DEVELOPMENT OF A MODIFIED HANDOVER DECISION ALGORITHM IN LONG TERM EVOLUTION ADVANCED NETWORK USING MOBILITY VECTOR PREDICTION TECHNIQUE

BY

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DEPARTMENT OF TELECOMMUNICATIONS ENGINEERING

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DEPARTMENT OF TELECOMMUNICATIONS ENGINEERING

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NIGERIA

SEPTEMBER, 2021

DECLARATION

I, Abbas Sani Sada declare that this dissertation entitled **“**Development of a Modified Handover Decision Algorithm in Long Term Evolution Advanced Network using Mobility Vector Prediction Technique” has been carried out by me in the Department of Telecommunications Engineering, Ahmadu Bello University, Zaria as part of the requirements for the award of the degree of Master of Science in Telecommunication Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Abbas Sani SADA (Student) ______________________ ________________

(Signature) Date

CERTIFICATION

This Dissertation titled **Development of a Modified Handover Decision Algorithm in Long Term Evolution Advanced Network Using Mobility Vector Prediction Technique** by Abbas Sani SADA meets the regulations governing the award of the degree of Master of Science (M.Sc.) in Telecommunications Engineering of the Ahmadu Bello University and is approved for its' contribution to knowledge and literary presentation.

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Dr. A. M. S. Tekanyi	________________	_____________
(Member, Supervisory Committee)	Signature	Date
Dr. A. D. Usman	________________	______________
(Head of Department)	Signature	Date
Prof. Sani. Abdullahi	________________	______________
(Dean. School of Postgraduate Studies)	Signature	Date

DEDICATION

In loving memory of my dear father, my best friend Late Alh. Sada Sani Store (M.Inst. M (UK) M-NIMARK, MNIM). And to my newly born daughter Bilqis Abbas Sada.

ACKNOWLEDGMENT

"Alhamdulillah" to Almighty Allah "Aza-Wajallah" for helping me throughout my life and in assisting me towards achieving this prestigious dissertation and qualification.

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ABSTRACT

Heterogeneous deployment of access points is considered as a promising technique for improved network performance in 4G Long Term Evolution Advanced (LTE-A) networks. While the heterogeneity of the network results in reduced cell sizes thereby improving network coverage, inter-cell handover process becomes more complex and frequent. This frequent handover is usually caused by small cell (SC) densification and speed of the UEs. Therefore, the different velocities and angles of movement of the mobile users in the cell area leads to excessive scanning process between neighbouring cells and this poses an inherent delay in the handover decision. This research is aimed at addressing unnecessary handovers which drops network quality. And also, to improve network throughput by considering signal to interference plus noise ratio (SINR). This SINR was to mitigate neighbour cell interference. An angle of movement of 30^0 was used to create a shortened candidate list of small cells (SCs) with high signal strength. This helps in reducing delay in searching for target small cells (SCs) for handover. And mobility vector prediction technique was incorporated so that low to medium speed user equipment (UEs) access the same small cell (SC). This helps in reducing the scanning for different target SCs and accurately execute handover. This research was carried out using LTE system level model in MATLAB and the performance of the improved algorithm was compared with the existing work. Probability of Handover was reduced by 33.33%, Probability of Unnecessary handover was also reduced by 44.44%. Network throughput was improved by 40%. To further improve on the strength of the developed algorithm; Radio link failure probability was reduced by 46.37% when compared with the conventional scheme. The results obtained show tremendous improvement in UE call quality.

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LIST OF ABBREVIATIONS

3GPP	Third Generation Partnership Project
4G	Fourth Generation
BER	Bit Error Rate
BS	Base Station
CA	Carrier Aggregation
CoMP	Co-ordinated Multi-Point
CSG	Closed Subscriber Group
dBm	Decibel to one milliwatt
eICIC	Enhanced Inter-Cell Interference Coordination
eNB	Evolved Node B
EPS	Evolved Packet System
ERWP	Enhanced Random Waypoint point
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FAPs	Femto Access Point
FBS	Femto Base Station
FDD	Frequency Division Duplexing
GPS	Global Positioning System
GSM	Global System for Mobile Communication
H	Hysteresis
HeNB	Home Evolved Node B
HFR	Handover Failure Ratio
HHM	Handover Hysteresis Margin
HO	Handover
HOM	Handover Margin
HSS	Home Subscriber Server
IMT-A	International Mobile Telecommunication-Advanced
IP	Internet Protocol
LET	Link Expiration Time
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MAHO	Mobile Assisted Handover
MANET	Mobile Adhoc Network

MATLAB	Matrix Laboratory
MBS	Macro Base Station
MC	Macrocell
MCHO	Mobile Controlled Handover
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MS	Mobile Station
MVPS	Mobility Vector Prediction Scheme
NCHO	Network Controlled Handover
NHO	Number of Handover
ODMRP-MP	On-Demand Multicast Routing Protocol with Mobility Prediction
OFDMA	Orthogonal Frequency Division Multiple Access
OP	Outage Probability
PPR	Ping-Pong Rate
Pu	Probability of Unnecessary Handover
QoS	Quality of Service
RACH	Random Access Channel
RLF	Radio Link Failure
RLS	Recursive Least Square
RPGM	Reference Point Group Mobility
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RWP	Random Waypoint
SAE	System Architecture Evolution
SAMP	Sectorized Ad hoc Mobility Prediction
SC	Small Cell
SINR	Signal to Interference plus Noise Ratio
SNR	Signal to Noise Ratio
TDD	Time Division Duplexing
TDMA	Time Division Multiple Access
Th	Threshold
TTT	Time to Trigger

UE	User Equipment

CHAPTER ONE

INTRODUCTION

1.1 Background

Third Generation Partnership Project (3GPP) defined Long Term Evolution-Advanced (LTE-A) network as a packet-based system specified as a 4G cellular network system (3GPP, 2013). The proliferation of new services and desire for higher data rate to support multimedia and Internet connectivity for mobile devices intensified the development of the LTE-A wireless cellular technology (Bhat *et al.,* 2012). Increasing consumer demand for mobile data and epileptic signal quality within buildings are two issues mobile network operators grapple with. The user equipment in LTE systems communicate to base stations. And the base stations are classified into Home evolved Node B (HeNB) and evolved Node B (eNB). HeNB supports Internet connectivity and is usually installed indoors to enhance coverage and data rate. This type of base station is low-powered and span few meters. Potential security threats are raised due to the fact that they are installed by subscribers not service providers (Bhat *et al.,* 2012). The rapid escalation of mobile data traffic demanded a better and safe systems. Hence, a state-of-the-art technology were developed to meet these demands (Andrews *et al.,* 2012). To achieve high throughput, the transmitter and receiver can be brought closer to each other to improve system capacity. For a continuous roaming of the UE in LTE, swift handover should be effective from a serving HeNB /eNB to a new HeNB /eNB. This will aid in avoiding call termination and degradation of service (Chen *et al.*, 2016). A small cell access point which is deployed at indoor environments such as homes and offices is a low-power, short range, and low-cost base station installed by a user for better indoor voice and data reception, which reduces the roaming connectivity distance of a user (Chandrasekhar *et al.,* 2008). Femtocells are operated with low transmission power with a maximum value of 20 dBm (Rose *et al*., 2011). The deployment of small cells is accompanied with a lot of advantages that are unique to both the mobile network operator and the network user (Salwe & Naik, 2016). The mobile network operator enjoys low cost of deploying extra infrastructure that was aimed at increasing network capacity (Haddad *et al*, 2016). This implies that the network operator simply provides a cost-effective means of improving capacity and macro cell reliability. Also, the use of small cells by a user within the home provides an efficient coverage area and the battery life of a UE is also improved due to low power radiation (Ali-Yahiya, 2011). In spite of their enormous benefits and sufficient coverage in the grey areas that could not be covered by Macro centric cells (MCs) and capacity enhancement, densification of small cells leads to a high number of cell handovers, interference, resource allocation and management challenges (Li et al., 2016). This is due to the unplanned nature of small cell deployment, employment of access control mechanisms and small femtocells radii (Haddad *et al,* 2016). Femtocells deployment requires complex mobility management processes to handle dense network layout. Due to their unplanned nature and access control techniques (Xenakis *et al.,* 2014).

1.2 Problem Statement

In small cells deployment scenario, excessive scanning process for neighbour cells at different velocities and angles of movement of each user poses an inherent delay in the handover decision process. 3GPP has been improving mobile communications in its standards. Previous works analysed handover in mobile communications using different mobility models based on average human walking speed, motorcyclists and vehicle speeds corresponding to low, medium and high user speeds. In addition, the use of velocity thresholds and artificial neural networks were also incorporated in recent works to achieve an efficient handover. Simulation parameters used by Alhabo & Zhang 2017 to evaluate the handover decision were inadequate especially for LTE-A networks which come with node densification to increase capacity. However, reduced scanning process for SCs was achieved by setting a velocity threshold of 15kmph. Interference from adjacent channels was mitigated by considering signal to interference plus noise ratio. And an effective handover was achieved by using mobility vector prediction technique.

1.3 Significance of Research

This work developed a modified handover decision algorithm in LTE-A network using mobility vector prediction technique. The essence of this, is to accommodate low to medium speed UEs on a single SC and high velocity UEs on a MC, thereby providing a mechanism that offers improved call quality and reduced handovers.

1.4 Aim and Objectives

The aim of this research is to develop a modified handover decision algorithm in LTE-A network using mobility vector prediction technique to minimize probability of unnecessary handover and improve network throughput.

The objectives of the research are as follows:

i. To develop a modified handover decision algorithm in LTE-A network using mobility vector prediction technique.
ii. To evaluate the modified handover decision algorithm using probability of handover, probability of unnecessary handover, network throughput and radio link failure probability as performance metrics.
iii. To compare the performance of the developed handover decision algorithm with the work of Alhabo and Zhang, 2017 using Probability of Unnecessary Handover and Network Throughput.
iv. To compare and validate the modified handover decision algorithm with the work of Alhabo and Zhang 2017 using radio link failure probability.

1.5 Scope of Study

This work will be limited to the development of a modified handover decision algorithm in LTE-A network using mobility vector prediction technique. The metrics to be used in the evaluation of the performance of the technique are probability of handover, probability of unnecessary handover, network throughput and radio link failure probability. Simulation was done using MATLAB R2020a version.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This research was carried out by reviewing literature from various authors to give a background basis for the work. In addition, fundamental concepts were also reviewed to fully understand the guiding principles and theoretical background of this research area and support model equations and concepts.

2.2 Review of Fundamental Concepts

In this chapter, some of the fundamental concepts that relate to the research work were discussed, including principles and model equations which support approaches implemented by previous researchers. This facilitates the decision making on different tool(s) and methodology which it takes to obtain better handover decision.

2.2.1 Long Term Evolution Architecture

Third Generation Partnership Project (3GPP) defined Long Term Evolution-Advanced (LTE-A) network as a packet-based system specified as a 4G cellular network system. In 2008, LTE released its first standard with download speed of 173Mb/sec (Jimaa *et al.*, 2011). Subsequent upgrades to the initial standard had been developed to achieve releases 9,10,11,12, and 13 (Astely *et al.*, 2013). With a bandwidth of over 20 MHz, along with an Orthogonal Frequency Division Multiple Access (OFDMA), layered OFDMA can be applied to get high data rates in LTE-A (Baig & Jeoti, 2011).

LTE systems support both Frequency Division Duplex (FDD) and Time Division Duplex (TDD), in addition to a variety of system bandwidths (1.4, 3, 5, 10, 15, and 20MHz) so as to be able operate in a variable spectrum allocation (Astely *et al.*, 2009). There is major dissimilarity between LTE FDD and LTE TDD. LTE FDD utilizes separate paired frequencies to download and upload data, while LTE TDD employs a single frequency band that alternates through time between downloading and uploading. The LTE system network architecture is flat all-IP (Internet Protocol) which minimizes the number of network elements. The Evolved Packet System (EPS) is the IP part of the LTE which was initially called System Architecture Evolution (SAE) (Jimaa *et al.*, 2011). The LTE-A (release 10) is an evolution from the initial release 8, which lack the International Mobile Telecommunication-Advanced (IMT-A) requirements. Enhancements from LTE release 8 were supported in LTE-A (Release 10) These enhancements include Co-ordinated Multi-Point (CoMP), Carrier Aggregation (CA) and heterogeneous networks, Multi-Input-Multi-Output (MIMO) antenna techniques, enhanced Inter-Cell Interference Coordination (eICIC). Further improvements that include capacity and coverage to ensure user fairness were also introduced in LTE-A.

2.2.2 Handover Procedure

Handover procedure transfers active call or data session while a user is changing cell connections. In mobile wireless networks, the purpose of handover is to keep ongoing connections uninterrupted and ensuring the quality of service and continuity of a mobile user (Li *et al.*, 2016).

In carrying out a handover process, there are parameters which are categorized as dynamic and non-dynamic. These dynamic parameters are Received Signal Strength (RSS), user velocity, throughput, handover latency and network load balancing while the non-dynamic parameters are bandwidth, power consumption network cost and security (Ravichandra *et al.*, 2013). Handover classifications are based on a number of factors. Horizontal and Vertical handovers are the most common network related handovers. Handovers of the same network and that ensures service continuity are horizontal handovers, while vertical handovers are handovers that transfer the active connections between different wireless technologies (Ravichandra *et al.*, 2013). Figure 2.1 illustrates the different handover classifications.

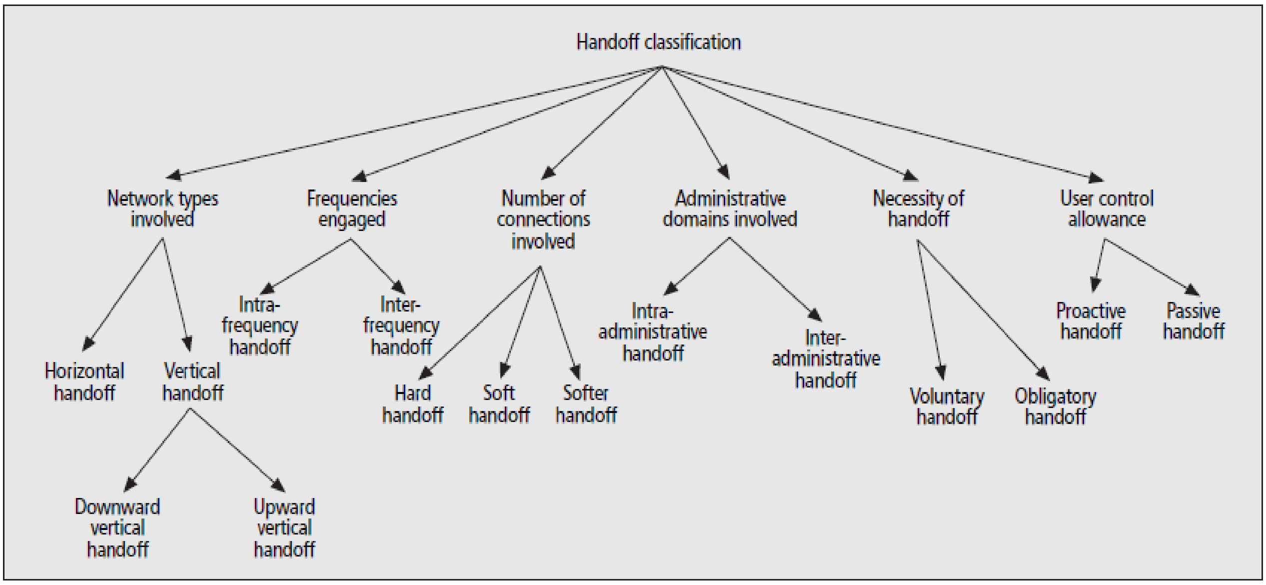

Figure 2.1: Handover Classification Tree (Nasser *et al.*, 2006)

2.2.2.1 Handover Decision Techniques

Handover decision stage involves the selection of the target cell for attachment during handover (Pan & Zhang, 2012). The actual resource availability and network load are the objectives of this stage in selecting the new channel for handover. Handover decision stage becomes more effective in dense network deployment of femtocells. This is due to their short-range communication paradigm and the unpredictable radio environment. (Xenakis *et al.,* 2014). The handover decision protocols used in mobile cellular communications are given as follows (Tripathi *et al.*, 1998):

i. Mobile Controlled Handover (MCHO): In MCHO mechanism, the UE takes its own measurement while also making handover decision.

ii. Network Controlled Handover (NCHO): The base station or network controls handover decision process.

iii. Mobile Assisted Handover (MAHO): MAHO protocol distributes handover decision process. Measurements are done by the UE and the network makes handover decision. An example of where the MAHO is used is the GSM. The average handover time is one second (Tripathi *et al.*, 1998).

