UNIVERSITY of RWANDA

Research Thesis Title:

Assessment of handover delay in mobile communication

(Case study: small to medium cities)

By

INGABIRE Clementine

A dissertation submitted in partial fulfilment of the requirements for the degree of Masters in MOC

Supervised by: Ass.Prof.MUSABE Richard

Done at Kigali, 1st August, 2024

DECLARATION

I declare that this dissertation entitled "**Assessment of Handover Delay in Mobile Communication**" is the result of my own work and has not been submitted for any other degree at the University of Rwanda or any other institution.

Signature: ……………………………………….

INGABIRE Clemantine

Date: ………………………………………

APPROVAL

This dissertation entitled "**Assessment of handover delay in mobile communication**" written and submitted by INGABIRE Clemantine in partial fulfilment of the requirements for the degree of Master of MOC; is hereby accepted and approved.

Signature…………………

Date……………………….

DEDICATION

I dedicate this work to my Family, colleagues, husband and supervisor. To my husband, **TURIKUMWE Jean Maurice**, thank you for your unending patience, love and encouragement. Your belief in me has been a cornerstone of my success, and I am deeply grateful for your support throughout this journey.

I also dedicate this work to my supervisors, whose guidance and wisdom have been instrument in shaping my academic journey. Your dedication to teaching and research has been truly inspiring and has significantly contributed to the completion of this thesis.

Finally, to all those who believe in me and supported me in any way throughout this journey, this work is a testament to your kindness and encouragement.

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ABSTRACT

Handover management plays a crucial role nowadays in wireless telecommunication networks. Mobile Equipment (ME) keep moving from one point of attachment to another point of attachment within a homogeneous handover, this process may cause call drops, link failure and signal loss. MATLAB is used to analyse the signal strength across small to medium cities using the path-loss model. The comparison among signal strength data in different places with the consideration of base station Height as a variable is performed. The contribution of the research is to demonstrate the most useful mechanism that should be implemented in small and medium cities that are being developed to reduce delays in handover across different distances. In this research, the expected result from MATLAB simulation is to show how the handover is performed with the signal strength variation by the path loss and base station height.

***Keywords*:** MOC, Path loss model, Handover, MATLAB

LIST OF ACRONYMS

MOC: Masters of operation Communication

1G: First generation

2G: Second generation

3G: Third generation

EM: Electromagnetic

LTE: Long-term evolution

WiMAX: Worldwide Interoperability for Microwave Access

hte: Height of Transmitter

hre: Height of receiver

QoS: Quality of Service

3GPP: 3rd Generation Partnership Project

IEEE: Institute of Electrical and Electronics Engineers

ME: Mobile Equipment

dBm: decibel milliwatts

MTN: Mobile Telephone Network

UE: User Equipment

BS: Base Station

GSM: Global System for Mobile Communication

LBA: Load balancing

DHA: Dynamic Hysteresis Adjusting

RLS: Recursive Least Squared

TCP: Transmission Control Protocol

SVR: Support Vector Regression

DDRL: Double deep reinforcement learning

PSO: Particle Swarm Optimization

RLC: Random Linear Codes

IIH: Intelligent Intersystem Handover

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CHAPTER 1: GENERAL INTRODUCTION

1.1.Introduction

Handoff (or handover) management enables the network to maintain a user's connection as the mobile terminal continues to move and change its access point to the network. In ordinary wireline networks, such as the telephone network, there is a fixed relation between a terminal and its location. Changing the location of a terminal generally involves network administration and it cannot easily be performed by the user [1].

Wireless technology has whitened potential capabilities for many research and innovation projects in recent years. Wireless devices are increasing exponentially while making use of a large amount of data communication with improved quality of service[1]. These devices communicate data using the cellular network. A cellular network also known as a mobile network is a wireless network distributed over land areas. These areas are called cells, and each cell gets a communication signal from at least one base station. These transceiver base stations are fixed in cell site locations and they can send and receive radio frequency waves/signals. A cellular network is wireless communication technology to send and receive information using electromagnetic waves (EM waves), and the progression or evolution of these transmission cellular technology over the years is known as generation (G)[2]. Countries like South Korea, and China are running 5G networks which is the current cellular network[3]. The first generation (1G) was introduced in the 1980s as the root, 2G in the 1990s, 3G in the 2000s, and 4G in 2010. There have been 10 years between two consecutive generations and in 2030 there could be 6G[4].

With the high demands for new data and real-time services in the wireless network; mobility users must always stay connected to the best available access network without signal interruption so there is a guarantee of the quality of services on users through their devices, applications running on their devices, platforms operating on a different network in existence[5]. In a cellular network, users stay connected with the so-called handoff process. Handoff switches users from one base station to another by maintaining an active user connection and it can occur if there is a decrease in the communication signal[6].

Handover is a major challenge in presence of the small cells paradigm involving barriers that cellular users are facing while using cell phones over the network[1]. In the case of high-speed movement, the handoff is the source of multiple unexpected interruptions of connection. Handoff occurs with the presence of obstacles that may be human (pedestrian), moving objects like vehicles, rotations from hand movement or the user, and finally fixed objects like buildings.[7].

1.2.Background and Motivation

The mobility of cellular network users is an important priority of the novel cellular communication technologies (3G, 4G, and 5G and further), and there is a huge need for many different customer services with better user satisfaction in the quality of services. This need requires wireless communication technologies to have higher transmission speeds with lossless transmission signals, low latency, mass connectivity, efficiency, and reliability. A lot of effort must be done for the continuous development of the used technologies with improved features to build new generations of cellular networks. The key to advancement in these technologies is to make a proper and effective handover mechanism that will result in an excellent cellular architecture that maximizes spectrum utilization. The 4G networks such as LTE and WiMAX are improved networks of 3G networks to increase the bandwidth into a high rate of data transmission.

Handover techniques are developed to work with different standards (i.e. IEEE 802.16m, 3GPP, etc.) but the 4G technology is facing a problem of meeting these different criteria and level of quality of services (QoS) arising from the requirements for cost, power consumption, latency, security, and speed of the mobile handsets[6].

