses indicated there was statistically significant difference between measurements taken at different environments and the combined accuracy. From Table 6.4, it can be seen that the partial Eta-Squared analysis represents a large effect of about 20 percent for predicted accuracy, two percent for lower bound accuracy and one percent for upper bound accuracy. This indicates that the environment where the measurements are taken mainly affects the predicted accuracy. This might be because the predicted accuracy is directly proportional to the cell size at each environment. The geographical locations on the other hand have large effects on all the accuracy measurements - 29 percent for predicted accuracy, large effects of 17 percent and 16 percent for lower bound accuracy and upper bound accuracy.

For a large percentage of the data collected, the predicted and provided accuracy at the different geographical environments and locations were quite different.

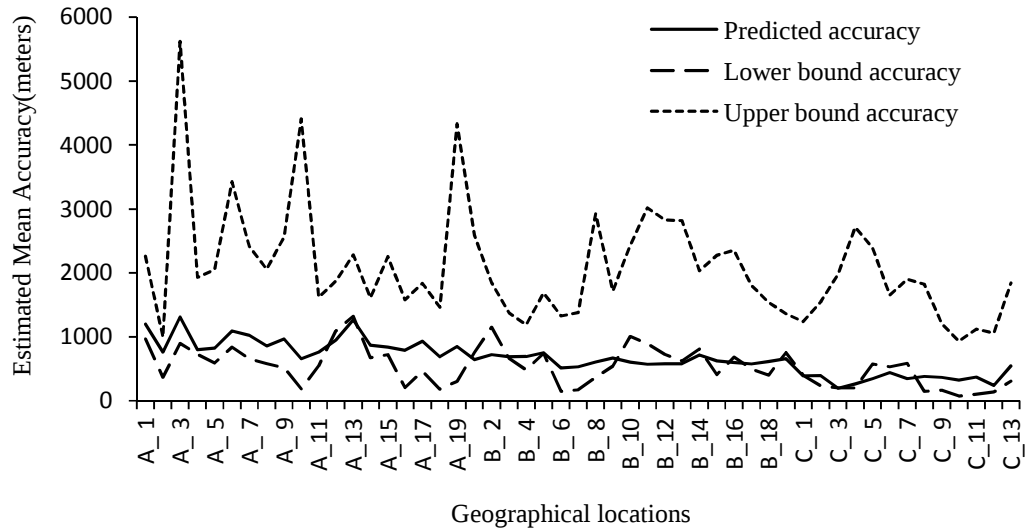


Figure 6.2: Mean plot of accuracy for LBS request sent from different geographical locations

b. Time of day/density of cell

MANOVA analysis was conducted to explore the impact of density of the cell on accuracy at the locations where LBS requests were made. The mean plots of predicted accuracy, lower bound accuracy and upper bound accuracy in the morning and evening are shown in Figure 6.3 and 5.4 respectively.

There was no statistically significant difference between data collected in the morning and night on all accuracy variables as shown in Table 6.4. The partial Eta-Squared was about 0.06 percent for lower bound accuracy and less than 0.01 percent for predicted accuracy and upper bound accuracy.

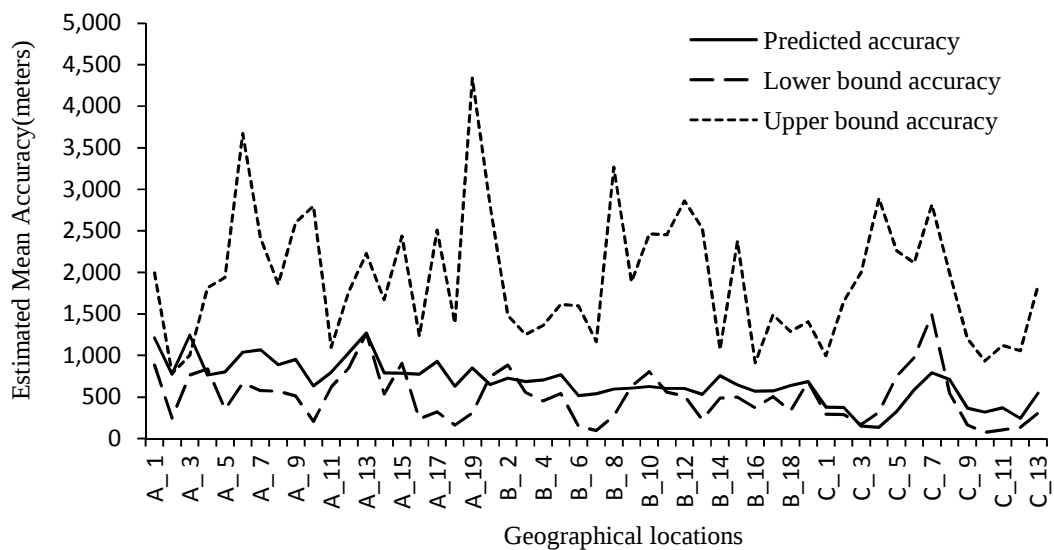


Figure 6.3: Mean plot for accuracy taken in the morning at different geographical locations

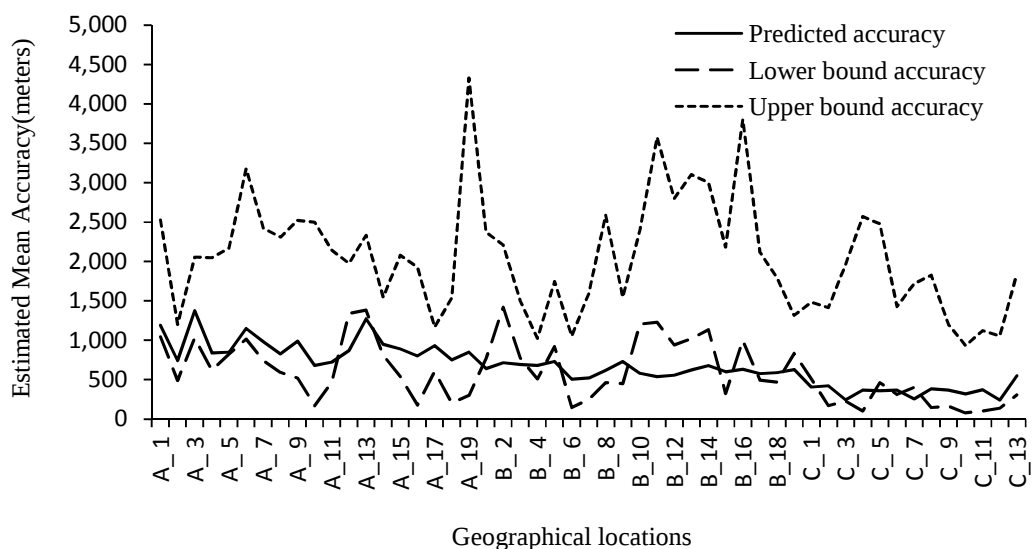


Figure 6.4: Mean plot for accuracy taken in the evening at different geographical locations

The density of the cell has minimal effect on the accuracy of LBS provided in these analyses because once the MS is connected to the BS, the process of position estimation is similar with either a heavy or light traffic. There are some

cases when the traffic is very high which leads to higher rate of call drops and inability to access LBS applications. When this occurs, most times the MS might not connect to the nearest BS but instead to any BS from which it can receive adequate signal from. This high traffic period occurred only about 7.2% of the time when data was collected. Therefore the scenario that might be presented during very high traffic periods is not well represented in the data analyses presented.

6.5 CRITICAL ANALYSES OF EMPIRICAL INVESTIGATION

The accuracy provided is very different from accuracy predicted based on environment, geographical location and time of day. The dependability of location information made available for LBS users was quite low and hence the accuracy predicted by the mobile location provider might not be useful and dependable to most LBS users [16]. This has a large effect on the ability of users to depend on the information made available by mobile location providers. In an emergency situation, if emergency location information is provided to an LBS user where the accuracy given by the LBS provider is based on the closest road without considering the length of the road, the ability to make reliable decisions based on the LBS provided is minimal. The inaccuracy is consistent for all environments and all locations considered and this might be one of the reasons why LBS are not a favourite among many people. The best form of advertising which is from a satisfied LBS user to another mobile user is impossible because customer satisfaction is quite minimal, if not impossible.

Predicted accuracy, lower bound accuracy and upper bound accuracy are not affected by the cell density of the BS where LBS requests are made. However, the reliability of LBS (probability of receiving the location information requested from the location providers) requests made on Provider 2's network reduced by about 5 percent and about 2 percent of all requests made on the network in the evening had to be repeated

twice or thrice before there was a response from the mobile location provider. Provider1's LBS responses were more reliable than Provider2's LBS response.

Although the LBS provided are inaccurate and undependable, they are relatively reliable with about 94 percent reliability. This makes it a desirable service if the issue of accuracy and dependability is improved.

Enhanced Cell-ID which was used for MS location estimation has accuracy as large as its coverage. Even though measurements were collected from urban and suburban areas with cell size of typically between 500 m and 1 km for urban and 1 km – 5 km in suburban areas (all divided by three for sectorized antennas), the provided accuracy was very different from the predicted accuracy which is the cell size of the serving BS that the MS requesting LBS is connected to.

This can be better observed using descriptive statistics presented in Table 6.5. Average predicted accuracy for Johannesburg CBD was 345, Soweto was 924 and Sandton was 628. These are distinctly different for the three environments considered. While average lower bound accuracy for Soweto, Sandton and Johannesburg CBD are 627, 617 and 307 respectively and average upper bound accuracy are 2460, 2007 and 1714, respectively.

Additionally, from the data collected and analyses carried out, it can also be concluded that positioning algorithms are not the only contributing source of error in the provision of LBS in South Africa. The accuracy and precision of the data and content delivered to the LBS user is also an important variable to be considered. If there were more precise and accurate spatial data, a major road closest to the specified cell should be divided into smaller bits by using junctions with other roads or other major landmarks.

Another important issue to consider is that the serving BS the MS is connected to might not be the BS closest to the MS but due to cell density and multipath this might

be the case. Therefore, practical LBS applications that can be deployed in the places investigated are mobile yellow pages, localized advertising and fleet management.

Table 6.5 Descriptive statistics of accuracy predicted and provided at different environments (meters)

	Soweto			Sandton			Johannesburg CBD		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Predicted accuracy	657	1310	924	510	749	628	196	547	345
Lower bound accuracy	182	1323	627	145	1150	617	76	618	307
Upper bound accuracy	993	4412	2460	1191	3015	2007	933	2714	1714

6.6 CONCLUSION

LBS support location-based activities users are about to embark on. A small error in the accuracy predicted may turn out to make a huge difference in the activity the location information is applied to [16]. Failures in LBS translate to a failure in the user being able to accomplish the activities the LBS were planned for. It is therefore of utmost importance to consider the geographical location and environment from which the LBS request is made in the algorithms used by the mobile location providers. Algorithms which calculate the predicted accuracy need to be changed or updated because it is significantly different from the provided accuracy.

Furthermore, spatial data has to be updated and made more accurate in order to improve the LBS presently offered to subscribers.

This chapter answers the second research sub-question. It presented the accuracy, dependability and reliability of LBS provided in South Africa through empirical investigative research. From the results presented, accuracy of LBS provided in South Africa is not high and hence not entirely dependable. There is a need to investigate the sources of error to improve the LBS accuracy. Therefore the next chapter

investigates the effect of error on the predicted accuracy given by the mobile location provider.

There is no published work on empirical investigation of LBS in South Africa as far as the researcher is able to ascertain. This chapter is also an important contribution to knowledge analysing and presenting results about LBS made available to LBS subscribers in South Africa.

CHAPTER SEVEN

7 ANALYSING ERROR INTRODUCED TO NETWORK-BASED POSITIONING AND LBS

7.1 INTRODUCTION

This chapter presents results of analyses carried out by the author when investigating factors that affect the accuracy of network-based positioning techniques. The first analyses was carried out on measurement data presented in Chapter Five (5) and the second analyses was carried out on over-the-air GSM data collected from a mobile network provider in South Africa. Due to the agreement entered into with the mobile network operator its name will not be mentioned in this thesis.

It was discovered from the previous chapter that some major factors affecting LBS accuracy are the geographical location, environment, and cell size. Others include geometry of the network where the LBS request was made and accuracy and precision of spatial data stored in the database.

7.2 RELATED WORK

Sharp et al in [87] derived analytical relationship between GDOP and positioning systems and they were able to establish through mathematical modelling the GDOP of evenly distributed BSs with three possible locations of the MS. The MS positions are - on the circumference of same circle with the BSs, along radials of the BSs and near a single BS. The GDOP derived from each scenario is different. The research however did not carry out any real-world analysis based on different environments and it was designed for short to medium-range outdoor and indoor locating systems. It is also important to note that the analysis presented considered typically rectangular or oval shaped BS arrangements.

Similar works were carried out in [140] where the author assumed the conventional hexagonal structure for the cell and the MS assumed to be at the centre of the polygon.

Bronk and Stefanski in their paper discussed the influence of geometry on the positioning accuracy of wireless networks using TDOA method for estimation [141]. They confirmed that bad geometry of BSs used for location estimation is the major source of the inaccuracy of simulated results. Bad geometry for location estimation can be eliminated by using additional measurements and by incorporating a different type of positioning method if there are no measurements.

Chen et al also investigated the relationship between the number of BSs, geometry of the BSs and GDOP for TOA and TDOA positioning methods. The number of BSs used for location estimation does not necessarily determine the accuracy but instead the GDOP coefficient of the geometry of BSs used for estimation [142].

Lv, Liu and Hu carried out analyses on the influence of geometry on GDOP in TOA and AOA positioning systems [143]. They were able to prove that GDOP changes with distance/ edges of the geometry and the angle of arrival of the radio signal and more sensitivity is noticed when a new BS is placed closer to the target.

7.3 INVESTIGATING THE EFFECT OF SOME PARAMETERS ON NETWORK-BASED POSITIONING USING LBS MEASURED DATA

This chapter investigates the effect of some parameters on accuracy predicted by the mobile location providers. This is because the predicted accuracy is firstly, directly related to the dependency of the LBS user to the location information given; secondly, can be varied and made more accurate by the LBS provider; and thirdly, it is directly related to the accuracy of the positioning method used. In addition, this chapter clarifies the dependability of the accuracy of LBS on the network parameters without considering the error introduced by spatial data. Some part of this research had been published in [134].

It should be noted that ANOVA analyses were investigated and presented in this chapter. The basic descriptive statistics are presented in Table 7.1 and a summary of ANOVA analyses and Eta-Squared analyses in Table 7.2.

Table 7.1: Summary of the descriptive statistics (meters)

	N	Mean	Standard Deviation
Environment			
Soweto	396	924	509
Sandton	436	628	256
Johannesburg CBD	106	345	304
Total	938	721	433
LBS Provider			
LBS Provider 1	665	787	445
LBS Provider 2	273	560	354
Total	938	721	433
LBS request			
LBS 1	191	943	380
LBS 2	150	515	197
LBS 3	171	912	454
LBS 4	153	721	539
LBS 5	129	490	207
LBS 6	144	622	438
Total	938	721	433
Time of day			
Morning	447	735	419
Evening	491	708	446
Total	938	721	433

ANOVA tests differences in means for the different groups in variables under consideration. It accomplishes this by analyzing the variance and statistical significance is tested. If significant, the effect size is calculated [138], [139]. One-way between groups ANOVA was used when there is one independent variable which has various groups (such as environment with Johannesburg CBD, Soweto and Sandton as groups) and one dependent continuous variable. One-way ANOVA was used for the analyses of type of environment, mobile location provider, and LBS request for the predicted accuracy. The repeated measures analyses of variance method was used for “time of day” independent variable because data was collected at the same locations at different times of the day.

Table 7.2: Summary of the ANOVA analyses

	Sum of Squares	df	F	Sig.	Partial Eta Squared
Environment					
Between Groups	35133046	2	117	.000	0.18
Within Groups	140510604	936			
LBS Providers					
Between Groups	10036738	1	57	.000	0.05
Within Groups	165606912	937			
LBS requests					
Between Groups	30304354	5	39	.000	0.15
Within Groups	145339296	933			
Time of day					
Between Groups	174421	1	0.93	.335	0.001
Within Groups	175469229	937			
Geographical Locations					
Between Groups	50838972	50	7.23	.000	0.26
Within Groups	124804679	888			
Total	175643650	938			

7.3.1 Environment

A one-way between-groups analysis of variance was conducted to explore the impact of environment. From the analyses, there is a statistically significant difference between data collected from Soweto, Sandton and Johannesburg CBD environment. Figure 7.1 summarizes the mean accuracy provided at the geographical locations where data was collected.

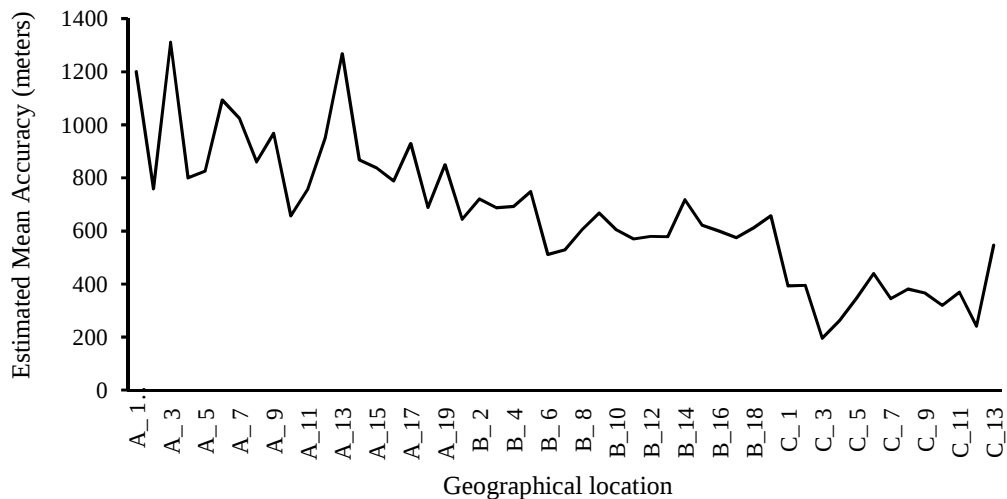


Figure 7.1: Mean plot of accuracy for environments

The ANOVA test reached statistical significance and the differences in mean scores were large, with Soweto, Sandton and Johannesburg CDB having mean accuracies of 396, 436 and 106, respectively. With a partial Eta-Squared value of 0.18 as presented in Table 7.2, 18 percent of the variance in accuracy is explained by the environment.

7.3.2 Mobile Location Provider

There was statistically significant difference between mobile location provider 1 and mobile location provider 2 as shown in Figure 7.2. From Table 7.1, it can be seen that there is about 200m between mean accuracy provided by the mobile location providers.

The effect size, calculated using Eta-Squared, was 0.05. About five percent of the variance in accuracy was explained by the location providers. This signifies that mobile location providers have moderate effect on the accuracy. This might be because the mobile operator with denser BS infrastructure offers better accuracy. This is shown in Figure 7.2.



Figure 7.2: Mean plot of accuracy for location providers

7.3.3 Geographical location

There was a statistically significant difference between the mean accuracies obtained at all geographical locations where data was collected. The ANOVA test reached statistical significance and the differences in mean scores were significant. The effect size, calculated using Eta-Squared, was 0.26 as shown in Table 7.2. This signifies that 26 percent of the variance in accuracy can be explained by the actual geographical locations. This is a relatively large effect on the accuracy.

7.3.4 Type of LBS Request

There is a statistically significant difference between various LBS requests made by the users as shown by the Eta-Squared value of 0.15 in Table 7.2. From Figure 7.3 the six LBS registered and requested gave different mean accuracy. The largest difference in mean accuracy given in the LBS request was about 400m and the smallest about 20m. The ANOVA test reached statistical significance and the differences in mean scores were large as shown in Tables 7.1 and 7.2.

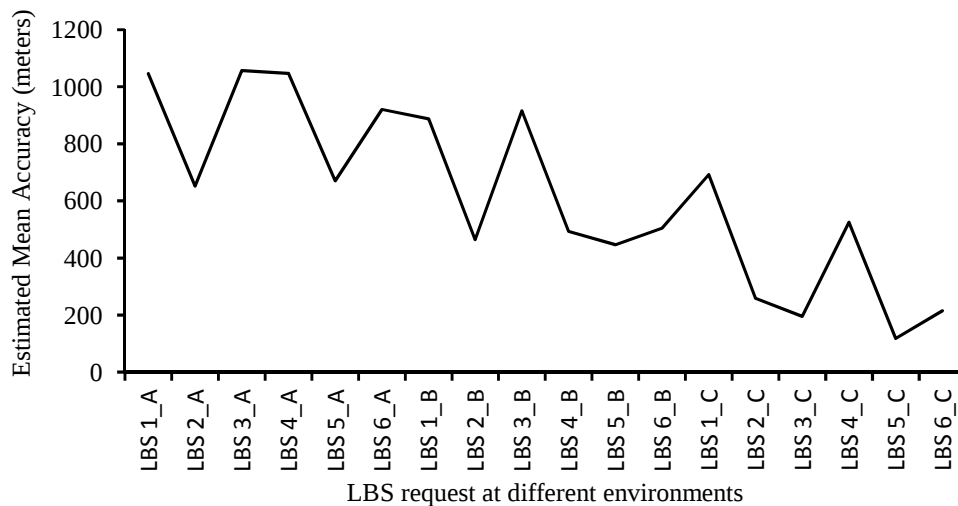


Figure 7.3: Mean plot of accuracy for various LBS requests at environments under consideration

This indicated that there is significant difference in the LBS requests and about 15 percent of the variance in accuracy is explained by the type of LBS request. This signifies a large effect on accuracy. The difference in accuracy given might be

explained by some requests made across the mobile network operators and also the cell density available from the mobile network operators.

7.3.5 Density of Cell

There was no statistically significant difference between morning and evening measurements. From Table 7.1, it can be seen that mean accuracy between morning and evening is relatively small. This is also reflected in the Eta-Squared analyses in Table 7.2. Only about 0.1 percent of the variance in accuracy is accounted for by the difference in time of day. Figure 7.4 shows figuratively the mean plot for accuracy at different times of the day based on survey data. This might be indicative of the number of subscribers on the network at the same time.

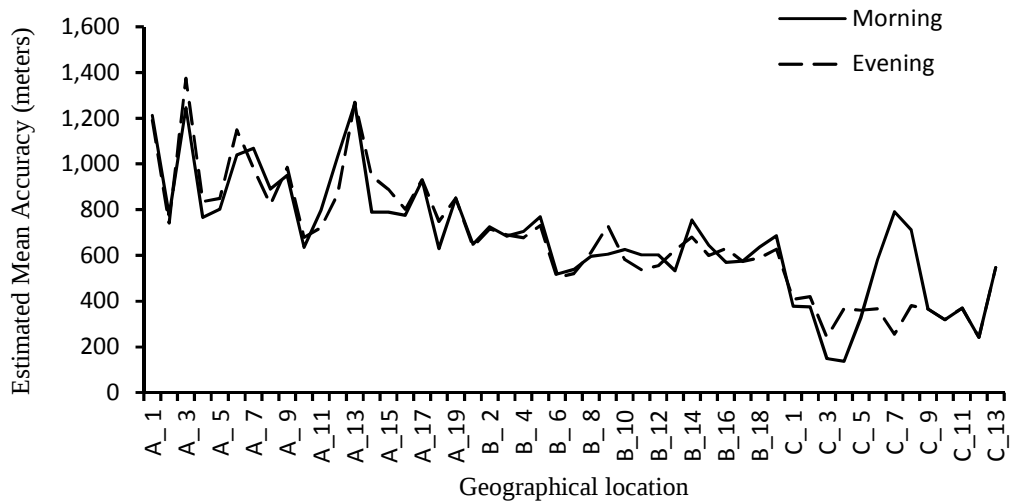


Figure 7.4: Mean plot for accuracy showing time of day

From the analyses of data collected, time of day does not affect the accuracy of LBS. It affects its reliability instead. About 99 percent of the failure rate recorded when data was collected was recorded in the evening. This might be due to the fact that when the network is saturated due to high usage by mobile subscribers calls might be rejected just like LBS request is rejected and the person requesting the LBS request is requested to try again.

7.4 CRITICAL ANALYSES OF THE EFFECT OF SOME ERROR

DEFINING PARAMETERS ON MEASUREMENT DATA

The objective of Section 7.2 of this chapter is to study the effect of some error sources on accuracy predicted. Accuracy predicted by the mobile location provider (which is the cell size of the sector antenna of the serving BS) is affected by various factors such as environment, geographical location and type of LBS service requested.

The geographical location from where the LBS request was made has the largest impact on the mean accuracy followed by the environment, the type of LBS request, LBS providers and negligibly by time of day. The density of the cell affects the reliability more and has insignificant effect on the accuracy.

These error sources were statistically significant enough to be accounted for when positioning. For improved LBS it is important to build some of these considerations into the positioning predicting algorithm employed to provide improved accuracy and dependability on location information by LBS users.

Having studied the impact of some error introducing parameters, such as geographical location, environment, type of LBS request to enhanced Cell-ID positioning technique, it is also important to study an important factor, the geometry of the network which affects only RSS-based positioning. RSS-based positioning is affected by the geometry of the network because measurements for location estimation are collected from three or more BSs at different locations relative to each other and to the MS. The remaining part of this chapter presents empirical investigations carried out on the effect of geometry on RSS-based positioning method.

7.5 INVESTIGATING THE EFFECT OF GEOMETRY ON RSS-BASED POSITIONING USING OVER-THE-AIR DATA

It is often mentioned in literature that geometry affects network-based positioning using more than three BSs for location estimation [10, 56] but there are no known published works providing evidence of this for practical network data. Therefore in order to develop a model to investigate the feasibility of predicting the accuracy of RSS-based positioning by making it geometry-aware, the effect of geometry on accuracy has to be established. The remaining part of this chapter investigates the effect geometry has on the accuracy of RSS-based positioning. Some part of these analyses has been published in [144].

The geometry of the network in this case is the layout pattern of the MS whose location is to be estimated and the BSs whose parameters are used for estimating the location of the MS. The geometry of the network can be represented by an interconnection of sides/edges and vertices, where the vertices are the location of the BSs and MS and the sides/edges are the distances from the BSs and MS.

7.5.1 Preamble

This investigative research was carried out by the author using simulations on drive test data collected from a mobile network operator. The drive test measurements were collected from over-the-air GSM mobile network data in the Gauteng Province of South Africa. Radio measurements were taken from two different environments; built-up urban areas and rural/suburban area with flat fields and some hilly terrain. The RSS measurements were collected at a MS receiving signals from fixed BSs with known location coordinates. Some of the data collected which is of importance in this research includes; position of the MS as estimated by GPS used as the bench mark for accuracy; RSS measurement of the serving BS and 6 neighbouring BSs as received by the MS; and the coordinates of the BSs. Measurements collected from 65 BSs were used. Four aforementioned RSS-based location methods (Chapter Two, Section 3.2.3(c), pages 60 - 65) were investigated to analyze the effect of distance between the BSs and MS and distance between the BSs on the accuracy of location estimation

algorithms. The RSS-based location methods are Centre of Gravity (COG), Centre of Trilateration (COT), Least Square method (LS) and Trilateration (TRI). These four methods are used to investigate the effect geometry has on different types of RSS-based geometric methods. Analyses carried out with the TRI method uses only RSS measurements from three BSs for estimating the location of the MS while the LS method uses all the RSS measurements available.

a. Correlation analyses

The aforementioned RSS-based geometric positioning algorithms were used to estimate the location of the MS, based on the RSS measurements and coordinates of the serving BSs and neighbour BSs. The estimated locations derived from these methods are then subtracted from the true position of the MS as estimated by the GPS. This is the “Location Error” for the positioning algorithms. Two dimensional coordinate systems were considered and this method can also easily be applied to a three dimensional coordinate system.