2.2.2.2 Handover Initiation Techniques

Handover initiation stage triggered the appropriate conditions to request a handover to a target cell. Handover initiation based on relative signal strength, based on relative signal strength with threshold, based on relative signal strength with hysteresis, based on relative signal strength with hysteresis and threshold are the most common techniques in a handover initiation process (Stallings, 2005).

i. Relative Signal Strength: When the signal strength at B supersedes that of point A, the UE is transferred from base station A to B. But the signal strength at B later drops below that of A, then the UE is handed back to base station A. In figure 2.2, handover at point L1, was illustrated while base station A has adequate signal strength but gradually fading as a result of multipath effects. At this stage, the UE becomes prone to ping-pong effect.

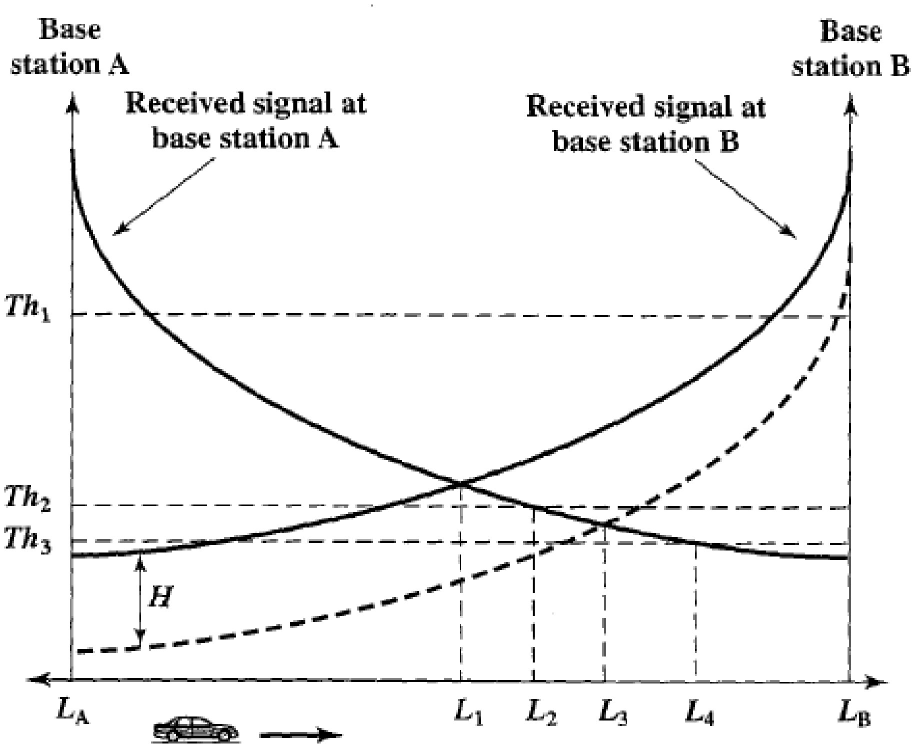

Figure 2.2: Handover between Two Cells (Stallings, 2005).

ii. Relative signal strength with threshold: Handover occurs only when the signal at the serving base station falls below a certain threshold and the signal from the other base station is stronger. When a high threshold is used, such as at Th1, the scheme performs same as that of relative signal strength scheme. And if the threshold is at Th2, handover occurs at L2. Whenever the threshold is set relatively low compared to the crossover signal strength at L1, such as Th3, the UE may drift far into the new cell (L4) before handover. The quality of the signal reduces significantly and may cause call drops. The effectiveness of a handover with threshold alone depends on prior knowledge of crossover signal strength between serving and candidate base stations (Stallings, 2005).

iii. Relative signal strength with hysteresis: In this technique, handover occurs if new base station signal is sufficiently stronger by a margin *(H)* than the current one. At this point, handover occurs at L3. This scheme averts the Ping-Pong effect, because once handover occurs, then effect of the margin *(H)* is reversed (Stallings, 2005).

iv. Relative signal strength with hysteresis and threshold: When the signal strength falls below a certain threshold for a current base station and the target base station signal is stronger by a hysteresis margin *(H)*. Then handover procedure occurs. Figure 2.2, shows handover occurs at L3 when the threshold is either at Th_1 or Th_2 and at L4 if the threshold is at Th_3 (Stallings, 2005).

2.2.2.3 Handover Performance Indicators

The following metrics were used in the performance evaluation of the handover algorithm:

The conventional handover occurred when the RSRP of the target cell, $P^r_{sc_i \to ue_j}$, is greater than the RSRP of the serving cell, $P^r_{m \to ue_j}$, i.e. $\left(P^r_{m \to ue_j} < P^r_{sc_i \to ue_j}\right)$ and is described as thus (Alhabo, 2017):

$$\eta := \left\{SCi \left| P^r_{m \to ue_j} < P^r_{sc_i \to ue_j}\right.\right\} \tag{2.1}$$

$$SC *_{conv} = \arg \max_{sc_i \in N * sc} P^r_{m \to ue_j} \in \eta \tag{2.2}$$

Where

η is the set of all SCs within the candidate SC list of d_{th} radius.

$SC *_{conv}$ is the best SC in set η in terms of downlink received power.

However, Alhabo and Zhang's criteria for HO is presented as thus:

$$\mathrm{Z} = \{SC_i |\, SNR^r_{sc_i \to ue_j} > SNR^r_{m \to ue_j}\} \tag{2.3}$$

$$SC *_{pro} = \arg \max_{sc_i \in\, Ssc} SNR^r_{sc_i \to ue_j} \epsilon \xi \tag{2.4}$$

Where

ξ is the set of all SCs within the UE trajectory.

$SC *_{pro}$ is the optimal SC is set ξ which satisfies the conditions in the algorithm which is used for determining distance threshold, angle threshold and SNR.

i. Probability of Handover: The probability of HO to SCs, P_{HO} is expressed (Alhabo, 2017) as:

$$P_{HO} = P_r \left[V_{ue_j} \leq V_{th} \wedge d_{act}^{ue_j \to sc_i} \leq d_{th} \wedge \left|\propto_{ue_{ji}}\right| \leq \propto_{in,th} \wedge SNR^r_{sc_i \to ue_j} > SNR^r_{m \to ue_j}\right] \tag{2.5}$$

where:

V_{ue_j} is the velocity of the UE

V_{th} is the HO velocity threshold

$d_{act}^{ue_j \to sc_i}$ denotes the actual distance between the UE and the SC

d_{th} is the distance threshold to form the SC list

$\left|\propto_{ue_{ji}}\right|$ is the angle between the UE_j and SC_i

$\propto_{in,th}$ is the angle threshold at which the SCs are included in the candidate list.

$SNR^{r}_{sc_i \to ue_j}$ is the signal to noise ratio received from SC at the UE side.

$SNR^{r}_{m \to ue_j}$ is the signal to noise ratio received from the MC at the UE side.

ii. Probability of Unnecessary Handover (P_u): Unnecessary handover is initiated when a serving radio link is still adequate for the UE and yet handover to another cell is performed. The probability of unnecessary handover is mathematically expressed as (Alhabo, 2017) as:

$$P_{unHO} = \Pr\left[ToS_{UE_{ji}} \leq T_{threshold} \right] \tag{2.6}$$

where $T_{threshold}$ denotes the minimum time required for the UE to perform handover from a small cell to macrocell or from macrocell to a small cell. And ToS_{UE_J} is the time of stay of the UE.

iii. Network Throughput: This is the rate at which data is being delivered to the mobile device or UE. The overall network throughput measurement is calculated (Alhabo, 2017) as:

$$Throughput = \sum_{c \in X} BW.\log_2 \left(1 + \frac{P^{r}_{c \to ue}}{\sigma^2} \right) \tag{2.7}$$

where set X= {1,2, ..., N_{sc}, N_m}, and (σ) is the thermal noise density.

iv. Radio Link Failure Probability: This is when a UE losses connection over an eNodeB in a network (Abdoul-Aziz et al., 2012):

$$RLFP = \begin{cases} \frac{2}{\pi}\,\theta_t & \text{if } \frac{R-r}{T} \leq v \leq \frac{d1}{T} \\ \frac{2}{\pi}\,\theta_R & \text{if } \frac{d1}{T} \leq v \leq \frac{R+r}{T} \end{cases} \tag{2.8}$$

where

$$\theta_t = \operatorname{arc}cos \left\{ \frac{(\boldsymbol{vT})^2 + \boldsymbol{R}^2 - \boldsymbol{r}^2}{\boldsymbol{2vTR}} \right\}$$

$$\theta_R = \operatorname{arc}cos \left\{ \frac{(\boldsymbol{vT})^2 + \boldsymbol{R}^2 + \boldsymbol{r}^2}{\boldsymbol{2vTR}} \right\}$$

2.2.2.4 LTE Handover Control Parameters

The handover control parameters used to control the handover procedure can be tuned by the handover algorithm in order to achieve a preferred performance. Hysteresis and time-to-trigger values are the two parameters used in controlling handover in LTE self-organizing networks. The valid hysteresis values vary between 0 and 10 dB at interval of 0.5 dB (3GPP, 2012). While the time-to-trigger values are 0, 0.04s, 0.064s, 0.08s, 0.1s, 0.128s, 0.16s, 0.256s, 0.32s, 0.48s, 0.512s, 0.64s, 1.024s, 1.280s, 2.560s, and 5.120s (3GPP, 2012). There are also 336 valid control parameter combinations from the hysteresis and time-to-trigger values (Jansen *et al.*, 2010).

2.2.2.5 Handover Procedure in LTE

S1-handover procedure and X2-handover procedure are the two types of handover procedures in LTE for UE's in active mode. With no X2 interface, S1-handover procedure is executed between two eNBs while the X2 handover is used when there is a direct link between source and target eNBs (Ermolayev, 2016). The UE starts the handover procedure by measuring reports of the handover event and sending these reports to the serving eNB. Downlink radio measurements were periodically done by the UE based on Reference Symbols Received Quality (RSRQ) and Received Power (RSRP) (3GPP, 2013). Once the configuration conditions are met, the UE reports the measurements of the handover event triggering. These measurement reports are used to identify the target cell for a handover and the serving eNB triggers the handover preparation (Dimou *et al.*, 2009). The preparation stage of the handover comprises of interchange of signalling messages between serving and target eNB and admission control of UE in the target cell as illustrated in figure 2.3. Once the handover preparation is completed, the handover decision is accomplished and command sent to the UE. Then the link between the serving cell and the UE is released. Consequently, using Random Access Channel (RACH) the UE tries to synchronize and access the target eNB. An uplink scheduling grant message from the target eNB is sent to the UE once successful synchronization at the target eNB is done. Then UE responds with a handover confirm message, which signifies the successful completion of the handover procedure at the radio access network part (Dimou *et al.*, 2009).

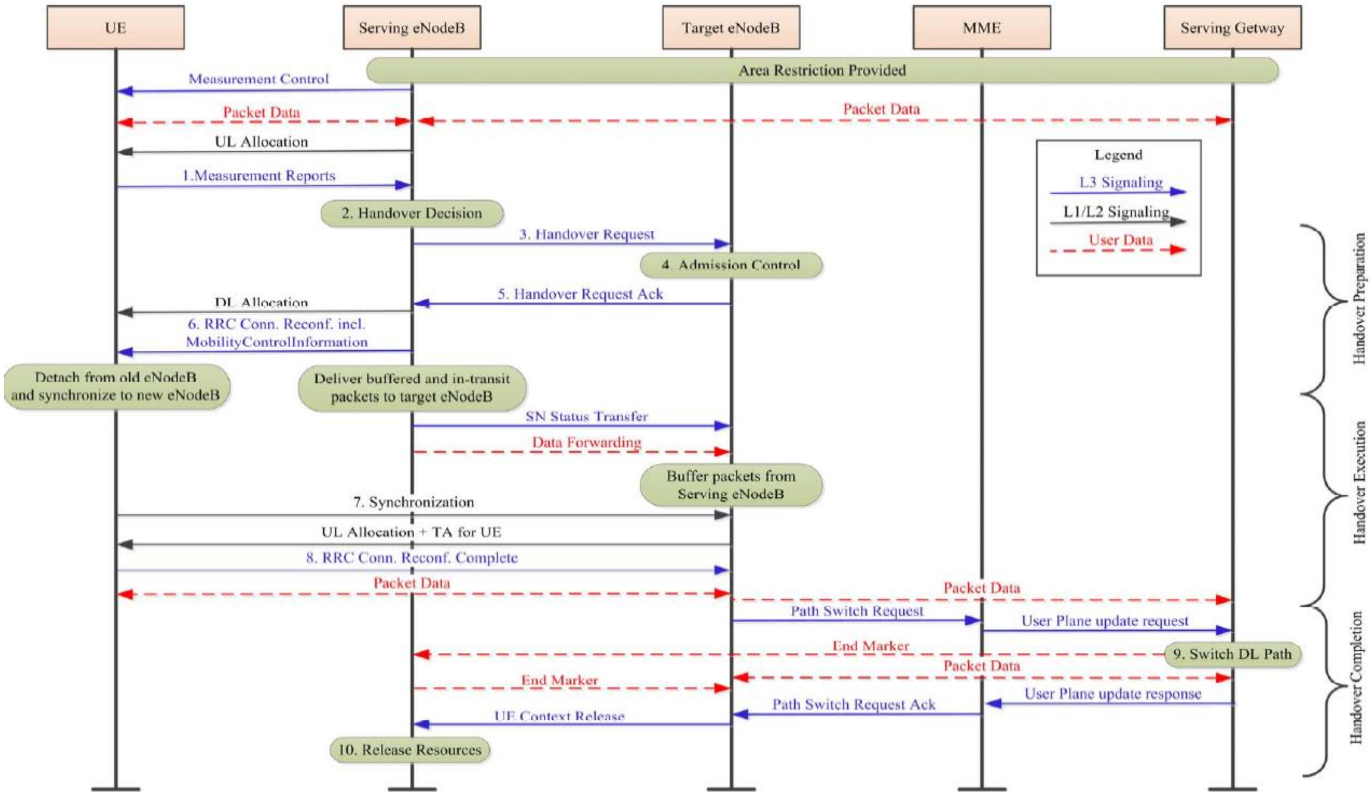

Figure 2.3: Handover Procedure specified in LTE Release 10 (Chen, 2014)

In figure 2.3, the UE sends measurement report to the serving eNodeB then the serving eNodeB executes handover decision based on the received measurement report and the radio resources management. Handover request was sent from the serving eNodeB to the target eNodeB. This handover request contains the required handover information. Admission control was performed by the target eNodeB to decide granting the handover request or not considering the resources. Target eNodeB then responds to the serving eNodeB with a handover request acknowledgment that provides new radio link establishment information from the target eNodeB. The serving eNodeB then sends handover command message that the UE is going to handover to another eNodeB, then all packets are forwarded from the serving eNodeB to the target eNodeB. Once receiving the handover command, then the UE immediately cuts off connection from the serving eNodeB and tries to synchronise and access the target eNodeB by utilizing Random Access Channel. The UE sends radio resources control to confirm the handover. S-GW switches the downlink path from the serving eNodeB to the target eNodeB and the corresponding information in mobility management entity is updated. Upon reception of UE context message, the serving eNodeB releases radio resources associated to the UE related to the control plane.

