HANDOVER PERFORMANCE FOR LTE-A AND BEYOND HETEROGENOUS NETWORKS

A THESIS SUBMITTED TO
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
KOCAELİ UNIVERSITY

BY

ADAM YAYA ABDELKERİM

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ELECTRONICS AND TELECOMMUNICATION ENGINEERING

KOCAELİ 2019

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October – 2019 Adam Yaya Abdelkerim

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φ_1	:	Distance (D) coefficient
Θ_i	:	Inner angle to the UE.
θ_i	:	Maximum entry angle
θ_e	:	Entry angle
θ_t	:	Time (T) expiration angle
θ_R	:	Radio link failure angle
$\Theta^v{}_{HO}$	:	Set of successful handover angle
$\Theta^v{}_{HOF}$	:	Set of handover failure angle
$\Theta^v{}_{RLF}$	:	Set of radio link failure
γ	:	Path Loss
α_s, α_t	:	The exponent of the corresponding Path loss model
A_s, A_t	:	Distance independent components of Path loss model
D	:	Inter-site distance (m)
d_1	:	User's first intersection distance (m)
d_2	:	User's second intersection distance (m)
d_s	:	User's distance to the source cell (Km)
d_t	:	User's distance to the target cell (Km)
H	:	Hysteresis Margin, (dB)
N	:	Noise(dB)
P_{HO}	:	Handover probability
P_{HOF}	:	Handover failure probability
P_{RLF}	:	Radio link failure probability
P_{t_s}, P_{t_t}	:	Transmitted powers of source and target cells respectively (dBm)
Q_{in}	:	Inbound threshold, (dB)
Q_{out}	:	Outbound threshold, (dB)
R	:	Small cell radius (m)
R_1	:	Handover execution in the small cell region
R_2	:	Hanover execution in the handover failure region
r	:	Handover failure region radius (m)
RSS_s	:	The signal strength of the source cell (dBm)
RSS_t	:	The signal strength of the target cell (dBm)
S	:	Radius of the outbound HO
$SINR_s$	:	Source cell SINR
T	:	Inbound HO time (ms)
T_R	:	Maximum time (ms)
T_p	:	Preparation time (ms)
v	:	User's velocity (m/s)
vT	:	User's distance in the inbound region (m)

List of Abbreviations

3GPP	:	3rd Generation Partnership Project
4G	:	4th Generation
ABI	:	Acquired Brain Injury
ABIARIB	:	Association of Radio Industries and Businesses, Japan
ATIS	:	Alliance for Telecommunications Industry Solutions, USA
BS	:	Base Station
CCSA	:	China Communications Standards Association
CIO	:	Cell Individual Offset
CSG	:	Closed Subscriber Group
C-plane	:	Control-plane
DCCH	:	Dedicated Control Channel
eNodeB	:	Evolved Node Base station
EPC	:	Evolved Packet Core
ETSI	:	European Telecommunications Standards Institute
E-UTRAN	:	Evolved Universal Terrestrial Radio Access Network
GPRS	:	General Packet Radio Service
GSM	:	Global System for Mobile Communications
HetNets	:	Heterogeneous Networks
HSDPA	:	High-Speed Downlink Packet Access
HSPA	:	High-Speed Packet Access
HSS	:	Home Subscriber Server
HSUPA	:	High-Speed Uplink Packet Access
IP	:	Internet Protocol
ITU-R	:	International Telecommunications Union-Radio Communication Sector
ITU-T	:	International Telecommunications Union-Telecommunication
LTE	:	Long Term Evolution
LTE-A	:	Long Term Evolution Advance
MIMO	:	Multiple Input Multiple Output
MME	:	Mobility Management Entity
OFDM	:	Orthogonal Frequency Division Multiplexing
OFDMA	:	Orthogonal Frequency Division Multiple Access
OPEX	:	Operational Expenditure
P-GW	:	Packet Data Network Gateway
QoS	:	Quality of Service
RAT	:	Radio Access Technology
RLC	:	Radio Link Control
RLF	:	Radio Link Failure
RRC	:	Radio Resource Control
RRH	:	Remote Radio Head
RSRP	:	Reference Signal Received Power
RSRQ	:	Reference Signal Received Quality
RSSI	:	Received Signal Strength Indicator
SeNB	:	Small cell evolved Node Base sation
SMS	:	Short Message Service
SNR	:	Signal to Noise Ratio
SON	:	Self-Organizing Networks
S-GW	:	Serving Gateway

TTA	: Telecommunications Technology Association, Korea
TTC	: Telecommunication Technology Committee, Japan
TTI	: Transmission Time Interval
TTT	: Time to Trigger
UE	: User Equipment
UMTS	: Universal Mobile Telecommunications System
UTRAN	: Universal Terrestrial Radio Access Network
U-plane	: User-plane

LTE-A VE ÖTESİNDE HETEROJEN AĞLARININ TETİKLEMELERİNİN AKTARIM PERFORMANSINA ETKİSİ

ÖZET

Gelişen hücresel iletişim sistemlerinde, makro hücrelerin kapsama alanları içinde küçük hücrelerin de yer alması beklenmektedir; bu çok aşamalı düzenlemeler el değiştirme (handover) gibi hareketlilik yönetimi sürecine zorluklar getirmektedir. Uzun Süreli Evrim-Gelişmiş (LTE-Advanced) ağlar için el değiştirme parametrelerinin seçimi ve optimizasyonu önemlidir. Bunlara ek olarak baz istasyonları arası mesafe ve kullanıcı hızı da optimum el değiştirme tetikleme zamanını etkilemektedir. Bu tezde, makro hücre ve küçük hücreler arasındaki bölgeler arası mesafeye bağlı olarak heterojen ağlarda el değiştirme sürecinin performansını analiz edebilen bir model geliştirilmiştir. Bu modelde dikkate alınan parametreler; araç hızı, hareketlilik yönetimi parametreleri ve hücre büyüklüğüdür. Özellikle, en yaygın anahtar performans göstergeleri, el değiştirme ve telsiz bağlantısı başarısızlık olasılıkları, farklı tetikleme zamanları için elde edilmiştir. Elde edilen sonuçlar, kullanıcının hız (km / s) değerine ve makro-küçük hücre arasındaki uzaklığa bağlı olarak uygun tetikleme zamanını belirleyerek el değiştirme performansında bir iyileşmeye ulaşıldığını göstermiştir. 3. Nesil Ortaklık Projesi'nden elde edilen bazı önemli istatistikler, heterojen ağ benzetimlerinde el değiştirme sürecine ait şikayetler, aktarma işleminin değişken kanal koşullarındaki başarısızlık olasılığını incelemek için geliştirilmiş bir analitik modele dahil edilir. Simülasyon analitik sonuçları doğrulamaktadır.

Anahtar Kelimeler: Alanlar Arası Mesafe, Devretme, Heterojen Ağlar, Tetikleme Süresi (TTT), Uzun Süreli Değerlendirme-Gelişmiş.

HANDOVER PERFORMANCE FOR LTE-A AND BEYOND HETEROGENOUS NETWORKS

ABSTRACT

The upcoming cellular communication systems are expected to deploy small-cells within the macro-cells coverage areas; these multi-tire arrangements bring the challenges to mobility management process such as handover. Optimization of handover parameters for Long Term Evolution-Advanced (LTE-Advanced) networks is significant and choosing an appropriate time to trigger according to inter-site distance and user's velocity is essential. In this article, the considered parameters are vehicular user velocity, mobility management parameters, and cell size. We develop a model capable of analyzing the performance of handover process in networks of heterogeneous nature depending on the inter-site distance between a macro cell and small cells. Particularly, the most common key performance indicators, handover, and radio link failure probabilities are analyzed for different time to trigger values in order to provide a firm network. The results presented that the investigated technique achieved a betterment in the handover performance by choosing the befitting time to trigger value for the user in each macro-small cell distance for specific velocity (km/h). Some important statistics acquired from a 3rd Generation Partnership Project - complaint handover process in networks of heterogeneous nature simulator are extracted and integrated into a developed analytical model to scrutinize the failure probability of handover process within fluctuating channel conditions. The simulation confirms the analytical results.

Keywords: Inter-Site Distance, Handover, Heterogeneous Networks, Long Term Evaluation-Advanced, Time to Trigger (TTT).

INTRODUCTION

Since its innovation, cellular telephone utilization is continuously developing in the global. To support the developing wide variety number of users, cellular network requirements are constantly evolving. First era (1G) mobile networks are brought in the 1980s. These networks are analog networks and could only provide fundamental voice services. With the 1990s, 2end era (2G) cellular networks are brought. 2G mobile networks are designed to be virtual and will provide information services with SMS messages beyond voice services. GSM become the most hit 2G cellular network widespread. In the second half of the 1990s, cellular telephone usage extended hastily along with the developing reputation of the internet. To support the information services in the cellular networks, GPRS is introduced. To offer higher data services for the customers, third-generation (3G) cellular networks are added in the overdue 1990s. 3G furnished outstanding data rate improvements over the 2G mobile networks. 2000s noticed an explosion of information usages with the developing number of multimedia offerings on the internet. To deal with internet growth at the cellular networks, 4^{th} generation cellular networks are presented.

Long Term Evolution (LTE), which is presented in 2008, is a 4G network standard. It gives higher capacity and information rate over the preceding cell network requirements and as of extensively utilized in the world. To offer higher carrier to the developing wide variety number of users and handle the expanding information, the LTE widespread is continuously evolving. LTE-Advanced, which is a noteworthy upgrade over LTE, was updated in 2011.

LTE-advanced has numerous enhancements over the LTE. One of the predominant upgrades is the presentation of heterogeneous networks because of the spectral efficiency of mobile networks strategies its hypothetical limits, to enhance network potential, the network topology can be modified. Traditionally, cell networks are homogeneous networks that are comprised of macrocells. On this kind of networks, to enhance network potential and coverage, low power microcell, picocell, femtocells, and relay stations could be implemented inside the coverage of high power macrocells. This sort of networks is referred to as heterogeneous networks (HetNets).

To assist the developing wide variety number of customers, the number of deployed cells is multiplied over the current years. This wide variety number can be extended more with the advent of HetNets. With the developing variety of cells, operational expenditure (OPEX) of the network is continuously developing for the mobile system's operators. To lower the OPEX, self-organizing networks (SON) are brought to the LTE. SON attempts to reduce the OPEX with automatizing the planning, control, and configuration of the network. at the same time as a user is in the cellular region, if it is going out of the coverage of its serving network, it needs to be switched to any other neighbor cellular network without disrupting the user’s session. This cellular network switching system is known as handover. Handover is a crucial concept within mobile networks. The system ought to transfer the user’s serving cell without dropping the user’s session. additionally, the system needs to not transfer the user’s serving network unnecessarily because the handover operation is a costly process that makes use of the precious radio resources. To offer higher carrier for the customers in cellular network mobility robustness optimization is needed as a use case for the SON. Handover parameter optimization is a hassle defined within the mobility robustness optimization use case.

The handover parameter optimization problem attempts to track the parameters used within the handover process to increase the successful handover rate. Historically, those parameters are set manually via the network operators after evaluation of the cell reports and logs. With the advent of SON, this technique can be modified.

To take care of the handover parameter improvement issue, a number of SON algorithms proposed inside the literature. Those issues commonly accumulate the measurements of handover failures and needless handovers from the cell reviews and track the handover parameters with the use of them. By and large, many of these calculations are proposed earlier than the birth of the heterogeneous networks and examined on homogeneous networks. In line with the technical reports [1], radio environment features are diverse within the heterogeneous networks and along these lines, handover overall execution drops drastically in comparison to homogeneous networks.

In this thesis, we propose another handover parameter enhancement calculation for LTE-A systems. The proposed calculation accommodates the LTE models and can be effortlessly connected on an LTE network without big adjustments. The proposed set of rules is intended for the HetNets. In heterogeneous systems, diverse cell sorts have distinctive inter-cellular interference situations at the cell edges. To tackle this issue, handover margins need to be differentiated in line with a neighbor cell. To offer this, cellular individual offset (CIO) values are tuned together with the hysteresis and time to trigger (TTT).

To test the proposed calculation, the SON calculation is executed and examined in a MATLAB simulation environment. Prior to the execution of the proposed arrangement, some mathematical derivations are calculated for the components of the handover technique. To evaluate the outcomes accumulated from the implementation of the proposed set of rules, several the formerly proposed algorithms also are carried out and evaluated within an identical environment. consistent with the outcomes, the proposed calculation performs superior to the alternative calculation at the same time as reducing the handover failures.

Reducing the coverage region of SCs lead to frequent handovers, handover failures (HOFs) and radio link failures (RLFs), which is the degradation of the signal from the serving cell, as a consequence of decreased Signal to Interference Noise Ratio (SINR). The interrupted handover process causes handover failure due to weak signal quality from the serving cell as mentioned in [2].

The above-given problem is to use the effect of distance and time triggering of macro-small cells on the handover performance in LTE-A HetNets to find out the dependency of TTT with MC-SC distance, select the appropriate TTT value for the user of each handover performance measurement with respect to the macro-small cells distance and user's velocity and overall mobility management in the system with respect the approach of Self-Organized Network as in [3].

The main aim and objective of this thesis are to propose a simple and effective model capable of analyzing delivery failures in small cells while considering all important variable of mobility management and achieving successful handover process by decreasing the handover failure and radio connection failure.

The capability of the proposal is simulated in Matlab and verified using the following scenarios.

- To show the dependency of the handover on the macro-small distance within the two-tier scheme, which means between macrocell and small cell in the same network.
- To express some mathematical derivation to prove the relationship between TTT and distance.
- To select the appropriate TTT value for the user of each handover performance measurement with respect to the macro-small cells distance and user's velocity.

The understanding of this thesis is achieved by three main steps. First, to collect information and boost our knowledge by reading the general information related to the problem statement which relates to LTE-A HetNets, mobility management, and handover performance. Second, examining the handover performance as a key factor of mobility in the HetNets in LTE-A with regard to, successful handover, handover failure, radio link failure probabilities by applying the time to trigger (TTT) and macro-small cell distance, and considering the parameters such as user's velocity, received signal strength (RSS) and Hysteresis. In addition, finding out the relation of different handover performance metrics as a function of macro-small cell distance and UE's velocity. The final step is to implement the mathematical equations into the simulation. And results are recorded to get an overall idea of handover decision making.

A research outline is to explain the structure of the thesis and the organization of the chapters so.

Chapter One, is the introduction part of the thesis and gives the background information about the problem statement, proposal solution, aim and objectives, and the thesis methodology. And it also gives a short explanation of how to achieve those objectives in the methodology.

Chapter Two, is the literature review, collecting information from several papers related to mobility management and finding out the strengths and weaknesses of each paper.

Chapter Three, is the system design of the methodology, consisting all the design methods and steps need to be undertaken to achieve the thesis goals.

Chapter Four, is the result and simulation parts, including the result discussion, simulation parameters, and justifying and interpreting the resulting outcome with respect to the project objectives.

Chapter Five, is the last and final chapter to give the conclusion of the thesis and recommendation of the future work are explained.

1. LITERATURE REVIEW

In this unit, the fundamentals of LTE is going to be elaborated. Additionally, quick facts will be given about a few principles in LTE, that needs to be examined to apprehend the thesis, are mentioned.

