Sudan University of Science and Technology

College of Engineering

School of Electronics Engineering

Performance Evaluation of Handover in Heterogeneous Networks (HetNets) Using Adaptive Time-To-Trigger

A Research Submitted In Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honors) In Electronics Engineering (communications)

Prepared by:

1. Altayeb Abdel Halem Almohtdi Alwasela.
2. Hana Hassan Babiker Mohammed.
3. Rawaa Abdel Moniem Elgassim.
4. Zeinab Yousif SidAhmed Khalid.

Supervised By:

Dr. Fath Elrahman Ismael Khalifa

October 2016

DECLARATION

''*An Investigation in Knowledge Pays the Best*

Interest''

DEDICATION

We dedicated this thesis to our families, friends and teachers, and to everyone who supported and encouraged us along the way to reach our goal, present and absent, near or far, may God bless you wherever you are, and May happiness finds its way to you all, thank you.

ACKNOWLEDGMENT

ABSTRACT

Future cellular networks are expected to consist of macro-cell overlaid with small-cells; these multi-tire deployments pose challenges to mobility management procedures like Handover. It's important to achieve a successful Handover procedure to reduce the probabilities of Handover Failure and Radio Link Failure which are the Handover performance metrics, by selecting appropriate Time-To-Trigger (TTT) according to inter-site distance and user's velocity; this was proposed as technique to improve the Handover performance. In this research using MATLAB to view the appropriate Time-To-Trigger value for the user for each Handover performance metrics according to the inter-site distance and user's velocity. The results indicated that the proposed technique achieved an improvement in the Handover performance by selecting appropriate Time-To-Trigger value for the user in each inter-site distance for specific velocity (60Km/h).

المستخلص

إن مستقبل الشبكات الخليوية يتوجه الى أن تكون مكونه من خلية كبيرة مضافا بداخلها خلايا صغيرة؛انتشار هذه التقسيمات المتعددة يشكل تحدى لإجراءات ادارة التنقل مثل التسليم. إن من المهم أن يتم إنجاز إجراء تسليم ناجح حتى يتم تقليل احتمالات حدوث فشل التسليم وكذلك فشل الربط الراديوي الممثلين لمقاييس اداء التسليم,عن طريق اختيار زمن مناسب لبداية اجراءات التسليم طبقا للمسافة بين موقع مركز الخلية الكبيرة ومركز الخلية الصغيرة وكذلك سرعة المستخدم حيث اقترحت كتقنية لتحسين اداء التسليم. في هذا البحث تم استخدام الماتلاب لعرض قيمة مناسبة لزمن البداية لإجراءات التسليم للمستخدم لكل مقياس لأداء التسليم طبقا للمسافة بين موقع مركز الخلية الكبيرة ومركز الخلية الصغيرة وكذلك سرعة المستخدم. وقد اشارت النتائج الي ان التقنية المقترحة حققت تحسنا في اداء التسليم عن طريق اختيار قيمة مناسبة لزمن البداية لإجراءات التسليم للمستخدم في كل مسافة لسرعة معينة (60 كلم/ساعة).

TABLE OF CONTENTS

LIST OF TABLES

TABLE NO.	TITLE	PAGE

LIST OF FIGURES

LIST OF ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership project
4G	Fourth Generation
BS	Base Station
eNB	Evolved NodeB
E-UTRAN	Evolved Universal Terrestrial Access Network
HeNB	Home evolved NodeB
HetNets	Heterogeneous Networks
HO	Handover / Handoff
HOF	Handover Failure
HSPA	High Speed Packet Access
Hyst	Hysteresis
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
MCDM	Multi-Criteria Decision Making
MeNB	Macro evolved NodeB
MeNB	Master evolved NodeB
MIMO	Multi-Input Multi-Output
MME	Mobility Management Entity
MT	Mobile Terminal
OFDM	Orthogonal Frequency Division Multiplexing

OFDMA	Orthogonal Frequency Division Multiple Access
PDCCH	Physical Downlink Control Channel
PeNB	Pico evolved NodeB
P-GW	Packet Data Network Gateway
PHO	Handover Probability
PHOF	Handover Failure Probability
PP	Ping-Pong
PRLF	Radio Link Failure Probability
RLF	Radio Link Failure
RSS	Received Signal Strength
RSRP	Received Signal Received Power
SeNB	Secondary evolved NodeB
S-GW	Serving Gateway
SINR	Signal-to-Interference and Noise Ratio
SMS	Short message service
SONs	Self-Organizing Networks
Tex	Execution Time
Tp	Preparation Time
TTT	Time-To-Trigger
UE	User Equipment

LIST OF SYMBOLS

inner   Is the angle formed by the straight line joining the user equipment location and the small cell site, and the line joining the macro cell site

θ_i Entry angle which is the maximum entry angle for which the inbound HO can be completed

θ_e Entry angle

θ_t Entry angle which is the maximum angle for which T expires within the HOF circle

θ_R Entry angle which is the maximum angle for which the distance covered by a UE within the HOF region is larger than vTR

Θ_{HO}^v Set of entry angles for given speed result in a successful handover

Θ_{HOF}^v Set of entry angles for given speed for which user equipment suffers from handover failure

Θ_{RLF}^v Set of entry angles for given speed for which user equipment suffers from radio link failure

γ Path loss exponent

α_t, α_s Are the exponents of the corresponding path loss models

A_{s_1}, A_{t_1} Are distance independent components of the path loss

D Inter-site distance

d_1 Distance covered by the UE from the entry point to the first intersection

d_2 Distance covered by the UE from the entry point to the second intersection

d_s Is the distance from the location of the user equipment located at the boundary of small cell to the serving cell in

	km
d_t	Is the distance from the location of the user equipment located at the boundary of small cell to the target cell in km
H	Hysteresis Margin
H'	Hysteresis margin of the small cell
P_{T_s}, P_{T_t}	Transmitted power from source cell and target cell respectively
Q_{in}	Threshold of target cell
Q_{out}	Threshold of serving cell
R	Small cell radius
R	Mean radius of small cell radius
r	Handover failure circle radius or inner circle radius
r	Mean radius of inner circle
RSS_s	Received Signal Strength received from the source cell
RSS_t	Received Signal Strength received from the target cell
S	Radius of the outbound HO
S	Mean radius of the outbound HO
$SINR_s$	Signal to Interference Noise Ratio of serving cell
T	The time needed for an inbound handover to be completed
T_R	Maximum time
T_p	Preparation time
TTT	Time-To-Trigger
v	User equipment speed
vT	Distance covered by the user equipment during the completed time of inbound Handover

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1. Preface

The next-generation of wireless systems represents heterogeneous networks that will have goal of offering heterogeneous services to users that may roam across various geographical and network boundaries. To support roaming terminals the future network will require the integration and interoperation of mobility management processes under a worldwide wireless communications infrastructure.

Mobility management enables telecommunications networks to locate roaming mobile terminals (MTs) for call delivery and maintain connections with MTs that change their point of attachment.

The wireless network consists of many small service regions called cells. Each cell is served by a base station (BS) that assigns channels to each MT within the cell. Location management tracks and locates the MT for the delivery of incoming calls while Handoff (Handover, HO) management allows a call in progress to continue as the MT changes channels or moves between cells. In location management the MT periodically performs location registration (location update) to notify the network of its new access point and store changes to its user location profile. Then when incoming calls arrive the network performs call delivery by querying the user profile to deliver the calls to the current cell location of the MT. In Handoff management ongoing calls are modified under two conditions when signal strength deterioration and user mobility. Deterioration of the radio channel results in intra-cell handoff, where the calls are transferred to new radio channels of

appropriate strength within the same cell or inter-cell handoff where the MT's connections are transferred to an adjacent cell. User mobility always results in inter-cell handoff. In each case the MT's connections may be passed to the new BS without interrupting communications with the old BS. This is called soft handoff. On the other hand if the connections are interrupted at the old base station and then established at the new BS the process is called hard handoff [1].

1.2. Problem Statement

Reduced coverage areas of small cells may result in frequent Handovers and Radio Link Failures (RLFs) which is the loss of connection with the serving node as a result of degraded Signal to Interference Noise Ratio (SINR).Also may result in Handover Failures (HOFs) which is the interruption of the HO process due to degradation of the signal quality received from the serving node and is declared in [2].

1.3. Proposed Solution

The solution to the above mentioned problems is to use the impact of Inter-Site Distance and Time-to-Trigger on Handover Performance in LTE-A Heterogeneous networks (HetNets) to select an appropriate Time-to-Trigger (TTT) value according to inter-site distance, user profile (i.e. speed) and overall mobility in the network automatically and in line with the concept of Self-Organized Networks (SON) [3].

1.4. Aim and Objectives

The aim of this project is to design an efficient Handover mechanism based on Inter-Site distance and Time-To-Trigger to achieve a successful handover procedure for the user, by decreasing the probability of Handover Failure (HOF) and Radio Link Failure (RLF).

The effectiveness of the scheme is simulated using a MATLAB code to verify the following objectives:

- Proving the dependency of the handover on the inter-site distance between the small cell and the overlaid macro cell in a two-tier scenario.
- Deriving closed-form expressions for the different Handover performance metrics as a function of inter-site distance, Time-To-Trigger and speed of UE.
- Show the appropriate TTT selection, based on inter-site distance and UE's speed.