1.3.Problem Statement

In small cities of Rwanda, where rugged mountainous terrain and dispersed telecommunication infrastructure, persistent delays in handover within telecommunications networks have led to significant degradation in the quality of service experienced by users as observed from the data gathered in small and medium cities that are being developed. These delays, intensified by geographical challenges and limited network coverage, manifest as dropped calls, intermittent data connections, and compromised voice quality for users. The unique topography of the region further complicates the establishment of robust telecommunication infrastructure, resulting in unequal access to reliable service for small city communities. Consequently, these delays result in dropped calls, intermittent data connectivity, and overall dissatisfaction among small city residents and businesses relying on telecommunication services. For instance, when moving in suburbs, the signal strength ranges from -83dBm to -110dBm.

1.4. Study Objectives

1.4.1 General Objective

The main objective of this research is to assess the handover delays in mobile communication within small cities and medium areas where dispersed telecommunication infrastructures cause poor reception of mobile signals. As 4G networks are being implemented, the signal strength parameter is taken into consideration due to its impact on the quality of service needed by the users.

1.4.2 Specific Objectives

The research achieved 3 specific objectives as follows:

- To Assess handoff methods used to reduce delays in mobile communication.
- To measure the signal strength of mobile signals across different areas in both small and medium city areas.
- To compare signal strength measured in different places using different base station heights and come up with the most useful model to be applied in small and medium cities

1.5 HYPOTHESES

Cellular communication has been in Rwanda at the beginning of 1989 with MTN-Rwanda, in 2009 with TIGO-Rwanda, and in 2012 Airtel-Rwanda. MTN-Rwanda and Airtel-Rwanda are the only companies operating cellular networks since TIGO-Rwanda has stopped working and handed over its clients to Airtel-Rwanda. The two companies are offering 2G, 3G, and 4G at the current moment. Although technologies are changing from their services in 2G – 4G, there was no official research about the handoff in the offered generation network services in Rural areas of Rwanda. Many clients are given 3G and 4G services but handoff from 4G services will be investigated as it is the best service offered by the two telecommunication companies.

1.6 STUDY SCOPE

The research has analyzed all handoffs happening in the 4G network as it is being implemented countrywide but it will select random base stations (BS) coverage areas and User Equipment (UE) and the results will be enough to generalize the handoff scenario cases. Night user connections will be excluded as there could not be a lot of handoffs compared to daytime. The analysis of handoff in small to medium cities will be enough samples to make conclusions about the reduction of handover delays in radio frequency propagation

1.7 SIGNIFICANCE OF THE STUDY

The successful implementation of the research has been assisted by finding challenges of existing methods of handoff and the improvement of these methods for providing better quality 4G network services that result in better customer satisfaction with 4G network access. A short delay in switching base stations that may cause the loss of network signal connection or offer poor signal strength will be reduced and this will guarantee a better performance of 4G services to intended users.

1.8 ORGANIZATION OF THE STUDY

The entire thesis has six chapters. The general introduction is covered in Chapter 1, the literature review in Chapter 2, and followed by research methodology in Chapter 3. Chapter 4 has the research analysis and design, chapter 5 presents the results of the analysis, and finally chapter 6 with the conclusion and recommendation.

1.9 CONCLUSION CHAPTER

This section provides enough introduction to the cellular communication network. It also shows why the mobility of users is an important priority for the wireless network while emphasizing the strong component of the topic which is a handoff in the 4G network. The study problem, objectives, scope, and significance were also discussed in detail and they are sufficient to recall the literature related to the topic of the ongoing research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This section discusses the understanding of the 4G handoff-related terms and the 4G handoff models that have been used. This part also shows various reasons for handoff in the 4G networks.

Handoff management is the process by which a mobile device holds its connection active when it shifts from one access point to the next access point, and one mobile device may undergo several access points without disconnection while performing two types of handoff [9]. In the horizontal handoff, the mobile device moves between two adjacent access points of the same network while in vertical handoff the mobile node is moving between two access points of different networks. Hard handoff or soft handoff are two main implementations of handoff where the hard handoff sets a new connection to the access point after it is released by the old serving access point, whereas the soft handover sets new and old connections with both access points in parallel [6].

The study of ROSLI SALLEH and XICHUN LI [11] proposed 4G network handoff by using an architecture of algorithm which is based on the status of the radio link (i.e. uplink traffic service and downlink traffic service).

The study of Ekaterina Otsetova-Dudin [6] shows that 4G technologies are based on adaptive and intelligent vertical transmission handoff approaches. The challenge for the handoff is related to heterogeneous network access (satellite, WLAN, WiMAX, GSM) and delay tolerance levels in some applications of live video streaming which needs high bandwidth. The use of load-balancing (LBA) and Dynamic Hysteresis Adjusting (DHA) methods were applied to achieve an excellent user-quality service experience for smooth and real-time video transmission. The hard handover was only applied to low-speed mobility users whereas soft handoff is responsible for higher-speed mobility users.

The networking community is challenged by inaccurate real-time bandwidth prediction and this becomes more dangerous for live video streaming; under-estimate will lead to unnecessarily low video quality and over-estimate will lead to video freeze. A proper adjustment algorithm must be done to estimate video rate adaption in live streaming applications (i.e. video /conferencing streaming) [12][13][14][15]. The study of Lee et al.[16]

has also proposed the Recursive Least Squared (RLS) and an adaptive filter to make real-time bandwidth predictions for the cellular network.

The study of He et al. [17] proposed a simple history-based TCP throughput prediction algorithm. The study of Jiang et al.[14] , and Mutanen et al.[18] made a Harmonic Mean of TCP throughput for downloading the previous chunks as the TCP downloading throughput prediction for the next chunk. Also, the study of Mirza et al. [19] and Smola et al.[20] have proposed a Support Vector Regression (SVR) model to predict TCP throughput. Another customized SVR predictive model was also proposed to guide the real-time chunk rate selection for DASH video streaming and video conferencing [12][21].

In [30] it is stated that horizontal handover is referred to as a conventional call transfer in the same technology of the connection layer, it is indicated also that horizontal handover is triggered when a mobile subscriber moves within homogeneous network technology under the same mobile operator. For example, a mobile user roaming within the coverage of their provider's network will have to switch in-between cellular towers as they travel within and outside of the range of different towers [30].