1.1. Background

Since the invention of the cellular system, the need for mobile phone usage is dramatically increased. In the early ’80s mobile phone system has introduced its first generation (1G) to support the increasing number of users, however, in the 1G network systems are analog and only provide voice communications. With the increasing the number of users in mobile phones in 1G , after one decade mobile networks has introduced second generation (2G) to enlarge its capacity with the growth of user’s number and provide more services, unlike 1G, which has used digital networks and allow the user to send and receive SMS along with voice services. Nevertheless, less than half a decade of 2G the usage of cell phones has increased rapidly, so the third generation (3G) has come to the service in the second half of the ’90s. The arrival of 3G into the cellular system was extraordinary and has improved remarkably over 2G networks, where data usage has started. At the beginning of the 2000s, data usage has grown with multimedia services [1].

To handle this growth on the mobile networks, the capacity of 3G was not big enough and the number of data users has increased effectively. Due to this growth of users on the data rate, the fourth generation (4G) has been introduced in the early 2000s, during this period 4G generation has come up with network standard which knowns as Long-Term-Evolution (LTE).

The 4G networks provide much better capacity and faster data rate compared to the previous generations. Since then on, these 4G networks standard has been used in the cellular system globally and keep developing its usage and upgrading its system with new technology. With that improvement and upgrade, LTE has upgraded to LTE-Advanced(LTE-A)[2].Figure 1.1. Cellular Network Evolution [2].

Figure 1.1. Evolution of cellular Networks

1.2. Long Term Evolution (LTE) Overview

LTE, which is the abbreviation of Long-Term Evolution, is widely described to offer high-speed information for cellular mobile and information terminals over radio surroundings. It is arranged to attain the requirements of 4G, which is the fourth era cellular telecommunication standards outlined with the aid of International Telecommunications Union - Radiocommunications Sector (ITU-R). The LTE specification is advanced with the aid of the 3rd Generation Partnership Project (3GPP). The 3GPP unites six telecommunications well-known development corporations (ARIB, ATIS, CCSA, ETSI, TTA, TTC), referred to as “Organizational companions” and presents their contributors with a solid environment to supply the reviews and specifications that outline 3GPP technologies [4]. The 3GPP systems has standards Releases. LTE is laid out in Release 8, which is posted in December 2008. Since then, the corporation constantly evolves the LTE specification with publishing new Releases.

LTE was introduced to achieve higher data rate compared to high-speed packet access (HSPA) in 3G, and LTE has a series of Releases which all are standard of 3G Partnership Project (3GPP). It normally based on Orthogonal Frequency Division

Multiplexing Access (OFDMA) and Multiple Input Multiple Output (MIMO) which allocate transmission bandwidth flexibly, improve spectral efficiency with higher speed data rate.

The whole wide variety of mobile subscriptions became around 7.9 billion in the third quarter (Q3) of 2018, with 120 million new subscriptions added at some stage in the quarter. The number of cell subscriptions grew at 3 percentage year-on-year and presently totals 7.9 billion. China had the maximum net additions for the duration of the quarter more than 37 million, accompanied by India more than 31 million and Indonesia about 13 million. The excessive subscription boom in China continues from the first quarter and second quarter and is possibly the result of an extreme competition amongst communications provider companies. The range of mobile broadband subscriptions is increasing at 15 percent year-on-year, growing through 240 million in Q3 2018. the overall is now 5.7 billion. The number of LTE subscriptions expanded by 200 million throughout the quarter to attain a total of 3.3 billion. The net addition for WCDMA/HSPA became around 60 million subscriptions. Over the equal duration, GSM/Edge-only subscriptions declined by 110 million. Other different technologies are declined by around 30 million. Subscriptions related to smartphones now account for more than 60 percent of all cellular telephone subscriptions. Around 360 million smartphones were sold in Q3, which equates to 86 percent of all mobile phones bought within the quarter.

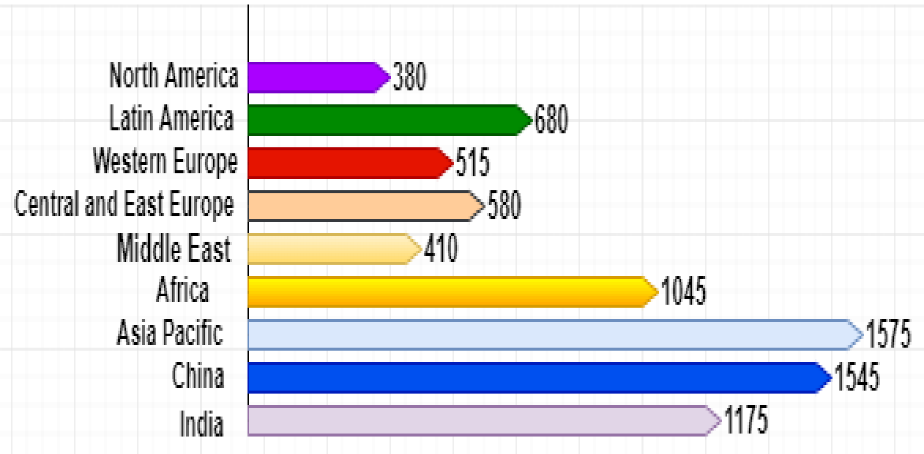

Figure 1.2. Mobile subscriptions Q3 2018 (million) [5].

The author in [5] has gathered the continental statistics and has shown the LTE-A potential in the upcoming 5G networks. Moreover, there is powerful momentum in the global LTE-A marketplace. In the united states, one of the essential communications carrier vendors released a 5G home internet service at in the early of October, and all four of the united states' foremost provider companies have publicly announced that they may start offering 5G services between the end of 2018 and mid-2019. Other markets waiting for significant 5G subscription volumes early include South Korea, Japan, and China. In Europe, a few spectrum auctions have already been held, and others will take place over the following couple of years. The first business 5G subscriptions in the region are predicted in 2019. LTE has been the dominant mobile access generation because at the end of 2017. The wide variety of LTE subscriptions maintains to develop explosively and is forecasted to attain 5.4 billion by the cease of 2024, While it's going to make up extra than 60 percent of all mobile subscriptions. The number of WCDMA/HSPA subscriptions has declined barely throughout 2018, although the technology remains estimated to account for close to 17 percent of all subscriptions in 2024. Cellular IoT connections and fixed wireless get right of entry to (FWA) subscriptions assisting new use instances will come on top of the cellular subscriptions shown within the graph beneath.

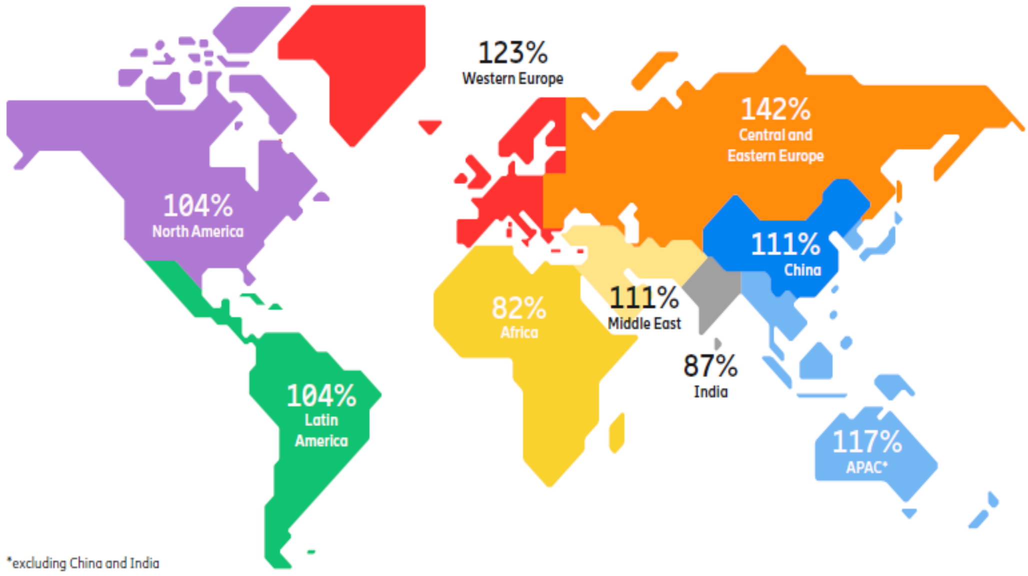

Figure 1.3. Subscription penetration Q3 2018 (percent of the population) [5]

A lot of the LTE requirements are evolved over preceding technology Universal Mobile Telecommunication Systems (UMTS) and HSPA network technologies. The necessities of LTE are described in [6]. A number of those necessities are:

- UE’s throughput: An average UE data packet per MHz should be between three to four instance Release 6 HSDPA for downlink and two to three Release 6 HSUPA for uplink.
- Peak data rate: System needS to assist downlink peak data rate of 100Mb/s and uplink peak data rate of 50Mb/s inside a 20 MHz spectrum.
- Spectrum efficiency: In a busy system, target of the spectrum efficiency could be from 3 to 4 times Release 6 for downlink (HSDPA) and 2 to 3-times Release 6 for uplink (HSUPA)
- Mobility: Network needs to assist mobility as much as 350 km/h, even up to 500 km/h relying on the frequency band.
- Coverage: Most cell range ought to be a hundred km. The information rate, throughput and mobility clauses may not be met strictly after 30 km.
- Spectrum: Network shall guide exclusive spectrum allocation sizes up to 20 MHz.

1.3. LTE-Advanced and Heterogeneous Networks Overview

This part introduces first on defining LTE-Advanced, explaining its structure and most applicable functions. After that, heterogeneous network approach is stated, alongside an explanation of most important challenges and strategies utilized in co-channel and devoted service deployments.

1.3.1. LTE-Advanced overview

Continues improvement of LTE in telecommunication system standard, LTE-Advanced has been proposed as the real 4G evolution and 3GPP has standardized LTE-A as it 10^{th} Release (Release 10), so LTE-A has been acknowledged by International Telecommunication Unit (ITU) and International Mobile Telecommunication-Advanced (IMT-Advanced) to be implemented over existing LTE system. However, all these development and achievement into cellular system evolution does not mean to forgo the previous networks evolutions but only upgrading and improving the network with newer technology over the old networks.

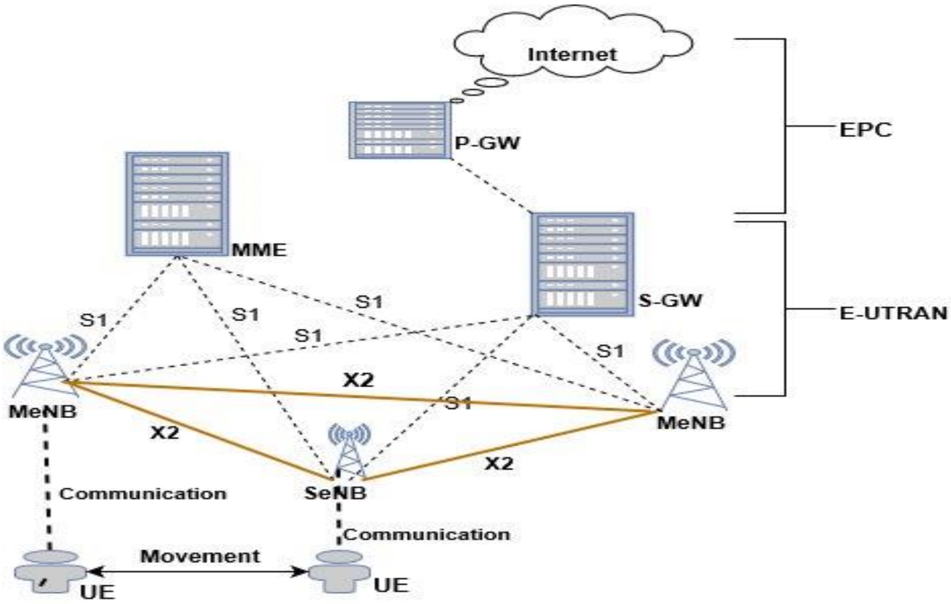

Figure 1.4. LTE-Advanced Framework

This astonishing improvement of this evolution is the advancement toward higher data rates particularly in overcrowded areas, so the main expectations toward this advancement are: increasing the data rate, controlling the delay and the capacity to satisfy the user's needs. From this point of view, 3GPP has increased data rate for LTE-Advanced to 3 Gbs for downlink (DL) and 1.5 Gbs for uplink (UL) by using MIMO and OFDMA techniques. So MIMO has increased the number of the antenna in the cellular network and that leads to interference and handover performance problems, then LTE-A has proposed a new network which known as heterogeneous networks (HetNets) to raise network satisfaction, controlling the delay and interference in overcrowded areas compared to homogeneous network.

1.3.2. HetNets improvement toward LTE-Advanced

The capacity gain in cellular networks uses different approaches, among these approaches, spatial frequency reuse is more favorable because it uses more cell sites. Moreover, studies show that most of the voice traffic and data traffic emerges from indoor and organizational surrounding networks [6-8]. This has led to the deployment of low-powered small cells into the homogeneous macrocell networks, these low-powered small cells are picocells, femtocells, metro cells, relays and so on. Figure 1.6 illustrates a layout with macrocell overlaid with various small cells. Among these small cells such as picocells, relay, microcells are outdoor focused and femtocells are normally used in a residential and very dense environment, as big companies. Nowadays statistics show that more than 50% of voice traffic and 70% of data traffic are utilizing indoor networks. So, for this reason, femtocells are deployed in a coordinative manner, where Small evolved Node Base sation (SeNB) can adaptively self-organize and optimize their transmission parameters.

Such type of cellular networks including different cells in an overlapping network with different parameters such as, power, carrier frequency, and backhaul networks is named as Heterogeneous Networks (HetNets).

1.3.3. Heterogeneous networks deployments

As stated in the preceding section, there are numerous exclusive forms of small cells which leads to distinct sorts of heterogeneous networks. Every HetNets have a specific deployment, coverage, and capacity features. The desires of the operator and their clients decide what kind of HetNet is most appropriate for a given scenario. An extensive classification of the distinct kinds of HetNets is given in [8-10].

