# Analysis of Handover Decision Making in Downlink Long Term Evolution Networks

By

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Submitted in fulfillment of the requirements of the Master of Technology degree in Information Technology

In the

Department of Information Technology in the Faculty of Accounting and Informatics

Durban University of Technology

Durban, South Africa

July, 2014

# DECLARATION

I, Israel O. Elujide, declare that this dissertation represents my own work and has not been previously submitted in any form for another degree at any university or institution of higher learning. All information cited from published and unpublished works have been acknowledged.

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# DEDICATION

To

My mum
(Mrs. R. Olaitan Elujide)

# ACKNOWLEDGMENTS

I am grateful to God and His Son, the source of wisdom and my inspirations, for successful completion of this work.

I would like to extend my gratitude to my supervisor, Prof. Olu Olugbara, for being always supportive and cooperative. I also appreciate my co-supervisors Dr Pius Owolawi and Prof T. Nepal for their encouragement and invaluable guidance throughout the dissertation.

I am grateful to my family for their love, support and encouragement throughout my study. I owe them everything and wish I could show them how much I love and appreciate them.

I am thankful to all my friends and colleagues for their support and advice during this work, especially Gbolahan Aiyetoro, Olutosin Oduwole, Stephen Fashoto, Olateju Mogbonjubola, Momed Neves and Stanley Oyewole.

Finally, my sincere gratitude goes to my heartthrob, Oluwabukola Rotimi, whose love and encouragement allow me to press forward. She certainly deserves more than I can possibly offer so I would like to give her a heartfelt "thanks."

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| | |
|---|---|
| 1G | First Generation |
| 2G | Second Generation |
| 3G | Third Generation |
| 4G | Fourth Generation |
| 3GPP | Third Generation Partnership Project |
| aGW | Access Gateway |
| AMPS | Advanced Mobile Phone System |
| ARQ | Automatic Repeat Request |
| CDF | Cumulative Distribution Function |
| CDMA | Code Division Multiple Access |
| CN | Core Network |
| CoMP | Coordinated Multipoint transmission or reception |
| CQI | Channel Quality Indicator |
| DAB | Digital Audio Broadcasting |
| DECT | Digital Enhanced Cordless Telecommunications |
| DFT | Discrete Fourier Transform |
| DL | Downlink |
| DVB | Digital Video Broadcast |
| E-UTRAN | Enhanced – UMTS Terrestrial Radio Access Network |
| eNodeB | Enhanced Node B |
| EPC | Evolved Packet Core |
| ETSI | European Telecommunications Standard Institute |
| FDD | Frequency Division Duplex |
| FDMA | Frequency Division Multiple Access |
| FPLMTS | Future Public Land Mobile Telecommunication Systems |
| GERAN | GSM EDGE Radio Access Network |
| GGSN | Gateway GPRS Support Node |
| GPRS | General Packet Radio System |
| GSM | Global System for Mobile Communication |
| GTP | GPRS Tunnelling Protocol |

| | |
|---|---|
| HSDPA | High Speed Downlink Packet Access |
| HSPA | High Speed Packet Access |
| HSUPA | High Speed Uplink Packet Access |
| HSS | Home Subscriber Server |
| IIR | Infinite Impulse Response |
| IP | Internet Protocol |
| IMS | IP Multimedia Subsystem |
| IMT | International Mobile Telecommunications |
| IS | Interim Standard |
| ITU | International Telecommunication Union |
| ITU-R | ITU Radiocommunication sector |
| L 1 | Layer 1 |
| L 3 | Layer 3 |
| LIPA | Local IP Access |
| LTE | Long Term Evolution |
| MAC | Medium Access Control |
| MATLAB | Matrix Laboratory |
| MBMS | Multimedia Broadcast Multicast Service |
| Mbps | Megabits per second |
| MCS | Modulation Coding Scheme |
| MDT | Minimization of Drive Tests |
| MME | Mobility Management Entity |
| MHz | Megahertz |
| NAS | Non Access Stratum |
| NMT | Nordic Mobile Telephone |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| OSI | Open Systems Interconnection |
| PAPR | Peak-to-Average Power Ratio |
| PCRF | Policy and Charging Rules Function |
| PDCP | Packet Data Convergence Protocol |
| PDN | Packet Data Network |

| | |
|---|---|
| P-GW | PDN GateWay |
| PHY | Physical Layer |
| PRB | Physical Resource Block |
| PS | Packet Switched |
| QoS | Quality of Service |
| RAN | Radio Access Network |
| RB | Resource Block |
| RLC | Radio Link Control |
| RNC | Radio Network Controller |
| RRC | Radio Resource Control |
| RRM | Radio Resource Management |
| SAE | System Architecture Evolution |
| SC-FDMA | Single Carrier-Frequency Division Multiple Access |
| SCTP | Stream Control Transmission Protocol |
| SGSN | Serving GPRS Support Node |
| SON | Self-Optimizing Networks |
| TACS | Total Access Communication System |
| TDD | Time Division Duplex |
| TDMA | Time Division Multiple Access |
| TTI | Transmission Time Interval |
| UDP | User Datagram Protocol |
| UE | User Equipment |
| UL | Uplink |
| UMTS | Universal Mobile Telecommunication System |
| UPE | User Plane Entity |
| USIM | Universal Subscriber Identity Module |
| UTRAN | UMTS Terrestrial Radio Access Network |
| U-plane | User Plane |
| WCDMA | Wideband Code Division Multiple Access |
| WiFi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |

# PUBLICATIONS FROM THE DISSERTATION

Elujide, I. O., Olugbara, O. O., Owolawi, P. A. and Nepal, T. 2013. Effect of Layer 3 Filtering on Local Averaging Handover Technique in Long Term Evolution Networks. In: Proceeding of *Southern Africa Telecommunication Networks and Application Conference (SATNAC) 2013*. 1-4 Sep. 2013. 79-83.

Elujide, I. O., Olugbara, O. O., Owolawi, P. A. and Nepal, T. 2013. Performance of Local Averaging Handover Technique in Long Term Evolution Networks. Submitted for journal publication.

# ABSTRACT

This dissertation reports on handover in downlink Long Term Evolution (LTE) networks. The LTE is seen as the technology that will bring about Fourth Generation (4G) mobile broadband experience. The necessity to maintain quality of service for delay sensitive data services and applications used by mobile users makes mobility and handover between base stations in the downlink LTE very critical. Unfortunately, several handover schemes in LTE are based on Reference Symbols Received Power (RSRP) which include measurement error due to limited symbols in downlink packets. However, prompt and precise handover decision cannot be based on inaccurate measurement. Therefore, the downlink LTE intra-system handover is studied with focus on user measurement report.

The study centers on preparation stage of the LTE handover procedure. Two different types of physical layer filtering technique namely linear averaging and local averaging are focused upon among others investigated. The performance of LTE conventional physical layer filtering technique, linear filtering, is compared with an alternative technique called local averaging. The output of each physical layer filtering is then used for LTE standardized radio resource layer filtering (otherwise called L3 filtering). The analysis of results from handover decision is based on simulations performed in an LTE system-level simulator. The performance metrics for the results are evaluated in terms of overall system and mobility-related performance.

The system performance is based on spectral efficiency and throughput while mobility-related performance is based on handover failure. The performance comparison of the results shows that local averaging technique provides improved system performance of about 51.2 % for spectral efficiency and 42.8% cell-edge throughput for high speed users. Local averaging also produces a reduction of about 26.95% in average number of handover failure when L 3 filtering is applied for low speed mobile terminal. This result confirms that both averaging techniques are suitable for LTE network. Moreover, in the case of high mobility local averaging tends to be better than linear averaging.

# CHAPTER 1

# INTRODUCTION

In the recent years, the rate of growth in telecommunication industry has been remarkable. This growth can be seen in network penetration of telecommunication carriers, increasing revenue from service provision, deployment of network facilities and competitions between carriers in the industry. Although the effect of this growth has rippled down to various segments of the industry but none compares to mobile communication. The growth in mobile communication in the past few years is visible in the explosive number of mobile subscribers and rapid trends of the mobile communication which is likely to continue in the near future.

The major development in mobile communication system started in 1970s with first trial implementation in Chicago. The trial system used a technology called Advanced Mobile Phone System (AMPS) and the first commercial version was launched in 1983 (Smith 2006). At this time, other countries also developed similar version of mobile communication technology. A popular version in Europe then was based on a technology called Nordic Mobile Telephone (NMT) operating in 450 megahertz (MHz) and 900 MHz band. Another variant of AMPS was later implemented in Britain known as Total Access Communication System (TACS). The success experienced by these technologies soon made mobile communication spread worldwide. Even though several other technologies were developed, these three were the most successful and considered the first generation (1G) of mobile communication system (Sesia, Toufik and Baker 2009 ; Smith 2006). The success of first generation mobile communication system was far more than imagined and actually revealed its flaws. The main weakness in the system is limited capacity meaning that the system functions well under a considerable number of mobile subscribers but performance degrades drastically when the number of mobile users becomes large and are densely concentrated in a location such as stadiums or metropolitan areas. Another major weakness in the 1G technology is security because the communications were subjected to eavesdropping. In order to mitigate these weaknesses considerable efforts were channel towards development of a new technology which led to the advent of second generation (2G) mobile communication system.

The 2G mobile communication system was developed to handle the limited capacity problem of 1G and addressed it by changing the technology from analogue to digital. Three versions of 2G technologies stood out namely Interim Standard (IS) 136, IS Code Division Multiple Access (CDMA) and Global System for Mobile Communication (GSM) (Smith 2006). IS 136, an improvement to AMPS technology, addressed the limited capacity problem by digitizing the voice channel while the control channel remained analogue. The digitization of the voice channel improved the capacity by allowing up to three subscribers to be serviced concurrently. However, the analogue segment of the system limited the service offering. IS CDMA was also a popular 2G technology. Contrary to IS 136 that used time for sharing communication access between users, IS CDMA made use of code. The use of code division for simultaneous frequency sharing between multiple users provided better capacity than analogue system where the whole frequency was dedicated to a single user. The GSM also addressed the challenges of 1G mobile communication by looking at NMT which was a popular technology in Europe. The widespread of the technology in Europe revealed the incompatibility problem of the analogues system between several countries. Hence, there is need for developing a standardized European-wide digital communication system and that led to creation of a group called Group Specialé Mobile (GSM) (Smith 2006). The activities of the group were then turned over to newly created ETSI in 1989 which finalized the technical specifications. The standardized specifications of GSM technology between European countries paved way for international roaming that was considered a huge success. Having seen the success of GSM, other countries outside Europe started adopting the technology. It was then realized that the technology was beyond Europe and took on a new name called Global System of Mobile Communication (GSM). Although the 2G system was a success compared to 1G mobile communication system yet it had its limitation. The 2G system was optimized for voice communication with several calling features and more secured than 1G system however, it was not well suited for data services.

