MITIGATING THE EFFECT OF PING PONG IN HANDOVER DECISION IN LTE ADVANCED NETWORKS BASED ON A MODIFIED ADAPTIVE AHP/TOPSIS TECHNIQUE

BY

Amina Umar MAZAMAZA,

B.Eng. (ABU) 2015

P17EGCM8030

Mazamazaamina@gmail.com

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DECLARATION

I declare that the work in this dissertation titled "Mitigating the effect of ping pong in handover decision in LTE Advanced based on Adaptive AHP/TOPSIS technique has been carried out by me in the Department of Electronics and Telecommunications Engineering. The information derived from the literature has been duly acknowledged in the text and a list of reference provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Amina Umar MAZAMAZA ______________________ ______________________

(Student) Signature Date

CERTIFICATION

This dissertation titled "**MITIGATING THE EFFECT OF PING PONG IN HANDOVER DECISION IN LTE ADVANCED NETWORKS BASED ON A MODIFIED ADAPTIVE AHP/TOPSIS TECHNIQUE"** by Amina Umar MAZAMAZA meets the regulations governing the award of Degree of Master of Science (MSc) in Telecommunications Engineering by the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Dr A. D. Usman ______________________ ______________________

(Chairman Supervisory Committee) Signature Date

Dr M. J. Musa ______________________ ______________________

(Member, Supervisory Committee) Signature Date

Dr. A. D. Usman ______________________ ______________________

(Head of Department) Signature Date

Prof. Sani A. Abdullahi ______________________ ______________________

(Dean School of postgraduate studies) Signature Date

DEDICATION

This work is dedicated to my father Engr. Umaru Mazamaza

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Alhamdulillah to Almighty Allah, for the abundant Blessings and Rahama He has showered on me. I acknowledgethe support of my father Engr. Umaru Mazamazaand mother Hafsah Mazamaza for their unflinching support towards achieving my dreams.

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ABSTRACT

With the continuous expansion of telecommunication networks, the need for high data rates and low latency for user equipment have become a research challenge in the industry. The Third Generation Partnership Project (3GPP) for Long Term Evolution (LTE) and Long Term Evolution Advanced (LTE-A) in release 8 and 10 respectively supporting different traffic of video, voice, and data created new technical challenges in seamless connectivity of user equipment on the move. Mobility management is an integral aspect of wireless communication taking into account the handover process which is a seamless connection between a cell and user terminals on the move. Adapting multiple handover control parameters such as time to trigger, hysteresis margin, velocity and load aids in making the process seamless. The aim of this research was to modify a handover decision technique based on adapting hysteresis margin to minimize handover problem due to the ping pong effect. Analytic Hierarchy Process - Technique for Order Preference by Similarity to Ideal Solution (AHP-TOPSIS) which was a multi-criterion technique used for ranking and selecting the best eNodeBand user equipment using parameters such as Received Signal Received Quality, Received Signal Received Power, Signal to Noise Ratio, location and velocity of user equipment. Triggering points value of hysteresis margin and time to trigger were then selected based on the adaptive technique for the handover decision process. The simulation results obtained showed decrease in handover ping pong probabilities with respect to increase in speed with a result of 29%, 28% and 13% at 3km/h, 30km/h and 120km/h respectively and also maintaining handover failure probability at 3km/h and 120km/h with a reduction of 10% at 30km/h.

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LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Project
AHP- TOPSIS	Analytical Hierarchical Process- Technique for Order of Preference by Similarity to Ideal Solution
BS	Base Station
dB	Decibel
dBm	Decibel- meter
DSA	Delay Sensitive Applications
eNodeB	Evolved node B
GRA	Grey Relational Analysis
HPP	Handover Ping Pong
HM	Hysteresis Margin
LTE	Long Term Evolution
LTE A	Long Term Evolution Advanced
MAHO	Mobile Assisted Handover
MCHO	Mobile Controlled Handover
MCDM	Multi Criteria Decision Making
ms	Millisecond

NCHO	Network Controlled Handover
SSA	Speed Sensitive Applications
QoS	Quality of Service
RLF	Radio Link Failure
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
SAW	Simple additive weighting
SC	Serving Cell
SINR	Signal to Interference plus Noise Ratio
SQ	Signal Quality
SS	Signal Strength
TS	Total Signal
TTT	Time to Trigger
UE	User Equipment
VHO	Vertical Handover

CHAPTER ONE

INTRODUCTION

1.1 Background of research

Recently, the continuous need for high data rates and low latency has become a focus of research in the wireless telecommunications networks. A wireless communication network is deployed over a geographical area to provide services such as voice, data and multimedia services to end users (Goyal & Kaushal, 2019).

One of the important challenges in wireless communication is in its ability to permit mobility without loss of connectivity or quality of service. Mobility management plays an important role in system optimization and robustness. Its main aim is to ensure seamless network without degradation in Quality of Service for mobile users. Mobility management is one of the most important areas in heterogeneous networks, which is still under research. Two different mobility managements exist in cellular networks: user equipment (UE) mobility which is with respect to spectrum and a base station (BS). Spectrum mobility is related to spectrum utilization in cognitive radio technology while mobility with respect to BS maintains the connection between UE and BS (Alhammadi*et al*.,2018)

Handover is a process in which a connected user's session is transferred from the current base station to a target base station. It is preferred for handover to occur seamlessly in its communication or else handover failure may occur. Handover failuremay be as a result of handover parameters not being properly configured which may lead totoo early handover, too late handover, handover into wrong cell or ping pong handover (Amer, *et al*., 2015). The success rate of a handover process in terms of speed and seamlessness is an indicator of user satisfaction.

The traditional handover decision method which involves comparison between the signal strength between the serving and target base stations only comes with its own limitation in terms of reliability. This led to the development of different self-optimizing handover algorithms which differ by tuning the handover control parameters to enhance the overall system network performance and Quality of Service. The main performance indicators include handover failure, handover ping pong rate, radio link failure, unnecessary handover etc.

Handover parameters need to be optimized for optimal selection of eNodeB and user equipment(UE). An optimization technique known as the Analytical Hierarchy Process - TechniqueforOrderofPreferencebySimilaritytoIdealSolution (AHP/TOPSIS) is used for this optimal selection based on weights of criteria based on order of priority.

1.2 Statement of Problem

This research is based on the modification of handover decision algorithm in LTE Advanced networks based on an adaptive AHP-TOPSIS technique. Handover control parameters such as reference signal received power, reference signal received quality, load, speed and distance were adapted based on AHP/TOPSISfor an optimal handover decision process.

1.3 Aim and Objectives

This research aims to modify a handover decision technique based on Adaptive Analytic Hierarchy Process - Technique for Order Preference by Similarity to Ideal Solutions (AHP-TOPSIS) to minimize the ping pong probability in an LTE Advanced wireless network.

The objectives of the research are as follows:

i. To modify ahandover decision technique based on adaptive AHP/TOPSIS
ii. To evaluateping pong probability, handover failure probability and radio link failure probability using the modified Adaptive AHP/TOPSIS Technique.
iii. To validatethe performance of the modified Adaptive AHP/TOPSIS technique with that of (Goyal & Kaushal, 2019) using ping pong probability and handover failure probability as performance indicators.

1.4 Scope and Justification of this Research

This research will be limited to modification of handover decisiontechnique based on adaptive AHP-TOPSIS technique. Ping pong effect is a major problem in handover decision which has not yet been fully exploited. This research will use multi criteria technique for optimal selection of user equipment and enodeB using parameters such as reference signal received power (RSRP), reference signal received quality(RSRQ), signal to noise ratio(SNR), load, speed and distance. Triggering points of hysteresis margin and time to trigger will also be applied adaptively to minimize handover ping pong probability. Integration of these two techniques will help to decrease computational delay by reducing the complexity of the system. The metrics to be used in the performance evaluation of this technique include: handover failure probability, ping pong probability andradio link failure probability. The simulation will be implemented using MATLAB R2017a version.

1.5 Organisation of this Report

This dissertation report is organised as follows: Chapter one is a highlight of the general introduction of this work. Chapter two includes the review of fundamental concepts and that of related literatures reviewed. Chapter three has the materials and method while Chapter four contains analysis, performance and discussion of the results. Finally, the conclusion and recommendation of this report is in Chapter five. At the end of this dissertation, the list of cited reference and MATLAB codes are provided in the appendices.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews literatures related to this work to provide thorough understanding of the research area, identify potential research gaps and also to provide a strong basis for the research. It also reviews the fundamental concepts in details to gain a better understanding of the guiding principles and theoretical background and also to establish its relevance to this research area.

2.2 Review of Fundamental Concepts

In this section, some of the fundamental concepts relating to this research are discussed, including guiding principles and model equations which support approaches implemented by previous research works reviewed. This facilitates the decision making on different tool(s) and methodology this report took to obtain better handover decision.

2.2.1 Long Term Evolution Advanced (LTE – A)

This is an evolved version of the Long Term Evolution (LTE) connectivity which incorporates additional functionality such as Carrier aggregation (CA), better use of existing multi antenna technique using Multiple Input Multiple Output (MIMO) and support for relay nodes. This version has better performance in terms of increase in stability, bandwidth and speed of LTE networks and connections(Triggs, 2019). It also provides an advanced set of standards and technologies with improved quality, coverage consistency and consistent data rate as compared to LTE. Figure 2.1 depicts the architecture of the LTE Advanced between different access technologies. It shows interconnection among different technologies such as femto cells, enodeBs and user equipment.

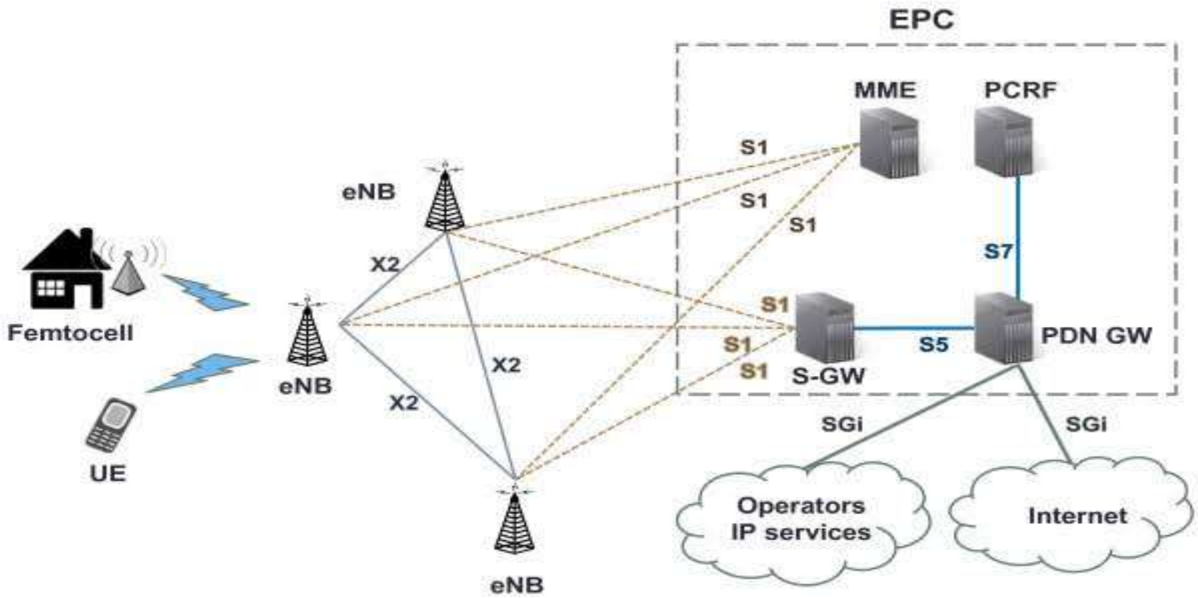

Figure 2.1: Architecture of Long Term Evolution Advanced (Thien-Toan *et al.,* 2012)

2.2.2 Mobility Management

Mobility Management is a factor considered in mobile cellular communications systems whose main aim lies in its ability to track the location of a mobile terminal on the move, allowing calls, SMS and other network services to have access to it. Some of its functions include handover, rerouting, location updates and paging(Shaukat, 2019). Mobility management is basically characterized into User Equipment mobility with respect to base station which involves the act of maintaining connection between a user equipment and a base station and that of spectrum which involves spectrum utilization most especially in cognitive radio(Alhammadi*et al.,* 2018). Mobility management comprises of mobility and interworking scenarios, handover decision metrics and mobility parameters, handover decision mechanism, handover performance measures and mobility protocols. Therefore, for seamless mobility, a combination of the various categories mentioned above can be used (Zekri, 2012). Mobility management is divided into namely location management and handover management as shown in Figure 2.2. The location management is a process were the network nodes track the mobile nodes through location registration and call paging while handover management involves keeping the connection between a node and a network while on the move(Sen, 2019).