A mobile network as shown in Figures 7.5 and 7.6 with two types of distance measurements being analysed designated as Case One and Case Two. Following the dashed lines in Figures 7.5 and 7.6, and assuming that at the star symbol, the MS is connected to BS1, BS2, BS3, BS7, BSa, BSb and BSc. BS1 is the serving BS. Where the MS is presently in Figure 7.5, it can receive signals from BS1, BS2, BS3, BS4, BS5, BS6 and BS7. Moving further down the path to the triangular symbol, it can receive signals from BS1, BS2, BS3, BS4, BS5, BS6 and BSd. The MS positions algorithms were analyzed in relation to its communication with a specific serving BS as it moves along the path. The serving BS remains constant and the neighbour BS changes as the MS moves along.

Likewise for Figure 7.6, BS1 represents the serving BS and BS2, BS3, BS4, BS5, BS6 and BS7 are the neighbour BSs that the MS is currently connected to. Distances from the MS to BS1, BS2, BS3, BS4, BS5, BS6 and BS7 are denoted

as d_1 , d_2 , d_3 , d_4 , d_5 , d_6 and d_7 respectively. D_1 , D_2 , D_3 , D_4 , D_5 , D_6 and D_7 denote distances from BS1 to BS2, BS2 to BS3, BS3 to BS4, BS4 to BS5, BS5 to BS6 and BS7 to BS1 respectively.

A standard Pearson product-moment correlation coefficient analysis [139] was carried out on the location errors on the aforementioned algorithms and the specified distances. This was to determine the effect distance has on location error which is directly related to the location accuracy. The analyses carried out are explained in the steps below:

Step one: Positioning methods aforementioned were used to estimate the location of MS.

Step two: Location error was calculated by subtracting estimated location of the MS from their actual location.

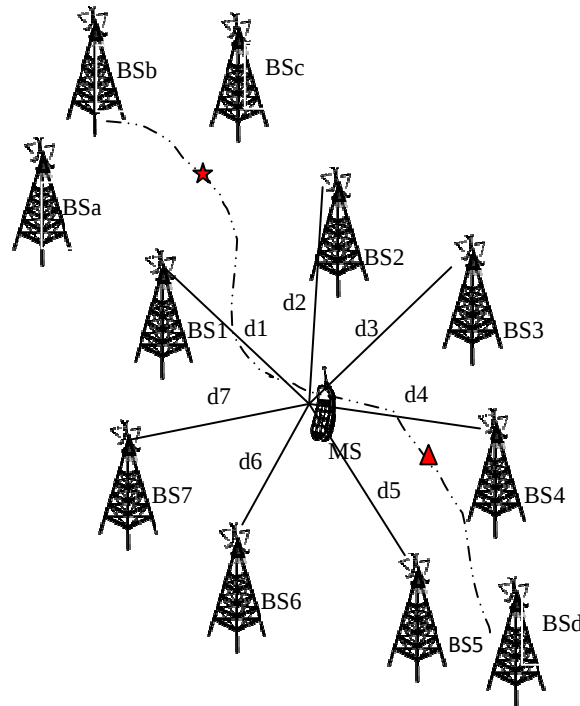


Figure 7.5: Case One

Step three: Actual distance of BSs to MS and BSs from each other as shown in Figures 7.5 and 7.6 was calculated using known coordinates of BSs and GPS coordinates of the MS.

Step four: A Pearson Correlation analyses was carried out to analyse how well related location errors obtained are to distances as described in Case One and Case Two.

Step five: Analyses were carried out on rural/suburban and urban environments.

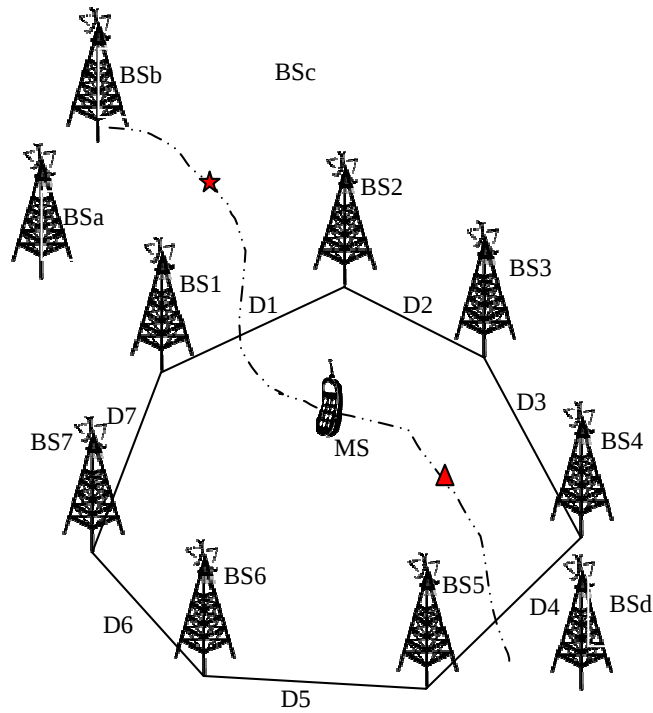


Figure 7.6: Case Two

7.5.2 Empirical Analyses and Result

“Pearson correlation coefficient analyses are used to describe the strength and direction of the linear relationship between two variables” [139]. Preliminary analyses were performed to ensure no violation of the assumption of normality and linearity.

RSS measurements are highly affected by interference in the wireless environment. Data used in the calculation of MS location using the positioning algorithms are collected from the mobile network. It is expected therefore that there are other variables interfering with the output such as multipath and shadowing. This might be why the curves on the graphs shown in Figures 7.7 – 7.10 are not smooth but they are good enough to explain the relationships analyzed.

It should be noted that some of the correlation relationships as shown in Tables 7.3 - 7.6 are negative correlations. The positive or negative correlation between variables and absolute value of correlation coefficient indicates the strength of the correlation. The negative values in the tables below have been normalized to show only the strength of the correlation for the purpose of Figures 7.7 – 7.10.

Error (actual location - estimated location) estimated from the positioning algorithms is directly proportional to accuracy obtained from the algorithms as Root Mean Square Error (RMSE). This is a widely used metric to evaluate the accuracy of the location estimates [81].

$$RMSE = \sqrt{\frac{1}{3n} \sum_{m=1}^n (\hat{x}_{MS} - x_{MS})^2 + (\hat{y}_{MS} - y_{MS})^2} \quad \dots 7.1$$

Where N is the number of location measurements considered, $[\hat{x}_{MS}, \hat{y}_{MS}^T]$ are the estimated coordinates, $[x_{MS}, y_{MS}]^T$ are the true coordinates of the mobile station of interest and $1 \leq m \leq n$.

A strong correlation between location errors and distances show a high dependency of the positioning algorithm on distances under consideration. This in turn explains the dependence of the accuracy obtained from the algorithm to the geometry/geometry of the BSs relative to the MS, and relative to each other. A weak correlation shows a weak relationship between the geometry, and accuracy of the positioning algorithm indicates a lower dependence.

a. Rural analyses: Case One

The relationship between Case One and location errors is summarized in Table 7.3 and Figure 7.7. There is a strong correlation between variable d4 and COG location errors, medium correlation between d1, d2 and COG location errors and small correlation between d3, d5, d6 and d7 and COG location errors. There is a small relationship between COT location errors with d1 and d2, medium correlation with d4 and a strong correlation with d5. COT location errors correlation with d3, d6 and d7 are very small. There is a small relationship between LS location errors with d1 and d2, medium correlation with d4 and a strong correlation with d5. LS location errors correlation with d3, d6 and d7 are very small. There is a small relationship between TRI location errors with d1 and d2, medium correlation with d4 and a strong correlation with d5. TRI location errors correlation with d3, d6 and d7 are very small.

Table 7.3: Rural analyses: Case One

Distance	COG	COT	LS	TRI
d1	0.46	-0.15	0.02	0.54
d2	0.41	-0.14	0.01	0.52
d3	-0.17	0.02	0.04	0.29
d4	0.98	-0.34	0.12	0.15
d5	-0.13	0.54	0.11	0.11
d6	0.13	0.03	0.12	0.12
d7	-0.13	-0.06	-0.06	0.22

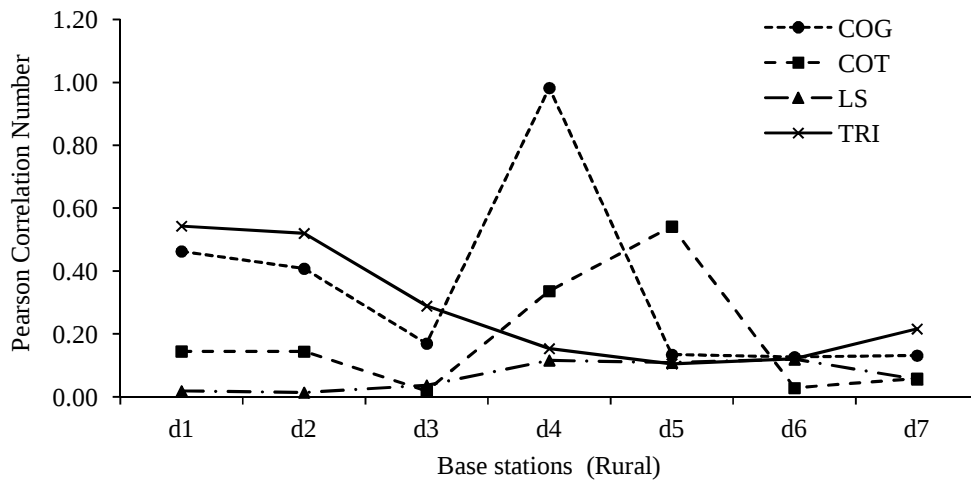


Figure 7.7: Correlation analyses of location errors with distances between the MS and BSs in a rural environment

For example, consider the COG distance relationship shown in Figure 7.7. COG's accuracy is more dependent on distance between the MS and the third BS than distances between the MS, and the first two BSs. It is least affected by distances between the MS and BSs 5, 6 and 7.

There is a small correlation between variable d4, d5 and d6 with LS location errors, while the other distances have relatively very small correlation with LS location errors. A strong relationship exists between TRI location errors with d1 and d2, medium correlation with small correlation with other distances.

b. Rural analyses: Case Two

Table 7.4 and Figure 7.8 summarize the correlation between distances in Case 2 and location errors.

There is a strong correlation between variable D3 and COG location errors, medium correlation between D2 and COG location errors and small correlation between D4, D5, D6 and D7 and COG location errors. It should be noted that some of the relationships are negative correlation. There is a relatively small relationship between D1 and COG location errors. There is a small relationship between COT location errors with D1 and D2, medium correlation with D4 and a strong correlation with D5. COT location errors correlation with D3, D6 and D7 are very small.

Table 7.4: Rural analyses: Case Two

Distance	COG	COT	LS	TRI
D1	-0.03	0.04	-0.18	0.59
D2	0.34	0.11	0.00	0.06
D3	0.81	-0.28	0.17	0.23
D4	0.14	0.56	0.10	0.16
D5	0.13	0.33	0.15	0.14
D6	0.29	-0.18	0.10	0.11
D7	-0.12	-0.11	-0.05	0.18

There is also a small correlation between variable D4, D5 and D6 with LS location errors, while the other distances have relatively very small correlation

with LS location errors. There is a strong relationship between TRI location errors with D1 and D2, medium correlation with small correlation with other distances.

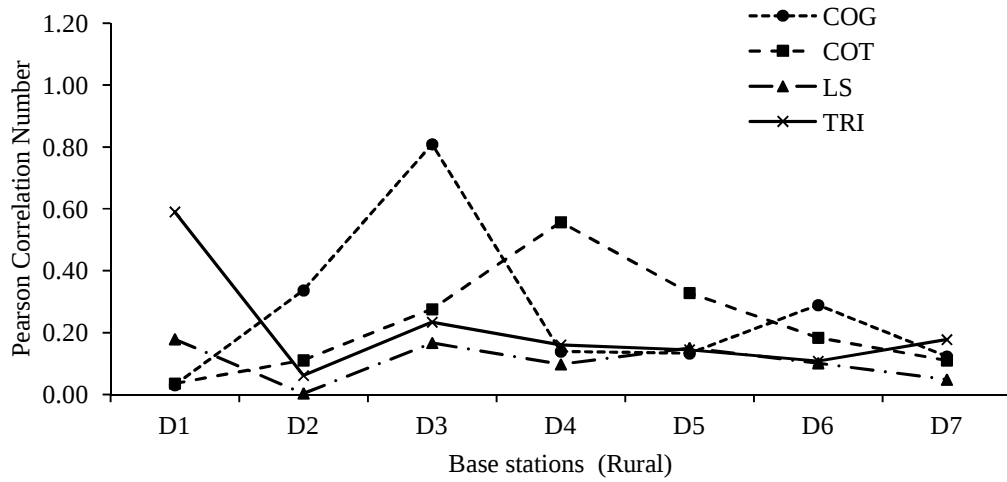


Figure 7.8: Correlation analyses of location errors with distances between BSs in a rural environment

The two cases studied in the rural environment showed that COG location errors have the strongest relationship with distances which points to a higher dependence on geometry of BSs and MS for its accuracy than COT and LS location errors. The two cases also show similarities in correlation with the distances especially d3 and d4 in Case One and D3, D4 and D5 in Case Two.

c. Urban analyses: Case One

The relationship between Case One and location errors is summarized in Table 7.5 and Figure 7.9. There is a strong correlation between all the distances and COG location errors. There is a small relationship between COT location errors with d5 and d7, medium correlation with d4 and a strong correlation with d1 and d2. COT location errors correlations with d3, d6 are very small.

There is also a small correlation between all distances with LS location errors except d6 with a relatively low correlation coefficient. On the other hand, there

is a strong relationship between TRI location errors with all the distances investigated in Case One.

Table 7.5: Urban analyses: Case One

Distance	COG	COT	LS	TRI
d1	0.92	-0.50	0.22	0.76
d2	0.93	-0.43	0.20	0.80
d3	0.58	-0.06	-0.13	0.84
d4	1.00	-0.36	0.22	0.68
d5	0.55	-0.12	0.28	0.45
d6	0.56	-0.03	0.01	0.67
d7	0.53	-0.18	0.11	0.43

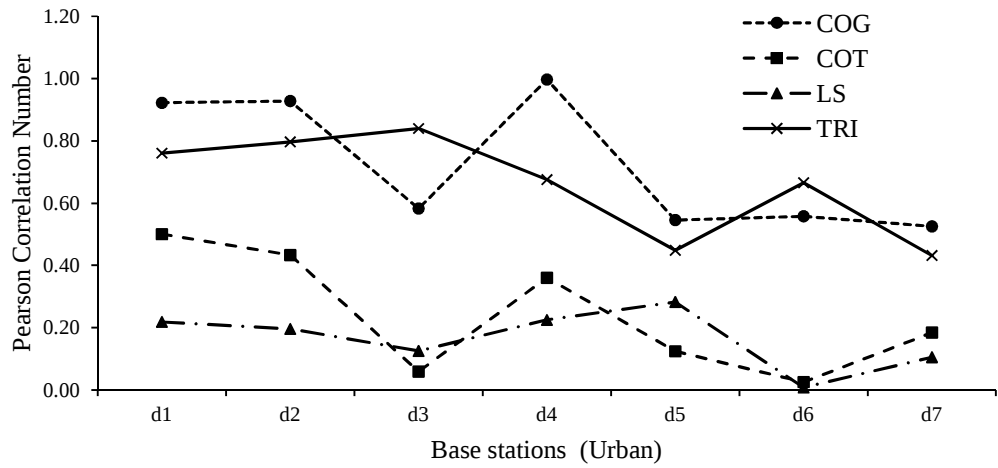


Figure 7.9: Correlation analyses of location errors with distances between the MS and BSs in an urban environment

d. Urban analyses: Case Two

Table 7.6 summarizes the correlation between distances in Case Two and location errors which are shown in Figure 7.10. There is a strong correlation between the variable D2, D3, D4 and D5 with COG location errors and small correlation between D1, D7. There is also a small relationship between COT location errors with D2 and D5, and a strong relationship with other distances.

There is very small correlation between LS location errors with D2 and D3, a small correlation with D1, D5 and D6 and a strong correlation with D4 and D7.

Furthermore, there is a strong relationship between TRI location errors with D2, D3 and D5, and small relationships with D1, D4, D6 and D7.

Table 7.6: Urban analyses: Case Two

Distance	COG	COT	LS	TRI
D1	-0.20	0.58	-0.28	0.06
D2	0.77	-0.28	0.03	0.79
D3	0.69	-0.42	-0.02	0.68
D4	0.53	-0.37	0.47	0.01
D5	0.66	-0.27	0.23	0.59
D6	-0.14	0.45	-0.29	-0.03
D7	-0.27	0.53	-0.35	-0.06

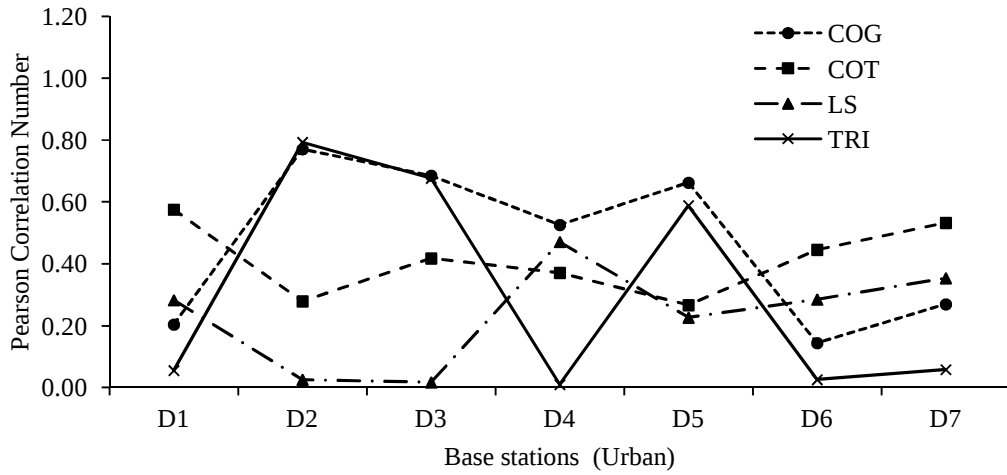


Figure 7.10: Correlation analyses of location errors with distances between the BSs in an urban environment

COG location errors also have the strongest relationship with distances in urban environment followed by COT with LS location errors being least affected. From Figures 7.3 and 7.4, there was a correlation with distances especially d3 and d4 in Case One and D2, D3, D4 and D5 in Case Two. In Figure 7.9, location errors are more correlated with the distances from the MS to the BSs than in Figure 7.10 which describes the BSs distance relationship with each other. Additionally, it can be seen that the distance of the MS to the BSs affects location errors more than distances of BSs to each other.

7.5.3 Critical Analyses of the Effect of Geometry on Network-Based Positioning

GDOP is the conventional method for geometry analysis in positioning methods as shown in [85, 87, 142] just to mention a few. It was first used in GPS location estimation analysis. The aforementioned papers had proved the importance of geometry consideration for more accurate MS location estimation. The analyses presented here is different from the GDOP analysis because it does not give a geometric metric. Instead, it presents the effect of each geometry variable (d_i and D_i) on accuracy for the location estimation algorithms considered.

From the analyses presented, it can be deduced that geometric positioning algorithms applied to urban environments are relatively more dependent on the geometry of the network where position measurements were collected than in rural environments. This might be because BSs in urban environments are more closely spaced than those obtained in rural environments.

In general, comparing the two cases in both rural and urban environments, the distances in Case One had more correlation with location errors than the distances in Case Two.

LS positioning algorithm is least affected by geometry in all cases and for all environments considered but it also gave the worst estimate of MS location from previous works [145]. Even though it was least affected by the correlation coefficients obtained in Tables 7.3 – 7.6, it is large enough to be considered. For example in Table 7.6, looking at correlation between LS location errors and D_7 the correlation coefficient is 0.35, which when squared, indicates a 12.25 percent shared variance. Distance between the BS1 and BS7 helps to explain about 12 percent of the variance in the effect of distance on LS location errors [139].

The COG positioning algorithm has the strongest correlation at distance d_3 and D_3 in all cases studied except Urban Case Two where it was the second strongest. This

shows that distance between BS3 and MS and BS2 to BS3 is an important variable in the accuracy obtained in COG positioning algorithm.

Varying correlation performance of all variables considered in rural and urban environments show that geometry affects the position error which is directly proportional to accuracy provided by the positioning algorithm. Analyzing the geometry of the BSs and introducing this into MS location calculations might improve the predictability of the accuracy of positioning algorithms.

It has been proved from the results presented that geometry indeed affects the accuracy of positioning algorithms and information about the geometry should be incorporated in the positioning algorithm for improved accuracy. Although GDOP is a more compact way of presenting the geometric metrics for location estimation purposes, consideration should be given to specific geometric parameters for different location estimation algorithms. This is because the relationship between the location estimation algorithms and individual geometric parameters is different.

7.6 CONCLUSION

The Chapter answers research sub-question three “What are the major sources of error in network-based positioning technology?” From the result analyses, the environment, geographical location and the mobile network affects the accuracy of Cell-ID positioning and network-based positioning in general (because they are all dependent on measurements from the network). Unfortunately, Cell-ID accuracy prediction cannot be changed - it can only be enhanced as the mobile providers did by using sectorized antennas. Other ways to improve the accuracy of Cell-ID which has been proved in literature [15, 53, 69] is hybrid methods using other network measurements such as using timing advance and RSS measurements.

Therefore the attention of the author was turned to investigate ways of improving RSS-based positioning methods by making them geometry-aware, which might be incorporated into the hybrid positioning methods for improved accuracy. A GSM

network was simulated and RSS-based positioning algorithm developed which incorporates the geographical location, the wireless environment and the geometry of the network.

In conclusion, the major factors that affect network-based positioning techniques as presented are the wireless environment, mobile operator's network, propagation model et cetera. The geometry of the network is also an important variable and should not be neglected.

CHAPTER EIGHT

8 ERROR-AWARE NETWORK-BASED POSITIONING

8.1 INTRODUCTION

Environment-aware positioning is the major type of error-aware positioning in literature which was investigated by [38] and adaptive selective positioning by [14]. This chapter investigates the feasibility of applying error-aware positioning to Cell-ID, TA and RSS based positioning.

The first part of this chapter investigates the feasibility of applying error-aware positioning to Cell-ID with TA positioning. TA positioning was not investigated separately because individually it can be quite inaccurate. The latter part of the chapter investigates RSS-based positioning.

The proof of the proposed concept was carried out through written suggestions and software simulations. Gathering the over-the-air data for analyses took over one year and consideration of many non-disclosure agreements. The positioning for LBS is handled by a third-party partner, the data and content by another and the application and service is provided by a further partner. It was therefore considered not feasible for the set duration of this research to investigate the proposed concept on the mobile provider network.

8.2 RELATED WORKS

A recent work was presented on geometry aware localization implemented for ad-hoc networks in order to improve the accuracy of positioning for sensor nodes [86] and the geometry aware localization with grouping gave better results overall than those without. The conventional hexagon cell system layout was used for the simulation.

Chu, Tseng and Feng carried out research through simulations on GDOP-assisted location estimation algorithms for wireless networks in [146]. They concluded that

the root mean square error was 250m less compared to the two-step LS method. The work fictitiously relocates the BSs in order to get better geometric layout before estimating the location of the MS.

Chen et al also investigated the relationship between the number of BSs, geometry of the BSs and GDOP. The number of BSs used for location estimation does not necessarily determine the accuracy but instead the GDOP coefficient of the geometry of BSs used for estimation [142].

8.3 FACTORS AFFECTING THE DEPENDABILITY OF CELL-ID POSITIONING IN AFRICA

The ability to predict the accuracy of Cell-ID based positioning in Africa with the goal of making it more dependable to the subscriber is quite challenging. This is because the accuracy of location information provided by Cell-ID based positioning in Africa is based on many factors (some of them have already been mentioned in this thesis). These factors include:

- o The cell size of the serving BS that the MS is connected to.
- o The mobile operator's mobile network, which depends on the location of the BS, BS parameters, geographical area, density of BSs, cell size, et cetera.
- o The positioning algorithms were developed on already existing mobile network infrastructure and software.
- o Many spatial data, maps and GIS solutions available in Africa are obsolete and they are relatively inaccurate when compared with those in developed countries due to lack of expertise, finances, constant changes in infrastructure, et cetera.
- o LBS development in Africa is built on imported LBS applications, algorithms and technological solutions from developed countries. Consequently, the applications made available to subscribers required adaptation.

8.3.1 Improving the dependability of Cell-ID based method in South Africa

From Figure 6.2, it can be seen that the dependability of the location information for emergency services and person locator services using enhanced Cell-ID is quite low. There is therefore a need to make the location information accuracy predicted by the LBS provider more dependable. This can be achieved by making sure that the predicted accuracy is close enough to the actual accuracy provided.

The error introduced can be reduced by:

- o Providing Africa adapted software solutions, which are adapted to Africa's road network, mobile network, et cetera.
- o Developing software solutions adapted to the unique requirements of positioning methods available for use.
- o GIS solutions to develop precise and accurate geospatial data, maps and geocode for Africa.
- o Taking into account the length of the nearest major road to the serving BS the MS is connected to. The road should be divided instead into sections by the use of landmarks or intersections with other roads.
- o Improving the accuracy of the Cell-ID positioning method using hybrid methods. Spirito et al collected some over-the-air data and simulated the Cell-ID +TA and Cell-ID +TA + RSS and they concluded that there was a significant reduction in average error and maximum error; with Cell-ID + TA + RSS outperforming the other hybrid method [15, 53].

It was inferred from this conclusion that an inclusion of TA and RSS can make the hybrid positioning accuracy better. An improvement in the accuracy of the RSS-based method will definitely improve the overall performance of the hybrid positioning algorithm. Therefore the author investigated the feasibility of improving RSS-based positioning by making it geometry-aware. This novel investigative research into geometry-aware RSS-based positioning hereby presented was carried out by the author.

8.4 FEASIBILITY OF IMPROVING THE ACCURACY OF RSS-BASED POSITIONING ALGORITHM BY MAKING IT GEOMETRY-AWARE

Effective analysis of the feasibility of improving the accuracy of RSS-based positioning algorithms by making them geometry-aware using a neural network model is covered in this section. The assumptions made during the simulation are presented as the section unfolds.

8.4.1 Introduction

Practicable Cell-ID and TA methods are based on the serving BS that the MS is connected to, while the RSS method is based on RSS from three or more BSs, i.e. the serving BS and two or more neighbouring BSs. The accuracy provided by Cell-ID, TA and RSS-based methods are dependent on many factors such as the wireless environment, propagation model, measurement and computational error, cell size for the aforementioned two and the geometry of the mobile network for the latter of the three.

RSS-based positioning is very inaccurate in urban and built-up areas because of multipath, diffraction, reflection, fading, et cetera. RSS method is more dependable in few suburban environments with relatively flat terrain and no high buildings, rural environments and slums. Considering that the rural environment and slums are home to the very poor and underprivileged in Africa, it is an important environment and suitable for RSS-based positioning or a hybrid involving it.

