MOBILITY MANAGEMENT FOR HETEROGENEOUS LONG TERM EVOLUTION MOBILE NETWORKS BASED ON DRIVE TEST MEASUREMENT

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DEDICATION

This thesis is dedicated to my beloved mother, father, family, teachers, and friends for their endless love and support. This thesis is also dedicated to my beloved daughters.

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ABSTRACT

Mobility for high-speed users has been a significant challenge for all mobile networks such as long-term evolution (LTE). Heterogeneous Network (HetNet) comprises numerous cells of varying sizes, various carrier frequency band and cell coverage. These differences make mobility difficult as its procedure time will increase due to a different level of required measurements. User equipment (UE) with a high speed of up to 140 km/h causes a high risk of disconnection to the handover (HO) procedure timing which is longer than UE with realistic speed. Several field measurements were conducted using the drive test (DT) tool to obtain real measurements of the LTE network deployed with different cell sizes and different operating frequency bands across highways. During the field measurements, there are frequent HOs and HO failures occurred, especially when UE with increasing speed up to 140 km/h in different HO environments in terms of peak hours or, site locations and LTE cell configuration. The handover preparation stage is affected by the UE speed increase. Moreover, the analyzed results show that HO preparation time increases as UE speed increases and HO execution time is slightly faster than the HO preparation time. The overall HO time was found to be less than 1 s for high-speed UE, indicating that the network environment influences the HO timing as compared to other studies conducted in a similar research area. In this thesis, UE speed is added as one of the main criteria to determine whether the network has to proceed HO with a routine UE HO or enforce UE to perform HO due to high speed which combined with regular HO parameters. Therefore, the matrix is defined with UE speed and reference signal received power (RSRP) as main conditions for the forcing handover knowing that RSRP is mainly used by mobile network operators (MNO). The algorithm calculates the HO waiting time once the speed and RSRP exceed the defined thresholds. The overall HO procedure is improved by 11% by using the forcing HO algorithm.

ABSTRAK

Kebolehgerakan untuk pengguna berkelajuan tinggi telah menjadi cabaran bererti untuk semua rangkaian mudah alih seperti evolusi jangka panjang (LTE). Rangkaian Heterogen (HetNet) terdiri daripada banyak sel dengan saiz yang berbeza-beza, pelbagai jalur frekuensi pembawa dan liputan sel. Perbezaan ini menyukarkan kebolehgerakan kerana masa prosedur mobiliti akan meningkat disebabkan oleh perbezaan tahap pengukuran yang diperlukan. Peralatan pengguna (UE) dengan kelajuan tinggi sehingga 140 km/j menyebabkan risiko tinggi terputus sambungan kepada pemasaan tatacara penyerahan (HO) yang lebih lama berbanding UE dengan kelajuan realistik. Beberapa pengukuran di tapak telah dijalankan menggunakan alat ujian pemacu (DT) untuk mendapatkan pengukuran sebenar rangkaian LTE yang diatur menggunakan saiz sel dan jalur frekuensi operasi yang berbeza merentasi lebuh raya. Semasa pengukuran medan, terdapat HO yang kerap dan kegagalan HO berlaku, terutamanya apabila kelajuan peralatan pengguna (UE) adalah sehingga 140 km/j dalam persekitaran HO yang berbeza dari segi waktu puncak atau, lokasi tapak dan konfigurasi sel LTE. Peringkat penyediaan HO dipengaruhi peningkatan kelajuan UE. Selain itu, keputusan yang dianalisis menunjukkan bahawa masa penyediaan HO meningkat apabila kelajuan UE meningkat dan masa pelaksanaan HO adalah lebih cepat sedikit daripada masa penyediaan HO. Masa HO keseluruhan didapati kurang daripada 1 saat untuk UE berkelajuan tinggi, menunjukkan bahawa persekitaran rangkaian mempengaruhi masa HO berbanding dengan kajian lain dalam bidang penyelidikan yang serupa. Dalam tesis ini, kelajuan UE ditambah sebagai salah satu kriteria utama untuk menentukan sama ada rangkaian perlu meneruskan HO dengan UE rutin atau menguatkuasakan UE untuk melakukan HO kerana kelajuan tinggi yang digabungkan dengan parameter HO biasa. Oleh itu, matriks ditakrifkan dengan kelajuan UE dan kuasa isyarat rujukan yang diterima (RSRP) sebagai syarat utama untuk HO memaksa dengan mengetahui bahawa RSRP digunakan terutamanya oleh Operator Rangkaian Mudah Alih (MNO). Algoritma mengira masa menunggu HO sebaik sahaja kelajuan dan RSRP melebihi ambang yang ditetapkan. Tatacara HO keseluruhan dipertingkatkan sebanyak 11% dengan menggunakan algoritma HO memaksa.