2.2.3 Mobility Prediction Techniques in Manets

The following are some mobility prediction techniques in MANETs (Doss *et al.,* 2004).

i. **On-Demand Multicast Routing Protocol with Mobility Prediction (ODMRP-MP):** In this scheme, accurate prediction of networks with less complex mobility patterns is supported. And does not provided for a sudden change in direction at a constant speed. This prediction technique is less efficient for scenarios in ad hoc networks, where a user's speed and direction are guaranteed to change.

ii. **Sectorized Ad hoc Mobility Prediction (SAMP):** This scheme was developed on the basis that in order to achieve high accuracy in movement prediction, areas of high cluster change probability are limited for the prediction process. The user movements in the network are predicted by using the cluster-sector scheme. The location of the user is known by the position of the cluster head in a cluster ad hoc network.

iii. **Link Expiration Time (LET):** In this scheme, non-random motion patterns of a user is being used to predict the future state of the network topology, thereby offering easy accessibility during the period of the change in the topology. The link expiration time (LET) between two nodes can be obtained by using the position information on data packets in Global Positioning Systems (GPS).

iv. **Reference Point Group Mobility (RPGM):** To predict the behaviour of the entire group, this mobility scheme utilizes the mobility of the logical centre of each group. Each user is allocated a reference point relative to its position with that of the group's centre.

v. **Mobility Vector Prediction Scheme (MVPS):** This model offers a greater flexibility in terms of the varying mobility pattern of a given node. Random movements, sharp turns, sudden stops, and turn backs, that are realistically impossible in real life are featured in most mobility models.

It does this by remembering the mobility state of the user and permitting only partial changes in the present mobility state. Realistic movement patterns of a user can be replicated by using this scheme.

However, the choice of the mobility vector prediction scheme is based on its efficiency in terms of remembering the state at which a node is moving before a sudden change in motion pattern of the node, thus effectively predicting a node state irrespective of its mobility pattern. Mobility vector prediction has the following advantages: mobility prediction, and simplicity in implementation and position updating.

Mobility Vector's versatility makes it suitable for implementing various simulations.

2.2.4 Mobility Vector Prediction Technique

Mobility Vector (MV) is a mobility scheme that provides a flexible mobility architecture for various motion patterns. This model permits for swift changes in the mobility state of a user by "Remembering" the initial mobility state of that user. Mobility Vector expresses the mobility of a user as the sum of two sub vectors, mathematically represented (Doss *et al.*, 2004):

$$\vec{B} = \left(bx_v, by_v\right) \tag{2.9}$$

$$\vec{V} = \left(vx_v, vy_v\right) \tag{2.10}$$

where, $\vec{B}$ is the base vector which describes the major direction and speed of the user and $\vec{V}$ represents Deviation vector that stores the mobility deviation from the base vector.
Therefore, the mobility vector from equations (2.9) and (2.10) is mathematically expressed as:

$$\vec{M} = \left(\vec{B} + \alpha\vec{V}\right) \tag{2.11}$$

where α is the acceleration factor.
For the purpose of this research, the base vector is assumed to be either the macrocell or the candidate small cells, while the deviation vector is assumed to represent the user equipment. Thus, the base vector shows the current mobility state of the macro cell or the candidate small cell and the deviation vector defines the direction and speed at which the user equipment moves towards either the candidate small cell or the macro cell.

2.3 Review of Similar Works

The review of similar works gives the extent to which research has gone in the resolution of the problem of handover. It also gives the tools and approaches used by other researchers and the problem they encountered in obtaining the results they achieved. It then helps in the decision making of the tool and approach to be used in order to obtain better results. The following are some of the researchers considered in this review.
Doss *et al.*, (2003) explored a user mobility prediction in hybrid and adhoc wireless networks. They employed a sectorized adhoc mobility prediction scheme for cluster change prediction. Node belongs to a cluster in the network and mobility affects cluster membership. Also, to achieve high accuracy, prediction process was restricted to areas of high cluster change probability. This scheme introduced sectorized cluster sector concept to reduce tracking area required and also introduced cluster-sector numbering for user movement prediction. Prediction accuracy, randomness factor, ratio of control overhead and user mobility support

were used as performance metrics. However, the scheme was only suitable for resource intensive mobile hybrid/adhoc data networks supporting high-speed user mobility. Because low speed and medium speed users' control overhead was low and for the high-speed users was high. The control overhead increases as area of tracking was increased.

Wastage of available bandwidth costs a fortune in communications networks. In order to prevent quick handover triggering or late handover triggering; a vertical handover triggering estimation (VHTE) algorithm was analysed by **Abdoul-Aziz *et al*., (2012)** to prevent connection breakdowns. The VHTE provided an optimum balance to reduce excessive wastage of resources and connection breakdowns by controlling and estimating when the need to trigger handover arises between cellular network and WLAN. The results demonstrated the method's ability to provide the flexibility from reduced wastage of resources and increased WLAN usage.

Johnson *et al*., (2013) adopted a mathematical model based vertical handover prediction method consisting of a well-defined objective function that took into consideration Received Signal Strength (RSS), User Equipment UE velocity, load, and cost per user bandwidth. The propagation model used in the work was Jake's model. In this work, the UE velocity was used to minimize time and cost of transmission. The performance metrics used in the work were evaluated in terms of handover numbers and user velocity. The simulation result showed a reduction in handover as the UE velocity increased. The setback in this work was that a scenario was not considered where the UE speed changed as a result of the UE's unpredictable behaviour, which resulted in unnecessary handovers, thereby degrading the user' QoS and subsequent dissatisfaction of the users.

Chen *et al*., (2014) explored a scheme that zones where the potential target eNodeBs are located by referring to the previous locations of the user equipment (UE). The target eNodeB was selected based on the weight and available channel among all candidate eNodeBs and then they were updated for handover along with the UE movement. This weight was checked to make sure the candidate eNodeB is the real target eNodeB with the long-term residence, and decrease number of handover and risk of disconnection. The scheme was evaluated based on the performance of packet drop rate, goodput per cell, and packet delay. However, the scheme had some setbacks where the performance dropped with the increase in Handover Margin (HOM) when the Time-to-Time (TTT) is small. Optimal value HOM and TTT should have been decided for the scheme. Also, smaller HOM is not always beneficial to LTE networks. Because the latter support soft handover. Therefore, a reliable model that considers previous signal strengths received signals in making the handover decision should be developed. Swift handover could be made with high reliability.

Kalbkhani *et al.*, (2014) analysed a handover decision algorithm based on RSS prediction to improve user throughput and reduce ping pong handovers. In this method, the base stations with higher RSS than the set threshold and higher than the RSS of the serving base station plus a hysteresis margin were identified. Thereafter, an adaptive Recursive Least Square (RLS) algorithm was utilized to identify the future RSS samples of the identified base station and the current base station. These estimated samples were used for future SINR samples. Then, the estimated SINR and predicted RSS were used to prune down the list of the candidate base stations. And the base station with the highest throughput was chosen. The algorithm was evaluated based on Throughput, Ping Pong Rate (PPR), Number of Handover (NHO), Outage Probability (OP) of the UE, and error in RSS prediction. This algorithm cell dwell time of the users in each femtocell was not taken into cognizance in making the handover decision. Also, the cell dwell time was not considered besides to the RSS and SNR criteria.

Lee and Yoo, (2014) considered a novel method that executed a handover decision by comparing the data capacities on a probabilistic path using the residence time of a mobile station (MS). It estimates the available data capacity from Macro Base Station (MBS) to Femto Base Station (FBS) during its residence time. The estimated path is the expected distance from the entry point of the current femtocell to any point of exit in the femtocell coverage area. Comparison of data capacities is done between FBS and MBS. Handover is executed when the data capacity from the FBS is greater than from the MBS, else the MS keeps associated with the MBS to avoid ping pong. The drawbacks of this work were that the MS was assumed to be moving at an average speed in a straight line inside a fairly small femtocell area. Also, the probabilistic path employed might vary from the actual path of the MS.

Wang *et al.*, (2014) considered a moving direction prediction-assisted handover scheme for LTE networks to reduce the number of handovers. To predict the UEs moving direction, their previous locations were tracked. And the next moving direction of the UEs was estimated by referencing previous locations with the cosine function to determine the candidate E-UTRAN NodeBs (eNBs) for the handover. An angle-based dynamic weight adjustment scheme was used to select an accurately target cell for handover. By selecting proper target eNB, the network transmission quality was improved. Accurate target cell selection was achieved by reducing handover times by an average of 17%. Packet loss ratio was reduced by 12% and packet delay time was reduced by an average 5%. To further improve on this scheme, measurement reports from the filtered candidate eNBs amongst candidate eNBs tend to increase unnecessary handover probability which approached 73% could be reduced because it reflects wastage of power. Handover failure which led to radio link failure occurred when the UE does not send measurement reports promptly.

A handover scheme for dense femto cell networks was proposed by **Al-Shahin, (2015)**. The direction of movement of the mobile user and the location of the neighbour Femtocell Access Points (FAPs) were the two parameters considered in the minimization of the neighbour cell list for reduced need to scan a large cell list. Two separate algorithms were used to predict moving direction and generating mobility rules. To determine the location of the FAPs, a user mobility analysis server was used. Results obtained showed that as the mobile user direction was predicted towards (west-south) direction, 65% reduction in the FAPs list was achieved and an 85% reduction was obtained when the prediction was made in the (east-south) direction. The problem with the handover scheme was that no parameter was set to aid in the selection of a suitable FAP for handover which could result in increased dropped packets and eventual degradation of the user's QoS.

To reduce ping pong effect and unnecessary handovers, a Navigation-assisted seamless handover technique was explored by **Chuang and Chen, (2015)**. A bi-casting scheme was used with Co-ordinated Multi-Point (CoMP) and Carrier Aggregation (CA) techniques in the handover procedure to increase throughput and avoid packet loss. The assumptions considered include the use of UE equipped GPS, UE supporting MIMO technique, geo-location server which made it possible for neighbouring HeNBs (femtocells) to know the location of other HeNBs. The scheme they used has two triggers: (i) cooperation process which was triggered when the RSRP value of the UE is less than a first threshold and (ii) a handover process which was triggered when the RSRP value is less than a second threshold. The navigation assisted handover decision made use of the UE which gave its destination and then the navigation system planned an optimal path to the destination. The performance metrics used in accessing the scheme include packet loss, normalized network throughput, average handover latency and number of handovers. However, with the addition of the geo-location server there was an added cost of signalling. Furthermore, there was increased power consumption because of the constant connection to the GPS and the geo-location server.

Habibzadeh *et al.*, (2015) proposed an algorithm for handover decision that was based on the traffic channel holding time and propagation RSS metrics. When the average signal power from the macro cell is below a set threshold and the average signal power from the femtocell is larger by a constant factor (hysteresis margin) then the user equipment gets connected to the femtocell. Also, when the estimated time duration spent in the femtocell is larger than the holding time, the user equipment also gets connected to the femtocell. The authors' pointed out that this was done to achieve a higher rate of handover to the femtocell while also decreasing the number of frequent handovers. Thus, delay associated with the scheme occurred when deployed in a densely populated area or in a highly mobile environment owing to the signalling overhead that would be incurred in trying to ascertain the nature of the target cell in a densely populated environment.

Femtocells were considered in exploring a handover decision algorithm by **Rajabizadeh and Abouei, (2015)** using the RSS and user velocity as decision criteria. A faraway femtocell was chosen by the algorithm as compared to adjacent femtocells available from the UE. This was based on the idea that selecting a distant femtocell instead of an adjacent femtocell subdues unnecessary handovers before reaching the target femtocell. However, by selecting such a femtocell as the target cell, the user could stay connected with that cell for a longer duration of time. This suggests that the time between two handovers is prolonged. The algorithm employed handed over high speed users to the macrocell in order to avoid unnecessary handovers. This work reduced the number of handovers and unfortunately led to call failure and/or poor handover performance when the user decided to stop abruptly at a cell preceding the already selected target. Also, interference that could occur due to the signal from a farther cell overlapping with an adjacent cell was not taken into consideration which could have adverse effects to the results.

An efficient and secured handover scheme for the LTE-A networks was evaluated by **Hadded *et al*, (2016).** Home Subscriber Server (HSS) used a certified public/private key pair for each node in the network. The results were achieved by registration of BSs to authenticate and with the HSS. Also, to authenticate and exchange keys with the MME, a procedure was proposed. And lastly, a secured and fast handover procedure was executed. Fewer packet exchanges were required for the scheme and that interprets to minimal overhead on the mobile device. This was much desired because mobile devices require low computational power and energy. This scheme could hinder networks attacks and the proposed key agreement procedures could achieve backward/forward secrecy. The scheme was not suitable for small cells deployment in LTE-A networks because it does not trust base stations operated by subscribers in closed access mode like femtocells which are deployed in small offices.

Xenakis *et al.*, (2016) proposed a novel handover decision algorithm which utilized measurement from candidate cells to optimize two Handover Hysteresis Margins (HHMs). Firstly, was used to evade cells that could compromise service continuity, while the secondly was to identify the cell with the minimum required UE transmit power. When the handover event was triggered, the serving cell acquired maximum transmit power, cell interference and downlink received signal transmit power for all candidate cells by using the private mechanism for non-standard use. Two adaptive HHMs were consequently assessed for all candidate cells and the subset of cells that sustain service continuity were identified. The handover execution phase was initiated when the cell that required minimum UE transmit power was selected. However, in using the candidate cell list as an input to the algorithm, there were delays associated with the handover decision since the list was not optimized.

Khan *et al*., (2017) presented a handover algorithm for hand-in procedure. In the work, a multi-step handover scheme was used for the purpose of reducing the number of unnecessary handovers, while also selecting the appropriate Femto Access Point (FAP) for the incoming UE. Three filtering phases were proposed to achieve it. The first of the filtering phases for the proposed scheme was to measure the power of the available candidate femto cells. The next phase was to filter out the femtocells which cannot support an unregistered UE. The final filtering phase was to determine whether the UE was registered in the closed subscriber group (CSG) or not. All three phases in the proposed scheme were set as input parameters to make the handover decision, for the purpose of minimizing unnecessary handover and improving UE throughput. The proposed handover algorithm yielded better performance than already existing hand-in algorithms. Delays that could arise from having to check, select, and measure for the available and target femto cell that could lead to degradation of the UE's QoS were not considered.

Van, (2017), improved on Random Waypoint (RWP) with Enhanced Random Waypoint model (ERWP) that focused on micro-mobility models in two dimensions. Two stochastic processes were used for change of speed and waiting control which made the mobility of the nodes more realistic and smoother. To make the movement of users (e.g., pedestrians and cars) more realistic than RWP model, principles that combine direction and speed control were adopted. The work represented the movement and user speed behaviour in the mobile region and indicated that the user velocity is continuous and will not have an abrupt change. The setback of the scheme was that the user velocity was taken as continuous and would not have a sudden change. Therefore, planning to use the traces generated by ERWP would accurately be used to examine the different wireless networks protocol.