The system simulated was modelled in two phases, the database build-up phase and the matching phase. The data build-up phase handles the build-up of the database used for the accuracy prediction while the latter handles the matching of the model geometry to the actual geometry and then the MS location is estimated.

8.4.2 Simulation Tools

MATLAB (MATrix LABoratory) is a high performance high-level language for technical computation. It integrates programming, computation and visualization in an easy to use interactive environment. This research used MATLAB for modelling,

computation, visualization (graphs), data analyses and algorithm development. Microsoft Excel was used for data storage; data was imported to MATLAB (7.11.0 (R2010b)) for analyses and exported to Microsoft Excel for storage. MATLAB functions, mathematical operations, programming, graphics and data analyses were used for the application development, neural network, and curve fitting toolboxes were also utilized.

8.4.3 Database Build-up Phase

The database build up phase is a simulated model of the mobile network with the geometry and MSs. The following components were modelled in this section:

- o Mobile network
- o Set positions of the MS
- o Wireless environment
- o Position location system
- o Geometry nonlinearities
- o Database
- o Neural network error model

a. Mobile network

The mobile system modelled is seven-cell geometry with each cell having a BS located at its centre and a cell radius of 15 – 35 km. Each BS has a cell coverage which is normally depicted in literature as a regular hexagon. The BSs are at the centre of each cell and these were indicated by triangles and the cell coverage by hexagons as shown in Figure 8.1. The BSs numbered 1 – 7 for BS1- BS7 respectively.

i. Overlapping coverage

BSs are normally arranged in the conventional method, with each cell having a hexagonal coverage just touching each other, which is practically inapplicable. Instead, a GSM MS can receive signal strength from six BSs for the purpose of handover and mobility. Therefore the conventional hexagonal

cell coverage was changed to circular which is more applicable. This allows for overlapping of cells within a given geometry. A sample of such arrangement is shown in Figure 8.2.

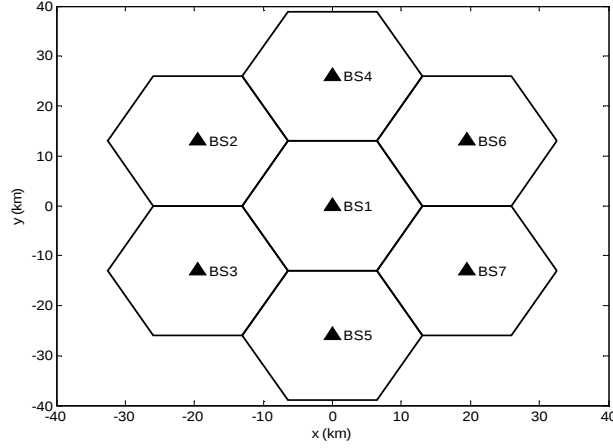


Figure 8.1: Conventional mobile network arrangements

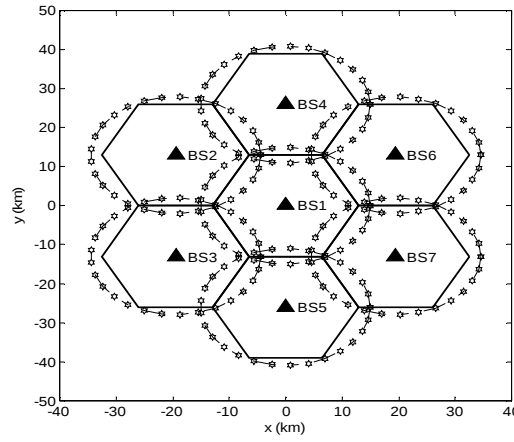


Figure 8.2: Mobile network geometry

Due to the regular hexagon adaptation of the cells and the symmetrical nature of the cell arrangements, the antenna characteristics at BS1 is a representative of the values at other neighbouring BSs. All BSs overlaps each other in order to also eliminate the need to consider the number of BSs overlapping as a parameter to be separately considered.

ii. Network density

Only a single MS was considered at different locations because the relationship simulated is not dependent on the density of the network. An omni-directional antenna was assumed for the MS and also for the BSs. The simulation was performed by assuming that the MS is the receiving antenna and location estimation is carried out in the MS. Furthermore, if more than one MS was considered, the neural network database becomes too large and will need a lot of programming time and analyses.

iii. Number of base stations

The maximum number of BSs a basic MS can receive RSS from is six. Consequently it was assumed that the maximum number of BSs from which the MS can receive adequate receive signal level quality of between 29 dBm and -114 dBm according to GSM specifications [71]. Since the area under consideration was a rural area, another assumption made was that the MS can receive adequate RSS from 6, 5, 4 and 3BSs. Less than three BSs was not considered because RSS will not provide an estimation of the location of the MS and then Cell -ID with TA will give a better accuracy. As mentioned earlier BSs 2 - 6 have decreasing proximity (distance) to the serving BS.

b. Set positions of the MS

In Figure 8.3, the MS was assumed to move in a horizontal line with MS in a start position. The start position(s) of the MS was (-35, 0) and the final position was (0, 0). The MS under consideration moves in the path indicated by the arrow in Figure 8.3.

In Figure 8.3, each point where analysis was made, which was where the true MS location was, is indicated by a small square. Only a few location points were considered for the purpose of analyses and graphical illustrations. This will enable better understanding of the analyses and enhance comprehensive

result presentation. Because of the symmetrical nature of the model geometry, the MS was moved through half of the geometry.

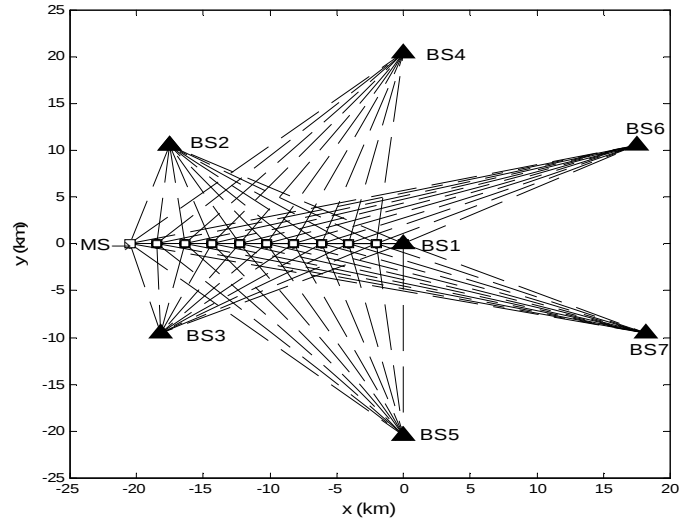


Figure 8.3: Simulated movements of MS

c. Environment

The distance dependent fading was modelled as a rural /suburban prediction by the Okumura Hata path loss model for open area or rural area prediction previously presented in Chapter Two (2) section 2.5.5, page 45.

The path loss model was used to estimate the average received power of the transmitted signal at the MS. Keeping all other parameters constant, the received signal strength changes with distance for any environment under consideration based on the path loss model used. With the cell size, the Okumura Hata model was used to calculate estimated signal strength at distances where the MS is located.

d. Location methods

The Geometric methods used for these analyses are the Centre of Gravity, Centre of Trilateration, Trilateration and Least Squares algorithms. These afore-

mentioned RSS-based algorithms were further explained in Chapter Three Section 3.2.3.

e. Geometry nonlinearities

Considering the fact that the theoretical mobile network arrangement is different from the physical network arrangement and all the possible locations of each BS cannot be simulated, provision for nonlinearity was provided and simulated.

- i. Each model BS has four quadrants, as shown in Figure 8.4. The relationship between each model BS and the actual BS matched with it are defined by Equations 8.1 – 8.4.

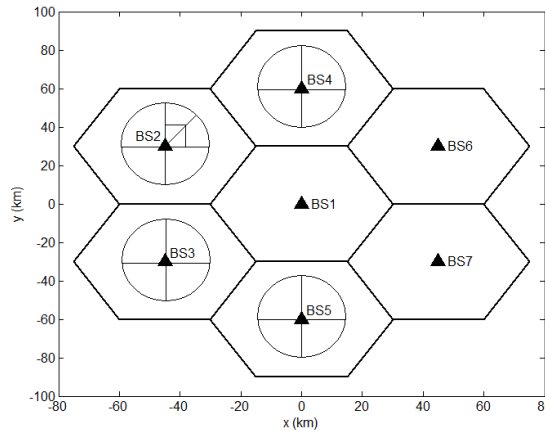


Figure 8.4: Some BSs showing the quadrants

- Quadrant1: When the actual BS is in quadrant1:

$$x(ABS)_{i1}, y(ABS)_{i1} = (x(MBS)_{i1} - \chi_1, y(MBS)_{i1} + \gamma_1) \quad \dots 8.1$$
- Quadrant2: When the actual BS is in quadrant2:

$$x(ABS)_{i2}, y(ABS)_{i2} = (x(MBS)_{i2} - \chi_2, y(MBS)_{i2} + \gamma_2) \quad \dots 8.2$$
- Quadrant3: When the actual BS is in quadrant3

$$x(ABS)_{i3}, y(ABS)_{i3} = (x(MBS)_{i3} - \chi_{i3}, y(MBS)_{i3} + \gamma_3) \quad \dots 8.3$$
- Quadrant4: When the actual BS is in quadrant4

$$x(ABS)_{i4}, y(ABS)_{i4} = (x(MBS)_{i4} - \chi_4, y(MBS)_{i4} + \gamma_4) \quad \dots 8.4$$

Where $x_{(MBS)i,k}, y_{(MBS)i,k}$ is the position of the i^{th} model geometry BS in the k^{th} quadrant and $x_{(ABS)i,k}, y_{(ABS)i,k}$ is the position of the i^{th} actual geometry BS in the k^{th} quadrant. χ_k is the deviation of the actual BS from the model BS in the x direction while γ_k is the deviation of the actual BS from the model BS in the y direction in the k^{th} quadrant, $k = 1 \dots 4$.

- ii. In each quadrant, there are grids of coordinates which the actual BS can be matched to.
- iii. Considering the grid of coordinates available for the actual BSs to be matched to the model BSs, for each BS with 4 quadrants, only one can be chosen at a time. Using the permutation without repetition formula, where n is the number of things to choose from and r of them is chosen ;

$$\frac{n!}{(n-r)!} = \frac{4!}{(4-1)!} = \frac{4!}{3!} = 4 \quad \dots 8.5$$

If the actual BS $x_{(ABS)i}, x_{(ABS)i}$ does not fit both model coordinates at $x_{(MBS)i}, y_{(MBS)i}$, then a quadrant is chosen which best matches the model coordinate.

Also, when there are measurements from many of BSs, permutation with repetition formula is used to estimate the number of combinations possible; n^r . When three actual BSs are considered for MS positioning, there are $4^3 = 64$ quadrant combinations, i.e. BS_a and BS_b and BS_c . If the actual BS fits the model BSs with the exception of two, then the number of combinations is 48 ($4^2 + 4^2 + 4^2 = 16 + 16 + 16$) i.e. BS_a and BS_b or BS_a and BS_c or BS_b and BS_c . If the actual BS fits the model BSs with the exception of one, then there are 12 combinations ($4 + 4 + 4$) i.e. BS_a or BS_b or BS_c . Where subscripts a, b and c represents the actual serving BS1, actual BS2 and BS3 respectively.

- iv. Total number of quadrant combination options considered is $64 + 48 + 12 = 124$. It should be noted that for each option, there are 10 likely positions (grids) of the model BS in each quadrant under consideration.

- v. The serving BS for the actual geometry and model geometry always fits because they are both used as the reference coordinate for the BSs and MS coordinates.

f. Built-up Database

The data captured from the build-up phase includes:

- Set positions of the BSs.
- True positions of the MS as it moves across the network.
- Distance between all BSs and the MS locations as it moves through the network.
- Estimated RSS of the MS at each location relative to all BSs.
- Calculated positions of the MS as estimated by geometric positioning methods considered (Centre of Gravity, Centre of Trilateration, Trilateration and Least Squares algorithms).
- Calculated location error derived from the difference between the MS true locations and its estimated locations.

g. Neural Network error model

An artificial neural network (ANN) is a data processing system that is inspired and roughly modeled after the massively parallel structure of the brain. It consists of simple, individual, highly interconnected processing elements called the artificial neurons [147, 148].

The inputs considered for the training of the neural network were those that define the geometry of the network. These are the distances between the MS and each BS used to estimate the position of the MS while the output is the error estimated from MS position estimations within the simulated cellular network. The more the data simulated the better the accuracy of the model and the longer the learning time.

Several simulations were ran with different number of samples/data and varying percentages for the training, validation and test data. For the results presented in this thesis, 10,000 samples were considered. 60% of the samples were used for training the network, 20% for measuring network generalization in order stop the training if it is not improving. The remaining 20% was used to test the accuracy of the network. The samples were then scaled linearly and normalized to give each input equal importance and for optimal network performance.

The steps taken for the design of the neural network is as suggested in [147] and [148]. A feedforward NN three layered system was designed with input, hidden and output layers. The input layer has 6 neurons; the hidden and output layers have twenty neurons and one neuron respectively. The number of the input and output neurons were determined by the nature of the problem while the number of hidden neurons was determined by experimentation. Increasing the number of hidden layers did not produce a better output.

The feedforward network was trained with the Levenberg-Marquardt backpropagation training function. The hyperbolic tangent sigmoid transfer function was used for the neurons at the hidden layer while a linear transfer function was utilized for the neurons at the output layer. The Levenberg-Marquardt algorithm was used because it was relatively fast and gives a good output though it uses a lot of memory space during training. The neuron activation functions were determined by experimentation.

Different training strategies were investigated such as basic batch training, gradient descent training and the gradient descent with momentum training methods. The last two training methods were much slower and did not give significant improvement to the performance of the neural network. Therefore, the batch training method was used for the simulation presented in this thesis.

The mean squared error indicative of the performance of the network was set to 0.1. When the validation test was carried out for the four geometric positioning methods considered, the average squared error between the network output and the target output when tested were all lower than 0.001.

Neural network was considered to be the best method for this aspect of the research because it is able to handle nonlinearities which might be introduced from the geometry matching. Furthermore, it has the capability to recall the pattern learnt.

h. Other Parameters

As the MS moves, the distance between the MS and the BSs changes. The RSS is directly related to the distances as shown by Equation 3.17. Since the relationship between distance and position error is of major interest in this research, all other input parameters were kept constant and only the MS was moved through a predefined path.

8.4.4 Matching Phase

This section of the simulation handles the matching and nonlinearities arising from the matching of the model geometry with the actual geometry. This phase of the model has the following components:

- o Geometry coordinate transformation,
- o Geometry matching and comparison,
- o Neural network matching and learning, and
- o Neural network system inference.

a. Geometry coordinate transformation

The longitudes, latitude, altitude (LLA) system of coordinates are the most commonly used today and commonly used to store coordinates in communication systems. Therefore there is a need to transform the GPS data (geodetic data) in LLA form to a form which can be used for local ranging,

bearing measurement and positioning. When the calculations are completed, the results are then converted back to GPS coordinates (LLA).

In South Africa, World Geodetic System 1984 (WGS84) (a form of LLA coordinate system) is utilized for the determination and storage of locations near the surface of the earth. Consequently, the coordinates needed for positioning which are in the WGS84 frame are transformed to a Cartesian frame with origin on the surface of the earth. The Cartesian frame has its horizontal axes oriented along the east, north and the vertical axis pointing up (ENU). The local ENU coordinates are formed from a plane tangent to the earth's surface fixed to a specific location. The specific location in this analysis is the serving BS coordinates. The transformation has to be carried out in phases as shown in Figure 8.5. The geodetic coordinates are first transformed to Earth-based coordinates and then to navigational coordinates.

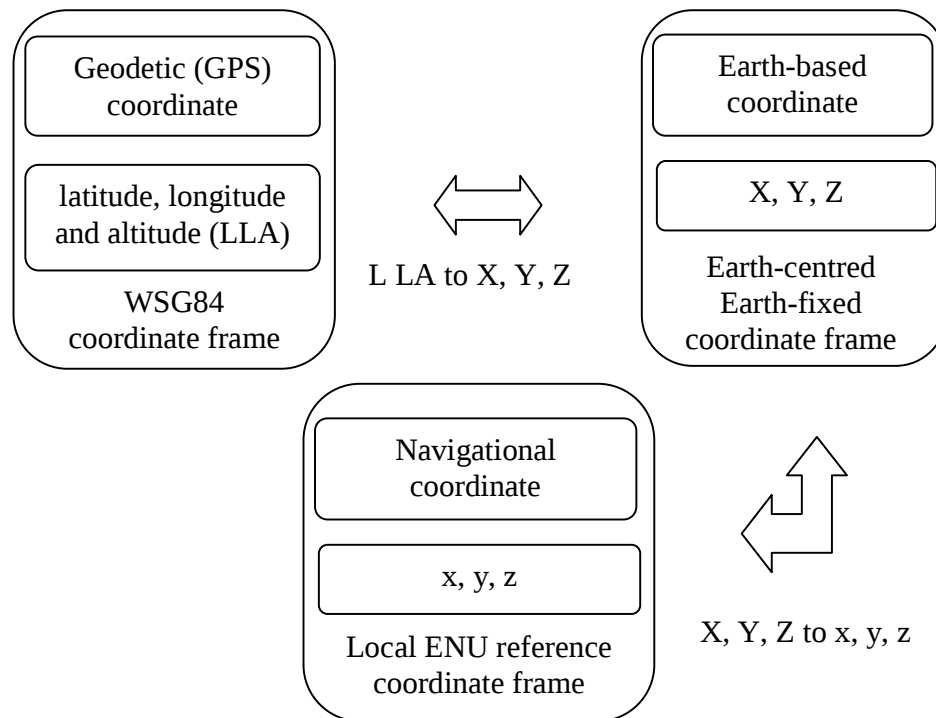


Figure 8.5 Coordinates transformation from LLA to x, y, z

Step 1: GPS coordinate in WGS84 coordinate frame.

The BS coordinates of the actual geometry are entered into the system.

Step 2: Conversion of WGS84 coordinate (ϕ, λ, h) to Earth-based coordinate (X, Y, Z)

The geometry's coordinates are converted from geodetic data to Earth-Centred Earth-Fixed (ECEF), which is the conventional Cartesian coordinate system and has its origin at the centre of the earth. Figure 8.6 shows diagrammatically the relationship between Cartesian ECEF and geodetic LLA coordinates.

The transformation from LLA to ECEF, is given by Equation 8.6:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} (N + h) \cos \phi \cos \lambda \\ (N + h) \cos \phi \sin \lambda \\ (N(1 - e^2) + h) \sin \phi \end{bmatrix} \quad \dots 8.6$$

Where, ϕ is the latitude, λ is the longitude, h is the height above ellipsoid in metres and N is the radius of curvature also in metres defined as:

$$N = a / \sqrt{1 - e^2 \sin^2 \phi}$$

The reference ellipsoid parameters for WGS84 are given as;

Ellipsoid semi-major axis (a)	= 6378137.0 m
Ellipsoid semi-minor axis (b)	= a (1-f) = 6356752.3 m
Ellipsoid flattening (f)	= 1/ 298.25722 m
Earth's first eccentricity (e)	= $\sqrt{(a^2 - b^2)/a^2}$
Earth's first eccentricity (e)	= $\sqrt{(a^2 - b^2)/b^2}$

While, the closed formula set for the transformation from ECEF to LLA is given as;

$$\lambda = \arctan Y/X \quad \dots 8.7$$

$$\phi = \arctan ((Z + e'^2 b \sin^3 \theta) / (p + e^2 a \cos^3 \theta)) \quad \dots 8.8$$

$$h = (p / \cos \phi) - N \quad \dots 8.9$$

Where $p = \sqrt{X^2 + Y^2}$ and $\theta = \arctan Za/pb$

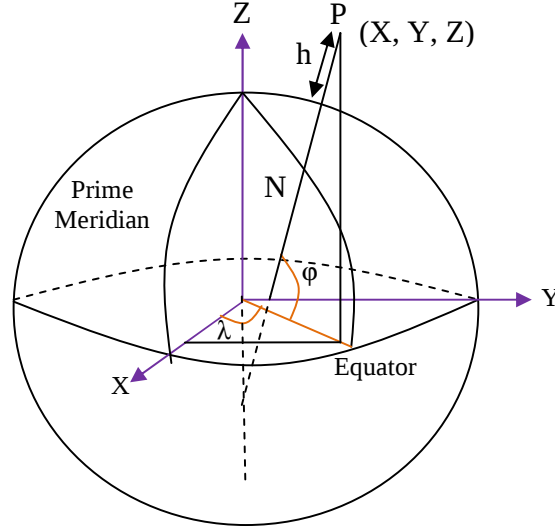


Figure 8.6 Relationship between Cartesian ECEF and geodetic LLA coordinate frames

Step 3: Conversion of Earth-based coordinate to Navigational coordinate

The ECEF coordinates are then transformed to local East, North, Up (ENU) Cartesian coordinate system which is far more intuitive and practical than ECEF or Geodetic coordinates in many targeting, positioning and tracking applications. The relationship between ENU and ECEF coordinate frame is shown in Figure 8.7. The ENU was calculated with a reference position relative to the analyses to be carried out. All other coordinates are measured relative to the reference position. The reference position used for this research as previously highlighted was the serving BS. This is because the serving BS was simulated to be at the centre of geometry as indicated in the model geometry in Figure 8.1.

Given the elementary rotation defined by Equation 8.10, the transformation from ECEF (X, Y, Z) to ENU (x, y, z) is given by Equation 8.11. The transformation requires a reference point as previously stated expressed in ECEF, which is denoted by (X_r, Y_r, Z_r) and this will serve as the origin of the ENU frame.

$$\mathbf{R}_L = \begin{bmatrix} -\sin \lambda & \cos \lambda & 0 \\ -\sin \phi \cos \lambda & -\sin \phi \sin \lambda & \cos \phi \\ \cos \phi \cos \lambda & \cos \phi \sin \lambda & \sin \phi \end{bmatrix} \quad \dots 8.10$$

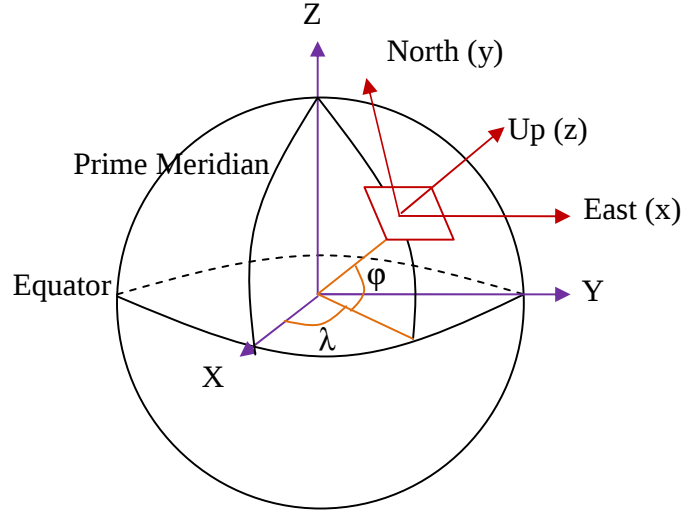


Figure 8.7: Relationship between ENU and ECEF coordinate frames

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \mathbf{R}_L \begin{bmatrix} X - X_r \\ Y - Y_r \\ Z - Z_r \end{bmatrix} \quad \dots 8.11$$

The ENU (x, y, z) to ECEF (X, Y, Z) transformation is given by Equation 8.12.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \mathbf{R}_L^T \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} X_r \\ Y_r \\ Z_r \end{bmatrix} \quad \dots 8.12$$

b. Geometry matching and comparison

There were two model geometries which the actual geometry was compared to. The geometry arrangement shown in Figure 8.1 and the second geometry is exactly like it but with an inverted orientation (the hexagons are vertical) as shown in Figure 8.8.

After the geometry transformation, the actual geometry was compared to the model geometry to get some important variables such as:

- i. The three closest BSs to the MS based on the RSS analyses (RSS is directly proportional to distance).
- ii. The actual coordinates were compared to both model coordinates to get the best match by following these steps:

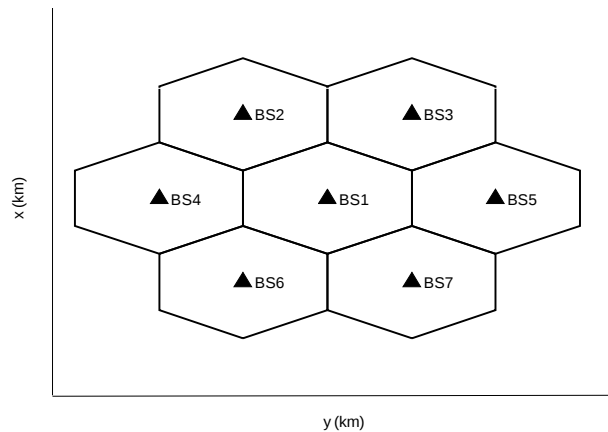


Figure 8.8: Inverted mobile network arrangements

- The serving BS coordinates is a fit because they are both at 0, 0.
- The size of the model geometry was estimated from the average distance (AveDist) between the serving BS and the other BSs in the actual geometry.
- The model geometry was varied between AveDist/10 and AveDist*2 in AveDist/10 spacing to get the best fit. For example, if the AveDist = 5 km, the distance between the model BSs would start from 0.5km to 10 km in spaces of 0.5 km.
- The number of actual BSs that best fits the model BSs within a 5 km radius was analysed.
- the best fit between the two-model geometry was then analysed by:
 - o Checking the number (n) of actual BSs which fits for each model BS tested. It should be $3 \geq n \leq 6$.

- o Checking if the actual BSs that fit the model BSs are not in a straight line. If they are all in a straight line, positioning cannot be calculated.
- o Check if the actual BSs are sectors BSs located on same coordinate.
- the 1st three actual neighbour BSs coordinates are then compared with the model BSs and if it does not fit, then:
 - o The quadrant the actual BS falls in with reference to the model BS under consideration was estimated.
 - o The grid within the quadrant which the actual BS fall in was then estimated also.

c. Neural network matching

Neural network was used for clustering, classification and learning of the dynamics of the system. Neural network matching was also carried out using the variables from the geometry comparison, quadrant option and grid estimations.

The input into the neural network system for matching includes:

- i. Geometry arrangements, i.e. if the model is 1, 2, 3, 4, 5, 6 but the actual BS matching it is in the form 1, 3, 4, 5, 6 considering the distance between the MS and BSs.
- ii. The quadrant option for each BS or if there is none.
- iii. The grid each actual BS falls into when considering the closest matching model BS.

d. Neural network system inference

The neural network inference system uses the above inputs to estimate the expected error locating a MS at a particular geographical location.

The output inferred from the system includes:

- i. A neural network recall of the error based on the system geometry to the nearest possible match.
- ii. A confidence interval based on the difference observed between the model geometry and the actual geometry.

8.4.5 Flowchart of Simulated System

Figures 8.9 and 8.10 show flow charts of the simulated system used to model the error from the mobile network match and predict the error of a MS position based on the distance from the MS to the BSs it is connected to and their geographical locations. That is the build-up and the matching phases.