1.5. Methodology

The realization of this project was achieved in three major steps, first enriched our knowledge by studying a general background related to our proposed problem, which contains Long Term Evolution (LTE), heterogeneous networks (HetNets) with its different deployment scenario, mobility management schemes and handover performance metrics. Second, this study examined the handover performance as a key factor of mobility management in heterogeneous networks (HetNets) in LTE-A in term of Successful Handover Probability, Handover Failure Probability and Radio Link Failure by applying the two different schemes of inter-site distance and Time-To-Trigger technique and a set of three parameters (Received signal strength (RSS),hysteresis (Hyst) and user's velocity) were also selected to develop a primary scenario of the Handover Performance by deriving closed-form expressions for the

probability of different Handover performance metrics as a function of inter-site distance and speed of User Equipment's (UEs).The next step was the implementation of the performance equations in the simulation. Initial performance metrics results were collected to get an overall idea of the handover decision making algorithm. Adding the other scheme and additional performance metrics as the project goes along for comparison purposes.

1.6. Research Outlines

Chapter one is an introduction that gives a background about the project, its aims and objectives, the problem statement and proposed solutions. It also gives a brief description on how to achieve those goals in the methodology.

Chapter two is the literature review that first gives an overall look on the mobility management schemes. The second part of the chapter is related works which include the analysis of several papers that were in the field of mobility management highlighting the pros and cons of each.

Chapter three is the system design (Methodology) contains all the methods and steps in great details that were undertaken to achieve the project's objectives.

Chapter four is results and discussions include simulation parameters, a discussion of the simulation and the resulted outcome from it, which are also justified.

Chapter five conclusion and recommendations is the achieved goals from the project and the recommendations for future studies.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1. Background

Since its invention, cell phone usage is constantly growing in the world. To support the growing number of users, mobile network standards are constantly evolving. First generations (1G) of mobile networks are introduced in the 1980s. These networks are analog networks and only provide voice services. With the 1990s, second generations of mobile networks are introduced. Second generations (2G) mobile networks are designed to be digital and provide SMS messages beyond voice services. In the second half of the 1990s, cell phone usage increased rapidly. Third generation (3G) mobile networks are introduced in the late 1990s. Third generations 3G provided remarkable data rate improvements over the 2G mobile networks. 2000s saw explosion of data usages with the growing number of multimedia services.

To handle this growth on the mobile networks, fourth generation (4G) mobile networks are introduced. Long-Term Evolution (LTE) which is introduced in 2008, is a fourth generations 4G network standard. It provides better capacity and data rate over the previous mobile network standards and currently widely used in the world. To provide better service to the growing number of users and handle the increasing data, the LTE standard is constantly evolving. LTE-Advanced which is a major update over LTE is introduced in 2011[4].

2.1.1. Long Term Evolution (LTE)

LTE (Long Term Evolution) was designed initially to achievemuch higher data rates than in **HSPA** network. It is defined by 3GPP also but in Release 8, 9 and 10. It is based on the OFDM/OFDMA/MIMO which will provide additional flexibility in allocating transmission bandwidth (5, 10, 15, 20 MHz) and enhanced spectral efficiency and support for higher speeds.

Peak data rates in the downlink channel is up to 299.6 Mbps and in the uplink channel is 75.4 Mbit/s depending on the user equipment category (with 4×4 antennas using 20 MHz of spectrum). In the later releases of **LTE** additional features has been added like carrier aggregation and relaying [5].

LTE-A HetNet consists of three main components: evolvedNodeB (eNB), Mobility Management Entity (MME), and Serving Gateway (S-GW)/Packet Data Network Gateway (P-GW). The eNB, including Macro eNB (MeNB) and Pico eNB (PeNB), performs the radio control functions such as packet scheduling and handover. MME is in charge of authorization, bearer establishment, and roaming. S-GW forwards data from and to eNB to serve user equipment (UE), while P-GW provides UE with the access to exterior network [6].
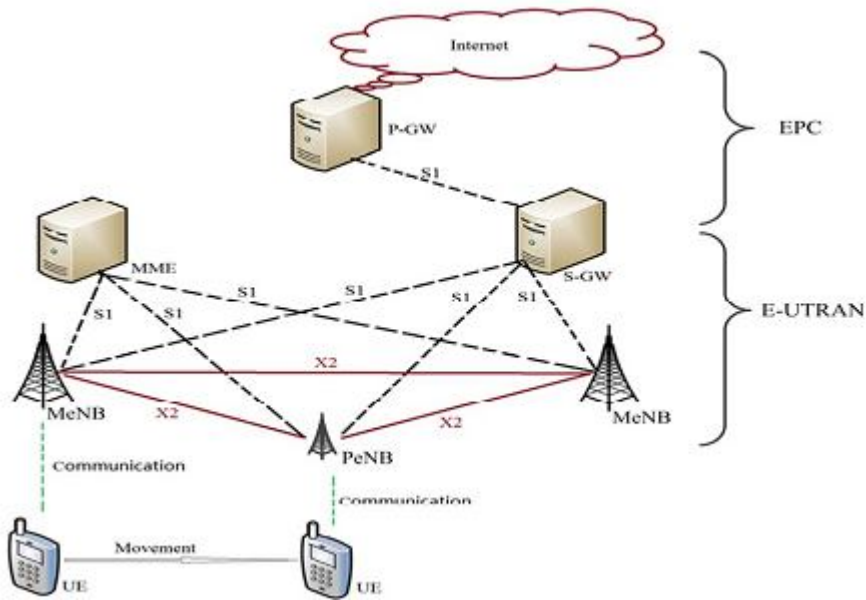
Figure 2.1: the structure of LTE-A network.

2.1.2. Small Cell

Small cells are basic eNodeBs that have lower transmit power than macro-cells. According to their transmit powers, small cells can be grouped as micro-cells, pico-cells and femto-cells.

Small cells are expected to be established to support high data rate in densely populated areas. As the numerous cells are established, it is not tractable to determine and optimize the parameters of every base station (BS) by human operators. For this reason, 3GPP has begun standardization of self-organizing network (SON). In the SON-based LTE systems, each E-UTRAN NodeB (eNB) which functions as a base-station is supposed to determine the optimal parameters autonomously [7][8].

2.1.2.1. Femto-Cell

Femto-cells are low powered network nodes that are deployed by the consumer to provide indoor coverage (10 meters). Their transmit power is generally less than 100 mWatt. Femto-cell named as Home eNodeB (HeNB).

2.1.2.2. Pico-Cell

Pico-cells have a higher transmit power and large cell radius; this makes it more appropriate for applications that demand large coverage (more than 100 meters).

2.1.2.3. Micro-Cell

A microcell is a cell in a mobile phone network served by a low power cellular base station (tower), covering a limited area such as a mall and hotel. Typically the range of a microcell is less than two kilometers.

2.1.3. Mobility Management

Mobility management enables the serving networks to locate a mobile subscriber's point of attachment for delivering data packets (i.e. location management), and maintain a mobile subscriber's connection as it continues to change its point of attachment (i.e. handoff management).The mobility management of an UE depends on the mobility state of the UE; besides, in the case of HO, it is also subject to deployment configuration of a serving cell and a target cell.

2.1.4. Handover (HO)

Handover management is the process by which a mobile node keeps its connection active when it moves from one access point to another. Some

parameters like Handover hysteresis (Hyst) and time-to-trigger (TTT) are typically used to make appropriate handover decision. These parameters in the network are automatically selected by the concept of Self-Organized Network (SON).
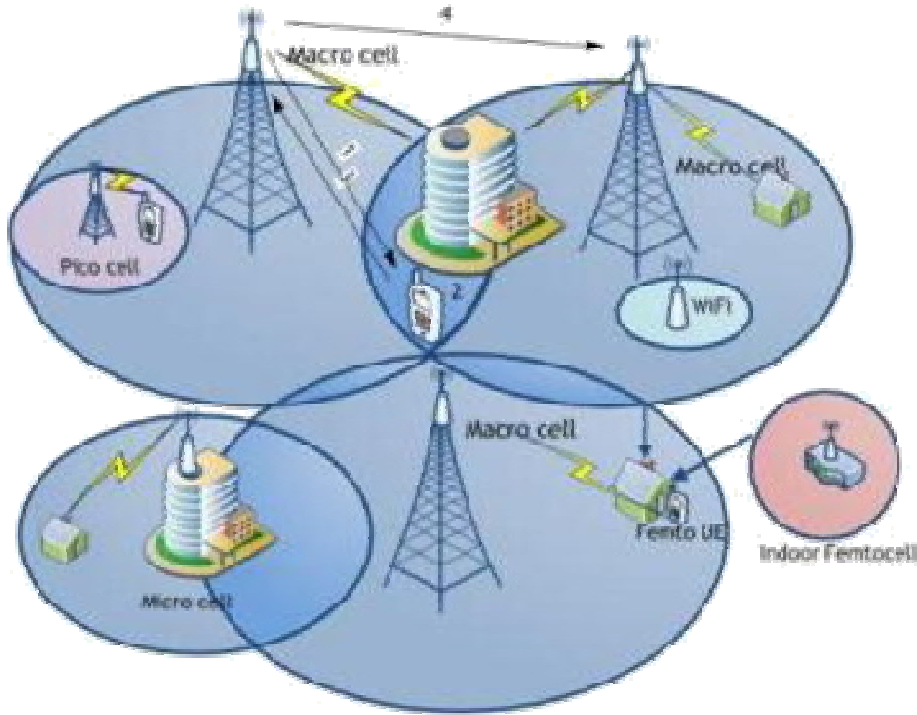

Figure 2.2: the heterogeneous networks scenarios and handover process

2.1.5. Self-Organizing Networks (SON)

SON is a concept that is introduced to automatism the planning, management, configuration, and optimization and healing efforts in mobile networks. The three main setup phases in this concept are self-configuration, self-Optimization and self –Healing [4].

2.1.5.1. Self-Configuration

The self-configuration process includes configuring the new deployed nodes, integration of these nodes to the network and putting them to operational state automatically, in other words a newly deployed nodemust add itself to the network without manual intervention.