Alhabo and Zhang, (2017) proposed a handover decision algorithm that uses distance between the User Equipment (UE) and the Small Cells (SCs) and the UE angle of movement, for the purpose of creating a shortened candidate list. The angles of movement tested were 20^{o}, 30^{o} and 60^{o} as thresholds and finally adopted 30^{o} angle for the purpose running their algorithm.

This assisted in reducing the ratio of the SCs in the candidate list. Thus, minimizing the energy resource that would have been dissipated in the process of scanning for the candidate cells (macrocell or small cells). Moreover, 5kmph (for pedestrian), 15kmph (for motorcycles) and 20kmph (for vehicles) were used corresponding the angles of movement for the purpose of accommodating UE speeds in the network. Unnecessary handovers were reduced which then helped in improving network throughput. By the introduction of the shortened SC list, the performance of the algorithm was improved upon. The number of unnecessary HOs were avoided because a smaller number of targets SCs were selected and the cell with the highest Signal-to-Noise Ratio (SNR) was selected as a candidate HO target. However, delay that could eventually arise from the scanning process could affect the performance of the HO process, especially in a scenario where the UE moves at varying speeds. Furthermore, no prediction scheme was utilized to effectively describe the user's movement towards the target cell, as this could have improved the results obtained.

Alhabo and Zhang (2017) proposed a novel load dependent handover margin for load balancing and throughput improvement in heterogenous networks. The paper considered the effect of inbound and inter-SC scenarios of HO. Optimization of NCL was done by utilizing the SINR threshold and ToS, where the effects of short ToS and interference minimizes the final NCL and was used for UE to be able to perform HO to the cell providing good data rate by choosing the best SC, which in turn offloads traffic from the MC to SC. The results minimized unnecessary HO and outage probability while maintaining good data rate. However, reductions in the small cell list need to be considered by considering the angle of movement of the users for reduction in the areas to be captured for effect service delivery.

To maintain QoS and reduce the number of unnecessary handoffs, **Sun, (2017)** proposed a machine learning approach based on reinforcement learning handoff SMART policy. 5G networks were deployed in some parts of the world to increase capacity 3GHz band. Then millimetre wave(mmWave) was born which can accommodate more users in the frequency band (30GHz-300GHz). SMART mechanism as artificial intelligent tools were adopted in some cases to incorporate the surrounding environment information analytics. Two approaches were used: first handoff trigger conditions were determined by the characteristics of millimetre wave channel. Secondly, base station (BS) selection was carried out by two algorithms SMART-S (for single UE) and SMART-M (for multiple UEs).

The number of handoffs were reduced by about 50% as compared to handoff policies that does not use machine learning. Despite the capability of SMART-M, it comes with computational costs. UE density threshold was set to identify sparse or dense UE distribution. AHP-TOPSIS method was proposed by **Goyal, 2019**; to select optimal eNB. AHP-TOPSIS scheme attach ranks to UEs which is then used to attach them to the appropriate eNBs. These eNBs are selected by considering RSRQ, RSRP, Uplink SINR, on UE location and current load on eNB to maintain good QoS. Then a Q-learning approach to minimize Handover Ping-Pong (HPP), too late and too early handover failure was chosen based on the optimal triggering points (time-to-trigger, hysteresis) obtained. Handover Failure Rate (HFR)was reduced from 28% to 35% and HPP from 25% to 33% as compared to conventional and FMCGS schemes.

However, recent research works focus on 5G networks, which is in turn accompanied with ultra-densification of cellular networks. Exponential increase in data traffic becomes a huge task to deal with. Therefore, consequent works would be focusing on mitigating transmission delay, packet losses, energy and power efficient mechanisms in order to guarantee QoS for users. Analytical Hierarchy Process (AHP)-Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). AHP for selection of HetNet and estimated power consumption of UEs. TOPSIS for selection of mobile network interface in the dynamic condition of networks. **Azari, 2020** focused on Handover and Radio Resource Management (H-RRM) problem in serving drone communications over cellular networks. The KPIs analysed were interference of drone communications and delay experienced in drone communications. These were the tools leveraged on to solve this dynamic and complex problem. In conventional handover schemes as opposed to drone communications, certain set of metrics were applied that triggers handovers based on measurement of RSRQ. But regarding radio links of drones and neighbour BSs; drone movement triggers frequent measurement reports due to its ability to achieve a higher altitude. Thus, frequent handover measurement reports result in frequent handover as compared to conventional RSS handover decision. However, interference also becomes a problem by UEs both (terrestrial & flying) over terrestrial networks.

Deep Q-learning algorithm in decision making for H-RRM for drone communications. Further increase in the cardinality of the set of BSs to which drone communication handover to; increases handover for the drone and terrain as it changes, measurement reports also changes.

From the literature reviewed, the following were the research gaps:

i. Change of speed from slow pace to a sudden rise in velocity.
ii. Movement pattern from stationary position to an unpredictable direction.
iii. Power consumption drains the battery of the UE by searching for available base station among many.
iv. Residence time at which the UE stays in a particular cell before changing to the next.

v. Signalling overhead caused by reception of multiple signals from nearby base stations.

vi. Frequent handovers as UEs roam in an LTE network at a faster speed.

The aforementioned research gaps were found to have caused a major drawback in achieving a seamless handover process, specifically in a dense small cell deployment. Although, the literature reviewed yielded acceptable results according to conventional methods they improved on. But there is still room for improvement in terms of the approaches and tools employed.

This research work proposed a modification on the work of Alhabo and Zhang, (2017). Where delay was inherent from the frequent neighbour cell scanning process and varying speed of the UE could result in wastage of resources in deciding where and when to handover to. And this could result in the degradation of the Quality of Service (QoS). A modified handover decision algorithm that utilizes a mobility vector model was proposed in this research. The scanning process will be reduced by considering the medium threshold velocity (for low to medium speed) UEs which are pedestrians and motorcyclists and signal-to-interference plus noise ratio (SINR). The neighbouring SCs with the greater received RSRP will be put in a shortened SC list. From this shortened SC list, the UE velocity will be monitored, the angle of movement and SINR will be considered. The SINR will help mitigate interference form neighbour cells. Also, the incorporation of the mobility vector prediction was to be able to provide a varying motion of the UE which closely relates to real life scenario and predict the motion pattern. With the parameters used by Alhabo & Zhang, this work achieved better results. The modified handover decision algorithm was able to reduce UE power consumption by limiting the number of targets SCs and in the same vein signalling overhead from adjacent cells was also reduced. Frequent handovers for fast moving UEs was also mitigated.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter explains the methodology used in carrying out the modelling of the architecture and the layout of the macro-small cells and the simulation of modified handover decision algorithm. A script-based model developed in MATLAB was used to achieve the results.

3.2 Materials

a. Laptop Computer.
b. MATLAB 2020a version for simulation.
c. Implementation of LTE system level model in MATLAB 2020a.
d. Work of Alhabo and Zhang (2017).

3.3 Methodology

Methodology adopted in this research work is as follows:

a. Replication of the work of Alhabo and Zhang (2017) as follows:
   i. Development of an LTE-A macrocell and small cell network architecture comprising of seven (7) macrocells and one hundred (100) small cells.
   ii. Adopting a random waypoint mobility model to model the movement pattern of UE location and its radius at constant velocity.
   iii. Obtaining the pathloss between the SC (small cell) and the outdoor UE, as well as the pathloss between the MC (macrocell).
   iv. Obtaining the RSRP distance between the UE and the SCs, and the UE angle movement in order to generate a shortened candidate list.
   v. Obtaining the candidate cell list and the shortened cell list which contains the signal strength profiles of the SCs detected by the UE.
   vi. Implementation of steps (i) through (v) in MATLAB R2020a version.
b. Development of the modified handover decision algorithm
   i. Repeat items (i) through (v) of step 1 with items (ii) having varying velocity by deploying the modified mathematical model.
   ii. The Mobility Vector Prediction technique (MV-P) will be applied to the handover decision algorithm.
c. Implementation of steps 1 and 2 is done using MATLAB R2020a version.

d. Comparison of the performance of the modified handover decision algorithm with the existing handover decision algorithm based on probability of handover, probability of unnecessary handover, network throughput and radio link failure probability was carried out.

3.4 Replication of the Handover Decision Algorithm

The replication of the work of Alhabo & Zhang, (2017) decision algorithm was done as discussed in subsequent sections. The replication was done to access the data and results of the work of Alhabo and Zhang, (2017) which was compared with this research for evaluation and validation purposes.

3.4.1 Development of an LTE-A Macro-Small Cell Architecture

The developed script model consists of seven (7) hexagonal macrocells and hundred (100) small cells as depicted in Figure 3.1. The macrocell area is densely populated with 100 small cells. The blue dot is the centre point of the UE, red stars are the UE, the black circles are the small cells, and other small cells that are fixed on lamp posts or buildings are indicated with brown colour. Blue triangles are the macrocell areas. The SCs overlaid by the MC provide the users with the network coverage in the simulation environment. Low to medium velocity UEs were covered by same SC in order to reduce the scanning process for three different velocity thresholds as it was done in the work of Alhabo, 2017. This reduction in the scanning and number of iterations saved battery power dissipation of the UE and also reduced frequent handing over between SCs as the UE is moving. The UE adopted a random waypoint model while roaming in the coverage area.

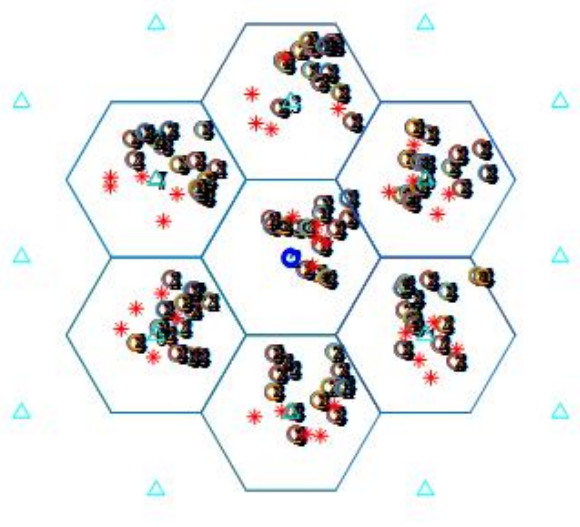

Figure 3.1: System Model

In this work, the UE speed thresholds for pedestrian and motorcyclist were set to ≤ 15kmph (Alhabo, 2017). The MATLAB scripts used to develop the macrocell-small cells architecture is shown in appendix C.

3.4.2 Mobility Model

The infrastructure less architecture of mobile users provides for flexibility in communication systems. Mobility prediction model also enable users to be located without the establishment of a physical link.

3.4.3 Path Loss Models

Path loss is signal degradation over distance. The path loss between a UE and a cell is different in different scenarios as shown in equations (3.1), (3.2) and (3.3) (Alhabo, 2017).

$$\delta om = 128.1 + 37.6\, log_{10}(d_m) \quad (3.1)$$

Where:

δom is outdoor path loss between MC and SC.

d_m is distance between UE and MC.

$$\delta os = 37 + 20\, log_{10}(d_{sc}) + \; q_{sc} \cdot W \; + L \quad (3.2)$$

Where:

δos is outdoor path loss to the SC.

d_{sc} is distance between UE and SC.

q_{sc} is number of walls between SC and UE.

W is wall partition loss.

L is outdoor penetration loss.

$$\delta is = 37 + 20\ log_{10}(d_{sc}) + \ q_{sc}\ \cdot W \quad (3.3)$$

Where:

δis is indoor path loss to the SC.

d_{sc} is distance between SC and UE.

q_{sc} is number of walls between SC and UE.

W is wall partition loss.

3.4.4 Reference Signal Received Power (RSRP)

The measured power received in LTE cell network is the RSRP, which is the average power level measured from a specific reference signal usually in OFDM symbols. The received RSRP threshold for the target cell was set as -70dBm and it is measured at the specific instance the UE enters the cell coverage area. This is equal to the pilot RSRP as indicated in (3.4) (Alhabo, 2017).

$$P^{r}_{x\rightarrow ue_y} = P^{r}_{xp\rightarrow ue_z} \quad (3.4)$$

where

$P^{r}_{x\rightarrow ue_y}$ base station received RSRP power from a target cell x

$P^{r}_{xp\rightarrow ue_z}$ represents pilot RSRP received from a target cell x at user z

3.4.4.1 Pilot Reference Signal Received Power (pRSRP)

The pilot RSRP is the average power measured by the UE at multiple resource elements, which are used to transfer reference signals as in shown in (3.5) (Alhabo, 2017):

$$P^{r}_{xp\rightarrow ue_z} = \frac{P^{t}_{x\rightarrow ue_z} - g_x\ g_{ue_z}}{l_{o_x} l_{oue_z} \xi_{x\rightarrow ue_z} \delta_{x\rightarrow ue_z}} \quad (3.5)$$

where

$P^{r}_{xp\rightarrow ue_z}$ represents pilot RSRP received from a target cell x at user z,

$P^{t}_{x\rightarrow ue_y}$ is the base station x transmitting power

g_x is base station x antenna gain

g_{ue_z} is antenna gain of user z,

l_{o_x} is base station x equipment loss,

l_{oue_z} is the UE equipment loss,

$\xi_{x \to ue_z}$ is shadow fading with a log-normal distribution with zero mean and $3dB$ standard deviation,

$\delta_{x \to ue_z}$ is path loss between base x station and user z.

Whereas the interference power received by user z from its adjacent base stations is expressed in equation (3.6):

$$P^r_{y \to ue_z} = \frac{P^t_{y \to ue_z} - g_y \, g_{ue_z}}{l_{o_y} l_{oue_z} \xi_{y \to ue_z} \delta_{y \to ue_z}} \qquad (3.6)$$

$P^r_{y \to ue_z}$ is received power from the interfering base station y

$P^t_{y \to ue_z}$ is interfering base station y transmitting power

g_y denotes Interfering y antenna gain

g_{ue_z} is User z antenna gain

l_{o_y} is interfering base station equipment loss

$l_{oue_z}$is interfering base station at user z

$\xi_{y \to ue_z}$ is shadow fading between interfering base station and user z

$\delta_{y \to ue_z}$ is path loss between the interfering base station y and user z

Therefore, Signal to Interference plus Noise Ratio ($SINR$) measured at user z was obtained as (Alhabo, 2017):

$$SINR_{x \to ue_z} = \frac{P^r_{x \to ue_z}}{\sum_{y=1, x \neq y}^{n_y} P^r_{x \to ue_z} + \sigma^2} \qquad (3.7)$$

and

n_y= total number of interfering base stations, and σ is the noise power

Substitute 3.5 and 3.6 in 3.7, we got the final SINR as (Alhabo, 2017):

$$SINR_{x \to ue_z} = \frac{P^r_{xp \to ue_z}}{\sum_{y=1, x \neq y}^{n_y} \frac{P^t_{y \to ue_z} - gy \, gue_z}{l_{o_y} l_{oue_z} \xi_{y \to ue_z} \delta_{y \to ue_z}} + \sigma^2} \qquad (3.8)$$

The $SINR$ received at user z from SCx is $SINR_{sc_x \to ue_z}$ and that received from MC is $SINR_{m \to ue_z}$ the outage threshold is $SINR_{th} = 5dB$.User equipment z measured the SINR received from both Macrocell (MC) and small cell (SC). The HO was performed to this SC as it has adequate resources to serve it. This helped in offloading the macrocell and increased network capacity and quality of the signal.