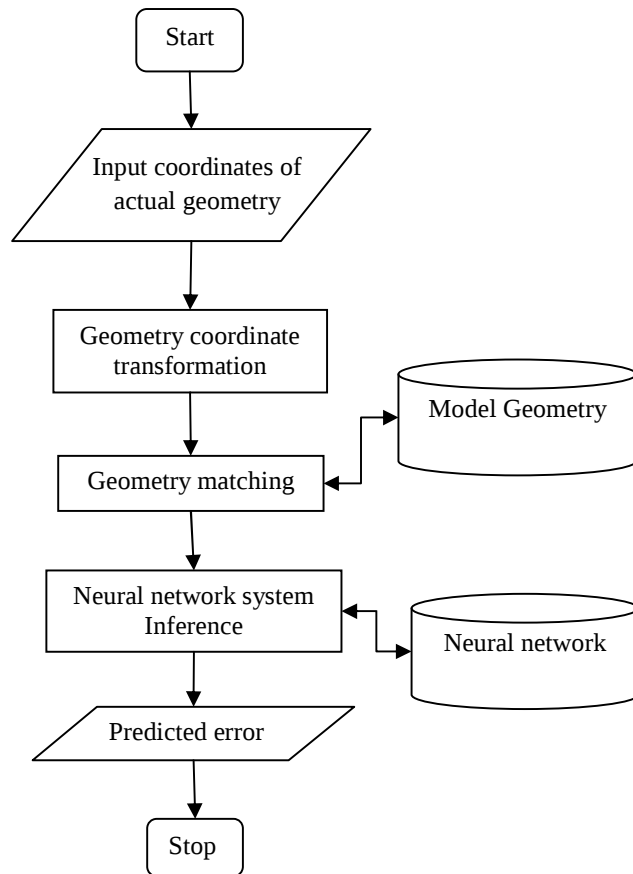


Figure 8.9: Flowchart of the matching phase

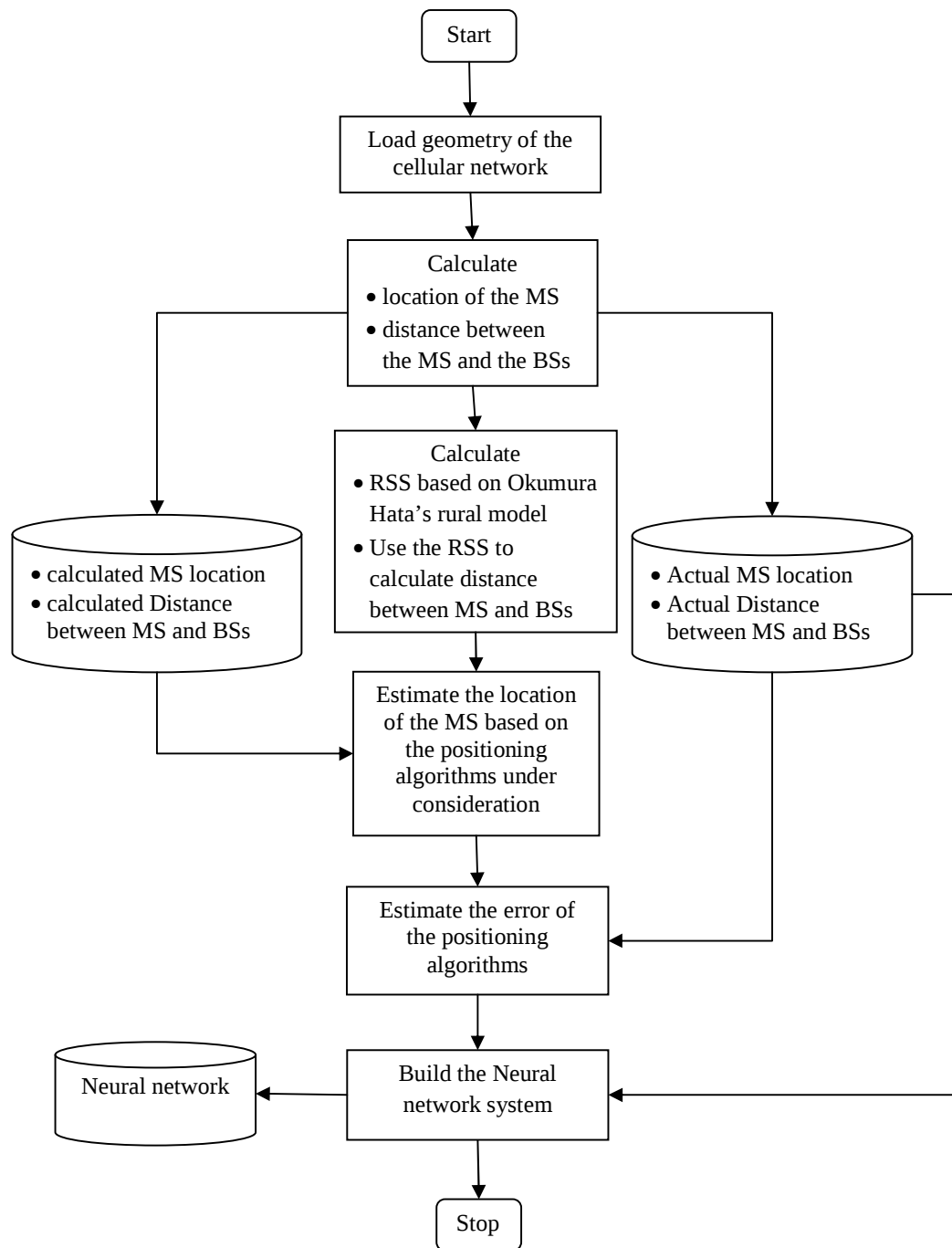


Figure 8.10: Flowchart of the build-up phase

8.5 RESULTS

The results from the simulation carried out on the geometry-aware RSS-based analyses are presented in this section.

8.5.1 Relationship between Size of Mobile Network Geometry and Positioning Error

The size of the geometry of each mobile network that the MS is connected to is different. Consequently to avoid simulating the positioning error model for each geometry size, it is necessary to obtain the relationship between geometry size and positioning error. The relationship between the simulated absolute error and the positioning methods under consideration is shown in Appendix D, Figures D1 – D4, pages 210 - 211. Due to the fact that the absolute positioning error is directly proportional to the distance, there is a multiplying factor which is constant for all geometry sizes. The positioning methods chosen were to test the feasibility of the method proposed. Other positioning methods can be used to implement these studies.

The basic relationship between the error obtained from simulating the positioning method and the simulated geometry (presented as the average distance between two BSs) are presented as Equations 8.13 - 8.16. Every 5 km, the error increases in multiples as shown in Table 8.1. Note that the length of side is the parameter that was used to describe the hexagon size. In addition, the length of the side of the hexagon was estimated as the average distance between all BSs from which the MS can receive a signal.

$$y_{COG} = 980x + 11000 \quad \dots 8.13$$

$$y_{LS} = -34x + 370 \quad \dots 8.14$$

$$y_{COT} = -830x + 14000 \quad \dots 8.15$$

$$y_{TRI} = 0.0081x^6 - 0.26x^5 + 3x^4 - 14x^3 + 29x^2 - 54x + 180 \quad \dots 8.16$$

Table 8.1: Relationship between geometry size and absolute error of positioning method

Average distance between two BSs				
5 km	10 km	15 km	20 km	25 km
$y_{\text{COG}} * 1$	$y_{\text{COG}} * 2$	$y_{\text{COG}} * 3$	$y_{\text{COG}} * 4$	$y_{\text{COG}} * 5$
$y_{\text{LS}} * 1$	$y_{\text{LS}} * 2$	$y_{\text{LS}} * 3$	$y_{\text{LS}} * 4$	$y_{\text{LS}} * 5$
$y_{\text{COT}} * 1$	$y_{\text{COT}} * 2$	$y_{\text{COT}} * 3$	$y_{\text{COT}} * 4$	$y_{\text{COT}} * 5$
$y_{\text{TRI}} * 1$	$y_{\text{TRI}} * 2$	$y_{\text{TRI}} * 3$	$y_{\text{TRI}} * 4$	$y_{\text{TRI}} * 5$

8.5.2 Results Based on Simulated Data

Data was simulated to test the accuracy predicting model for the RSS-based positioning method developed. There were eight simulated geometries in their local coordinate form and referenced to the serving BS.

With at least 3 actual BSs within 5 km of any other three model BSs the model is able to predict its accuracy. If there are more than 3, for example 6 matching BSs, the model predicts its accuracy based on 3, 4, 5 and 6 BSs. The simulated geometries were first matched with the model geometries as shown in Appendix D (Figures D.5 – D.20, pages 212 - 219) and accuracy estimated using the neural network model. Figures 8.11 – 8.19 shows the difference between the estimated accuracy and the predicted accuracy, with confidence intervals shown as error bars.

a. Three base stations analyses

When the MS receive signals from only three BSs, the MS can be estimated with all the positioning methods considered. Figures 8.11 – 8.13 show the estimated accuracy predicted. LS and TRI positioning methods have the same results when only 3 BSs are used for positioning. This is because they use the same concept fundamentally to estimate location. LS and TRI gave the worst prediction accuracy with simulated geometry eight.

The major reason might be because the MS is furthest from the serving BS in simulated geometry eight. COT gave the worst prediction accuracy with simulated geometry four and COG with simulated geometry three. Although

COG did not give the worst results with simulated geometry four, it has the largest confidence interval with simulated geometry four. This might be because simulated geometry four has the largest average distance between the MS and the 3 BSs used for positioning.

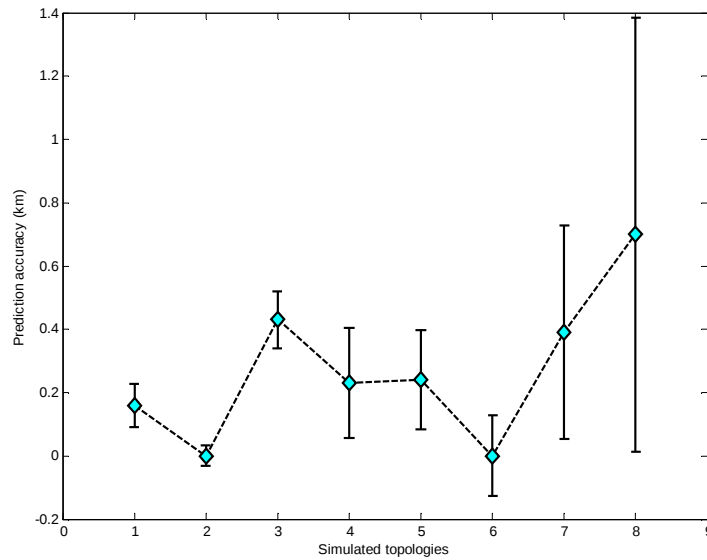


Figure 8.11: Prediction accuracy when LS method is used for MS location estimation with MS receiving signal from 3BSs

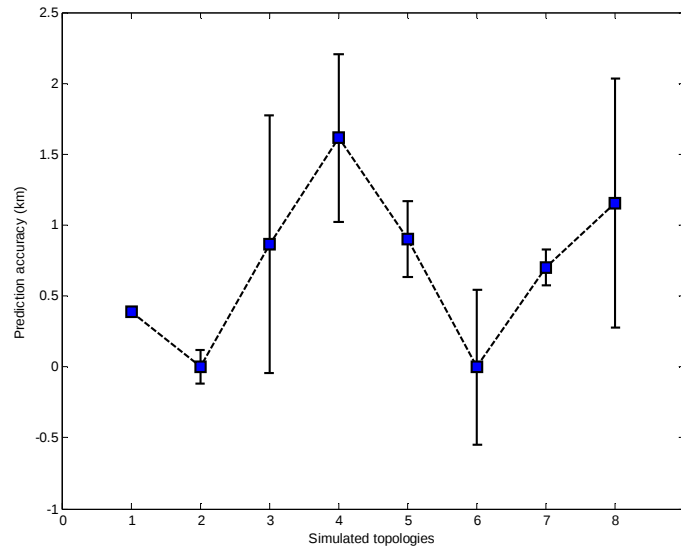


Figure 8.12: Prediction accuracy when COT method is used for MS location estimation with MS receiving signal from 3BSs

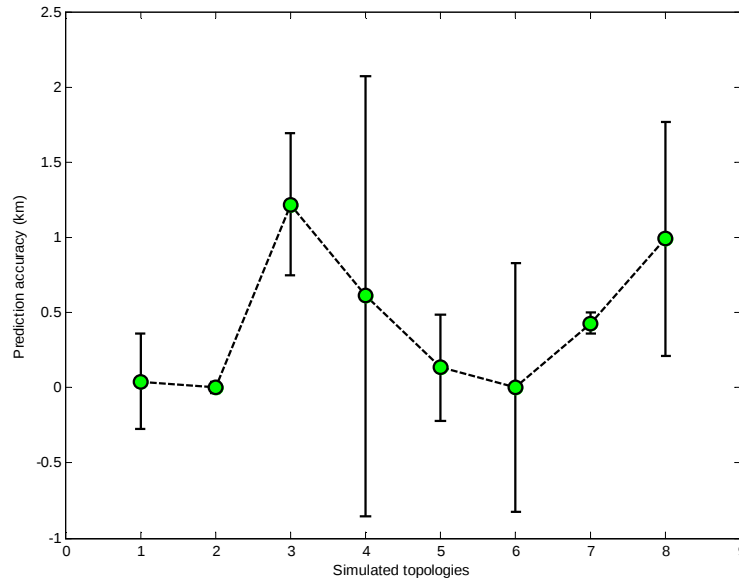


Figure 8.13: Prediction accuracy when COG method is used for MS location estimation with MS receiving signal from 3BSs

Overall, the prediction model was able to predict the accuracy of the positioning methods for simulated geometry one, two and six relatively more accurately. The total deviation from the simulated accuracy is 4.3 km for COG, 5.62 km for COT and 2.15 km for LS and TRI positioning methods.

b. Four base stations analyses

With four BSs, the average confidence interval for COG improved to about 1.7 km though the average deviation from the estimated values increased to about 10.53 km. The confidence interval for the LS method remained relatively close to the previous at about 2.3 km but the total deviation increased to 2.3 km. Figures 8.14 and 7.15 show the results presented.

c. Five base stations analyses

When considering estimation with 5BSs, both the LS and COG have the lowest confidence interval of 0.69 and 0.98 respectively. This might be because the BSs were positioned in such a way as to optimize the location estimation, although COG method gave the highest deviation of about 15.21 km. COG

method was relatively constant but gave a wide variation of confidence as shown in Figure 8.17.

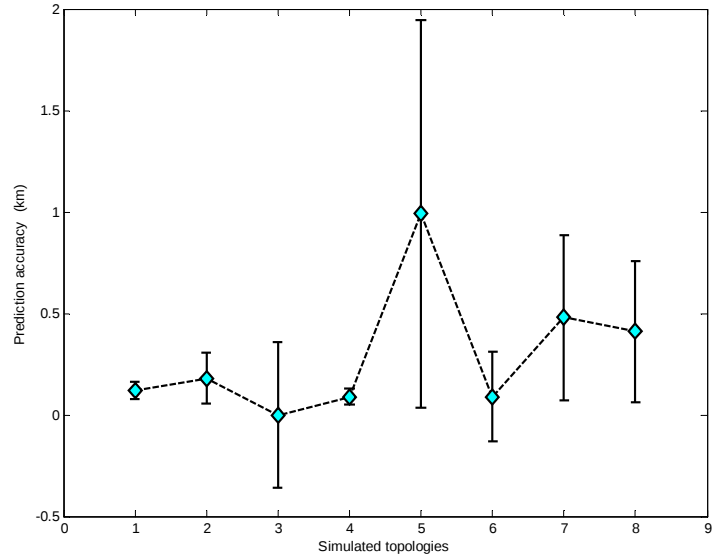


Figure 8.14: Prediction accuracy when LS method is used for MS location estimation with MS receiving signal from 4BSs

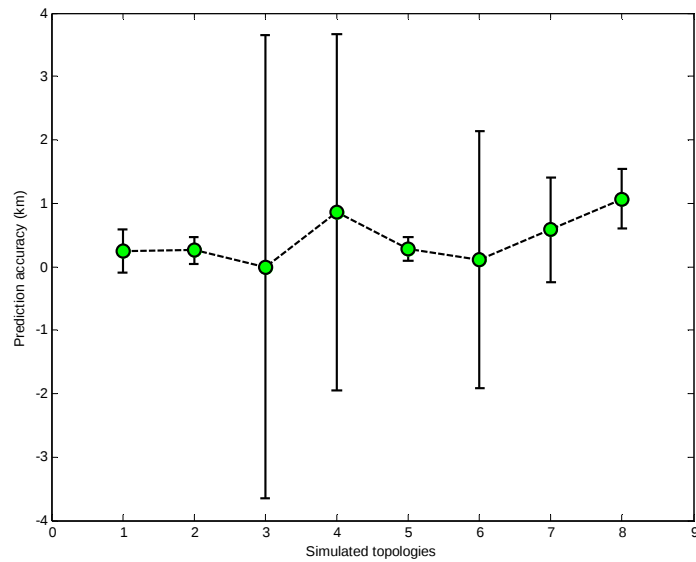


Figure 8.15: Prediction accuracy when COG method is used for MS location estimation with MS receiving signal from 4BSs

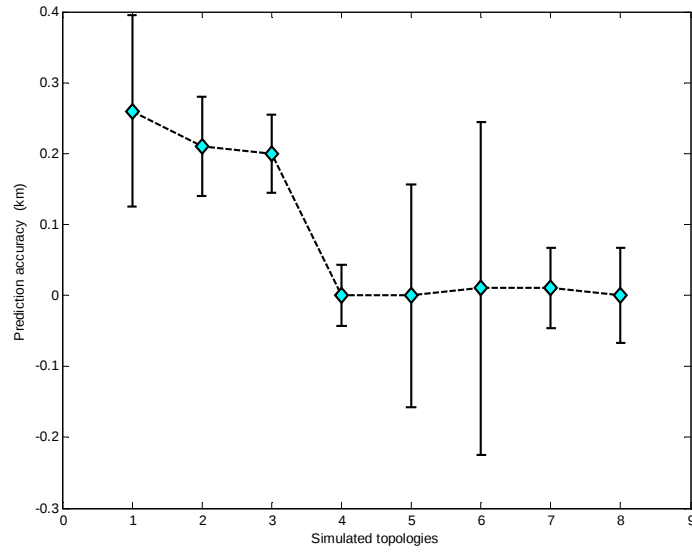


Figure 8.16: Prediction accuracy when LS method is used for MS location estimation with MS receiving signal from 5BSs

d. Six base stations analyses

COT and LS gave the worst confidence interval when estimation was carried out using 6 BSs with 7.84 km and 2.72 km respectively. The error was 5.92 km for COG and 2.19 km for LS. As shown in Figures 8.18 and 8.19

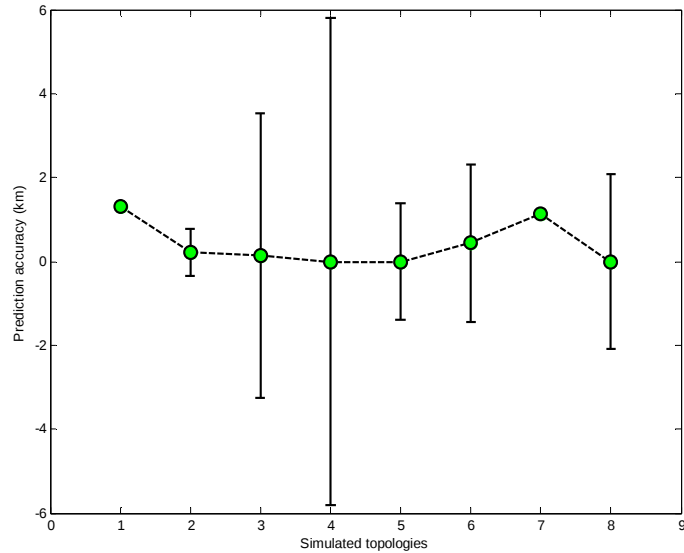


Figure 8.17: Prediction accuracy when COG method is used for MS location estimation with MS receiving signal from 5BSs

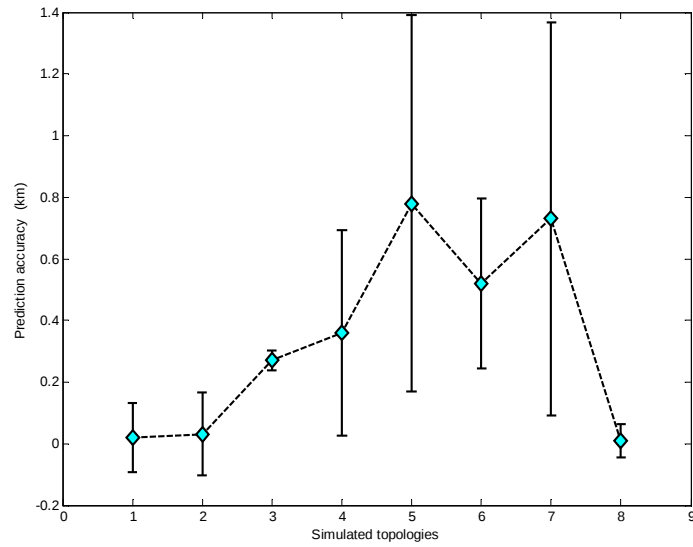


Figure 8.18: Prediction accuracy when LS method is used for MS location estimation with MS receiving signal from 6BSs

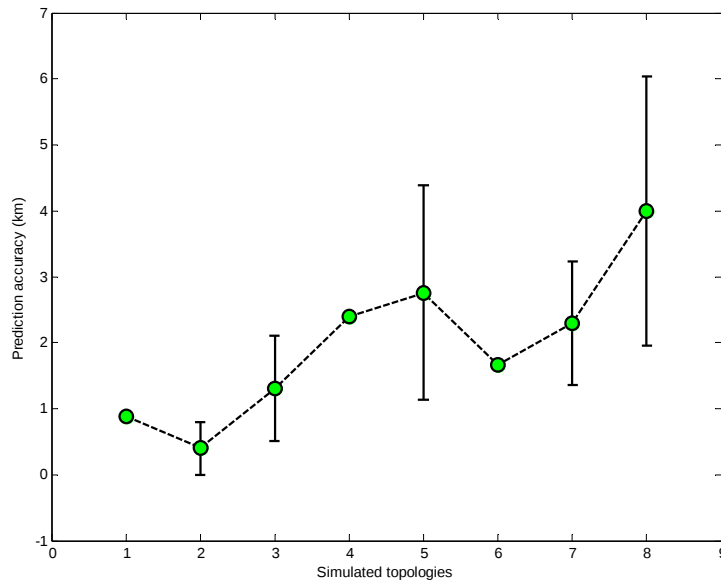


Figure 8.19: Prediction accuracy when COG method is used for MS location estimation with MS receiving signal from 6BSs

8.5.3 Results based on Field Data

The results of analyses presented in this section are based on field data collected over-the-air for the mobile network during a drive test to analyse the effectiveness of the proposed method.

a. Mobile geometries considered

The over-the-air data available from the Mobile Operator were only for urban and suburban areas. This is because drive test is not carried out in rural areas because of the cost of data collection and analyses. The ARPU in rural areas is relatively low compared to urban and suburban areas. The model was tested against eight (8) geometries in a suburban mobile network.

The World Geodetic coordinates were given and these were converted to Earth Centred Earth Fixed and the local coordinates. The pictorial representations of the coordinates are as shown in Figures D.22 – D.36.

The shortfall of using a suburban mobile network data was that:

- o The RSS values are more distorted because of multipath.
- o There are little or no omni-directional antennas therefore the sector antennas might have one or two neighbour BSs at the same geographical location.
- o Does not obey the hexagon mobile network planning reference model.
- o Average distance between BSs is about 1.5 km to 2 km compared to rural areas which is about 26 km – 52 km and typical suburban areas with cell size of about 5 km.

8.6 CRITICAL ANALYSES OF RESULTS

The coordinates of the simulated geometries were all matched by the model geometry and the accuracy of the MS predicted as shown in Appendix D, Figures D.5 – D.20, pages 212 - 219. Unfortunately, from results shown in Figures 8.11 – 8.19 there are

many different factors that affect the geometry of the BSs in relation to the accuracy of MS location estimation.

Though the simulated geometries were matched and accuracy predicted, the dependability of the results is low and widely diverse. Each geometry has a different accuracy and hence a different predictability and dependency. Therefore reliability of the information might not be the best for LBS users.

Considering the field geometries, there were no three BSs which are a match with model BSs considering the model geometry. Even considering the provision for nonlinearities introduced into the modelling of the BSs such as the quadrants, the nonlinearities of actual geometries considered did not match any of the provisions. Critically analysing the results, five major issues are discussed which might explain the results.

8.6.1 Multipath Effects and Geometry

Geometry found on each GSM network is uniquely different. The difference is not only in terms of cell size and varying distance between each BS on the network but also the fact that geometry is formed based on the BSs from which the MS can receive adequate signal strength from. Getting a good enough geometry can be very challenging because the MS might not be connected to the BSs nearest to it due to multipath. Multipath causes the signals to be diffracted, reflected and refracted so that some signals from very far BSs are considered better than the signals from closer BSs.

8.6.2 Geometries on a Practical Network versus Conventional Geometries

The conventional geometry is in the form of a hexagon with the serving BS at the middle and the neighbour BSs surrounding it. This is unfortunately not the same with the arrangement in practice. In practice, geometry is uniquely different and even though the model geometry used for this research has the provision for nonlinearities, it cannot match well enough from the results the nonlinearities encountered on a practical GSM network.

On a practical GSM network, the BSs are unevenly spaced depending on the density of people within a given area, the ARPU expected from the area, the type of services offered, topography, et cetera. Consequently, the distance between BS1 and BS2 might be very different from the distance between the serving BS and BS1 and so on. The average distance was the parameter used to estimate the cell size of the model matching geometry. This implies that the matching geometry might only match some BSs appropriately while other BSs will fall out of the coverage area.

8.6.3 The Matching Method

Each arrangement for the matched BSs is different. For example, the model BS is ordered in a particular fashion, with the 1st neighbour, 2nd neighbour,... , nth neighbour as shown in Figure 8.2. The actual BSs might not be arranged in the same way which results in the inaccuracy of the predicted accuracy. The only way to combat this is to have a database for each possible arrangement of the model geometry. Given the fact that building the database for the single arrangement implemented took about 50 hours on a high powered computer, covering all the different arrangements will make the program build-up and matching phases much longer. This will probably have little or no effect on the overall result of the research work.

8.6.4 RSS-based Positioning Methods for Rural Areas

In rural areas where the settlements are sparsely spaced and the density of subscribers small, mobile operators have large set up omnidirectional BSs. This implies that most settlements might only receive adequate signals from just a single BS. This reception might only be possible when they are at a particular location, probably an elevated plane. The ability to receive adequate signals from three BSs for RSS-based positioning is thus minimal.

8.6.5 GDOP Assisted Location Estimation Algorithms

An alternative to the model matching to improve the accuracy of location estimation is using the GDOP coefficient. Some work has been carried out on improving the

accuracy of geometric location estimation by the use of GDOP for TOA and TDOA estimation methods but non for RSS-based MS location estimation as far as the researcher can ascertain.

8.6.6 Practical Implementation

For a practical implementation of the proposed geometry-aware RSS-based positioning, geometry might require its own accuracy prediction model. This is due to the fact that geometry is uniquely different. This will require a lot of manpower, a high powered computer and a large database which makes the proposed method closer to the requirement for fingerprinting or database correlation methods. Though the proposed method is as tasking as the fingerprinting method, it will not be as accurate because it is based on geometric methods. Fingerprinting will definitely be a better option to use.