2.1.5.2. Self-Optimization

The self-optimization process includes optimization of configuration parameters, to provide better service during operation. The node can use observations of itself or the measurements sent from the mobile terminals to optimize its parameters.

2.1.5.3. Self-Healing

The self-healing process includes diagnosing and healing the failures in theNetworkwith changing the required parameters and algorithms in the system to minimize theimpact. After diagnosing and reporting the failure, the system can trigger recoveryand compensation actions. While the compensation actions try to minimize the effectof the failure, with changing the required configuration parameters on the associatedcells, the recovery actions try to recover the affected cell from the failure.

2.2. Related Works

The following papers describe the related works that has been done to date which helped to propose the new approach:

In [5] Mobility Management for LTE HetNet using MCDM Algorithm are proposed, eNB HetNet environment the signal power of the

neighbor eNBs plays an important role in making handover decision. This scheme triggers handover for the user equipment (UE) any time even before the Time-To-Trigger (TTT) window is over. The scheme also triggers handover promptly when the received signal power is too low while a suitable target eNB of good quality is decided. The best candidate cell for handover is decided by multi-criteria decision making algorithms (MCDM) based on the movement direction, residence time, downlink Signal to Interference and Noise Ratio(SINR), and received reference signal received power (RSRP) of the UE. This handover mechanism triggering handover whenever the downlink SINR is less than a threshold may frequently incur unnecessary handover and frequent switching from one cell to another waste the resource.

Paper [9] provides Two -Step Handover algorithm consisting of early Handover Preparation and Ping-Pong Avoidance. Early Handover Preparation will assure a successful expedited transmission of handover command, in turn, help to relieve hand over failure Problems. Also it will improve to recovery from radio link failure (RLF) with providing multiple prepared target cells. But this premature Handover commandcauses increased Ping-Pong (pp) rate. "Ping -Pong Avoidance" will delay handover execute on just before Physical Downlink Control Channel (PDCCH) outage limit to suppress unnecessary handovers. In this scheme the user equipment (UE) can decide an optimal handovertime and an optimal target eNB based on the measurement. Because the UE has the best knowledge of its radio conditions in a timely manner, so its decision can be the best optimum.

In [10] a novel handover scheme for small-cell users in a Heterogeneous networks (HetNets) is proposed, utilizing a cooperation-based cell clustering scheme for reducing the handover occurrence ratio. This scheme requires relatively less signaling overhead among small cells than other cell-cooperation scheme. Users' equipment (UEs) with slower speeds can further reduce this handover ratio. For example, if the UE speed is 3[km/h] (pedestrian speed), this ratio becomes approximately 0.07. As the handover threshold value increases, this handover ratio decreases. If the UE changes its direction more frequently, this handover ratio can be significantly reduced but if a UE speed is high this causing frequent handover (unnecessary handover).

Paper [11] provides Dual connectivity algorithm, Dual Connectivity in Long-Term Evolution (LTE) network improves mobility robustness by allowing users to be connected simultaneously to MeNB (Master eNB) and SeNB (Secondary eNB). The increase in per-user throughput is achieved by aggregating radio resources from at least two eNBs and this waste the radio resources.

CHAPTER THREE

Performance Evaluation of Handover in HetNets Using Adaptive TTT

CHAPTER THREE

PERFORMANCE EVALUATION OF HANDOVER IN HETEROGENEOUS NETWORKS USING ADAPTIVE TTT

To achieve this research a three phases plan was followed as shown in Figure 3.1, they will be explained as follows
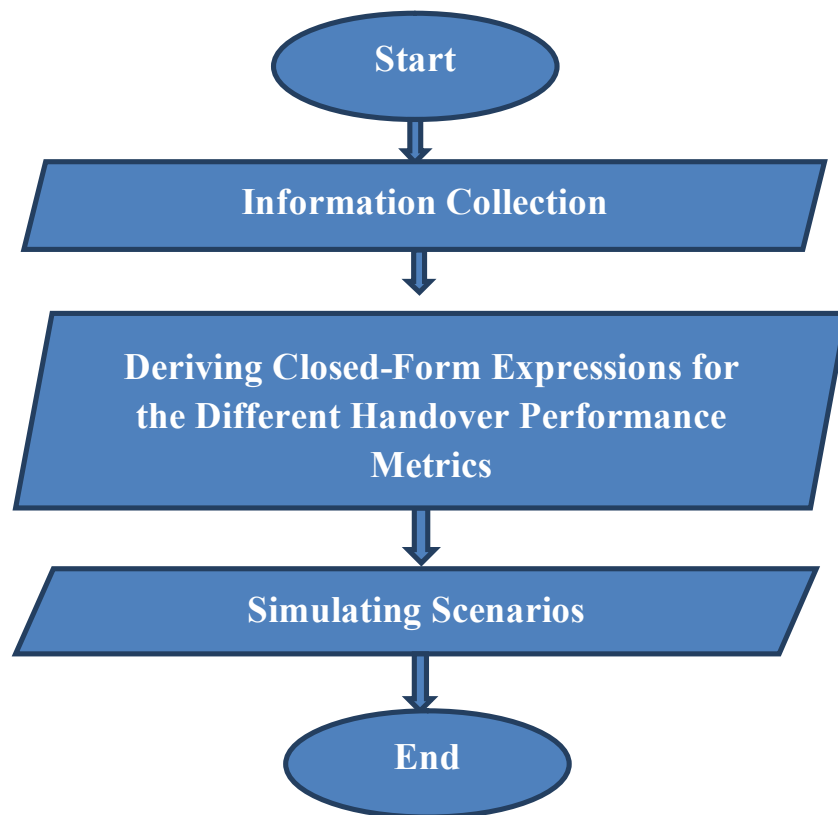
Figure 3.1: Flow Chart for Methodology Steps

3.1. Information Collection

The first step was to enrich our knowledge by studying a general background about Long Term Evolution (LTE), heterogeneous networks (HetNets) with its different deployment scenario and mobility management schemes in different cell size. Also handover procedure with its different types, and specifying the handover performance metrics.

3.2. Deriving Closed-Form Expressions for The Different Handover Performance Metrics

In this step the study examined the handover performance as a key factor of mobility management in heterogeneous networks (HetNets) in LTE-A in term of Successful Handover Probability, Handover Failure Probability and Radio Link Failure by applying the two different schemes of inter-site distance and Time-To-Trigger technique and a set of three parameters (Received signal strength (RSS), hysteresis (Hyst) and user's velocity) were also selected to develop a primary scenario of the Handover Performance by deriving closed-form expressions for the probability of different Handover performance metrics as a function of inter-site distance and speed of User Equipment's (UEs).

Reduced coverage areas of small cells may result in frequent Handovers and Radio Link Failures (RLFs) which is the loss of connection with the serving node as a result of degraded Signal to Interference Noise Ratio (SINR). Also may result in Handover Failures (HOFs) which is the interruption of the HO process due to degradation of the signal quality received from the serving node and is declared in three cases, Firstly, when

the RLF timer, namely T310, is still running at the end of the HO preparation time (Tp). Secondly, a HOF occurs if at the expiration of T310, TTT timer is active. Finally, if after HO execution time (Tex) target SINR is below the threshold, a HOF event is declared [2].

Handover performance is studied in a two tier deployment consisting of a small cell located at a distance D (inter-site distance) from the center of the overlaid macro cell. Handover initiates when the received signal strength (RSS) from t he target cell becomes an offset better than the source cell for a period equal to Time-To-Trigger (TTT). The offset is known as Hysteresis Margin. The above definition can be expressed as follows

$$RSS_t \geq RSS_s + H \tag{1}$$

Where RSS_t and RSS_s are the Received Signal Strength received from the target and the source cells respectively, while H Stands for the Hysteresis Margin.

Let us consider generic user equipment (UE) located at the boundary of the small cell defined in (1), at distance d_t from the target cell, and d_s from the source cell (both of them expressed in km).The relationship between d_s and d_t is then described by equation number (2)

$$d_s = \sqrt{D^2 + 2Dd_t \cos(_{inner}) + d^2{}_t} \tag{2}$$

Where $_{inner}$ is defined as the angle formed by the straight line joining the UE location and the small cell site, and the line joining the small cell and the macro cell sites (see figure 3.2).

Focusing on (1), it can be reformulated as equation number (3)

$$d_t^{\alpha_t} \leq d_s^{\alpha_s} \cdot 10^{\gamma - \frac{H}{10}} \tag{3}$$

Where α_t and α_s are the exponents of the corresponding path loss models and

$$\gamma = \frac{(P_{T_t} - P_{T_s}) + (A_{s_1} - A_{t_1})}{10} \tag{4}$$

Where A_{s_1} and A_{t_1} are distance independent components of the path loss While P_{T_t} and P_{T_s} stand for the transmitted power from target and source cell respectively.

If we define the small cell radius (R) as the maximum d_t (for a given $inner$) for which (3) holds, the radius may be calculated from equation number (5)

$$R = 10^{\frac{\gamma - 0.1H}{\alpha_t}} \cdot \left(D^2 + 2RD \cos(_{inner}) + R^2\right)^{\frac{\alpha_s}{2\alpha_t}} \tag{5}$$

At the edge of the region defined by (1), (3) or (5), TTT initiates and should expire within it in order for a Handover to be executed successfully. However if at expiration of TTT , the UE is located inside the small cell but the Signal to Interference and Noise Ratio $(SINR)$ received from the source cell is below threshold(Q_{out}), there is a handover failure (HOF). This Region, where $SINR_s \leq Q_{out}$, is depicted in (Figure 3.2) as a white colored circle (the inner circle, also Known as HOF circle) and has a radius hereof denoted as r. Similarly to (5) r is given by equation number (6)

$$r = 10^{\frac{\gamma + 0.1Q_{out}}{\alpha_t}} \cdot (D^2 + 2rD \cos(_{inner}) + r^2)^{\frac{\alpha_s}{2\alpha_t}} \tag{6}$$

Once a UE is associated to the small cell the outbound Handover procedure starts when (1) holds. Note, however, that in this case the macro cell plays the role of target cell and the small cell is the source cell. The radius of the outbound HO namely S (the dark shaded circle in figure 3.2) may be calculated from equation number (7)

$$S = 10^{\frac{-\gamma + 0.1H'}{\alpha_s}} \cdot (D^2 + 2SD \cos(_{inner}) + S^2)^{\frac{\alpha_t}{2\alpha_s}} \qquad (7)$$

Where H' is the hysteresis margin used to handoff from the small cell to the macro cell. The mean radius R can be expressed by equation number (8)

$$R = \mathbb{E}[R] = \frac{1}{\pi} \int_0^\pi R \, d_{inner} \qquad (8)$$

Likewise, the mean of r and S are given by $r = \mathbb{E}[r]$ and $S = \mathbb{E}[S]$, respectively.