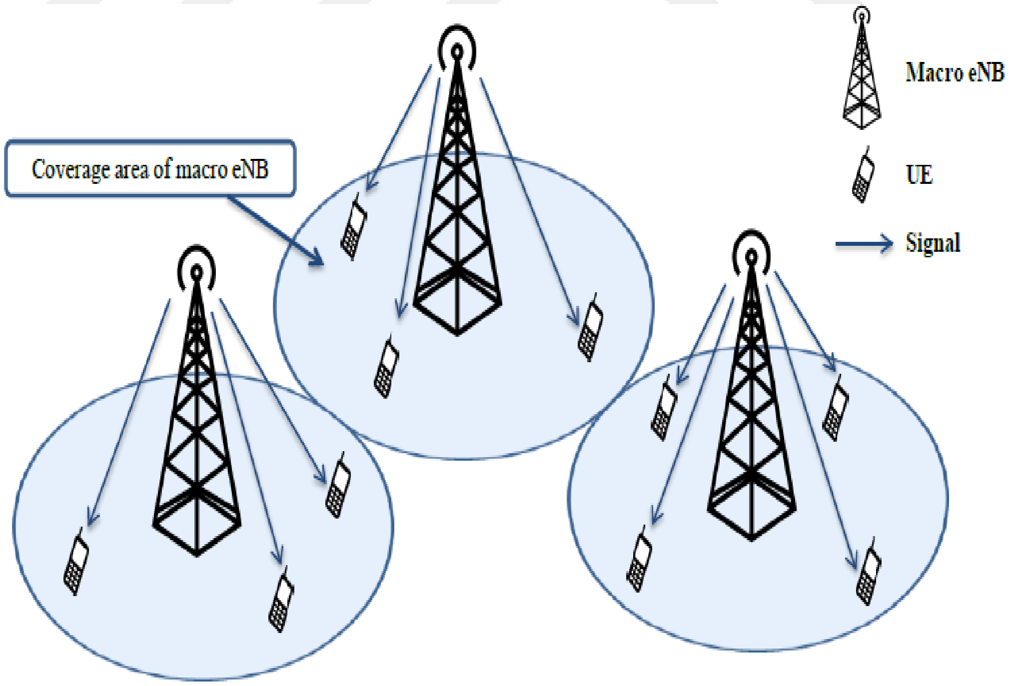

Figure 1.5. Homogeneous Network Deployment

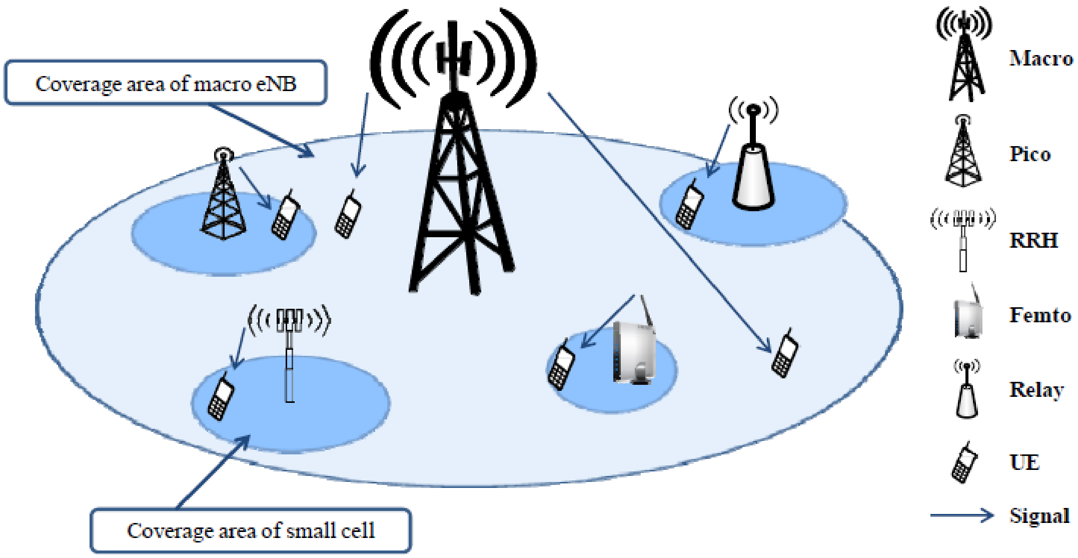

Figure 1.6. Heterogeneous Networks (HetNets) Layout [8].

Heterogeneous networks in LTE-A system consist of three main elements which are: evolved node B (eNB), Mobility Management Entity (MME) and Serving /Packet data Gateway (G-GW/P-GW). eNB is the combination of macrocell (MeNB) and small cell (PeNB/FeNB) and it performs packet scheduling and handover operations.

1.3.3.1. Public access services in HetNets

Low powered nodes are deployed by operators to target particular public access areas including railway stations and airport facilities. They are open to all contributors of the public, even though there may be a preferential grade of provider for first responders consisting of police and public protection personnel. The term public access services antenna is now and again used to denote small cells (typically picocells) set up in a high-traffic urban region.

1.3.3.2. Closed access services

Femtocells are small stand-alone low-power nodes which are commonly established indoors. In contrast to picocells, femtocell offerings are effective only to paid subscribers who are stated to shape a Closed Subscriber Group (CSG). They guide easy plug-and-play structure and do not require expert set up by means of operators. Femtocells connect with the operator’s network via the subscriber’s net carrier, some common values are indexed in Table 1.1. It could be seen that, even though corporation femtocells have a smaller percentage of the market, they yield greater income consistent with unit than residential femtocells. In addition, business femtocells can be classified into Small and Medium businesses/enterprises (SMB or SME), Medium to large (MLE) or large enterprises.

Tabel 1. 1. Characteristic of CSG-Based indoor HetNets [8]

Deployment	Coverage	Tx Power	Capacity	Market share	Revenue
Residential	500 sq.m	20 mW	8 users	85	70 %
SME/SMB	700 sq.m	100 mW	32 users	15	30 %
Large	1000 sq.m	250 mW	64 users		

1.3.4. Characteristic of HetNets

HetNets have numerous functions that set them aside from macro-only networks, some of that have already been mentioned in the preceding sections. This section provides an extensive assessment of a number of essential features.

1.3.4.1. Traffic offloading

Media-hungry cellular gadgets and mobile site visitors have been experiencing an exponential increase within the past decade as shown in figures 1.2 and 1.3. The massive traffic demand has overloaded cellular radio access networks (RANs), which in evaluation experience in a far slower capacity increase. It turns into an essential task for mobile operators to deal with the heavy traffic demand in a timely and cost-efficient way.

Offloading user equipment (UE) traffic from the macro is one of the essential features of small cells. The quantity of offloading is based on the criterion by which the base station is associated with the UE. The main fundamental criterion is the downlink reference signal received power (RSRP), but it does not result in much offloading because a macrocell's transmitting power is much greater than that of the small cell. Including a small cell bias, RSRP is an example of an association approach that will increase offloading. The macrocell and the pico cell can operate at different frequencies of the provider. This is especially true for future HetNets where small cells could be deployed in higher-frequency bands in the newly available spectrum. RSRP does not seize the distinguishing data inside the macrocell and small cell provider frequencies within the interference stages.

1.3.4.2. Self organizing networks (SONs)

Self-organizing networks (SON) are the crucial class of base station functionalities via which the numerous base stations in the network (extensively the small cells) can detect their conditions, coordinate with other base stations and automatically configure their parameters, for example, cell identity, automated power control gains, and so forth. Formerly those properties formed part of the network configuration equipment and techniques which have been configured by the operators manually. The manual techniques work for a small number of homogeneous macrocell deployments but do now not scale in a dense small-cell-based totally heterogeneous system. SONs are consequently essential to small cell deployments. A SON optimizes network parameters for controlling interference which has a big effect on overall performance. It also manages the traffic load among various cells and diverses RANs networks and gives the client the most ideal administration while keeping up a satisfactory dimension of by and large system execution overall performance. SONs lessen OPEX and hence set aside some cash for administrators.

1.3.4.3. 3GPP

The third generation Partnership Project (3GPP) is a standards corporation which develops protocols for cellular telephony. Its first-class recognized work is the improvement and protection of cellular network generations.

The main alternate from preliminary generations of mobile systems to latter releases is extended collaboration among diverse corporations, leading to the procedure of standardization. At present, 3GPP has nearly 400 member organizations from all around the globe from network operators, base station, UE providers, and chipset manufacturers to commercial and educational laboratories. Throughout the standardization procedure, technical proposals are debated and mentioned from distinct angles

1.4. Small Cells

Small cell is a concept that the size of cells is smaller, coverage areas are shorter and, use lower transmission power and lower cost in implementation and deployment. Supporting the larger cells to provide a better quality of service (QoS) at both cell-edge and, cell-centered areas. However, small cells have a different range of coverage areas, Figure 1.7 shows the range of different node in a HetNet layout.

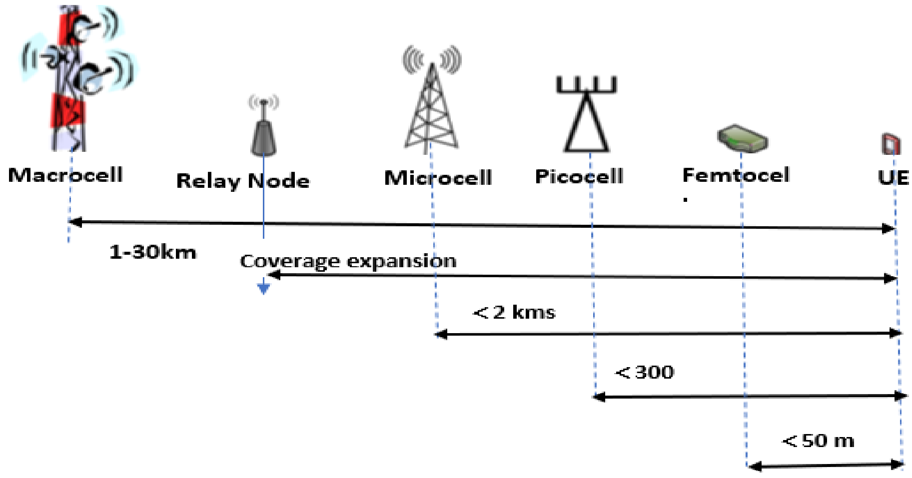

Figure 1.7. Cell's Range in Heterogeneous Networks

Expectations of HetNets are to improve the connectivity and performance by enabling dynamic traffic offloading within the network. Therefore small cells play a major role in HetNets by improving the coverage area and, the capacity beyond 4G cellular systems know as 4.5G in Turkey. Moreover, the small cell has a different type of access control which is given in three different types:

- Open access: open to all users in the same cellular networks
- Close access: Only subscribed users can get access, so it is named as closed subscriber group (CSG).
- Hybrid access: It has a limited number of users that are not in a closed subscriber group capability.

The small cell cannot be operated alone, must be implemented inside the macrocell coverage area, and also must be deployed according to the user equipment requirements. The summarized overview of macrocell and the low powered cell is shown in table.1.2. [9,10] with their transmitted power, coverage area, placement, and access.

Tabel 1. 2. Macrovell and Small Cells Nodes Parameters [9]

Type of Nodes	Transmitted powers	Coverage	Placements	Access
Macrocell	46 dBm	Few kms	Outdoor	Open to all UE
Microcell	30-37 dBm	< 2 kms	Outdoor	Open to all UE
Picocell	23-30 dBm	< 300 m	Indoor/Outdoor	Open to all UE
Femtocell	30 dBm	< 50 m	Indoor	Open or CSG
Relay	30 dBm	300 m	Outdoor	Open to all UE
RRH	30 dBM	300 m	Indoor/Outdoor	

1.4.1. Macro cell

Macrocells base stations (MeNB) control large coverage areas approximately 40 kilometers with very high power of transmission about 40 to 100 W, and the capacity of macrocell depends on the implementation of the cell. In LTE-system macrocell networks are named as homogeneous networks and are the main source of small cells nodes (SeNB), although. facing several challenges such as interference, and overloading, and so on.

1.4.2. Microcell

Microcells are normally outdoor nodes to support the macrocells capacity to offload and uses less power of transmission, and coverage area about 2 to 10 Watts and 2 kilometers respectively. Microcells are used in 3G networks, as well as in LTE, for the outdoor purpose to cooperate with macrocells.

1.4.3. Pico cell and Remote radio head

Pico and RRH cells are the smaller cell in size which operators have to install them to support the coverage area of macrocells in indoor regions, in addition, they are normally used for voice traffics and data connectivity at the same time. And their coverage area is about 300 meters. Furthermore, picocells normally suffer from lower signal to interference plus noise ratio (SINR) due to incidental positioning on the networks, so the interesting point between macro and pico is the huge difference of the transmit power of the two cells which causes the smaller downlink coverage of the picocell compared to the macrocell. Nevertheless, for uplink is not the same case, because pico and macro use the same transmit power strength from EUs to the all base station nodes. In short, uplink only depend on the users transmit power. So due to its smaller downlink coverage, picocell needs to be deployed in a planned manner in indoor and outdoor areas.

1.4.4. Femto cell

Femtocells are the hottest growing cells in the current cellular systems, which are introduced to support 3G and beyond 4G users equipment's, commonly used in cellular air interfaces such as CDMA200, UMTS, LTE, and LTE-A, so obviously femtocells are tightly connected with macrocells network, and so their usage is perfect for the user's equipment particularly.

The installation of a femtocell is as simple as plug and play for normal users, so the network architecture and specifications are easy to deploy. In case of femto used as closed subscriber group HetNets architecture, only registered users can access to the network. Hence, the interference issue will raise into HetNets from neighboring femto, very close non-registered users, or from the main macrocell node. Therefore, the installation of femto needs to consider a suitable control strategy to get optimum support from the operators.

Due to their simplicity, lower power, and low complexity, the focal point on femtocells is exponentially growing. In short, femtocells are generally used indoor networks with very low transmission power and with simple architecture focusing more on data connectivities

1.5. System Architecture

In contrast to its former, to facilitate the structure of the network, LTE is framed to be a complete packet switched network primarily based on IP. The LTE network structure is constituted of two predominant components; the evolved universal Terrestrial Radio access network (E-UTRAN) and the evolved Packet center (EPC). E-UTRAN is the radio interface of the network. Its obligations encompass management of radio access and offering user and manage-plane (u-plane) assist to the customers. EPC is the center part of the network and it's far liable for mobility management, coverage control, and safety.

1.5.1. E-UTRAN network

The E-UTRAN offers radio interface UE and control-plane(c-plane) protocols for the UE. The u-plane protocols offer control of user information transmission overall the network, at the same time as the c-plane protocols control user data transmission and control the connection between the user and the network. the network structure of the E-UTRAN is illustrated in Figure 1.8.

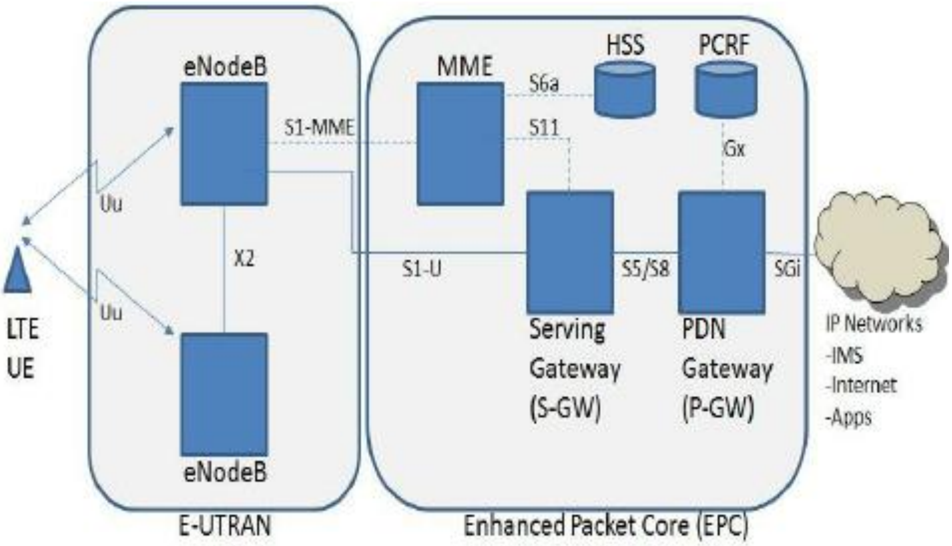

Figure 1.8. E-UTRAN Architecture Network including the deployment of SC.

E-UTRAN includes only one component, the evolved base stations referred to as eNodeB or eNB. The duties of eNodeB are indexed in [7].