8.7 CONCLUSION

It has been confirmed that the error variables are indeed dynamically varying and the accuracy is dependent on every one of the variables in different forms. Single LBS provided to a MS has an entirely different relationship with the error sources and no two MSs have exactly the same scenario. Therefore it is challenging to build a geometry-aware model for a generic case. Even a statistical model will have widely varying variables and might prove unsuccessful.

It is possible to improve the accuracy of the algorithms by making them environment-aware and by improving the location information stored and maintained by the appropriate bodies. It is, however, not feasible to make the RSS-based algorithm geometry-aware using an artificial neural network (multi-layer perceptron) due to the varying effects the distance between the MS and BSs and the distance relative to each BS have on each other.

This Chapter answers the research sub-question five “Is a model feasible and robust enough to tackle the nonlinearities and uncertainties of its dynamically varying

parameters?” From the analysis carried out and presented, it is not feasible to make a generic geometry-aware model or generic error-aware model using an artificial neural network (multi-layer perceptron) to improve the accuracy of RSS-based positioning methods.

CHAPTER NINE

9 CONCLUSIONS AND RECOMMENDATION

9.1 INTRODUCTION

The evolution of mobile networks over the past three decades has been phenomenal, from first generation (1G) analogue networks to the GSM in the 1990s. Africa, although a new player in the field, is hoping to harness all services available on the network for the use of its subscribers. LBS is one of such services which can help bring services to subscribers based on their geographical location and hence help the majority of the African populace to harness all that mobile technology has to offer. LBS are services that need a specified QoS for its effective usage by the LBS user. This research focused on investigating the feasibility of improving LBS provided using network-based positioning techniques.

Firstly, a literature review was performed on LBS as a type of service on GSM networks and later narrowed down to network-based positioning techniques. Before further work could be carried out, there had to be an established need for LBS in Africa. As there is no published work in this area, an investigative research was carried out on two developed countries the United States of America and the United Kingdom and four African countries. South Africa, Nigeria, Kenya and Egypt to infer and understand the best options to the effective development, deployment and adoption of LBS in Africa. Data collection was carried out through a survey of literature from different sources such as journal papers, conferences, mobile network operator's reports, newspaper articles, online publications and others. Data was collected for the aforementioned countries and areas.

In order to establish the need to improve LBS accuracy provided in Africa, the quality of available LBS and factors affecting its quality was investigated. LBS measurement data was collected from South Africa, the country where mobile technology is most developed within Africa. An empirical investigation and analyses was carried out on

the data using maps collected from Gauteng City-Region Observatory (GCRO) and using Statistical Package for Social Sciences (SPSS) and ARCGIS 9.2.

A statistical analysis was also carried out on over-the-air mobile network data with the aim of deducing the effect of geometry on the accuracy of RSS-based geometric positioning techniques. The factors affecting the quality of LBS once established can then be used to model and develop an error-aware network-based positioning of the MS.

Lastly, suggestions were drawn from the results of the feasibility of making Cell-ID positioning more error-aware. A model was also developed investigating the feasibility of making the RSS-based geometric positioning techniques error-aware with a major consideration given to the geometry of the BSs whose measurements are used for position estimation. For the feasibility studies, simulations were used on the system, and MATLAB was used to model the accuracy prediction system. A neural network accuracy prediction system was developed based on the GSM hexagonal mobile network geometry, simulated RSS-based positioning error estimations and simulated MS with distances from the MS to each BS in the mobile network recorded. The error-aware neural network system can then predict the location of a MS once the over-the-air data is made available to it. There was also provision made for nonlinearities in matching of the model geometry and actual geometry.

9.2 KEY FINDINGS

Research presented in Chapter Five confirmed that LBS penetration in Africa is still significantly low and Africa definitely needs LBS not just any LBS, but dependable and accurate LBS tailored to the needs of the African people. Results obtained from analyses of the measurement data in Chapter Six concluded that the dependability of LBS presently offered is also not encouraging.

It was also discovered that although location estimation algorithms affect the reliability, dependability and accuracy of LBS, they are not the only factors that need

to be considered in the case of Africa. Other major factors that should also be considered include:

- o The accuracy of the spatial data available in Africa.
- o The poor town planning and address system.
- o The size and coverage of the spatial data available in Africa.
- o Provision of LBS not adapted to the needs of African.
- o Algorithms not tailored particularly to the provision of LBS but instead adapted. Positioning algorithms were developed on already existing mobile network infrastructure and software.
- o Lack of legislation for LBS.

Of all the factors highlighted, this research narrowed down and was geared towards improving the provision of LBS by improving network-based positioning algorithms by making them error-aware.

Prior to studying and building the error-aware algorithm, it is important to know and understand the dynamically varying error parameters in Africa. Results presented in Chapter Seven show that the accuracy of network-based positioning methods is dependent on these amongst so many others:

- The mobile network,
- Environment,
- Geographical location, and
- Geometry of the network.

This research is the first known study (as far as the researcher can ascertain) of LBS in Africa, LBS accuracy in Africa, and studying the feasibility of error-aware network-based positioning algorithm, especially the study into geometry-aware positioning algorithms for RSS-based methods using matching. This research work also studied the feasibility of introducing the geometry of the network as one of the

tools to improve the dependability of LBS methodology. The methods proposed are novel and not found in any existing literature as far as the researcher can ascertain.

There are many important parameters to be considered in predicting the accuracy of LBS accessible to end users. This research investigates firstly the feasibility of making Cell-ID positioning techniques error-aware. It has been discovered that although it is possible to improve the accuracy it is impossible to make it error-aware and predict its accuracy. The accuracy of Cell-ID positioning is directly proportional to the cell size as indicated in Chapter Eight. As the environment changes, the cell size changes and the accuracy also changes. The best ways to improve the accuracy using Cell-ID were summarized in Chapter Eight, and repeated here;

- o Providing Africa adapted software solutions, which are adapted to Africa's road network, mobile network, et cetera.
- o Developing software solutions adapted to the unique requirements of positioning methods available for use.
- o GIS solutions to develop precise and accurate geospatial data, maps and geocode for Africa.
- o Taking into account the length of the nearest major road to the serving BS the MS is connected to. The roads should be divided into sections by the use of landmarks or intersection with other roads.
- o Improving the accuracy of the Cell-ID positioning method using hybrid methods. Spirito et al collected some over-the-air data and simulated the Cell-ID +TA and Cell-ID +TA + RSS and they concluded that there was a significant reduction in average error and maximum error with Cell-ID + TA + RSS outperforming the other hybrid method [15, 53].

The RSS-based method cannot be used in urban and built-up suburban environments due to its high inaccuracy caused by signal propagation challenges especially multipath. Considering RSS-based positioning technique for rural areas, major conclusions were reached. Assuming positioning is carried out in a rural environment

with little signal propagation challenges, the accuracy of RSS-based location method is highly dependent on the geometry of the BSs where position estimation measurements are obtained.

The conventional hexagon mobile network simulation used for mobile network analyses and research has major limitations. It represents an ideal situation but this is rarely the case in practice. To reduce the complexity of simulation, not all parameters were considered, others have been approximated while others assumed. Although the simulated RSS-based feasibility method performed quite impressively during simulations and was able to match and predict the accuracy, it fell short when applied to field data.

This implies that geometry and relative distance between the MS and BSs used for positioning will give a different level of accuracy. Employing the same methods in practice makes it quite challenging and almost impossible to be able to predict. Some parameters have to be met:

- The environment must have very little or no signal propagation challenges for example multipath, fading, et cetera.
- Geometry of the actual mobile network must match the geometry of the model mobile network.
- The MS must be able to receive adequate signal strength from three or more BSs.
- At a typical rural set up in Africa, the MS can only get signals from at most two or three BSs.
- Owing to the distance between the MS and BS, the MS might not receive the adequate signal strength from the MS. In some rural area mobile subscribers have to stand on an elevated position to get adequate radio signals from a single BS for voice communication.

In conclusion, other methods need to be explored to improve dependability of LBS information provided to MS users in Africa. The feasibility of increasing the dependability by making the positioning algorithm error-aware is not practicable.

9.3 CONTRIBUTION TO KNOWLEDGE

The following contributions have been made to knowledge as stated previously in Chapter Four:

A comprehensive analysis of the potential and challenges of LBS in Africa, presented in Chapter Five.

An empirical analysis of the dependability, reliability and accuracy of LBS in Africa, presented in Chapter Six.

A comprehensive analysis of some error parameters affecting network-based positioning technique accuracy, presented in Chapter Seven.

Methods of improving the accuracy of LBS in Africa, presented in Chapters Five - Eight.

A geometry-aware model RSS-based positioning technique for GSM networks was developed and presented in Chapter Eight.

Feasibility of an error-aware network-based positioning to improve LBS accuracy presented in Chapter Eight.

9.4 RECOMMENDATION

It has been established that error parameters affecting network-based positioning are indeed dynamically varying and cannot be predicted for any particular location. Therefore the possibility of making the network-based positioning error-aware is impossible because the factors affecting MS positioning varies with geographical location, BS or BSs used for positioning, distance of MS relative to the BS or BSs,

distance of BS relative to each other (when more than one BS is used for positioning), movement of the MS, movement of things around the MS, height of the MS user above the ground, cell size etc.

Making the network-based positioning algorithm error-aware can only be carried out by using the fingerprinting method which is expensive, labour intensive and has to be updated frequently with the constant change in infrastructure in Africa as a developing country. Therefore the most feasible method for Africa is Cell-ID or enhanced Cell-ID based positioning methods assisted by TA and RSS measurements.

9.5 FURTHER WORK

Further work can be carried out on increasing LBS information dependability by:

- Investigating, designing and developing LBS adapted to African needs with enough location information for the services intended.
- Studying the possibilities of regulating LBS in Africa.
- Improving GIS information and geographical data for Africa.
- Implementing a hybrid of network-based positioning methods in Africa.

Conclusively, though many authors had advocated the inclusion of these accuracy varying factors (especially network geometry) in positioning methods to make it error-aware, it has been proved through various methods in this research that though theoretically possible, it is practically not feasible.

9.6 CONCLUSION

From the research, it was discovered that the deployment of LBS in Africa for GSM subscribers is relatively slow and presently only commercially available in South Africa and little enthusiasm is shown by MS users to LBS. This may be because services are not adapted to the needs of the African populace and a challenge with dependability. Little drive for LBS is also given by mobile operators for services

supporting legacy MSs. This might be because of low average revenue per user (ARPU) of a large percentage of subscribers. More of the dependability concerns were reiterated by the LBS measurement data analyses which points out that on average the actual accuracy provided by the location provider is 4 times less than the predicted accuracy as observed thereby making location information available very undependable.

Some of the factors contributing to the undependability as investigated were location information, environment, geographical location and the location providers' mobile network. Geographical location accounted for 26 percent variance in accuracy, 18 percent by the environment and 5 percent by the location provider's mobile network. Further results were obtained on the effect of mobile network geometry on location accuracy. Varying correlation performance of some RSS-based positioning methods considered in rural and urban environments shows that geometry affects position error which is directly proportional to accuracy provided.

Analyzing the error factors such as geographical location, environment and geometry of the BSs and introducing them to MS position predicting algorithm might improve the predictability of positioning algorithms and consequently dependability of location information. LBS can be adapted to meet some location related and dependent needs of the African continent with dependable location information.

Results deduced from the feasibility analyses indicate that it is feasible to improve location information predictability made available by Cell Identification (Cell-ID) and Timing Advance (TA) positioning methods. This can be achieved by using improved prediction algorithms, incorporating up-to-date geographical information and hybrid technologies. Feasibility analyses were then carried out on RSS-based positioning methods using MATLAB simulations to deduce the possibility of improving location information predictability through geometry information. It was confirmed that although the geometry of the network affects RSS-based methods, the

environment and geographical location are the major determining factor in its accuracy.

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APPENDICES

APPENDIX A. POVERTY RATE IN AFRICA

Table A.1 Population in poverty [25]

Population below poverty line					% Population living				
Country	Survey Year	Rural	Urban	National	year	below \$1 /day	below \$2 /day	Year	Gini coefficient
Algeria	2000-2006	...	...	22.6	2000	0.9	...	2000	35.3
Angola	2001	94.3	57	68	2000	54.3	...	2000	58.6
Benin	1999	33	23.3	29	2003	47.3	73.7	2003	38.6
Botswana	2003	...	...	30.3	1994	31.2	...	2003	61
Burkina Faso	2003	52.3	19.9	46.4	2003	56.5	81	2003	39.6
Burundi	2006	37	...	36.2	2006	81.3	87.6	2006	33.3
Cameroon	2001	49.9	22.1	40.2	2001	32.8	50.6	2001	44.6
Cape Verde	2002	55.1	25	36.7	2001	20.6	...	2001	50.5
Cent. Afr. Rep.	2003	...	...	50.2	2003	62.4	...	2003	43.6
Chad	1996	67	63	64	2003	61.9	...	2003	39.8
Comoros	...	...	...	...	2004	46.1	...	2004	64.3
Congo	2005	57.7	55.4	50.1	2005	54.1	...	2005	47.3
Congo, Dem. Republic	2005	...	...	71.3	2006	59.2	...	2006	44.4
Côte d'Ivoire	2002	49	24	38.4	2002	23.3	48.8	2002	48.4
Djibouti	2002	...	...	42.1	2002	18.8	...	2002	40
Egypt	1999-2000	...	...	16.7	2005	2	43.9	2005	32.1
Equat. Guinea	2003	...	...	38.1	...	...	...	...	...
Eritrea	2000-2006	...	...	53	...	...	...	...	...
Ethiopia	2000-2006	45	37	44.2	2005	39	77.8	2005	29.8
Gabon	2005	45	30	33	2005	4.8	...	2005	41.5
Gambia	2003	63	...	61.3	2003	34.3	82.9	2003	47.3
Ghana	2006	39.2	10.8	28.5	2006	30	78.5	2006	42.8
Guinea	1994	...	...	40	2003	70.1	50.2	2003	43.3
Guinea Bissau	2002	...	...	65.7	2002	48.8	96.7	2002	35.5
Kenya	2005-06	49.1	33.7	45.9	2005	19.7	58.3	2005	47.7
Lesotho	2000-2006	...	...	68	2003	43.4	56.1	2003	52.5
Liberia	2002	...	...	76.2	2007	83.7	...	2007	52.6
Libya	2000-05	...	...	14	...	...	...	...	...
Madagascar	2005	73.5	52	68.7	2005	67.8	85.1	2005	47.2

Population below poverty line					% Population living				
Country	Survey Year	Rural	Urban	National	year	below \$1 /day	below \$2 /day	Year	Gini coefficient
Malawi	2006	47	25	45	2004	73.9	76.1	2004	39
Mali	2005	...	...	47.5	2006	51.4	90.6	2006	39
Mauritania	2000	61.2	25.4	46.3	2000	21.2	63.1	2000	39
Mauritius	...	...	...	...	...	...	...	2006	38.9
Morocco	1999	27.2	12	19	2007	2.5	14.3	2007	40.9
Mozambique	2002/03	55.3	51.5	54.1	2003	74.7	78.4	2003	47.1
Namibia	...	...	...	...	2004	32.8	55.8	2004	60
Niger	2000-2006	66	52	63	2005	65.9	85.3	2005	43.9
Nigeria	2000-2006	...	...	34.1	2004	64.4	90.8	2004	42.9
Rwanda	2005-06	62.5	41.5	56.9	2006	57	83.7	2006	46.7
São T. & Príncipe	2001	...	...	53.8	...	...	...	...	...
Senegal	2001	...	...	53.9	2005	33.5	63	2005	39.2
Seychelles	...	...	...	...	...	...	...	...	...
Sierra Leone	2004	79	56.4	70.2	2003	53.4	74.5	2003	42.5
Somalia	...	...	...	...	...	...	...	...	...
South Africa	2000	...	...	45	2000	26.2	34.1	2000	57.8
Sudan	...	...	...	...	...	...	...	...	...
Swaziland	2001	75	...	69.2	2001	62.9	22.5	2001	50.7
Tanzania	2000-2001	38.7	29.5	35.7	2000	88.5	89.9	2000	34.6
Togo	1995	...	...	72.2	2006	38.7	...	2006	34.4
Tunisia	2005	...	...	3.8	2000	2.6	6.6	2000	40.8
Uganda	2003	41.7	12.2	37.7	2005	51.5	...	2005	42.6
Zambia	2003	74	52	68	2004	64.3	94.1	2004	50.7
Zimbabwe	2000-2006	48	7.9	34.9	2004	61.9	...	2004	50.1

APPENDIX B. LOCATION-BASED SERVICES IN DEVELOPED COUNTRIES

Table B.1: A summary of location-based services in USA (adapted from [149])

Company	LBS service	Service
Sprint-nextel	Emergency	Emergency calls Automotive Assistance
	Navigation	Directions Traffic management Navigation Group management
	Information	Travel services MAP Point of interest
	Tracking	People tracking Vehicle tracking Personnel tracking
Verizon	Emergency	Emergency calls Automotive Assistance
	Navigation	Directions Navigation Group management
	Information	Travel services Mobile Yellow pages MAP Point of interest
	Tracking	People tracking Vehicle tracking Personnel tracking
AT&T	Emergency	Emergency calls Automotive Assistance
	Navigation	Directions Traffic management Navigation
	Information	MAP Point of interest
	Tracking	People tracking Vehicle tracking

Table B.2: Location-based services in 6 European countries [150]

Country	Company	Services	Country	Company	Services
Germany		100% penetration(6/2006)	Italy	Vodafone Italy	130% penetration (9/2006) Navigation Yellow pages Traffic information Fleet management Navigation
	Vodafone D2	Gas stations Restaurants ATM finder Yellow pages “find your friends”		Telecom Italia Mobile	Taxi finder Fleet management Traffic information
	O2	Fleet management Home billing Yellow pages Fleet management ATM finder Entertainment info		WIND H3G	-- --
	T-Mobile	Gas stations Navigation Taxi finder Home billing Navigation Car finding Home billing “find your friends” Fleet management	Switzerland	Swisscom	97% penetration (12/2005) Maps Navigation “Friend finder” Yellow pages Weather Home billing Weather Tourist guide Navigation Traffic information Yellow pages
	E-plus			Sunrise	--
Greece	Vodafone	117% penetration (12/2005) Fleet management Navigation Gas stations Navigation(i-mode)		Orange CH	Business customers MVNO: Swisscom network MVNO:Orange network
	Cosmote	Tourist guide(Voice portal) Navigation (maps)		Tele2 In&Phone SA Migros	
	TIM	Yellow pages		Coop	
	Mo’MAD	MVNO: TIM network	Austria	Mobilcom	104% penetration(7/2006) Navigation, car security Road help, Travel calculator Yellow pages Fleet management Fleet management Yellow pages Yellow pages
	Frog Mobile	MVNO: cosmote network		T-Mobile A	Entertainment guide Traffic information Fleet management
UK	O2	121.2% penetration (1/2006) Traffic information Maps(i-mode)		One	
	Orange	Nearest bank, cinemas, train station, weather services		Hutchison 3G Austria	“Friend finder” Navigation
	Vodafone UK	Fleet management Yello pages Maps and navigation (Vodafone Live!)		Tele-ring YESSS! Tele2 A	Yellow pages *MVNO: One network MVNO ² : One network
	Hutchison 3G UK	Maps, Navigation Nearest hotels, restaurants and shops			
	BT cellnet				
	Virgin Mobile				
	Tesco				
	EasyMobile				
	Talk Talk Mobile				