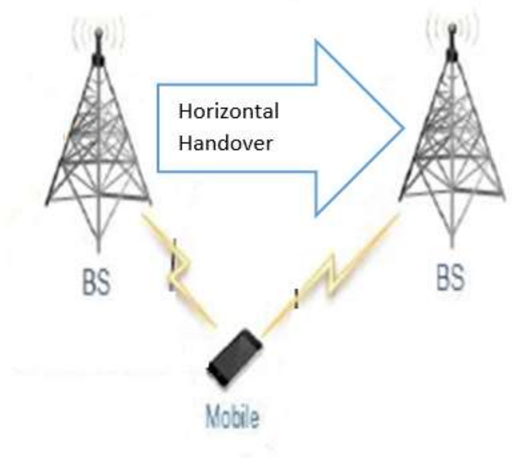

Figure 1: Horizontal handover [28]

The study of Jaydip Sen [27] indicated the three stages in the handover process. The first is when a mobile device, a network agent, or the changing network conditions trigger handoff initiation. The second stage is for a new connection generation, where the network must find new resources for the handover connection and perform any additional routing operations. lastly, data-flow control needs to maintain the delivery of the data from the old connection path to the new connection path according to the agreed-upon QoS guarantees. Depending on the movement of the mobile device, it may undergo various types of handovers In general, handovers/offs are classified into two types: Intra-system handover (horizontal handover) and Inter-system handover (Vertical handoff)

The study by Duan, B., Li, C., Xie, J., Wu, W. and Zhou, D [32] indicated that to reduce the delay of the handover of wireless communications, several different approaches have been explored. A simple but effective algorithm of distributed load balancing is presented to reduce the service interruption ratio due to frequent handovers at high speed.

2.2. The Reviewed Papers

S/N	**Author**	**topic**	**Handover statement**	**Country**	**Challenges**
1	I.H.Usman E.E. Omizegba & L. Maijama'a, 2020	Review of handover Decision Algorithms in wireless communication	Handover decisions are taken based on combined system metrics, throughput, spectral efficiencies, low outage probability and seamless connection	Nigerian	No research conducted that shows if the signal strength become weak without reaching the handover zone along long distance
2	Mollel, M.S., Abubakar, A.I., Ozturk, M., Kaijage, S., Kisangiri, M., Zoha, A., Imran, M.A. and Abbasi, Q.H., 2020.	Intelligent handover decision scheme using double deep reinforcement learning.	double deep reinforcement learning (DDRL) basically in an urban environment	Tanzania	This algorithm is more useful for urban areas only where many mm waves are detected in which the mobile equipment is required to select the optimum base attained by considering both the number of handovers and system throughput. The gap

					is that if the mobile user is out of availability of many mm waves and the signal becomes weak there is no alternative proposed.
3	Imoize, A.L., Udeji, F., Isabona, J. and Lee, C.C., 2023.	Optimizing the Quality of service of Mobile Broadband Networks for a dense Urban Environment	Minimal optimization techniques using Particle Swarm Optimization (PSO)	Nigeria, Lagos	4G LTE was studied and how to optimize the QoS considering three locations in Lagos, however not considered out of the city.
4	Al-Khalidi, M., Al-Zaidi, R., Thomas, N. and Reed, M.J., 2023.	Intelligent Seamless handover in Next Generations networks	Random linear codes (RLC) are used to achieve seamless handover, best in high mobility environments. the delay is reduced up to 26%, handover failure to less than 2% of total handovers	Sub Saharan	The study shows a great delay reduction in handover in most high mobility not in small city areas where the signal may be even weak as compared to the one in the considered area.
5	Mathonsi, T.E., Kogeda, O.P. and Olwal, T.O., 2023.	Intelligent intersystem handover delay reduction algorithm for heterogeneous wireless networks	They proposed the use of an intelligent intersystem handover (IIH) algorithm, an average of handover delay 1.9s	Sub-Saharan countries	The delay reduction is quite good however, they did not specify the applied area if it is in a more dense area, urban or Rural area

6	Mei, L., Gou, J., Cai, Y., Cao, H. and Liu, Y., 2022.	Realtime mobile bandwidth and handoff predictions in 4G/5G networks	They use Neural Network models, they developed deep-learning-based real-time bandwidth prediction models that generate predictions for the available bandwidth in the next few seconds based on the past bandwidth, Accuracy 80%	Sub-Saharan countries	The research was conducted based on data collected in public transportation only. No other specifications are mentioned in rural areas.

Table 1: The table Presents the findings from the reviewed papers

2.3. Gaps:

The reviewed related works proposed solutions to the problems in mobile communication by implementing new technologies, such as based on uplink traffic service and downlink traffic service, however, all of them focus on urban areas none of the works focused on the small and medium cities, especially in the mountain areas as it is found in Rwanda country. The considered research is also on heterogeneous handover by focusing on developed countries, using developed technology, however for the developing country where Rwanda is located, no known research has yet been conducted, and there is a gap. Handover management in small and medium areas is still a challenge. Hence, there is almost no data found on handover management in Rwanda.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

This chapter explains how the research was conducted to achieve the objectives set. To achieve set objectives mainly quantitative research methodology was used. Hence, the chapter is divided into: the research approach, data collection through field visits survey and Paper review, Analysis of data and Simulation of the proposed method.

3.2. Research Approach

The first step of the research was to investigate the problem to be solved. To perform the investigation, the quantitative method was used where the field survey approach was conducted to gather primary data from small city areas and near urban areas. In the field survey conducted, signal strength measurements were taken using an application called Network Signal Info stored in a mobile phone (sum sang Galaxy A21sF088) in the coverage of MTN Rwanda. A convenience random sampling technique was employed to select 3 different places. The Mobile phone was used to investigate handover behaviour and signal strength while moving in the selected area in time T, ensuring comprehensive coverage of the research objectives.