There are two major principal interfaces described to attach the entities of LTE; X2 and S1 interfaces. The X2 interface is the communication line between the eNodeBs and used to switch user and control-plane data. The S1 interface is used to attach the eNodeBs to EPC.

1.5.2. Evolved packet core (EPC)

Evolved Packet Core (EPC) is the main part of the LTE system. EPC is wide-range evolution over preceding 2G and 3G core network requirements. In GSM, the main network is a circuit switched network. In GPRS, even as information is transmitted with packet switching, circuit switching is used for voice and SMS messages. In 3G, this idea is stored at the center network. In place of the use of each of packet and circuit switching, to simplify the structure. So, LTE is designed to be a completely IP primarily based packet switching system. The duties of EPC are mobility management, security control, session management, and policy control and charging, the overall structure of EPC is shown in figure.1.9. EPC network is based on the following basic logical factors:

- Mobility Management Entity (MME): MME is a key aspect of the requirements-described evolved packet core (EPC) and its duty is to offer UE mobility and assist subscriber authentication, roaming, and handovers to alternative networks
- Serving Gateway(S-GW): is the core network entity that communicates UE data to and from the eNodeB using S1 interface. Its main responsibility is to switch UE information from eNodeB to a new eNodeB in case of handover occurs.
- Packet data network Gateway (P-GW): Internet alone can not control mobility, so P-GW is used to communicate with the external data networks, such as internet and cellular mobiles. The main function of P-GW is to allocate IP addresses to the user equipment using the S1 interface through S-GW.
- Home Subscriber Server (HSS): HSS is the home for every subscriber and keeps all the data stored and provide to MME when its necessary.

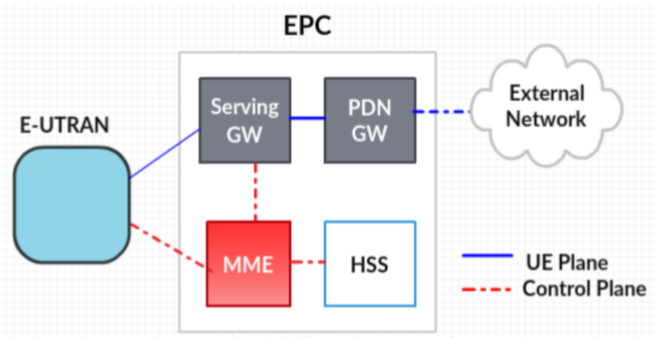

Figure 1.9. Basic of EPC Architecture Network

To summarize the system architecture, EPC interfaces with E-UTRAN using UE plane (u-plane) and control plane (c-plane), LTE is the combination of this two architecture E-UTRAN and EPC, its focus mainly on the mobility management and handover process.

2. HANDOVER MANAGEMENT IN HETNETS

2.1. Handover and Mobility Management in LTE-Advanced.

The main difference between homogeneous and heterogeneous networks is that, homogeneous networks are macrocell based networks, whereas, heterogenous networks are low powered nodes (LPN) deployment throughout the macrocell. The advantages of deploying low powered nodes (SCs) into the macrocell networks are: Offloading the traffic from overloaded macrocell and increasing the capacity due to the frequency reuse between macrocell and small cell. In short, the total network coverage will be increased by adding small cells into the macrocell, so user equipment can access the network efficiently.

However, deploying small cells into macrocell (HetHets) will introduce some challenges, for instance, site selection and reselection, and handover process, these challenges are essential in mobility management. Due to the imbalance transmit power and coverage area will raise these challenges, so site selection and handover performance need to be taken seriously.

2.1.1. Handover procedure

In cellular system keeping the UE active all the time is one of the essential quality measurements. Transferring an active user from one cell to another cell needs handover procedure, so commonly, handover scenario has been done for user equipment's from crossing one base station Bs(A) to another base station Bs(B) and the overlapping signal is the handover region in which user equipment could receive signal from BS(A) and BS(B) at the same time.

Successful handover must be provided to the user's reliability by the system without disconnecting any session. In cellular networks, there are two types of handovers. First, Hard Handover, where user equipment loses connection with the source cell before connecting to the target cell and the time between the signal drop from the source cell and signal linking to the target cell is very short that user does not notice the signal drop.

Second, Soft Handover, where user equipment connects to the target cell before disconnecting from the source cell. And hard handover is generally used in LTE networks.

Generally, there are three states of the handover process to be completed as shown in Figure 2.1.

- State 1: it is an earlier stage, which is before A3 event trigged
- State 2: A3 is trigged but handover command is not successfully received
- State 3: handover command is received successfully but the handover process is not completed yet.

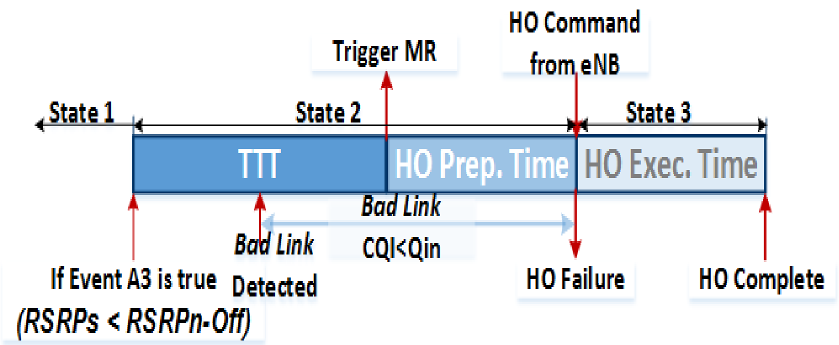

Figure 2. 1. Handover State Block diagram [9].

HetNets define two types of handover according to the characteristic of the source and target cells.

- Intra-E-UTRAN Handover, which handover is executed between the Nodes in the HetNets.
- Inter-RAT Handover, which handover is executed between E-UTRAN and other 3GPP radio access technologies.

2.1.1.1. Intra-E-UTRAN handover

S1 or X2 interfaces perform handover in Intra-E-UTRAN and during the handover procedure user can change its mobility management entity and S-GW.

S1 based handover can change both serving MME and S-GW but X2 based handover can only change serving S-GW. Moreover, handover performance can be done in three phases which are: handover preparation, handover execution, and completion.

2.1.1.2. Handover preparation phase

There are several steps in the handover preparation phase, which are as shown in figure.2.2. and figure 2.3.

1. The measurement report is sent to the serving cell by its UE
2. Based on the measurement report the serving cell decides if the UE needs to do a handover and if a handover is needed then the target cell must be identified,
3. Interface based handover will be decided by the serving cell, in X2 based handover request message is sent to the target cell by serving cell, but S1 based handover request message is sent to MME by serving cell.
4. After receiving the “handoverrequest” message, access control on the content of the message will be performed by the target cell, then, user’s requirement resources will be distributed and “handoveracknowledgment” message will be sent to the source cell.

2.1.1.3. Handover execution phase

1. “Connectionreconfiguration” message is sent to the UE by the source cell.
2. Status transfer message is sent to the target cell.
3. Packet data is transferred to the target cell using X2 or S1 interface.
4. User equipment connects with the downlink of the target cell by releasing the resources of the source cell.
5. Finally, the user can access the target cell by setting a secure link and sending a message that connection configuration is completed to the target cell to approve the handover execution is done successfully.

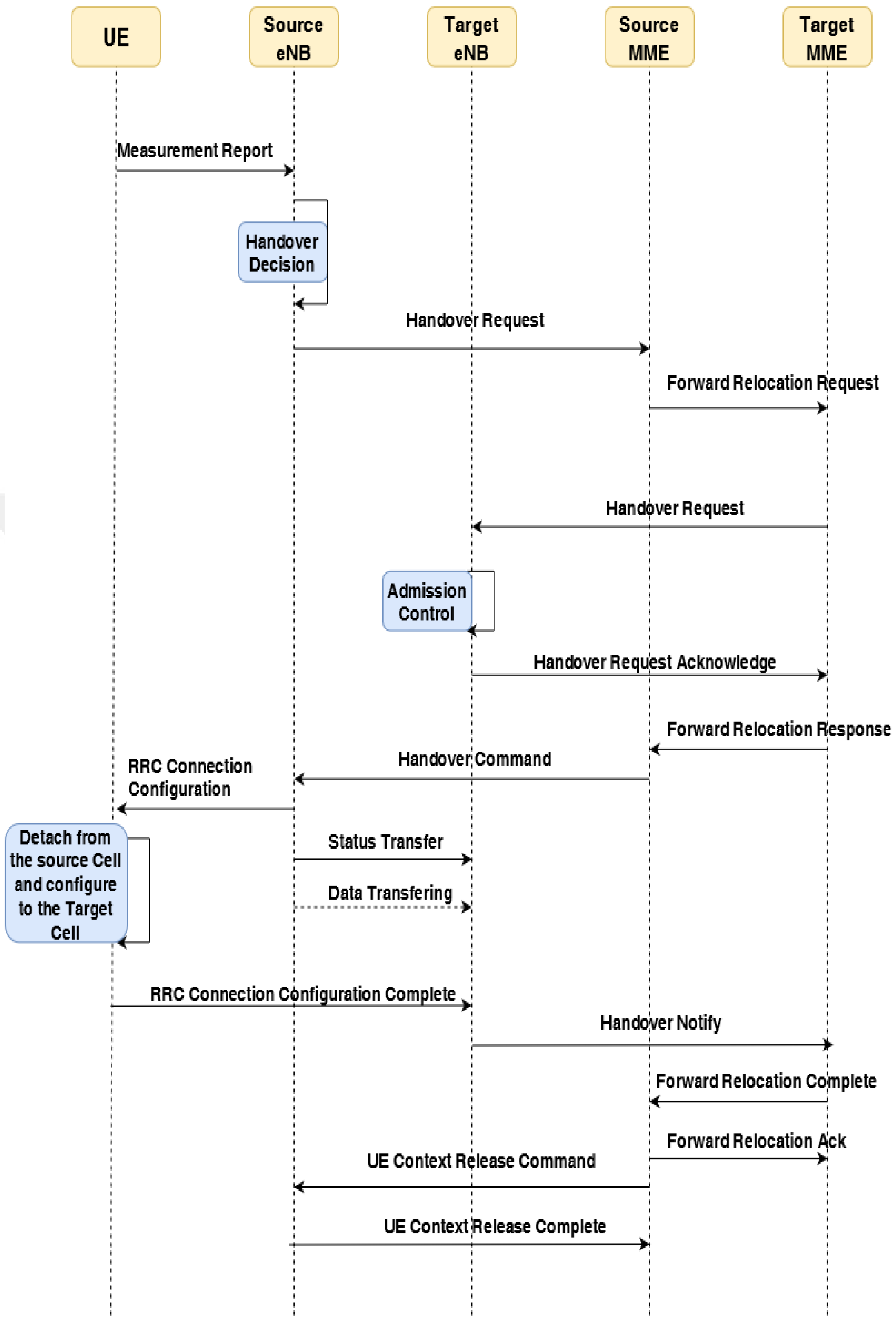

Figure 2. 2. System Model of HO Procedure in LTE-Advanced based on S1.

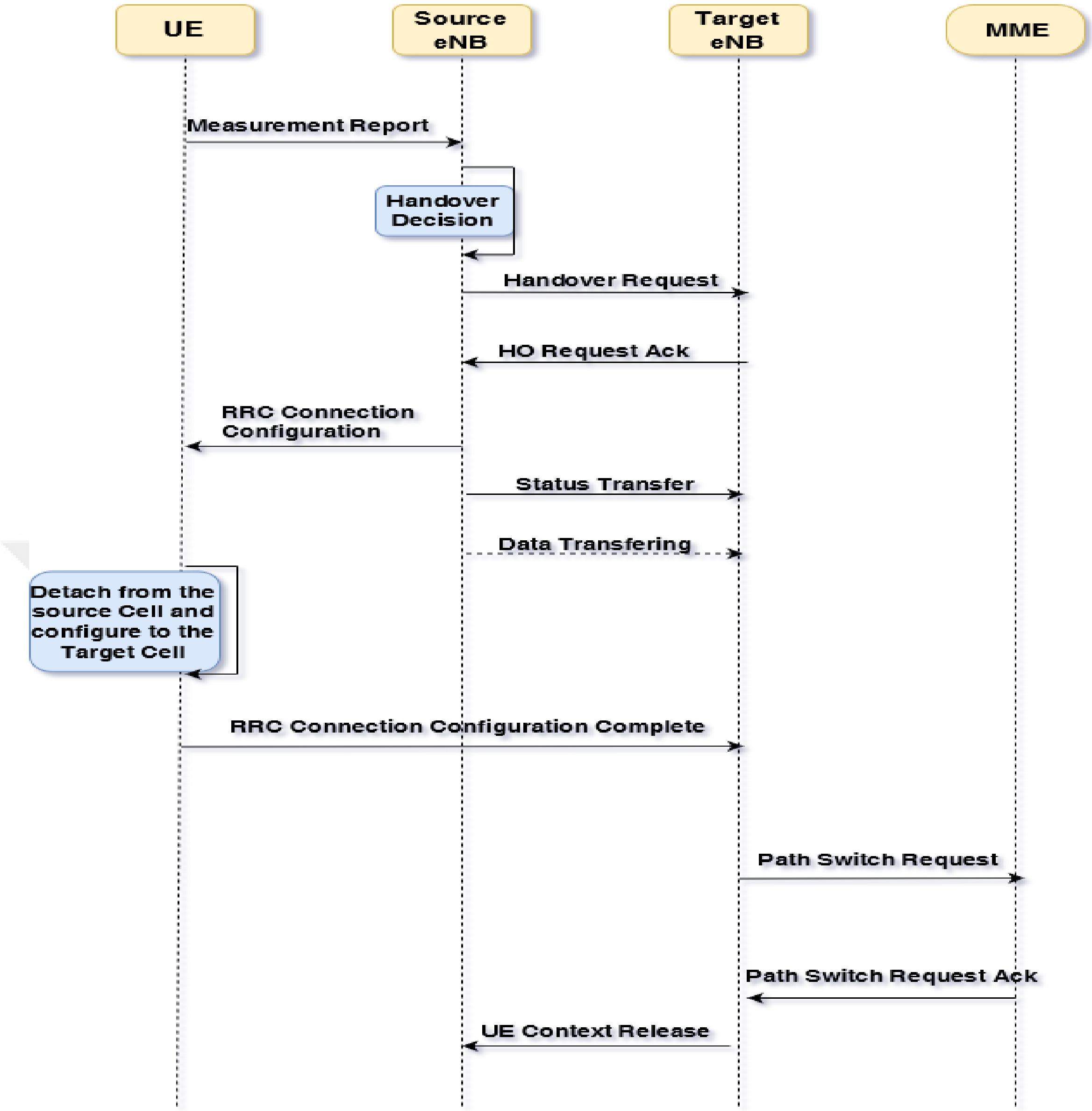

Figure 2. 3. System Model of HO Procedure in LTE-Advanced based on X2

2.1.1.4. Handover completion phase

1. After target cell received a "configurationcompleted" message, then the target cell sends handover to notify message to target MME.
2. Target MME sends "forwardrelocationcompleted" message to the source MME, then, the source MME "forwardrelocationacknowledge" message to the target MME.
3. Finally, the source MME commands the source cell to release the UE context and UE sends back UE "contextreleasecomplete" message to the source MME.