The popularity of Internet and multimedia communication introduced new level of challenges for mobile communication. Although users want to retain the experience with voice communication yet they also want to participate in various level of communication services possible such as e-mail, Instant Messaging (IM), social media, web browsing and so on. Not only do users want to enjoy these services but also unwilling to sacrifice mobility. In order to provide these level of requirements, it becomes imperative to develop a new advanced technology. This led to creation of third generation (3G) mobile communication technology. On seeing the level of demand for 3G mobile communication, several organizations started addressing the issues in the 80s. The work was pioneered by International Telecommunication Union (ITU) and was termed Future Public Land Mobile Telecommunication Systems (FPLMTS) which was later changed to IMT-2000. The focus of ITU-2000 initially covers specific areas such as user data rates, multimedia service provision, operating bandwidths and flexibility between carriers to support mobile subscribers. The focus was later reviewed and five technologies were selected for terrestrial mobile communication services which are Wideband CDMA (WCDMA), CDMA 2000, Time Division-Synchronous CDMA (TD-SCDMA), Universal Wireless Communications 136 (UWC-136) and Digital Enhanced Cordless Telecommunications (DECT) (Smith 2006). Although these technologies were able to provide a reasonable access to data services on terrestrial mobile network however there is a new level of demand by users which is mobile broadband access. This consequentially ushers in the fourth generation (4G) mobile communication.

The need for mobile broadband springs up as a result of the explosion of packet data on cellular system which cannot be adequately handled by legacy cellular technologies like Global System for Mobile Communications (GSM). The need brings about competition between several access technologies.  The major competitors for provision of mobile broadband on wireless devices are mobile Worldwide Interoperability for Microwave Access (mobile WiMAX), Long Term Evolution (LTE) of Universal Mobile Telecommunications System (UMTS) and Ultra-Mobile Broadband (UMB) (Ortiz 2007; Vaughan-Nichols 2008; Miyahara 2009). The concern is not only the provision of mobile broadband but also sustainability and suitability of the technology towards future provision. This makes Third Generation Partnership Project (3GPP) to wade in competition for provision of mobile broadband. The 3GPP thereby develops a technology path with series of developmental progression to succeed the second generation (2G) technology, GSM, with more advanced capabilities. The technology path chosen is LTE with a view to advancing the expansion trend towards future next generation wireless cellular technology. This makes LTE to be the most popularly adopted of all the competing technologies (Gessner and Roessler 2009). The widespread adoption of LTE facilitated continual improvement of its system specification and made LTE to be seen as the technology that will help achieve the provision of mobile broadband in the near future.

The aims of LTE technology to enhance the technology of radio access network to facilitate efficient service delivery. The LTE radio access technology differs from that of legacy technology because it has capability to provide multi-user access in both frequency and time domain (Sesia, Toufik and Baker 2009; Zukang *et al.* 2012). However, LTE radio access network like most cellular networks also faces challenge of terminal mobility (Rappaport 1996; Wang *et al.* 2009).

## 1.1 MOTIVATION

Mobility is movement of communication terminals and continuous connectivity within the cell coverage area. The continuous connectivity of mobile users within the cell without a reduction in services accessibility or users' satisfaction in term of service performance poses a serious problem. The problem becomes acute when a user traverses to another cell. As a user crosses to another cell, the on-going processes on user's device may need to be transferred to a new set of network nodes (base station, relay node and mobility management entity) within split second. The transfer is called handover. Handover is a transfer of user equipment call or data session from one cell to another cell to support user mobility and achieve better quality of service (De la Roche and Allen 2012). The transfer should be done seamlessly without service interruption to ongoing processes or the user being aware of such transfer. Therefore, maintaining continuous connectivity, avoiding service interruption and ensuring user satisfaction as well as making effective use of radio network resources make handover in cellular network very critical.

## 1.2 RESEARCH PROBLEM

Mobility of user is an important factor in most modern wireless technology with a target of high quality of service (QoS) and user satisfaction. Theoretical targets are sometimes hard to achieve in real life considering effects of other factors on wireless medium such as geographical landscape, building, weather and interference from other wireless equipment using the same medium (Rappaport 1996). In order to maintain a significant level of QoS especially for mobile user, it is important to keep track of the wireless medium and put it to good use. Hence, every mobile user needs to keep track of its wireless medium status.

As each mobile user moves within the cell, it sends reports of its wireless medium to base station (serving base station) at interval which could either be periodic or non-periodic (Donthi and Mehta 2010). The report gives the base station an estimate of the channel quality of downlink for this particular user. Then, the base station uses the measurement report from the user in combinations with other parameters to determine when it is necessary to transfer (handover) the user to one of its neighbouring base stations (target base station). If the report about the radio link of the wireless medium given by the user to its serving base station is erroneous, then two problems ensue:

a) Firstly, the serving base station may fail to negotiate resources needed for user's handover at appropriate time thereby resulting in early or late handover initiation.

b) Secondly, the radio link may deteriorate to an extent that when the handover command is eventually issued, the quality of the radio link may not be able to support the services of the user which either results in poor QoS or termination of services.

Hence, it is important to improve on accuracy of the downlink measurement to enhance promptness and accurate handover decision for maintaining the high QoS demands of mobile users.

## 1.3 OBJECTIVES

This work investigates Intra Radio Access Technology (Intra-RAT) handover between homogenous LTE networks. It also assesses the measurement techniques in downlink LTE. The challenges of downlink measurement for LTE handover are presented and two types of measurement techniques are focused among others being studied. The main goal is to improve the downlink measurement for the handover decision to facilitate prompt and accurate handover decision making. To this end, the following objectives are identified:

a) Analysis of features relevant to LTE downlink measurement for Intra-RAT handover

b) Elucidation on LTE downlink measurement techniques with specific focus on the most widely used technique which is used as a benchmark for the proposed technique

c) Development of handover decision based on measurement from each of these techniques - that is, the most common and proposed technique

d) Evaluation and comparison of the handover decision developed using the techniques

The section below describes the approach adopted to achieve the above-mentioned objectives, factors and tools used to realize the aim.

### 1.3.1 METHODOLOGY

LTE is a fairly new technology and standardization of several parts of the technology is still ongoing. This implies that references and previous work on this specific subject in the domain are limited. Therefore, 3GPP standardization documents and technical drafts as well as previous work on handover in cellular network are relied upon.

In order to provide necessary background for this work, preliminary study of the LTE technology is done. This provides useful information on various aspects of the technology such as architecture, protocols and network elements used for this work.

This is followed by specific literature study and review of the research problem. The literature study gives adequate insight into what is expected in terms of input and output. Thereafter, a discussion is presented on method used and simulation tool chosen for investigating the performance of the downlink handover measurement techniques. This is followed by integration of the downlink measurement techniques and handover decision into the simulation tool. Then, the work is being reviewed and several simulation scenarios are investigated until desired result is achieved. The flow chart in Figure 1.1 shows the successive steps followed during this study.

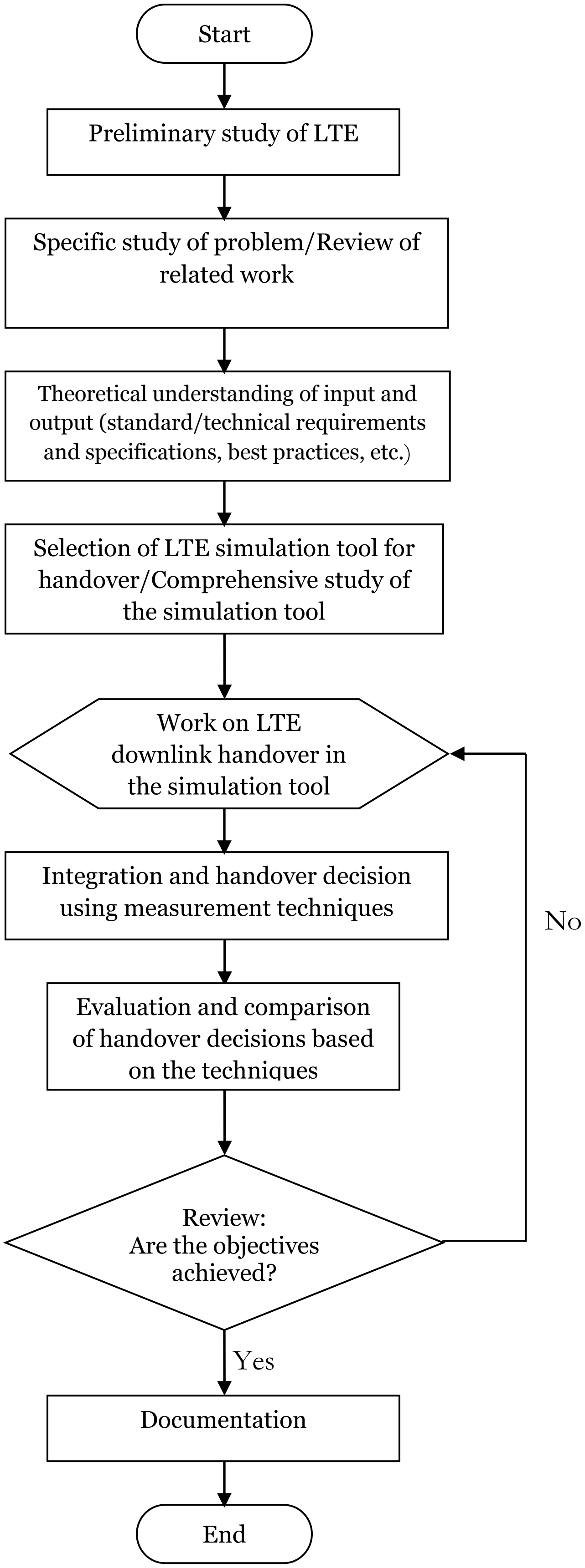


Figure 1.1: Flow chart of research study

### 1.3.2 SIMULATION TOOL

An LTE system-level simulator is chosen to implement the study. The simulator is designed by Ikuno, Wrulich and Rupp (2010) using object-oriented MATLAB programming. The choice of the software tool is informed by the availability of other LTE system aspects, free non-commercial use of the simulator for academic research purposes, the adaptability of software modules to achieve research objectives and reliability of result (Mehlführer *et al.*2011). The simulation tool is user friendly with each LTE functional part clearly separated. The object oriented nature of the programming eliminates redundancy and replication of the software modules. The tool also benefits from a reservoir of functions available in the MATLAB function library which are necessary for accurate computations of complex mathematical equations. However, the simulation tool requires high computational power of a workstation. After the necessary adjustment and modification of software module, a simulation script containing the information for desired scenario is used as input. The overall LTE system of the software tool functions based on the specification and configuration in the simulation script. The output of the scenario is displayed in the MATLAB command window and stored as a simulation trace in a separate file. The simulation trace is then analyzed and presented in a readable manner such as graphs.