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LIST OF ABBREVIATIONS

1G	-	First Generation
2G	-	Second Generation
3GPP	-	Third Group Partnership Project
4G	-	Fourth Generation
5G	-	Fifth Generation
BCCH	-	Broadcast Control Channel
BCH	-	Broadcast Channel
BER	-	Bit Error Ratio
BTS	-	Base Transceiver Station
CA	-	Carrier Aggregation
CCCH	-	Common Control Channel
CDMA	-	Code Division Multiple Access
CIR	-	Carrier to Interference Ratio
CN	-	Core Network
CS	-	Circuit Switch
CSG	-	Closed Subscriber Groups
DCCH	-	Dedicated Control Channel
DLSCH	-	Downlink Shared Channel
DT	-	Drive Test
DTCH	-	Dedicated Traffic Channel
eNB	-	Evolved Node B
EPS	-	Evolved Packet Core
E-UTRAN	-	Evolved Universal Terrestrial Radio Access
FDD	-	Frequency Division Duplexing
GPRS	-	General Packet Radio Service
GSM	-	Global System for Mobile
HARQ	-	Hybrid Automatic Repeat Request
HeNB	-	Home Evolved Node B
HetNet	-	Heterogeneous Network
HHO	-	Horizontal Handover

HO	-	Handover
HOM	-	Handover Margin
HSPA	-	High-Speed Packet Access
HSS	-	Home Subscriber Server
IMT	-	International Mobile Telecommunication
ITU	-	International Telecommunication Union
LTE	-	Long Term Evolution
MAC	-	Medium Access Control
MCCH	-	Multicast Control Channel
MCH	-	Multicast Channel
MIB	-	Master Information Block
MIMO	-	Multi-Input Multi-Output
MM	-	Mobility Management
MME	-	Mobility Management Entity
MNO	-	Mobile Network Operator
MS	-	Mobile Station
MTCH	-	Multicast Traffic Channel
NAS	-	Non-Access Stratum
NSR	-	Noise Signal Ratio
OFDM	-	Orthogonal Frequency Division Multiplexing
PBCH	-	Physical Broadcast Channel
PCCH	-	Paging Control Channel
PCFICH	-	Physical Control Format Indicator Channel
PCH	-	Paging Channel
PCRF	-	Policy and Charging Rule Function
PDA	-	Personal Digital Assistant
PDCCH	-	Physical Downlink Control Channel
PDCP	-	Packet Data Convergence Protocol
PDSCH	-	Physical Downlink Shared Channel
PHICH	-	Physical Hybrid-ARQ Indicator Channel
PHY	-	Physical Layer
PLMN	-	Public Land Mobile Network
PMCH	-	Physical Multicast Channel

PRACH	-	Physical Random-Access Channel
PUCCH	-	Physical Uplink Control Channel
PUSCH	-	Physical Uplink Shared Channel
QoS	-	Quality of Service
RACH	-	Random Access Channel
RAN	-	Radio Access Network
RAT	-	Radio Access Technology
RAT	-	Radio Access Technology
RF	-	Radio Frequency
RF	-	Radio Frequency
RIP	-	Received Interference Power
RLC	-	Radio Link Control
RN	-	Relay Node
RRC	-	Radio Resource Control
RRC	-	Radio Resource Control
RSRP	-	Reference Signal Received Power
RSRQ	-	Reference Signal Received Quality
RSS	-	Received Signal Strength
RSSI	-	Received Signal Strength Indicator
SCH	-	Synchronization Channel
S-GW	-	Serving Gateway
SIB	-	System Information Block
SINR	-	Signal to Interference and Noise Ratio
SIR	-	Signal to Interference Ratio
TA	-	Tracking Area
TDD	-	Time Division Duplexing
TTI	-	Transmission Time Interval
TTT	-	Time to Trigger
UE	-	User Equipment
UL-SCH	-	Uplink Shared Channel
UMTS	-	Universal Mobile Telecommunications Service
VHO	-	Vertical Handover