Using the same generic UE located at distance R from the center of the small cell. This UE moving at speed v crosses the small cell coverage area with an entry angle θ_e (See figure 2). Due to symmetry, the whole analysis will be done hereafter for $0 \leq \theta_e \leq \frac{\pi}{2}$. In this situation, this UE may perform a HO; suffer from a HOF and RLF. Before proceeding with the analysis of the aforementioned probabilities, it is necessary to define a set of important angles.

First let $(TTT + T_p)$ be the time needed for an inbound HO to be completed from now on denoted as T. The distance covered by the UE during time T is then equal to vT. Accordingly if we define θ_i as the

maximum entry angle for which the inbound HO can be completed (as shown in figure 3.2), it may be expressed by equation number (9)

$$\theta_i = \arccos\left(\frac{vT}{2R}\right) \qquad (9)$$

With $0 \le v \le \frac{2R}{T}$. If $v > \frac{2R}{T}$ the UE will not handoff to the small cell regardless of the entry angle. The second angle to consider θ_t is defined as the maximum angle for which T expires within the HOF circle (Figure 3.2). θ_t may be expressed by equation number (10)

$$\theta_t = arccos\left(\frac{(vT)^2 + R^2 - r^2}{2vTR}\right) \qquad (10)$$

Where $\frac{R-r}{T} \le v \le \frac{R+r}{T}$. Note that, if $v < \frac{R-r}{T}$ the UE will not suffer from a HOF even if the entry angle $\theta_e = 0$. Likewise, if $v > \frac{R-r}{T}$, there will not be a HOF either.

The RLF occurs after the UE has moved over the HOF region for more than a particular time, usually 1s. If we define this maximum time as T_R, the UE will suffer from a RLF if the distance covered within the HOF circle is above vT_R while a HO is not yet successfully completed. Thus the maximum angle for which the distance covered by a UE within the HOF region is larger than vT_R, is given by equation number (11)

$$\theta_R = arcsine\left(\sqrt{\frac{r^2}{R^2} - \left(\frac{vT_R}{2R}\right)^2}\right) \qquad (11)$$

Where $\frac{R-r}{T} \leq v \leq \frac{2r}{T_R}$. Otherwise θ_R is not defined and a UE will not suffer from RLF. It is worth noting that for a given entry angle $\theta_e = \theta_R$, the UE intersects the HOF circle at two points. Thus if we denote the distance covered by the UE from the entry point to the first intersection as d_1 and to the second intersection as d_2 they may be expressed by equations number (12) and (13) respectively

$$d_1 = \sqrt{R^2 - r^2 + \left(\frac{vT_R}{2}\right)^2} - \frac{vT_R}{2} \tag{12}$$

$$d_2 = d_1 + vT_R \tag{13}$$

Then we calculated the handover performance metrics probabilities as follow:

3.2.1. Inbound Handover Probability:

UE can only perform a successful HO if the entry angle is smaller than θ_i. Otherwise the UE's TTT timer expires after leaving the small cell coverage area and the HO process is not completed. However, and despite having $\theta_e < \theta_i$, the HO could not be completed successfully due to either a HOF (i.e. $\theta_t \geq \theta_e$) or an RLF (i.e. $\theta_R \geq \theta_e$ and $\frac{R-r}{T} \leq v$). If we define Θ_{HO}^v HO as the set of entry angles that, for a given v, result in a successful HO, the PHO is then given by equation number (14)

$$P_{HO} = \frac{2}{\pi} \int_{\theta_e \in \Theta_{HO}^v} \theta_e d\theta_e \tag{14}$$

With regard to Θ_{HO}^v, it will be $\Theta_{HO}^v=[0,\theta_i]$ when the HO is completed before reaching the HOF circle (i.e. $v<\frac{R-r}{T}$), $\Theta_{HO}^v=[\theta_t,\theta_i]$ when T expires inside the HOF circle(i.e. $\frac{R-r}{T}\le v\le\frac{2r}{T_R}$)and θ_R doesnot exist, $\Theta_{HO}^v=[\theta_t,\theta_i]$while $\theta_R<\theta_t$ (if θ_R exists), $\Theta_{HO}^v=[\theta_R,\theta_i]$ if $vT\ge d_2$ and θ_R exists, and finally$\Theta_{HO}^v=[0,\theta_i]$ when θ_R does not exist and $\frac{R+r}{T}<v\le\frac{2R}{T}$. Thus,

$$
P_{HO}=\begin{cases}
\dfrac{2}{\pi}\theta_i & if\ 0\le v<\dfrac{R-r}{T}\\[2mm]
\dfrac{2}{\pi}(\theta_i-\theta_t) & if\ \dfrac{R-r}{T}\le v\le\dfrac{R+r}{T}\ and\ \nexists\ \theta_R\\[2mm]
\dfrac{2}{\pi}(\theta_i-\theta_t) & if\ \dfrac{R-r}{T}\le v<\dfrac{d_2}{T}\ and\ \exists\ \theta_R\\[2mm]
\dfrac{2}{\pi}(\theta_i-\theta_R) & if\ \dfrac{d_2}{T}\le v\le\dfrac{2R}{T}\ and\ \exists\theta_R\\[2mm]
\dfrac{2}{\pi}\theta_i & if\ \dfrac{R+r}{T}<v\le\dfrac{2R}{T}\ and\ \nexists\theta_R\\[2mm]
0 & otherwise
\end{cases}
\tag{15}
$$

3.2.2. Handover Failure Probability

A HOF occurs if T expires within the HOF circle. Analogously to P_{HO}, the set of entry angles for which a UE suffers from a HOF, namely Θ_{HOF}^v, is defined as $\Theta_{HOF}^v=[0,\theta_t]$ for $\frac{R-r}{T}\le v\le\frac{R+r}{T}$ and $\Theta_{HOF}^v=\emptyset$ otherwise. Therefore,

$$
P_{HOF}=\begin{cases}
\dfrac{2}{\pi}\theta_t & if\ \dfrac{R-r}{T}\le v\le\dfrac{R+r}{T}\\[2mm]
0 & otherwise
\end{cases}
\tag{16}
$$

3.2.3. Radio Link Failure Probability

The probability of RLF (PRLF) is different from 0 only when θ_R exists. Thus, assuming that θ_R exists, the RLF presents two possible situations (see Figure 3.2): first, if $R - r \leq v\,T \leq d_1$, there is a RLF only after a previous HOF (and consequently, the set of angles that cause a RLF is $\Theta_{RLF}^v = [0, \theta_t]$); second, when $d_1 < v\,T \leq 2\,R$, only UEs with an entry angle below θ_R suffer from RLF (i.e. $\Theta_{RLF}^v = [0, \theta_R]$). Therefore,

$$
P_{RLF} = \begin{cases} \dfrac{2}{\pi}\,\theta_t & if \ \dfrac{R-r}{T} < v \ \leq \dfrac{d_1}{T} \\[2mm] \dfrac{2}{\pi}\,\theta_R & if \ \dfrac{d_1}{T} < v \ \leq \dfrac{2R}{T} \\[2mm] 0 \ otherwise \end{cases} \tag{17}
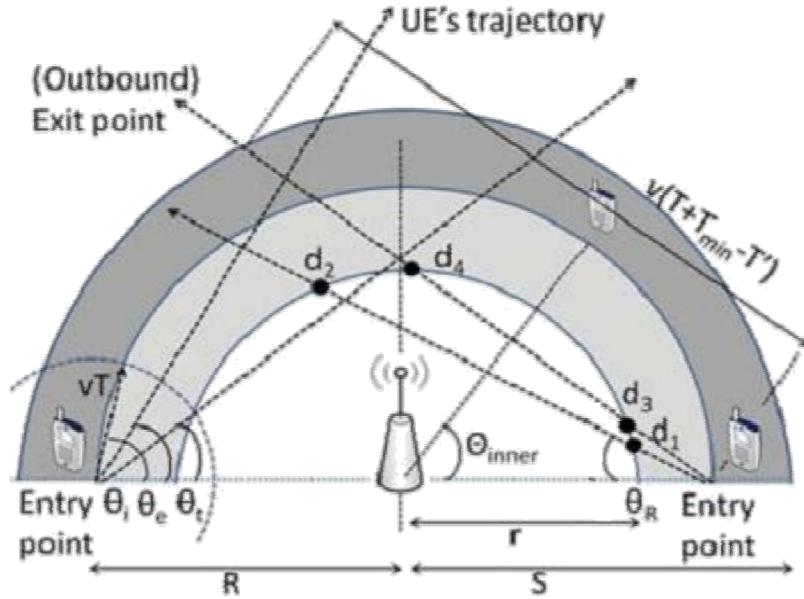$$

Figure 3.2: Small Cell Area and Considered Angles

3.3. Simulating Scenarios

After constructing the performance equations and implementing them into MATLAB. The simulation will be for the probabilities of the performance metrics (handover, handover failure and radio link failure) represented on the vertical axis, and the distance between macro and small cell represented on the horizontal axis. According to the selected value of Time-To-Trigger the probability of handover metric is changing related to the inter-site distance. Different simulation scenarios were derived dependant on a certain parameters such as inter-site distance, Time-To-Trigger and user's velocity In order to visualize the results of the handover performance metrics and for easier comparison between the two different schemes.