3.4.5 Set of Candidate Small Cells

Set of candidate small cells (SCs) for UE_y in one MC, is denoted as S_{SC}, and can be defined by the following equation (Alhabo, 2017):

$$S_{sc} = \left\{ |SC_x \in N_{sc}| \ \left(d_{act}^{ue_z \to sc_x} \leq d_{th} \right) \wedge \left| \propto_{ue_{zx}} \right| \leq \propto_{xn,th} \right\} \qquad (3.9)$$

The shortened candidate list constitutes the set of SCs. From which, the SC with the maximum signal to interference plus noise ratio (SINR) was selected for handover.

3.4.5.1 Ratio of Small Cells in the Candidate List

Considering the SC radius; the ratio of the SCs was evaluated based on the distance threshold of a given SC given by d_{th}. And distance threshold is proportional to the cell radius. Higher ratio of the SCs translates to a higher number of SCs in the list therefore the improved technique reduced the ratio by a significant value.

3.4.5.2 Angle of Movement

From the work of Alhabo & Zhang; the number of candidate SCs for potential handover were determined using angle of movement. Figure 3.3 shows the angle between UE_Z and SC_x, α_{UEzx} based on $\vec{u}$ and $\vec{v}$ vectors as (Alhabo, 2017):

$$\alpha_{UEzx} = arc\ cos\ \left(\frac{x_u x_v + y_u y_v}{\sqrt{{x_u}^2 + {y_u}^2} \cdot \sqrt{{x_v}^2 + {y_v}^2}} \right), \forall_i = 1,2, \ldots, N *_{sc} \qquad (3.10)$$

Where $x_u = x_2 - x_1, x_v = x_3 - x_1$, $y_u = y_2 - y_1$, $y_v = y_3 - y_1$,

And $N *_{sc}$ is the total number of SCs that are located within d_{th} distance from the UE.

An angle of 30^0 was illustrated in Figure 3.2, which the UE is roaming in the coverage area which is Southwest (SW) movement to East (E). This was set as the angle threshold to reduce the number of candidate SCs for handover.

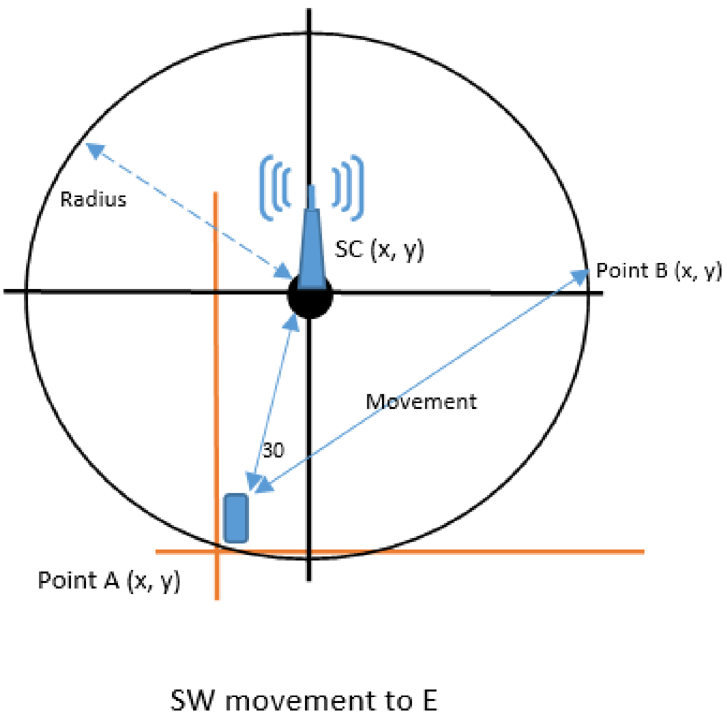

Figure 3.2: Angle of Movement

At the angle of 30^0 threshold, a lower number of SCs were reflected in the shortened candidate list which then corresponds to a skimmed number of potential SCs for handover execution. More so, this ensured a drastic reduction in the number of SCs that are going to be considered. The higher the angle of movement, the higher the number of SCs in the shortened candidate list. And the aim was to accommodate UEs with higher signal strength in the SCs.

3.5 Flow chart of the existing handover decision algorithm.

The flow chart for the work of Alhabo and Zhang 2017 is illustrated in Figure 3.4. The algorithm starts by receiving neighbour small cells that have an RSRP level that is greater than a threshold P_{th}.

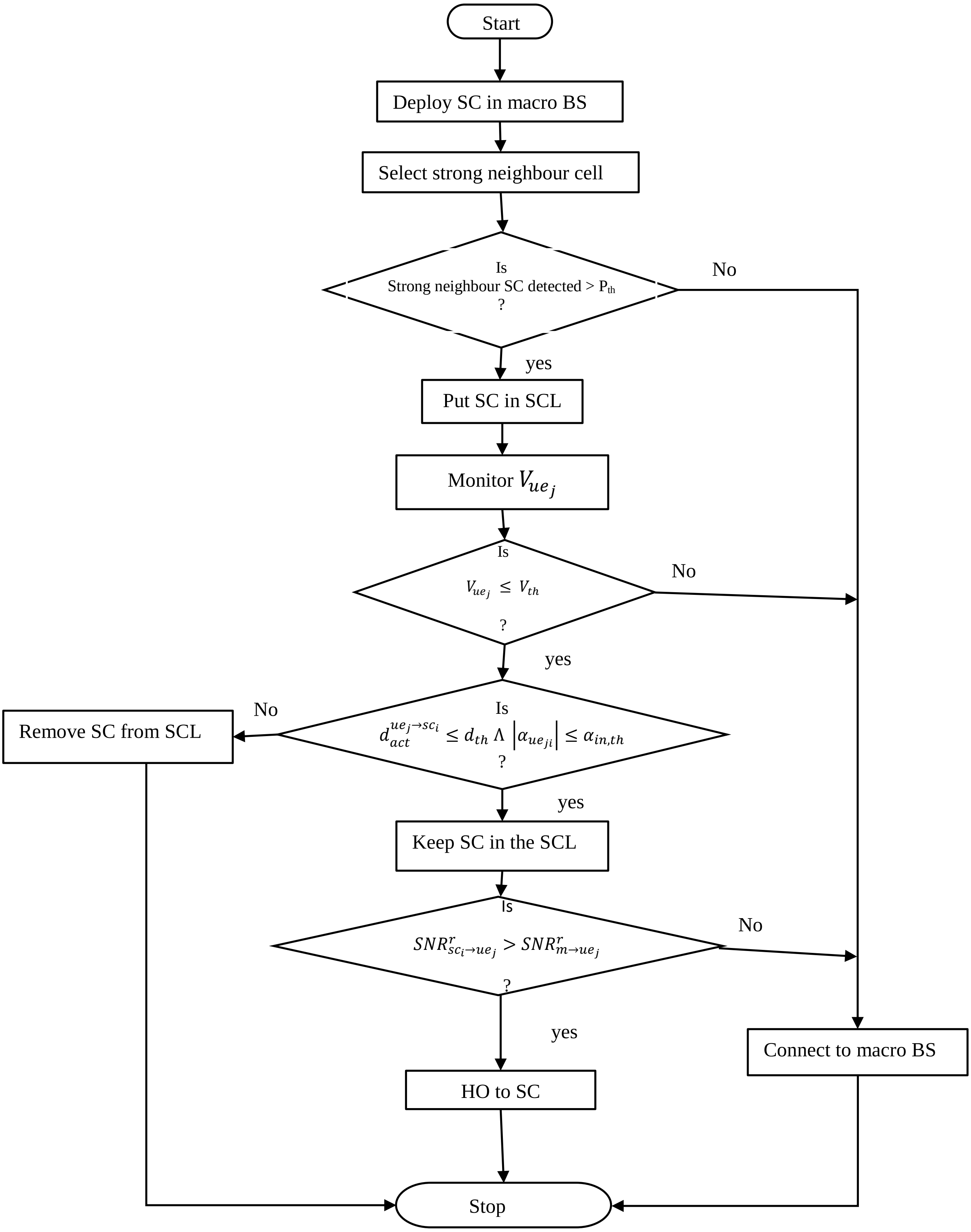

Figure 3.3: Flowchart of Alhabo and Zhang, (2017). (See Appendix H)

These small cells are then put in a shortened candidate list then a velocity threshold is used to control the handover process. If the UE is moving at a high speed, it attaches to a macro cell while if the UE is moving within the set velocity thresholds of 5kmph, 15kmph, 20kmph-then it forms a circle and the UE is located at the centre with a radius d_{th}. Consequently, angle thresholds of 20^0, 30^0 and 60^0 were used to accommodate number of users in the small cell list. And SNR is used at the receiving end to handover to the small cell with higher signal quality.

3.6 Development of Modified Handover Decision Algorithm

The modified handover decision algorithm considered low to medium users which is aimed at reducing the number of iterations and scanning for a neighbour cell for handover. This was achieved by setting a velocity threshold of 15kmph and an angle of 30^0 was set so as to accommodate medium velocity UEs in the candidate list. More so, for improved network throughput; signal to interference plus noise ratio was incorporated to mitigate the effect of interference from neighbouring cells. Finally, a mobility vector model ensured precise location and accurate handover was executed to the SC.

Furthermore, probability of handover for the modification is mathematically expressed (Alhabo, 2017) as:

$$\mathrm{P_{HO}} = \mathrm{P_r}\left[\mathrm{V_{ue_z}} \leq \mathrm{V'_{th}} \wedge \mathrm{d_{act}^{ue_z \to sc_x}} \leq \mathrm{d_{th}} \wedge \left|\propto_{\mathrm{ue_{zx}}}\right| \leq \propto_{\mathrm{xn,th}} \wedge \mathrm{SINR^r_{sc_x \to ue_z}} \mathrm{SINR^r_{m \to uez}} \wedge \mathrm{MVP}\right] \tag{3.11}$$

Where

$\mathrm{V'_{th}}$ represents $15km/hr$

SINR is the Signal to Interference Plus Noise Ratio

MVP denotes Mobility Vector Prediction (3.12)

$$SINR_{x \to ue_z} = \frac{P^r_{xp \to ue_z}}{\sum_{y=1, x \neq y}^{n_y} \quad \frac{P^t_{y \to ue_z} - g_y \, g_{ue_z}}{l_{o_y} l_{oue_z} \xi_{y \to ue_z} \delta_{y \to ue_z}} + \sigma^2}$$

Where:

$P^r_{xp \to ue_z}$ is pilot RSRP received from a target cell x at user z

$P^t_{y \to ue_z}$ is the transmitting power of the interfering base station y

n_y is total number of interfering base stations

σ denotes the noise power

g_y is the antenna gain of base station y

g_{ue_z} is antenna gain of user z

l_{o_y} is base station y equipment loss

l_{oue_z} is user equipment loss z

$\xi_{y \to ue_z}$ is the shadow fading between interfering base station and user z

$\delta_{y \to ue_z}$ is path loss between the interfering base station y and user z

The shape of a cell coverage area realistically depends on obstacles like geographic terrains, interference and environmental factors.

$SINR^r_{m \to ue_z}$ and $SINR^r_{sc_x \to ue_z}$ are the SINR received at user z from MC and SCx respectively, the SINR received from both MC is being measured by User z, $SINR^r_{m \to ue_z}$, and SC, $SINR^r_{sc_x \to ue_z}$ the HO is performed to this SC provided that this SC has enough capacity (resources) to serve this UE. This process then will offload the traffic from the MC and increase the network capacity (Alhabo, 2017).

3.6.1 Flow Chart of the Modified Handover Decision Algorithm

The modified handover decision algorithm flow chart is illustrated in Figure 3.4.

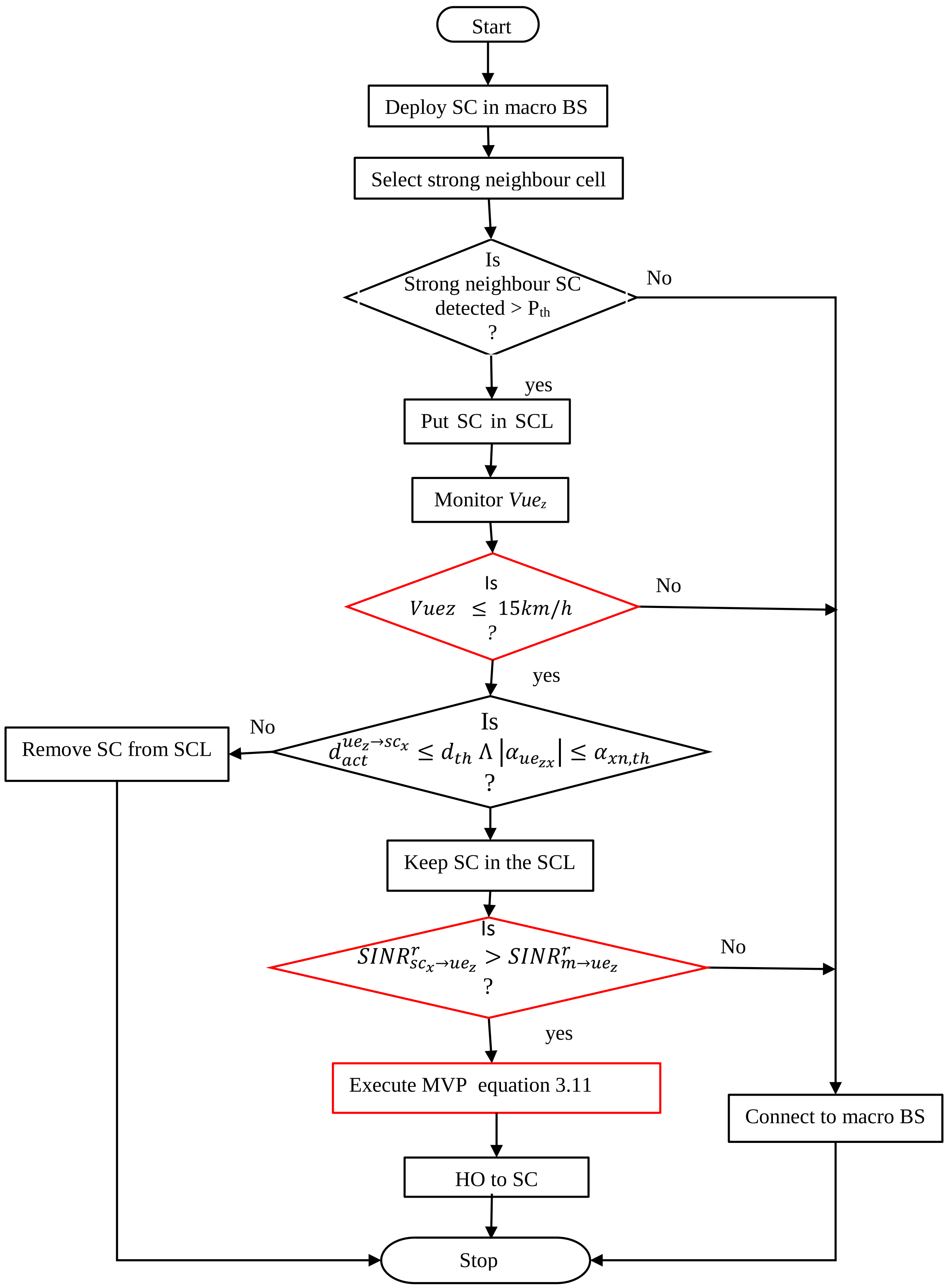

Figure 3.4: Flowchart of the Modified Handover Decision Algorithm. (See Appendix H)

It starts by deploying small cells in a macro cell area and an RSRP of greater than -70dBm was set to ensure the small cells are of higher RSRP signal strength. A shortened candidate list was then formed which contains only these small cells with the minimum RSRP level. If the RSRP level is below this minimum RSRP level, then the UE will be handed over to a macro cell. Because a macro cell accommodates small cells of lower signal strength and wider coverage. A velocity range of from 0kmph to 15kmph was set for mobile users in order to accommodate for pedestrians and motorcyclists within the speed range (Iñiguez, 2014). Users moving in vehicles were categorised as high speed and therefore when the users speed falls below 30kmph, drivers pay more attention to break frequently. And call connections last long enough to perform two consecutive HOs. Therefore, there is rarely measurement report of UEs for handover when the traffic speed is in the 15kmph bracket. (Chang *et. al*, 2015). However, this work adopted 15kmph as the velocity threshold for medium speed UEs. And then UEs moving at higher velocity above 15kmph were handed over to MC. This implies that the modified algorithm reduced the target SCs for UEs to connect to. While MCs accommodate only 20kmph and above UE speeds. More so, distance and angle thresholds were used to reduce the number of small cells in the list. SINR was then used to mitigate adjacent channel interference at cell edges and improve signal quality. Finally, a mobility vector prediction technique was adopted to predict the UE moving direction and decide the appropriate network for a successful handover.