2.1.2. Measurement report metrics in LTE-A

In HetNets HO performance decisions generally are made by the serving cell, however, specific conditions must be sent by the UE. So, there are two measuring report metrics are used in the HetNets system.

- Reference signal received power (RSRP): Handover performance will be measured according to the reference signal power and compares the source receive signal and target receive signal.
- Reference signal received quality (RSRQ): in this case, RSRQ is used to calculate the quality of the signal and observed in the OFDM symbol.

However, this research based on RSRQ, in other word, received signal strength (RSS), so RSS or RSRQ are based on the measurement reporting events measured which, periodically. So, measurement reporting events criteria are defined as following [11]:

- Event A1: the signal of the serving cell becomes better than the threshold.
- Event A2: the signal of the serving cell becomes worse than the threshold.
- Event A3: the signal of the target cell becomes better than the serving cell.
- Event A4: the signal of the target cell becomes better than the threshold.
- Event A5: the signal of the serving cell becomes worse than threshold one and the signal of the target cell becomes better than threshold two.

According to the measurement configurations, the threshold and the offset values are set and sent by the serving cell. After an event occurred, before sending any measurement report, the event conditions must be checked and processed within a given time. This time is called time to trigger (TTT).

2.1.3. Handover parameter optimization

Providing improved mobility for UEs in an active condition all the time needs to optimize the handover parameters. However, handover failures and unnecessary handover are caused by choosing wrong handover parameters, and these failures are taken place when the radio link failure occurred between the users and the cell during the handover process.

Handover failure downturns the network performance because it is using the system resources to recover from the failure, and this leads to session drop if the network cannot be recovered. UE keeps trying to re-establish its connection with the strongest signal cell during the handover failure. So, there are several scenarios that cause handover failure as shown in figure.2.4.

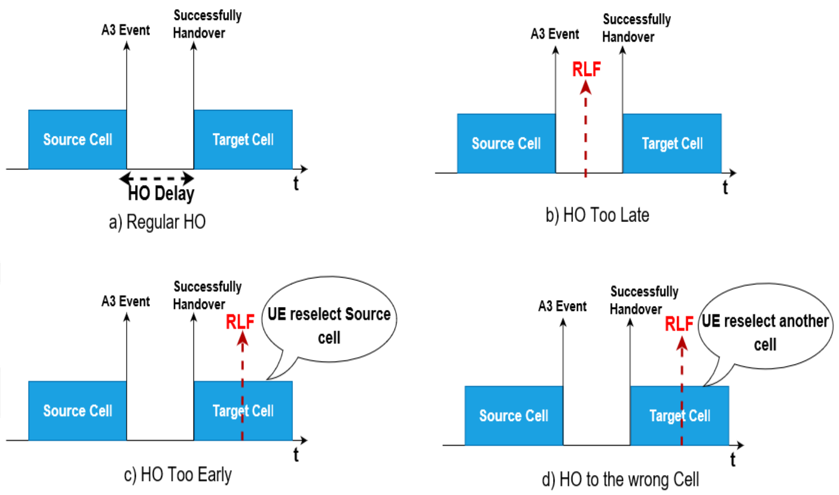

Figure 2. 4. Radio Failure Robustness Scenarios

- Regular HO: This is the early stage of HO scenario, A3 event will decide which signal will be given to the UE according to the HO characteristics.
- Handover Too Late: In this situation, RLF happens at the source cell before or during HO procedure, while UE tries to re-establish its connection to the target cell, target cell sends RLF indication message to the source cell after the connection re-establishment is done by the UE. And the source cell reports the handover as handover is too late.
- HO Too Early: RFL happens in the target cell after or during HO procedure, so UE tries to retain its connection to the source cell. After the connection is retained, then RLF indication message is sent to the target cell by the current cell indicating that handover failure is occurring on my side and handover report type is sent by the target cell to inform that handover is too early.
- HO To the Wrong Cell: After successful handover to the target cell, RLF happens immediately, the UE tries to re-establish its connection to another cell neither serving cell nor the target cell.

3. RELATED WORK

The driving force for emerging small cell deployments is the need for mobile operators to support the demands of their customers, which is limited in capacity due to macro-only deployments. Therefore, a transformation from the traditional cellular networks to the newly emerged dense multi-tier networks is required. These deployments are widely accepted to be implemented in LTE-A networks, namely HetNets. HetNets utilizes macrocells (MCs) to support the coverage for the whole area, and small cells (SCs) to support the coverage for high populated regions with a higher data rates [2,13,14]. By adding SCs into the macro cell, the coverage area can be increased, and the number of serving users can be increased by offloading traffic of the MC to SCs. Although that is advantageous of SCs, however, there are few problems are arisen, such as interference management and determining which base station (BS) serves the user according to the user's location. The received power at UEs is reported to BS and according to the highest received power, serving base station is determined. Due to user mobility, the serving BS can be changed. It is known as handover (HO). HO becomes an important topic for HetNets to keep the UEs in active mode all the time.

In the literature, there are few papers which study HO performance [15-19]. It can be stated that HO performance depends on hysteresis margin (H), and time-to-trigger (TTT) values. These studies mainly deal with how to reduce frequent HO and handover failure (HOF) probabilities. Various algorithms have been proposed to select suitable values for H and TTT. The authors in [4,14] express that reducing the coverage region of SC leads to frequent handovers, handover failures (HOFs) and radio link failures (RLFs), mainly for high-speed user equipment (UEs). UE factors are defined as user speed, location, and distance which are tightly related to TTT values. Hence the proposed mitigation strategy in [14] should be specific to UE such as Mobile Ad-hoc Networks (MANETs) and wireless sensor networks (WSN) concepts. Frequent HO is caused by fast UEs including unnecessary HOs, which have been the main focus of many types of research works [16].

In addition to this, an efficient handoff algorithm and balancing the irregular transmission power between macro-small BSs is to integrate both signals from Macro Base Station (MBS) and Small Base Station (SBS) are discussed in [3,17]. Moreover, to avoid RLF probability which is generally caused by TTT values, TTT selection could be based on the UE speed and the target/source cells. Furthermore, the appropriate balancing of TTT based on velocity and cells to find a stability of RLF and extending this work more on mobility can be found in [18,19].

The above-given works focus on the theoretical and managing mobility in HetNets studies. In [20,21] have given some mathematical derivations of HO and layover time of UE on a hexagonal cellular network. And also they focus on the call drop and call block probabilities in order to determine the performance of HO optimization need to be done. Furthermore, some mathematical derivation are shown for measuring the HO probabilities in [21,23]. Moreover, handover variables such as TTT and velocity are analyzed in [24,25], and also, they consider the layer-3, which the filtering of handover measurement is carried out. As far as we know, apart from the preliminary result given in [26,27], no more analytical work was found in the findings that study the HF probabilities in HetNets.

The author in [28] evaluated the parameters of handover and suggested a unique heterogeneous cell networks handover approach to limit the range of handover and handover failure. And dual connectivity with control and data plane cut up and Coordinated Multipoint (CoMP) transmission was proposed in the suggested method in order to optimize the network transmission parameters. Moreover, the author in [29] has proposed a scenario with a number of multiple mobile stations with a different wireless local access point, LTE-base stations and location using a random mobile station manner, the suggested systems obtained a success rate of 99 percent. The output of the proposed forecast schemes in terms of the precision ratio outperformed the output of the current forecast systems.

There are various methods to evaluate the user’s mobility. The writers suggest a solution in [30] that changes the values of TTT, threshold, and hysteresis by looking at the amount of UE cell border crossings. Moreover, to the UE’s velocity to the L3 filtering stage as a parameter. To discover the number of border crossings of cells, the writers suggest a deterministic model calculating the value over two parameters, UE speed,and serving cell circumference. The amount of cell border crossing has been calculated in [31] by counting the number of modifications in cell identity that has changed.Whereas high speed trains have greater mobility, several alternatives have b een attempting to improve the parameters of the handover specifically for high speed railway situations. In [32], the writers suggest using distinct values of hysteresis and TTT depending on the train velocity. In [33], the writers substitute a threshold value for the TTT value. The L3 filtering operates frequently in this solution according to a defined Tu duration. Only when the amount of successful L3 filtering reaches a specified predefined threshold value, source threshold handover requirement will be met. In case of separated velocity classes, the solution describes separate threshold values.

We propose a scenario in this thesis to find out the appropriate TTT value for the user for each handover performance measurement with respect to the macro-small cells distance and user's velocity.

The main objective of this thesis is to propose a simple and effective model capable of analyzing delivery failures in small cells while considering all important variable of mobility management. By means of common circular deployment, handover leads to locations at the edge, radio link also considered. Considering the linear mobility model of the UE, HOFs potentials for both macro and small cells are expressed in closed form for different scenarios, such as UE moving angle, the impact of velocity and the distance on the user equipment. In addition, an important statistical scenario has been drawn from a system-level simulation compatible with the 3GPP system, to help provide semi-analytical statements about the HOF. Each theoretical result is obtained through simulations, and investigations are conducted on the effect of H, TTT, and distance on HOF and the wireless link.

4. HANDOVER PARAMETERS FORMULATION

4.1. Problem Formulation of Handover Parameters

In this thesis, we assume that *M* SCs are deployed in a MC in order to support cell traffic. However, to obtain high performance from small cells, the handover process is critical. To determine which UE takes service from MC or SC, not only UE position in the MC is considered, but also TTT value is determined appropriately. In this section, we derive our formulation in order to select the appropriate TTT which is suited with HO, HOF and RLF probabilities.

Our system model is given in Figure.4.1. The coverage area of the SC is represented inside of the red-dotted circles, then HO performance investigates two-tier network which consists of a small cell positioned at a distance D (macro-small cell distance) within the macro-cell coverage area, as shown in Figure.4.1. LTE measurement report Trigger introduces A3 event which is target cell signal becomes better than the serving cell. Based on HO process procedure UEs pass through small cell coverage area and it checks whether if there is HO to execute (or not). HO decision is based on A3 event. According to A3 event, UE from the current cells send a signal to the target cell and it compares their received signal strength (RSS) if the received signal from the target cell is greater than the received signal from the current cell plus the hysteresis margin (H) as in (1). The effect of fading and shadowing is discussed, in addition to path loss model is considered and are given in Table.5.2. Before the HO is executed the RSS condition should be suitable for a TTT. Thus,

$$\mathrm{RSS}_t \geq \mathrm{RSS}_s + \mathrm{H}, \tag{4.1}$$

where the subscript t and s denote the target cell and source cell, respectively, and H is the hysteresis margin, all of them are expressed in dB unit [3]. Rearranging (1) may be rewritten as follows:

$$P_{T_t} + A_{0_t} - \alpha_t 10\log_{10} d_t \geq P_{T_s} + A_{0_s} - \alpha_s 10\log_{10} d_s + H, \quad (4.2)$$

where P_{T_t} and P_{T_s} are stand for emitted power (in dB) by the target and the current respectively, A_{0_t} and A_{0_s} are the distance independent from the path loss model (γ) and α_t and α_s are path loss exponent model and we assume that they are equal to each other $\alpha_s \cong \alpha_t$. Redeveloping the (2) gives:

$$d_s^{\alpha_s} \leq d_t^{\alpha_t} 10^{\gamma \frac{H}{10}}, \quad (4.3)$$

d_t is the distance between small cell user location and the small-cell (SC) BS. Also d_s is the distance between SC and the macro-cell (MC).

$$\gamma = \frac{P_{T_t} - P_{T_s} - (A_{0_t} - A_{0_s})}{10} \quad (4.4)$$

The angle Θ_i is the inner angle from the SC to a random UE_i position, then the relation between d_t and d_s is shown by

$$d_s = \sqrt{D^2 + 2Dd_t\cos(\theta) + d_t^2} \quad (4.5)$$

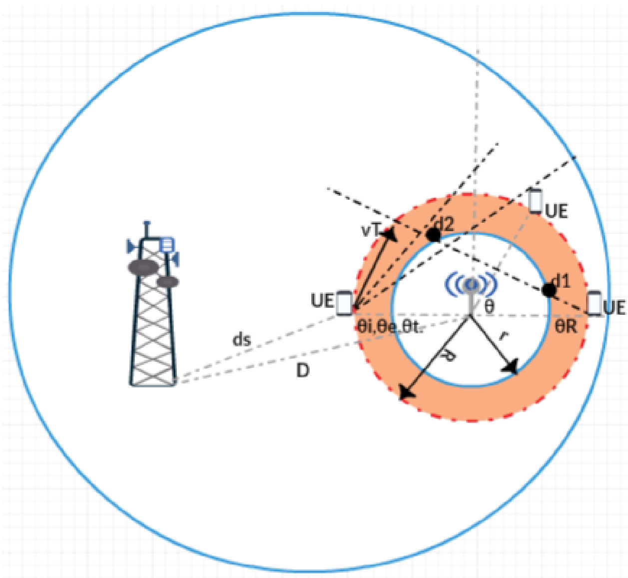

Figure 4. 1. Macro-Small Cell HO Senario based [3].

And so

$$d_t \le 10^{\frac{\gamma-0.1H}{\alpha_t}} \left(D^2+2Dd_t\cos(\theta)+d_t^{\,2}\right) \tag{4.6}$$

After appropriate estimation and assuming $\alpha_s \cong \alpha_t$ (6) then

$$d_t \le R \tag{4.7}$$

With

$$R = \left(10^{\frac{D}{\frac{2(\gamma-0.1H)}{\alpha_S}}} -1 \right) \times (\cos(\Theta_i) \pm \sqrt{\cos(\Theta_i)^2 + 10^{\frac{2(\gamma-0.1H)}{\alpha_S}} -1}) \tag{4.8}$$

$$R \cong D.\varphi_1 \tag{4.9}$$

If $\varphi_1 \ge 0$, then R is a positive number and in short it can be expressed R increases as D is increased. The green coloured circle in the Fig. 1 is the coverage area of SC and where (7) is defined , TTT of the inbound HO starts at $(d_t = R)$. if the TTT counter expires within this area , but SINR is below Q_{out} which coloured in red small circle in figure 1 , so likewise in (7) and (8) the following expressing can be written down

$$d_t \prec \gamma \tag{4.10}$$

$$r = \left(10^{\frac{D}{\frac{2(\gamma+\frac{Q_{out}-N}{10})}{\alpha_S}}} -1 \right) \times (\cos(\Theta_i) \pm \sqrt{\cos(\Theta_i)^2 + 10^{\frac{2(\gamma+\frac{Q_{out}-N}{10})}{\alpha_S}} -1}) \tag{4.11}$$

N is the transmitted noise power and expressed in dB.