LIST OF SYMBOLS

W	-	Watt
mW	-	Milliwatt
TTT	-	Time to trigger
HOM	-	Handover margin
m	-	Meter
dBm	-	Decibel-meter
TA	-	Tracking Area
Ms	-	Milliseconds
RSRP	-	Reference Signal Received Power
RSSI	-	Received Signal Strength Indicator
RSRQ	-	Reference Signal Received Quality
fd(t)	-	Doppler frequency
v	-	Velocity of user
fc	-	Carrier frequency
$cos\theta$	-	Cosine the angle between UE and cell
C	-	Speed of light
N	-	Number of resource blocks in LTE
ptx	-	Transmitted power of cell in LTE
Pl	-	Pathloss
RSRPt	-	Target cell Reference Signal Received Power
RSRPs	-	Serving cell Reference Signal Received Power
λ	-	Lambda
SINR	-	Signal to Interference and Noise Ratio
MM	-	Mobility Management

CHAPTER 1

INTRODUCTION

1.1 Background

Wireless communication has become one of the necessities of life for everyone around the world, and it is the most fundamental aim that differentiates data speed between cellular generations. Mobile users (MS) and apps are making life hard for Mobile Network Operators (MNOs) to provide seamless communication. Mobile operators must improve seamless connectivity, and mobility will be a major issue in the future. In a mobile telecom network, the location of user equipment (UEs) changes based on user activity. This UE mobility should be controlled by the cellular network so that incoming calls can be delivered to the UEs. The movement of users triggers a UE to handover (HO), also known as mobility management, from one place to another. Figure 1.1 illustrates a simple cell-to-cell handover.

Figure 1. 1 UE Handover Between Two Cells

LTE handover should take place regardless of network access technology. The operators may need to seamlessly combine several techniques to deliver unlimited content to customers in a global environment where Fourth-Generation (4G) or Long-Term Evolution (LTE) networks and beyond are spreading. The combination of different wireless network technology is needed to deliver "seamless" interoperability, integration, and convergence between these heterogeneous systems; therefore, the use of vertical handover (VHO) techniques are required (Kashmar et al., 2016). Handover, also known as handoff, is when a cell phone moves from one wireless cell to another, disconnects from a current cell and connects to a new cell. Handover can be classified into different categories; if the handover is between the same wireless access technology, it is called horizontal handover (HHO). The handover is referred to as vertical handover distinct wireless access techniques. Figure 1.2 shows the types of handovers, whereas Figure 1.3 illustrates the handover management idea. According to 3GPP, the LTE system must support mobility for low mobile speed from 0 to 15 km/h and higher mobile speed between 15 and 120 km/h.

Moreover, mobility across the cellular network will be maintained at speeds from 120 to 350 km/h (or even up to 500 km/h, depending on the frequency band). However, the impact will be on handovers, and the quality (i.e., interruption time) shall be less than or equal to that provided in circuit switch (CS) domain handovers (3GPP/ETSI, 2010). To achieve this goal, LTE must mitigate delay and packet loss in voice transmission and ensure high-speed data delivery reliability.

Heterogeneous (HetNet) wireless networks can also introduce various GSM, GPRS, HSPA, UMTS, and even LTE radio access technology that turns into the new wireless 4G standard. The central promise of interconnecting these heterogeneous networks is to improve performance through high data rates and reliable Quality of Service (QoS) support for video telephony, streaming, and multi-casting (Malathy & Muthuswamy, 2018). It is also identified as a network consisting of a combination of macrocells and low-power nodes, some of which may be configured with limited access, and others without wired backhaul.