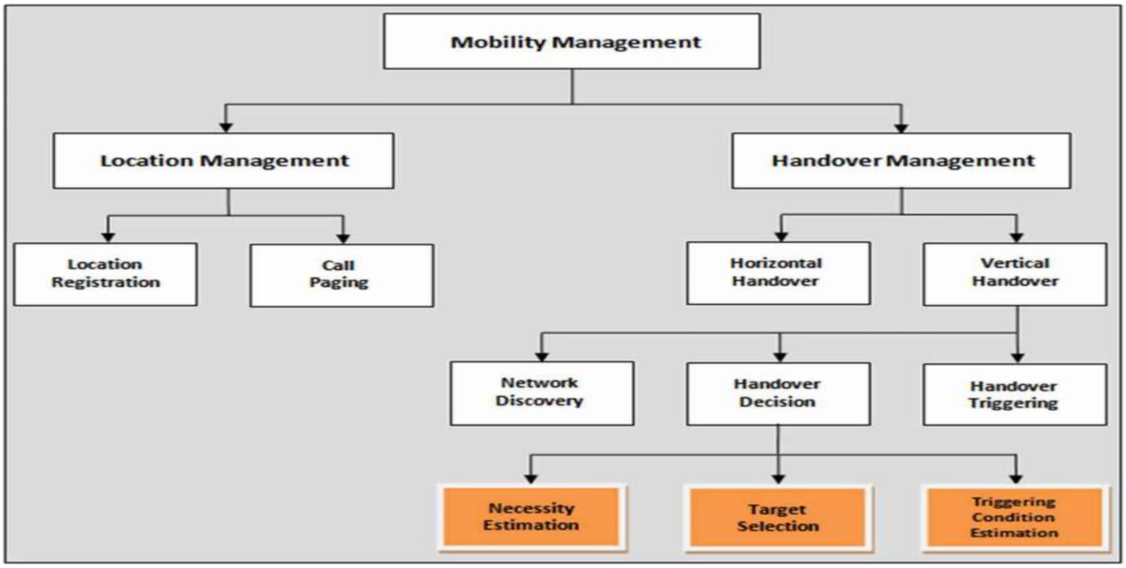

Figure 2.2: Hierarchy of Mobility Management in a Heterogeneous Network (Mahmood,*et al*.,2018)

2.2.3 Handover Procedure and Need for Handover

Handover is a process involved in the transfer of an ongoing data or voice calls from one location to another while on the move. Figure 2.3 depicts the handover process and its two broad categories. It is important that this procedure to be fast, seamless and successful for good user satisfaction. A seamless handover deals with the quality of service as user equipment moves from one cell coverage to another while a lossless handover occurs when no data is lost during the procedure (Chavarría, 2014)

Radio network depreciation, decrease in the network parameters of the base station are some of the factors that indicate the need for handover (Orimogunje*et at*.,2018). This handover procedure is clearly depicted in Figure 2.3

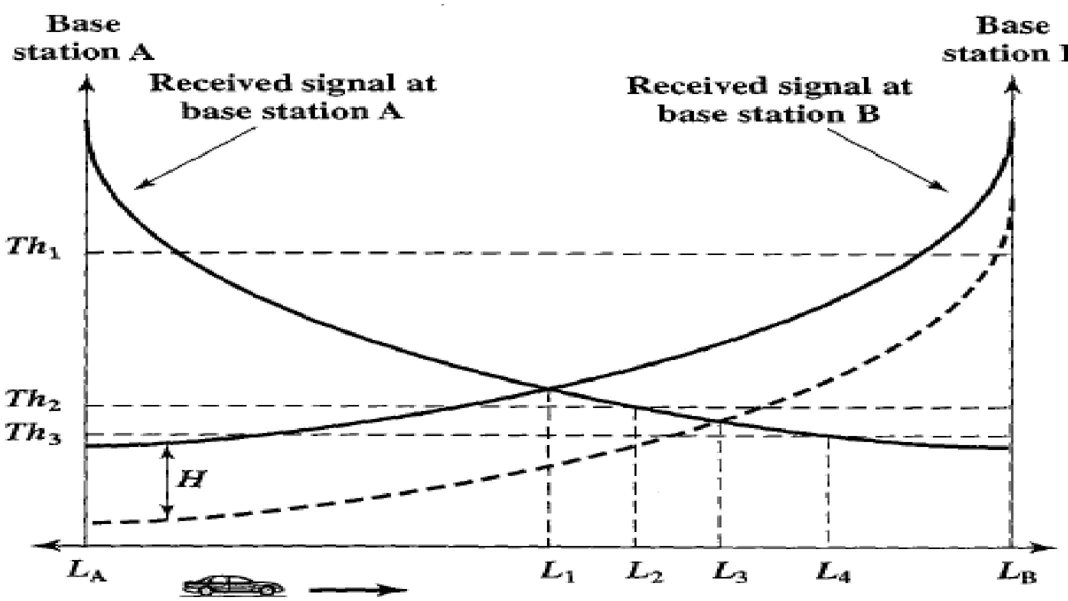

Figure 2.3: Handover Process (Stallings, 2015)

The concept of the traditional handover depicted in Figure 2.3 is based on the comparison between Received Signal Received Power (RSRP) of serving base station and that of target base station. The handover process is initiated with the condition as shown in equation 2.1(Goyal & Kaushal, 2019). This equation explains the relationship between the received signal strength of the serving cell and that of the target cell.

$RSRP_t = RSRP_S + HM$(2.1)

where:

$RSRP_t$ is Reference Signal Received Power for the target base station.

$RSRP_S$ is Reference Signal Received Power for the serving base station.

HM is Hysteresis Margin

2.2.4. Handover Categories

Handover process is broadly categorized into Horizontal and Vertical, Hard and Soft handover **(Orimogunje*et al*.,2017)**

i. **Horizontal and Vertical Handover:**Horizontal handover is a procedure that occurs between same radio access technology while vertical handover involves different network access technology.

ii. **Hard and Soft Handover:** Hard handover which is also called break before make is a process where all the connections are discarded before a new set of connections are made while Soft handover also known as Connect Before Break involves new connections being added before disconnecting with the old set of connections (Chavarría, 2014).

2.2.5 Handover Strategies: These are strategies required to detect and execute handover process namely: Mobile Controlled Handover (MCHO), Network Controlled Handover (NCHO), and Mobile Assisted Handover (MAHO) (Orimogunje *et al*.,2017)

i. **Mobile Controlled Handover (MCHO):**In this handover process, the mobile equipment monitors both signal strength and quality of signal of the serving and target cells. It initiates the handover process.

ii. **Network Controlled Handover (NCHO):**In this scheme, both base station and Mobile equipment have their different functions. The base station monitors the signal strength and quality while the network supervises the quality of signal from both serving and target base stations by measuring the Received signal strength indicator (RSSI).

iii. **Mobile Assisted Handover (MAHO):**Here, the mobile equipment and base stations both provide the data by measuring the quality of the received signal strength indicator (RSSI) for the network to make the handover decision. It is used in GSM and IS-95 CDMA.

2.2.6 **Vertical Handover (VHO) Phases in LTE**(Goudarzi*et al*., 2015) are:

i. Handover Initiation: In this phase, mobile terminal makes the necessary measurements used for handover initiation to a new access point (AP).

ii. Handover Decision: This is the core step of every handover process. This is where the measurement results obtained from handover initiation are compared with a set of predefined values to decide whether to handover or not.

iii. Handover Execution: In this phase, the actual handover process takes place. This is where the mobile node switches from its current network connections to the best available base station.

Table 2.1 Overview of the Existing Vertical Handover Decision Strategies(Zekri, 2017)

S/N	VHO DECISION SCHEME	DESCRIPTION	PROS	CONS
1.	RSS Threshold based	Dynamic RSS threshold is calculated & compared with the current RSS to determine the handover time for data & cellular networks.	- Reduced false handover initiation - Reduced handover failure	Increased handover failures from data to cellular networks. -Wastage of network resources

Table 2.1 Shows an overview of the existing vertical handover decision strategies (Zekri, 2017)

2.	Prediction based Scheme	Predictive received signal strength (RSS) threshold is used forhigh speed nodes to attain continuity of service.	- Reduced connection breakdown - Unnecessary handover avoidance -Load balancing in target networks	- Ping-Pong Effect - High link utilization -Increased Handover latency
3.	Context aware mobility prediction based scheme	User's mobility patterns and historical data are collected as context for making a handover decision.	- Used to reduced ping-pong for low speeds -This is suitable in uncertain network environments	- Instability for variable speeds - Longer handover delay - Higher packet loss
4.	Multi attributes decision making scheme	AHP is used to define weight of each parameter GRA is used to rank available network TOPSIS is used to rank and the highest rank is considered first	-Adaptive and applicable to wide range of conditions -Multi Criteria Consideration -Flexibility	Medium complexity

Table 2.1 Shows an overview of the existing vertical handover decision strategies (Zekri, 2017)

5	Adaptive priority based scheme	This scheme is mostly able to adapt and trade off Quality of service (QoS) with changes in bandwidth usage	-It can accept a call with less band-width than required by call. - Reduction in the probability of handover failure and hence will achieve a smaller handover dropping probability.	- Signaling overhead - Power consideration. - It is only suitable for limited environments and is non-applicable for most systems.

2.2.7 Handover Measurements

There are multiple parameters that can be used for handover measurement. These measurements include:

i. **Received Signal Strength Indicator (RSSI):** This represents the entire power received including unwanted power and noise from other sources (Usat, 2019). This value decreases as a mobile terminal moves away from the connected base station. Connection has to be re-established to another stronger network in order for connectivity to be continued.

ii. **Reference Signal Received Power (RSRP):** This is defined as the average power that a signal can carry within a considered bandwidth. This is a signal strength related metric and is mostly used for cell reselection and handover decision.

iii. **Reference Signal Received Quality (RSRQ):** This parameter is used to rank candidate cells according to signal quality and also used for cell reselection and handover decision making. It is defined by equation (2.2)(Afroz*et al.*,2015)

$$RSRQ = \frac{N \times RSRP}{RSSI} \quad (2.2)$$

where:

N is number of resource block

$RSRQ$ is reference signal received quality. This is measured in dB

$RSRP$ is reference signal received power. This is measured in dB

$RSSI$ is received signal strength indicator. This is measured in dBm

iv. **Signal to Interference plus Noise Ratio(SINR):** This is a measure for signal quality measured in decibel. It is an indicator for the quality of signal in a network by quantifying the relationship between radio frequency condition and throughput(Rocca, 2019)

$$SINR = \frac{S}{I+N} \quad (2.3)$$

where:

S: Signal power

I: Average interference power

N: Background Noise

v. **Velocity**(Goyal & Kaushal, 2019): The speed of User Equipment (UE) is important in a handover process. At high speed, number of frequent handover becomes high, ping pongand handover failure become a problem. This leads to the optimal control of handover parameters for optimization.

vi. **Load on eNodeB**(Goyal & Kaushal, 2019): This is used for optimal selection of eNodeB. The parameter is used to check the number of available UE on a target eNodeB.

2.2.8 Handover Control Parameters

i. **Hysteresis Margin (HM):** This is a value provided for maintaining the minimum difference between the received signal strength of the current base station and that of the target base station. This parameter helps in handover decision by making the RSRP of a neighbouring base station weaker than that of the current base station. This parameter can help to reduce handover ping pong. HM value is between 0 to 30dB with the variation of 0.5dB(Goyal & Kaushal, 2019).

ii. **Time To Trigger (TTT):** This is the time taken to trigger a measurement report when a specific event criteria has been met. The extension of this value can reduce ping pong and unnecessary handover but can increase handover failure and delay. If the value is reduced, too early handover problem may occur also. (Pahal & Rathee, 2016).The values for TTT specified are 0, 0.04, 0.064, 0.08, 0.1, 0.128, 0.16, 0.256, 0.32, 0.48, 0.512, 0.64, 1. 024, 1.28, 2.56 or 5.120 in seconds as specified by 3GPP(Goyal & Kaushal, 2019).

2.2.9 Major handover Problems

i. **Radio Link Failure:** This is defined as a ratio between the number of handover failures and the number of all handover attempts. The number of handover attempts is given bythe sum of the number of the failed handover and the number of successful handovers (Goyal & Kaushal, 2019):

$$HF = \frac{Nfail}{Nho} = \frac{Nfail}{Nfail + Nsucessful} (2.4)$$

where:

$Nfail$ is number of handover failure

$Nsucessful$ is number of successful handover

Causes of Radio Link Failure(RLF)

a. **Too Early Handover**: RLF occurs shortly after a successful handover to the target cell, and then UE reconnect to the serving cell.

b. **Too late Handover:** RLF occurs in serving cell before handover or during the handover procedure, then UE reconnect to the target cell (different from the serving cell).

c. **Wrong cell handover:** RLF occurs shortly after a successful handover to the target cell, and then UE reconnect to another cell which is neither the serving cell nor the target cell. (Zheng *et al*.,2013)

ii. **Handover Failure rate (HFR):** This is the ratio of number of handover failure to total number of handover attempted (Goyal & Kaushal, 2019).

$$HRF\% = \frac{N_{hof}}{N_{total \quad handover \quad attempted}} (2.5)$$

where

N_{hof} is Number of handover failure

$N_{total\ handover\ attempted}$ is the total number of handover attempted.

iii. **Ping Pong Handover:** It occurs when the Mobile Station (MS) is handed over from one cell to another but quickly handed back to the original cell. Some of the factors that affect this ping pong handover include speed, time to trigger and hysteresis margin.The ping pong handover ratio represents the number of ping pong handovers (NPP) divided by the total number of handovers including: i) the number of ping pong handovers, ii) the number of handovers without ping pong (NnPP), i.e., with stay longer than minimum time to stay (MTS), and iii) the number of failed handovers (Nfail) (Silva *et al*., 2017)

$$HPP = \frac{Nnpp}{Nnpp + Npp + Nfail} \quad (2.6)$$

where:

$Nnpp$ represents number of non ping pong handover

Npp represents number of ping pong handover

$Nfail$ represents number of handover failure

2.2.10 Multi Criteria Decision Making (MCDM)(Priya*et al*.,2019)

The problem of handover involves dealing with limited available network options from various technologies and service providers with respect to different criteria. MCDM technique can be used for access network selection via the use of several parameters with relatively different importance such as cost, user preferences, services etc. Some of the popular MCDM algorithms include:

i. **Simple Additive Weighting(SAW):** This is a technique where the result of the overall score of the candidate network is determined using the weighting sum of all the attribute values.

ii. **Technique for Order Preference by Similarity to Ideal Solution (TOPSIS):** Here, the chosen candidate network is closest to the ideal solution and farthest to the worst case solution.

iii. **Analytical Hierarchical Process (AHP):** This involves decomposing a network selection problem into sub problems, then each sub problem is assigned a weight value.

iv. **Grey Relational Analysis (GRA):** In the case, candidate networks are ranked and the one with the highest rank will be selected(Priya*et al*.,2019)