CHAPTER FOUR

RESULTS AND DECISIONS

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Simulation Explanation

The simulation is explained between the probabilities of the performance metrics (handover, handover failure and radio link failure) and inter-site distance taking into account the Time-To-Trigger and UE's speed.

The scenario under study consists of a small-cell overlaidwith a macro-cell, with a distance between the macro cell siteand the small cell site (D) that ranges from 40m to 240m.UE moves randomly over the layout moving at 60km/h(a very high speed in an urban scenario) and heading for thesmall cell coverage area with a random entry angle and movingon a straight line. The transmitted power of the macro and thesmall cell is 46 and 20 dBm, respectively [12][13]. Although arange of 16 possible TTT values are defined in [14], only theresults (both simulated and analytical) for an illustrative subsetof them have been included (specifically, TTT equal to 128,256, 320 and 512 ms). The rest of the simulation parameterscan be found in Table 4.1.

Table 4.1: Simulation Parameters

Parameters	Values
Bandwidth	10MHz
Macro and small cell Frequency	2GHz
Macro cell transmitted power	46 dBm
Small cell transmitted power	20 dBm
HO A3 Hysteresis Margin	3 dB
TTT values	128, 256, 320, 512 ms
HO Preparation Time	50 ms
HO Execution Time	40 ms

4.2. Simulation Results

The results of the simulation were presented in plots for each handover performance metrics to show how each probability is going to effect on the evaluation of the handover. Different graphs of a Successful Handover Probability, Handover Failure Probability and Radio Link Failure Probability respectively against inter-site distance (D) with reference to four different Time-To-Trigger (TTT) values.

4.2.1. Fixed Value of Time-To-Trigger

From the point of view of the operator; fixed value for a Time-To-Trigger is selected. One fixed value of TTTwas chosen for a comparison purpose. From the figures below it is obvious that a fixed Time-To-Trigger (TTT) is not effective at all the inter-site distances (D).

4.2.1.1. Time-To-Trigger Equal to 512 ms

For aheterogeneous network that has fixed TTT=512ms; the figures (4.1, 4.2, 4.3) show the effect of this value on the handover performance metrics.

It is obvious that 512ms gives a zero probability of a successful handover from D=40m until D=60m, and probability of handover failure is zero from D=40m until D=70m and above D=70m almost failure occurs. Also radio link failure probability is zero from D=40 until D=140 and get higher when D increase.
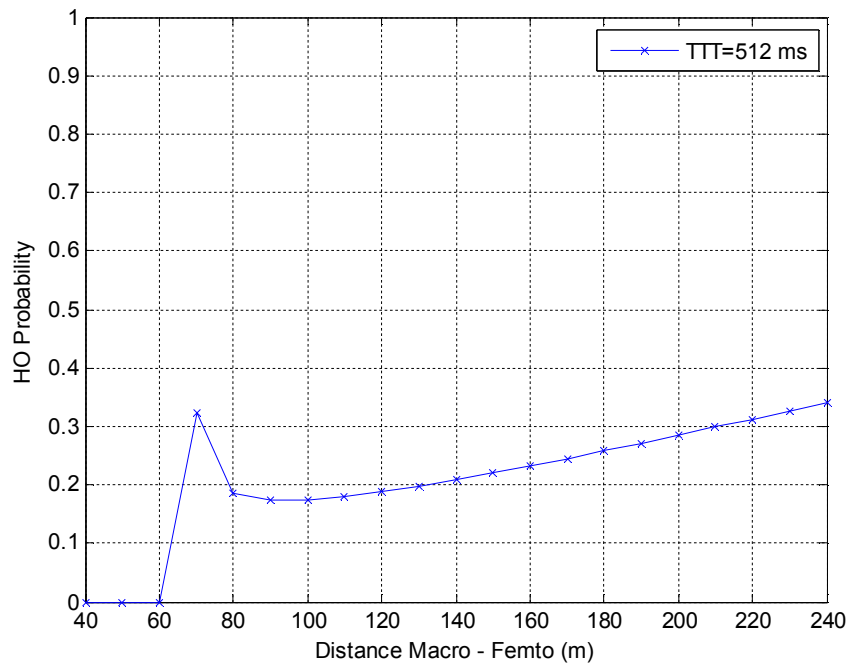

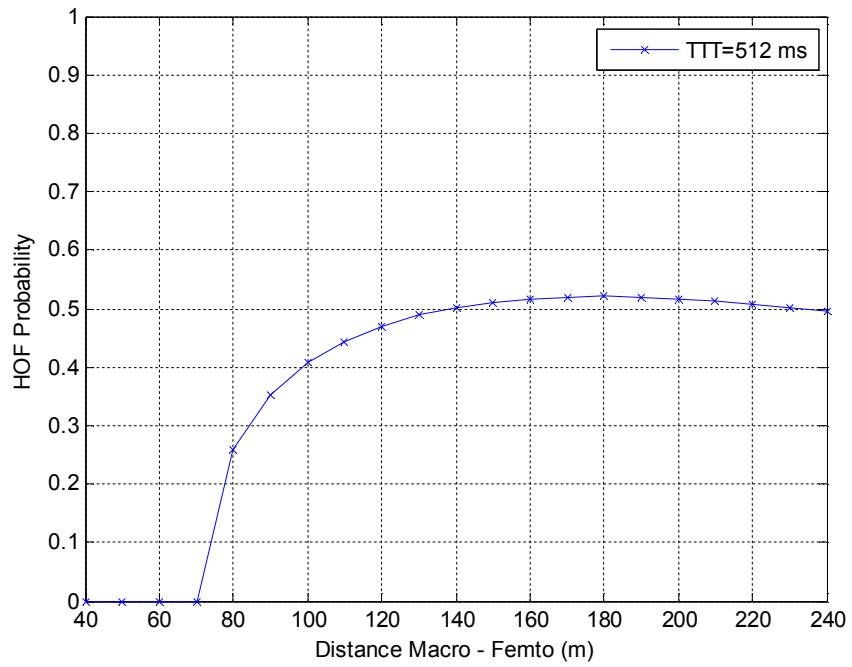Figure 4.1: HO with TTT=512 ms
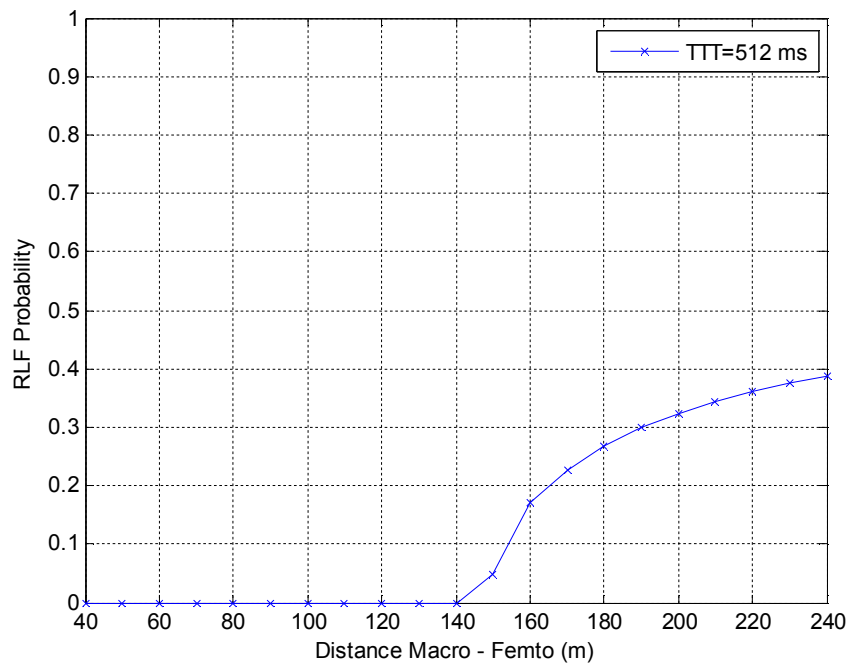
Figure 4.2: HOF with TTT=512 ms

Figure 4.3: RLF with TTT=512ms

4.2.2. Adaptive Time-To-Trigger Values

Appropriate TTT value should beselected according to inter-site distance, user profile (i.e. speed)and overall mobility in the network automatically and in linewith the concept of Self-Organized Networks (SON).