Heterogeneous (HetNet) networks are installed with a mixture of classical (high-power) pico, femto, and relay nodes. This sort of network, which may have a combination of open and closed subscriber access, is distinguished by significant differences in the transmit power used by distinct types of network nodes. In particular, such power disparities place the low-power nodes (pico, femto, and relay) at a disadvantage over the high-power nodes (macrocells). Chapter 2 shows more details about HetNet, which requires higher frequencies per cell radius size and frequency.

Therefore, mmWaves have been recently added to International Mobile Telecommunications (IMT) and defined to be above 6 GHz due to the high demand for high bandwidth (up to 1 GHz) and high data rates, especially in dense urban environments. High frequencies above 6 GHz are required to be used as IMT (WP5D, 2015).

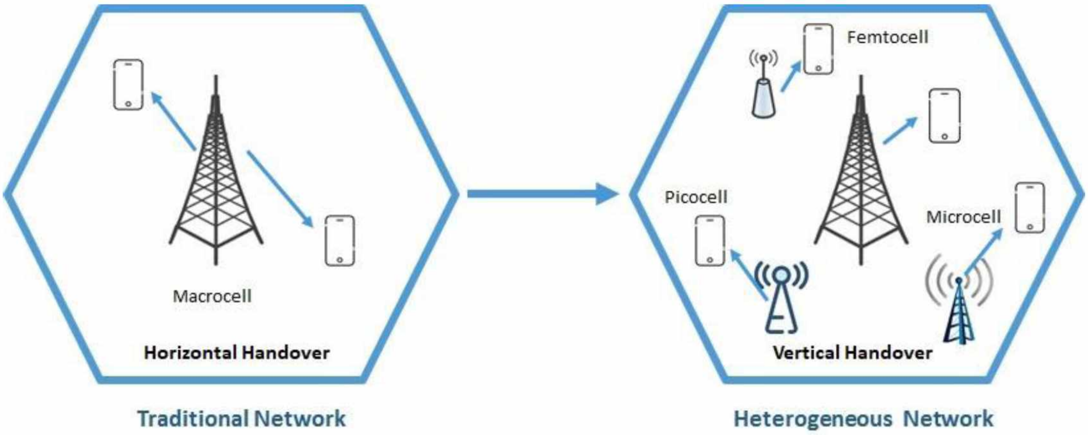

Figure 1. 2 Horizontal and Vertical Handovers

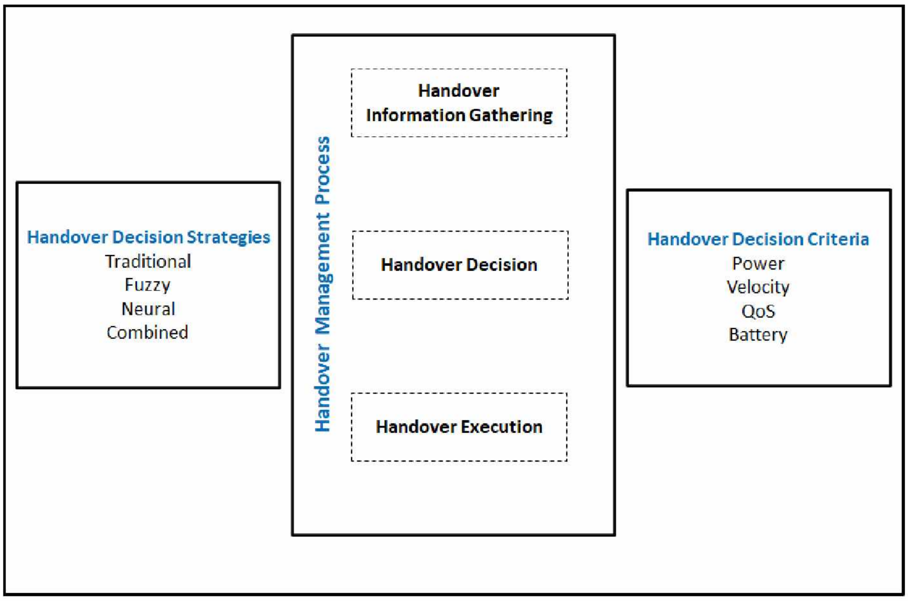

Figure 1. 3 Handover Management Concept

Mobile operators are constantly striving to maximize the use of their awarded spectrum licenses while also providing excellent customer satisfaction. This can be achieved by expanding the use of frequency licenses to cover the entire country with high-quality service. Therefore, cellular technologies are deployed across several frequency bands. For example, the 700 MHz, 800 MHz, 1800 MHz, 2100 MHz, 2300 MHz, and 2600 MHz frequency bands are used to deploy the LTE sites, while the 800 MHz, 900 MHz, and 1800 MHz bands are used to deploy 2G and 3G technologies. The reframing frequency bands occur after the shutdown of the legacy cellular technologies.