## 1.4 THESIS LAYOUT

The research study is mobility related evaluation. An adequate understanding of the technology concepts and standards is fundamental to perform such thorough study. Knowledge of the specifications and requirements for functionality and performance is equally important to know if the technology implementation satisfies the conditions stated in the 3GPP standards. Therefore this thesis provides an extensive overview of concepts in the technology before delving into theory and simulation of handover measurements.

The layout of this thesis is as follows. Chapter 2 introduces LTE in general as a fourth generation (4G) mobile network technology. Chapter 3 then focuses on handover within LTE. Chapter 4 presents the implementation in the simulation tool and discussion of results. Then Chapter 5 provides a conclusion to the study in this thesis and considerations for future work.

# CHAPTER 2

# LONG TERM EVOLUTION

This chapter presents an overview of Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) of Universal Mobile Telecommunication Systems (UMTS) which is recognized as the fourth generation (4G) mobile network technology. The key concept of LTE technology and specifications are explained in this chapter. The specifications, white papers and technical documents for this new cellular technology are so vast and various aspects of the specifications are still being reviewed. In order to keep with length constraint of the thesis, this chapter gives a brief introduction to LTE technology and dwells only on key aspects of the technology relating to handover.

## 2.1 MOTIVATION FOR LTE DEVELOPMENT

The LTE is developed by 3GPP as the technology to handle the demand of UMTS: a technology that would provide a robust and sustainable wireless access than presently offered by other available technologies. It should also support the exponential growth of broadband needs of mobile users due to service and network systems convergence. The provision of the mobile broadband should not only be limited to home or workplace but everywhere. The ubiquitous provision of mobile broadband necessitates viewing from both users' and operators' perspective. For users, the concern is on provision of high downlink data rate that will enable real-time user services like video streaming, online gaming and mobile television. In addition to high downlink data rate, accessibility of a wide range of mobile devices, security, cost of service and convenience are also important. The concern of operators, on the other hand, spans through issues such as increased bandwidth access, migration from existing system to the new system, efficient utilization of wireless spectrum and provision of higher capability to enable provision of new services. Easing these concerns makes it important to standardize various aspects of the LTE system. The standardization targets issues relating to LTE system deployment and service performance requirements. The requirements involve various aspects of LTE such as system architecture which focuses on system convergence by defining how to accommodate existing 3GPP and other wireless technology, interface specification as well as testing and verification.

## 2.2 LTE OVERVIEW

The 3GPP inaugurated project that commenced standardization of LTE at a workshop in Toronto in November 2004 (Dahlman *et al.* 2010). The project involves a number of telecommunication standardization bodies, researchers and development engineers. The collaboration for the project led to joint development of specifications for LTE radio access and non-radio aspect of the system. The standardization includes both the radio access, Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and non-radio aspect, Evolved Packet Core (EPC). Figure 2.1 shows the LTE technology radio access network, E-UTRAN, and the core network, EPC.

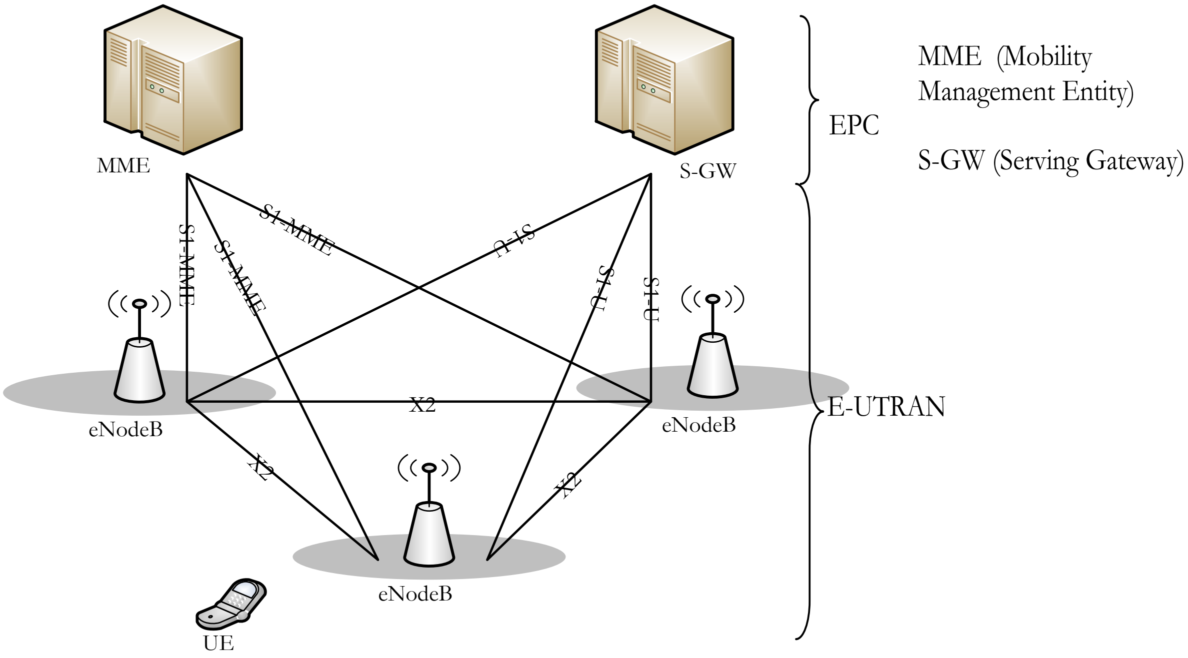


Figure 2.1: LTE Network (3GPP 2008a)

The standardization involves setting new high level requirements to improve service provisioning. A brief description of LTE requirement in comparison with other previous 3GPP technology is shown in table 1.

Table 2.1: Comparison of 3GPP Technology

| | WCDMA | HSPA | HSPA+ | LTE |
|---|---|---|---|---|
| Maximum downlink speed | 384 kbps | 14 Mbps | 28 Mbps | 100 Mbps |
| Maximum uplink speed | 128 kbps | 5.7 Mbps | 11 Mbps | 50 Mbps |
| Latency (approximate) | ~150 ms | < 100 ms | < 50 ms | ~10 ms |
| 3GPP Release | Rel. 99/4 | Rel. 5/6 | Rel. 7 | Rel. 8 |
| Initial roll-out year (approx.) | 2003/2004 | 2005/6 (HSDPA)<br>2007/8 (HSUPA) | 2008/2009 | 2010 |
| Access technology | CDMA | CDMA | CDMA | OFDMA/SC-FDMA |

The objective of these requirements is to develop a framework for the evolving 3GPP technology to achieve the following (3GPP 2008b; David *et al.* 2009):

- Simplified system network architecture for only packet-switched traffic
- Seamless mobility between different radio-access technologies and increased cell-edge bit rate to facilitate uniformity in provision of service
- Increased service provisioning and reduced cost per bit, this implies more services and better user experience at relatively low cost.
- Increased peak data rates compared with existing technology such as a second generation (2G) Global System for Mobile Communication (GSM) and third generation (3G) High Speed Packet Access (HSPA).
- Provision of wider coverage at higher data rates and flexibility in spectrum utilization between existing frequency and new frequency bands
- Reasonable power consumption of the mobile devices

## 2.3 LTE REQUIREMENTS

The key requirements of LTE system are designed to ensure a competitive edge for about ten-year-frame. Ensuring the competitiveness of the technology facilitates setting stringent targets for the evolving radio access of LTE and also leads to the creation of formal documentation for the requirements called Study Item. The requirements in the Study Item are being revised from time to time and are called LTE Release. For instance, LTE Release 8 was finalized in June 2008 and work on LTE Release 12 is still ongoing. Figure 2.2 shows the progression of some LTE Releases, some aspects of LTE technology defined in the document and the frozen date.

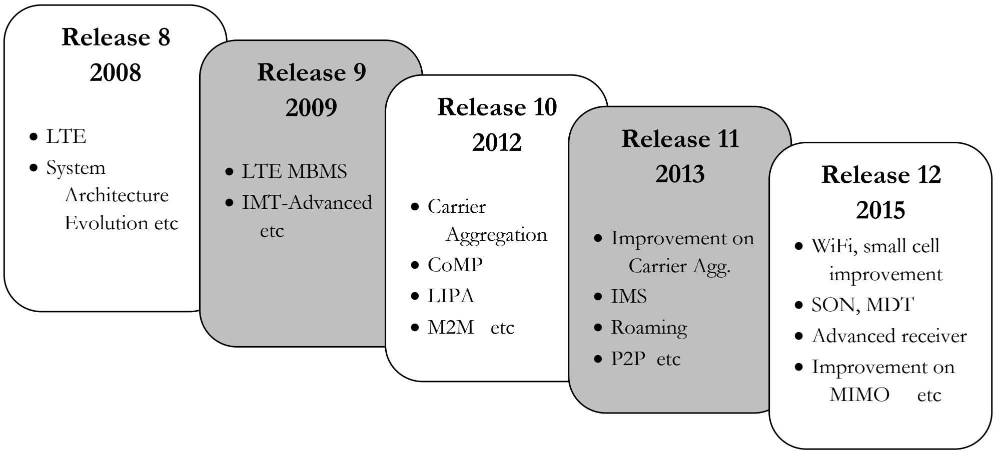


Figure 2.2: Progression of LTE Release

The LTE Releases focus on enhancing the capability of E-UTRAN and EPC with regards to service and system aspect in the evolving technology. In specific terms, some of the key capability, system performance and deployment requirements for LTE as defined in Release 8 (3GPP 2008b) are summarized as follows.

### 2.3.1 CAPABILITY RELATED REQUIREMENTS

**Peak data rate**: targets transmission rate of 100 megabits per second (Mbps) for downlink (DL) and50 Mbps transmission rate for uplink (UL) within 20 megahertz (MHz) operating bandwidths

**Latency**: addresses delay experienced by user equipment as a result of transition from non-active to active states to enable data transmission. The requirement is split into user-plane and control-plane. The user plane latency target for the transition from inactive to active state is below 10 milliseconds (ms) while connection setup latency for transition from idle state to active state should be less than 100 ms.

**Mobile terminal capacity**: for operation within the 5 MHz spectrum allocation, the number of supported mobile terminals should not be less than 200. Likewise, in a higher operating bandwidth beyond 5 MHz at least 400 mobile terminals should be supported.

### 2.3.2 SYSTEM PERFORMANCE REQUIREMENTS

**User throughput**: is used to assess the delivery of consistent user experience across the cell coverage area and usually scaled with spectrum bandwidth. The target is set in terms of average user throughput and cell edge user throughput. The average user throughput per megahertz specification for both downlink and uplink are 3-4 times and 2-3 times that of Release 6 respectively (3GPP 2008b).

**Cell spectral efficiency**: is the target to be achieved within cell in terms of the normalized system data rate of bandwidth and the number of cells. Peak spectral efficiency target is 52 and 2 *bits per second per hertz* (bps/Hz) for DL and UL respectively. Average cell spectral efficiency target is set to be 1.69 bps/Hz *per cell* for DL and 0.74 bps/Hz *per cell* for UL. Likewise, the cell edge user spectral efficiency requirement is 0.05 and 0.024 bps/Hz *per cell* for DL and UL respectively.