2.2.10.1 Analytic Hierarchy Process - Technique for Order Preference by Similarity to Ideal Solutions (AHP-TOPSIS)

AHP is a method used to determine the weights of different criteria and TOPSIS is used to obtain the final ranking. The integration of these two techniques have the advantage of defining weights of different multiple criteria which makes it more flexible and adaptive to wide range of conditions (Berdie *et al*., 2017)

This technique is explained as follows:(Goyal & Kaushal, 2019)

i. The parameters employed are referencesignal received power (RSRP), referencesignal received quality (RSRQ), signal to noise ratio (SNR), Load on eNodeB and received signal strength indicator (RSSI) for ranking the eNodeBs. user equipment(UE) are ranked based on application running on them, distance away from eNodeB and speed.

i. Normalized decision is obtained using the mathematical expression in equation (2.8)

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{l} y_{ij}^2}} \quad (2.8)$$

where:

r_{ij} is normalized decision

y_{ij} is the performance of the jth attribute of ith alternative

l is the number of alternatives

ii. Weighted normalized decision $N_{(i,j)}$ is obtained by multiplying each attribute with its own associated weight W_j. Here delay sensitive applications are given priority over speed sensitive applications for ranking UE while in eNB selection, RSRP, RSRQ and SINR are used. This is expressed in equation 2.9 as (Goyal & Kaushal, 2019)

$$N_{(i,j)} = W_j \times r_{ij} \quad (2.9)$$

where:

` $N_{(i,j)}$ is weighted normalized decision

W_j is associated weights

r_{ij} is normalized decision

iii. Positive and negative ideal values are obtained using separation measures. The high priority alternative will then be close to the positive ideal solution. This is shown mathematically as (Goyal & Kaushal, 2019)

For $i = (1,2,3 \ldots \ldots .. t)$

$S_i^+(t) = \sqrt{\sum_{i=1}^{l}(d_{ij}(t) - d_i^+)^2}$ (2.10)

For $i = (1,2,3 \ldots \ldots .. t)$

$S_i^-(t) = \sqrt{\sum_{i=1}^{l}\left(d_{ij}(t) - d_i^-\right)^2}$(2.11)

where

$S_i^+(t)$ is positive ideal value based on separation measures

$S_i^-(t)$ is negative ideal value based on separation measures.

iv. Closeness to ideal solution is then calculated by using the positive and negative ideal solution. Then rank of the alternative is found and the one with the higher value is served first. It is expressed mathematically in equation (2.12) as (Goyal & Kaushal, 2019)

$C_i^+ = \frac{S_i^-(t)}{S_i^+(t)+S_i^-(t)}$, $0 < C_i^+ < 1$(2.12)

where

C_i^+ is closeness to the ideal solutions

The next sub section describes the adaptive technique that is used to find the optimal triggering points.

2.2.11 Adaptation of Hysteresis Margin

The conventional handover decision is based on comparison between the received signal received power(RSRP) of the target eNodeB and that of the serving eNodeB. Handover is initiated when the RSRP of the target eNodeB exceeds that of the serving eNodeB by at least ahysteresis margin (HM) level. This is shown in equation (2.13). The purpose of HM is to avoid the uncessary handover between two eNodeBs (Silva, *et al*., 2018).

$$RSRP_{target} = RSRP_{serving} + HM \quad (2.13)$$

where

$RSRP_{target}$ is received signal received power of the target base station which is measured in dBm

$RSRP_{serving}$ is received signal received power of the serving base station which is measured in dBm

HM is the hysteresis margin which is measured in decibel (dB)

In equation (2.13), the HM is not dependent on user equipment's distance away from the base station. The adaptive technique is based on the modification of the actual HM based on distance of the user equipment away from the base station. This is shown mathematically in equation (2.14). The equation further shows the relationship between hysteresis margin and distance between serving cell (SC) and User Equipment (UE) (Zhang, 2018)

$$HM_{adaptive} = Max\{HM_{max} \times \left(1 - \frac{d}{R}\right)^4 ; 0\} \quad (2.14)$$

where:

HM_{max} is the maximum hysteresis margin measured in dB (This value can be set up only at the middle of the eNodeB)

HM_{min} is the minimum hysteresis margin measured in dB (This value can be set up only at the edge of the eNodeB. This value is set up at zero because that is the minimum standard value for the parameter

d is the distance between the serving eNodeB and the user equipment

R is the distance between the target eNodeB and user equipment

α is adaptive co-efficient which is set at the default of 4 so as to minimize path loss effect (Zhang, 2018)

The parameters d and R cannot be easily determined by the network or the user equipment. This research proposes to replace these parameters by other parameters that can be used more effectively.

The path loss model describes the relationship between path loss and the distance of a user equipment away from the base station as shown in equation (2.15)(Becvar & Mach, 2010)

$$PL(d) = X(f) + N \log_{10} d \tag{2.15}$$

where

X(f) shows the dependence of path loss model on frequency

N is the path loss exponent with the value of 4 for outdoor environment

The level of received signal at a specific distance depends on path loss and transmission power which is defined in equation (2.16) (Becvar & Mach, 2010)

$$RSSI(d) = P_{tx} - PL(d) \tag{2.16}$$

where

P_{tx} is the transmission power

$RSSI(d)$ is the received signal strength indicator

Long Term Evolution Advanced (LTE-A) takes into consideration basically received signal received power (RSRP) which is an essential standard used in orthogonal frequency division multiplexing(OFDM). This parameter can be used to provide the accurate measurement for a signal power for handover decision in LTE Advanced networks. This parameter is replaced with the RSSI used in equation (2.16)

RSS is then replaced with RSSI in equation (2.16) in this research to generate equation (2.17)

$$RSS(d) = P_{tx} - PL(d) \tag{2.17}$$

Furthermore, the distance d can be written as an exponential function based on equations (2.15) and (2.17) as shown in equation (2.19)

$$P_{tx} - (X(f) + N \log_{10} d) = RSS$$

$$d = 10^{\frac{1}{N}(P_{tx} - X(f) - RSS)} \tag{2.18}$$

Considering equation (2.18), equation (2.14) can be modified

$$HM_{adaptive} = Max\{HM_{Max} \times \left(1 - \frac{10^{\frac{1}{N}(X(f) + RSS - P_{TX})}}{10^{\frac{1}{N}(X(f) + RSS_{min} - P_{TX})}}\right)^4 ;\ 0\} \tag{2.19}$$

This can be further simplified in equation (2.19) assuming same frequency and transmitted power for both serving and target cells.

$$HM_{adaptive} = Max\{HM_{Max} \times (1 - 10^{\frac{1}{N}(RSS - RSS_{min})})^4; 0\} \tag{2.20}$$

where:

RSS is received signal strength

RSS_{min} is minimum received signal strength. This corresponds to the cell radius and the RSS level at which user equipment is able to receive data

The total received signal strength has to be related to the difference between the maximum and minimum RSS observed in the area. Thus the adaptive HM level is defined mathematically in equation (2.21)

$$HM_{adaptive} = Max\{HM_{Max} \times \left[1 - 10^{\frac{1}{N}\left(\frac{RSS_{act} - RSS_{min}}{RSS_{min} - RSS_{max}}\right)}\right]^4 ; 0\} \quad (2.21)$$

where

RSS_{act} is the actual received signal strength which can be easily measured during user equipment operation

RSS_{max} is the maximum received signal strength. It utilizes the data gotten from previous RSS values in the area reported by the user equipment.

RSS_{min} is the lowest received signal strength at which UE will still be able to receive data.

2.2.12 Review of Similar Works

The review of similar works gives the extent to which this research has gone in the resolution of the problem of handover ping pong. It gives the state of the art methods and techniques used by other researchers to mitigate handover ping pong. It then helps in the decision making of the tool and approach to be taken in order to obtain improvement.

There are many attempts made to analyze handover performance especially minimizing ping pong probabilities among which are the works of: **(Park *et al*., 2015)**proposed a Zero Handover Failure with unforced and automatic Time to Execute Scaling (ZEUS) handover algorithm. A geometric model based on hysteresis margin was used as a tradeoff between handover failure and handover ping pong where zero handover failure rate was achieved without increasing the overall ping pong rate. This technique could achieve zero handover failure rate and ping pong simultaneously but it could not be adapted in fast moving real life scenario. Also, the limitation in parameters led to inaccuracies in deriving the ping pong rate.

A distributedself-organizing algorithm was proposed by **(Nguyen *et al*., 2017)**for small cell networks to minimize the number of radio link failures by automatically tuning time to trigger and offset parametersthen updating the completed offset together with A3Offsets in order to fine tune the offsets. This technique clearly decreased handover failure rate by 1% but due to trade off, the handover ping pong probability increased which eventually increased the network degradation.

Analysis was also carried out to minimize unnecessary handover while maintaining the handover failure to an acceptable level in heterogeneous networks by **(Alhabo *et al*., 2017)**.The time to stay, hysteresis margin, signal to interference plus noise ratio and reference signal received power with a threshold were used to minimize the unnecessary handover. The result showed that using the time threshold metric of 1.97 seconds,unnecessary handover (UHO)and handover failure(HOF) were minimized. Although the threshold significantly mitigated the UHO, there still was a significant delay. So integrating this technique with a predicted time can further minimize the delay encountered.

An enhanced vertical handover decision algorithm based on multi criteria in a heterogeneous wireless networks to minimize number of handover and handover failure probability was proposed by **(Abdullah & Zurkarnain, 2017)**. This was based on the concept of taking advantage of multiple different access technologies with a multi criterion technique known as Technique for Order Preference by Similarity to Ideal Solution(TOPSIS)for optimal ranking. This was done to select best network based on network, mobile and equal priorities. The results obtained showed that handover decision based on network priority yields better performance by 60% compared to equal with 22.9% and mobile priority with 40.29% for reduced number of handovers probability. Also 43%, 24.65% and 33.79% for network, equal and mobile priority respectively for handover failure probability. This work depicts clearly the heterogeneity in the system but multiple criteria such as load, distance and type of application can also be employed for optimal analysis of the network.

(Silva *et al*., 2017)proposed a fuzzy logic based handover decision scheme to minimize the number of redundant handovers and handover failure ratio in mobile networks with dense cells deployment. User equipment’s velocity, received signal strength power and received signal strength quality were the input parameters employed using a fuzzy logic system to select the highest rank combination and also to generate dynamic hysteresis margin at the output. This dynamic hysteresis margin generated is used to improve the handover decision process in a self-optimizing manner. This algorithm was able to suppress the problem of ping pong and keep it below a negligible value of 1% in all scenarios. The effect of handover failure ratio and total number of handover were notably reduced but more criteria such a location, time to trigger and signal to interference plus noise ratio need to be exploitedfor a more robust handover decision algorithm.An improvement of this work was done by **(Silva *et al*., 2018)**whoproposed a self-tuning handover decision algorithm for optimizing handover control parameters in dense small networks based on fuzzy logic. The novelty of this work was in the introduction of a new fuzzy based threshold derived based on comparison of signal level with velocity, received signal strength received power and received signal strength received quality. This fuzzy logic based threshold represents an added value in order to improve the accuracy of the handover decision while the control parameters employed allows the ability to estimate whether handover to a new cell is efficient or not. The result obtained showed that for handover failure, the proposed algorithm outperforms others compared in the work by 5% and handover Ping Pong below 1%. Although the algorithm is fast and clearly deals with the problem of uncertainty, the fuzzy rule base used encountered inaccuracy in their derivations coupled the complexity of the technique increased the overall processing delay of the system.

A survey of handoff management in heterogeneous wireless networks was carried out by (**Dhand & Dillon, 2018)**. The handover concept was clearly explained and parameters such as energy efficiency and quality of service were analyzed for seamless vertical handover. Emphasis was also made on the need for accurate analysis and measurement of multiple parameters. This work also analyzed the issues and challenges encountered in next generation wireless networks and also the need for efficient and effective algorithm for handover management. The need for cross layer based optimization solution is a major challenge and was recommended that by the incorporation of new mobility management schemes such as adapting parameters to changing environment and real life scenarios. Multi criteria such as velocity, direction, signal to noise ratio(SNR) should also be considered for accurate measurement for mobility optimization. **(Zhang *et al*., 2018)**proposed a self-optimization energy efficient based handover decision algorithm aimed at minimizing handover ping pong rate. The performance metrics hysteresis margin and time to trigger were selected dynamically coupled with signal to interference plus noise ratio were employed to mitigate ping pong rate while current network energy efficiency state based was used for energy reduction gain. The energy efficiency model established was for checking the energy status of both base station and mobile terminal when changing the handover control parameters. This technique showed how ping pong ratio was minimized to 5% while improving the system energy efficiency by 4%. Although parameters employed provided improved self-optimization for a smart phone, a more realistic power consumption with more detailed parameters should be employed for a more robust system.

An integration of LTE Advanced and millimeter wave networks to mitigate radio link failure rate, ping pong handovers and maximize spectral efficiency was proposed by **(Alhammadi *et al*., 2018)**. Hysteresis margin and time to trigger were dynamically paired to improve system performance for at different speeds. This dynamic scheme was efficiently implemented taking into account the current state information but considering also the past information can help in predicting better metrics and effectively minimizing the handover problems better. Delay was introduced into this system due to the inability of the two performance metrics to be adapted and a threshold can be introduced to the margin to better mitigate the ping pong and radio link failure. **(Abdullah*et al*., 2018)**proposed an improved handover decision algorithm based on multi criteria to minimize the probability of number of handover and handover failure. Technique for Order Preference by Similarity to Ideal Solution(TOPSIS) was used which required speed, cost function, radio and network topology to serve as inputs to offer flexibility to determine the weights based on mobile, network and equal weights. The weights are employed to calculate the impact of every criterion to select the most suitable network for the handover decision process. The performance indicators employed were cost function, mobile speed, RSS and network occupancy using worldwide interoperability for microwave access (WIMAX), wireless local area network (WLAN) and Long term evolution (LTE) interfaces. The result showed that network weight generated higher output based on number of handover and handover failure probability with 60% and 43% as compared to mobile weight with 40.29% and 33.79% and equal weight with 22.9% and 24.62%. This research employed multiple criteria to analyze these interfaces with respect to handover failure but in the process limited the algorithm to small network deployment and inability to process complex systems.