4.2.2.1. Handover Probability (HO)

Figure 4.4 explains the probability of successful handover, it is important to point out its dependency on the entry angles (θ_i,θ_t), mean radius of small cell (R) and mean radius of inner circle or handover failure region (r) as illustrated in figure 3.2. In particular, the probability of handover grows when θ_i(entry angle for which the inbound handover can be completed) grows and/or θ_t (entry angle for which T expires within the handover failure circle) falls. Thus, for a given speed (v=60km/h) and the time needed for an inbound handover to be completed (T),θ_i, rises when R grows (or in other words, when D is increased) according to [15]. Conversely, it may be observed in [16] thatθ_t, decreases as R rises. Figure 4.4 presents the dependency of a successful handover on the Time-To-Trigger (TTT) which selected according to the value of the inter-site distance (D) and user equipment speed (v=60km/h) i.e. when D=40m the accurate value of TTT is 256ms that gives the highest probability of handover due to entry angles (θ_i,θ_t),R and r mentioned above.
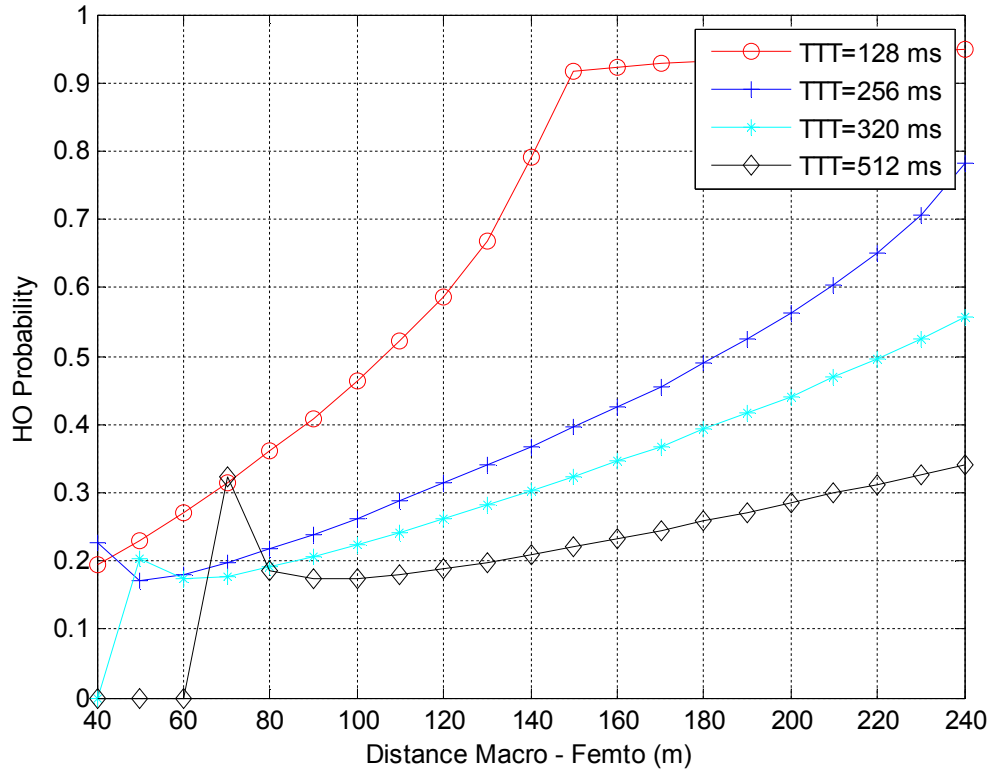
Figure 4.4: Handover Probability

4.2.2.2. Handover Failure Probability (HOF)

It is also important to point out its dependency on, θ_t (entry angle for which T expires within the handover failure circle), R (radius of small cell) and r (radius of inner circle or handover failure region). As for HOF probability, HOF probability $\neq 0$ if $\frac{R-r}{T} \leq v \leq \frac{R+r}{T}$. Therefore, it is tightly coupled with the size of the coverage area (R) and the HOF region (r).

Figure 4.5 presents the dependency of the probability of handover failure on the Time-To-Trigger (TTT) which selected according to the value of the inter-site distance (D) and user equipment speed(here, v=60km/h)

i.e. when D=40m the accurate values of TTT are 512ms and 320ms that gives the zero probability of handover failure.
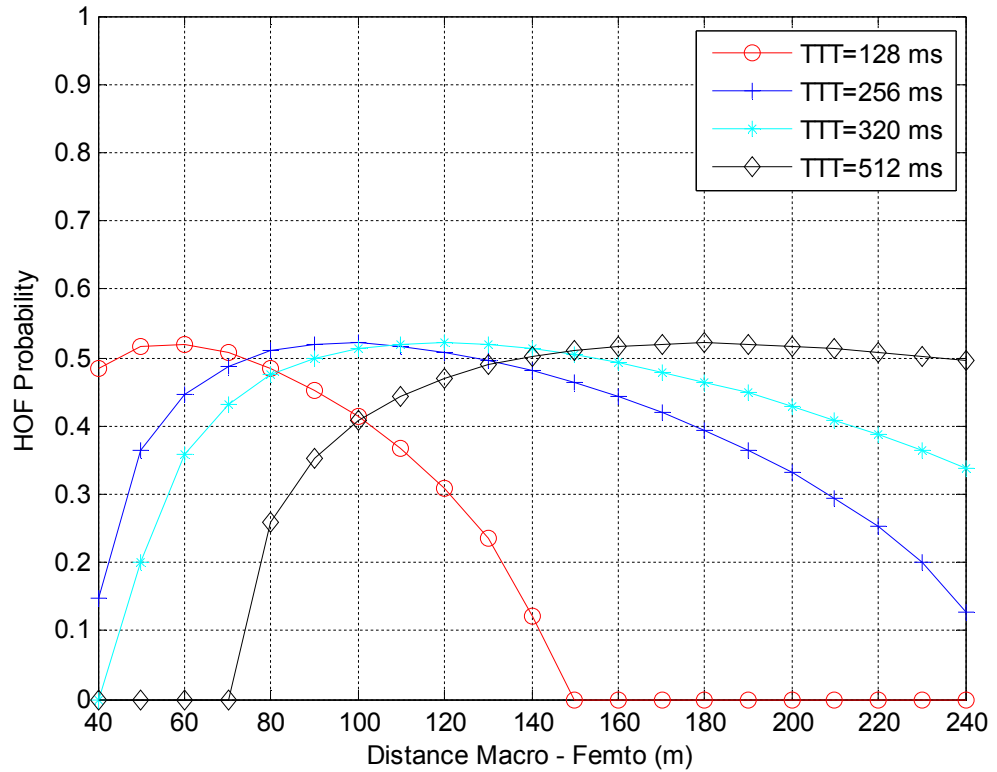
Figure 4.5: Handover Failure Probability

4.2.2.3. Radio Link Failure Probability (RLF)

Finally, Figure 4.6 completes the analysis with the RLF probability. As expected, it may be observed that RLF probability=0 as long as HOF region is not large enough to yield $vT_R \leq 2r$. Moreover, T must be long enough so that the UE does not complete successfully a HO, while the time spent inside the HOF region is at least equal to T_R Therefore, RLF probability≠0 for large D and T.

It's obvious that the probability of RLF remains zero for all TTT values till D=140m, then they will split out resulting in a slight increasing in the RLF probability to reach 0.4 at D=240m for 512ms value of TTT, whereTTT at 128ms will keep stable at zero level during all distances.
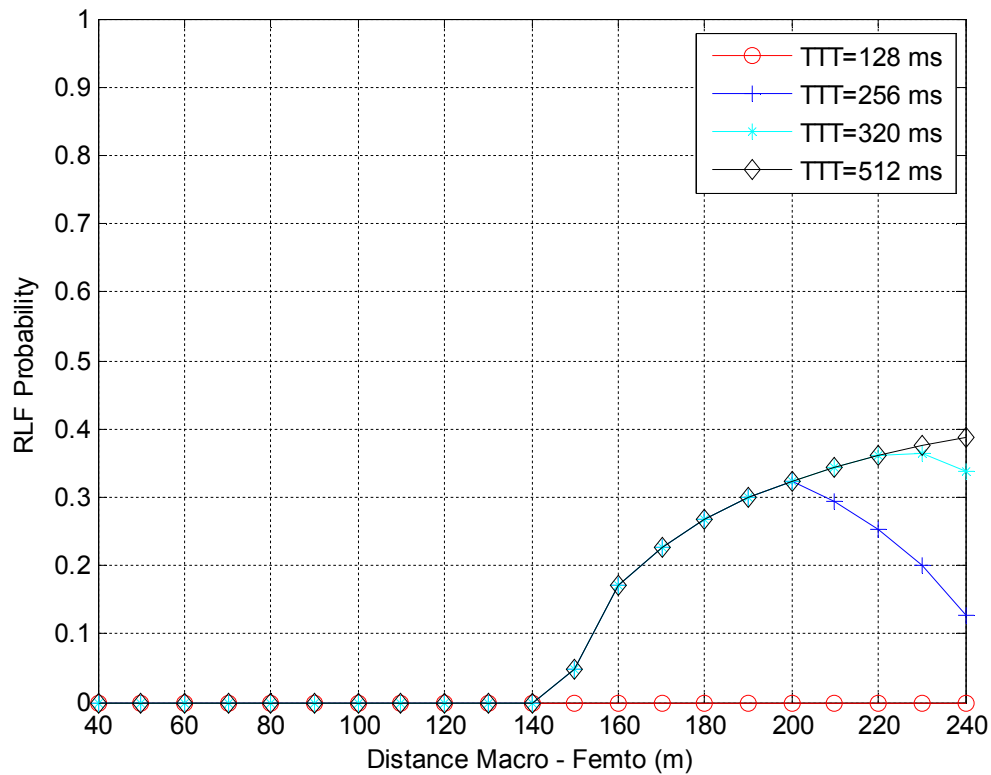

Figure 4.6: Radio Link Failure Probability

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

CHAPTER FIVE

CONCLUSION ANDRECOMMENDATIONS

5.1. Conclusion

In this work, a Handover performance analysis in terms of Handover Probability, Handover Failure Probability and Radio Link Failure Probability was carried out using the impact of inter-site distance and Time-To-Trigger on Handover performance in LTE-A HetNets. Specifically, we have proven the dependency of the Handover metrics on the inter-site distance between the small cell and the overlaid macro-cell center in a two-tier scenario Furthermore; closed-form expressions for the aforementioned probabilities were derived as a function of inter-site distance and speed of the UEs.

It has been shown that the appropriate TTT is selected based on inter-site distance and UE's velocity in a more flexible way to enhance HO performance.