3.3. Data Collection

The data collection phase of this research employs a random selection approach to ensure the representativeness and generalizability of the findings. Given the vastness of the population, comprising a wide area of coverage, a systematic random sampling technique is utilized to select a manageable statistically representative sample which is 50 units of distance. This systematic approach ensures that each point of distance stands an equal chance of being selected, thereby minimizing selection bias and enhancing the statistical validity of the results. Additionally, it is worth noting that the selected distance is situated at the extreme periphery of coverage of two base stations and represents a small to medium city area. Furthermore, between two major telecommunication companies in Rwanda, MTN Rwanda and Airtel Rwanda, the coverage of MTN Rwanda was selected over Airtel Rwanda for its widespread accessibility and reliability within the region under study. By employing systematic random sampling and leveraging the coverage of MTN Rwanda, this research aims to strike a balance between practical feasibility and statistical rigour, facilitating robust analyses and meaningful interpretations of the research outcomes.

In this research also the data was collected from random papers written on handover management in developing countries.

3.4 . Data Analysis

In the data analysis stage of the research, collected data undergoes rigorous examination and interpretation to derive meaningful insights and draw conclusions about the research objectives. The data is represented in the figures plotted in MatLab. Hence, the observation was made by considering the calculations of the strength of the signal in comparison to the base station height while the frequency is constant at 100MHz.

CHAPTER 4: RESEARCH ANALYSIS AND DESIGN

4.1. Introduction

This chapter focuses on analyzing and designing cellular network performance using signal strength data. The study utilizes the Okumura-Hata path loss model and MATLAB calculations to analyse signal strength variations across different geographical areas. The research aims to uncover trends and patterns in signal strength data and path loss calculations to inform strategic decisions for optimizing cellular network performance.

4.2. System simulation and design

System design and simulation are based on the radio frequency transmitter structure and the consideration of path loss modeling and signal coverage.

4.2.1. RF transmitter block diagram

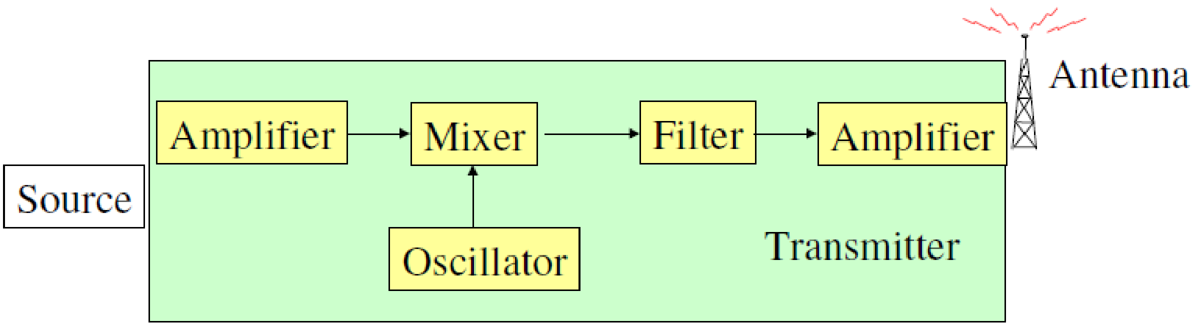

Figure 2: RF transmitter

Block Description

Refer to [42], The block components are defined as follows:

Source: This is the signal's origin that needs to be transmitted.

Amplifier: The initial amplifier increases the strength of the signal from the source.

Mixer: A mixer is a three-port device that uses a nonlinear or time-varying element to achieve frequency conversion.

Oscillator: The oscillator generates a signal at a specific frequency the mixer uses. In a general sense, an oscillator is a nonlinear circuit that converts DC power to an AC waveform.

Filter: The filter removes any unwanted frequencies from the mixed signal, allowing only the desired frequency to pass through.

Amplifier: The second amplifier is used in the final stage of transmitters to increase the radiated power level.

Antenna: An antenna is defined as a device that converts a guided electromagnetic wave on a transmission line to a plane wave propagating in free space.

4.3. Free Space propagation and Path loss Models for macro cellar areas

A path loss model is a mathematical framework used to predict an electromagnetic wave's power density (attenuation) reduction as it propagates through space. Path loss models are essential in wireless communications for designing and analysing the performance of communication systems. They help in understanding how signals degrade over distance and through various obstacles, aiding in network planning, antenna placement, and frequency selection [37]

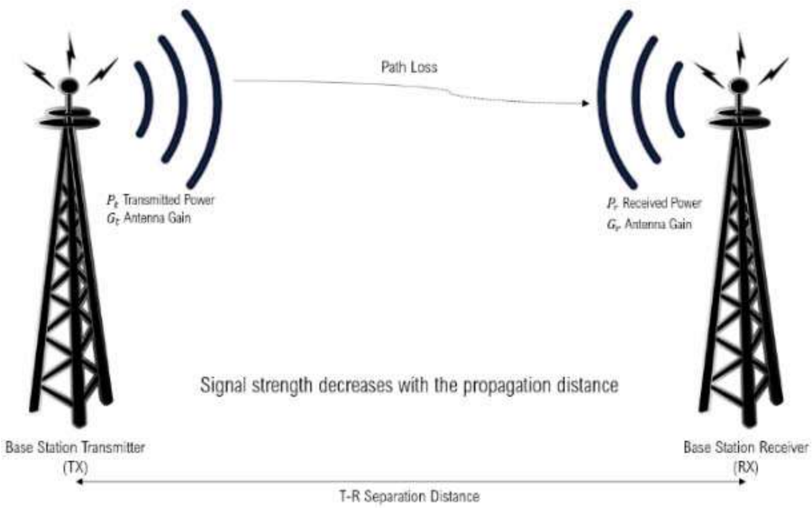

Figure 3: Path loss between transmitter and receiver [40]

Ideally, by considering a clear line of sight between the transmitter and receiver with no obstacles, the path loss increases with the square of the distance and is influenced by the frequency of the signal.