Another interesting work was in adapting hysteresis margin (HM) and time to trigger (TTT)pairs based on distance and speed of user equipment by **(Zhang, 2018)**. This work was aimed at binding a UE to within its serving cell coverage with respect to distance while TTT uses speed of user equipment to mitigate radio link failure and handover ping pong probability. Adaptive technique which is a suitable technique used for optimizing handover decision had a limitation in terms of flexibility and optimization as multiple parameters such as received signal strength, load, direction and location were not incorporated for optimal target cell selection. The most recent work was proposed by **(Goyal & Kaushal, 2019)** on handover optimization scheme for LTE Advanced based on AHP/TOPSIS and Q learning to minimize handover ping pong and failure rate. This technique employed the use of multi criteria performance metrics such as RSRP, RSRQ, Current load, Uplink SNIR, direction and location of user equipment based on AHP/TOPSIS technique to rank ENodeB and UE while the Q learning technique to choose appropriate HM and TTT for the handover decision process. The result shows that the proposed scheme minimizes the handover failure rate and Handover ping pong by 28%, 25% and 35% and 33%. The hybridization of the AHP- TOPSIS and Q learning reduced the subjectivity, computational cost and also ease of application but cannot be analyzed optimally in a large dense network. Q learning which works based on trial and error method led to delay in the system which reduced the efficiency of the system. Adaptive technique, Energy efficient mechanism with guaranteed QoS requirements such as transmission delay, battery consumption, packet loss during handover and handover ping pong effect can also be investigated for a more optimized system.

In Summary, the major challenge of vertical handover is mobility management where the need for efficient and effective new handover management scheme is required. The current and future works done to solve this issue involvesadapting parameters based on changing environment and in its ability to incorporate several parameters such as velocity and direction should be considered for mobile node accuracy of movement (Dhand & Dillon, 2018).

From the literatures reviewed above, it clearly shows how ping pong effect is a major problem inhandover decision which has not yet been fully exploited. This research will use multi criteria technique for optimal selection of user equipment and enodeB using parameters such as reference signal received power (RSRP), reference signal received quality(RSRQ), signal to noise ratio(SNR), load, speed and distance. Triggering points of hysteresis margin and time to trigger will also be applied adaptively to minimize handover ping pong probability. Integration of these two techniques will help todecrease computational delay by reducing the complexity of the system.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes in details the procedure carried out in the concept of adaptive handover decision in LTE Advanced wireless networks

3.2 Materials

a. Hp Laptop
b. Matlab R2017a

3.3Methodology

The methodologies adopted in carrying out this report are as follows:

3.3.1 Replication of the work of (Goyal & Kaushal, 2019)

a. Development of an LTE A network architecture comprising of 19 eNodeB with a radius of 1km and 40 user equipment.

b. Adopting a random mobility model to model the movement pattern of the user equipment based on different velocities of range between 3km and 120km.

c. Obtain the Received Signal Received Power, Received Signal Received Quality, Uplink Signal to Interference to Noise ratio using the simulation parameters used in the work of (Goyal & Kaushal, 2019).

d. Selection of eNodeB based on the attributes obtained and weights provided based on AHP-TOPSIS method.

e. User Equipment are then prioritized based on either delay sensitive application (which is given higher priority) or speed sensitive applications (with lower priority) using AHP-TOPSIS method.

ii. Development of a modified handover decision algorithm

a. Repeat item (a) to (e) of item (i)
b. Generate adaptive hysteresis margin based on the modified equation of adaptive hysteresis margin shown in equation (2.23)
c. Generate corresponding time to trigger values based on 3GPP standard values.

ii. Implementation of steps (i) and (ii) using MATLAB R2017a Version

iii. Evaluating the effect of ping pong rate, handover failure rate and radio link failure rate using the developed Adaptive AHP/TOPSIS Technique.

iv. Comparison of the performance of the proposed algorithm with that of (Goyal & Kaushal, 2019) using the performance indicators of ping pong probability and handover failure probability.

3.4 Replication of optimal eNodeB selection using AHP/TOPSIS method

The detailed procedure for the replication of optimal eNodeB selection is described in this section.

3.4.1Obtain the criteria values and calculate the ranks based on these values

i. Received Signal Received Power (RSRP)

RSRP is the average power a signal can carry within a considered bandwidth and deteriorates over a distance between the serving BS and the target BS. In this work the

RSRP reporting range used is between the range of -44dBm to -140dBm whose values are based on 3GPP standard(CableFree, 2019).

ii. Received Signal Strength Indicator (RSSI)

This measures the total average power of a signal and the values used in this work are between the range of -57dBm to -116dBm based on 3GPP standard(3GPP, 2019)

iii. Received Signal Received Quality

This is a key indicator for measuring signal quality and is calculated based on equation 3.1 using the values used for both RSSI and RSRP. The number of resource block (N) used across 20MHz is 100(CableFree, 2019)

$$RSRQ = \frac{N \times RSRP}{RSSI} \quad (3.1)$$

where:

N is number of resource block across a bandwidth of 20MHz.

$RSRQ$ is received signal received quality

$RSRP$ is received signal received power

$RSSI$ is received signal strength indicator

iv. Signal to Noise ratio

SNR value is usually specified by UE vendors. The range of values used for this research work is 8.2 to 51.2 dB based on 3GPP standard values(Geier, 2019)

v. Load on eNodeB

Load on eNodeB was chosen based on number of UEs an eNodeB can handle at a time. The total number of UEs used were 40 and eNodeBs were 19. The values used are chosen at random between the range of 1 to 15 UEs for a realistic approach. Only actively connected devices were considered.

vi. Delay Sensitive Applications: This is given a value of 1 when it is being run in a UE and 0 when not applied in a UE. Higher priority is given to delay sensitive applications than speed sensitive applications to overcome the problem of latency which has a direct impact on ping pong effect.

vii. Speed Sensitive Applications: This is given a value of 1 when it is being run in a UE and 0 when not applied in a UE. This has a lower priority than delay sensitive applications.

3.5 Selection of eNodeB by using the AHP-TOPSIS Method

The steps involved for optimal selection of eNodeB based on AHP/TOPSIS technique are described in this sub section.

3.5.1 Obtain Criteria values of RSRP, RSRQ, RSSI, SNR and Load for 19eNodeBs.

The values for RSRP, RSSI and SNR which are standard values based on (3GPP, 2019), RSRQ values were obtained using equation 3.1 and values for load as explained in 3.4.1 (v) are shown in Table 3.1

Table 3.1 Criteria Values of RSRP, RSRQ, RSSI, Load and SNR

ENodeB	**RSRP(dB)**	**RSRQ**	**SNR(dB)**	**LOAD**	**RSSI(dB)**
ENB1	-70.00	16.83	51.2	03	-79
ENB2	-75.00	14.25	48.2	05	-100
ENB3	-80.00	13.81	43.2	02	-110
ENB4	-85.00	28.33	38.2	03	-57
ENB5	-90.00	13.15	33.2	12	-130
ENB6	-95.00	30.59	28.2	06	-59
ENB7	-100.00	28.79	23.2	04	-66

Table 3.1 Criteria Values of RSRP, RSRQ, RSSI, Load and SNR

ENB8	-105.00	26.25	18.2	07	-76
ENB9	-110.00	24.30	13.2	01	-86
ENB10	-115.00	22.76	08.2	10	-96
ENB11	-120.00	21.50	23.2	08	-106
ENB12	-125.00	20.47	18.2	15	-116
ENB13	-130.00	28.06	13.2	09	-88
ENB14	-85.00	16.31	08.2	03	-99
ENB15	-90.00	25.52	23.2	01	-67
ENB16	-99.00	24.43	18.2	07	-77
ENB17	-76.00	19.25	13.2	11	-75
ENB18	-68.00	18.20	08.2	06	-71
ENB19	-58.00	20.84	21.3	13	-62

3.5.2Defining weights for each criterion: Weights are defined based on handover requirement priority. These priorities are determined based on order of importance for handover decision in LTE Advanced networks. RSRP is considered to have the highest priority, SNR with the next prioritythen RSRQ and Load with equal priority and RSSI with least priority as follows:RSRP with a weight of 24%, RSRQ with a weight of 21%, RSSI with a weight of 11%, SNR with a weight of 23% and load with a weight of 21% (Goyal & Kaushal, 2019)

3.5.3 Determination of the normalized values based on equation 2.8and the values obtained are shown on Table 3.2

Table 3.2 Normalized values of RSRP, RSRQ, SNR, Load and RSSI

ENodeB	RSRP (dBm)	RSRQ (dB)	SNR (dB)	LOAD	RSSI(dBm)
ENB1	-0.167475617	0.172404889	0.433428369	0.088542200	-0.20684
ENB2	-0.179438162	0.145928424	0.408032176	0.147570334	-0.26182
ENB3	-0.191400706	0.141506351	0.365705186	0.059028134	-0.28800
ENB4	-0.203363250	0.290150083	0.323378197	0.088542200	-0.14924
ENB5	-0.215325794	0.134703161	0.281051208	0.354168802	-0.34037
ENB6	-0.227288338	0.313292662	0.238724219	0.177084401	-0.15447
ENB7	-0.239250882	0.294804897	0.196397230	0.118056267	-0.17280
ENB8	-0.251213426	0.268815518	0.154070241	0.206598468	-0.19898
ENB9	-0.263175970	0.248870181	0.111743251	0.029514067	-0.22516
ENB10	-0.275138514	0.233080122	0.069416262	0.295140668	-0.25135
ENB11	-0.287101058	0.220269320	0.196397230	0.236112534	-0.27753
ENB12	-0.299063603	0.209667276	0.154070241	0.442711002	-0.30371
ENB13	-0.311026147	0.287434775	0.111743251	0.265626601	-0.23040
ENB14	-0.203363250	0.167056108	0.069416262	0.088542200	-0.25920
ENB15	-0.215325794	0.261364342	0.196397230	0.029514067	-0.17542
ENB16	-0.236858373	0.250163013	0.154070241	0.206598468	-0.20160
ENB17	-0.181830670	0.197165515	0.111743251	0.324654735	-0.19636
ENB18	-0.162690600	0.186349913	0.069416262	0.177084401	-0.18589
ENB19	-0.162690600	0.213400706	0.180312974	0.383682868	-0.16233

3.5.4 Analysis of the weighted Normalized values using equation 2.9(Goyal & Kaushal, 2019) and values obtained for RSRP, RSRQ, SNR, Load and RSSI are shown on Table 3.3

Table 3.3 Weighted Normalized Values of RSRP, RSRQ, SNR, Load and RSSI

EnodeB	RSRP (dBm)	RSRQ(dB)	SNR (dB)	LOAD	RSSI(dBm)
ENB1	-0.040194148	0.036205027	0.099688525	0.043864379	-0.02275
ENB2	-0.043065159	0.030644969	0.093847400	0.046057598	-0.02880
ENB3	-0.045936169	0.029716334	0.084112193	0.004386438	-0.03168
ENB4	-0.048807180	0.060931517	0.074376985	0.006579657	-0.01642
ENB5	-0.051678191	0.028287664	0.064641778	0.026318628	-0.03744
ENB6	-0.054549201	0.065791459	0.054906570	0.030705065	-0.01699
ENB7	-0.057420212	0.061909028	0.045171363	0.008772876	-0.01901
ENB8	-0.060291222	0.056451259	0.035436155	0.015352533	-0.02189
ENB9	-0.063162233	0.052262738	0.025700948	0.021932190	-0.02477
ENB10	-0.066033243	0.048946826	0.015965740	0.078955883	-0.02765
ENB11	-0.068904254	0.046256557	0.045171363	0.098694853	-0.03053
ENB12	-0.071775265	0.044030128	0.035436155	0.032898284	-0.03341
ENB13	-0.074646275	0.060361303	0.025700948	0.019738971	-0.02534
ENB14	-0.048807180	0.035081783	0.015965740	0.048250817	-0.02851
ENB15	-0.051678191	0.054886512	0.045171363	0.065796569	-0.01930
ENB16	-0.056846010	0.052534233	0.035436155	0.035091503	-0.02218
ENB17	-0.043639361	0.041404758	0.025700948	0.065796569	-0.02160
ENB18	-0.039045744	0.039133482	0.015965740	0.024125409	-0.02045
ENB19	-0.039045744	0.044814148	0.041471984	0.085535540	-0.01786

3.5.5 Determination of the ideal best and ideal worst value

The ideal best value donated by V+ signifies the maximum value for the weighted normalized value of a criterion while the ideal worst value donated by V- is the minimum value for the weighted normalized value of a criterion. The values for each criterion is shown on Table 3.4

Table 3.4 Maximum and Minimum Values of RSRP, RSRQ, SNR, Load and RSSI

	RSRP(dBm)	**RSRQ (dB)**	**SNR (dB)**	**LOAD**	**RSSI(dBm)**
(V+)	-0.074646275	0.065791459	0.099688525	0.092969310	-0.01642
(V-)	-0.039045744	0.028287664	0.01596574	0.006197954	-0.03744

3.5.6 Determination of the separation measures using

i. The positive ideal solution using equation 2.10and negative ideal solution using equation 2.11.
ii. The relative closeness to positive ideal solution using equation 2.12
iii. Ranking of the values of closeness to ideal solution based on preference order.