3.6.2 Simulation Parameters and Assumptions

Simulation parameters and values used in this work were adopted from the work of Alhabo and Zhang (2017) as shown in Table 3.1.

Table 3.1: Basic Simulation Parameters

SN	Description	Value
1	Number of hexagonal macrocell	7
2	Number of SCs within MC	100
3	Small cell placement	Random 3GPP TS36.814
4	RSRP power level P_{th}	-70dBm
5	Distance threshold d_{th}	$2R_{scx}$
4	Velocity threshold V_{th}	15 km/h
5	Moving angle threshold $\alpha_{xn,th}$	30^o
6	System bandwidth	5 MHZ
7	Macrocell transmit power	45dBm
8	Macrocell antenna gain	15dBi
9	Macrocell radius	500 m
10	Small cell transmit power	2dBm
11	Small cell antenna gain	0dBi
12	Outdoor penetration loss (L)	10dB
13	Number of walls	Random

Table 3.2: Other parameters adopted for simulation

	Conventional	**Alhabo & Zhang, 2017.**	**Improved**
Velocity threshold V_{th} (km/h)	5, 15, 20	5, 15, 20	15
Distance threshold d_{th} (m)	$2R_{scx}$	$2R_{scx}$	$2R_{scx}$
Moving angle threshold $\alpha_{xn,th}$	-	20^o, 30^o, 60^o	30^o

Assumptions made are:

Effects of direction was assumed to be random.

The UE was connected to a SC as soon as it enters the cell coverage area and received minimum RSRP level. This is to ensure proper offloading of the MC and the traffic is transferred to the SC. Handover executions were assumed to be successful.

3.7 Performance Evaluation

Probability of handover, probability of unnecessary handover, network throughput and radio link failure probability were used to evaluate the performance of the modified handover decision algorithm.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the performance of the modified handover decision algorithm and that of the existing handover decision algorithm. This was carried out based on the probability of unnecessary handover and network throughput. The results obtained from the simulation are discussed and its significance to this research is also explained.

4.2 Results

This section presents the results obtained from the simulation setup and they are based on the probability of handover, probability of unnecessary handover, network throughput and radio link failure probability.

4.3 Probability of Handover

The probability of handover for the improved method is illustrated in Figure 4.1. This indicates a lower level of handovers for low to medium speed users. The plot shows a drop in the probability of handover as the UE velocity increases. This happens when it crosses the velocity threshold of 15kmph set by the improved algorithm. It then begins to rise as the UE velocity is increasing because higher speed UEs are handed over to MC. Hence, probability of handovers for the UEs on MC are higher than in SCs.

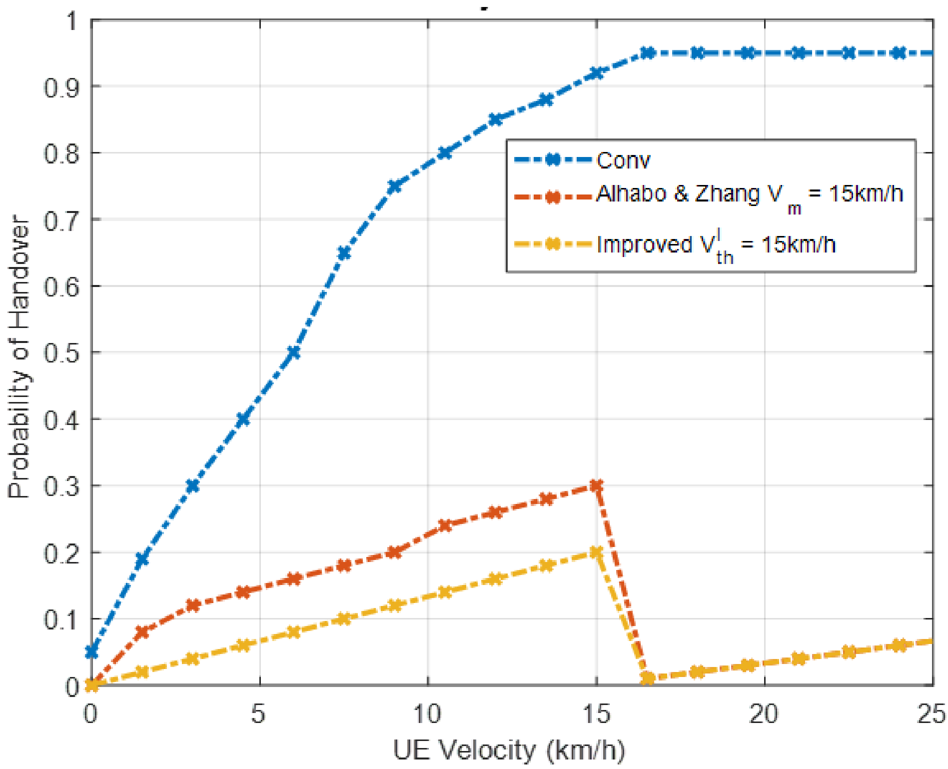

Figure 4.1: Probability of Handover

The probability of handover for the conventional method was generated using equation 2.5. It has the highest probability of handover due to an increase in UE velocity. So also, that of Alhabo and Zhang 2017 was generated using equation 2.5. It showed a lower level of handover for 15km/h velocity threshold. The improved handover probability was generated using equation 3.11. It shows the lowest level of handover at the velocity threshold of 25km/h because of the SINR and mobility vector prediction metrics. The sharp decline at 15km/h owes to the fact that the handover is to small cells (SC) and the UEs with a velocity of less than or equal to 15km/h. However, for high speed users which are above the velocity threshold, the handover happens between adjacent macro cells. This reduction in handover probability reduces the going back and forth by the UE to connect to a better network.

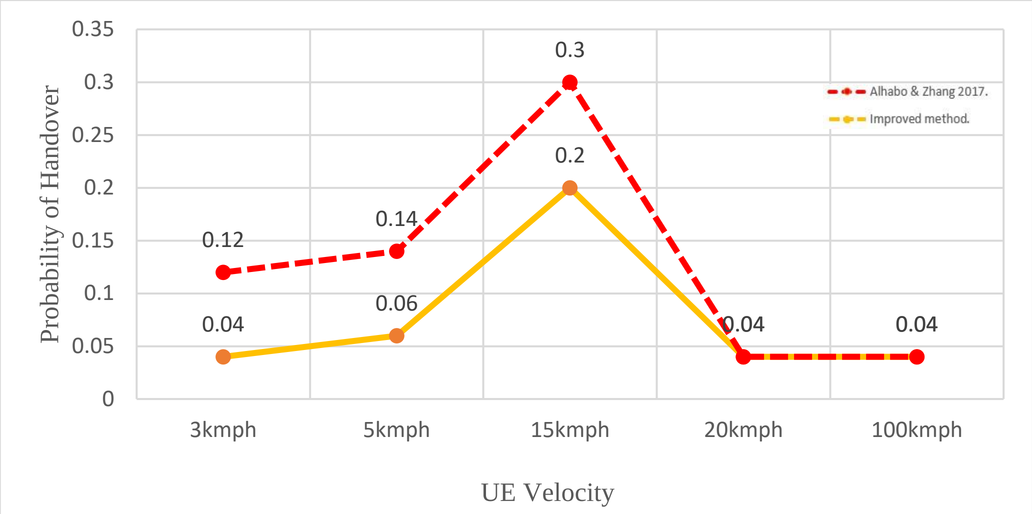

Figure 4.2: Probability of Handover for different UE velocities.

Figure 4.2 illustrates probability of handover for 3kmph, 5kmph, 15kmph, 20kmph, and 100kmph. This clearly shows improvement at the threshold of 15kmph. And this algorithm does not hold capacity for high speed users, as high-speed users are handed over to a macrocell. The slight improvement witnessed from the existing work was as a result of the signal to interference plus noise ratio and mobility vector prediction parameters included in the simulation.

4.3.1 Probability of Unnecessary Handover

The probability of unnecessary handover against the UE velocity was plotted in the figure 4.3. It was compared with the conventional handover scheme using equation 2.6. And the work of Alhabo & Zhang 2017 was generated using equation 2.6. The plot for the Improved algorithm was generated using equation 2.6. But the signal to interference plus noise ratio and mobility vector parameters included in the modified scheme yielded a better result as compared with existing work. This indicates low to medium speed UEs were accommodated in a single SC while UEs moving above the set threshold were handed over to neighbour MC for effective load distribution.

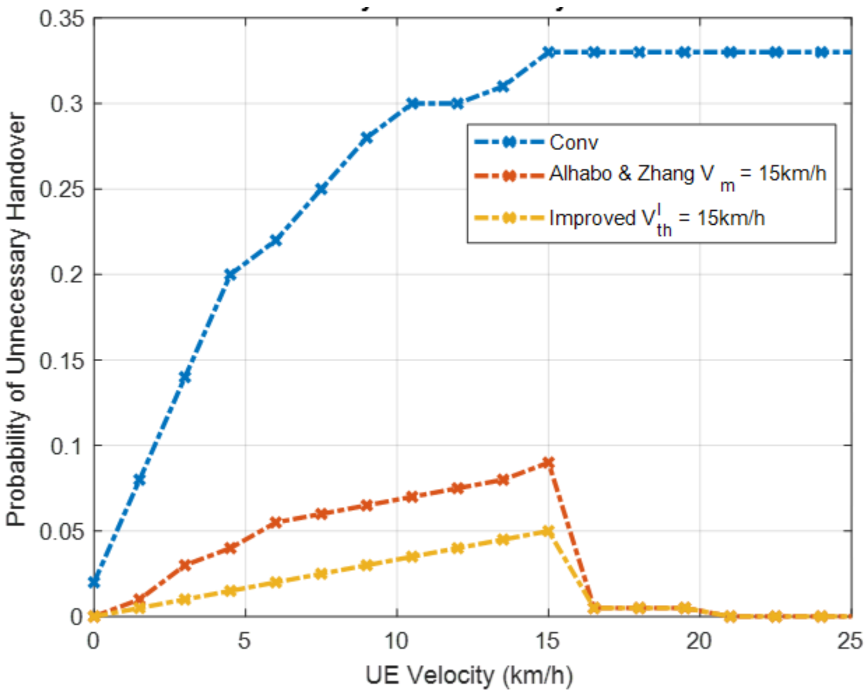

Figure 4.3: Probability of Unnecessary Handover

This shows a lower level of unnecessary handover owing to the fact that signal to interference plus noise ratio mitigates neighbour cell interference and mobility vector prediction accurately determines the proper target UE. The use of angle threshold 30^0 and shortened candidate list drastically reduced the number of targets SCs which as a result decreases the scanning process that consumes power. This angle threshold reduced SC list and reduced unnecessary handover. It however, helps to conserve the energy needed by the UE and reduces the excessive dissipation of energy of the UE battery.

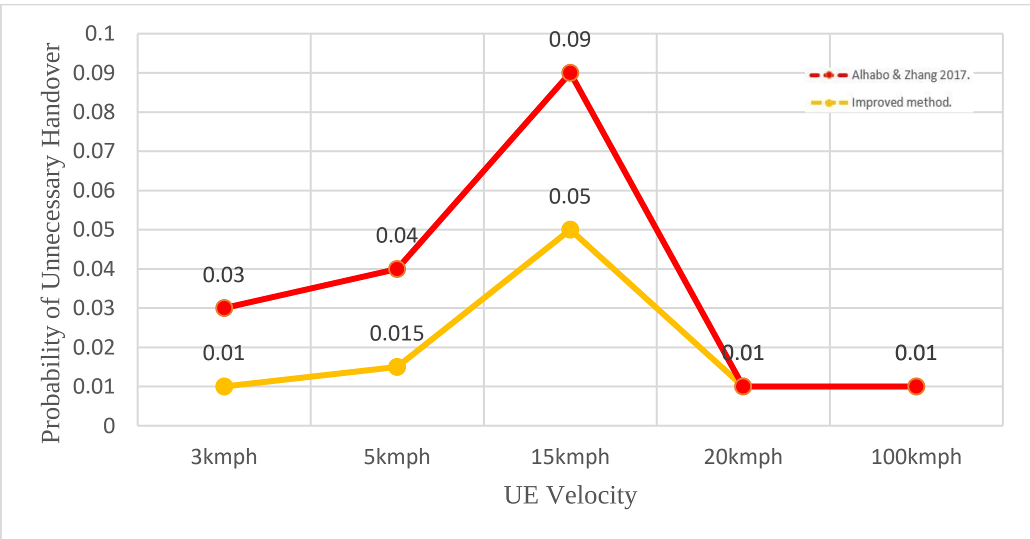

Figure 4.4: Probability of Unnecessary Handover for different UE velocities.

Figure 4.4 illustrates reduction in the probability of unnecessary handover as compared with the existing work using as low as 3kmph and as high as 100kmph. The utilization of the 30^0 angle threshold helped in reducing the candidate cells for handover. Also, 15kmph velocity threshold helped in avoiding handover to high speed UEs to mitigate unnecessary handover. Therefore, unnecessary handovers were reduced drastically for low to medium speed users. Whereas for high speed users, unnecessary handovers were avoided by transfering the users to a macro cell.

4.3.2 Network Throughput

Throughput is the average data rate transmitted over communication link. This naturally drops as the velocity of UEs increase momentarily. Due to this, low to medium speed users usually have higher throughput as compared to high-speed users. Figure 4.5 indicates throughput for the conventional handover scheme which was generated using equation 2.7. The work Alhabo and Zhang improved on the conventional scheme by setting thresholds for velocity and angle of movement. Signal to interference plus noise ratio was also introduced instead of signal to noise ratio which helped in improving the signal strength. It can also be shown that the network throughput gradually drops as UEs increase their velocity. High speed UEs tend to have lesser throughput than low speed UEs because they are linked to MCs.