Path loss is given by:

$$PL(dB) = 40log_{10}(d) - 20log_{10}(hte) - 20log_{10}(hre)$$

Where **hte** and **hre** are the heights of the transmitter and receiver antennas respectively

The received power in free space is calculated by the equation

$$P_r(d) = \frac{P_t G_t G_r}{L_p L}$$

The received power levels can be determined in dB units as

$$P_r\,(dB) = 10logP_t + 10logG_t + 10logG_r - 10logL_p \qquad [39]$$

4.4. Okumara Hata Model

The Okumura-Hata model provides mathematical formulae that approximate the original Okumura curves. The Okumura-Hata model is a widely used planning tool for land mobile radio systems because of its simplicity. The model introduces restrictions on the acceptable frequency range from 150 to 1500 MHz. The measured distance from the transmitter site from 1 km to 20 km and the transmitter antenna heights of the values between 30 and 200 meters above the surrounding terrain.

However, this model is suitable to the design the terrestrial land mobile systems rather than cellular systems due to the limitation of travelled distance.

It may also be noted that there are only four main parameters required for the determine the path loss: frequency, height of received mobile antenna, height of base station, and the propagation distance between the base station and received antenna in Okumura-Hata model.

The standard formula for median path loss in urban areas is given by:

$$L_{PU} = 69.55 + 26.16\log(f_c) - 13.82\log(h_{te}) - \alpha(h_{re}) + (44.9 - 6.55logh_{te})\log(d)$$

Where

L_{PU}=Path loss in Urban areas

F_c= the frequency in (MHz) ranging from 150Mhz to 1500Mhz

h_{te}=Transmitter base station antenna ranging from 30m to 200m

h_{re}= Receiver antenna height ranging from 1m to 10 m d=Transmitter – Receiver separation distance in the unit of a kilometer

$\alpha(h_{re})$ = correction factor for an effective mobile antenna height

It is the condition of the coverage area that can be determined from the following conditions among others:

$\alpha(h_{re})dB = (1.1logf_c - 0.7)h_{re}(1.5logf_c - 0.8)$ for small to medium cities. [40]

CHAPTER 5: RESULTS AND ANALYSIS

5.1. Introduction

In this chapter, we describe how the height of base station antennas significantly impacts path loss, signal strength, and handover processes in modern cellular networks. Using MATLAB, we analyze how different antenna heights affect these factors through path loss models and signal strength calculations. By examining received power with and without Gaussian noise, the study highlights the importance of optimal base station placement for robust coverage and minimal handover events. These insights are crucial for network engineers to design and optimize efficient, high-quality cellular networks.

5.2 Simulation results

5.2.1 Base station height is 60 meters, Fc=1000MHz

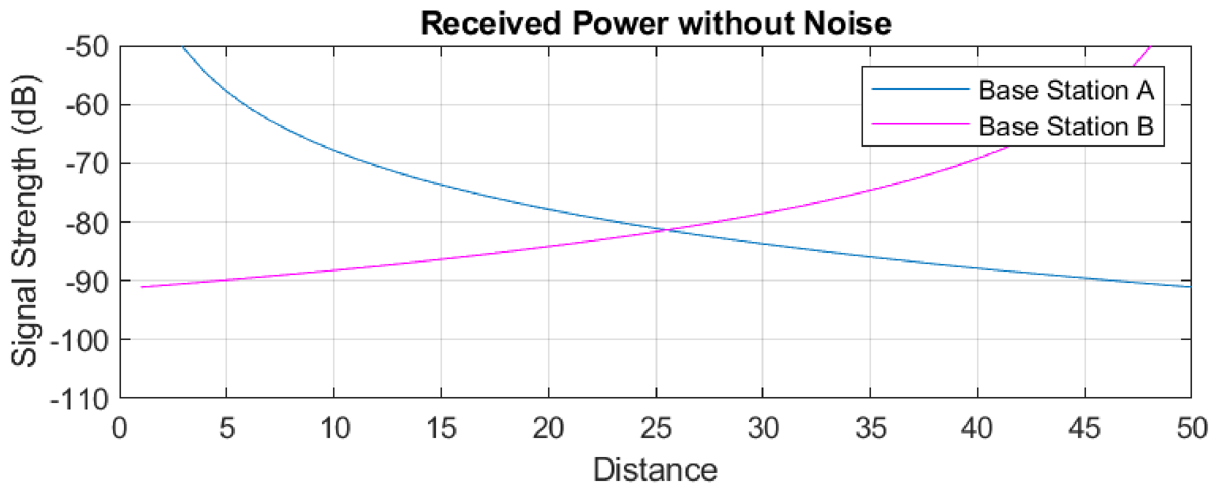

Figure 4: Received power without Noise, Free space propagation, height is 60 meters