**Mobility**: is the performance requirement relative to the speed of the mobile terminal across the cellular network. The specification is that radio access network should be optimized for low terminal speed between 0-15 *kilometres per hour (*km/h*)* while higher performance should be guaranteed at higher terminal speed between 15-120 km/h. For higher terminal speed between 120-350 km/h, mobility of the user across the cellular network should be sustained.

**Coverage**: is to enable flexibility in various deployment scenarios to support reuse of the existing radio access network sites and same carrier frequency while complying with the user throughput, cell spectral efficiency and mobility performance target. The E-UTRAN coverage target should support deployment scenarios of varying cell range such as 0-*5 kilometres* (km), 0-30 km and 0-100 km.

### 2.3.3 DEPLOYMENT REQUIREMENTS

**Spectrum flexibility**: specifies allocation of spectrum into different sizes such as 1.25, 2.5, 5.0, 10, 15 and 20 MHz. This allows scalability and optimal usage of available spectrum to support transmission in the downlink and uplink as well as facilitate operation in both paired and unpaired spectrum.

**Coexistence and Internetworking**: states the requirements for inter-networking between the LTE radio access and other 3GPP systems. The specification states target for E-UTRAN terminal, E-UTRAN measurement and handover interruption time between the various systems. For instance, handover interruption time for real-time services of terminal moving from E-UTRAN to Universal Terrestrial Radio Access Network (UTRAN) is less than 300 ms while the handover interruption time requirement for non-real-time service between E-UTRAN and GSM EDGE Radio Access Network (GERAN) is less than 500 ms.

An overview of LTE key requirements is shown in Table 2.2.

Table 1.2: Overview of LTE Requirements (3GPP 2008b)

| Parameter | Detail |
|---|---|
| Data type | All packet-switched data (voice and data)<br>No circuit switched |
| Channel Bandwidth | 1.25, 1.36, 2.5, 5.0, 10, 15 and 20 MHz |
| Duplex Schemes | FDD and TDD |
| Mobility | 0-15 km/h (optimized)<br>15-120 km/h (high performance)<br>120 – 350 km/h (connection maintenance) |
| Latency | < 10 ms (inactive to active state)<br>< 100 ms (idle to active – connection setup) |
| Spectral Efficiency | Downlink: 3-4 times of Release 6 (HSDPA)<br>Uplink: 2-3 times of Release 6 (HSUPA) |
| Access Schemes | OFDMA (downlink)<br>SC-FDMA (uplink) |

## 2.4 NETWORK ARCHITECTURE

The network architecture is designed to suit the objectives of Long Term Evolution of UMTS. The LTE network architecture is shown in Figure 2.3 and simplified to support only packet-switched services. The architecture aims to provide optimized Internet Protocol (IP) connectivity during mobility. The overall LTE architecture is split in two subsystems which are E-UTRAN and EPC. The E-UTRAN is the radio access network that provides wireless coverage to users while EPC is the core network. The EPC interconnects the RAN with other network entities in the core network as well as service gateways. A significant improvement to LTE architecture with respect to mobility is the decentralization of Radio Resource Management (RRM) function. This reduces complexity in system integration by collapsing network nodes such as Radio Network Controller (RNC) that performs coordination and resource management functions between base stations (NodeB) and other network entities in 3G architecture. The absence of the RNC in LTE integrates some of its functionalities into the base station which is called E-UTRAN NodeB (eNodeB) and thereby enhancing the intelligence of eNodeB. The eNodeB manages all activities in the E-UTRAN and also interacts with the core network. The core network, that is the EPC, is also all IP-based and therefore coordinates routing of user and control data traffics as well as voice traffics from user plane over packet-switched network.

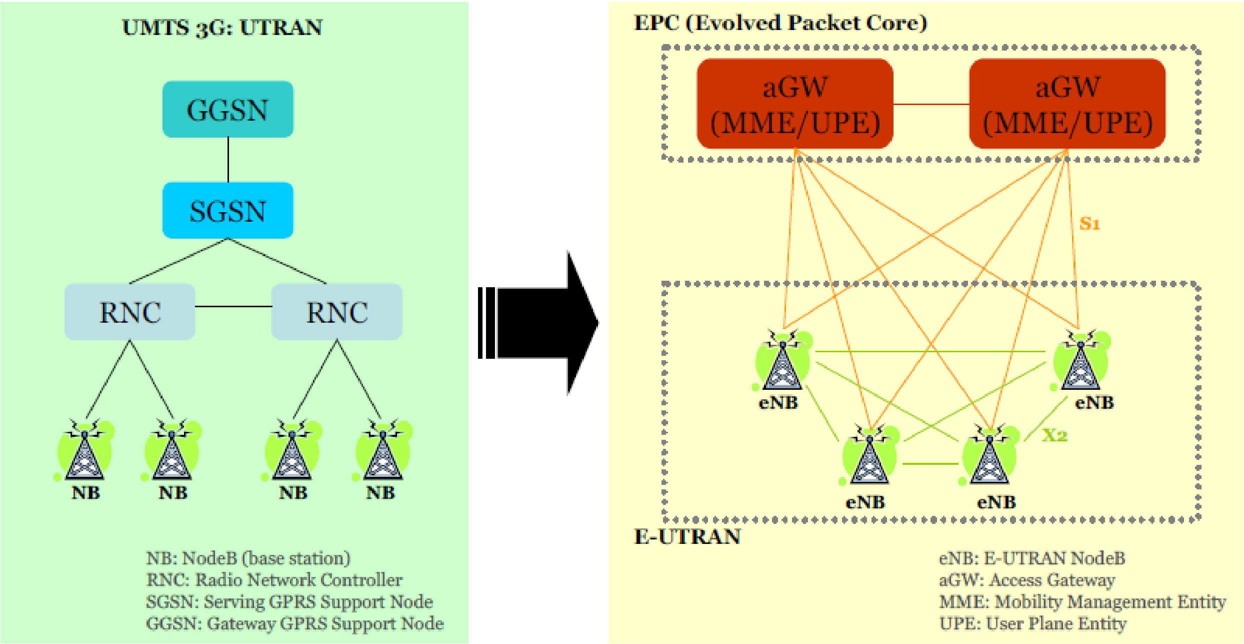


Figure 2.3: LTE Network Architecture (3GPP 2008a)

### 2.4.1 EVOLVED UTRAN (E-UTRAN)

The E-UTRAN is a packet-switched radio interface or radio access part of LTE network. It consists of a network of eNodeB. Another important element of the radio access, though not considered as part of E-UTRAN, is mobile terminals also called user equipment (UE).

The UE is a mobile terminal usually a handheld device that connects to eNodeB over the radio interface. The connection between the UE and the network is secured through Universal Subscriber Identity Module (USIM). The USIM provides a unique identity to the UE and sufficient security through function such as encryption, authentication and data integrity.

The eNodeB connects UEs by providing the wireless access coverage. It also serves as the anchor between the UE in E-UTRAN and EPC. Since there is no centralized RNC in the E-UTRAN, the eNodeB performs coordination of user traffics and resource management function between UEs. Each eNodeB interconnects with its neighbours through an interface called X2 and to the EPC by means of S1 interface. The interconnections between the eNodeB in the E-UTRAN allow scalability and prevent single point of failure. Also, the interfaces that provide interconnections between various network elements are all standardized to allow interoperability between different vendors.

### 2.4.2 EVOLVED PACKET CORE (EPC)

The EPC consists of several logical nodes and is responsible for overall control of UE in radio network with other packet data network (PDN). The logical nodes which made up an essential part of the EPC are the PDN Gateway (P-GW), Serving Gateway (S-GW) and Mobility Management Entity (MME). Figure 2.4 shows LTE Evolved Packet System (EPS).

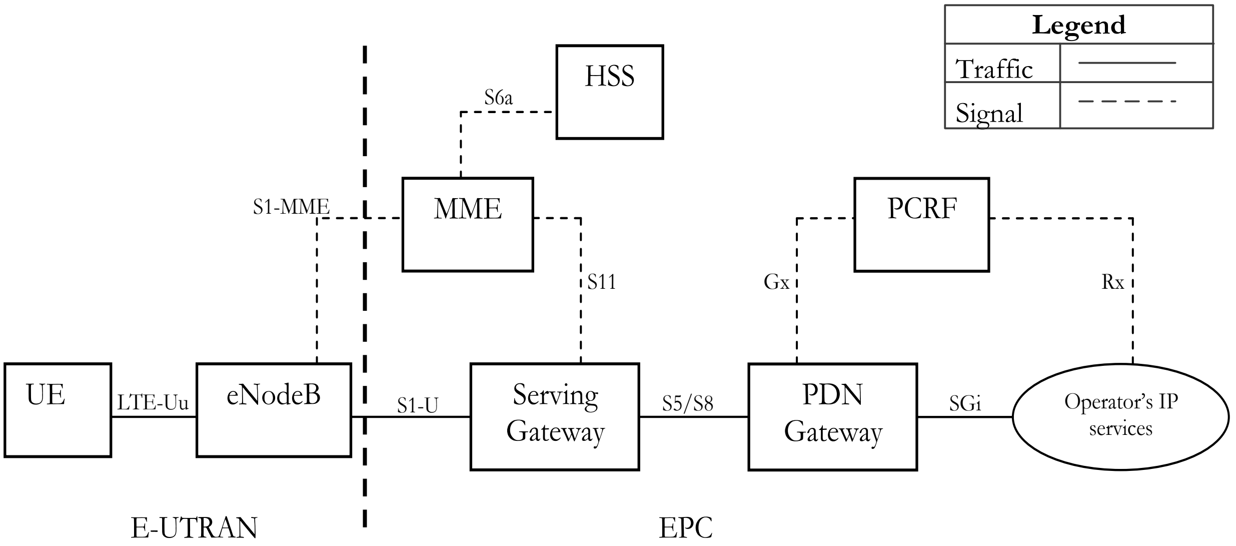


Figure 2.4: Evolved Packet System (Sesia, Toufik and Baker 2009)

PDN Gateway (P-GW) is the element at network edge which serves as a point of connection to external data network. P-GW is responsible for allocation of IP address to the UE and the connection with operator's IP services such as IP Multimedia Subsystem (IMS). The IP address assigned by P-GW is used for Internet connectivity and service provisioning over control interface SGi. The P-GW facilitates enforcement of QoS and flow-based charging rules of Policy Control and Charging Rules Function (PCRF). It also filters the downlink user packet into respective QoS-based bearers and functions as mobility anchor for other non-3GPP technologies.

Serving Gateway serves as the local mobility anchor when UE moves between the eNodeB. The S-GW is responsible for retention of data packets in the buffer when the UE change mode from CONNECTED to IDLE while receiving data from the P-GW (Sesia, Toufik and Baker 2009). The S-GW relays data transmission from serving eNodeB to P-GW and also enables switching of data tunnel between source eNodeB and target eNodeB during handover.