4.2. Calculation of Closed-form of Handover parameters

We introduce another scenario based on different angle, let say R is the distance from the center of the SC to UE position. this UE having an entering angle θ_i and traveling at speed v around the SC coverage area. $0 < \theta_i < \frac{2}{\pi}$, in this condition UE execute HO , but it suffers from HOF and RLF. Preparation Time T_p (adding to the TTT , $(TTT+T_p)$ is needed for HO to executed completely for the maximum entry angle we have to introduce θ_i and express as:

$$\theta_i = \arccos(\frac{vT}{R}) \tag{4.12}$$

For the handover failure circle in the Fig 4 , θ_t is the maximum angle for and T has to expire in the HOF region. Using the Cosine Law we express θ_t as follows

$$\theta_t = \arccos(\frac{(vT)^2 + R^2 - r^2}{2vTR}) \tag{4.13}$$

For the RLF to occur T_R has to be at the maximum point after the UE passed over HOF region , usually $T_R = 1s$, so which mean RLF will not occur if the HOF is below the distance vT_R. Thus the maximum angle for that is defined as θ_R and expressed as follow:

$$\theta_R = \arcsin(\sqrt{\frac{r^2}{R^2} - (\frac{vT_R}{2R})^2}) \tag{4.14}$$

Then, if (13) doesn't satisfy the condition , θ_R will not be introduced and RLF will occur at the UE , and now we have distances d_1 *and* d_2 which are expressed as UE entry position for different intersection (first and second intersection respectively). We write down as:

$$d_1 = \sqrt{R^2 + r^2 - (\frac{vT_R}{2})^2} - \frac{vT_R}{2} \tag{4.15}$$

$$d_2 = d_1 + vT_R \tag{4.16}$$

Based on the above-mentioned mathematical equation we can relate the UE movement angle with the distance travelled and can express them in term of HO, HOF and RLF probabilities. To note that RLF is always zero if θ_R does not exist. After some calculation, we derived probability of HO, HOF and RLF, respectively based on radius of SC and MC, also the location of UE:

4.2.1. Handover probability

The goal of seamless handover is to offer a given QoS while the UE travells from the coverage of one network to the coverage of different cellular network. In LTE seamless handover is carried out to all radio bearers carrying control plane information.

Seamless handover is depend on the entry angle and maximum angle (θ_e, θ_i), if the entry angle (θ_e) smaller than the maximum angle (θ_i) , $\theta_e \prec \theta_i$ then UE performs handover successfully. In th other hand, TTT will expire after UE leaving the small cell coverage region and handover will not be completed due to handover failure ($\theta_t \geq \theta_e$) or radio link failure ($\theta_R \geq \theta_e$). If we introduce a new variable $\Theta^V{}_{HO}$ as a set for entry angle with respect V , then successful handover probability can be written as

$$P_{HO} = \int_{\theta_e \in \Theta^V{}_{HO}} \theta_e d\theta_e \tag{4.17}$$

If the set of entry angle $\Theta^V{}_{HO}$ = [0, θ_i] , then handover will be completed before reaching the HOF region, if $\Theta^V{}_{HO}$ = [θ_t, θ_i] time (T) is out inside HOF region and RLF has occurred (θ_R does not exist) and re-arranging the seamless HO probability as follows:

$$P_{HO} = \begin{cases} \frac{2}{\pi}\theta_i & \text{if } 0 \leq v \prec \frac{R-r}{T} \\ \frac{2}{\pi}(\theta_i - \theta_t) & \text{if } \frac{R-r}{T} \leq v \leq \frac{R+r}{T} \\ \frac{2}{\pi}(\theta_i - \theta_t) & \text{if } \frac{R-r}{T} \leq v \leq \frac{d_2}{T} \\ \frac{2}{\pi}(\theta_i - \theta_R) & \text{if } \frac{d_2}{T} \leq v \leq \frac{2R}{T} \\ \frac{2}{\pi}\theta_i & \text{if } \frac{R+r}{T} \leq v \leq \frac{2R}{T} \\ 0 & \ldots\text{otherwise} \end{cases} \tag{4.18}$$

4.2.2. Handover failure probability

The proposed SON set of rules uses too early and too late handover reviews to track the handover parameters. In LTE specification, after these events, the UE attempts to re-establish a connection to server, target or any other neighbor network. After connection re-establishment, the UE sends a RLF Indication message that consists of the specific data about the event. usually, these messages are used to pick out the RLF activities.

Mcell UEs reach the MUE HOF region before or after TTT expires, there will be HOF and UE fails to send measurement report. Therefore, UE can not connect with the SC.

UE suffers from HOF if the set of θ_e is gives as $\Theta^v_{HOF} = [\ 0,\theta_t\ ]$ and between $\frac{R\text{-}r}{T} \le v \prec \frac{R+r}{T}$.

$$P_{HOF} = \begin{cases} \frac{2}{\pi}\theta_t & \text{if } \frac{R\text{-}r}{T} \le v \le \frac{R+r}{T} \\ 0 & \text{Otherwise} \end{cases} \tag{4.18}$$

4.2.3. Radio Link Failure Probability

As shown in figure 2.6, too late HO, too early HO and wrong HO, are defined as radio link falilure handovers.

The procedure of RLF detection scenario is presented in algorithm.1 ,lets say handovering from the source cell to the target cell, so first UE's timer is started, RFL cell ID is identified for UE which experience RLF, and also last visited cell ID of UE is identified. In addition, current cell ID that UE is connected to after RLF occurs. Finally, RLF is detected and reported to MC and SC base stations.

$$P_{RLF} = \begin{cases} \frac{2}{\pi}\theta_t & \text{if } \frac{R\text{-}r}{T} \le v \le \frac{d_2}{T} \\ \frac{2}{\pi}\theta_R & \text{if } \frac{d_2}{T} \le v \le \frac{2R}{T} \\ 0 & \text{otherwise} \end{cases} \tag{4.19}$$

After constructing the performance equations and imposing them into MATLAB. The simulation will be for the possibilities of the overall performance metrics (handover, handover failure and radio connection failure) represented at the vertical axis, and the space among macro and small cells represented at the horizontal axis. consistent with the selected values of Time-To-trigger the probability of handover metric is converting associated with the inter-network distance. exclusive simulation schemes were derived dependant on a particular parameters along with inter-site distance, Time-To- trigger and user's speed in an effort to visualize the outcomes of the handover overall performance metrics and for simpler comparison among the two different schemes.

5. RESULT AND DISCUSSION

5.1. Simulation Explanation

This work has utilized the urban scenario environment given in [4,16] to evaluate the reliance of HO performance. The environment was extensively simulated and consisted of both small and macro cells. The cells were considered for an inter-network distance (D) with a range of 40-90mm. The simulations also included a macro and small cell tier as 1st interference ring in reflecting the underlying co-channel interference. The speed of the users under this environment was set to 60km/hr respectively. The simulations also incorporated the broad range of TTT values introduced in [3,7]. Some of these values are depicted in the following figures for illustration and clarification purposes while Table I contains the rest of the parameters.

Table 5. 1. Simulation Parameters

Bandwidth	10 MHz
Macro and Small Cell Frequency	2 GHz
Macro cell Path-Loss	$128.1 + 37.6 \log_{10}(d\ km)$
Small cell Path-Loss	$140.7 + 36.7 \log_{10}(d\ km)$
Macro cell transmitted power	46 dBm
Small cell transmitted power	20 dBm
HO A3 Hysteresis Margin	3 dB
TTT values	128, 160, 256, 480, 640
HO preparation Time	50 ms
HO Execution Time	40 ms

5.2. Simulation Environment

Simulation environment is done in Matlab to evaluate the reliance of HO performance. The environment was extensively simulated and consisted of both small and macro cells. The cells were considered for an inter-network distance (D) with a range of 40-240m. The simulations also included a macro and small cell tier as 1st interference ring in reflecting the underlying co-channel interference. The speed of the users under this environment was set to 60km/hr respectively.

The results of the simulation had been presented in plots for every handover overall performance metrics to demonstrate how every possibility goes to effect on the assessment of the handover. distinctive graphs of a successful Handover probability, Handover Failure likelihood and Radio link connection Failure probability respectively against inter-site distance (D) almost about four exclusive Time-To-trigger (TTT) values.

5.2.1. Reference value of TTT

From the factor of the operator’s view; a constant value for a Time-To-cause is selected as a reference point. So, in this paper one constant value of TTT has been selected for a comparison reason. From the figures below it is apparent that a set Time-To-trigger (TTT) isn't always effective at all the inter-site distances (D).

5.2.2. TTT equal to 480 ms

For a heterogeneous network that has fixed TTT=480ms; the figures (5.8, 5.9, 5.10) show the effect of this value on the handover overall performance metrics. it's miles apparent that 480ms offers a zero chance of a successful handover from D=40m till D=50m and chance of handover failure is zero from D=40m until D=60m and above D=60m nearly failure takes place. also, radio link connection failure possibility is zero from D=40 till D=a hundred and forty and get higher while D growth.

Demonstrating the TTT reference value for handover, handover failure and radio link failure on different graphes and then in the adaptive section we add more TTT values in comparative with the reference point.

Analyszing the below figures, figure 5.1 illustrates the handover probability, and it clearly shows that HO probability is zero when distance (D) is from 40m to 50m and afterward handover probability occurs, for instance when D= 60m HO probability approximately is equal to 0.18 and so on for the reference TTT=480ms.

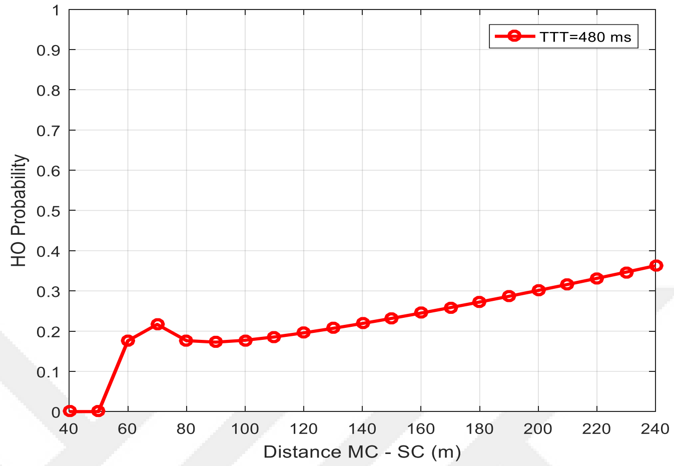

Figure 5. 1. Handover Probability for reference TTT=480 ms

Figure 5.2. reveals handover failure probability remained zero from distance (D) equal 40ms to 60ms as well, thereupon, HO failure is shot up sharply, obviously , when D= 240 handover probability is almost 0.5.

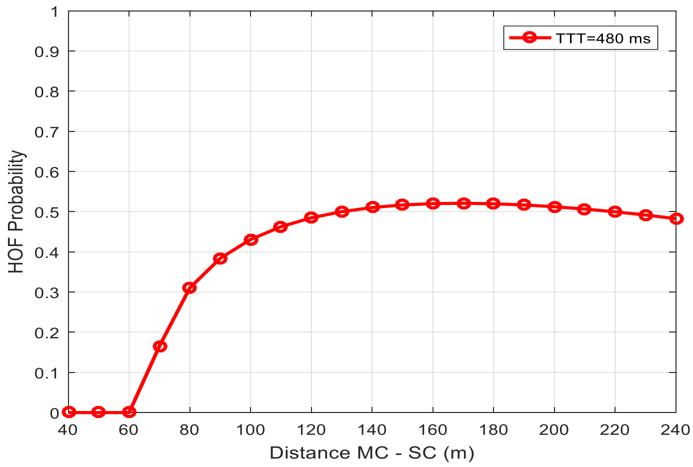

Figure 5. 2. Handover failur probability for reference TTT=480 ms

For radio link failure in figure.5.3 shows that RLF probability is zero when distance (D) at starting point till D= 140 ms and eventually increases when UE gets away from the source BS, in other words, after D=140ms when D increases RLF growths respectively.

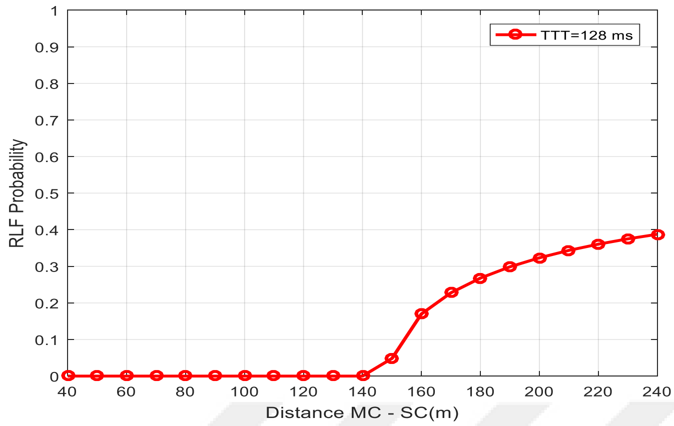

Figure 5. 3. RLF probability for reference TTT=480 ms

5.2.3. Adaptive TTT values

Adding new TTT values to the TTT reference (480 ms) and beselecting the suitable TTT value according to the UE values speed, inter-site distance and overall mobility in the network,

As prior mentioned, the performance evaluation of the simulations was done by using the parameters namely; RLF (PRLF) and HOF (PHOF) probabilities. Nonetheless, the probabilities of performing a HO (PHO) can also be used for the same evaluation. In this case, when a UE enters a small cell's radius of coverage, it may experience any of the following: suffer from RLF, perform a HO (whether it is a PP or otherwise), or not performing a HO (because of either a high TTT value or HOF). These probabilities are related by the following equation:

$$PNHO = 1 - PHO - PRLF \quad (5.20)$$

Generally, the execution of HO is done with (1) holding for a TTT period. According to principle, a user moving at a given speed v, will execute a HO given that its traced out trajectory within R1 radius is lengthier than the product of v and TTT. Now, considering the growth of the small cell's area of coverage (R) with D (as depicted in (8)), then the PHO should increase with the increase in D and falls with the increase in v.

Similarly, the HOF region determined by r increases with the increase in D and in turn, the PHOF should increase as well. The choice of desirable TTT due to these counteracting factors, plays a crucial part in improving the performance of the HO. The consequence of such opposite trends as reflected in the earlier presented metrics is analysed and depicted in the following figures (Figure.5.4 through Figure 5.6).

5.2.3.1. Handover probability

The PHO of a moving UE with speed of 60km/hr are shown in Fig.5.11. When the PRLF is zero, then the two probabilities are complementary (see equation (5.20)). It should be noted that the PRLF equals zero for both A1 and A2. Consequently, the PHO analysis is the same for the combined inter-state distance range of 40m ≤ D < 160m. As depicted in Figure.5.11, the deployment of the small cell far from the center of the macro cell results into a rise in the PHO, while R increases at the same time with the increase in D. Still, a maximum PHO may simply be observed in A1 and A2 for high TTT values which is attributed to two factors. The first factor is related to the likelihood of TTT counter expiring within the small cell's area of coverage and growing of PHO, which is due to the increase in R.

The second factor in this case is also attributed to the growth of r and in effect the rise in the probability of having a HOF. As seen in Figure.5.12, the number of HOFs make up for the growth of R when D > 70m and D > 90m for TTT values of 480ms and 640ms respectively, which causes the PHO to fall. However, this occurrence does not happen with low values of TTT due to the PHOF being high even for small values of D. For the A3 and A4 case scenarios, the increase in the coverage area of the small cell causes an upward trend to be maintained by the PHO. However, the effect of high values of R and D is the increase of PRLF and the fall of the SINR. In turn, this rise in PRLF restricts the PHO in A4.

The presented results demonstrate that the performance of the HO is largely influenced by both the coverage area (R) of the small cell and the HOF region's (r) size. However, the distance (v · TTT) covered by the user prior the TTT counter's expiration, also determines the impact of both R and r. That is, it dictates whether the values of R and

r are big or otherwise. The same effect determines why the value of the PHO is higher when TTT values are small and for a given speed.