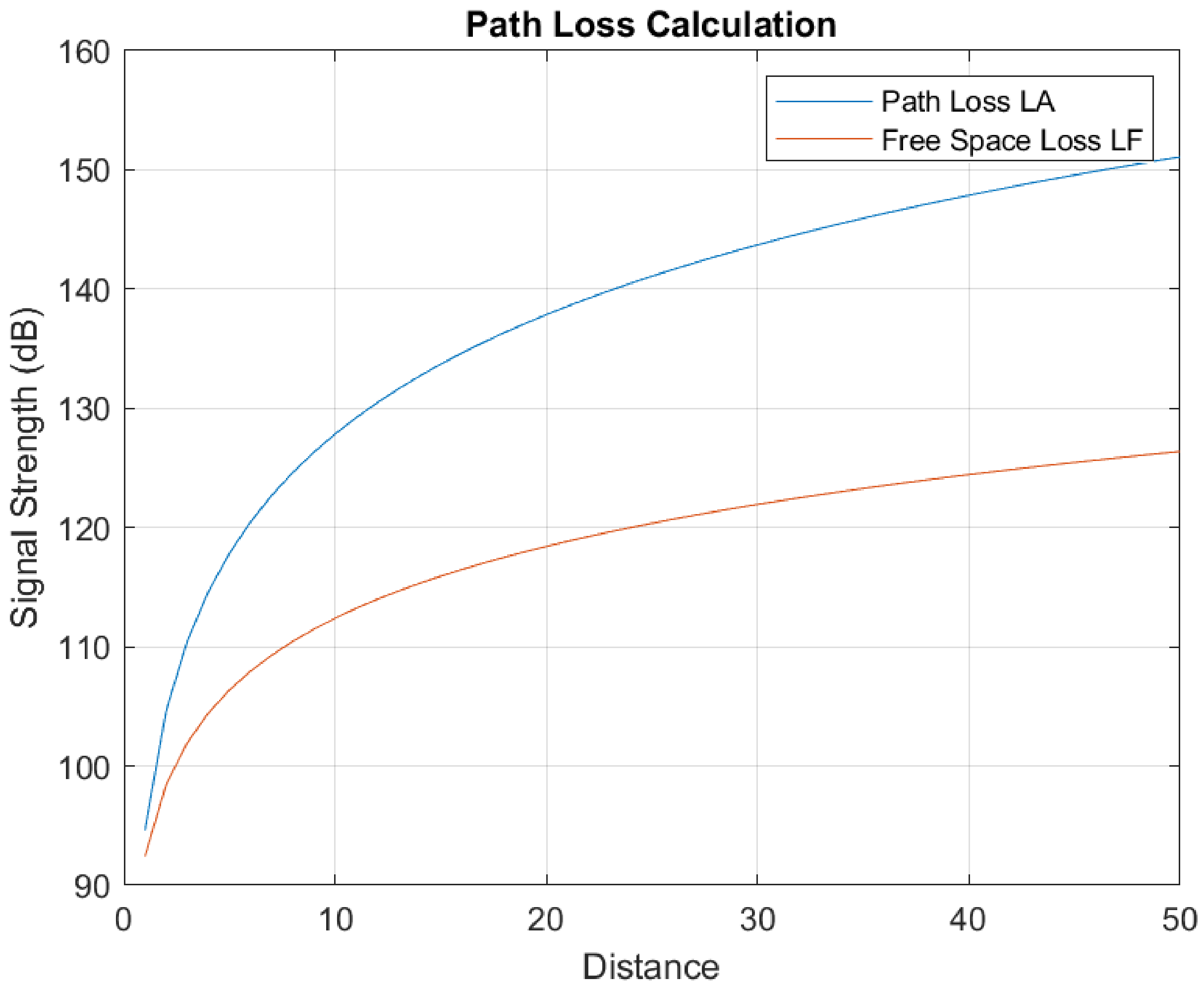

Figure 5: Path loss and Free space loss, base station height is 60 meters

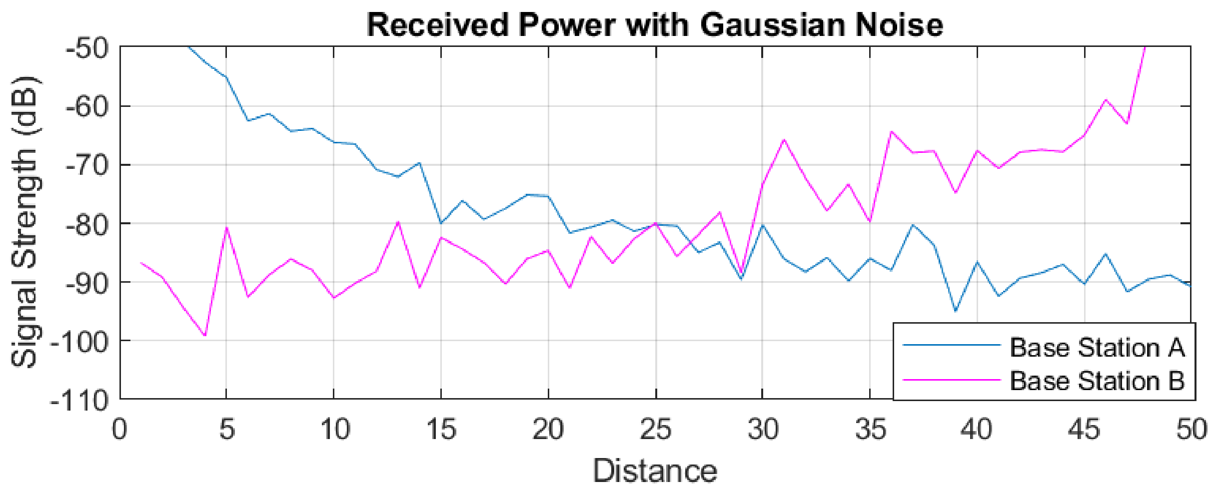

Figure 6: Received Power with Gaussian Noise, base station height in 60 meters

X-Axis: Distance (in arbitrary units, typically representing distance from the base station)

Y-Axis: Signal Strength (in dB)

Curves:

- **Base station A**: Received power at Base Station A with Gaussian noise (standard deviation = 3)
- **Base station B**: Received power at Base Station B with Gaussian noise (standard deviation = 5)

Description: This plot shows the received power at the mobile station from two different base stations (A and B) including the effect of Gaussian noise. The noise simulates real-world conditions where the signal might be affected by various sources of interference.

By considering the handover process, with a large coverage area from higher antennas, mobile devices can stay connected to a single base station for longer distances, however, at the point of handover, the moving mobile device may encounter a call drop as shown in the figure within the distance ranging from 20 to 30 unit of distance. The handover happens within the range of -87 dB of signal strength.

5.2.2 Base station height is 200 meters, fc=1000MHz

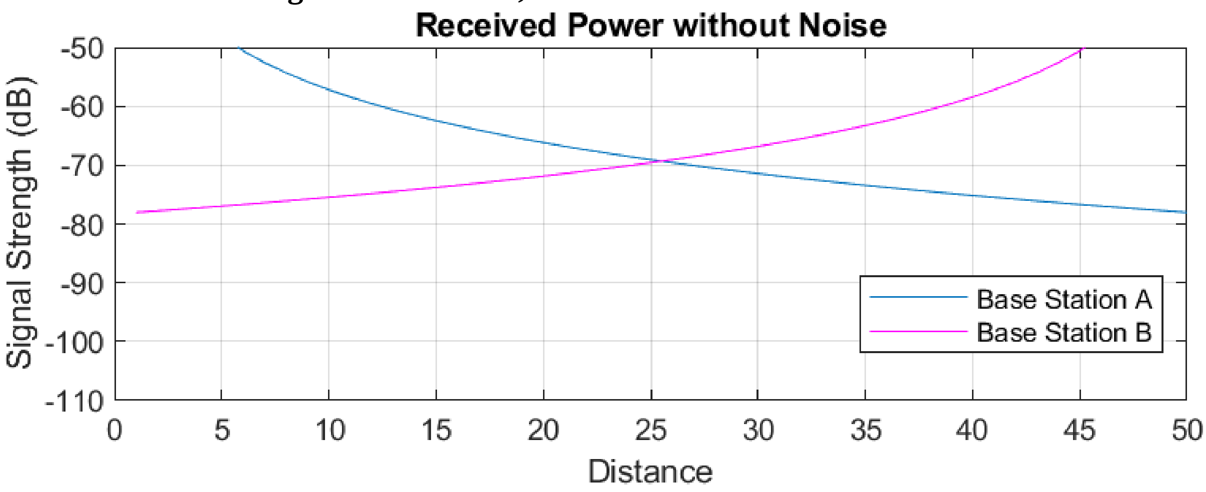

Figure 7: Received power without Noise, Free space propagation, height is 200 meters