5.2. Recommendations

This research couldn't cover the handover in different situations in details; due to lack of time. In future work, the following points have to be more elaborated:

- Classify UE speeds into groups and apply the proper Time-To-Trigger value to each groups based on inter-site distance and the specific group speed.
- Selection of efficient Time-To-Trigger value in accordance with small cell size type and UE speeds need to be investigated to achieve the low Radio Link Failure rate.
- Determine appropriates Time-To-Trigger values for Handover between different sizes of the serving and target cell.
- Looking for other Handover performance metrics.

REFERENCES

1. Ian F. Akyildiz, Janise McNair, Joseph Ho, Huseyin Uzuinalioglu, and Wenye Wang, "Mobility Management in Current and Future Communications Networks", July/August 1998

2. 3GPP Technical Report 36.839, "Evolved Universal Terrestrial Radio Access (E-UTRA); Mobility enhancements in heterogeneous networks", V11.1.0 September 2012

3. Georgios Kollias, Ferran Adelantado,Christos Verikoukis, "The impact of inter-site distance and Time -to-Trigger on Handover performance in LTE-A HetNets", 2015

4. Tuning of handover parameters in lte-a heterogeneous networks, emrah tunçel, September 2014

5. Hanzo, L., et al., "MIMO-OFDM for LTE, WIFI and WIMAX: Coherent versus Non-Coherent and Cooperative Turbo-Transceivers". 2010.

6. Xianda Chen, Young Ho Suh, Seung Wan Kim, and Hee Yong Youn, "Reducing Connection Failure in Mobility Management for LTE HetNet using MCDM Algorithm", June 2015

7. 3GPP TS 36.300 v8.9.0, "E-UTRA and E-UTRAN; overall description; Stage2," June 2009.

8. 3GPP TR 36.902 V1.2.0, "Self-configuring and self-optimizing network use cases and solutions," May 2009

9. *Hyun-Seo Park; Ae-Soon Park; Jae-Yong Lee; Byung-Chul Kim, "Two-Step Handover for LTE HetNet mobility enhancements", Oct. 2013*

10. *Hansung Leem, JaYeong Kim, Dan Keun Sung, Yunjung Yi, and Byoung-Hoon Kim, "A Novel Handover Scheme to Support Small-cell Users in a HetNet Environment", 2015*

11. *S. C. Jha; K. Sivanesan; R. Vannithamby; A. T. Koc, Dual Connectivity in LTE small cell networks, Dec. 2014*

12. *3GPP Technical Report 36.872,"Small cell enhancements for E-UTRAand E-UTRAN - Physical layer aspects", V12.1.0, Dec. 2013*

13. *3GPP Technical Report 36.842,"Study on Small Cell enhancementsfor E-UTRA and E-UTRAN; Higher layer aspects", V12.0.0, Jan. 2014*

14. *3GPP TS 36.331 V8.4.0, "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC);Protocol specification,"*

15. *Yejee Lee, Bongjhin Shin, Jaechan Lim, Hong, Daehyoung, "Effects oftime-to-trigger parameter on handover performance in SON-based LTEsystems", Communications (APCC), 2010 16th Asia-Pacific Conferenceon , pp.492,496, Oct. 31 2010-Nov. 3 2010*

16. *S. Barbera, P.H. Michaelsen, M. Saily, K. Pedersen, "Mobility performance of LTE co-channel deployment of macro and pico cells",Wireless Communications and Networking Conference (WCNC), 2012IEEE, pp.2863,2868, 1-4 April 2012*

APPENDIX A: SIMULATION CODES

A.1. Fixed Values of Time-To-Trigger

A.1.1. Handover Probability TTT= 512 ms

```
clc,clear,closeall
v= 60; %UE speed in (Km/h)%
B=0.73; %The numerical solution shows that in the
simulated scenario the ratio (r/R = B) remains
approximately constant and equal to 0.73%
TTT= 512; %Time-to-Trigger in (ms)%
T= TTT+50; %the time for an inbound HO= Time-to-
Trigger + HO Preparation Time%
TR=1000; %RLF occurs after the UE has moved inside
the HOF region for more than TR%
valueofHO= zeros(1,21);
valueofD=[40 50 60 70 80 90 100 110 120 130 140
150 160 170 180 190 200 210 220 230 240];
%Distance range between 40 to 240 (m)%
i= 0;
D= 30; %Distance in (m)%
whilei<= 20
i= i+1;
     D= D+10;
     F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
     Q=integral(F,0,90);
     R= Q/pi; %Small cell radius (Source cell)%
     r= R*B;%Macro cell radius (Target cell)%
thetai=acos((v*T)/(2*R)); %the maximum entry angle
for the inbound HO to be completed%
```

```matlab
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
%the maximum angle for which T expires before the
UE gets out of the HOF region%
thetaR=asin(sqrt(((r^2)/(R^2))-
(((v*TR)/(2*R))^2))); %the maximum angle that will
lead to RLF%
        d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-
((v*TR)/2); %the distance covered by the UE from
the entry point to the first intersection%
        d2=d1+(v*TR); %the second intersection%
%Inbound Handover Probability%
if          (0<=v&&v<(R-r)/T)
            HO=(2/pi)*thetai;
elseif    ((R-r)/T<=v&&v<=(R+r)/T)
            HO=(2/pi)*(thetai-thetat);
elseif   ((R-r)/T<=v&&v<(d2)/T)
            HO=(2/pi)*(thetai-thetat);
elseif   ((d2)/T<=v&&v<=(2*R)/T)
            HO=(2/pi)*(thetai-thetaR);
elseif  ((R+r)/T<v&&v<=(2*R)/T)
   HO=(2/pi)*thetai;
else
     HO=0;
end
valueofHO(i)= HO;
end
plot(valueofD,valueofHO,'-xb','LineWidth',2)
axis([40 240 0 1])
xlabel('Distance Macro - Femto (m)')
ylabel('HO Probability')
legend('TTT=512 ms')
grid
```

A.1.2. Handover Failure Probability TTT=512 ms

```matlab
clc,clear,closeall
v= 60; %UE speed in (Km/h)%
```

```matlab
B=0.73; %The numerical solution shows that in the
simulated scenario the ratio (r/R = B) remains
approximately constant and equal to 0.73%
TTT= 512; %Time-to-Trigger in (ms)%
T= TTT+50; %the time for an inbound HO= Time-to-
Trigger + HO Preparation Time%
valueofHOF= zeros(1,21);
valueofD=[40 50 60 70 80 90 100 110 120 130 140
150 160 170 180 190 200 210 220 230 240];
%Distance range between 40 to 240 (m)%
i= 0;
D= 30; %Distance in (m)%
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi; %Small cell radius (Source cell)%
    r= R*B; %Macro cell radius (Target cell)%
%Handover Failure Probability%
if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
thetat=acos((((v*T).^2)+(R.^2)-
(r.^2))./(2*v*T.*R)); %the maximum angle for which
T expires before the UE gets out of the HOF
region%
    HOF=(2/pi)*thetat;
else
    HOF=0;
end
valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-xb','LineWidth',2)
axis([40 240 0 1])
xlabel('Distance Macro - Femto (m)')
ylabel('HOF Probability')
legend('TTT=512 ms')
grid
```

A.1.3. Radio Link Failure Probability TTT=512 ms

```
clc,clear,closeall
v= 60; %UE speed in (Km/h)%
B=0.73; %The numerical solution shows that in the
simulated scenario the ratio (r/R = B) remains
approximately constant and equal to 0.73%
TTT= 512; %Time-to-Trigger in (ms)%
T= TTT+50; %the time for an inbound HO= Time-to-
Trigger + HO Preparation Time%
TR=1000; %RLF occurs after the UE has moved inside
the HOF region for more than TR%
valueofRLF= zeros(1,21);
valueofD=[40 50 60 70 80 90 100 110 120 130 140
150 160 170 180 190 200 210 220 230 240];
%Distance range between 40 to 240 (m)%
i= 0;
D= 30; %Distance in (m)%
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi; %Small cell radius (Source cell)%
r= R*B;%Macro cell radius (Target cell)%
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2); %the
distance covered by the UE from the entry point to
the first intersection with the HOF circle%
%Radio Link Failure Probability%
if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v &&
v <= (R+r)/T)&&(v*TR)<= (2*r))
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
%the maximum angle for which T expires before the
UE gets out of the HOF region%
      RLF=(2/pi)*thetat;
```

```matlab
elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T <
v && v <= (2*R)/T)&&(v*TR)<= (2*r))
thetaR=asin(sqrt(((r^2)/(R^2))-
(((v*TR)/(2*R))^2))); %the maximum angle that will
lead to RLF%
        RLF=(2*thetaR)/pi;
else
    RLF=0;
end
valueofRLF(i)= RLF;
end
plot(valueofD,valueofRLF,'-xb','LineWidth',2)
axis([40 240 0 1])
xlabel('Distance Macro - Femto (m)')
ylabel('RLF Probability')
legend('TTT=512 ms')
grid
```