Mobility Management Entity (MME) is a key element of the EPC and the centre of mobility architecture. The connection of MME to the eNodeB over the S1-MME interface is shown in Figure 2.4. The MME functions only as a signalling entity and hence does not participate in forwarding data packet. The basic idea is isolating signalling and traffic so as to enable network capacity of each to growth independently (Khan 2009). Some of the functions of MME include management of tracking area list, selection of P-GW/S-GW, locating UE in IDLE mode, roaming and bearer management. It also performs user authentication and security function through the S6a interface with Home Subscriber Sever (HSS) and hence facilitates access restriction for roaming as well as enforcing user's predefined QoS profile. The MME is also plays major role in interworking with other legacy network and during intra-system handover.

## 2.5 LTE PROTOCOL STRUCTURE

This section explains the protocol structure for LTE system. LTE protocol is similar to the conceptual model defined by Open System Interconnection (OSI) reference model (Zimmermann 1980). In the OSI model, the function of each communication system is split into various partitions consisting of abstract layers. Each layer within the protocol stack communicates with one directly linked to it (above or below) and sometimes adds more features to the layer below. The function definition at each layer allows easy standardization and also provides a framework whereby changes in functionality at a layer do not affect the other layers. Similarly, the LTE protocol structure is divided into series of abstraction layers and further separated into user and control plane which allow independence.

On the user plane, the data packets created by applications from the core network are encapsulated using a specific protocol and tunnelled from the P-GW through the eNodeB to the user. The control plane, on the contrary, deals with the signalling messages and radio specific functionality from the MME to the user (Rayal 2010; Ali-Yahiya 2011). Figure 2.5 and Figure 2.6 show the protocol stack for the EUTRAN user plane and control plane respectively.

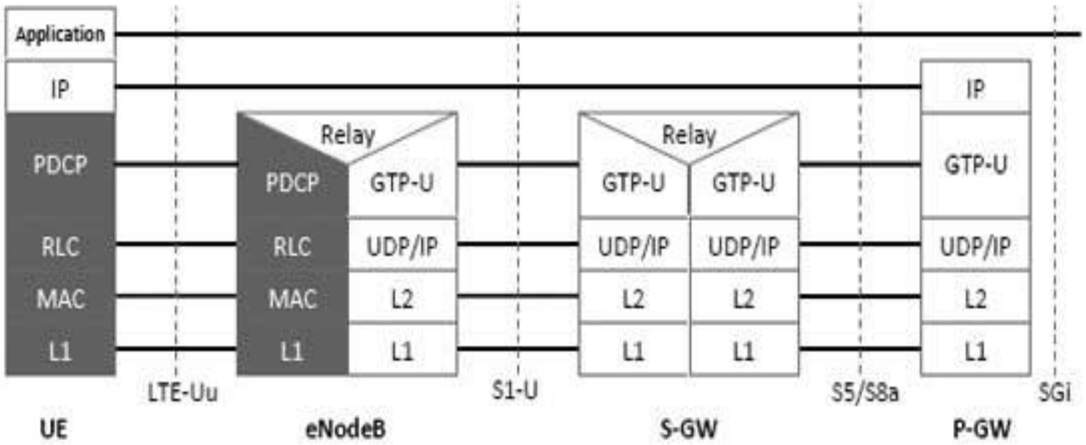


Figure 2.5: User plane protocol stack

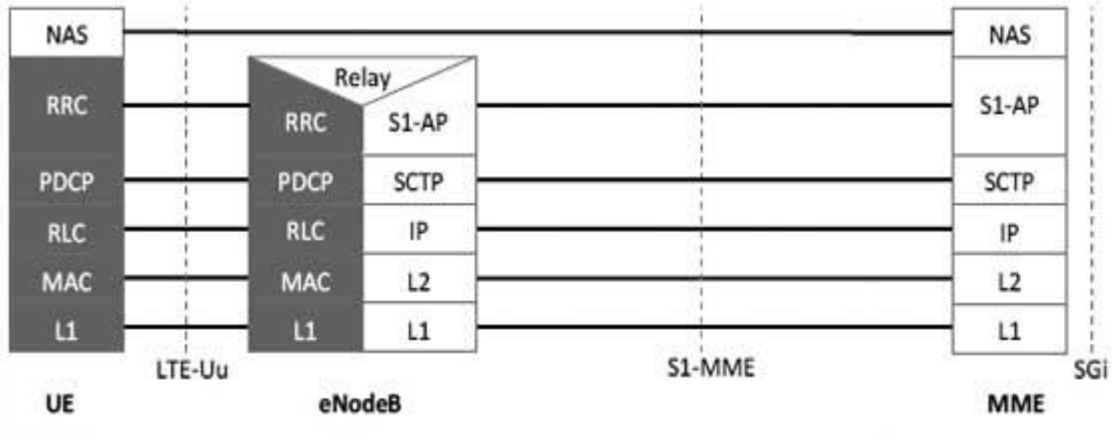


Figure 2.6: Control plane protocol stack

The absence of centralized controller node in LTE architecture transfers the responsibility for coordination to the eNodeB. For instance, buffering of data packet during handover due to user mobility in the E-UTRAN is performed by eNodeB. This explains why both the data and control traffic in Figure 2.5 and Figure 2.6 are tunnelled through the eNodeB. The explanations of the functionalities of other layers in both user and control plane of the LTE protocol structure are given below.

### 2.5.1 INTERNET PROTOCOL (IP)

The Internet Protocol (IP) is the highest layer in the user plane protocol structure. It is responsible for carrying all the traffics types present in the network.

### 2.5.2 NON ACCESS STRATUM (NAS)

The NAS is the highest layer in the control plane protocol structure. It connects UE directly to the MME. It is responsible for mobility management function and session management procedures such as the establishment and maintenance of IP connectivity of the UE to the PDN.

### 2.5.3 RADIO RESOURCE CONTROL (RRC)

The RRC is also called Layer 3 (L3). It is the access stratum protocol of the control plane. It deals with the handling of UE-eNodeB signalling, admission control, handover decision, management of UE as well as processing of physical layer measurements and configuration.

### 2.5.4 PACKET DATA CONVERGENCE PROTOCOL (PDCP)

This is responsible for IP header compression to reduce overhead and data protection. The IP header compression is performed during handover by reducing the number of bits transmitted over the radio interface. The data protection function is provided by using the appropriate ciphering mechanism to ensure the integrity of data transmitted.

### 2.5.5 RADIO LINK CONTROL (RLC)

The RLC layer facilitates segmentation of IP packets into smaller units and corresponding reassembling (concatenation) of the segmented packets at the receiving end. It also handles Automatic Repeat reQuest (ARQ) functionality to safeguard error-free delivery of data packets transmitted.

### 2.5.6 MEDIA ACCESS CONTROL (MAC)

The MAC layer deals with multiplexing of logical-channels, retransmission of hybrid-ARQ and scheduling functionality. The services from the MAC layer is presented to the RLC layer through the logical channels. The scheduling functionality is resident in the eNodeB for dynamic distribution of resources between users in both uplink and downlink.

### 2.5.7 PHYSICAL LAYER (PHY)

The Physical Layer is also referred to as Layer 1 (L 1). The PHY layer handles radio interface measurements, coding/decoding, antenna-mapping, modulation/demodulation functions. The PHY layer (L 1) measurements are presented directly to L 3 for processing which is vital to handover decision. The PHY layer services are presented to the MAC layer through transport channels.

# CHAPTER 3

# HANDOVER IN LTE

This chapter presents an important aspect of LTE technology that is mobility which has several advantages. The mobility entails that nomadic users are always connected within the radio access network. As a mobile user moves within the radio access network, the connection of the user has to be transferred (handover) between cells to maintain continuous service provision. The key principle in handover design is enabling seamless mobility and uninterrupted service transition between cells during handover.

## 3.1 LTE HANDOVER OVERVIEW

Handover is an essential part of Radio Resource Management (RRM) and it involves transfer of user equipment (UE) call or data session from one cell to another to facilitate continuous connection. The main aim of handover is the maintenance of quality of service and preservation of cellular system capacity. Handover in LTE is UE-assisted network controlled. The handover is of two types which are Intra Radio Access Technology (Intra-RAT) and Inter Radio Access Technology (Inter-RAT). LTE Intra-RAT handover is purely hard handover and involves transfer between similar (LTE) technologies while Inter-RAT handover is soft handover involving dissimilar technologies.

This study investigates LTE Intra-RAT handover which is hard handover. The hard handover, also called “break-before-make”, implies termination of connection with serving eNodeB of the old cell before establishing a connection with target eNodeB in the new cell. The brief interruption in the user plane by hard handover may cause data loss. Therefore, a mechanism must be in place to reduce the amount of data loss. Seamless or lossless mode is used for downlink packet data forwarding to minimize the amount of data loss in the user plane (Amin and Yla-Jaaski 2013; Sesia, Toufik and Baker 2012).

## 3.2 LTE AIR INTERFACE

The LTE air interface is viewed as a matter of utmost concern since it may create bottlenecks in the radio link. The air interface sometimes contributes to several user delays in wireless networks because of the nature of the wireless environment. For example, a user's delay involving handover may result in reduced quality of service for ongoing communication or service termination. Therefore, a special attention is given to LTE air interface technology such as carrier technology, modulation schemes and antenna technology.

The LTE air interface adopts multicarrier technology. The multicarrier technology subdivides the available transmission bandwidth into parallel sub-channels. A classic example of multicarrier technology is frequency division multiplexing in which each user is separated from another spectrally allowing multiple users to use separate channels and aggregate channel bandwidth is equal to the transmission bandwidth (Cimini Jr 1985). Orthogonal Frequency Division Multiplexing (OFDM) is a special case of frequency division multiplexing where available transmission bandwidth is subdivided into multiple overlapping narrowband sub-channels which are mutually orthogonal. Figure 3.1 shows a comparison between OFDM and a classical multicarrier technology. The mutually orthogonal overlapping sub-channels in OFDM eliminate the use of guard-bands, employed to reduce adjacent channel interference, and thus increase spectral efficiency.