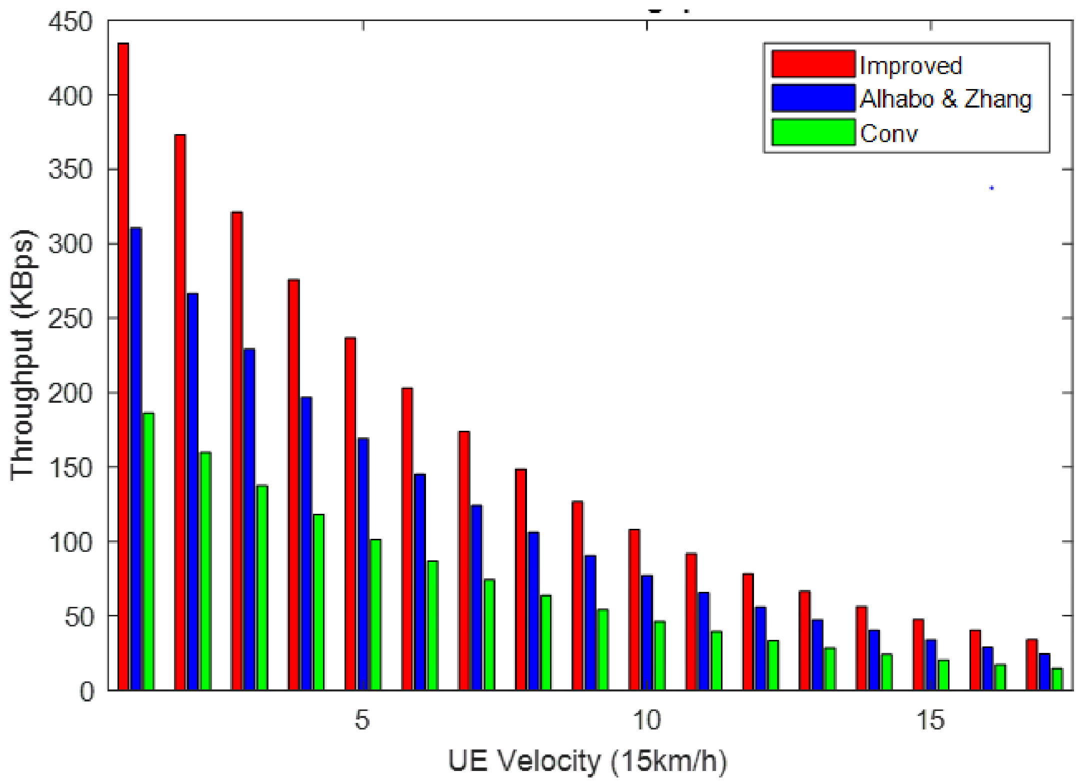

Figure 4.5: Network Throughput

The conventional has the lowest throughput while the existing (i.e., Alhabo and Zhang, 2017) shows an increase in the network throughput. The conventional handover uses only RSRP while the existing used shortened candidate list and signal to noise ratio (SNR). However, the improved method which was generated using equation 2.7 shows a greater improvement in the network throughput. Because it used shortened candidate list, signal to interference plus noise ratio (SINR) and mobility vector prediction. The small cell list holds a capacity by accommodating low to medium speed (i.e., pedestrians and motorcyclists). Thereby the signal received by the UEs is nearly steady and not easily fluctuated by variation in speed. This signal quality improvement corresponds to better signal quality and satisfactory user experience.

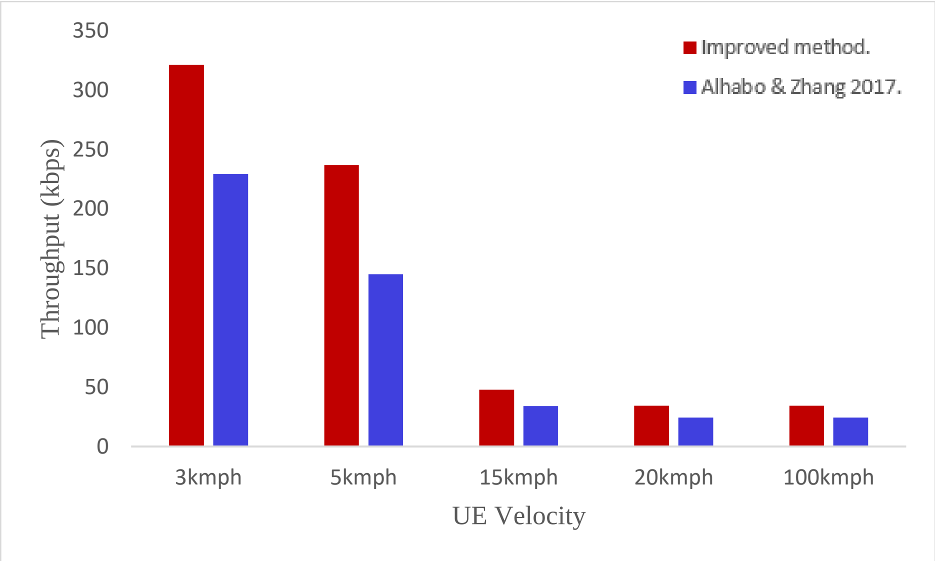

Figure 4.6: Network Throughput for different UE velocities.

Figure 4.6 illustrates network throughput at very low speed of 3kmph and high speed of 100kmph. This modified algorithm was able to maintain higher throughput owing to the fact that low speed users have the highest throughput because they are accommodated by small cells and high-speed users are served by macro cell. The SINR introduced helped to achieve better throughput for high speed UEs because it dealt with interference from neighbouring cells.

4.3.3 Radio Link Failure Probability

Radio link failure probability was introduced to further test the improved algorithm in terms of its performance. As shown in figure 4.7, it was then compared with a conventional scheme of 3GPP release 10.

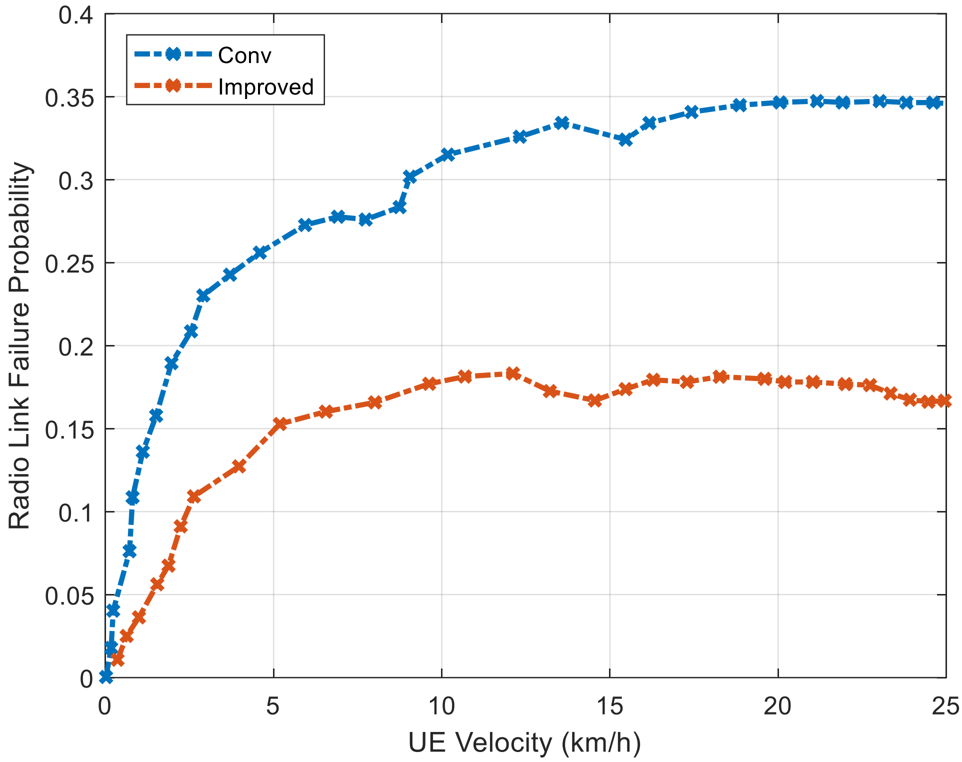

Figure 4.7: Radio link failure probability

Radio link failure is detected by the UE and it occurs when there is a continuous failure to handover to a target cell. The network quality is usually threatened by interference and signal strength degradation. Figure 4.7 was generated using equations 2.8 for the conventional handover decision scheme and for the improved handover decision. The improved method used additional parameters to give a better result. Thus, signal to interference plus noise ratio, mobility vector prediction and lower velocity threshold. This was generated to compare and test the robustness of the developed algorithm. As the UE velocity increases, the probability of radio link failure increases as well. However, it is more so in the conventional. Using the improved algorithm, the probability of radio link failure is not as high. This suggests that the UE does not lose its connection easily in anticipation of a better connection while moving in the network coverage.

4.4 Summary of Results

From the results discussion, it can be seen that the modified handover decision algorithm improved the performance of the existing handover decision algorithm successfully. This modified scheme performed better in terms of probability of handover, probability of unnecessary handover, network throughput and radio link failure probability.

The developed handover decision algorithm achieved 44.44% reduction in the probability of unnecessary handovers as compared to the work of Alhabo & Zhang, 2017. This reduction in the probability of unnecessary handover was achieved by considering the medium speed users and the angle thresholds at which the UEs are moving. Also, 33.33% reduction in the probability of handover. As a result, the network throughput was improved by 40%. This was achieved by mitigating interference from neighbouring cells. These results were compared with the work of Alhabo & Zhang 2017. Furthermore, radio link probability was used to validate or test the capacity of the modified handover decision algorithm when compared with the conventional handover decision algorithm as specified by 3GPP release 10, 2011. This radio link failure probability recorded 46.37% reduction.

Probability of Handover: -

$$\%\ Reduction\ in\ P_{HO} = \frac{P_{HO\ IMPROVED} - P_{HO\ EXISTING}}{P_{HO\ EXISTING}} \tag{4.1}$$

$$\%\ Reduction\ in\ P_{HO} = \frac{0.2\ -\ 0.3}{0.3} = 33.33\%$$

Probability of Unnecessary Handover: -

$$\%\ Reduction\ in\ P_{UNHO} = \frac{P_{UNHO\ IMPROVED} - P_{UNHO\ EXISTING}}{P_{UNHO\ EXISTING}}$$

$$\%\ Reduction\ in\ P_{UNHO} = \frac{0.05\ -\ 0.09}{0.09} = 44.44\%$$

Network Throughput: -

$$\%\ Improvement\ on\ Throughput = \frac{IMPROVED - EXISTING}{EXISTING}$$

$$\%\ Improvement\ on\ Throughput = \frac{34.09\ -\ 47.73}{47.73} = 40\%$$

Radio Link Failure Probability: -

$$\%\ Reduction\ in\ RLFP = \frac{IMPROVED - EXISTING}{EXISTING}$$

$$\%\ Reduction\ in\ RLFP = \frac{0.017\ -\ 0.32}{0.32} = 46.37\%$$

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Summary

This research developed a modified handover decision algorithm in LTE-A using mobility vector prediction technique. Performance evaluation and comparison of results were carried out based probability of handover, probability of unnecessary handover, network throughput and radio link failure probability.

This chapter summarizes the research, conclusions reached, significant contributions and recommendations

5.2 Conclusion

In this research thesis, a modified handover decision algorithm that reduced the excessive scanning process for a neighbour cell was developed. A velocity of 15kmph was set as the velocity threshold to accommodate low to medium speed UEs. These UEs will be connected to one SC. And then UEs moving above the set threshold will be handed over to macro cell (MC). An angle which determines the number of SCs in the shortened SC list was set to 30^0. This was to ensure only SCs with high SINR are located within the UE trajectory for potential handover. Mobility vector prediction technique was adopted to predict the direction of the UE and locate it for a handover from one network to the other as the UE roams in the LTE-A network. In addition to prediction; this mobility vector was used to allow slight changes and stores previous locations of UEs in the network.

5.3 Significant Contributions

The contributions achieved in this research are as follows:

i. Probability of unnecessary handover was reduced by 44.44%.
ii. Reduction in the probability of handovers was achieved by 33.33%.
iii. Network throughput was improved by 40% when compared with the handover decision algorithm by Alhabo & Zhang 2017.
iv. Radio link failure probability was reduced by 46.37%. However, this was adopted to monitor and avoid consistent failure to handover to a mobile user. This also aided in achieving a successful connection to the neighbour base station in the network. The modified handover decision algorithm achieved reduced neighbour cell interference by using signal to interference plus noise ratio.

UEs moving at an angle of 30^0 threshold were used to create a candidate of UEs with high signal strength and UE velocity threshold of 15kmph was used to control the HO to the target SC.

Effective handover was achieved by adopting mobility vector prediction technique in order to be able to predict the users' moving direction and locate their position in the LTE-A network.

5.4 Recommendation for future work

The recommendations drawn for further works are as follows:

i. Handover could further be reduced by considering real-time/location and group of UEs.

ii. Further researches using state-based prediction algorithms are underway and could be introduced to improve on the prediction accuracy of the UEs; especially the UEs that follow a fixed routine pattern.

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Appendix A: M-File of UE Starting point

```
% Start of Simulation

SimTime = 10  % 100 Simulation time
userxx=zeros(3,No_UE); useryy=zeros(3,No_UE);

mov_step = 5;

for t = 1:SimTime
    for m=1:No_UE
        pause(1)
        xx = ceil(3*rand(No_UE,1)); %direction
        UE_dir(t,m) = xx(m);
        if UE_dir(t,m) == 1
            UE_xpos(t,m) = UE_xpos(t,m) + mov_step;
            UE_ypos(t,m) = UE_ypos(t,m) + mov_step;
            %line([UE_pos(t-1,1) UE_pos(t,1)], [UE_pos(t-1,2) UE_pos(t,2)])
UE_xpos(t,m) = UE_xpos(t,m) + mov_step; UE_ypos(t,m)=UE_ypos(t,m)- mov_step;
   end
        line([UE_xpos(t,m) UE_xpos(t,m)], [UE_ypos(t,m) UE_ypos(t,m)])
        %Find the distance for UE to Macro base station
for bs=1:No_BS
     userxx(t,m)= UE_xpos(t,m)-xloc(bs);useryy(t,m)=UE_ypos(t,2)- yloc(bs);
     % d=sqrt(userxx(i,k)^2+useryy(i,k)^2)/1000;
         if userxx(t,m)>0
            theta=atand(useryy(t,m)/userxx(t,m));
         if theta>0
            A=-min(12*(abs(theta-60)/70)^2,20);
         else
            A=-min(12*(abs(theta+60)/70)^2,20);
        end
         else
           theta=atand(useryy(t,m)/userxx(t,m)); theta2=theta+180;
          if abs(theta) <60
            A=-min(12*(abs(theta)/70)^2,20);
          elseif theta>60
            A=-min(12*(abs(theta-60)/70)^2,20);
          else
            A=-min(12*(abs(theta+60)/70)^2,20);
          end
         end
disUE_BS(m,bs)=sqrt((UE_xpos(t,m)-xloc(bs))^2+(UE_ypos(t,2)-yloc(bs))^2);
PL_Macro(m,bs)=128.1+37.6*log10(disUE_BS(m,bs)/1000);
Pr_Macro(m,bs)=Ptm+Gtm+Grm-PL_Macro(m,bs)-shadowingm*randn(1)+A;
end
 SINR_Macro(t,m)= SINR(Pr_Macro(m,:))
 UE_xpos(t,m) = UE_xpos(t,m) + mov_step;

%Find the distance for UE to Pico base station
for fs=1:No_PC
disUE_FS(m,fs)=sqrt((UE_xpos(t,m)-femto_xloc(fs))^2+(UE_ypos(t,2)-
femto_yloc(fs))^2);
PL_Femto(m,fs)=140.7+36.7*log10(disUE_FS(m,fs)/1000);
PL_Femto(m,fs)=127.1+30.0*log10(disUE_FS(m,fs)/1000); % %
Pr_Fe mto(m,fs)=Pt+Gt+Gr-PL_Femto(m,fs)-shadowing*randn(1) ;
end
SINR_Femto(t,m)= CAL_SINR(Pr_Femto(m,:))

end
end
```

```
%-------------------------------------------
%Generate ms randomly- initial position of MS
%-------------------------------------------


ang_deg=360*rand(1,MS);
% angular position randomly
ang_rad=ang_deg*pi/180;
rad=11*rand(1,MS);
% radial distance randomly
% BS_ID=ceil(BS*rand(1,MS))
xlocms=rad.*cos(ang_rad) ;
ylocms=rad.*sin(ang_rad) ;
ms=[xlocms' ylocms'];
% I added semi colom
xlocms=ms(:,1);
ylocms=ms(:,2);
plot (xlocms', ylocms','bo');
axis equal
hold on
```