The cellular network consists of both new and legacy technologies; when new technology standards are released and commercially launched by telecom operators, not all cellular networks and legacy technology will be replaced by the new one. The use of various technologies in a cellular system means differences such as the spectrum of each technology; thus, different sizes of cells are considered within the same operators. Besides, the mobility management technique used by different cellular technology may differ. Therefore, Heterogeneous Networks (HetNet), which may consist of 3G, LTE-4G, and the recently released generation (5G), are being introduced to meet customer demands of high coverage, reliable network, seamless connectivity, and high-quality services. Heterogeneous networks are very congested with user equipment (UEs) and Personal Digital Assistant (PDAs), making them extremely complicated. Therefore, more challenges are being addressed to achieve customer satisfaction when using the mobile network. Mobility and spectrum limitation is the most challenging topic for the HetNet and upcoming mobile generation. All mobile operators around the world are competing for enough spectrum to serve their customers and enterprise customers with several services across multiple technologies. Moreover, many regulatory bodies worldwide have already started to allocate spectrum via auction, which can cost billions of dollars Thus, Mobile Network Operators (MNOs) must make proper use of the allocated spectrum properly.

1.2 Problem Statement

Successful mobility, also known as handover (HO), is considered a major challenge when UE moves vertically between different technologies or within the same technology but different deployment scenarios in HetNet. Mobility in HetNet is also considered a crucial key that directly affects mobile network quality of service in the excellent handover, leading to less than 2% call drops and nearly 100% seamless connectivity. In contrast, poor handover technique causes poor QoS and an awful customer experience. Moreover, handover delay is one of the HetNet mobility challenges for cells with varying radius sizes. Highway mobility is considered as a most annoying issue for MNOs as the UE can reach speeds of up to 120-140 km/h, which is the fastest speed limit in most countries worldwide (B. Katz, J. Ma, H. Rigdon, K. Sykes, Z. Huang, and K. Raboy, 2017; Katz et al., 2017). Furthermore, the highway speed limit in Saudi Arabia where the field measurement of handover is 140 km/h; therefore, this thesis's velocity is considered the maximum speed limit. The user velocity should be considered as the highway speed limit is changeable according to the government authorities' evaluations and decisions; hence, the speed limit was changed in some roads recently from 120 to 140 km/h. In such cases, mobile operators must consider the UE speed during HO preparation because speed should be measured, and they must manage the HO procedure overall to avoid call drop. Besides, the inter-site distance between two adjacent cells on the highway should be included in the measurement alongside speed; therefore, handover delay due to additional required measurements is another challenge for high-speed mobility.

The reduction of cell size and increase of user speed increase the handover problems such as increased handover failure, frequent handover, handover delays, ping pong rate, and bad user experience for high-speed users (Tayyab et al., 2019). There is a clear interference problem between neighboring mobile cellular sites, limiting network performance due to a mixture of small cells (Chopra et al., 2017). Simultaneously, the failure of handover, which can be defined as multiple unnecessary handovers for the same UE within a dense area of cells with high speed (Hasan et al., 2018). Sivanesan et al. (2015) stated that the rate of frequent handover failure increased when the UE speed is 120 km/h across small cells. Furthermore, increasing user velocity across small-scale cells will lead to a high rate of call drop assuming that UE speed is up to 350 km/h and cellular cell size is less than 1 km, then Hanover must be performed every 10 seconds or less (Gupta & Singh, 2019). Furthermore, the work in (Gimenez et al., 2016) that was selected as a benchmark, is very similar to this research in terms of measurement and the handover timing and delay were the most challenging during the mobility management performance. Therefore, handover must be performed within a very limited time regardless of the heavy load of signaling on both serving and target cells during the preparation and execution of multiple handovers to ensure seamless connectivity on high-speed users. The problems in this thesis are summarized as follows:

i. Handover performance is considered as a challenge for other related researches, including the selected benchmark, due to several factors, such as speed limit, in each research and the nature of the deployed LTE network; thus, the handover performance may differ depending on the measurement's scenario and actual UE speed.