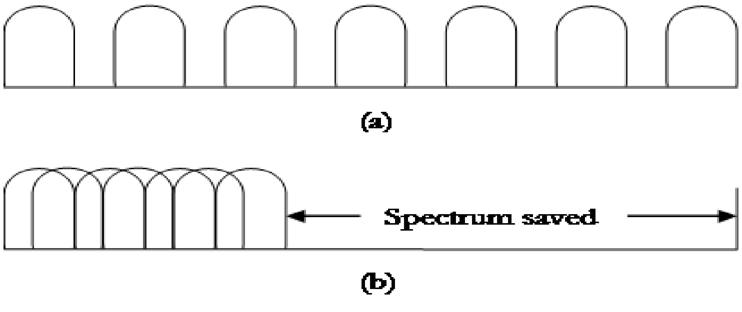
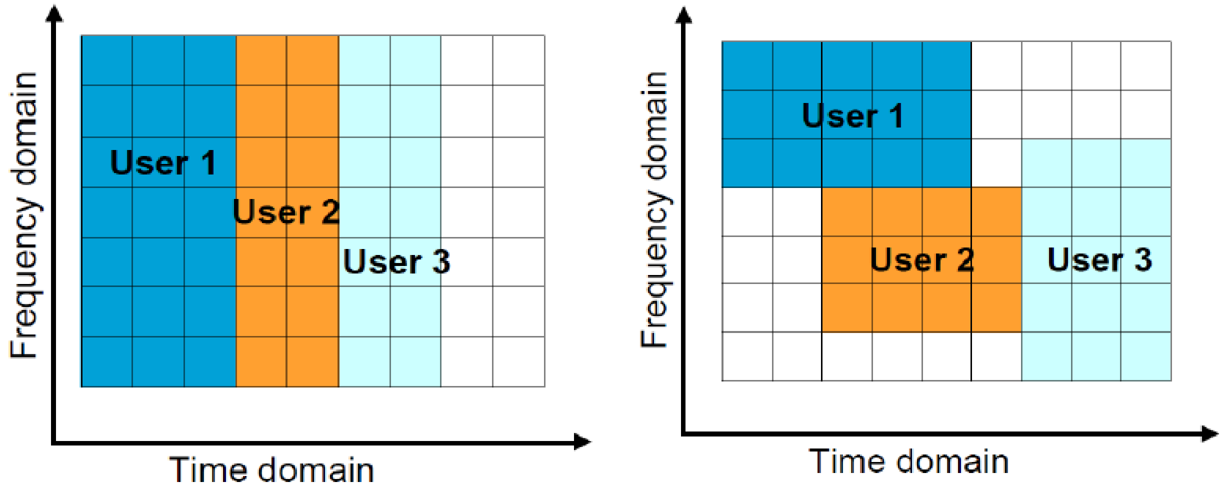


Figure 3.1: Comparison of spectral efficiency in OFDM to classical multicarrier modulation: (a) Classical multicarrier system spectrum (b) OFDM system spectrum (Sesia, Toufik and Baker 2012)

The OFDM is used in broadcast wireless systems such as Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB) as well as low-power wireless systems like Wireless Fidelity (Wi-Fi). These systems benefits from OFDM low-complexity receiver architecture, robustness against multipath fading and ability to operate in different channel bandwidth depending on available spectrum (Cimini Jr 1985; Sesia, Toufik and Baker 2012). In basic OFDM implementation, a single user receives data on all the sub-channels as shown in Figure 3.2 (a). An extended version of OFDM for multiuser communication system, Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier Frequency Division Multiple Access (SC-FDMA), is used for LTE. The multiple access concepts are achieved as shown in Figure 3.2 (b) by allocating a portion of the sub-channels to different users at the same time thereby enabling multiple users to receive data simultaneously (Nogueroles *et al.* 1998; Sesia, Toufik and Baker 2012 ). Therefore in LTE, OFDMA is used for downlink and SC-FDMA for uplink.



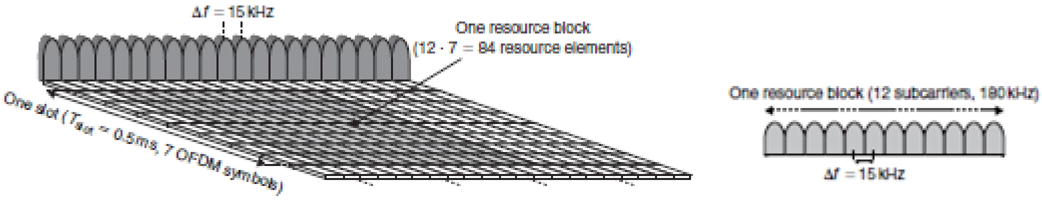
(a) (b)

Figure 3.2: Comparison between multiuser communication systems:

(a) OFDM allocates users in time domain only (b) OFDMA allocates users in both time and frequency domain (Gunawan 2011)

### 3.2.1 DOWNLINK TRANSMISSION SCHEME (OFDMA)

The LTE downlink transmission scheme is based on OFDMA. The OFDMA behaves like OFDM by dividing a single signal into several sub-channels or subcarriers. The splitting of one extremely fast signal to relatively slow multiple signals is beneficial for mobile access and allows robustness against multipath distortion experience by a single signal. The signals from several subcarriers are then collected at the receiver to obtain high speed transmission. Also in OFDMA, a portion of the subcarriers is dynamically assigned to several users thereby facilitating multiuser access. The allocation in time domain is also performed to achieve multiuser access by dividing a group of subcarriers within the same frequency domain to different users for specific time duration. The time domain multiple allocations of subcarriers are called Time Division Multiple Access (TDMA). A group of subcarriers in time-frequency blocks is known as Physical Resource Block (PRB). Figure 3.3 (a) shows a group of subcarriers representing one PRB in both time and frequency domain.



**(a)** **(b)**

Figure 3.3: LTE downlink physical resource block (Dahlman *et al.* 2010)

Figure 3.3 (b) is the frequency domain illustration of a downlink subcarriers group representing one resource block. The resource block consists of 12 consecutive subcarriers, with 15 kilohertz (kHz) subcarrier spacing, corresponding to resource block bandwidth of 180 kHz. Therefore, LTE downlink carrier ranges from six to hundreds of resource block according to downlink transmission bandwidth of 1.25 MHz to 20 MHz.

### 3.2.2 UPLINK TRANSMISSION SCHEME (SC-FDMA)

The uplink transmission scheme of LTE is based on SC-FDMA. The SC-FDMA is chosen because it reduces the variation in instantaneous transmit power, the Peak-to-Average-Power-Ratio (PAPR), experienced with OFDM. This attribute makes possible the design of an efficient and a cost-effective power amplifier. Therefore, the SC-FDMA is generally referred to as Discrete Fourier Transform (DFT) based OFDMA. Similar to OFDMA, SC-FDMA also operates in time-frequency domain and signal processing has a lot in common which allows parameters in both downlink and uplink to be harmonized.

## 3.3 LTE FRAME STRUCTURE

The transmission in downlink and uplink are arranged into radio frames with duration of 10ms. The radio frame is further divided into ten 1ms subframes with each being split into two slots of 0.5ms. The radio frame structure for both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are supported. The generic frame structure for LTE is shown in Figure 3.4.

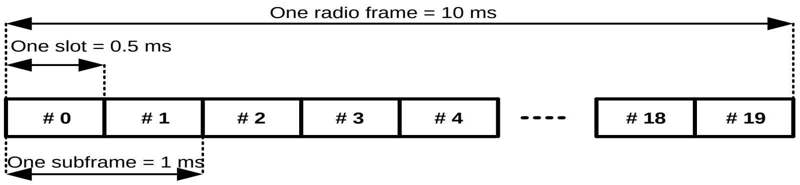


Figure 3.4: LTE frame structure (3GPP 2008a)

The subframes within one radio frame can be used for either downlink or uplink transmission (3GPP 2006; 3GPP 2008a; Dahlman *et al.* 2010). For instance, all subframes operating in FDD are used entirely for either downlink or uplink transmission. The subframes in TDD, on the other hand, are flexibly assigned for use between downlink and uplink.

### 3.3.1 UE MEASUREMENT

The UE control plane protocol, Access Stratum (AS), handles radio-related functionalities and also interacts with the Non-Access Stratum (NAS). The radio-related functions of AS is dependent on the state of UE whether it is connected or not. The UE state, in other words, is called the Radio Resource Control (RRC) state which is either RRC_CONNECTED or RRC_IDLE (ETSI 2009; Sesia, Toufik and Baker 2012). The UE in active mode, that is RRC-CONNECTED state, has to monitor the control channel to facilitate dynamic allocation of network (E-UTRAN) shared resource. Therefore, the UE provides the E-UTRAN with measurements on its downlink channel quality (from its cell and neighboring cells) to enable selection of the appropriate cell to connect. The UE measurement is necessary to allow mobility of the user within and between the E-UTRAN. Two types of UE measurements specified for E-UTRAN are Reference Signal

Received Power (RSRP) and Reference Signal Receive Quality (RSRQ) (3GPP 2010;ETSI 2009).

**RSRP:** is the measurement performed by UE over the cell-specific reference signals. The cell-specific reference signals are multiplexed into OFDM resource elements and transmitted only on some subcarriers. The reference signals are available to all UEs in a cell for determining phase reference demodulation of downlink control channels and for generating Channel State Information (CSI) feedback (Dai *et al.* 2012; Sesia, Toufik and Baker 2012). The mapping of the reference signal, R0, to downlink radio frame is illustrated in Figure 3.5. In order to determine channel estimates on the remaining resource elements that do not bear reference signals, interpolation is performed over the reference signals. Therefore, RSRP is defined as the linear average over the power contributions of the resource elements that bear cell-specific reference signal within a measurement bandwidth (3GPP 2010). If receiver diversity is in use by the UE, the measured value is equivalent to the linear average of power contribution on combined diversity branches.

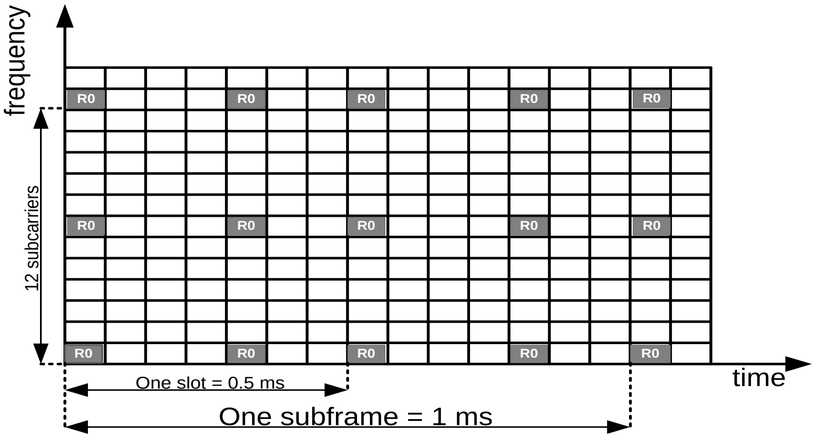


Figure 3.5: LTE downlink distribution of reference signal

**RSRQ:** is determined as ratio of RSRP to RSSI (Reference Signal Strength Indicator). The RSSI is the linear average of total received power over the reference signal including the interference from all other sources such as adjacent channel interference, serving and non-serving cell interference and thermal noise (3GPP 2010). The RSRQ enables the UE to determine the received signal quality in terms of signal and interference. The

RSRQ is therefore essential for handover within the E-UTRAN since the quality varies with location of users within the cell. The RSRQ is defined in equation (3-1)

$$RSRQ = \frac{N * RSRP}{RSSI} \tag{3-1}$$

where N is the number of resource blocks used for calculating the RSRP. It should also be noted that the number of resource block used in the calculation of RSRP and RSSI must be the same (3GPP 2010).