The above plot shows the received power at the mobile station from two different base stations (A and B) without any noise. It represents the ideal signal strength purely based on path loss calculations.

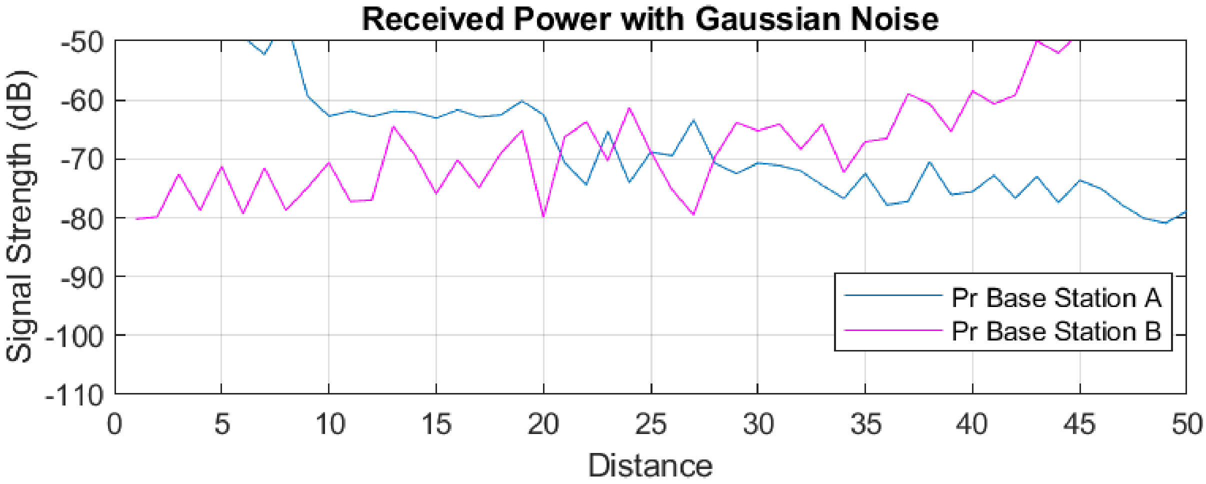

Figure 8: Received Power with Gaussian Noise, base station height in 200 meters

X-Axis: Distance (in arbitrary units, typically representing distance from the base station)

Y-Axis: Signal Strength (in dB)

Curves:

- **Pr Base station A**: Received power at Base Station A with Gaussian noise (standard deviation = 3)
- **Pr Base station B**: Received power at Base Station B with Gaussian noise (standard deviation = 5)

Description: This plot shows the received power at the mobile station from two different base stations (A and B) including the effect of Gaussian noise. The noise simulates real-world conditions where the signal might be affected by various sources of interference.

By considering the handover process, with a large coverage area from higher antennas, mobile devices can stay connected to a single base station for longer distances, however, at the point of handover, the moving mobile device may encounter several handovers as shown in the figure within the distance ranging from 20 to 30 unit of distance. The handover happens within the range of -70 dB of signal strength.