ii. The handover timing is directly affected due to the high-speed user because the handover preparation time takes longer than the time during the standard handover measurement, resulting in a longer HO preparation time at high speeds of up to 140 km/h across HetNet LTE.

iii. Handover failure is likely when UE speed is up to 140 km/h across HetNet LTE due to the possibility that the high-speed user leaves the target cell before the handover procedure is completed.

Handover delay may occur when UE moves at a high speed of 140 km/h between two adjacent LTE cells vertically. The HO preparation time, including HO measurement, will be longer than in typical HO situations and overall HO time. Therefore, the high-speed UE may cross the HO area between the cells before the serving cell receives the required measurement report to decide whether to proceed with the HO procedure or drop the call.

1.3 Objective

This thesis's main aim is to improve mobility management performance in terms of reducing frequent handover, which is a root cause of call drop, by designing a seamless mobility handover algorithm that can be used in highways HetNet. The thesis is completely aligned with the real mobility handover scenario in mobile operators, given that these operators each have over 20 million users; therefore, the mobility challenge is very high. The specific objective of this thesis:

i. Use drive test measurements to identify the most critical problems such as handover failures, handover delay and call drops in handover performance for a Mobile Network Operator (MNO) when UE speed is up to 140 km/h.

ii. To propose a forcing handover algorithm based on real-time measurement of driving UE speed and Reference Signal Received Power (RSRP) during the handover preparation phase.

iii. Analyze and evaluate the handover preparation time and the handover waiting time, which is required to trigger a successful handover, during HetNet LTE by using the real measurement data.

1.4 Scope of the Research

i. The research is centered around the high-speed mobility management in HetNet, where both macro cells and small cells are deployed in LTE networks with different frequency bands based on the real setup applied in Mobile Network Operator in the Middle East, where the allowed speed is between 80 and 90 km/h on city roads and from 120 to 140 km/h on highways.

ii. This research is limited by using real measurement data and data provided by the mobile operator as the main source for evaluating the forcing handover algorithm, which is used for high-speed users. Moreover, the actual UE speed is measured in this research, rather than estimated.

iii. Drive test measurements were performed using UE speed, ACTIX, and TEMS software, which are widely used by mobile operators and vendors globally to evaluate the network performance, including handover performance.

iv. The drive test measurements were conducted twice with more than 5 hours interval between activities due to the difficulty of allocating the required mobile network resources such as optimization engineers and drive test tools.

v. The driving speed was difficult to maintain on a constant value due to several factors such as different speed limits from one road to another, traffic conditions, traffic lights, and possible safety concerns for other high-speed users. Therefore, the drive test is measured at various speeds.

vi. The selected observation areas for this research are limited by several factors such as the number of deployed HetNet LTE sites, and the speed limit of each area. In addition, the adjacent cells along the highways are considered, but all remaining cells outside the direction of the highway are not considered.

vii. The handover performance is measured using real data of the conducted measurements and no analytical modeling is considered to evaluate the HO performance.

Figure 1.4 illustrates the scope of this research.