Appendix B: M-file of UE point in each MC

```
No_PC=1; %19
init_pico=-0.5*radius+radius*rand(2,1);
picounity=0;
j=1;k=1;l=1;f=0;% M=120;
picox=zeros(No_BS,No_PC);picoy=zeros(No_BS,No_PC);
II=zeros(1,3); %19


UE generation
userx=zeros(3,No_UE);usery=zeros(3,No_UE);
for i=1:3
    k=1;
    while k<=No_UE
        userx(i,k)=      init_pico(1)+xloc(i);       %(1000/sqrt(3)*rand()-
500/sqrt(3))+xloc(i);
        usery(i,k)=init_pico(1)+yloc(i);  %(500*rand()-250)+yloc(i);
        distance=sqrt((userx(i,k)-xloc(i))^2+(usery(i,k)-yloc(i))^2);
        h=1;judge=0;
        picoUEdis=3; %50
        while h<=3 %19
            l=1;
           while l<=No_PC
               picoUEdis=sqrt((userx(i,k)-picox(h,l))^2+(usery(i,k)-
picoy(h,l))^2);
               if picoUEdis<3
                   judge=1;
                   break;
               end;
               l=l+1;
           end;
           if judge==1
               break;
           end
           h=h+1;
        end
```

```
        ifabs(userx(i,k)-xloc(i))+abs(usery(i,k)-
yloc(i))/sqrt(3)<=500/sqrt(3)&&distance>25&&picoUEdis>10
          %userx(i,k)=userx(i,k)+macroposx(i);
%usery(i,k)=usery(i,k)+macroposy(i);
          k = k+1;
        end
     end
end
```

Appendix C: M-file of Small Cells Ratio in the List

```
 % title('Small Cells Ratio in the List')
grid on
spd = 17;

data1 = data.data1; data2 = data.data2; data3 = data.data3;
time=0:spd;
time=1.5*time;
% Next, make the vector real time

        %-----------------------
        %Angle Initial Value
        %-----------------------
        angle(i_cell,j)=atan2(ydiff,xdiff);
        angdeg(i_cell,j)=angle(i_cell,j).*180/pi;

        %angle of MS wrt right horizontal line

        if angdeg(i_cell,j)<0
            ang(i_cell,j)=angdeg(i_cell,j)+360;
        elseif angdeg(i_cell,j)>=0
            ang(i_cell,j)=angdeg(i_cell,j);
        end

        % MS angle base on the minimum distance BS
        if dist1_bs_init_assign(j)== 1
            ms_ang(:,j)=ang(1,j)

        elseif dist1_bs_init_assign(j)== 2
            ms_ang(:,j)=ang(2,j)

        elseif dist1_bs_init_assign(j)== 3
            ms_ang(:,j)=ang(3,j)

        elseif dist1_bs_init_assign(j)== 4
                ms_ang(:,j)=ang(4,j)

                elseif dist1_bs_init_assign(j)== 5
                    ms_ang(:,j)=ang(5,j)

                    elseif dist1_bs_init_assign(j)== 6
                        ms_ang(:,j)=ang(6,j)

                    else dist1_bs_init_assign(j)== 7
                            ms_ang(:,j)=ang(7,j)
                        end
```

Appendix D: M-file Forming Shortened Candidate List

```
No_PC=7; %19
init_pico=-0.5*radius+radius*rand(2,1);
picounity=0;
j=1;k=1;l=1;f=0;% M=120;
picox=zeros(No_BS,No_PC);picoy=zeros(No_BS,No_PC);
II=zeros(1,7); %19

for i=1:No_BS
    j=1;
    while j<=No_PC
picox(i,j)=init_pico(1)+xloc(i);%(1000/sqrt(3)*rand()-500/sqrt(3))+xloc(i);
        picoy(i,j)= init_pico(2)+yloc(i);%(500*rand()-250)+yloc(i);
        distance=sqrt((picox(i,j)-xloc(i))^2+(picoy(i,j)-yloc(i))^2);
        h=1;judge=0;
        picodis=5; %50
        while h<=i
            l=1;
           while l<j
picodis=sqrt((picox(i,j)-picox(h,l))^2+(picoy(i,j)-picoy(h,l))^2);%
   if picodis<4 %40
   judge=1;break;
      end;
      l=l+1;
      end;
      if judge==1
      break; end
       h=h+1;end;
        if
abs(picox(i,j)-xloc(i))+abs(picoy(i,j)-
yloc(i))/sqrt(3)<=500/sqrt(3)&&distance>75&&picodis>4
     j = j+1;end
    end
    II(i)=i;
end
```

Appendix E: M-File of Modified Handover Decision Algorithm

```
%Handover decision
for b=1:length(xloc)
 distBS(t,b) = sqrt((UE_pos(t,1) - xloc(b))^2 + (UE_pos(t,2) - yloc(b))^2);
 PL(t,b)=32.44+20*log10(f)+20*log10(distBS(t,b)/1000);
 Pr(t,b)=Pt+Gt+Gr-PL(t,b)-8*randn(1);
 distBS2(t) = sqrt(UE_pos(t,1) - BS2(1))^2 + (UE_pos(t,2) - BS2(2))^2
 %pause(1)
      if distBS1(t) > distBS2(t); BS_Serv(t) = 1;
      else
        BS_Serv(t) = 2;
       end
     end

 AXIS([-2000 2000 -2000 2000])
 [xx,yy]=min(distBS(t,:));
min_distBS(t)=xx;BS_serve(t)=yy;[gg,kk]=max(Pr(t,:));xxyy=sorkt(Pr(t,:));
```

```
min_distBS(t)=xx;BS_serve_dist(t)=yy;RSSI(t)=xxyy(:,1);BS_serve_RSSI(t)=xxy
y(:,2);
 % Pc=gg(1)
RSSw=10.^(RSSI/10);Pc=10*log10(RSSw(1));Pnw=10^(Pn/10);
Pinw=sum(RSSw)-RSSw(1)+Pnw; Pin=10*log10(Pinw);SINR(t)=Pc-Pin;
 %Femto cell
femtocell_loc= femtocell(n,x_init,y_init,R_femto)
for i=1:7
     for j=1:n*n
distFC(t,j)=sqrt((UE_pos(t,1)-femto_xloc(i,j))^2+(UE_pos(t,2)-
femto_yloc(i,j))^2);
PL(t,j)=32.44+20*log10(f)+20*log10(distFC(t,j)/1000);Pr(t,j)=Pt+Gt+Gr-
PL(t,b)-8*randn(1);
     end
 end
global R_femto
global NoUE_Per_Sec
global No_Sec
global radius
global BS_locx
global BS_locy

f=2100;
% in MHz
n=2;
x_init = 0;
y_init = 0;
radius = 350;
R_femto=0.01*radius;
Ptm=46;
% in dBm
Gtm=14;
% in dBi
Grm=0;
% in dB
Ptf=30;
% in dBm
Gtf=5;
% in dBi
Grf=0;
% in dB
shadowingm = 8;
% in dB macrocell
shadowingf = 10;
% 5x5 Grid shadowing
Pn=-115;
% in dBm
No_BS=7;
% Number of Macro Cell
No_FS=14;
% Number of Small Cell 7x14+2
No_UE=5;
% Number of User Equptment
velo = 15;
% 15 km/h
bandwidth=10^7;
% LTE bandwidths 1.4MHz=6RBs,3MHz=15RBs,

% 5MHz=25RBs,10MHz=50RBs,15MHz=75RBs and 20MHz=100RBS
TTI=1;
% e.g TTI=2xRBs
```

```
Nu=12;
% No of subcarriers in each physical resorce block
for time =1:TTI

draw_top_femto
pause(0.1)
UE_generation
pause (0.1)

%%%%%%%%%%%sensing throughput tradeoff for CRN%%%%%%%%%%%
spk = velo;
Pd=0.9;
Pf=1-Pd;
PH1=30.9; %2
PH0=1-PH1;
SINRp=-spk;
SINRs=20;
T=10000e-3; %10
SINRP=10.^(SINRp/10);
SINRS=10.^(SINRs/10);
C0=log2(1+SINRS);
C1=log2(1+SINRS/(1+SINRP));
fs=1e+6; %6
t=1e-3:0.5e-3:9e-3; %9 it was 5
a=(2*SINRP+1).^0.5*qfuncinv(Pd);
b=(2*SINRP+1).^0.5;
for i_cell=1:length(t)
R1(i_cell)=(1-t(i_cell)/T)*C1*PH1*(1-qfunc(1/b*(qfuncinv(Pf)-
(t(i_cell)*fs).^0.5*SINRP)))  %R1(i)=(1-t(i)/T)*C0*PH0*(1-
qfunc(a+(t(i)*fs).^0.5*SNRP))
R2(i_cell)=(1-t(i_cell)/T)*C1*PH1*(1-qfunc(1/b*(qfuncinv(Pf)-
(t(i_cell)*fs).^0.5*SINRP)))
R3(i_cell)=(1-t(i_cell)/T)*C1*PH1*(1-qfunc(1/b*(qfuncinv(Pf)-
(t(i_cell)*fs).^0.5*SINRP)))
end
datar1 = R1*1.5; datar2 = R2*2.5; datar3 = R3*3.5;

figure(6)
bpcombined = [datar3(:), datar2(:), datar1(:)];
hb = bar(bpcombined, 'grouped');
set(hb(1), 'FaceColor','r');
set(hb(2), 'FaceColor','b');
set(hb(3), 'FaceColor','g');
xlabel('UE Velocity (15km/h)');
ylabel('Throughput (KBps)');
legend('Improved', 'Alhabo & Zhang','Conv');
% title('Network throughput');


ang = 0 : 1 : spk;
%angle
capacity_loss = 0.5*(1 - ((1/sqrt(3)))*(((2*pi)/3)-ang)*((0.84*R/R)^2));
figure(7)
plot ( ang,capacity_loss*20.5,'-.>', ang,capacity_loss*10.5,'-.>',
ang,capacity_loss,'-.>','lineWidth',2);
xlabel('Distance threshold "d_t_h " (candidtate list circle radius as a
function of R_s_c)');
ylabel('The Ratio of Candidate Small Cells (%)');
legend('Conv', 'Alhabo & Zhang t_i_n_t_h =30^0', 'Improved t_x_n_t_h =
30^0');
```

```
% title('Small Cells Ratio in the List')
grid on
spd = 17;

data1 = data.data1; data2 = data.data2; data3 = data.data3;
time=0:spd;
time=1.5*time;
% Next, make the vector real time

figure (8)
plot(time, data1, '-.x', time, data2, '-.x', time, data3, '-
.x','lineWidth',2);
xlabel('UE Velocity (km/h)');
ylabel('Probability of Handover');
legend('Conv', 'Alhabo & Zhang V_m = 15km/h', 'Improved V^l_t_h = 15km/h');
% title('Probability of Handover');
xlim([0 25])
%ylim([0 0.15])
grid on

data4 = data.data4; data5 = data.data5; data6 = data.data6;
time=0:spd;
time=1.5*time;
% Next, make the vector real time

figure (9)
plot(time, data4, '-.x', time, data5, '-.x', time, data6, '-
.x','lineWidth',2);
xlabel('UE Velocity (km/h)');
ylabel('Probability of Unnecessary Handover');
legend('Conv', 'Alhabo & Zhang V_m = 15km/h', 'Improved V^l_t_h = 15km/h');
title('Probability of Unnecessary Handover');
xlim([0 25])
%ylim([0 0.15])
grid on
```

Appendix F: M-File of Radio link failure probability

```
%Radio Link Failure Probability plot
load conv1;
load imprv1;
datacv = conv1(:,2);datacv2=conv1(:,1); dataoim = imprv1(:,2);dataoim2 =
imprv1(:,1);
%datacv = conv2(:,2);datacv2=conv2(:,1); dataot = other2(:,2);dataot2 =
other2(:,1); dataoim = imprv2(:,2);dataoim2 = imprv2(:,1);
spd = 17;
time=0:spd;
time=1.5*time;% Next, make the vector real time
figure ()
plot (datacv2, datacv/2.8571, '-.x','lineWidth',2); hold on
plot(dataoim2, dataoim/3.8, '-.x','lineWidth',2); hold off
xlabel('Velocity UE(km/h)');
ylabel('Radio Link Failure Probability');
legend ('Conv', 'Improved','location','northwest');
title('Radio Link Failure Probability');
xlim([0 25]);ylim([0 0.4])
grid on
```

Appendix G: Tables of Results

Table 4.1: Probability of Handover simulation results:

	3kmph	**5kmph**	**15kmph**	**20kmph**	**100kmph**
Alhabo & Zhang 2017. (Pr. HO)	0.12	0.14	0.3	0.04	0.04
Improved method. (Pr. HO)	0.04	0.06	0.2	0.04	0.04
Percentage (%) reduction.	66.67	57.14	33.33	0	0

Table 4.2: Probability of Unnecessary Handover simulation results:

	3kmph	**5kmph**	**15kmph**	**20kmph**	**100kmph**
Alhabo & Zhang 2017. (Pr. unHO)	0.03	0.04	0.09	0.01	0.01
Improved method. (Pr.unHO)	0.01	0.015	0.05	0.01	0.01
Percentage (%) reduction.	66.67	62.50	44.44	0	0

Table 4.3: Network Throughput simulation results:

	3kmph	**5kmph**	**15kmph**	**20kmph**	**100kmph**
Alhabo & Zhang 2017. (Throughput)	229.3	145	34.09	24.40	24.40
Improved method. (Throughput)	321	236.8	47.73	34.16	34.16
Percentage (%) Improvement.	39.99	63.31	40	40	40

Table 4.7: Radio link failure probability simulation results:

	5kmph	**15kmph**	**20kmph**
Conventional scheme (RLFP)	0.2726	0.3241	0.3465
Improved method. (RLFP)	0.1528	0.1738	0.1781
Percentage (%) reduction.	-43.95	-46.37	-94.55

Appendix H:

Algorithm 1 Alhabo and Zhang 2017 Pseudo code.

1. If strong neighbour SC detected > P_{th} then
2. Put the SC in a shortened candidate list
3. Monitor V_{ue_j}
4. If $V_{ue_j} \leq V_{th}$ then
5. If $d_{act}^{ue_j \to sc_i} \leq d_{th} \wedge \left|\alpha_{ue_{ji}}\right| \leq \alpha_{in,th}$ then
6. Keep *Sci* from the shortened candidates list
7. Else
8. Remove SC *Sci* from the shortened candidates list
9. End if
10. End if
11. if maximum $SNR_{sc_i \to ue_j}^{r} > SNR_{m \to ue_j}^{r}$ then
12. Handover to SC
13. End if
14. End if

Algorithm 2 Modified Handover Decision Pseudo code.

1. If strong neighbour SC detected > P_{th} then
2. Put the SC in a shortened candidate list
3. Monitor Vue_z
4. If $Vuez \leq 15km/h$ then
5. If $d_{act}^{ue_z \to sc_x} \leq d_{th} \wedge \left|\alpha_{ue_{zx}}\right| \leq \alpha_{xn,th}$ then
6. Keep SC Sci from the shortened candidates list
7. Else
8. Remove SC *Scx* from the shortened candidates list
9. End if
10. End if
11. if maximum $SINR_{sc_x \to ue_z}^{r} > SINR_{m \to ue_z}^{r}$ then
12. Execute MVP equation 2.11
13. Handover to SC
14. End if
15. End if