² MVNO – Mobile virtual network operator

APPENDIX C. LOCATION POINTS CONSIDERED

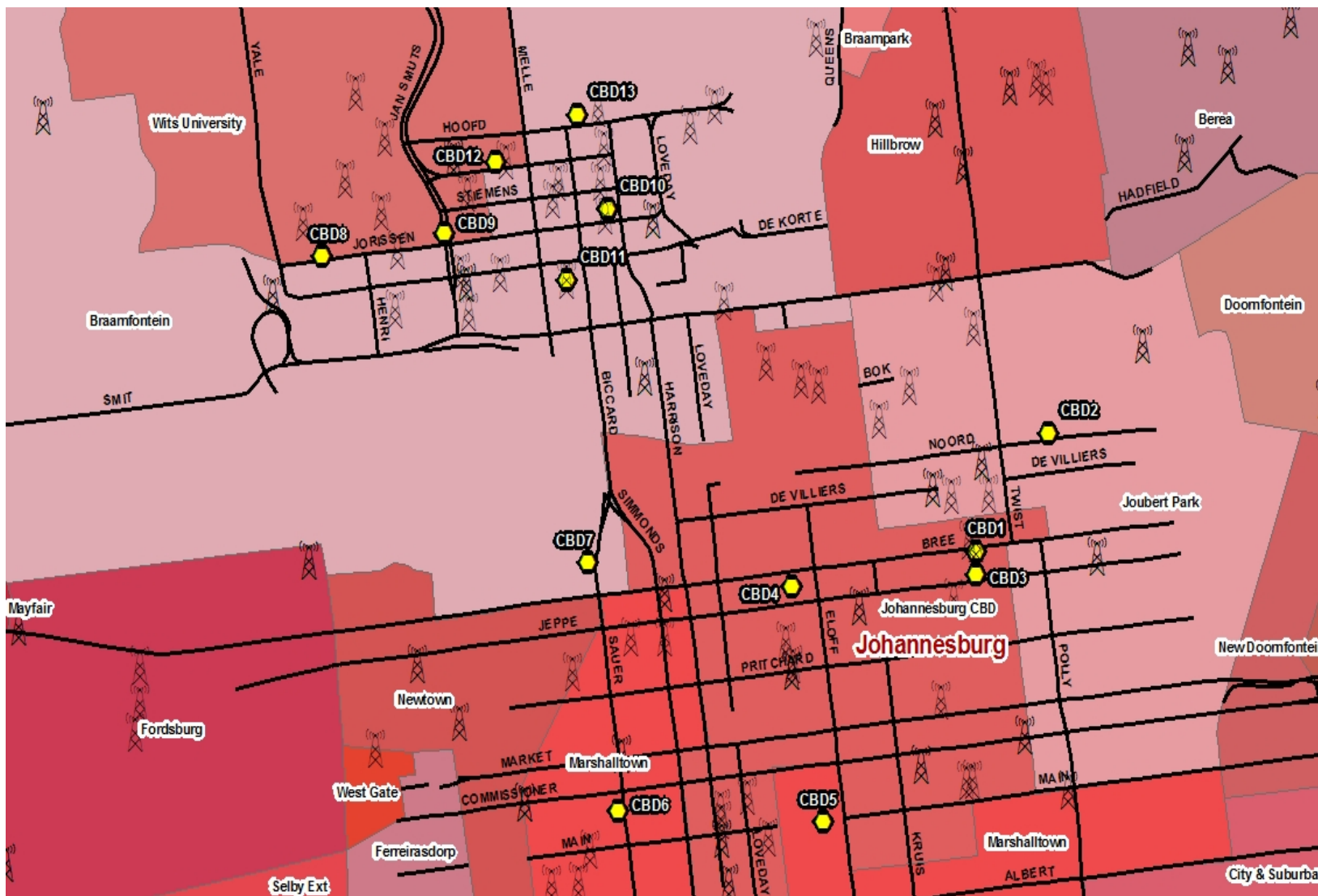


Figure C.1: Location points considered at Johannesburg Central Business District

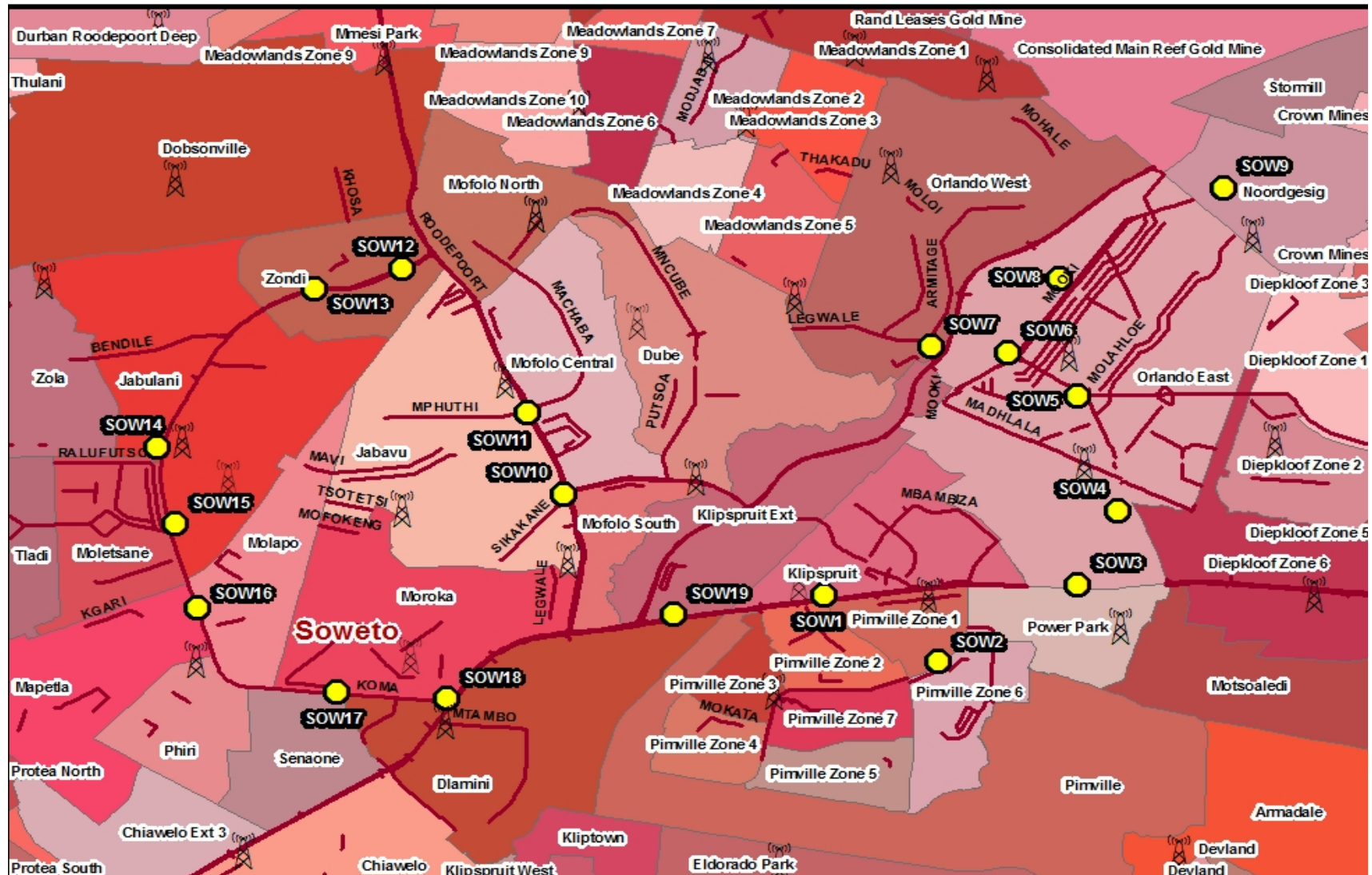


Figure C.2: Location points considered at Soweto

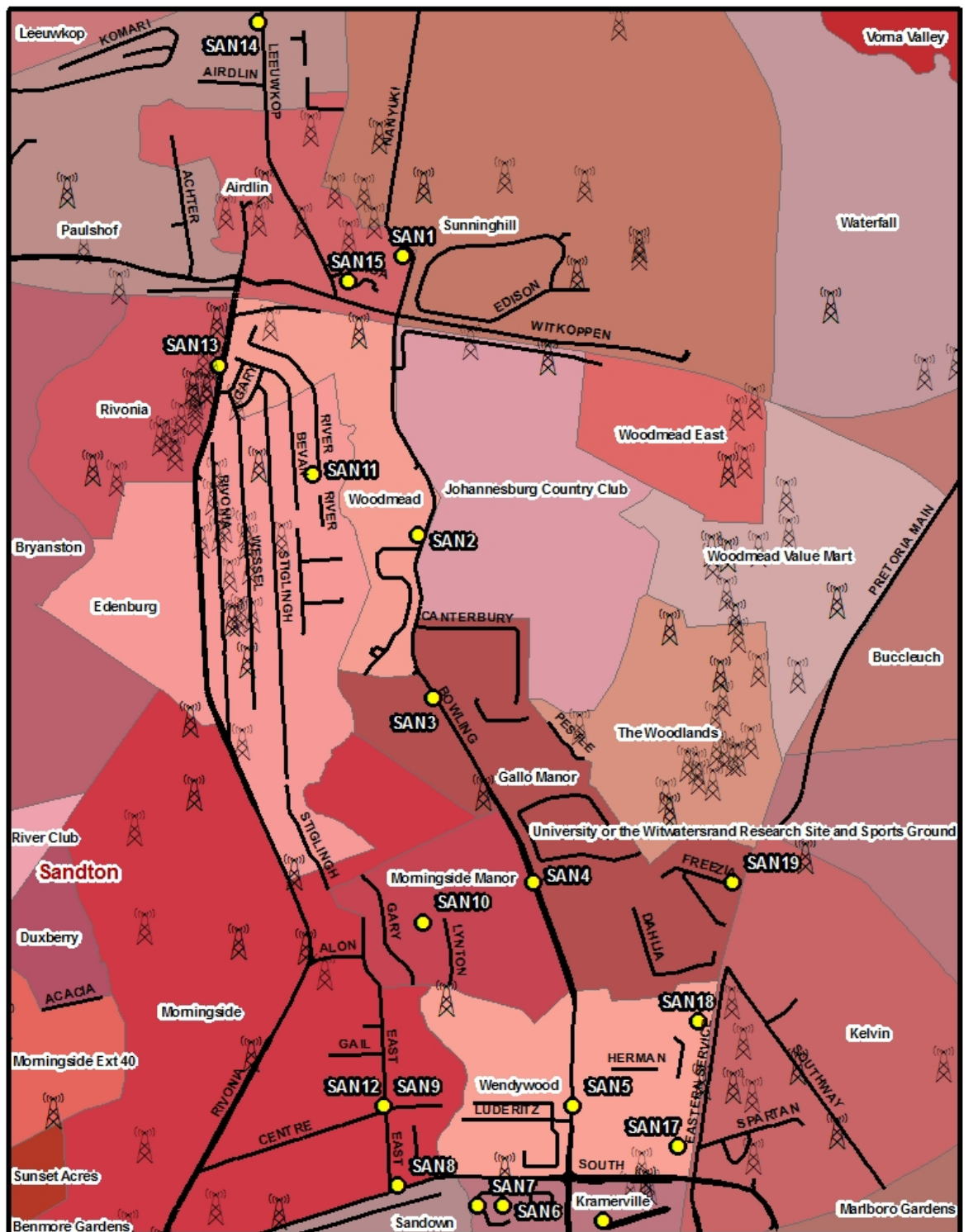


Figure C.3: Location points considered at Sandton

APPENDIX D. SIMULATION RESULTS

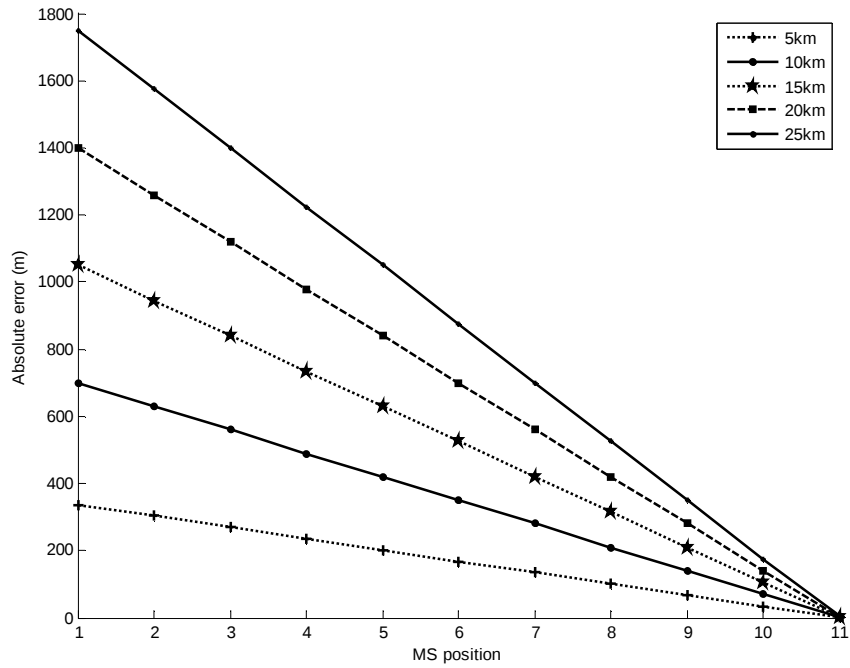


Figure D.1: Relationship between errors obtained by LS positioning and cellular network geometry

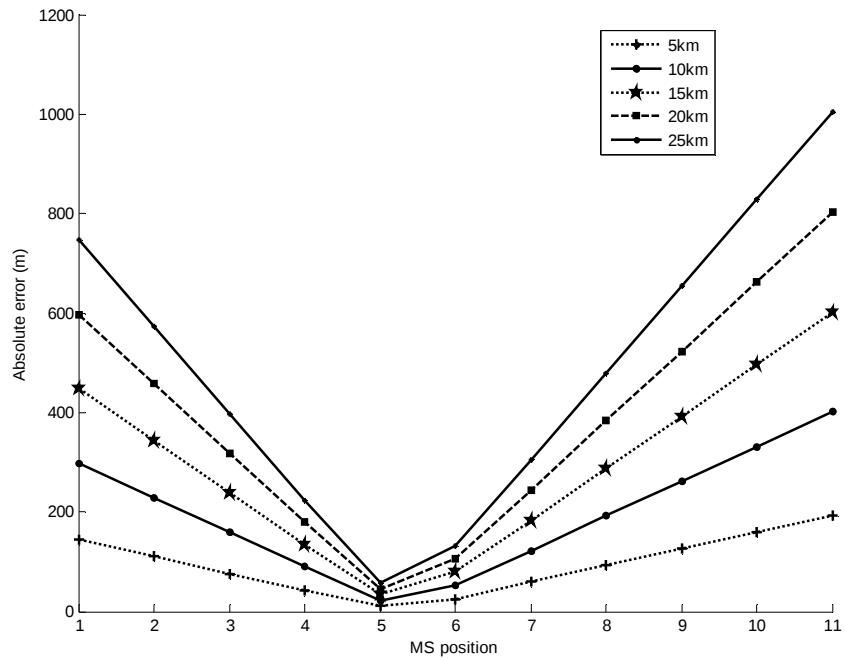


Figure D.2: Relationship between errors obtained by TRI positioning and cellular network geometry

Appendix D. Simulation Results Continued

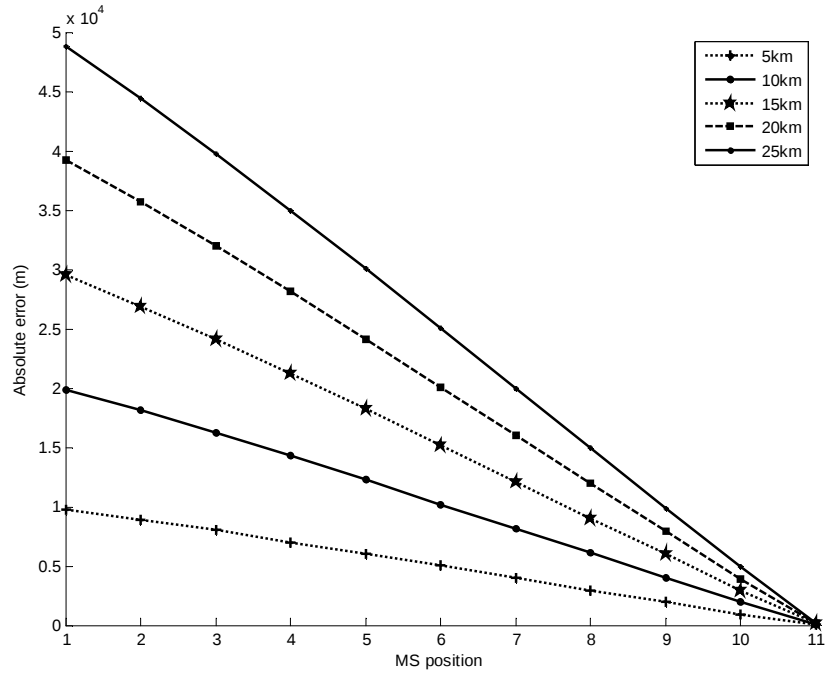


Figure D.3: Relationship between errors obtained by COG positioning and cellular network geometry

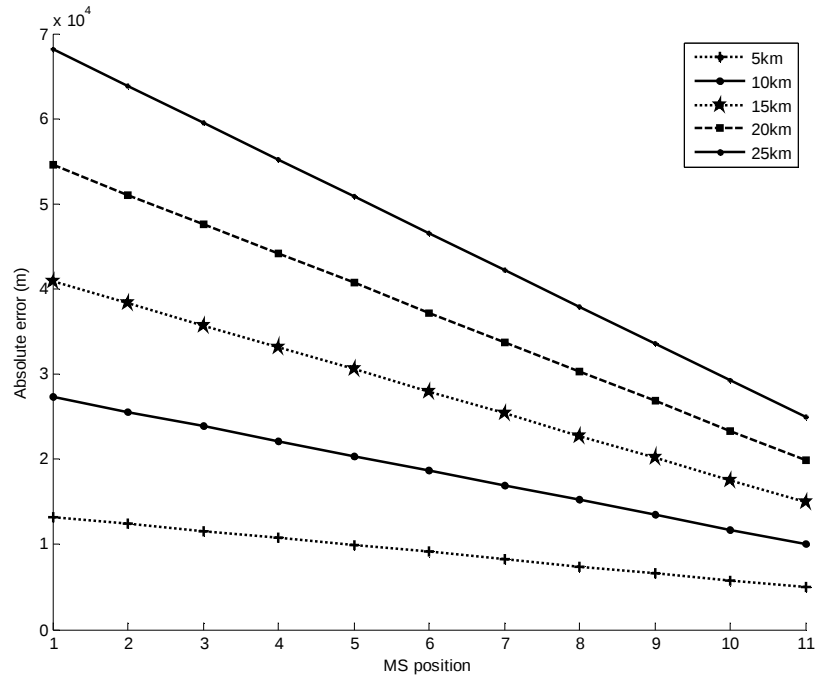


Figure D.4: Relationship between errors obtained by COT positioning and cellular network geometry