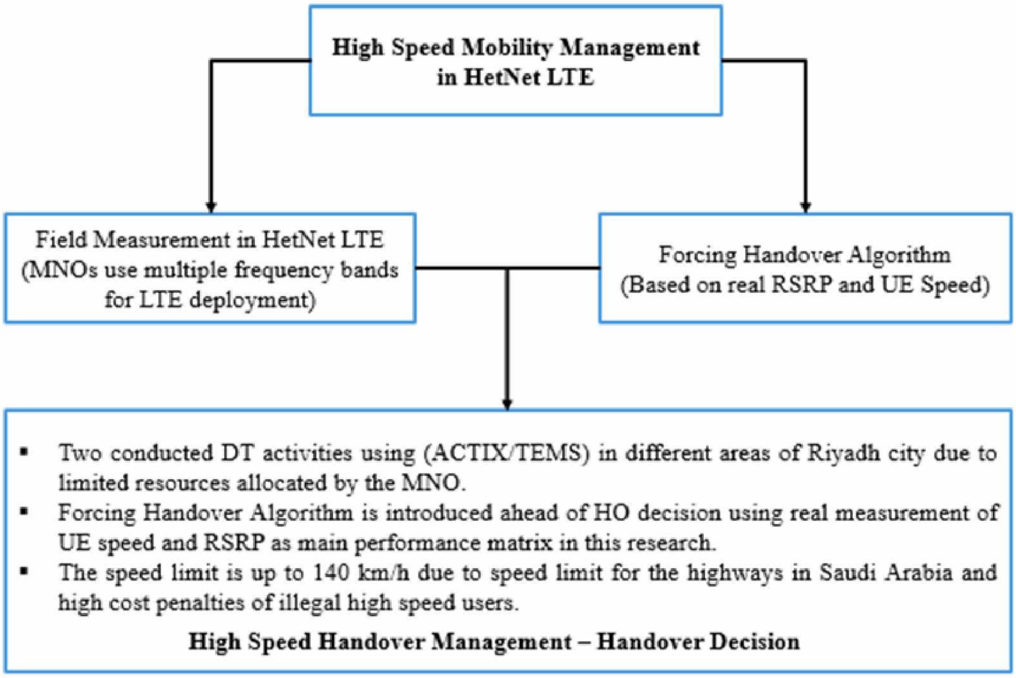

Figure 1. 4 Scope of This Research

1.5 Significance of the Study

The significance of this thesis is represented by a comprehensive and practical solution that addresses recent trends toward advanced cellular networks in real mobile operators, which consists of different cell sizes operating with varying frequency bands, duplexing techniques, and changed output power. Currently, UE speed is not considered part of the handover procedure in the mobile operators' handover algorithm that is now implemented, which uses the received power strength and signal quality as the main criteria for a handover decision. Furthermore, Huawei claims that the eNB estimates the moving speed by evaluating historical cell information in the last dedicated duration; if the handover time is greater than specific network configured parameters, the eNB will consider the UE a fast-moving UE. Therefore, dedicated eNBs with dedicated frequency bands for high-speed users are recommended, as well as dividing the highway base station from the public network; however, the network deployment costs are very high. The thesis offers an improvement to the vertical handover performance for high-speed vehicles traveling at speeds of up to 140 km/h by reducing the handover timing and the call drops based on real case scenarios implemented in mobile network operators. In the thesis, UE speed is considered during the handover procedure to either proceed for a normal handover process or enforce the handover by using a forcing handover algorithm due to the user exceeding the speed limit. Moreover, the HO area between the two cells is evaluated across the highways by increasing the macro cell size and coverage using adaptive techniques.

1.6 Thesis Organization

The thesis is organized as follows:

The chapter 2 contains a literature review on the overall LTE network architecture and handover types in the network. Besides, handover and mobility management are detailed along with both vertical and horizontal handovers. Chapter 2 also explains the concept of heterogeneous networks, such as normal cells and small cells. Related work and UE speed mobility management algorithms are also presented in this chapter.

Chapter 3 presents an overview of the research methodology applied in this work. The chapter starts by introducing the proposed design and algorithm and then followed the scope of the work. The research flow chart illustrates the handover scenarios. The chapter also presents mathematical equations that are used in the proposed handover algorithm. Finally, mobile operator configuration is presented in this chapter.

Chapter 4 introduces the research findings and discussion. The conducted drive test measurements are illustrated by showing how and where the drive tests were performed, and the tools used to measure the handover parameters such as signal strength and signal quality of LTE network and analyze the log files. The results are demonstrated and analyzed to show the measurement areas and recorded mobile parameters, such as the signal strength, coordinates, and time. The chapter also highlights the handover procedures and issues, such as frequent handovers, ping pong, and call drops.

Finally, Chapter 5 concludes the problems and objectives of this thesis. The efforts of the applied algorithm are explained along with the limitations faced during this thesis. The chapter also proposes recommendations and future work.

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