Table 3.5 Selection of eNodeB based on AHP/TOPSIS technique

ENodeB	**RSRP (dBm)**	**RSRQ (dB)**	**SNR (dB)**	**LOAD**	**RSSI (dBm)**	**Si+**	**Si-**	**Ci+**	**Rank**
ENB1	-0.0402	0.0362	0.0997	0.0186	-0.0228	0.0874	0.0863	0.50	05
ENB2	-0.0431	0.0306	0.0938	0.0310	-0.0288	0.0791	0.0823	0.49	04
ENB3	-0.0460	0.0297	0.0841	0.0124	-0.0317	0.0954	0.0690	0.58	11
ENB4	-0.0489	0.0609	0.0744	0.0185	-0.0164	0.0828	0.0719	0.54	07
ENB5	-0.0517	0.0282	0.0646	0.0743	-0.0374	0.0628	0.0847	0.43	02
ENB6	-0.0545	0.0657	0.0549	0.0371	-0.0170	0.0743	0.0674	0.52	06
ENB7	-0.0574	0.0619	0.0452	0.0248	-0.0190	0.0891	0.0548	0.62	15
ENB8	-0.0603	0.0564	0.0354	0.0434	-0.0219	0.0831	0.0570	0.59	13
ENB9	-0.0632	0.0523	0.0257	0.0062	-0.0248	0.1157	0.0376	0.75	18

ENB10	-0.0660	0.0489	0.0160	0.0620	-0.0277	0.0919	0.0660	0.58	12
ENB11	-0.0689	0.0462	0.0452	0.0496	-0.0305	0.0739	0.0632	0.54	08
ENB12	-0.0718	0.0440	0.0354	0.0930	-0.0334	0.0700	0.0961	0.42	01
ENB13	-0.0746	0.0603	0.0257	0.0558	-0.0253	0.0834	0.0707	0.54	09
ENB14	-0.0488	0.0351	0.0160	0.0186	-0.0285	0.1196	0.0193	0.86	19
ENB15	-0.0517	0.0548	0.0452	0.0062	-0.0193	0.1056	0.0453	0.70	16
ENB16	-0.0568	0.0525	0.0354	0.0433	-0.0222	0.0843	0.0538	0.61	14
ENB17	-0.0436	0.0414	0.0257	0.0682	-0.0216	0.0876	0.0661	0.57	10
ENB18	-0.0390	0.0391	0.0160	0.0372	-0.0205	0.1101	0.0370	0.75	17
ENB19	-0.0390	0.0448	0.0415	0.0806	-0.0179	0.0725	0.0827	0.47	03

3.6 Selection of UE by using the AHP-TOPSIS Method

This involves the optimal selection on user equipment based on AHP/TOPSIS technique.

3.6.1 Obtain Criteria values of Speed sensitive application(SSA), delay sensitive application(DSA), velocity and distance for 40 UEs. A value of 1 is given when an application is active while 0 for when an application is not active. The values for the speed and distance away from eNodeB for 40 UEs as proposed in (Goyal & Kaushal, 2019). These values are then arranged on Table 3.6

Table 3.6 Criteria Values of SSAs, DSAs, Velocity and Location

UE	**DSAs**	**SSAs**	**Velocity (Km/h)**	**Location(Km)**
UE1	1	0	03	0.025
UE2	0	1	06	0.050
UE3	1	1	09	0.075
UE4	1	0	12	0.010
UE5	0	1	15	0.125
UE6	1	1	18	0.150
UE7	1	0	21	0.175

Table 3.6 Criteria Values of SSAs, DSAs, Velocity and Location

UE8	0	1	24	0.200
UE9	1	1	27	0.225
UE10	1	0	30	0.250
UE11	0	1	33	0.275
UE12	1	1	36	0.300
UE13	1	0	39	0.325
UE14	0	1	42	0.350
UE15	1	1	45	0.375
UE16	1	0	48	0.400
UE17	0	1	51	0.425
UE18	1	1	54	0.450
UE19	1	0	57	0.475
UE20	0	1	60	0.500
UE21	1	1	63	0.525
UE22	1	0	66	0.550
UE23	0	1	69	0.725
UE24	1	1	72	0.600
UE25	1	0	75	0.625
UE26	0	1	78	0.650
UE27	1	1	81	0.675
UE28	1	0	84	0.700
UE29	0	1	87	0.725
UE30	1	1	90	0.750
UE31	1	0	93	0.775
UE32	0	1	96	0.800
UE33	1	1	99	0.825
UE34	1	0	102	0.850
UE35	0	1	105	0.875
UE36	1	1	108	0.900
UE37	1	0	111	0.925

Table 3.6 Criteria Values of SSAs, DSAs, Velocity and Location

UE38	0	1	114	0.950
UE39	1	1	117	0.925
UE40	1	0	120	1.000

3.6.2 Define weights for each criterion.

Weights are defined based on handover requirement priority as follows:

Delay Sensitive application with a weight of 35%, Speed sensitive application with a weight of 15%, Speed with a weight of 25% and distance with a weight of 25% (Goyal & Kaushal, 2019)

3.6.2 Determination of the normalized Matrix using equation 2.8 and the Table 3.7 shows the values obtained based on the equation for each criterion.

Table 3.7 Normalized values of DSA, SSA, Velocity and Distance

UEs	**DSAs**	**SSAs**	**Velocity (Km/h)**	**Location(Km)**
UE1	0.19245009	0	0.006720649	0.006698875
UE2	0	0.196116135	0.013441297	0.013397750
UE3	0.19245009	0.196116135	0.020161946	0.020096625
UE4	0.19245009	0	0.026882595	0.002679550
UE5	0	0.196116135	0.033603243	0.033494374
UE6	0.19245009	0.196116135	0.040323892	0.040193249
UE7	0.19245009	0	0.047044541	0.046892124
UE8	0	0.196116135	0.053765189	0.053590999
UE9	0.19245009	0.196116135	0.060485838	0.060289874
UE10	0.19245009	0	0.067206487	0.066988749
UE11	0	0.196116135	0.073927135	0.073687624
UE12	0.19245009	0.196116135	0.080647784	0.080386499
UE13	0.19245009	0	0.087368433	0.087085373

Table 3.7 Normalized values of DSA, SSA, Velocity and Distance

UE14	0	0.196116135	0.094089081	0.093784248
UE15	0.19245009	0.196116135	0.100809730	0.100483123
UE16	0.19245009	0	0.107530378	0.107181998
UE17	0	0.196116135	0.114251027	0.113880873
UE18	0.19245009	0.196116135	0.120971676	0.120579748
UE19	0.19245009	0	0.127692324	0.127278623
UE20	0	0.196116135	0.134412973	0.133977498
UE21	0.19245009	0.196116135	0.141133622	0.140676372
UE22	0.19245009	0	0.147854270	0.147375247
UE23	0	0.196116135	0.154574919	0.194267371
UE24	0.19245009	0.196116135	0.161295568	0.160772997
UE25	0.19245009	0	0.168016216	0.167471872
UE26	0	0.196116135	0.174736865	0.174170747
UE27	0.19245009	0.196116135	0.181457514	0.180869622
UE28	0.19245009	0	0.188178162	0.187568497
UE29	0	0.196116135	0.194898811	0.194267371
UE30	0.19245009	0.196116135	0.201619460	0.200966246
UE31	0.19245009	0	0.208340108	0.207665121
UE32	0	0.196116135	0.215060757	0.214363996
UE33	0.19245009	0.196116135	0.221781406	0.221062871
UE34	0.19245009	0	0.228502054	0.227761746
UE35	0	0.196116135	0.235222703	0.234460621
UE36	0.19245009	0.196116135	0.241943352	0.241159496
UE37	0.19245009	0	0.248664000	0.247858370
UE38	0	0.196116135	0.255384649	0.254557245
UE39	0.19245009	0.196116135	0.262105298	0.247858370
UE40	0.19245009	0	0.268825946	0.267954995

3.6.4Analysis of the weighted Normalized values using equation 2.9 and values obtained using the equation for all criteria shown on Table 3.8

Table 3.8 Weighted Normalized Values of DSAs, SSAs, Velocity and distance

	DSAs	**SSAs**	**Velocity (Km/h)**	**Location(Km)**
UE1	0.067357531	0	0.001680162	0.001674719
UE2	0	0.02941742	0.003360324	0.003349437
UE3	0.067357531	0.02941742	0.005040486	0.005024156
UE4	0.067357531	0	0.006720649	0.000669887
UE5	0	0.02941742	0.008400811	0.008373594
UE6	0.067357531	0.02941742	0.010080973	0.010048312
UE7	0.067357531	0	0.011761135	0.011723031
UE8	0	0.02941742	0.013441297	0.013397750
UE9	0.067357531	0.02941742	0.015121459	0.015072468
UE10	0.067357531	0	0.016801622	0.016747187
UE11	0	0.02941742	0.018481784	0.018421906
UE12	0.067357531	0.02941742	0.020161946	0.020096625
UE13	0.067357531	0	0.021842108	0.021771343
UE14	0	0.02941742	0.023522270	0.023446062
UE15	0.067357531	0.02941742	0.025202432	0.025120781
UE16	0.067357531	0	0.026882595	0.026795500
UE17	0	0.02941742	0.028562757	0.028470218
UE18	0.067357531	0.02941742	0.030242919	0.030144937
UE19	0.067357531	0	0.031923081	0.031819656
UE20	0	0.02941742	0.033603243	0.033494374
UE21	0.067357531	0.02941742	0.035283405	0.035169093
UE22	0.067357531	0	0.036963568	0.036843812
UE23	0	0.02941742	0.038643730	0.048566843
UE24	0.067357531	0.02941742	0.040323892	0.040193249
UE25	0.067357531	0	0.042004054	0.041867968
UE26	0	0.02941742	0.043684216	0.043542687

Table 3.8 Weighted Normalized Values of DSAs, SSAs, Velocity and distance

UE27	0.067357531	0.02941742	0.045364378	0.045217405
UE28	0.067357531	0	0.047044541	0.046892124
UE29	0	0.02941742	0.048724703	0.048566843
UE30	0.067357531	0.02941742	0.050404865	0.050241562
UE31	0.067357531	0	0.052085027	0.051916280
UE32	0	0.02941742	0.053765189	0.053590999
UE33	0.067357531	0.02941742	0.055445351	0.055265718
UE34	0.067357531	0	0.057125514	0.056940436
UE35	0	0.02941742	0.058805676	0.058615155
UE36	0.067357531	0.02941742	0.060485838	0.060289874
UE37	0.067357531	0	0.062166000	0.061964593
UE38	0	0.02941742	0.063846162	0.063639311
UE39	0.067357531	0.02941742	0.065526324	0.061964593
UE40	0.067357531	0	0.067206487	0.066988749

3.6.5Determination of the ideal best and ideal worst value

The ideal best value donated by V+ signifies the maximum value for the weighted normalized value of a criterion while the ideal worst value donated by V- is the minimum value for the weighted normalized value of a criterion. These values for DSAs, SSAs, Velocity and Location are shown on Table 3.9

Table 3.9 Ideal best and Ideal Worst Values for DSAs, SSAs, Velocity and Location.

	DSAs	**SSAs**	**Speed(km/h)**	**Distance(km)**
V+	0.067357531	0.02941742	0.067206487	0.066988749
V-	0	0	0.001680162	0.000669887

3.6.6 Determination of the separation measures using the positive ideal solution using equation 2.10 and negative ideal solution using equation 2.11. The relative closeness to positive ideal solution using equation 2.12 and also ranking of the values to closeness to ideal solution based on preference order are depicted on Table 3.10

Table 3.10 Selection of UE based on AHP/TOPSIS Technique

	DSA	**SSA**	**Velocity (Km/h)**	**Location (Km)**	**Si+**	**Si-**	**Ci**	**RANK**
UE1	0.067357531	0	0.001680162	0.001674719	0.118161	0.001005	0.008432	01
UE2	0	0.02941742	0.003360324	0.003349437	0.090146	0.073569	0.449373	18
UE3	0.067357531	0.02941742	0.005040486	0.005024156	0.11064	0.029927	0.212903	05
UE4	0.067357531	0	0.006720649	0.000669887	0.116014	0.00504	0.041638	02
UE5	0	0.02941742	0.008400811	0.008373594	0.083029	0.074209	0.471952	20
UE6	0.067357531	0.02941742	0.010080973	0.010048312	0.105084	0.031999	0.233427	07
UE7	0.067357531	0	0.011761135	0.011723031	0.107382	0.01496	0.122279	03
UE8	0	0.02941742	0.013441297	0.013397750	0.075912	0.075517	0.498693	23
UE9	0.067357531	0.02941742	0.015121459	0.015072468	0.099726	0.035405	0.262004	08
UE10	0.067357531	0	0.016801622	0.016747187	0.102310	0.022071	0.177448	04
UE11	0	0.02941742	0.018481784	0.018421906	0.068796	0.077459	0.529617	26
UE12	0.067357531	0.02941742	0.020161946	0.020096625	0.0946	0.039804	0.296153	10
UE13	0.067357531	0	0.021842108	0.021771343	0.097493	0.029185	0.230388	06
UE14	0	0.02941742	0.02352227	0.023446062	0.061679	0.079989	0.564624	30
UE15	0.067357531	0.02941742	0.025202432	0.025120781	0.089746	0.044906	0.333496	12
UE16	0.067357531	0	0.026882595	0.026795500	0.092973	0.036300	0.280803	09
UE17	0	0.02941742	0.028562757	0.028470218	0.054562	0.083054	0.603520	33
UE18	0.067357531	0.02941742	0.030242919	0.030144937	0.085210	0.050497	0.372104	13
UE19	0.067357531	0	0.031923081	0.031819656	0.088793	0.043416	0.328389	11
UE20	0	0.02941742	0.033603243	0.033494374	0.047445	0.086596	0.646041	34
UE21	0.067357531	0.02941742	0.035283405	0.035169093	0.081047	0.056434	0.410484	15
UE22	0.067357531	0	0.036963568	0.036843812	0.085005	0.050532	0.372829	14

Table 3.8 Weighted Normalized Values of DSAs, SSAs, Velocity and distance

UE23	0	0.02941742	0.03864373	0.048566843	0.033988	0.095199	0.736907	35
UE24	0.067357531	0.02941742	0.040323892	0.040193249	0.077316	0.062616	0.447477	17
UE25	0.067357531	0	0.042004054	0.041867968	0.081662	0.057648	0.413812	16
UE26	0	0.02941742	0.043684216	0.043542687	0.033212	0.094894	0.740748	36
UE27	0.067357531	0.02941742	0.045364378	0.045217405	0.074082	0.068980	0.482168	21
UE28	0.067357531	0	0.047044541	0.046892124	0.078821	0.064764	0.45105	19
UE29	0	0.02941742	0.048724703	0.048566843	0.026095	0.099548	0.792308	37
UE30	0.067357531	0.02941742	0.050404865	0.050241562	0.071413	0.075477	0.513835	25
UE31	0.067357531	0	0.052085027	0.051916280	0.076539	0.071881	0.484306	22
UE32	0	0.02941742	0.053765189	0.053590999	0.018978	0.104479	0.846278	38
UE33	0.067357531	0.02941742	0.055445351	0.055265718	0.069374	0.082078	0.541939	28
UE34	0.067357531	0	0.057125514	0.056940436	0.074867	0.078997	0.513423	24
UE35	0	0.02941742	0.058805676	0.058615155	0.011861	0.109651	0.902386	39
UE36	0.067357531	0.02941742	0.060485838	0.060289874	0.068023	0.088758	0.566129	31
UE37	0.067357531	0	0.062166	0.061964593	0.073845	0.086114	0.538350	27
UE38	0	0.02941742	0.063846162	0.063639311	0.004745	0.115031	0.960388	40
UE39	0.067357531	0.02941742	0.065526324	0.061964593	0.067566	0.093267	0.579902	32
UE40	0.067357531	0	0.067206487	0.066988749	0.073501	0.09323	0.559164	29

3.7 **Development of the improved vertical handover decision schemeusing adaptive control technique**

The developed vertical handover decision scheme accommodated modification by adapting the appropriate triggering points of hysteresis margin and time to trigger.