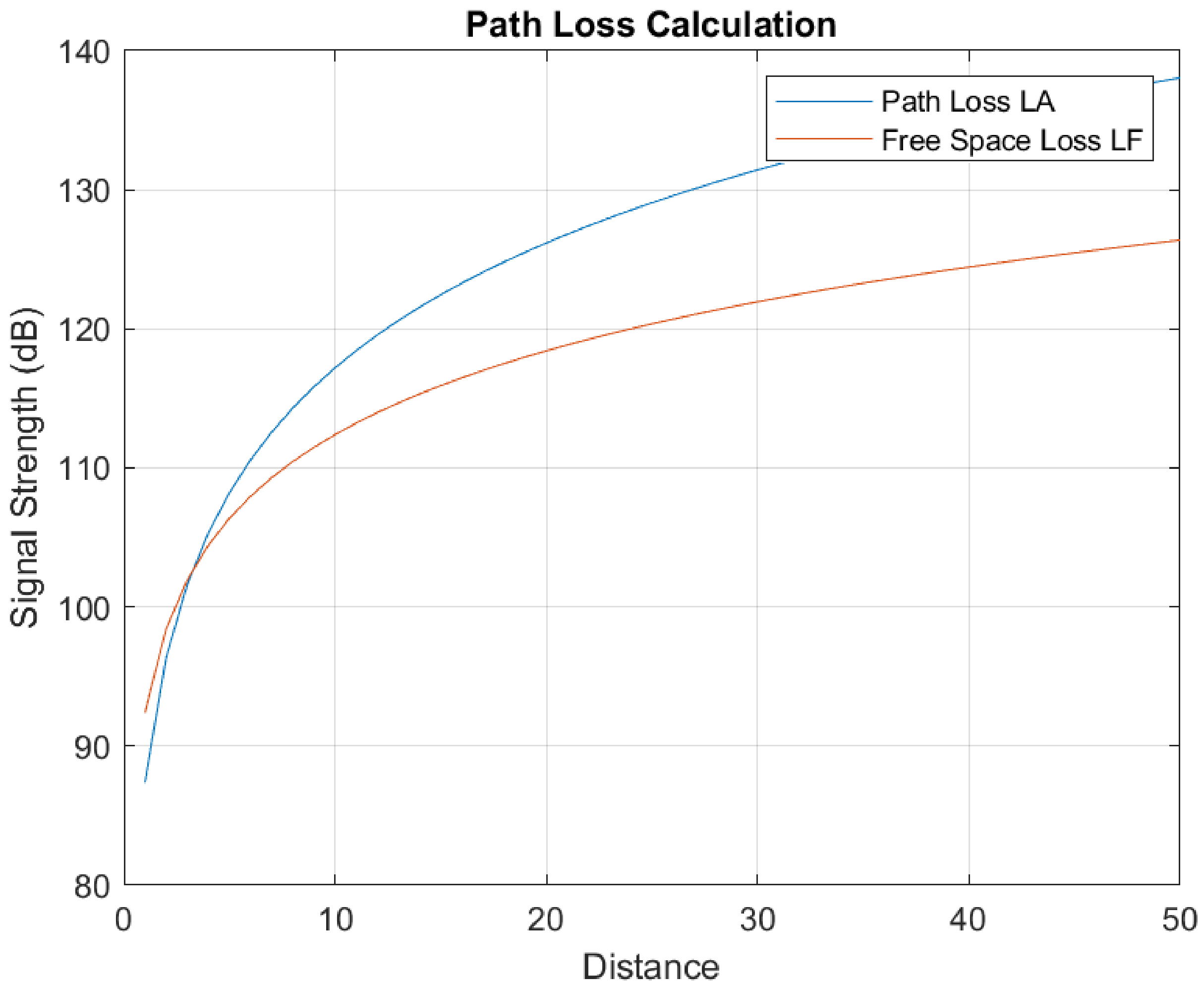

Figure: Path loss and Free space loss, base station height is 200 meters, fc 1000MHz

The terms 13.82 * log10(hte) and 44.9 - 6.55 * log10(hte) are subtracted in the path loss equations. As the height of transmitting antennas (hte) increases, log10(hte) increases, making the terms large. Hence, Larger subtracted terms reduce the overall path loss (LA and LB), indicating that the higher the base station, the lower the path loss experienced by the signal. Therefore, Lower path loss means stronger signals at greater distances which extends the effective coverage area of the base station

Higher antennas result in larger coverage areas for each base station, reducing the frequency of handovers because the mobile station can remain within the coverage area of a single base station for a longer time.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The height of the base station antenna plays a crucial role in determining the coverage area, signal strength, and quality, all of which directly impact the handover process. Higher antennas typically lead to fewer, smoother handovers, better signal quality, and more efficient network performance. However, planning is required to manage potential challenges such as shadow zones, call drops and increased infrastructure costs.

6.2. Recommendation

The number of mobile users is increasing rapidly in both urban areas and rural areas. To fulfil the requirements of QoS for all users wherever they are, it is important to have the signal able to be propagated in each area. This is the reason for recommending telecommunication companies to use this research as a baseline to overcome the problem of poor signal in specific areas as it is the best way when the dead zone is not wide. We recommend others to conduct more research countrywide and specify where and when signal boosting is needed.

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Appendices

MatLab codes

```
hte = 200;   % height of transmitting base station antenna in meters

hre = 10;    % height of receiving antenna of a mobile station in meters

sdA = 3;     % standard deviation of noise for Base station A

sdB = 5;     % standard deviation of noise for Base station B

noiseA = sdA * randn(1, 50);

noiseB = sdB * randn(1, 50);

fc = input('Enter the input frequency = ');


% Arrays to store results

LA = zeros(1, 50);

LB = zeros(1, 50);

LF = zeros(1, 50);

SrA = zeros(1, 50);

SrB = zeros(1, 50);

PrA = zeros(1, 50);

PrB = zeros(1, 50);


for d = 1:50

   % Path loss calculation Between Mobile & base station A

   LA(d) = (69.55 + 26.6 * log10(fc)) - (13.82 * log10(hte)) - ...

          ((1.11 * log10(fc) - 0.7) * hre + (1.56 * log10(fc) - 0.8)) + ...

          ((44.9 - 6.55 * log10(hte)) * log10(d));


   % Path loss calculation Between Mobile & base station B
```

```
    LB(d) = (69.55 + 26.6 * log10(fc)) - (13.82 * log10(hte)) - ...
        ((1.11 * log10(fc) - 0.7) * hre + (1.56 * log10(fc) - 0.8)) + ...
        ((44.9 - 6.55 * log10(hte)) * log10(51 - d));

    % Path loss calculation for free space model
    LF(d) = 32.4 + 20 * log10(fc) + 20 * log10(d);

    % Received power at A without noise
    SrA(d) = 60 - LA(d);

    % Received power at B without noise
    SrB(d) = 60 - LB(d);

    % Received power at A with Gaussian noise sd=3
    PrA(d) = 60 - LA(d) + noiseA(d);

    % Received power at B with Gaussian noise sd=5
    PrB(d) = 60 - LB(d) + noiseB(d);
end

% Calculate delay spread
[max_peak_value, max_peak_index] = max(abs(LA));  % Assuming LA represents the channel impulse response
first_peak_time = max_peak_index;  % Assuming time steps are 1 unit per index
delay_spread = 2 * (find(abs(LA) > max_peak_value * 0.707, 1, 'last') - first_peak_time);  % 0.707 is approximately 1/sqrt(2)
```

```
fprintf('Delay spread: %.4f time units\n', delay_spread);

% Plotting
figure;

subplot(2, 1, 1);
plot(PrA);
hold on;
plot(PrB, 'm');
axis([0 50 -110 -50]);
xlabel('Distance');
ylabel('Signal Strength (dB)');
title('Received Power with Gaussian Noise');
legend('Base Station A', 'Base Station B');
grid on;

subplot(2, 1, 2);
plot(SrA);
hold on;
plot(SrB, 'm');
axis([0 50 -110 -50]);
xlabel('Distance');
ylabel('Signal Strength (dB)');
title('Received Power without Noise');
legend('Base Station A', 'Base Station B');
```

```
grid on;


figure;

plot(LA);

hold on;

plot(LF);

xlabel('Distance');

ylabel('Signal Strength (dB)');

title('Path Loss Calculation');

legend('Path Loss LA', 'Free Space Loss LF');

grid on;
```