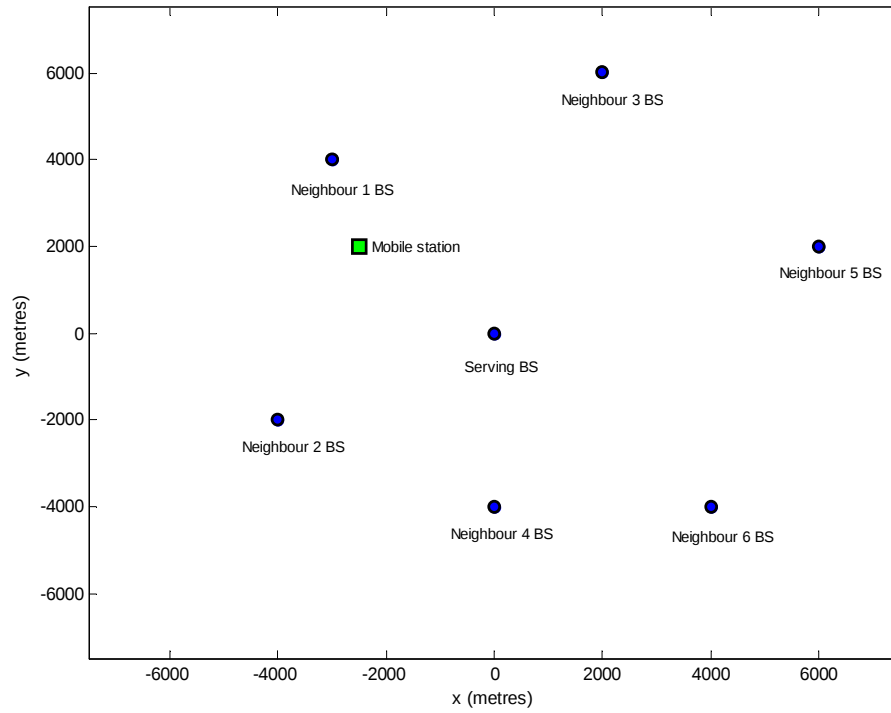


Figure D.5: Local coordinate for simulated geometry one

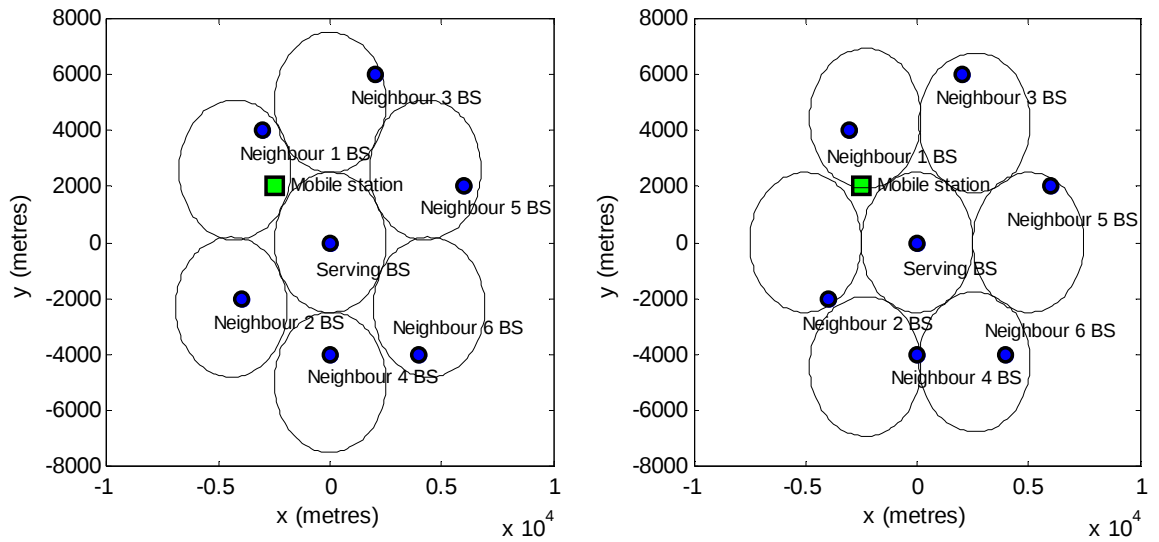


Figure D.6: Matching simulated geometry one with the model geometries

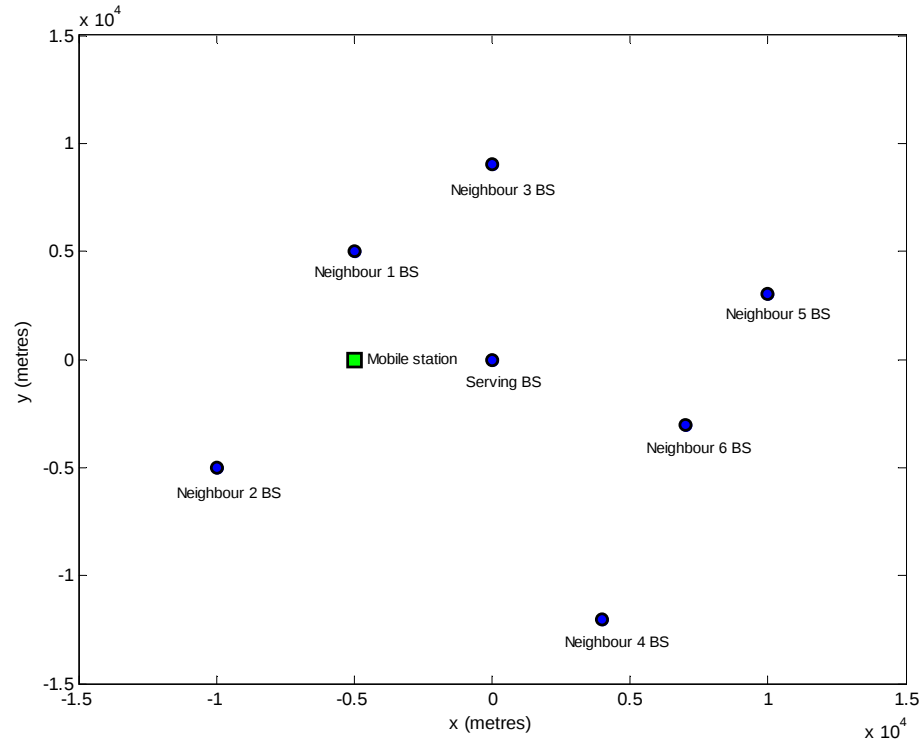


Figure D.7: Local coordinates for simulated geometry two

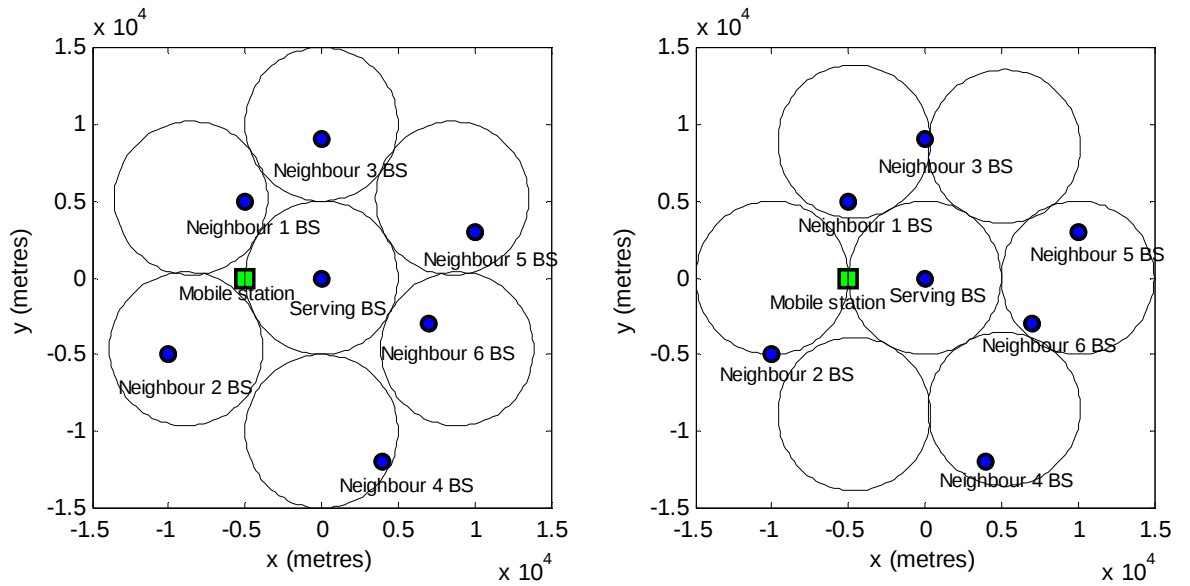


Figure D.8: Matching simulated geometry two with the model geometries

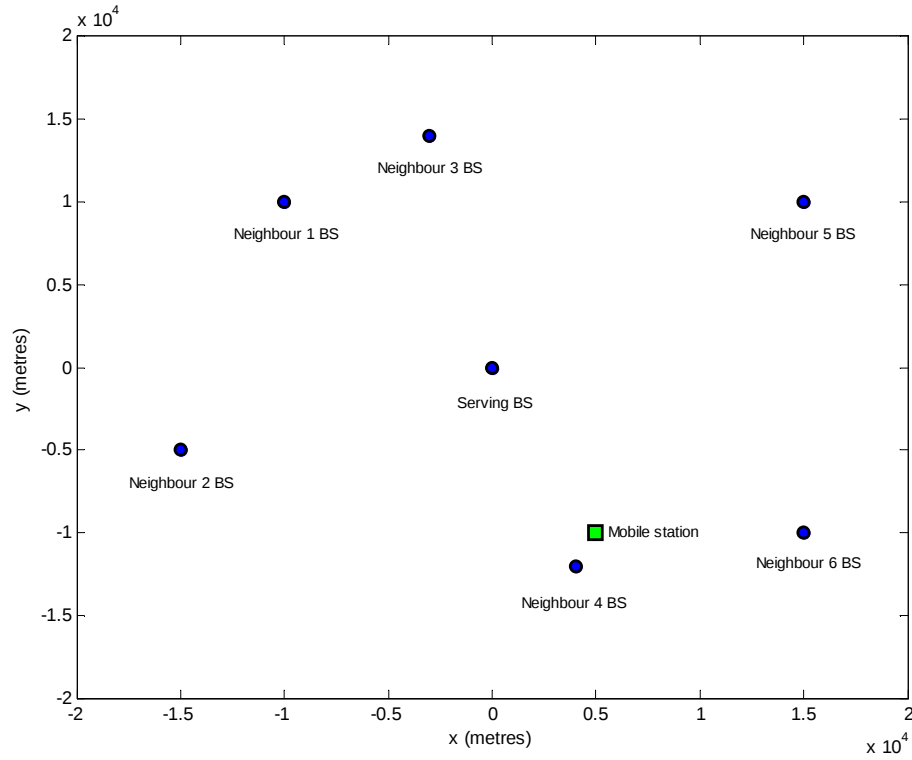


Figure D.9: Local coordinates for simulated geometry three

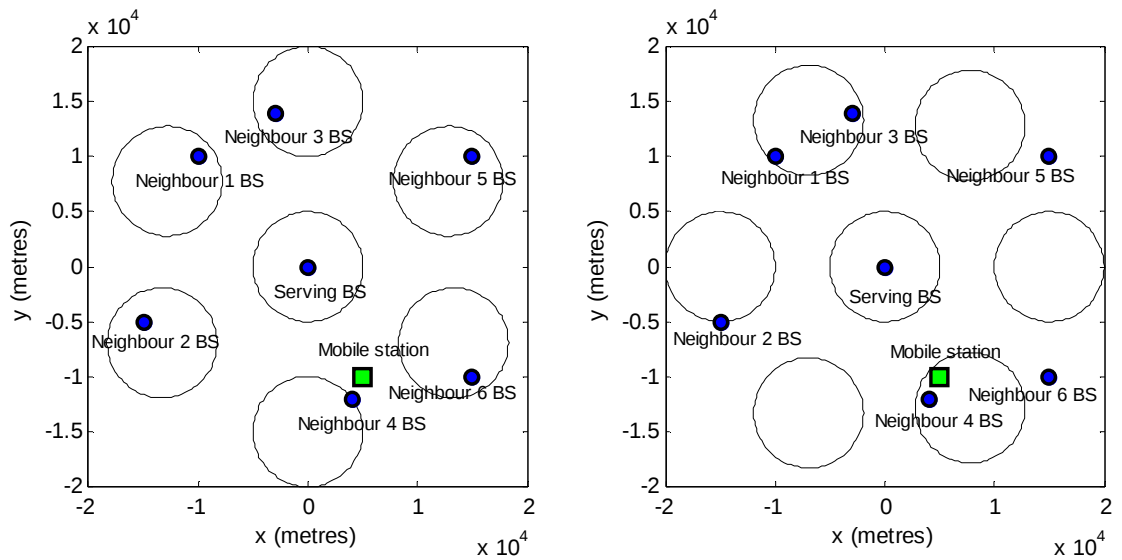


Figure D.10: Matching simulated geometry three with the model geometries

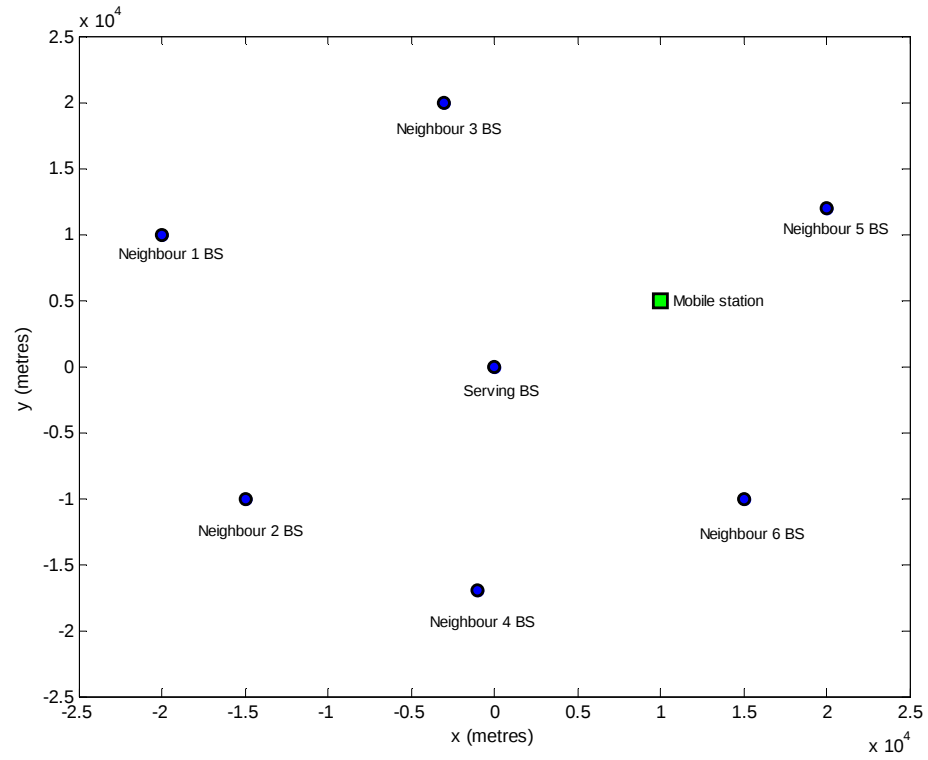


Figure D.11: Local coordinates for simulated geometry four

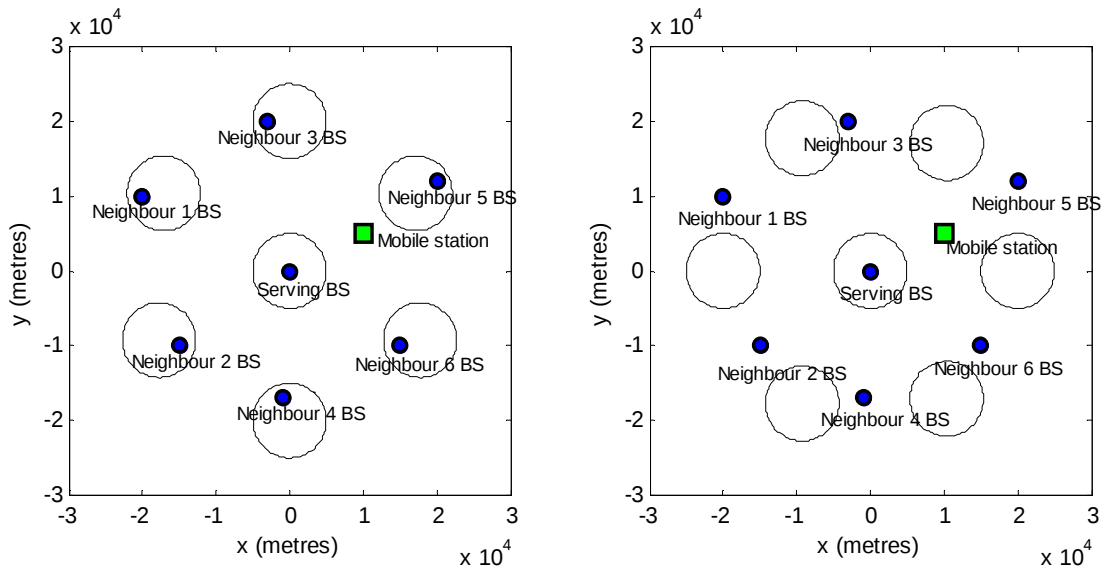


Figure D.12: Matching simulated geometry four with the model geometries

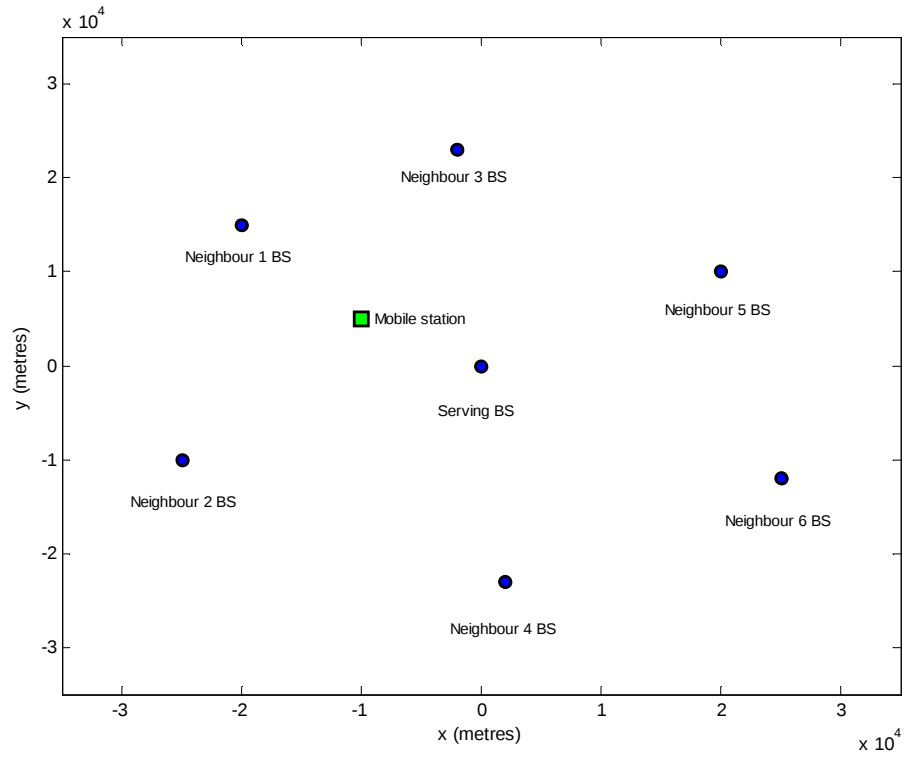


Figure D.13: Local coordinates for simulated geometry five

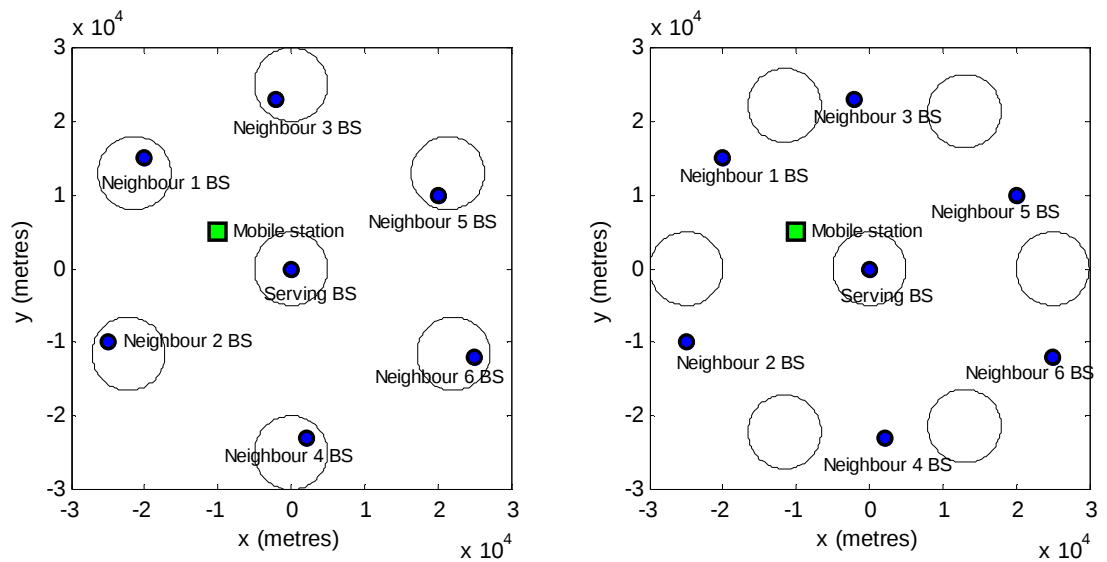


Figure D.14: Matching simulated geometry five with the model geometries

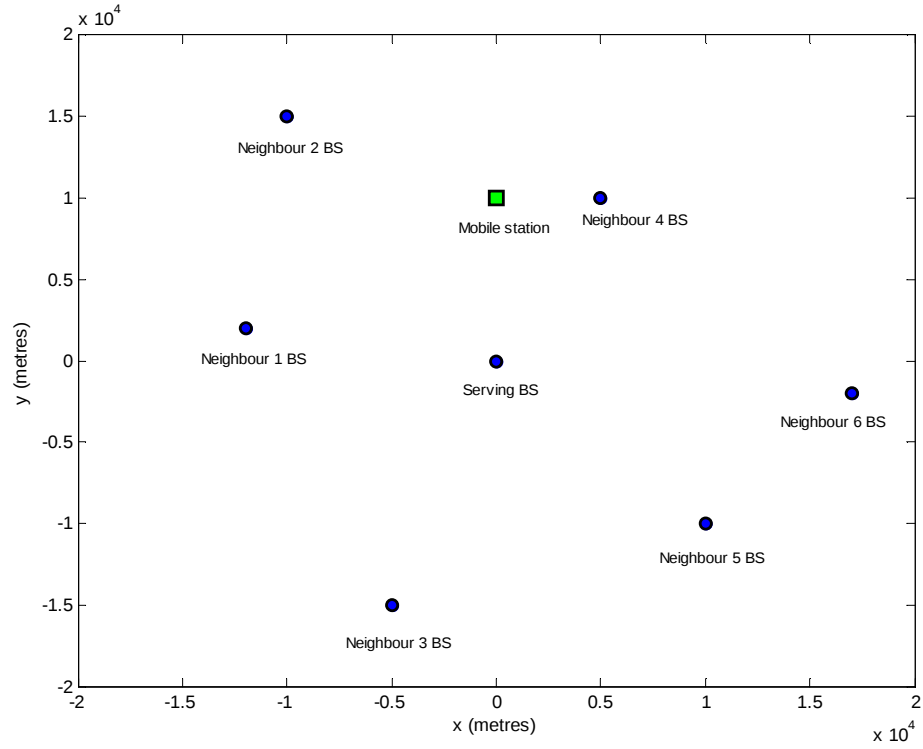


Figure D.15: Local coordinates for simulated geometry six

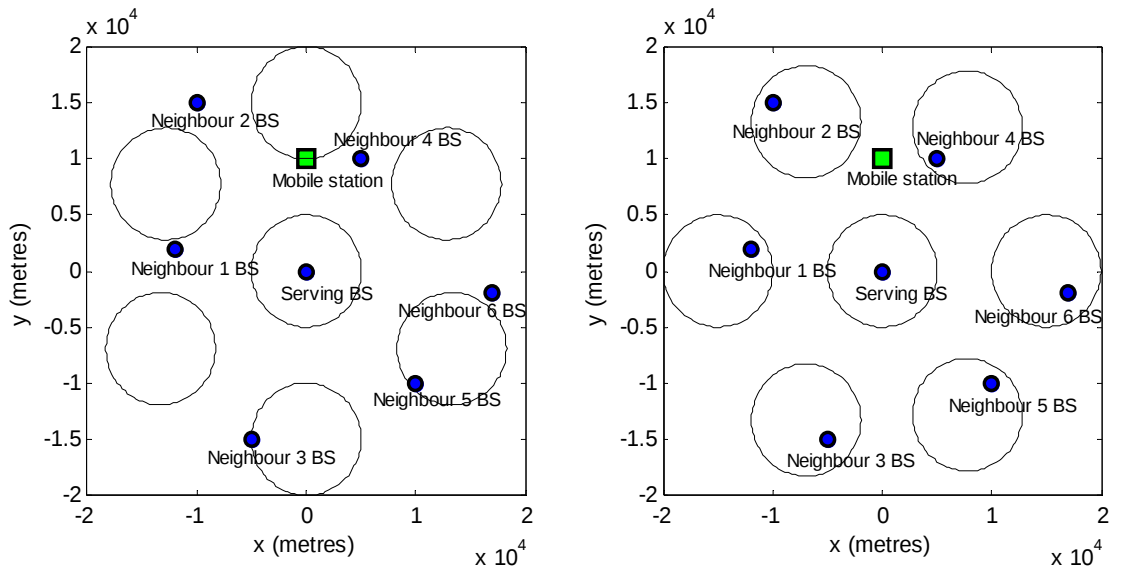


Figure D.16: Matching simulated geometry six with the model geometries

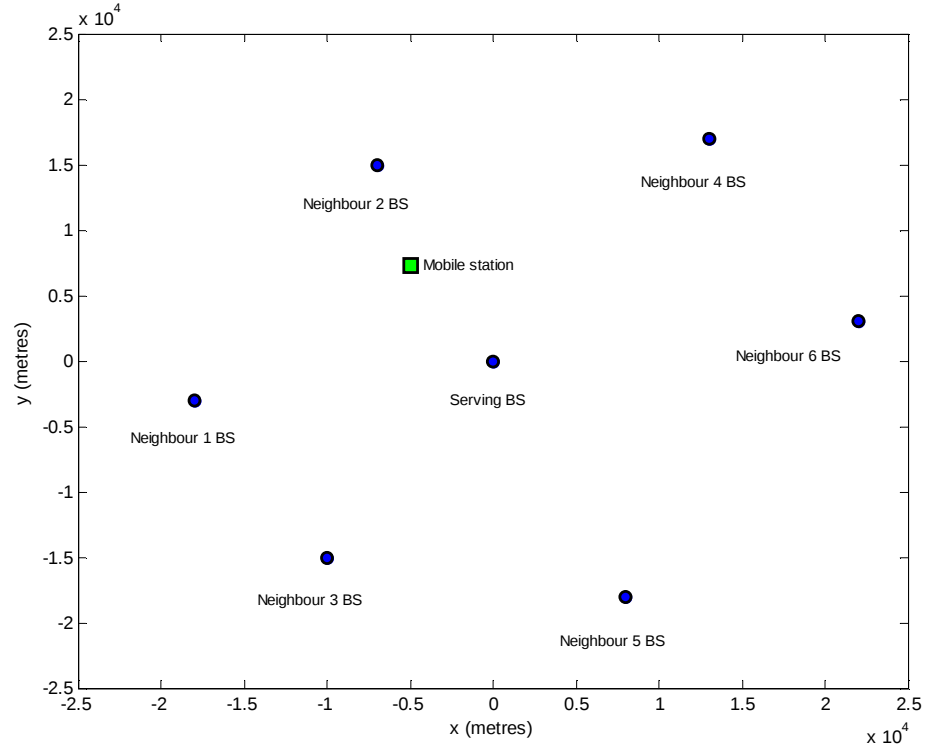


Figure D.17: Local coordinates for simulated geometry seven

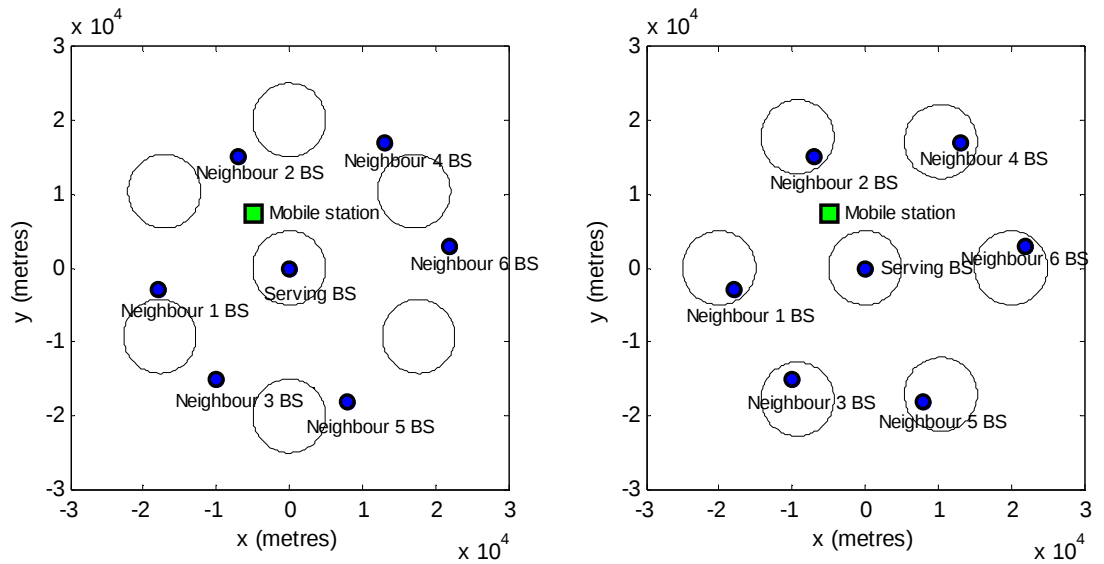


Figure D.18: Matching simulated geometry seven with the model geometries

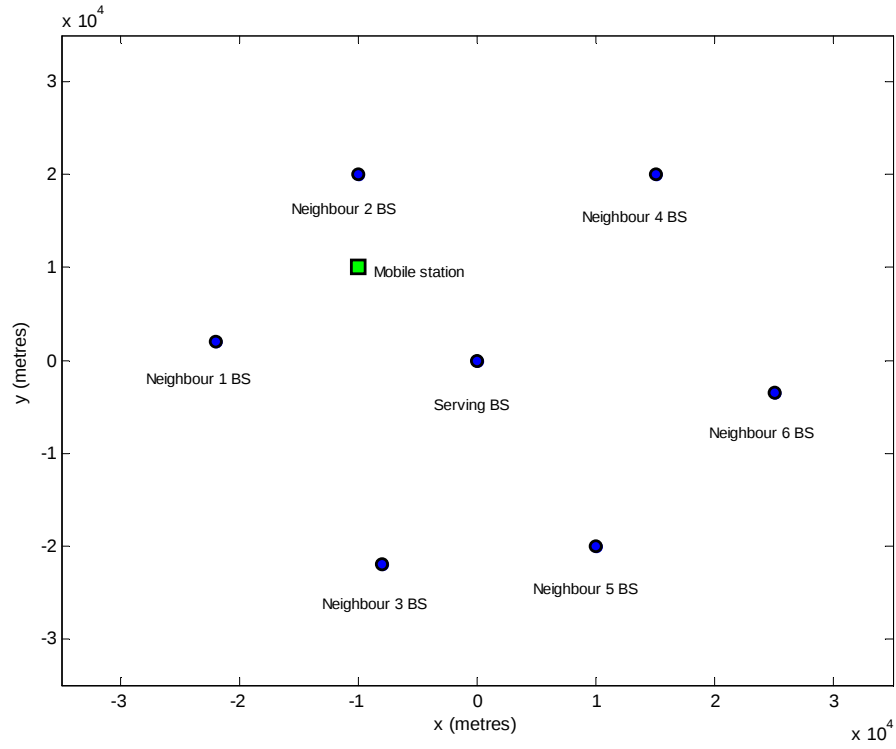


Figure D.19: Local coordinates for simulated geometry eight

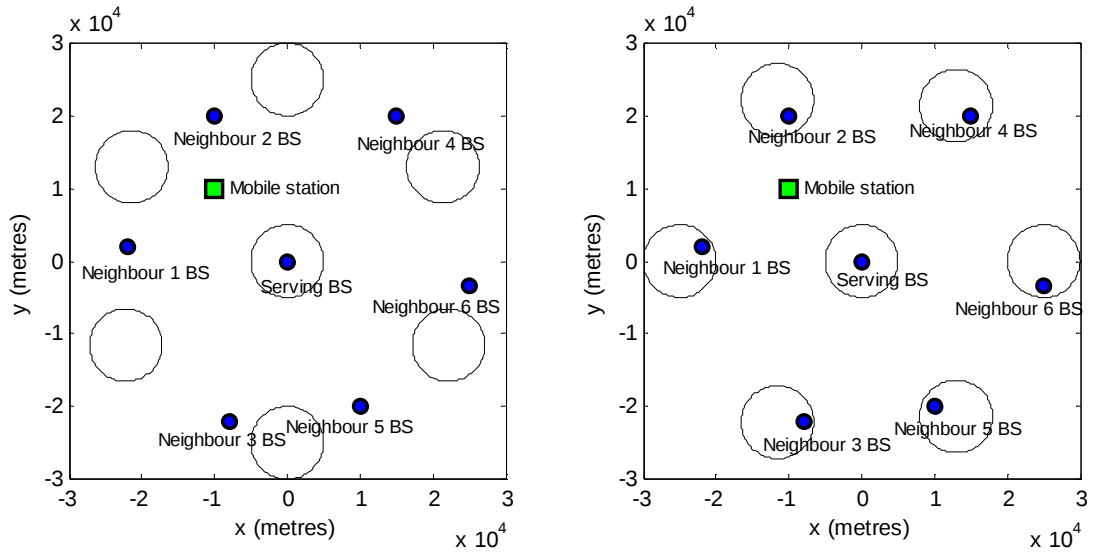


Figure D.20: Matching simulated geometry eight with the model geometries

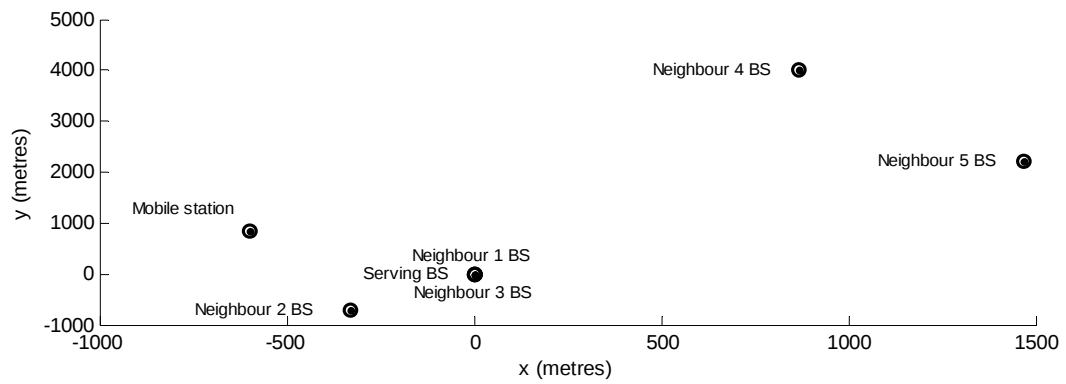
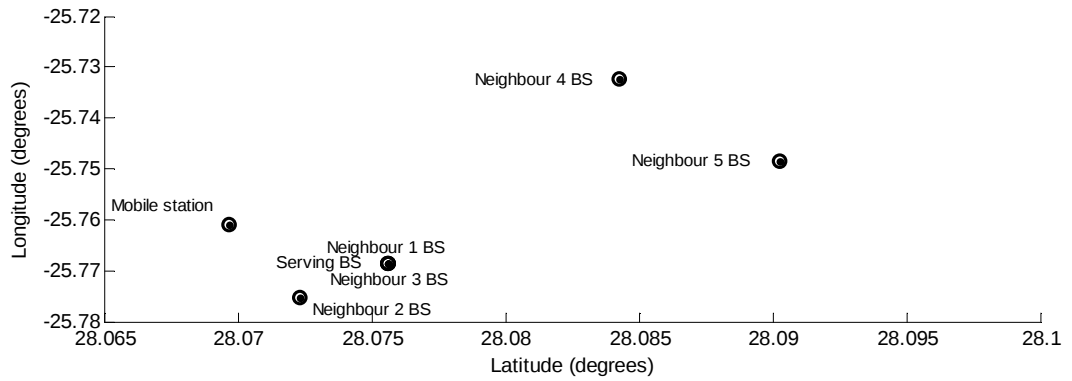


Figure D.21: Geodetic coordinate and the local coordinate for geometry one

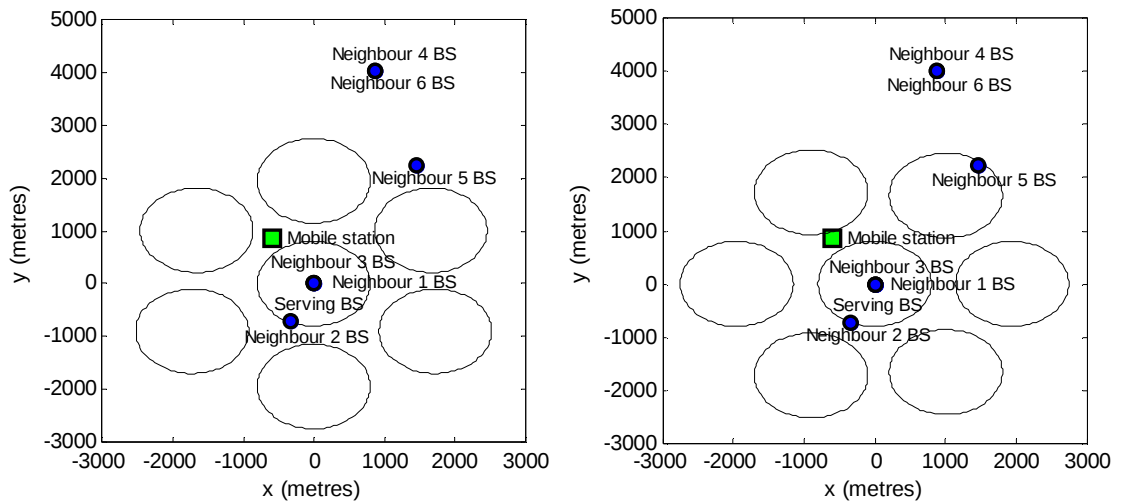


Figure D.22: Matching field data geometry one with the model geometries

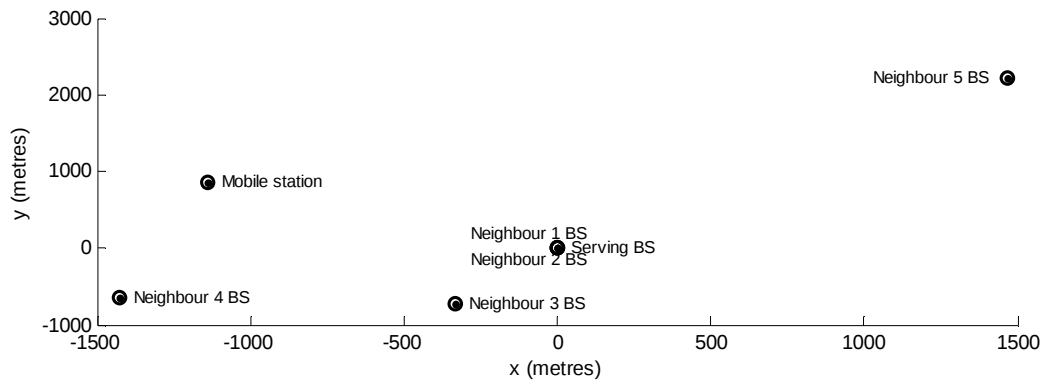
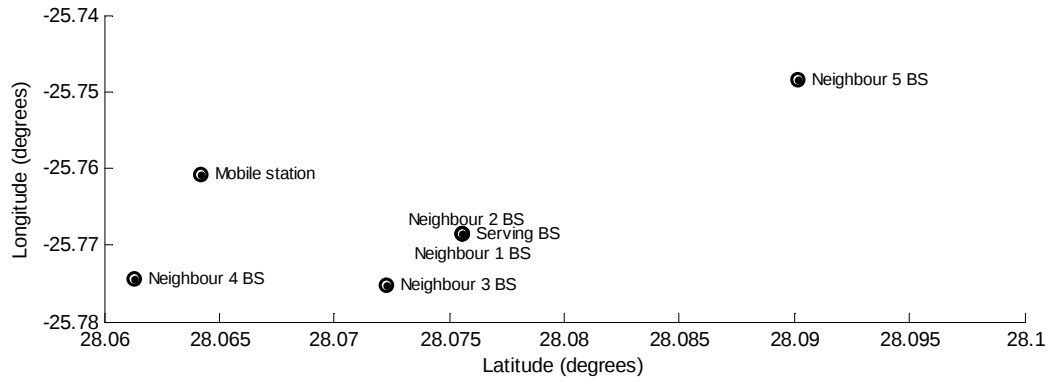