The UE measurement is performed on the downlink and used for handover. In order to use UE measurement for handover, the measurement must to be processed at the PHY layer (L 1) and RRC layer (L 3) as shown is Figure 3.6 (ETSI 2012a). The following sections explain the concepts of L 1 and L 3 processing of downlink handover measurement.

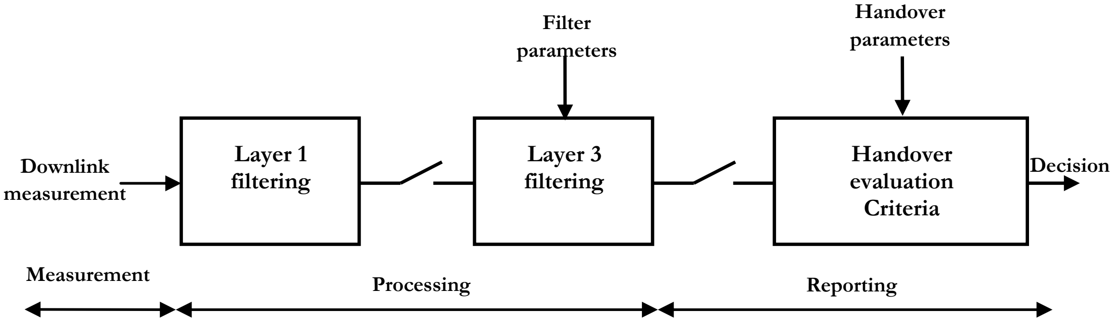


Figure 3.6: LTE handover measurement and filtering

### 3.3.2 L 1 FILTERING

The downlink measurement is performed on the physical layer (L 1) of LTE. The physical layer of LTE is based on OFDMA access technology and is known to be robust against multipath distortion experienced on high frequency selective channel. The robustness is achieved by splitting the distortion or fading across several subcarriers to simplify channel equalization at the receiver. At the receiver, the whole knowledge of the channel is needed to perform coherent detection and decoding. Figure 3.7 depicts LTE downlink channel estimation process.

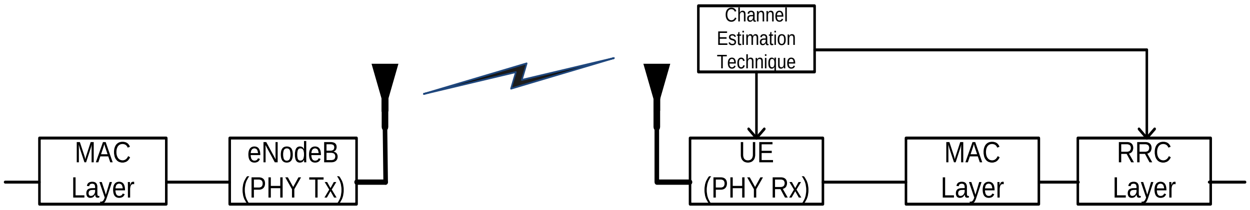


Figure 3.7: LTE downlink channel estimation process

The channel estimation over the resource elements with reference signals is easily achieved by using OFDMA channel estimation techniques. However, this is not easily done for resource elements without reference signals i.e. the data-carrying resource elements. It should be noted that accurate estimation of channel quality is dependent on contributions of all the resource elements in the downlink (Kalakech *et al.* 2012). A popular approach for estimating channel quality on data-carrying resource elements is by using interpolation filtering (Chin, Ward and Constantinides 2007; Dai *et al.* 2012). Several interpolation filters have been proposed considering tradeoffs between complexity and performance. The common filtering is linear filtering and is used for handover in LTE (Zheng and Wigard 2008; Kurjenniemi, Henttonen and Kaikkonen 2008; Aziz and Sigle 2009; Elnashar and El-Saidny 2013). The sparse distribution of reference signal in downlink LTE frame affects accurate estimation by linear filtering which is usually accompanied by estimation errors (Anas *et al.* 2007a). The accuracy of the estimation becomes worse for highly frequency-selective channel experienced by high mobility users. It is important to note that support for high mobility users is one of the requirements for LTE networks and a suitable filtering technique with reliable result will be preferred.

Therefore, a local scattering function based on multi-taper spectral estimation method is employed as an alternative filtering technique (Thomson 1982; Percival and Walden 1993; Matz 2005) in this research. A similar technique, local averaging, was used by Mark and Leu (2007) on cellular network for filtering L 1 signal. The viability of the local averaging technique for reliable handover was investigated by Tamilselvan, Hemamalini and Manivannan (2008). Since LTE network belongs 3GPP cellular network family of technology, the filtering technique is considered suitable. Also, the L 1 filtering technique is implementation dependent and not restricted by LTE standard (3GPP 2011).

### 3.3.3 L 3 FILTERING

The L 3 filtering is standardized for handover decision in LTE and to ensure that an instantaneous L 1 measurement does not trigger an undesirable action (Anas *et al.* 2007b; 3GPP 2009). It has been observed that application of L 3 filtering eliminates "ping-pong" handover - a situation whereby user handover to a cell for a better quality and due to interference handover again to the original cell with a few time (Anas *et al.* 2007b). The L 3 filtering is performed on local averaged L 1 signal to make it suitable for handover decision in LTE. The effect of L 3 filtering is then observed on handover performance.

## 3.4 LTE DOWNLINK CHANNEL ESTIMATION

This section presents architecture of an OFDM transmitter and receiver used in LTE downlink and also explains the concept of channel estimation by using the filtering techniques. Figure 3.8 shows a typical implementation of an OFDM transmitter.

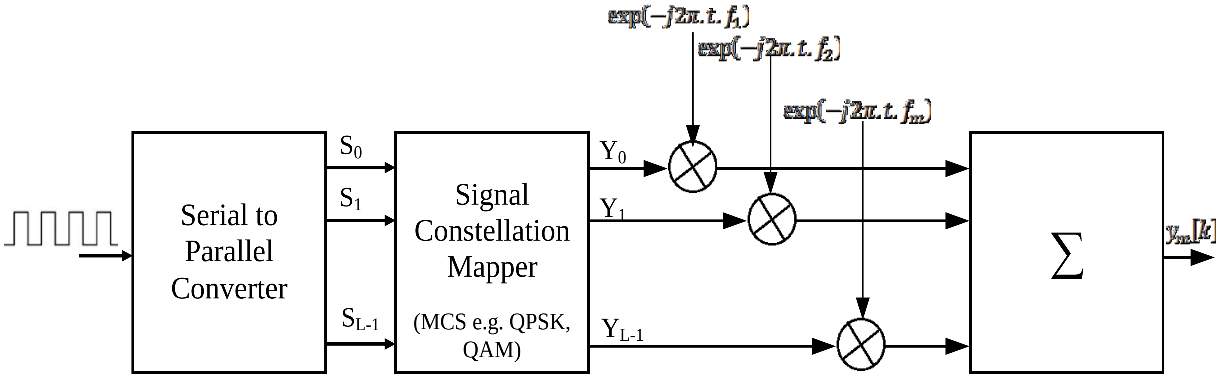


Figure 3.8: An implementation of an OFDM transmitter

As shown in Figure 3.8, a serial data symbol is passed through a serial to parallel converter to generate an L-dimension parallel data block $S[k] = [S_0[k], S_1[k], \ldots, S_{L-1}[k]]^T$. Each component of the parallel data streams is independently modulated resulting in complex vector $Y[k] = [Y_0[k], Y_1[k], \ldots, Y_{L-1}[k]]^T$ used as input to an M-input Inverse Fast Fourier Transpose (IFFT) to generate a time-domain M complex samples $y[k] = [y_0[k], y_1[k], \ldots, y_{M-1}[k]]^T$ given by equation (3-2).

$$y_m[k] = \frac{1}{\sqrt{M}} \sum_{L=1}^{M} Y_L[k] \exp\left(2\pi j L \frac{m}{M}\right) \qquad (3\text{-}2)$$

An entire OFDM system with both transmitter and receiver are shown in Figure 3.9.

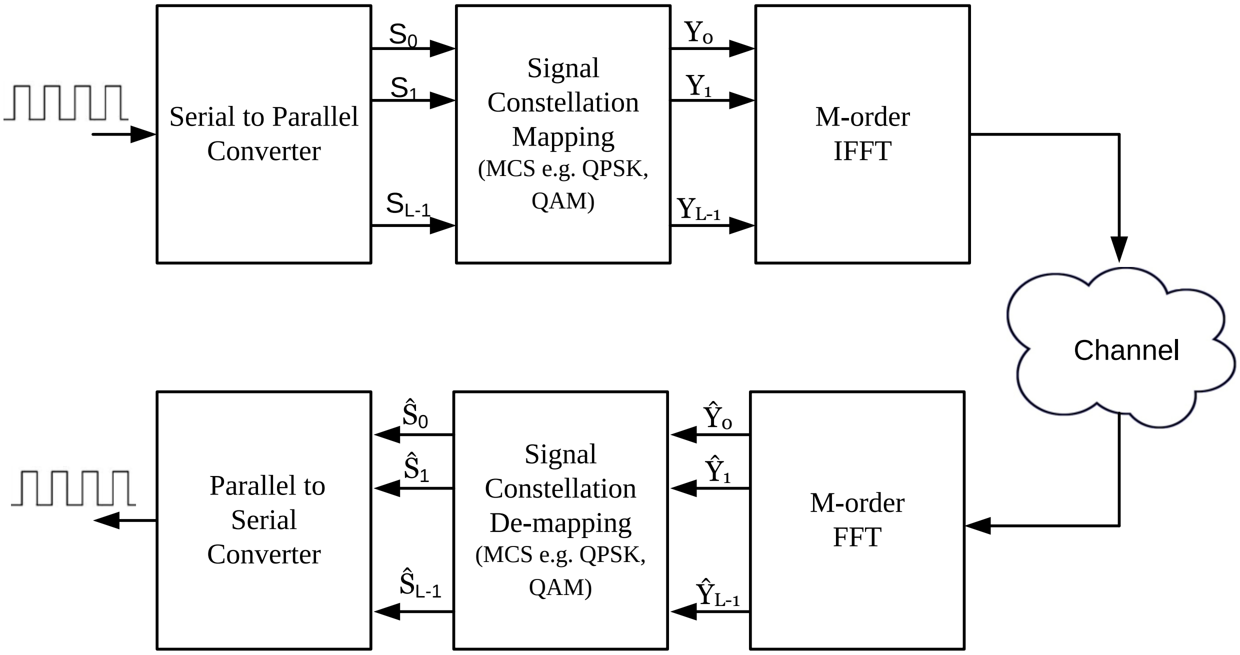


Figure 3.9: An OFDM Communication System

The OFDM signal is the transmitted over a multipath channel and the conjugate operation is performed on the receiver. An equivalent FFT operation is used to obtain the frequency domain vector of the transmitted signal on the receiver. If $y(t)$ is the transmitted symbol at time instant $t$ when $h(t)$ is continuous time channel impulse and $n(t)$ is the additive noise, then received signal in multipath environment is given as

$$x(t) = y(t) * h(t) + n(t) \qquad (3\text{-}2)$$

Considering the presence of cyclic prefix (CP) in the transmitted symbol, the received discrete time OFDM symbol x[k] using vector notation becomes

$$\begin{bmatrix} x_0[k] \\ \vdots \\ x_{M-1}[k] \end{bmatrix} = \begin{bmatrix} y_0[k] & y_{M-1}[k] & \cdots & y_{M-CP+1}[k] \\ \vdots & \ddots & \ddots & \vdots \\ y_{M-1}[k] & y_{M-2}[k] & \cdots & y_{M-CP}[k] \end{bmatrix} . \begin{bmatrix} h_0[k] \\ \vdots \\ h_{CP-1}[k] \end{bmatrix} + \begin{bmatrix} n_0[k] \\ \vdots \\ n_{M-1}[k] \end{bmatrix} \tag{3-3}$$

$$\begin{bmatrix} x_0[k] \\ \vdots \\ x_{M-1}[k] \end{bmatrix} = \text{Å} . \begin{bmatrix} h_0[k] \\ \vdots \\ h_{CP-1}[k] \end{bmatrix} + \begin{bmatrix} n_0[k] \\ \vdots \\ n_{M-1}[k] \end{bmatrix} \tag{3-4}$$