3.7.1Hysteresis Margin and Time to Trigger

This research adopted the adaptive hysteresis margin and time to trigger selection technique. The 3GPP standard for specified range value of HM based on 3GPP is 0 to 30 (dB). Table 3.11 shows the HM and TTT pair based on received signal strength of the user equipment.RSS values used were based on standard, maximum received signal also set to be the highest(-40dBm)and minimum received signal was set as the lowest (-140dBm) based on(CableFree, 2019). The adaptive HM values were obtained using equation 2.21 while the TTT values were used based on 3GPP standard as explained in the work of (Goyal & Kaushal, 2019).

Table 3.11 Generation of adaptive hysteresis margin and Time to trigger

RSRPserving (dBm)	**RSRPtarget (dBm)**	**RSRQserving (dB)**	**RSRQtarget (dB)**	**TSserving (dBm)**	**TStarget (dBm)**	**HM Mod-adaptive (dB)**
-70.00	-68.00	16.83544	20.83870	-53.16	-47.16	-18.4470
-75.00	-68.00	14.25000	18.19718	-60.75	-49.80	-36.4188
-80.00	-76.00	13.81818	19.25333	-66.18	-56.75	-25.5028
-85.00	-99.00	28.33333	24.42857	-56.67	-74.57	19.99673
-90.00	-90.00	13.15384	25.52238	-76.85	-64.48	-30.5305
-95.00	-85.00	28.78787	16.31313	-66.21	-68.69	4.09543
-100.00	-130.00	28.78787	28.06818	-71.21	-101.93	22.85343
-105.00	-125.00	26.25000	20.47413	-78.75	-104.53	20.33441
-110.00	-120.00	24.30232	21.50943	-85.70	-98.49	12.80434
-115.00	-115.00	22.76041	22.76041	-92.24	-92.24	0
-120.00	-110.00	21.50943	24.30232	-98.49	-85.70	-22.3388
-125.00	-105.00	20.47413	26.25000	-104.53	-78.75	-63.1138
-130.00	-100.00	28.06818	28.78787	-101.93	-71.21	-95.9345
-85.00	-95.00	16.31313	28.78787	-68.69	-66.21	-4.74290
-90.00	-90.00	25.52238	13.15384	-64.48	-76.85	15.13145
-99.00	-85.00	24.42857	28.33333	-74.57	-56.67	-59.9706
-76.00	-80.00	19.25333	13.81818	-56.75	-66.18	13.78459
-68.00	-75.00	18.19718	14.25000	-49.80	-60.75	16.44961
-68.00	-70.00	20.83870	16.83544	-47.16	-53.16	11.42302

The HM values of 8.1, 9.6, 14.0 and 0 (dB) with the correspondingTTT values of 128, 256, 320 and 512(ms) from Table 3.11 where selected and shown on Table 3.12. The reason for this is to maintain the tradeoff between ping pong rate and radio link failure rate. Too small TTT value decreases ping pong rate but increases RLF rate and vice versa. These HM and TTT pair values evaluated form Table 3.11 are shown on Table 3.12

Table 3.12 Pair of Values for the modified adaptive HM and TTT

HMmod-adp(dB)	8.1	9.6	14.0	0
TTT(ms)	128	256	320	512

3.8 Performance metrics and their equations

Handover Performance as key factor in mobility management in LTE Advanced networks is measured in terms of Handover Ping Pong Probability(HPPP), Handover Failure Probability(HOFP) and Radio Link Failure Probability (RLFP).

i. Handover Ping Pong Probability (HPPP)

This calculates the frequency of unnecessary handover in a system. The HPPP counts when the UE disconnects its communication link from the serving eNodeB and establishes a new connection with the target eNodeB, and then bounces back to the serving eNodeB under a time period that is less than the critical ping-pong interval T_c. $T_c$is defined as a short time period (which is assumed to be 2 s) required to calculate the unnecessary handover between neighbouring cells. The HPPP should be considered if the condition shown mathematically in equation 3.8 is satisfied (Alhammadi *et al*., 2018)

$$HPPP = P_r(T_i \leq T_c) \qquad (3.8)$$

where

T_i is the time passed by the UEs starting from the handover initiation in eNodeB and its return to the same eNodeB

T_c is the critical ping pong interval

ii. Handover Failure Probability(HFP)

Handover failure occurs with expiration of minimum time to stay when TTT is still active

This is represented mathematically in equation 3.9(Issaka *et al*., 2012)

$$P_{HOF} = \begin{cases} \frac{2}{\pi}\theta_t \text{ if } \frac{R-r}{T} \leq v \ \leq \frac{R+r}{T} \\ 0 \qquad \qquad Otherwise \end{cases} \quad (3.9)$$

where

$$\theta_t = ar \cos\{\frac{(vT)^2 + R^2 - r^2}{2vTR}\}$$

iii. Radio Link Failure Probability(RLFP)

This is recorded when a UE losses connectivity over eNB in a network which is represented mathematically in equation 3.10 (Issaka *et al*., 2012)

$$RLFP = \begin{cases} \frac{2}{\pi}\theta_t \text{ if } \frac{R-r}{T} \leq v \ \leq \frac{d1}{T} \\ \frac{2}{\pi}\theta_R \text{ if } \frac{d1}{T} \leq v \ \leq \frac{R+r}{T} \end{cases} (3.10)$$

where

$$\theta_t = ar \cos\{\frac{(vT)^2 + R^2 - r^2}{2vTR}\}$$

R is the distance between the eNodeB and the outbound

r is the distance between the eNodeB and the inbound

v is velocity of UE

T is time needed for a handover to occur

3.9 **Flow chart of handover decision based on work of (Goyal & Kaushal, 2019)**

The flow chart of the work of (Goyal & Kaushal, 2019) is shown in Figure 4.1. It depicts the handover decision process used from the start using the AHP/TOPSIS technique and Q learning to the end. The flow chart shows how RSRP was used to make handover decision. This led to mathematical computations based on AHP-TOPSIS technique to rank user equipment and enodeB then Q learning used for generating triggering points of hysteresis margin and time to trigger before handover is being executed.

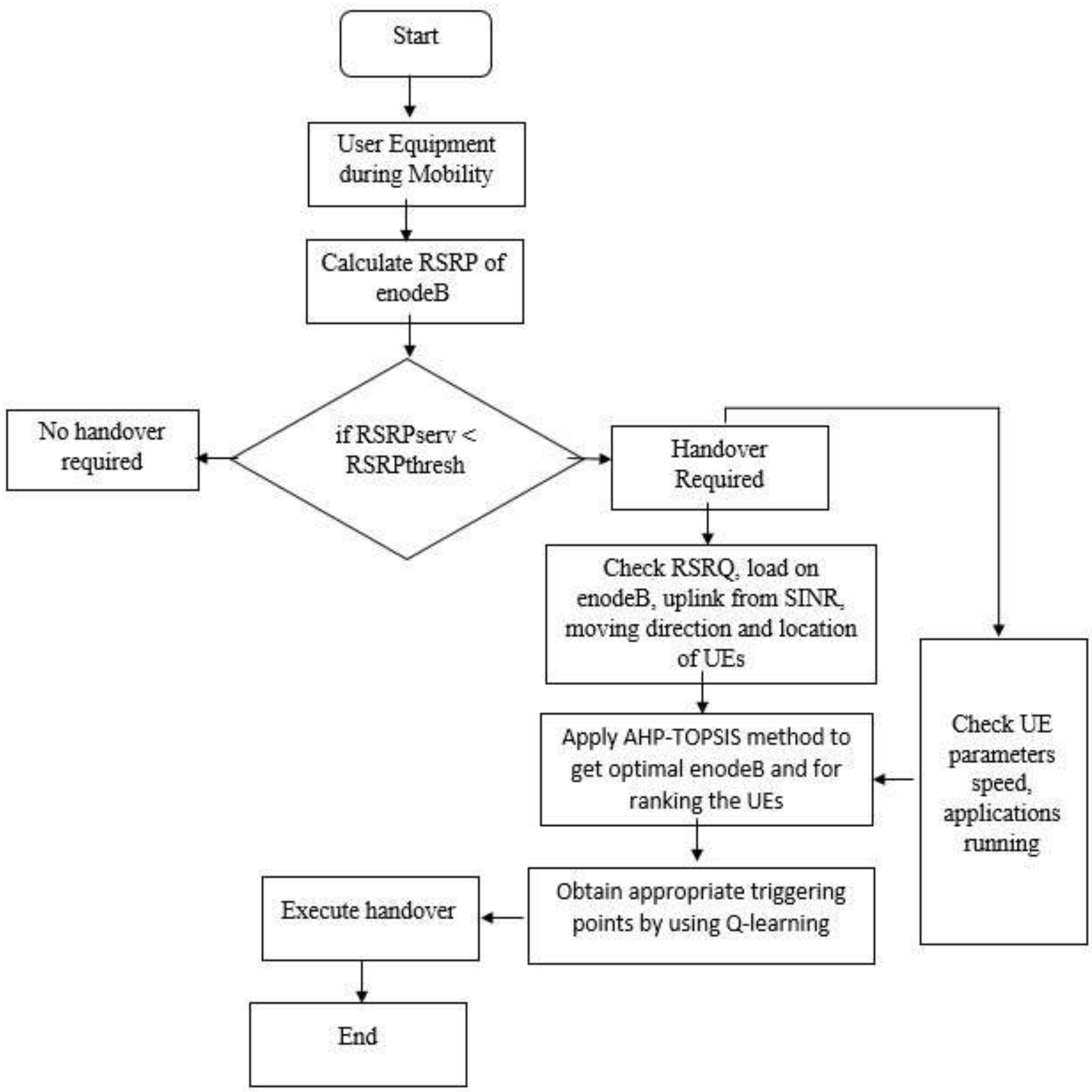

Figure 3.1 Existing Flowchart of the Handover Decision based on AHP/TOPSIS and Q Learning

3.10 Proposed Flow chart based on Adaptive AHP/TOPSIS Technique

The flow chart that will be used for this work is shown in Figure 4.2. It shows the handover decision process that will be adapted using the Adaptive AHP/ TOPSIS technique. The flow chart shows how RSRP was used to make handover decision. This led to mathematical computations based on AHP-TOPSIS technique to rank user equipment and enodeB then a modified adaptive technique is used for generating triggering points of hysteresis margin and time to trigger before handover is being executed.