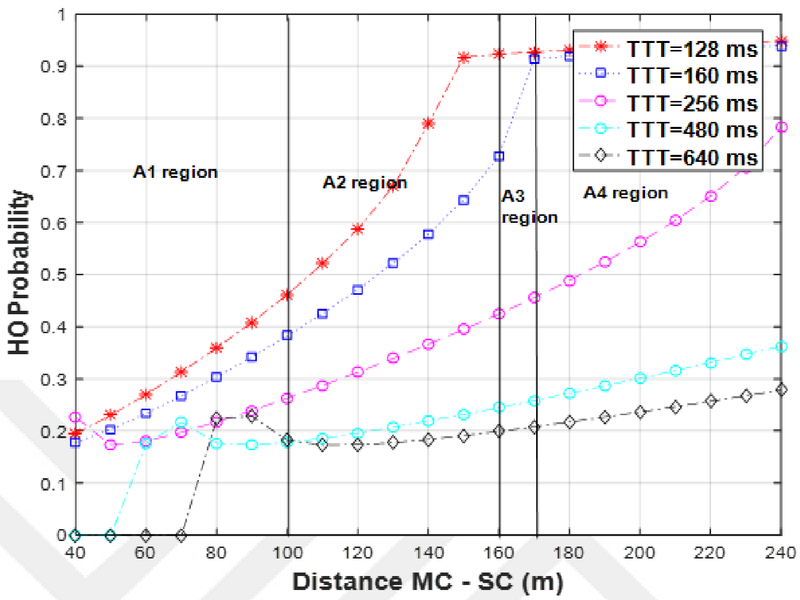

Figure 5. 4. Handover Probability for different values of Time To Trigger.

5.2.3.2. Handover failure probability

secondly, Figure.5.12. presents a plot of the PHOF and as mentioned earlier, a HOF would occur because of the TTT counter being expired within the HOF region (r). In this case, the counter for TTT is activated at R distance from the small cell while the HOF begins at a distance r from the small cell. Consequently, the PHOF is dependent upon the relation between the distance R – r and the product of v and TTT.

For example, if a given UE is moving between the centers of macro and small cells, then it will experience a HOF provided that $R - r \leq v \cdot TTT \leq R + r$.

The effect of this (as depicted in Figure.5.12.) is a high PHOF in small cells near the center of the macro cell for low values of TTT, and a lowering of the PHOF with the small cells being positioned away from the macro cell.

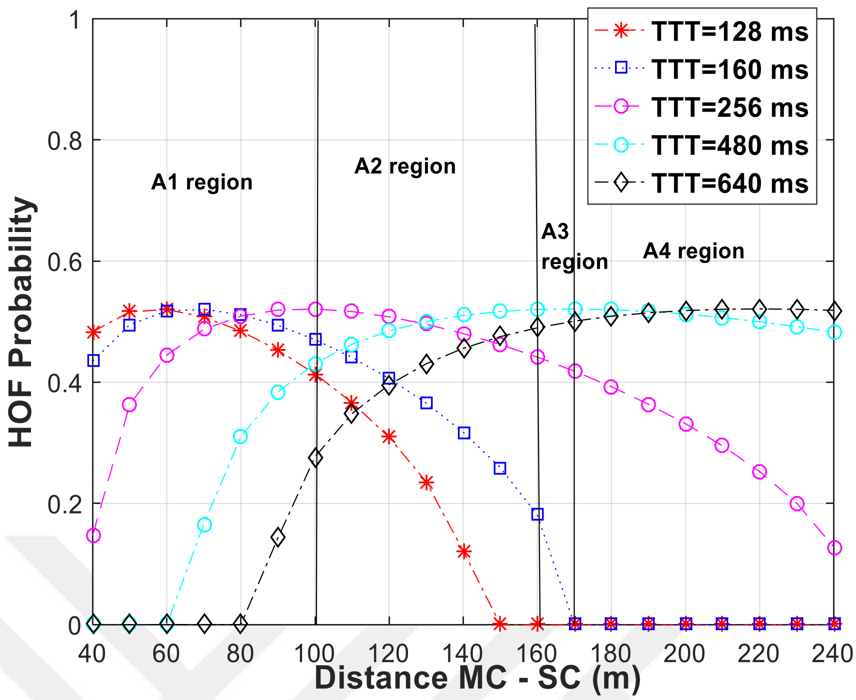

Figure 5. 5. HFP with various Time To Trigger values

5.2.3.3. Radio link failure probability

It can be noted that there are two components for the source cell's SINR: the first is the RSS received from the macro cell (source) while the second is related to the interference from the small cell (target). Both components depend on the distances to the source (D – R) and target (R) cells respectively. Given a low range of entry angles, there's a declaration of RLF events for small values of TTT. Hence, the SINR's value at the "D – R" and "R1" distances is of special significance (as depicted in Figure.5.13). More precisely, there will be a growth of the RLF when there is a faster growth in D than in R1. However, there will be a decrease of RLF with more growth of R than D. This trade-off may be seen in A4 from Figure.5.13 with TTT values of 128ms and 160ms. That is, there is more growth of R than D when there is a gradual increase of D. On the contrary, there is a faster growth of D than R when the location is closer to the edge of the macro cell where the adjacent macro cell's interference is stronger. This can be observed in Figure.5.13 for D ≥ 170m and with the upward trend.

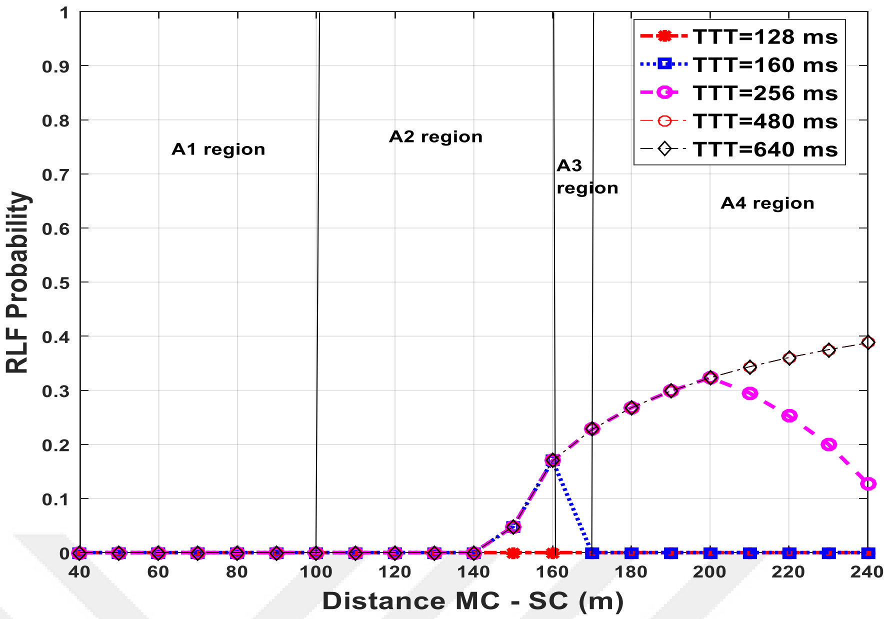

Figure 5. 6. Radio Link Failure Probability with respect TTT

In this method, we use MUE HF and PUE HF probabilities as functions UE speed (velocity). In figure.5.7. macro user HO probabilities is plotted for various UE speed (velocities) , “grouping method”, we fix the value of TTT for various UE speeds, however , the MUE HF is getting better with the sampling time (T_d) when is degraded , for instance , when MUE moving with speed of 120 km/h , it gets better nearly 10 per cent when the sampling time is (50ms).

The other results indicate that , MUE HF in order of 10 per cent for the other velocities. In short , the worst case for this scenario. From another stand point, where PUE HF is used and plotted in figure.5.8 , we realized that when the speed of the UE increases , the PUE HF increases respectively and it gets better when the sampling time gets lower. For example, the PUE HF probability for UE velocity 120 km/hr improves by approximately 5 percent when sampling period is reduced from 200 ms to 50 ms.

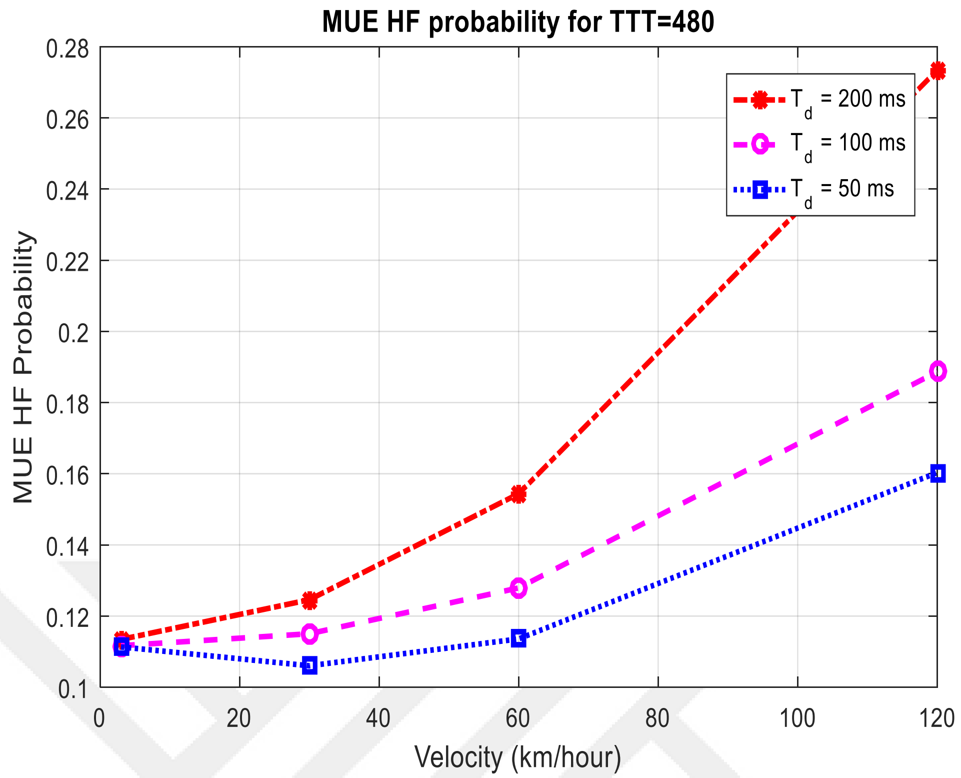

Figure 5. 7. MUE HF Probability based on velocity

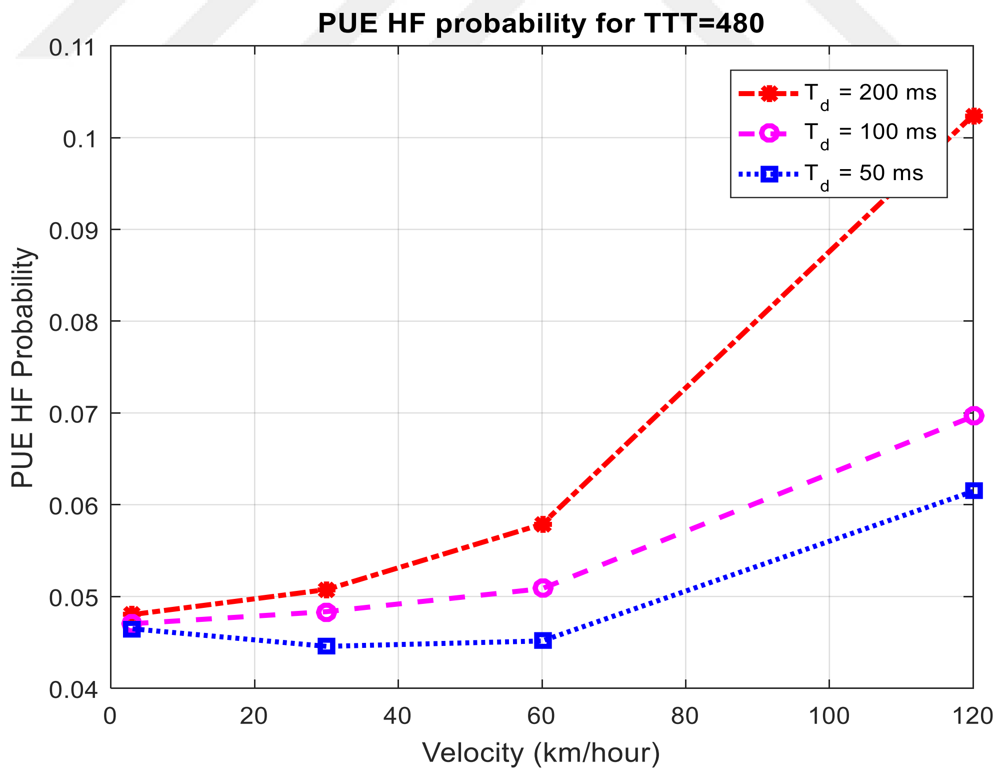

Figure 5. 8. PUE HF Probability based on velocity

6. CONCLUSION AND FUTURE WORK

6.1. Conclusion

This work has addressed the problem related to mobility management within the HetNets environment, with much attention being paid to the choice of the TTT value. The work has demonstrated through comprehensive simulations that, the distance between the small and macro cells including the UE speed, play a crucial part in determining the performance of the system. The performance in this case, has been evaluated in terms of RLF, HO, HOF probabilities.

In turn, the work has shown that high values of TTT are desirable when it comes to small inter-site distances. On the other hand, better results are provided by lower values of TTT when small cells are positioned within the edge of the macro cell. With the presented results, it is recommended for future work to explore the HO performance in multi-tier HetNets from an analytical model as well as optimization point of views.

6.2. Future Work

In the future, we plan to focus on rapidly growing HetNet architectures for 5G devices incorporating tiny cells from mmWave to massive MIMO. Whereas the implementation of small cells for 5G devices by mmWave and massive antennas promises a substantial rise in per-user performance and general system capability, Due to the distinctive propagation features of the mmWave signal and beam antennas, handover will be a significant problem. In specific, deep shadowing correlated with the propagation of mmWave signal requires a powerful LoS element for the user devices to receive the mWave signal. For this reason , massive MIMO and mmWave are anticipated on using very large antennas and enable directivity gains by supporting directional beamforming, Nevertheless, the existence of a variety of obstructions such as human barriers, antenna alignment, high building walls all will lead in handover failure and radio links failures. Consequently, handing over becomes a major issue if small cells for 5G devices are adopted by mmWave. Hence, in the future, we will investigate more heterogeneous implementations involving microwave and mmWave cells and suggest handover systems that can utilize mmWave cells ' with large information rate capacities for high-speed users while preserving user session continues.