A.2. Variable Values of Time-To-Trigger

A.2.1. Handover Probability

```matlab
clc,clear,closeall
v= 60;   %UE speed in (Km/h)%
B=0.73;   %The numerical solution shows that in
the simulated scenario the ratio (r/R = B) remains
approximately constant and equal to 0.73%
TTT= 128;  %Time-to-Trigger in (ms)%
T= TTT+50;  %the time for an inbound HO= Time-to-
Trigger + HO Preparation Time%
TR=1000; %the RLF occurs after the UE has moved
over the HOF region for more than TR%
valueofHO= zeros(1,21);
valueofD=[40 50 60 70 80 90 100 110 120 130 140
150 160 170 180 190 200 210 220 230 240];
%Distance range between 40 to 240 (m)%
```

```matlab
i= 0;
D= 30;   %Distance in (m)%
whilei<= 20
i= i+1;
     D= D+10;
     F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
     Q=integral(F,0,90);
     R= Q/pi;   %Small cell radius (Source cell)%
     r= R*B;    %Macro cell radius (Target cell)%
thetai=acos((v*T)/(2*R));%the maximum entry angle
for the inbound HO to be completed%
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
%the maximum angle for which T expires before the
UE gets out of the HOF region%
thetaR=asin(sqrt(((r^2)/(R^2))-
(((v*TR)/(2*R))^2))); %the maximum angle that will
lead to RLF%
     d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-
((v*TR)/2); %the distance covered by the UE from
the entry point to the first intersection%
     d2=d1+(v*TR); %the second intersection%
%Inbound Handover Probability%
if        (0<=v&&v<(R-r)/T)
          HO=(2/pi)*thetai;
elseif    ((R-r)/T<=v&&v<=(R+r)/T)
          HO=(2/pi)*(thetai-thetat);
elseif   ((R-r)/T<=v&&v<(d2)/T)
          HO=(2/pi)*(thetai-thetat);
elseif   ((d2)/T<=v&&v<=(2*R)/T)
          HO=(2/pi)*(thetai-thetaR);
elseif  ((R+r)/T<v&&v<=(2*R)/T)
   HO=(2/pi)*thetai;
else
    HO=0;
end
valueofHO(i)= HO;
end
plot(valueofD,valueofHO,'-or','LineWidth',2)
```

```matlab
axis([40 240 0 1])
holdon
%Scenario with TTT= 256%
TTT= 256;
T= TTT+50;
i= 0;
D= 30;
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
thetai=acos((v*T)/(2*R));
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
thetaR=asin(sqrt(((r^2)/(R^2))-
(((v*TR)/(2*R))^2)));
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
d2=d1+(v*TR);
if        (0<=v&&v<(R-r)/T)
          HO=(2/pi)*thetai;
elseif   ((R-r)/T<=v&&v<=(R+r)/T)
          HO=(2/pi)*(thetai-thetat);
elseif   ((R-r)/T<=v&&v<(d2)/T)
          HO=(2/pi)*(thetai-thetat);
elseif   ((d2)/T<=v&&v<=(2*R)/T)
          HO=(2/pi)*(thetai-thetaR);
elseif  ((R+r)/T<v&&v<=(2*R)/T)
   HO=(2/pi)*thetai;
else
    HO=0;
end

valueofHO(i)= HO;
end
plot(valueofD,valueofHO,'-+b','LineWidth',2)
%Scenario with TTT= 320%
```

```matlab
TTT= 320;
T= TTT+50;
i= 0;
D= 30;
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
thetai=acos((v*T)/(2*R));
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
thetaR=asin(sqrt(((r^2)/(R^2))-
(((v*TR)/(2*R))^2)));
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
d2=d1+(v*TR);
if         (0<=v&&v<(R-r)/T)
           HO=(2/pi)*thetai;
elseif    ((R-r)/T<=v&&v<=(R+r)/T)
           HO=(2/pi)*(thetai-thetat);
elseif   ((R-r)/T<=v&&v<(d2)/T)
           HO=(2/pi)*(thetai-thetat);
elseif   ((d2)/T<=v&&v<=(2*R)/T)
           HO=(2/pi)*(thetai-thetaR);
elseif  ((R+r)/T<v&&v<=(2*R)/T)
   HO=(2/pi)*thetai;
else
     HO=0;
end
valueofHO(i)= HO;
end
plot(valueofD,valueofHO,'-*c','LineWidth',2)
%Scenario with TTT= 512%
TTT= 512;
T= TTT+50;
TR=1000;
i= 0;
```

```matlab
D= 30;
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
thetai=acos((v*T)/(2*R));
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
thetaR=asin(sqrt(((r^2)/(R^2))-
(((v*TR)/(2*R))^2)));
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
d2=d1+(v*TR);
if        (0<=v&&v<(R-r)/T)
          HO=(2/pi)*thetai;
elseif    ((R-r)/T<=v&&v<=(R+r)/T)
          HO=(2/pi)*(thetai-thetat);
elseif   ((R-r)/T<=v&&v<(d2)/T)
          HO=(2/pi)*(thetai-thetat);
elseif   ((d2)/T<=v&&v<=(2*R)/T)
          HO=(2/pi)*(thetai-thetaR);
elseif  ((R+r)/T<v&&v<=(2*R)/T)
   HO=(2/pi)*thetai;
else
    HO=0;
end
valueofHO(i)= HO;
end
plot(valueofD,valueofHO,'-dk','LineWidth',2)
xlabel('Distance Macro - Femto (m)')
ylabel('HO Probability')
legend('TTT=128 ms','TTT=256 ms','TTT=320
ms','TTT=512 ms')
grid
```

A.2.2. Handover Failure Probability

```matlab
clc,clear,closeall
v= 60;      %UE speed in (Km/h)%
B=0.73;      %The numerical solution shows that in
the simulated scenario the ratio (r/R = B) remains
approximately constant and equal to 0.73%
TTT= 128;   %Time-to-Trigger in (ms)%
T= TTT+50; %the time for an inbound HO= Time-to-
Trigger + HO Preparation Time%
valueofHOF= zeros(1,21);
valueofD=[40 50 60 70 80 90 100 110 120 130 140
150 160 170 180 190 200 210 220 230 240];
%Distance range between 40 to 240 (m)%
i= 0;
D= 30;      %Distance in (m)%
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi; %Small cell radius (Source cell)%
    r= R*B;   %Macro cell radius (Target cell)%
%Handover Failure Probability%
if (((v*T)/(1+B))  <= R && R <= ((v*T)/(1-B)))
thetat=acos((((v*T).^2)+(R.^2)-
(r.^2))./(2*v*T.*R)); %the maximum angle for which
T expires before the UE gets out of the HOF
region%
    HOF=(2/pi)*thetat;
else
    HOF=0;
end
valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-or','LineWidth',2)
```

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

```matlab
if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
thetat=acos(((((v*T).^2)+(R.^2)-
(r.^2))./(2*v*T.*R));
    HOF=(2/pi)*thetat;
else
    HOF=0;
end
valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-*c','LineWidth',2)
%Scenario with TTT= 512%
TTT= 512;
T=TTT+50;
i= 0;
D= 30;
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
thetat=acos(((((v*T).^2)+(R.^2)-
(r.^2))./(2*v*T.*R));
    HOF=(2/pi)*thetat
else
    HOF=0
end
valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-dk','LineWidth',2)
xlabel('Distance Macro - Femto (m)')
ylabel('HOF Probability')
legend('TTT=128 ms','TTT=256 ms','TTT=320
ms','TTT=512 ms')
grid
```

A.2.3. Radio Link Failure Probability

```
clc,clear,closeall
v= 60; %UE speed in (Km/h)%
B=0.73; %The numerical solution shows that in the
simulated scenario the ratio (r/R = B) remains
approximately constant and equal to 0.73%
TTT= 128; %Time-to-Trigger in (ms)%
T= TTT+50; %the time for an inbound HO= Time-to-
Trigger + HO Preparation Time%
TR=1000; %the RLF occurs after the UE has moved
over the HOF region for more than TR%
valueofRLF= zeros(1,21);
valueofD=[40 50 60 70 80 90 100 110 120 130 140
150 160 170 180 190 200 210 220 230 240];
%Distance range between 40 to 240 (m)%
i= 0;
D= 30; %Distance in (m)%
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;   %Small cell radius (Source cell)%
r= R*B;     %Macro cell radius (Target cell)%
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2); %the
distance covered by the UE from the entry point to
the first intersection with the HOF circle%
%Radio Link Failure Probability%
if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v &&
v <= (R+r)/T)&&(v*TR)<= (2*r))
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
%the maximum angle for which T expires before the
UE gets out of the HOF region%
      RLF=(2/pi)*thetat;
elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T <
v && v <= (2*R)/T)&&(v*TR)<= (2*r))
```

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

```matlab
end
plot(valueofD,valueofRLF,'-+b','LineWidth',2)
%Scenario with TTT= 320%
TTT= 320;
T= TTT+50;
i= 0;
D= 30;
whilei<= 20
i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v &&
v <= (R+r)/T)&&(v*TR)<= (2*r))
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
        RLF=(2/pi)*thetat;
elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T <
v && v <= (2*R)/T)&&(v*TR)<= (2*r))
thetaR=asin(sqrt(((r^2)/(R^2))-
(((v*TR)/(2*R))^2)));
        RLF=(2*thetaR)/pi;
else
    RLF=0;
end
valueofRLF(i)= RLF;
end
plot(valueofD,valueofRLF,'-*c','LineWidth',2)
%Scenario with TTT= 512%
TTT= 512;
T= TTT+50;
TR=1000;
i= 0;
D= 30;
whilei<= 20
i= i+1;
```

```matlab
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 +
651/2500).^(1/2))/7;
Q=integral(F,0,90);
R= Q/pi;
r= R*B;
d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v &&
v <= (R+r)/T)&&(v*TR)<= (2*r))
thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
    RLF=(2/pi)*thetat
elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T <
v && v <= (2*R)/T)&&(v*TR)<= (2*r))
thetaR=asin(sqrt(((r^2)/(R^2))-
(((v*TR)/(2*R))^2)));
    RLF=(2*thetaR)/pi
else
    RLF=0
end
valueofRLF(i)= RLF;
end
plot(valueofD,valueofRLF,'-dk','LineWidth',2)
xlabel('Distance Macro - Femto (m)')
ylabel('RLF Probability')
legend('TTT=128 ms','TTT=256 ms','TTT=320
ms','TTT=512 ms')
grid
```