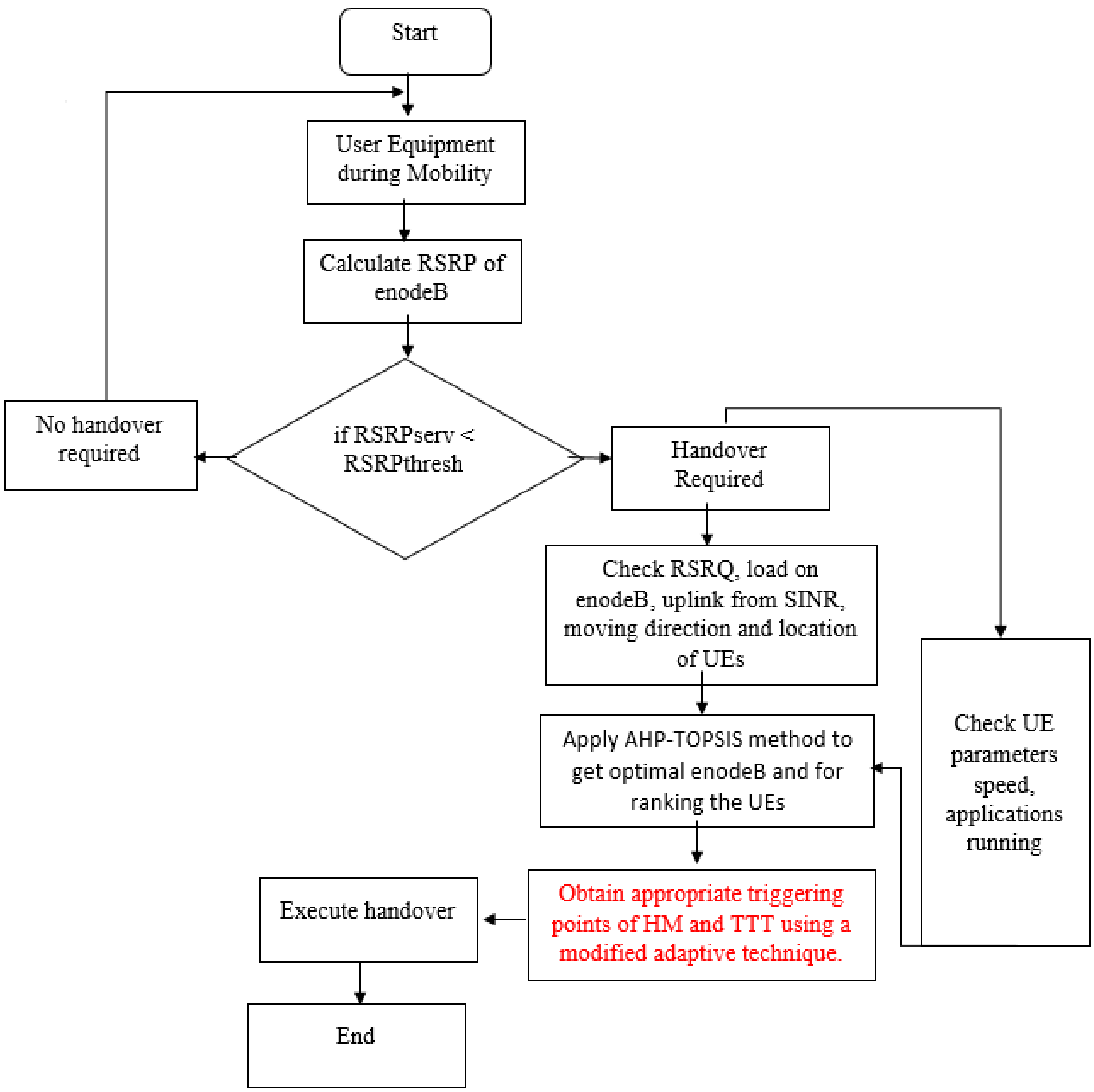

Figure3.2 Flow Chart of the Proposed Handover Decision based on Adaptive AHP/TOPSIS

3.11 Simulation Parameters

The simulation parameters used in this work is shown as Table 3.14

Table 3.14 Simulation Parameters (Goyal & Kaushal, 2019)

Parameters	Values
RSS_{Thresh}	-46dBm
Traffic Type	Delay and Speed sensitive
Mobility direction	Random
Velocity	3, 30 and 120km/h
Number of eNB	19
Number of UEs	40
Number of eNB/Cluster	3
Shadowing Standard deviate	8dB
HMmax	30dB
HMmin 0	

The assumptions made in order to carry out methodologies i ii and iii.

i. The effect of direction was neglected

ii. Only Radio Resource Control (RRC) connected devices were considered as load.

3.8Conclusion

The work presented in this chapter covers the step by step method and methodology used to achieve all the three objectives of this report.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results of optimal selection of eNodeB and UE based on AHP/TOPSIS are being discussed. The performance analysis of handover ping pong probability and handover failure probability at speeds of 3km/h, 30km/h and 120km/h are discussed. The simulation results of the improved vertical handover decision algorithm and that of the existing vertical handover decision algorithm based on ping pong rate and handover failure rate are also discussed. The comparison between the proposed technique and that of Goyal & Kaushal, 2019 in terms of ping pong probability and handover failure probability.

4.2 Results

The simulation results obtained are discussed in this section. The results are based on optimal selection of eNodeB and User Equipment, also on ping pong probability, handover failure probability and radio link failure probability.

4.2.1 Selection of eNodeB by using AHP/TOPSIS

In Table 4.1, 19 eNodeBs are ranked and the alternative closest to 1 is selected as the least in order of priority as it has the best network parameters so does not require immediate handover. From Table 4.1, it can be observed that eNB12 with the lowest value of 0.42 as compared to 1 is ranked first and will be considered as the highest priority. ENode14 with the highest of 0.86 as compared to 1 is ranked the lowest and has the lowest priority.

Table 4.1 Optimal eNodeB selection based on AHP/TOPSIS

eNodeB	CLOSEST TO IDEAL SOLUTION	RANK
ENB1	0.50	05
ENB2	0.49	04
ENB3	0.58	11
ENB4	0.54	07
ENB5	0.43	02
ENB6	0.52	06
ENB7	0.62	15
ENB8	0.59	13
ENB9	0.75	18
ENB10	0.58	12
ENB11	0.54	08
ENB12	0.42	01
ENB13	0.54	09
ENB14	0.86	19
ENB15	0.70	16
ENB16	0.61	14
ENB17	0.57	10
ENB18	0.75	17
ENB19	0.47	03

4.2.2 Selection of User Equipment using AHP/TOPSIS

Table 4.2 shows the optimal selection of UE among 40 different UEs at different speeds and locations from eNB. These UEs are ranked and the alternative closest to 1 is selected as the least alternative in order of priority as it has the best network parameters so does not require immediate handover.UE1 which has the lowest value of 0.008432 as compared to the 1is ranked highest in order of priority and UE38 with the highest value of 0.960388 as compared to 1 is ranked as the least in order of priority.

Table 4.2 Optimal Selection of UE based on AHP/TOPSIS

USER EQUIPMENT (UE)	ALTERNATIVE CLOSEST TO 1	RANK
UE1	0.008432	01
UE2	0.449373	18
UE3	0.212903	05
UE4	0.041638	02
UE5	0.471952	20
UE6	0.233427	07
UE7	0.122279	03
UE8	0.498693	23
UE9	0.262004	08
UE10	0.177448	04
UE11	0.529617	26
UE12	0.296153	10
UE13	0.230388	06

Table 4.2 Optimal Selection of UE based on AHP/TOPSIS

UE14	0.564624	30
U15	0.333496	12
UE16	0.280803	09
UE17	0.60352	33
UE18	0.372104	13
UE19	0.328389	11
UE20	0.646041	34
UE21	0.410484	15
UE22	0.372829	14
UE23	0.736907	35
UE24	0.447477	17
UE25	0.413812	16
UE26	0.740748	36
UE27	0.482168	21
UE28	0.45105	19
UE29	0.792308	37
UE30	0.513835	25
UE31	0.484306	22
UE32	0.846278	38
UE33	0.541939	28
UE34	0.513423	24
UE35	0.902386	39

Table 4.2 Optimal Selection of UE based on AHP/TOPSIS

UE36	0.566129	31
UE37	0.538350	27
UE38	0.960388	40
UE39	0.579902	32
UE40	0.559164	29

4.2.3 Handover Ping Pong Probability(HPPP)

Figure 4.1 shows the HPPP at different speeds of 3km/h, 30km/h and 120km/h based on different TTT values of 128, 256, 320 and 512 (ms). It can be observed that HPPP at TTT values of 256ms and 512ms was 0 which indicates a negligible impact of ping pong at all the three different velocities. At same velocities of 3km/h, 30km/h and 120km/h, the HPPP are 0.15 and 0.14, 0.13 and 0.13 then 0.15 and 0.14 at 128ms and 320ms respectively. This low values of HPPP indicates the minimal level of call dropping and eventually the degradation of the network performance.

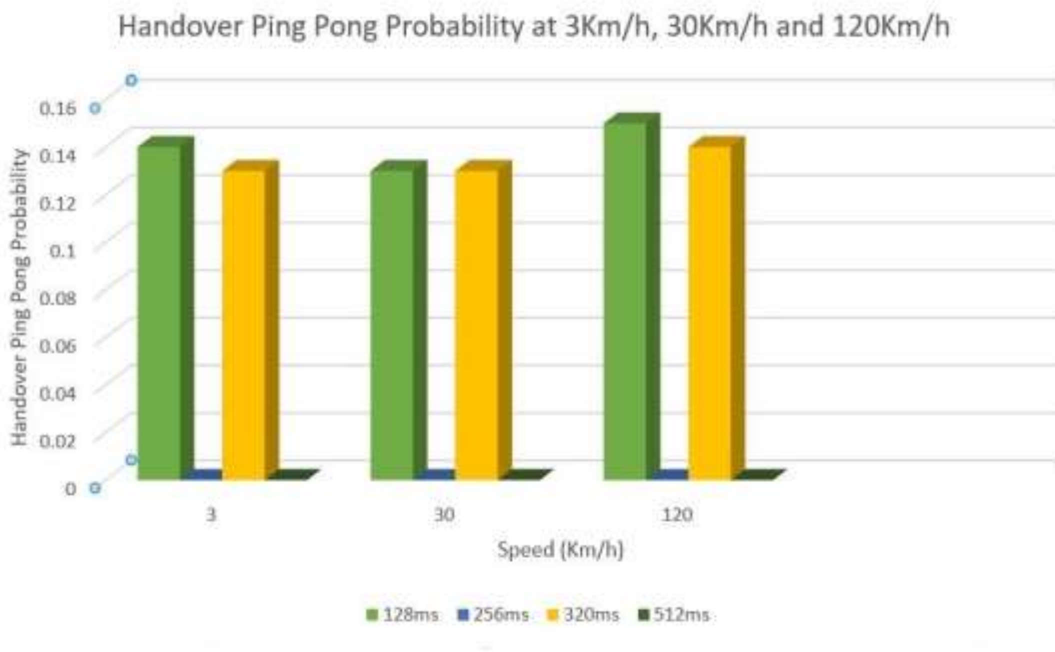

Figure 4.1 Handover Ping Pong Probability at 3km/h, 30km/h and 120km/h

4.2.4 Handover Failure Probability(HFP)

Figure 4.2 shows the HFP at different speeds of 3km/h, 30km/h and 120km/h based on different TTT values of 128, 256, 320 and 512 (ms). The result obtained at 3km/h was 0.12, 0.11, 0.12 and 0.1 while at 30km/h the HFP was 0.13, 0.14, 0.12 and 0.1 also at 120km/h the HFP was 0.13, 0.14, 0.14 and 0.12 respectively. From the results obtained it clearly shows that average HFP increases as speed increases although the results were at the minimal level. This also signifies minimal effect on call dropping and eventually network performance degradation.

Figure 4.2 Handover Failure Probability at 3km/h, 30km/h and 120km/h

4.2.5 Radio Link Failure Probability(RLFP)

Figure 4.3 shows the radio link failure Probability at the speeds of 3km/h, 30km/h and 120km/h based on different TTT values of 128ms, 256ms, 320ms and 512ms. It showed 0 RLFP at 120km/h due the high speed and the limited small distance involved. Also it obtained at 3km/h values of 0, 0.32, 0.37 and 0.44 while at 30km/h, it was 0, 0.31, 0.36 and 0.41 at 128ms, 256ms,320ms and 512ms TTT values respectively. This indicates decrease in RLFP as speed increases.

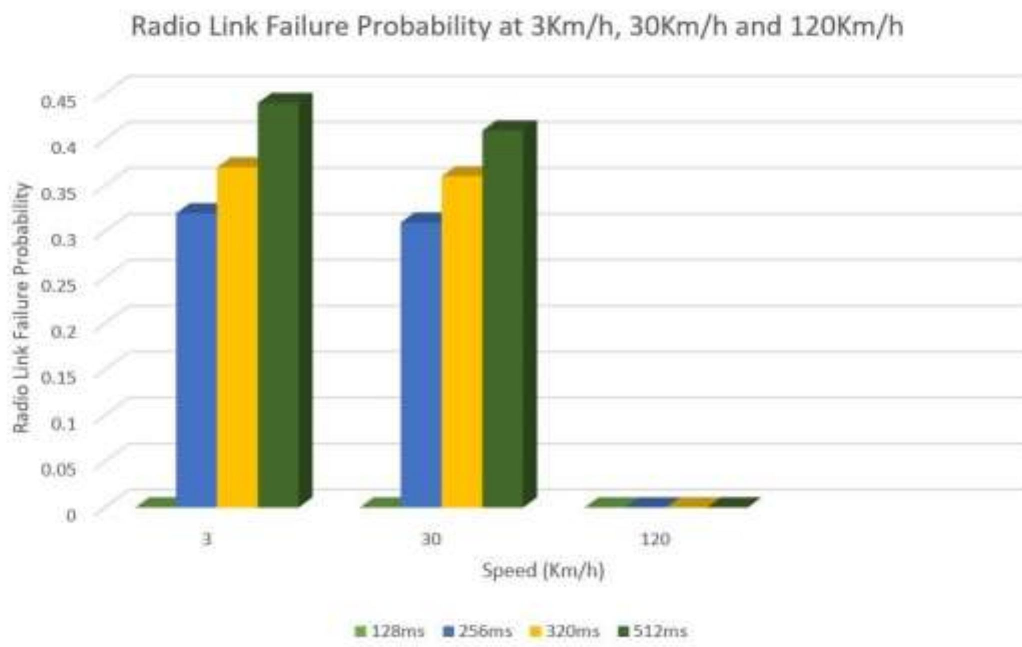

Figure 4.3 Radio Link Failure Probability at 3km/h, 30km/h and 120km/h

4.3 Validation between Proposed Technique and that of Goyal & Kaushal (2019)

This section shows the validation results of developed technique with the work of Goyal & Kaushal, 2019 based on handover ping pong probability and handover failure probability.

4.3.1 Handover Ping Pong Probability

Figure 4.4 Shows the comparison between the proposed technique using adaptive control and the base paper technique using Q learning. The result showed improvement of 29%, 28% and 13% at 3km/h, 30km/h and 120km/h respectively as compared to the work of Goyal & Kaushal (2019). This shows that the improvement in handover ping pong probability as compared to Goyal & Kaushal (2019).