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APPRENDIXS

APPRENDIX-A

Matlab codes

Handover Probability

```
clc,
clear,
close all
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-toTrigger + 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)%
i= 0;
D= 30;
%Distance in (m)%
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;   %Small cell radius (Source cell)%
    r= R*B;    %Macro cell radius (Target cell)%
    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,'-.r*')
axis([40 240 0 1])
hold on

%Scenario with TTT= 160%
TTT= 160;
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;
    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,':bs')
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;
    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,'--mo')
hold on

%Scenario with TTT= 480%
TTT= 480;
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;
    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,'-.oc')
hold on
%Scenario with TTT= 640%
TTT= 640;
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;
    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')
xlabel('Distance MC - SC (m)')
ylabel('HO Probability')
legend('TTT=128 ms','TTT=160 ms','TTT=256 ms','TTT=480
ms','TTT=640 ms')
grid on
```

Handover Failure Probability (HFP)

```
                   %Handover Failure Probability%

 clc,
clear,
close all
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-toTrigger + 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)%
i= 0;
D= 30;
%Distance in (m)%
```

```
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;  %Small cell radius (Source cell)%
    r= R*B;   %Macro cell radius (Target cell)%

    %Handover Failure Probability%
    if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
        thetat=acos((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R)); %the
maximum angle for which T expires before the UE gets out of the
HOF region%
        HOF=(2/pi)*thetat;
    else
        HOF=0;
    end
    valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-.r*')
axis([40 240 0 1])
hold on

%Scenario with TTT= 160%

TTT= 160;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
    if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
        thetat=acos((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R));
        HOF=(2/pi)*thetat;
    else
        HOF=0;
    end
    valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,':bs')
hold on

%Scenario with TTT= 256%

TTT= 256;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
```

```
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
    if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
        thetat=acos((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R));
        HOF=(2/pi)*thetat;
    else
        HOF=0;
    end
    valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'--mo')
hold on
%Scenario with TTT= 320%

TTT= 480;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
    if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
        thetat=acos((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R));
        HOF=(2/pi)*thetat;
    else
        HOF=0;
    end
    valueofHOF(i)= HOF;
end
plot(valueofD,valueofHOF,'-.oc')
hold on

%Scenario with TTT= 640%

TTT= 640;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
    if (((v*T)/(1+B)) <= R && R <= ((v*T)/(1-B)))
        thetat=acos((((v*T).^2)+(R.^2)-(r.^2))./(2*v*T.*R));
        HOF=(2/pi)*thetat;
    else
        HOF=0;
    end
    valueofHOF(i)= HOF;
end
```

```
plot(valueofD,valueofHOF,'-.dk')
xlabel('Distance MC - SC (m)')
ylabel('HOF Probability')
legend('TTT=128 ms','TTT=160 ms','TTT=256 ms','TTT=480
ms','TTT=640 ms')
grid on
```

Radio Link Failure Probability (RLF)

```
%%%%%% Radio Link Failure Probability %%%%%%%%

clc,
clear,
close all
v= 60;    %UE speed in (Km/h)% it is urban speed
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-toTrigger + 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)%
i= 0;
D= 30;
%Distance in (m)%
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;  %Small cell radius (Source cell)%
    r= R*B;   %Macro cell radius (Target cell)%
    d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2); %the distance
covered by the UE from the entry point to the first intersection
with the HOF circle%

    %Radio Link Failure Probability%
    if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <=
(R+r)/T)&&(v*TR)<= (2*r))
        thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R)); %the
maximum angle for which T expires before the UE gets out of the
HOF region%
        RLF=(2/pi)*thetat;
    elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <=
(2*R)/T)&&(v*TR)<= (2*r))
        thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2))); %the
maximum angle that will lead to RLF%
        RLF=(2*thetaR)/pi;
    else
        RLF=0;
    end
```

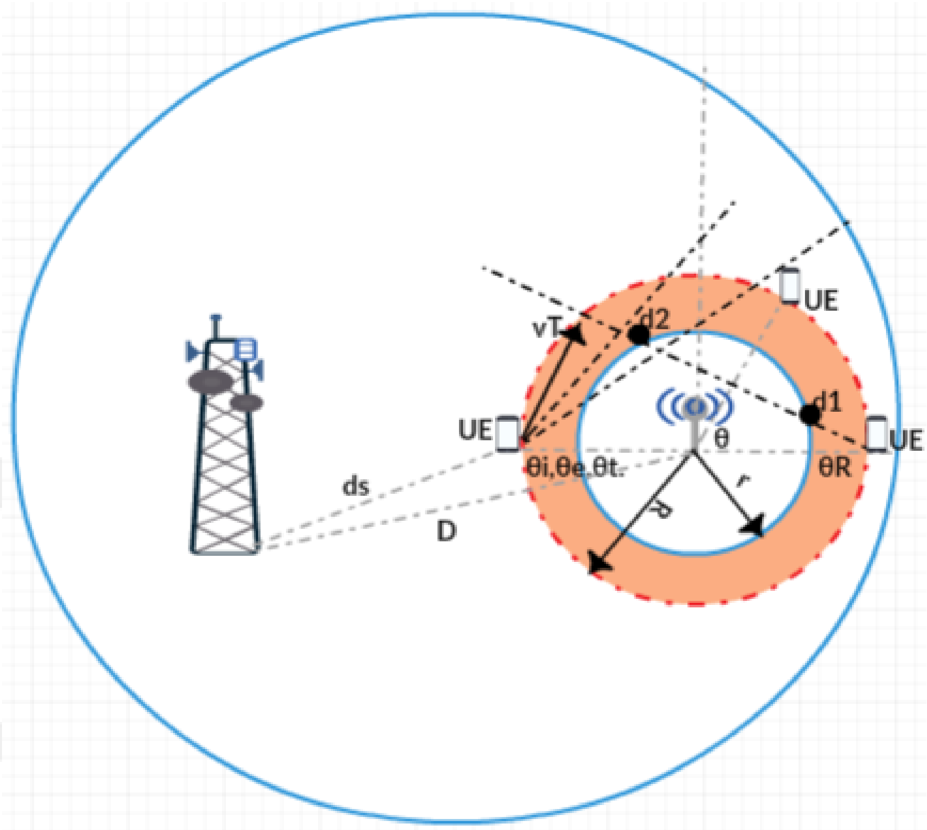
```
    valueofRLF(i)= RLF;
end
plot(valueofD,valueofRLF,'-.r*','LineWidth',2)
axis([40 240 0 1])
hold on
%Scenario with TTT= 160%
TTT= 160;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
    d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
    if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <=
(R+r)/T)&&(v*TR)<= (2*r))
        thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
        RLF=(2/pi)*thetat;
    elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <=
(2*R)/T)&&(v*TR)<= (2*r))
        thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2)));
        RLF=(2*thetaR)/pi;
    else
        RLF=0;
    end
    valueofRLF(i)= RLF;

end

plot(valueofD,valueofRLF,':bs','LineWidth',2)

hold on
%Scenario with TTT= 256%
TTT= 256;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
    d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
    if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <=
(R+r)/T)&&(v*TR)<= (2*r))
        thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
        RLF=(2/pi)*thetat;
    elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <=
(2*R)/T)&&(v*TR)<= (2*r))
        thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2)));
        RLF=(2*thetaR)/pi;
    else
```

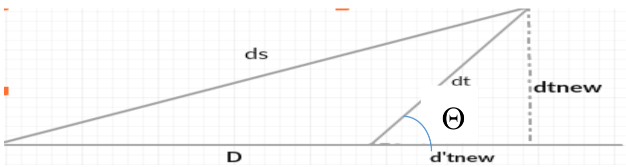
```
        RLF=0;
    end
    valueofRLF(i)= RLF;

end

plot(valueofD,valueofRLF,'--mo','LineWidth',2)
hold on

%Scenario with TTT= 480%
TTT= 480;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
    d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
    if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <=
(R+r)/T)&&(v*TR)<= (2*r))
        thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
        RLF=(2/pi)*thetat;
    elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <=
(2*R)/T)&&(v*TR)<= (2*r))
        thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2)));
        RLF=(2*thetaR)/pi;
    else
        RLF=0;
    end
    valueofRLF(i)= RLF;

end

plot(valueofD,valueofRLF,'-.or')
hold on

%Scenario with TTT= 640%
TTT= 640;
T= TTT+50;
i= 0;
D= 30;
while i<= 20
    i= i+1;
    D= D+10;
    F=@(inner)(187*D*cos(inner))/14 +
(50*D*((34969*cos(inner).^2)/10000 + 651/2500).^(1/2))/7;
    Q=integral(F,0,90);
    R= Q/pi;
    r= R*B;
    d1=sqrt((R^2)-(r^2)+((v*TR)/2)^2)-((v*TR)/2);
    if (((R-r)/T < v && v <= (d1)/T)&&((R-r)/T <= v && v <=
(R+r)/T)&&(v*TR)<= (2*r))
        thetat=acos((((v*T)^2)+(R^2)-(r^2))/(2*v*T*R));
        RLF=(2/pi)*thetat;
```

```
    elseif (((R-r)/T <= v && v <= (2*R)/TR)&&((d1)/T < v && v <=
(2*R)/T)&&(v*TR)<= (2*r))
        thetaR=asin(sqrt(((r^2)/(R^2))-(((v*TR)/(2*R))^2)));
        RLF=(2*thetaR)/pi;
    else
        RLF=0;
    end
    valueofRLF(i)= RLF;

end



plot(valueofD,valueofRLF,'-.dk')

xlabel('Distance MC - SC (m)')
ylabel('RLF Probability')
legend('TTT=128 ms','TTT=160 ms','TTT=256 ms','TTT=480
ms','TTT=640 ms')
grid on
```

APPRENDIX-B

Mathematical expression





$$\mathrm{dnew} = \mathrm{dtsin}(\Theta\mathrm{inner})$$

$$\mathrm{d'tnew} = \mathrm{dtcos}(\Theta\mathrm{inner})$$

$$\mathrm{ds}^2 = \mathrm{dnew}^2 + (\mathrm{D} + \mathrm{d'new})^2$$

$$\mathrm{ds}^2 = \left(\mathrm{dtsin}(\Theta\mathrm{inner})\right)^2 + \left(\mathrm{D} + \mathrm{dtcos}(\Theta\mathrm{inner})\right)^2$$

$$\mathrm{ds}^2 = \mathrm{dt}^2 \sin^2(\Theta\mathrm{inner}) + (\mathrm{D} + \mathrm{dtcos}(\Theta\mathrm{inner}))^2 =$$

$$\mathrm{dt}^2 \sin^2(\Theta\mathrm{inner}) + \mathrm{D}^2 + 2\mathrm{Ddtcos}(\Theta\mathrm{inner}) + \mathrm{dt}^2 \cos^2(\Theta\mathrm{inner})$$

$$= \mathrm{d}^t(\sin^2(\Theta\mathrm{inner}) + \cos^2(\Theta\mathrm{inner})) + \mathrm{D}^2 + 2\mathrm{Ddtcos}(\Theta\mathrm{inner}) =$$

$$\mathrm{dt}^2 + \mathrm{D}^2 + 2\mathrm{Ddtcos}(\Theta\mathrm{inner})$$

$$ds = \sqrt{dt^2 + D^2 + 2Ddtcos(\Theta inner)}$$

$$\cos(\theta_i) = \frac{vT}{2R} \rightarrow \theta_i = \arccos\left(\frac{vT}{2R}\right)$$

$$\text{dnew} = vT\sin(\theta_t)$$

$$d'\text{tnew} = vT\cos(\theta_t) - R$$

$$r^2 = \text{dnew}^2 + (d'\text{new} - R)^2 = (vT\sin(\theta_t))^2 + (vT\cos(\theta_t) - R)^2$$

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

$$r^2 = vT^2\sin^2(\theta_t) + vT^2\cos^2(\theta_t) + R^2 - 2vTR\cos(\theta_t)$$

$$r^2 = vT^2 + R^2 - 2vTR\cos(\theta_t)$$

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

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

$$2r = \sqrt{(vT_R)^2 + (2R\sin(\theta_R))^2}$$

$$4r^2 = (vT_R)^2 + (2R\sin(\theta_R))^2$$

$$r^2 - (vT_R)^2 = 4R^2\sin^2(\theta_R) \rightarrow \sin^2(\theta_R) = \frac{4r^2 - (vT_R)^2}{4R^2} \rightarrow \frac{r^2}{R^2} - \frac{(vT_R)^2}{4R^2}$$

$$\sin(\theta_R) = \sqrt{\frac{r^2}{R^2} - \frac{(vT_R)^2}{4R^2}} \rightarrow \boxed{\theta_R = \arcsin\left(\sqrt{\frac{r^2}{R^2} - \left(\frac{vT_R}{2R}\right)^2}\right)}$$

APPRENDIX-C

Algorithms

Algorithm.1. the procedure of RLF detection

```
HO from the source cell to the target cell ,
    UE's timer start.
if  RLF detected then
  get the UE's identification(ID) which
experience      RLF and its connected    cell ID.
Stop the UE's time.
   if UE's connectedCell= last visistedCell
     then too early HO
     end if
else if UE's Timer less threshold timer
     then wrong HO
else
 too late HO
else if HO from the target cell to a new Cell
stop the UE's timer
if UE's timer less threshold timer then
  if targetCell= last vistedCell then Pinpong HO
   else continuous HO
     end if
   end if
end if
```

ALGORITHM for MUE HF

****

Check the circle whether in the blue circle or not

If $the\ distance\ d_{MUE\ HF} \leq r_m$

$distance\ refers\ to\ total\ distance\ travelled\ by\ the\ MUE$

$from\ ideal\ pico\ coverage\ to\ the\ MUE\ HF\ circle$

$then\ MUE\ will\ occurs\ (\ MUE\ HF = 1\ )$

else

$MUE\ HF\ is\ not\ in\ the\ blue\ circel\ and\ chcek\ the\ interestion\ on\ the\ circle$

if *there is an intersect on the blue circle*

then MUE HF will take place (MUE HF =1)

else

MUE HF is false MUE HF =0

if the distance $d_{MUE\ HF\ Td}$ > R and No MUE HF is zero

then No HF is true (system has no HF) and HO is zero (no Handover)

elseif the distance $d_{MUE\ HF\ Td} \leq$ R and MUE HF is zero

then No HF is will be obtained and HO will take place successfully

else

HO is unsuccessful

End

ALGORITHM for PUE HF

If the distance $d_{PUE\ HF\ Td}$ < R and HO is successful

then calculate UE distance

define distance with respect the UE angle

define X and Y co ordinate for pico bound

then find new position for UE

keep updating the UE position until the Maximum position of UE

then calculate the distance $d_{PUE\ HF\ Td}$

else

check ping pong distance

define pp check using MUE at max location and PUE at max location

calculate distance ping pong

d_{pp} is the distance from MUE at max to PUE at max location

if $d_{PUE\ HF\ Td} \geq r_p$

PUE HF will occurs

elseif

$d_{PUE\ HF\ Td} < r_p$

PUE HF is will not occurs

end

checking ping pong

if d_{pp} check $\leq VT_{pp}$ and PUE HF is doesn't happen

then ping pong will occur

else

pp will not happen

end

else

PUE HF dosent take place (PUE HF = 0)

PP will not happen (pp = 0) end

PERSONAL PUBLICATIONS AND ACHIEVEMNTS

Adam Y. A. , Sultan A. Ç. , Effect of distance and time triggering of macrosmall cells on handover performance in lte-a heterogenous networks, *International Marmara Science and Social Sciences Congress* (IMASCON), Kocaeli, 26-28 April, 2019.

AUTOBIOGRAPGHY

He was born in 1988 in N'djanmena (Chad), and had completed primary and secondary school in bilingual school of Mousouro (Chad), after that moved to the capital city N'djamena to complete his High school in King Faycal high school . He startedhis high education in 2009, after completing undergraduate degree of Electrical and Computer Engineering in 2014 at International Islamic University Malaysia, and then moved to Turkey to learn Turkish Language in 2015, then started his master at graduate school of natural and applied sciences of kocaeli university department of Electronics and Communication Engineering.