Figure D.23: Geodetic coordinate and the local coordinate for geometry two

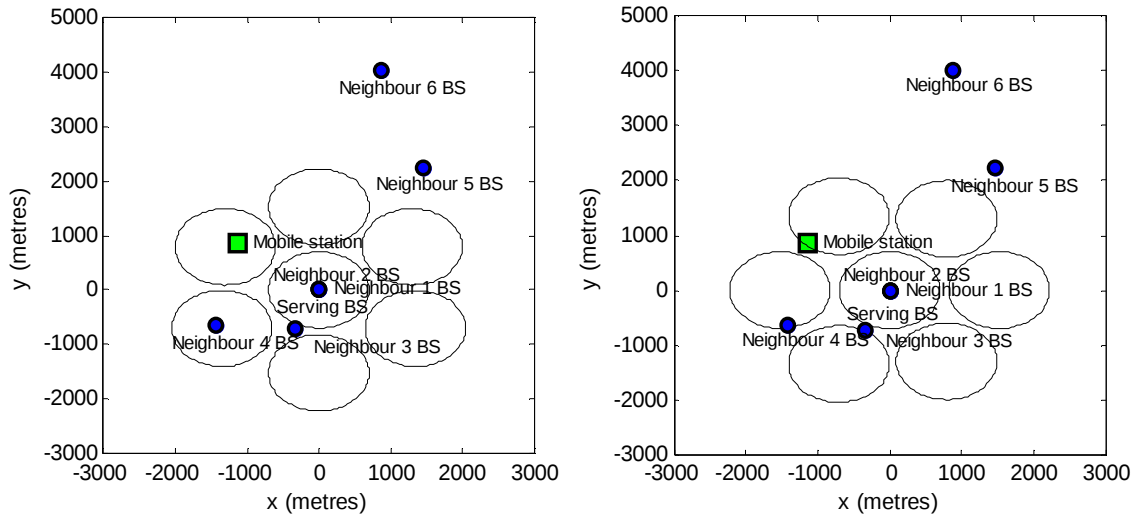


Figure D.24: Matching field data geometry two with the model geometries

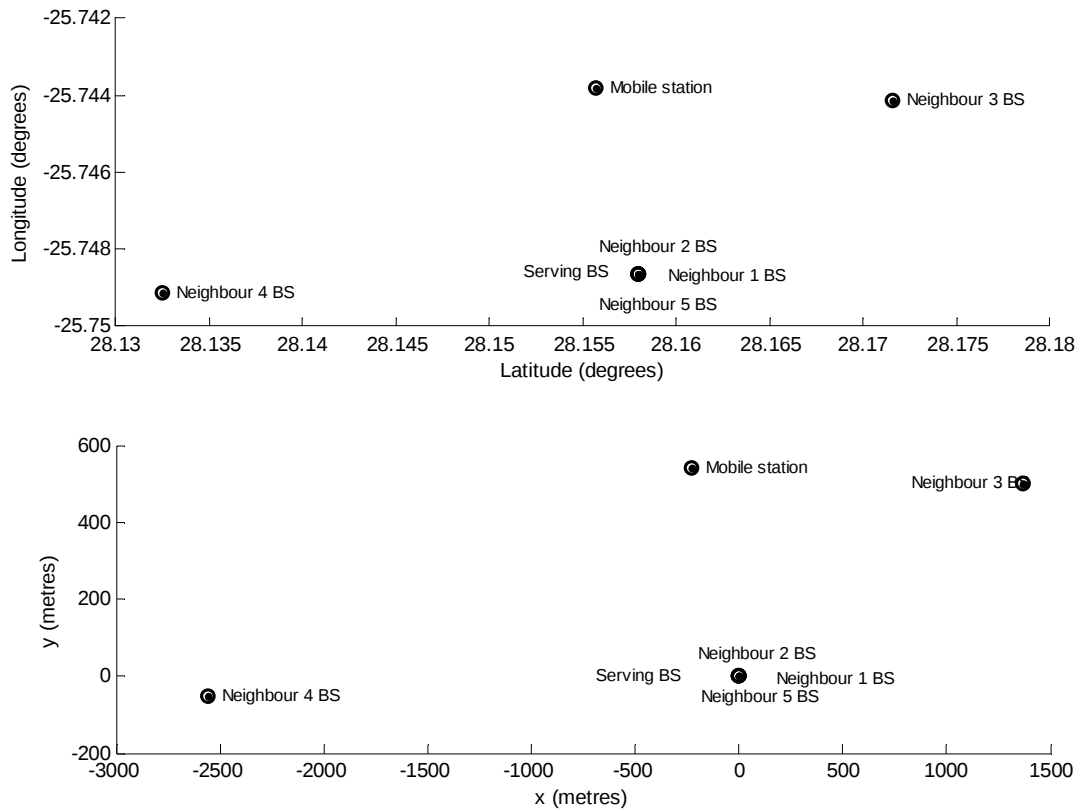


Figure D.25: Geodetic coordinate and the local coordinate for geometry three

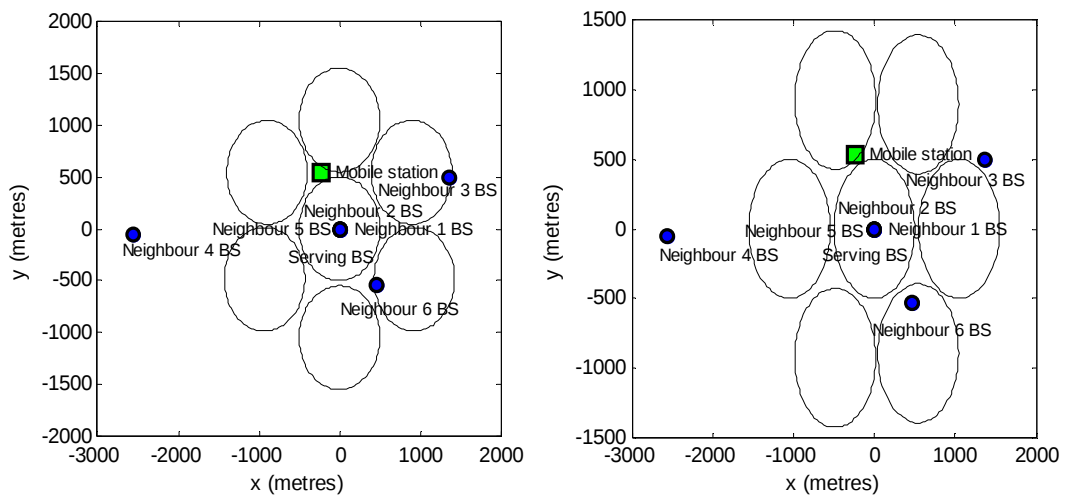


Figure D.26: Matching field data geometry three with the model geometries

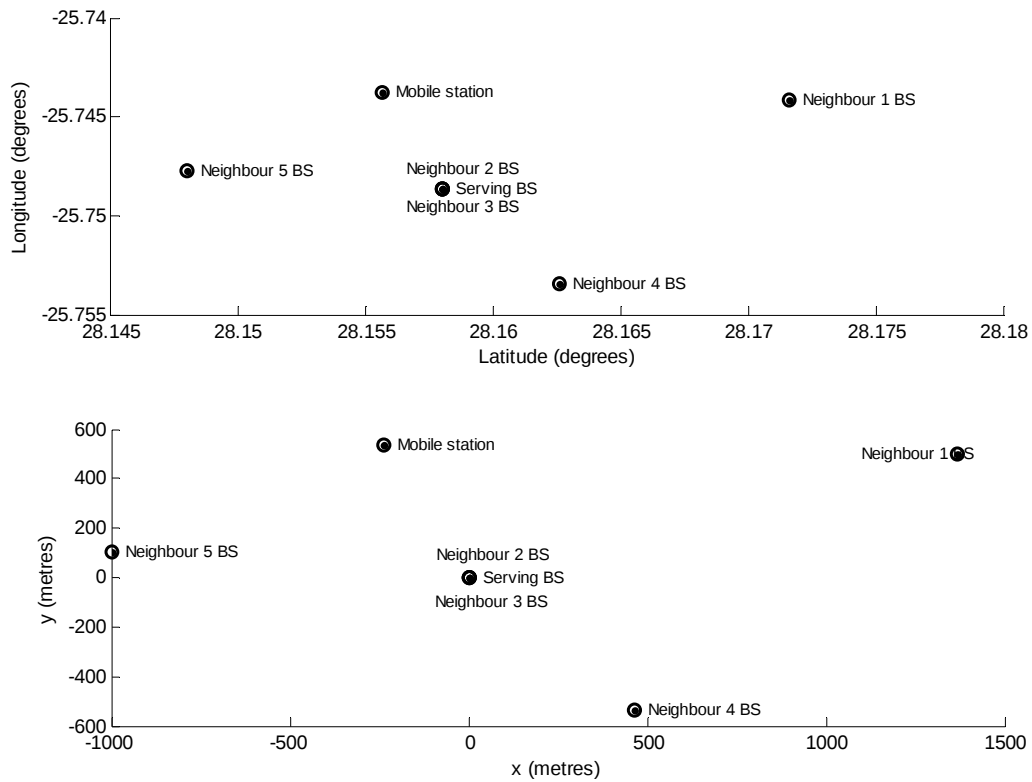


Figure D.27: Geodetic coordinate and the local coordinate for geometry four

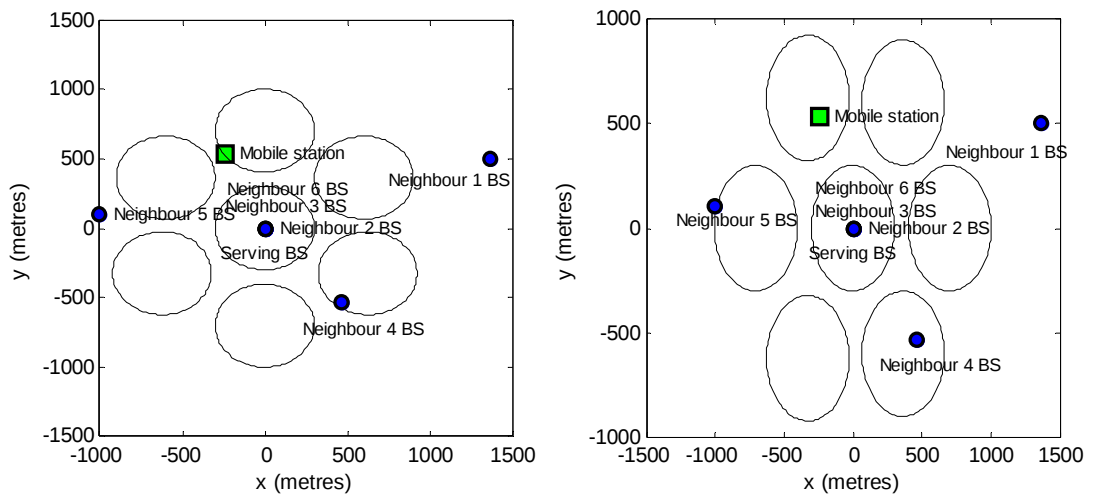


Figure D.28: Matching field data geometry four with the model geometries

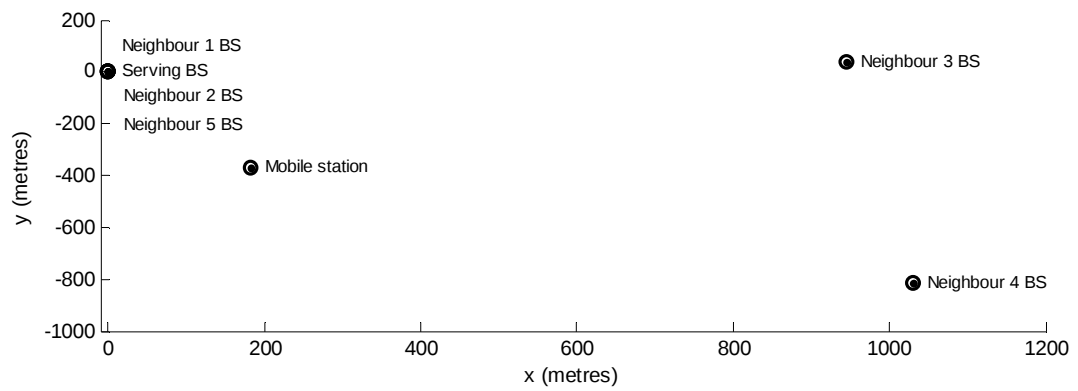
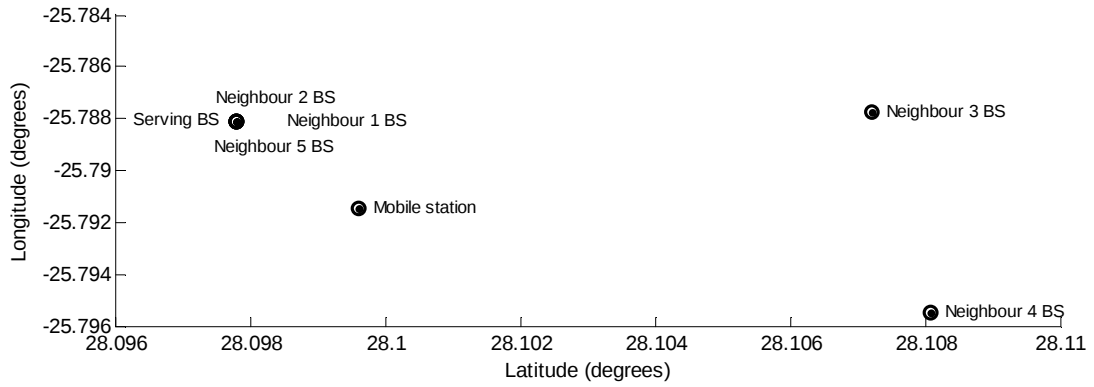


Figure D.29: Geodetic coordinate and the local coordinate for geometry five

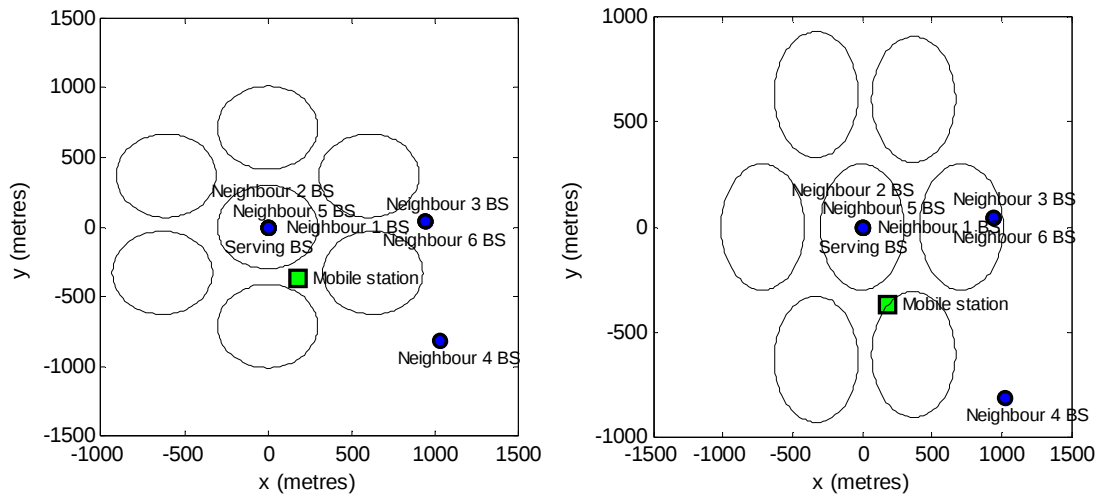


Figure D.30: Matching field data geometry five with the model geometries

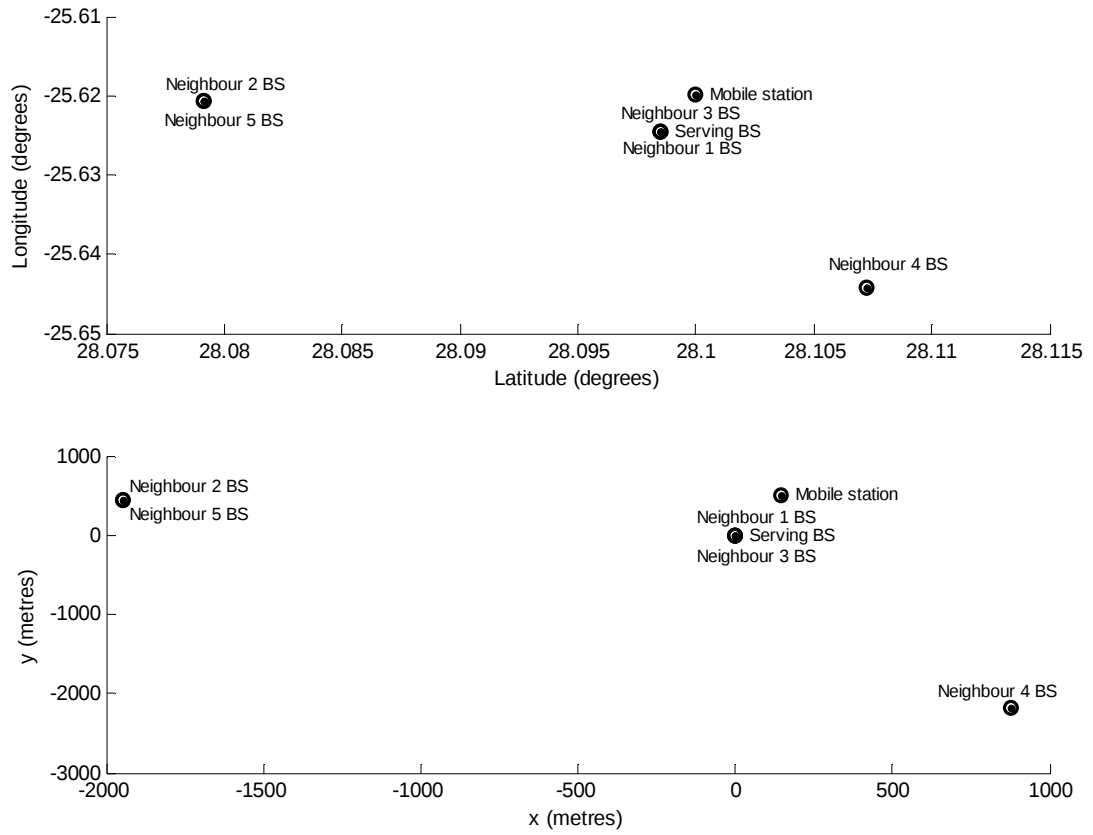


Figure D.31: Geodetic coordinate and the local coordinate for geometry six

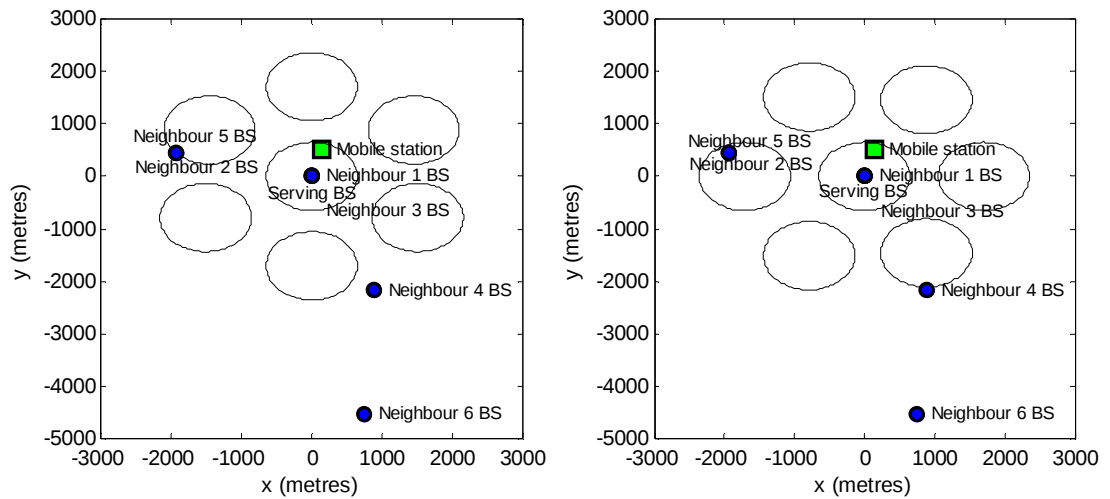


Figure D.32: Matching field data geometry six with the model geometries

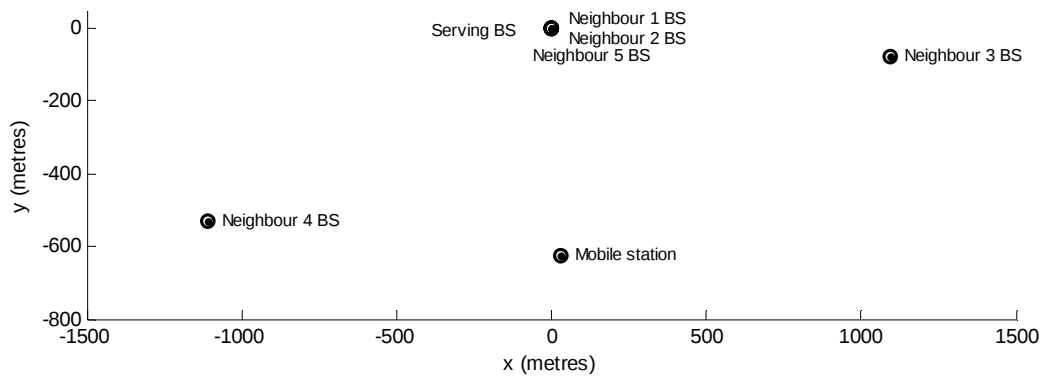
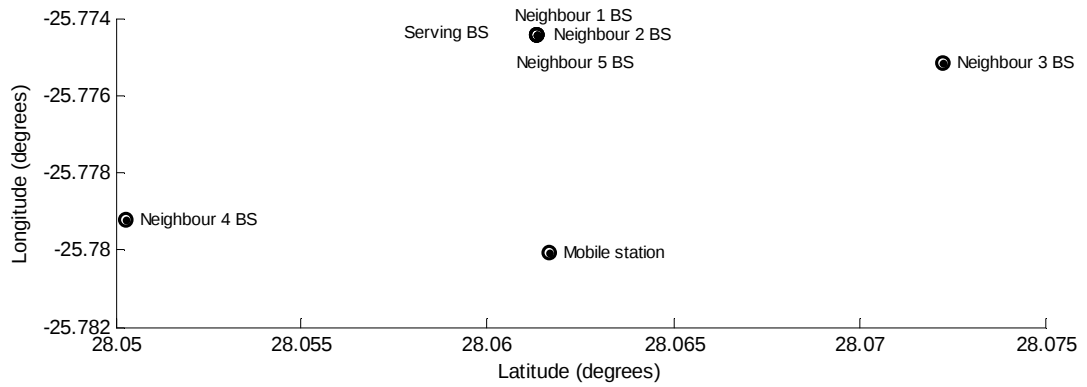


Figure D.33: Geodetic coordinate and the local coordinate for geometry seven

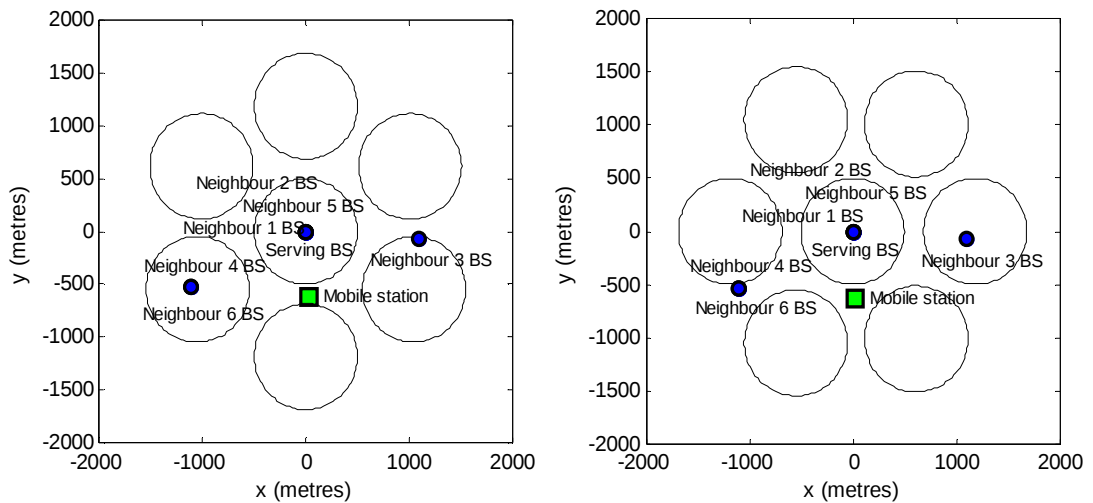


Figure D.34: Matching field data geometry seven with the model geometries

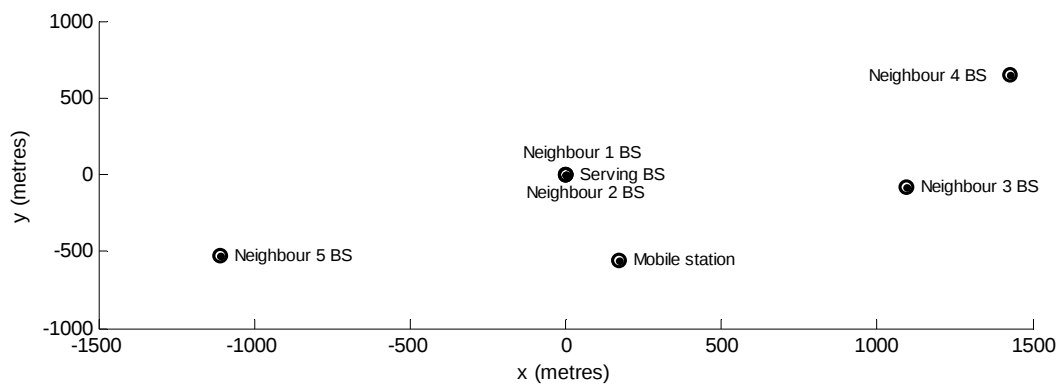
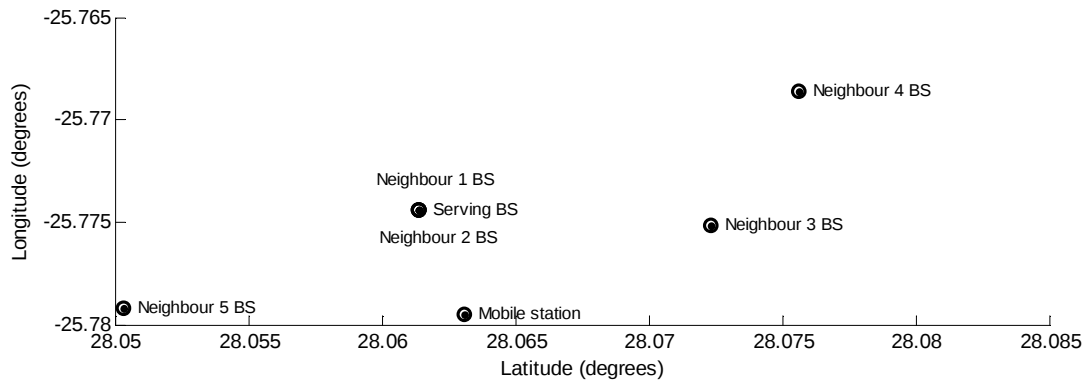


Figure D.35: Geodetic coordinate and the local coordinate for geometry eight

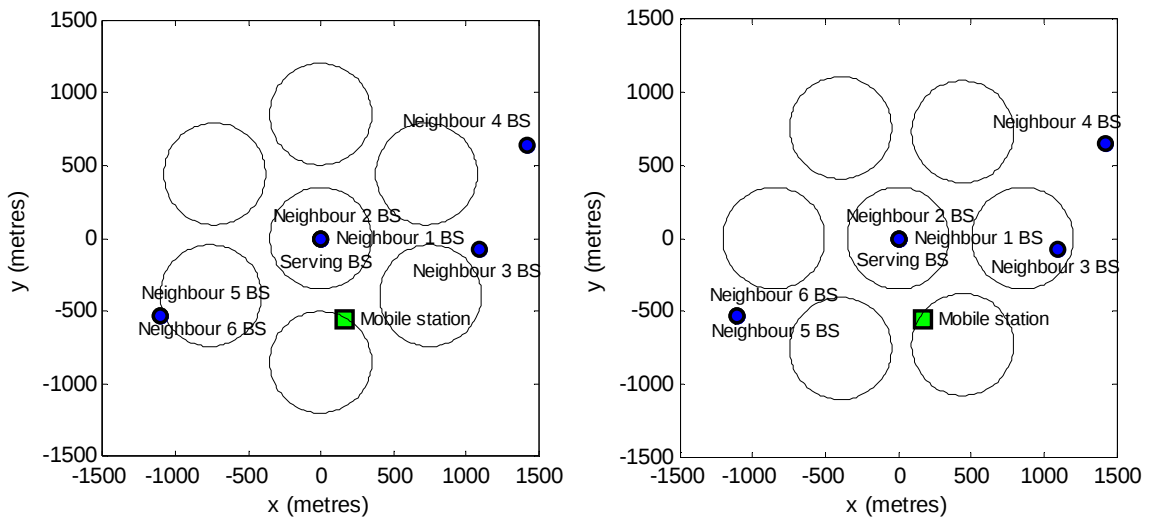


Figure D.36: Matching field data geometry eight with the model geometries