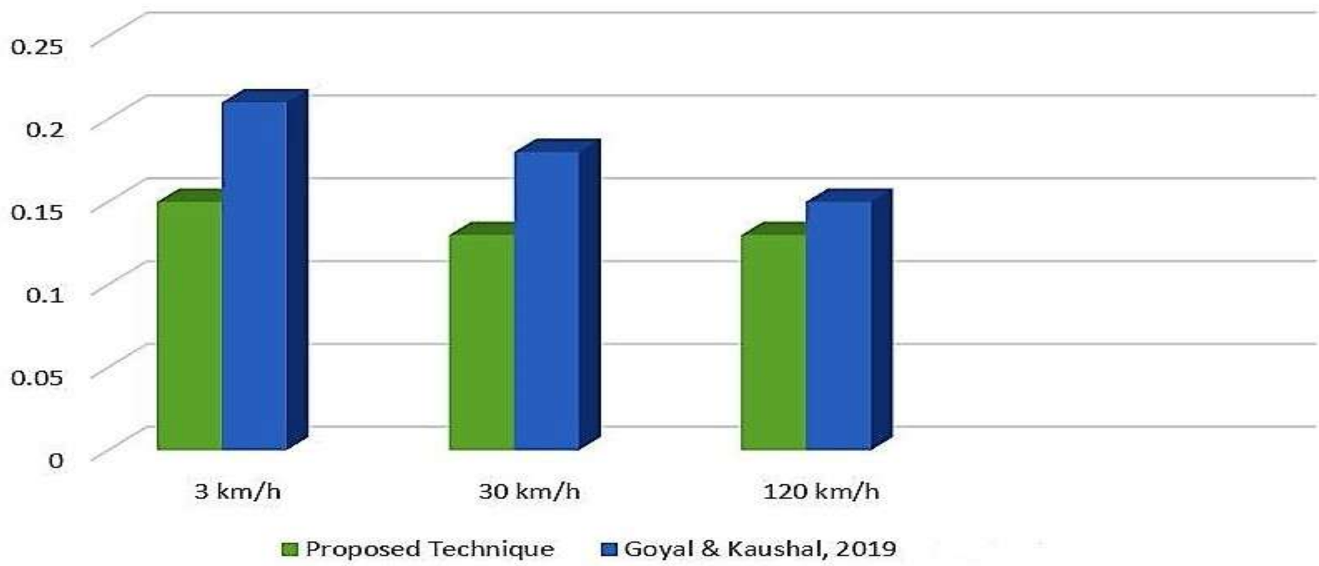

Figure 4.4 Handover Ping Pong Probability

4.3.2 Handover Failure Probability

Figure 4.5 shows the validation between the proposed technique using adaptive control and the base paper technique based on Q learning. The result from Figure 4.5 shows handover failure probabilities at 30km/h and 120km/h have been maintained with an improvement of 10% at 60km/h as compared to the work of Goyal & Kaushal (2019).

Figure 4.5 Handover Failure Probability

4.4 Summary of Results

From the discussion above, it can be shown that AHP/TOPSIS technique was used for optimal selection of both eNodeB and UE. Handover ping pong, Handover failure probabilities and Radio Link Failure Probabilities were also analyzed based on different TTT values at the speeds of 3km/h, 30km/h and 120km/h.The results showed good performance based on the performance indicators in terms of HPPP and HFP also the inverse relationship between HPPP and RLFP.This result also showed handover ping pong probability improvement of 29%, 28% and 13% at 30km/h, 60km/h and 120km/h respectively. The result also showed handover failure probability was maintained at 30km/h and 120km/h with an improvement of 10% at 60km/h.

CHAPTER FIVE

CONCLUSION

5.1 Conclusion

This research proposes, an improved adaptive based handover decision technique to minimize handover ping pong probability. AHP/TOPSIS technique was used for optimal selection of UE and eNodeB and adapting triggering point conditions of hysteresis margin and time to trigger values to enhance handover decision process.This is to minimize the effect of ping pong and subsequently handover failure based on speed and distance between a UE and eNodeB. The results obtained showed how eNodeB and UE are ranked based on order of necessity. The results obtained for Handover Ping Pong Probability (HPPP) were 0.15, 0.13 and 0.13 at 3km/h, 30km/h and 120km/h respectively. This shows that HPPP decreases with increase in velocity. Handover Failure probabilities (HFP) at same speeds were also 0.13, 0.14 and 0.14 respectively as they increase with increase in velocity. This shows a minimum tradeoff between HPPP AND HFP. These results obtained as HPPP decrease can lead to call dropping also decreases and subsequently degradation of network performance. Radio Link Failure Probability (RLFP) was 0 at 120km/h due to the high speed and limited distance covered while with values of 0.44 and 0.41 at 3km/h and 30km/h respectively. This also shows how RLFP decreases with increase in velocity. Comparison and Validation of results with that of Goyal and Kaushal, 2019 based on HPPP and HFP were also obtained. An improvement of 29%, 28% and 13% at 30km/h, 60km/h and 120km/h respectively as compared to that of Goyal & Kaushal, 2019. The result also showed handover failure probability was maintained at 30km/h and 120km/h with an improvement of 10% at 60km/h.

5.2 Significant Contributions

The contributions of this dissertation are as follows:

i. Development of a handover decision scheme using adaptive control based technique at 3km/h, 30km/h and 120km/h to achieve: 29%, 28% and 13% reduction in handover ping pong probability respectively.
ii. The developed vertical handover decision scheme also maintained the handover failure rate probability at 3km/h and 120km/h with a reduction of 10% at 30km/h
iii. The adaptive nature of the proposed handover scheme outperformed that of Goyal & kaushal (2019) at all speeds

5.3 Recommendation for Further Study

In view of the current results obtained thus far, the following are recommended for further study:

i. Subsequent researchers can work on incorporating an offset parameter with the aim of addressing handover failure effect
ii. Researchers can further extend this work by incorporating energy efficient mechanism with guaranteed quality of service requirements such as battery consumption and packet loss during handover.
iii. Cognitive algorithms can be exploited for smart user equipment terminals for handover decision.

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APPENDIX A

MATLAB m-FILE "Handover Ping Pong Probability"

```
v= 30; %UE speed in (Km/h)%

B=0.3; %The numerical solution shows that in the simulated scenario the ratio (r/R = B) remains approximately constant and equal to 0.73%

TTT= 128; %Time-to-Trigger in (ms)%

T= TTT+50; %the time for an inbound HO= Time-to- Trigger + HO Preparation Time%

valueofHOPP= zeros(1,21);

valueofD=[40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240];

%Distance range between 40 to 240 (m)%

i= 0;

D= 30; %Distance in (m)%

while i<= 20

i= i+1;

D= D+10;

F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000 +651/2500).^(1/2))/7;

Q=integral(F,0,90);

R= Q/pi; %Small cell radius (Source cell)%

r= R*B; %Macro cell radius (Target cell)% %Handover Failure Probability%

if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))

    thetat=acos(((((v*T).^2)+(R.^2)- (r.^2))./(2*v*T.*R));

    %the maximum angle for which T expires before the UE gets out of the HOF region%

HOPP=(2/pi)*thetat;

else

HOF=0;

end

valueofHOPP(i)= HOPP;

end
```

```
plot(valueofD,valueofHOPP,'-or','LineWidth',1)
axis([40 240 0 1])
hold on
%Scenario with TTT= 256%
TTT= 256;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000
+651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
if (((v*T)/(1+B)) <= R && R >= ((v*T)/(1-B)))
   thetat=acos(((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R));
HOPP=(2/pi)*thetat;
else
HOPP=0;
end
valueofHOPP(i)= HOPP;
end
plot(valueofD,valueofHOPP,'-+b','LineWidth',1)
%Scenario with TTT= 320%
TTT= 320;
T= TTT+50;
i= 0;
D= 30;
```

```
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000 +651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
    thetat=acos((((v*T).^2)+(R.^2)- (r.^2))./(2*v*T.*R));
HOPP=(2/pi)*thetat;
else
HOPP=0;
end
valueofHOPP(i)= HOPP;
end
plot(valueofD,valueofHOPP,'-*c','LineWidth',1)
%Scenario with TTT= 512%
TTT= 512;
T=TTT+50;
i= 0;
D= 30;
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000 +651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
```

```
if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
    thetat=acos(((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R));
HOPP =(2/pi)*thetat;
else
HOPP=0;
end
valueofHOPP(i)= HOPP;
end
plot(valueofD,valueofHOPP,'-dk','LineWidth',1)
xlabel('Distance(m)')
ylabel('HOPP Probability at 120km/h')
legend('TTT=128 ms','TTT=256 ms','TTT=320 ms','TTT=512 ms')
grid
```

APPENDIX B

MATLAB m-FILE "Handover Failure Probability"

```
v= 30; %UE speed in (Km/h)%

B=0.3; %The numerical solution shows that in the simulated scenario the ratio (r/R = B) remains approximately constant and equal to 0.73%

TTT= 128; %Time-to-Trigger in (ms)%

T= TTT+50; %the time for an inbound HO= Time-to- Trigger + HO Preparation Time%

valueofHOF= zeros(1,21);

valueofD=[40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240];

%Distance range between 40 to 240 (m)%

i= 0;

D= 30; %Distance in (m)%

while i<= 20

i= i+1;

D= D+10;

F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000 +651/2500).^(1/2))/7;

Q=integral(F,0,90);

R= Q/pi; %Small cell radius (Source cell)%

r= R*B; %Macro cell radius (Target cell)% %Handover Failure Probability%

if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))

   thetat=acos(((((v*T).^2)+(R.^2)- (r.^2))./(2*v*T.*R));

   %the maximum angle for which T expires before the UE gets out of the HOF region%

HOF=(2/pi)*thetat;

else

HOF=0;

end

valueofHOF(i)= HOF;

end
```

```
plot(valueofD,valueofHOF,'-or','LineWidth',1)
axis([40 240 0 1])
hold on
%Scenario with TTT= 256%
TTT= 256;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000
+651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
if (((v*T)/(1+B)) <= R && R >= ((v*T)/(1-B)))
   thetat=acos((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R));
HOF=(2/pi)*thetat;
else
HOF=0;
end
valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-+b','LineWidth',1)
%Scenario with TTT= 320%
TTT= 320;
T= TTT+50;
i= 0;
D= 30;
```

```
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000 +651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
    thetat=acos(((((v*T).^2)+(R.^2)- (r.^2))./(2*v*T.*R));
HOF=(2/pi)*thetat;
else
HOF=0;
end
valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-*c','LineWidth',1)
%Scenario with TTT= 512%
TTT= 512;
T=TTT+50;
i= 0;
D= 30;
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000 +651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
```

```
if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
    thetat=acos(((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R));
HOF =(2/pi)*thetat;
else
HOF=0;
end
valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-dk','LineWidth',1)
xlabel('Distance(m)')
ylabel('HOF Probability at 120km/h')
legend('TTT=128 ms','TTT=256 ms','TTT=320 ms','TTT=512 ms')
grid
```

APPENDIX C

MATLAB m-FILE “Radio Link Failure Probability”

```
v= 30; %UE speed in (Km/h)%

B=0.53; %The numerical solution shows that in the simulated scenario the ratio (r/R = B) remains approximately constant and equal to 0.73%

TTT= 128; %Time-to-Trigger in (ms)%

T= TTT+50; %the time for an inbound HO= Time-to- Trigger + HO Preparation Time%

TR=1000; %the RLF occurs after the UE has moved over the HOF region for more than TR%

valueofRLF= zeros(1,21);

valueofD=[40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240];

%Distance range between 40 to 240 (m)%

i= 0;

D= 30; %Distance in (m)%

while i<= 20

i= i+1;

D= D+10;

F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;

Q=integral(F,0,90);

R= Q/pi; %Small cell radius (Source cell)%

r= R*B; %Macro cell radius (Target cell)%

d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2); %the distance covered by the UE from the entry point to the first intersection with the HOF circle%

%Radio Link Failure Probability%

if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <= (R+r)/T)&&(v*TR)<= (2*r))

    thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));

%the maximum angle for which T expires before the UE gets out of the HOF region%

RLF=(2/pi)*thetat;

elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <= (2*R)/T)&&(v*TR)<= (2*r))
```

```
thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2))); %the maximum angle that will lead to RLF%
RLF=(2*thetaR)/pi;
else
RLF=0;
end
valueofRLF(i)= RLF;
end
plot(valueofD,valueofRLF,'-or','LineWidth',2)
axis([40 240 0 1])
hold on
%Scenario with TTT= 256%
TTT= 256;
T= TTT+50;
i= 0;
D = 30;
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 +(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <= (R+r)/T)&&(v*TR)<= (2*r))
thetat=acos(((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
RLF=(2/pi)*thetat;
elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <= (2*R)/T)&&(v*TR)<= (2*r))
  thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2)));
```

```
RLF=(2*thetaR)/pi;
else
RLF=0;
end
valueofRLF(i)= RLF;
end
plot(valueofD,valueofRLF,'-+b','LineWidth',2)
%Scenario with TTT= 320%
TTT= 320;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 +(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <= (R+r)/T)&&(v*TR)<= (2*r))
    thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
RLF=(2/pi)*thetat;
elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <= (2*R)/T)&&(v*TR)<= (2*r))
    thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2)));
RLF=(2*thetaR)/pi;
else
RLF=0;
end
```

```
valueofRLF(i)= RLF;
end
plot(valueofD,valueofRLF,'-*c','LineWidth',2)
%Scenario with TTT= 512%
TTT= 512;
T= TTT+50;
TR=1000;
i= 0;
D= 30;
while i<= 20
i= i+1;
D= D+10;
F=@(inner)(187*D*cos(inner))/14 + (50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <= (R+r)/T)&&(v*TR)<= (2*r))
   thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
RLF =(2/pi)*thetat;
elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <= (2*R)/T)&&(v*TR)<= (2*r))
   thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2)));
RLF =(2*thetaR)/pi;
else
RLF =0;
end
valueofRLF(i)= RLF;
end
plot(valueofD,valueofRLF,'-dk','LineWidth',2)
```

```
xlabel('Distance (m)')
ylabel('RLF Probability')
legend('TTT=128 ms','TTT=256 ms','TTT=320 ms','TTT=512 ms')
grid
```