Since peak values occur at diagonal locations, therefore FFT of the matrix Å with the subcarriers with varying peak values produces a diagonal matrix (Van de Beek *et al.* 1995; Golub and Van Loan 2012). This implies that Å can be expressed as a Hermitian matrix product of vector *Y*, that is: $\text{Å} = F^H Y F$ where $F$ is the FFT matrix and $Y$ is a diagonal matrix whose elements are given by the equation 3.5 and 3.6 respectively.

$$F[k] = \frac{1}{\sqrt{M}} \exp\left(-2\pi j L \frac{m}{M}\right) \tag{3-5}$$

$$Y_m[k] = \frac{1}{\sqrt{M}} \sum_{L=1}^{M} y_L[k] \exp\left(-2\pi j L \frac{m}{M}\right) \tag{3-6}$$

Therefore, the frequency domain representation of the received signal sample $X[k]$ after the FFT is given by

$$\begin{bmatrix} X_0[k] \\ \vdots \\ X_{M-1}[k] \end{bmatrix} = \begin{bmatrix} Y_0[k] & 0 & \cdots & 0 \\ \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & Y_{M-1}[k] \end{bmatrix} . \begin{bmatrix} H_0[k] \\ \vdots \\ H_{M-1}[k] \end{bmatrix} + \begin{bmatrix} N_0[k] \\ \vdots \\ N_{M-1}[k] \end{bmatrix} \tag{3-7}$$

$$X[k] = Y[k].H[k] + N[k] \tag{3-8}$$

Since the Channel Frequency Response (CFR) H can be expressed in terms of Channel Impulse Response (CIR) as $H = F.h$ (Van de Beek *et al.* 1995), then equation (3.8) becomes

$$X = Y.Fh + N \tag{3-9}$$

### 3.4.1 LINEAR FILTERING

The linear filtering is the common approach for determining a channel estimate over reference signals. The channel estimation can be done in either frequency or time domain (Dai *et al.* 2012; Sesia, Toufik and Baker 2012). The value of channel estimate is then interpolated between several reference signal positions. For instance, the de-correlation of reference signal performed in the frequency domain to determine Channel Transfer Function (CTF) on reference signal is given by equation (3-10):

$$\hat{v}_i = v_i + \tilde{v}_i \tag{3-10}$$

$$\hat{v}_i = F_i h + \tilde{v}_i \tag{3-11}$$

For $i$ is an element of (0,…, M) where M is the number of available reference signals, $v_i$ is the CFR on the reference signal and $\tilde{v}_i$ is the white noise vector.

If a generic linear filter $D$ is used to perform interpolation for determining a channel estimate over a subcarrier at index $n$, then the CTF at subcarrier $n$ can be written as

$$\hat{v}_n = D\hat{v}_i \tag{3-12}$$

The estimation error of the interpolated CTF estimate on subcarrier $n$ can be expressed as the difference between the actual and estimated value and is given by,

$$\tilde{v}_n = v - \hat{v}_n \tag{3-13}$$

$$\tilde{v}_n = Fh - D(F_i h + \tilde{v}_i) \tag{3-14}$$

$$\tilde{v}_n = (F - DF_i)h + D\tilde{v}_i \tag{3-15}$$

The common linear filters make use of techniques such as Least-Squares (LS) and Minimum Mean-Square Error (MMSE) (Van de Beek *et al.* 1995; Dai *et al.* 2012; Kalakech *et al.* 2012). The LS and MMSE channel estimate on subcarrier at index $n$ are presented in equations (3-16) and (3-17) respectively.

$$\hat{v}_n = F(F_i^H F_i)^{-1} F_i^H \hat{v}_i \tag{3-16}$$

$$\hat{v}_n = F(F_i^H F_i + \sigma_{\tilde{v}_i}^2 C_h^{-1})^{-1} F_i^H \hat{v}_i \tag{3-17}$$

$C_h = \mathrm{E}[hh^H]$ is the covariance matrix of channel and $\sigma_{\tilde{v}_i}^2$ is the additive noise variance.

The LS is simple to implement but cannot be applied directly to LTE because of ill-condition of the matrix inversion on the unmodulated subcarriers (Sesia, Toufik and Baker 2012). The MMSE produces a more accurate estimate than LS. However, MMSE is computationally complex because it requires second order characteristics of the channel to perform the channel estimation (Van de Beek *et al.* 1995).

### 3.4.2 LOCAL AVERAGING FILTERING

This is an L 1 filtering technique used as alternative to linear filtering and is performed as a convolution of exponential filter with the downlink received signal (Mark and Leu 2007). The technique is based on local scattering function  that estimates the power spectrum of measured data, a portion of the reference element, using an orthogonal window (Matz 2005; De la Roche and Allen 2012). The individual estimate of the spectra from the independent window data is aggregated and averaged to obtain a low variance estimate of the channel (Thomson 1982; Percival and Walden 1993). Figure 3.10 shows a schematic representation of local averaging filtering technique based on local scattering function.

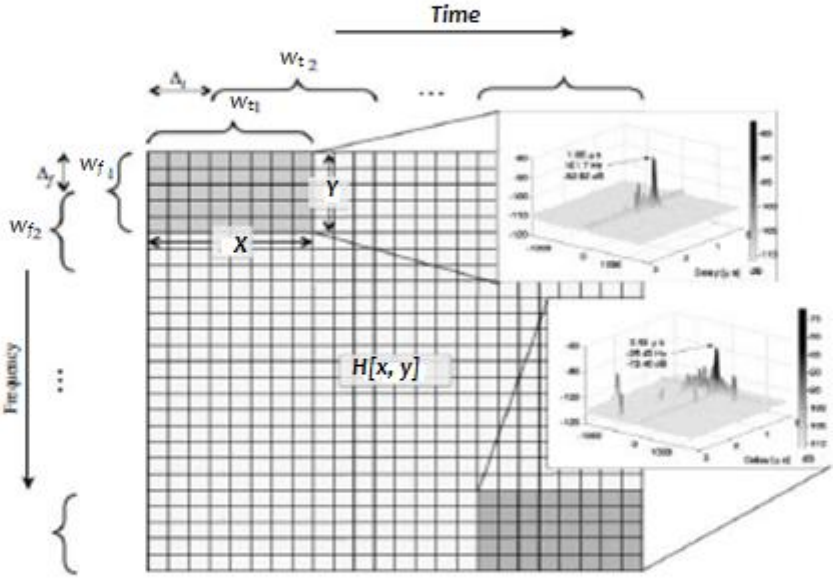


Figure 3.10: A schematic representation of local averaging filtering technique (De la Roche and Allen 2012)

Considering the Figure 3.10, the channel frequency response of the sampled spectra in time and frequency domain is represented by $H\ [x, y]$ where $x$ an element of $(0, \ldots, X\text{-}1)$ and $y$ an element of $(0, \ldots, Y\text{-}1)$ are the time and frequency domain components respectively. If the index of each tapped spectral at a specific period corresponds to $w\ [t,$

*f]*, then the relative sampled spectral index in time and frequency domain are respectively given by x' $\in$ ($-\frac{X}{2}$, ..., $\frac{X}{2}-1$) and y' $\in$ ($-\frac{Y}{2}$, ..., $\frac{Y}{2}-1$). Therefore, the local scattering function estimate at each index, corresponding to a discrete sample, is given by

$$\xi[w_t, w_f] = \frac{1}{MN}\sum_{p=0}^{MN-1} |H^{(Q_p)}[w_t, w_f]|^2 \tag{3-18}$$

$$H^{(Q_p)}[w_t, w_f] = \sum_{x'=-\frac{X}{2}}^{\frac{X}{2}-1} \sum_{y'=-\frac{Y}{2}}^{\frac{Y}{2}-1} H.Q_p \tag{3-19}$$

where M and N denotes the total number of tapped spectral used both in time and frequency domain. The $Q_p$ is the window function expressed as

$$Q_p = f_{av}[n] = \frac{e^{-n/N_{av}}}{1-e^{-1/N_{av}}} \quad n = 0, 1, 2, 3, \ldots \tag{3-20}$$

where $f_{av}$, represented by equation (3-20), is the exponential filter used for the local averaging and $N_{av}$ is the averaging window size.

### 3.4.3 L 3 FILTERED LOCALLY AVERAGED L 1 SIGNAL

The L 3 filtering is performed using first order Infinite Impulse Response (IIR) filter. In order to make local averaging filtering suitable for handover decision in LTE, the L 3 filtering is performed on locally averaged L 1 signal and effect of L 3 filtering is observed in handover performance. The expression for an L 3 filter configuration as specified in (3GPP 2009) is represented by a function shown in equation (3-21).

$$Q_n = \left\{1 - \left({}^1\!/_2\right)^{\frac{c}{4}}\right\}.Q_{n-1} + \left({}^1\!/_2\right)^{\frac{c}{4}}.\xi \tag{3-21}$$

where $Q_n$ is the updated L3 output of first order IIR filter used for handover evaluation criteria, $Q_{n-1}$ is the previous L3 filtering output, $\zeta$ is the latest output of local averaged L1 filtering and $c$ is the L3 filter coefficient.

## 3.5 HANDOVER PROCEDURE IN LTE

One of the major goals of handover in LTE is to provide a seamless transition of UE from one cell to another without interruption to user's voice or data services. The transition between the cells, from serving cell to target cell, comes with stringent delay requirements. Also, the handover in LTE is UE-assisted network controlled handover.

The handover procedure in LTE is initiated with UE performing measurement of attributes on its serving cell and neighbouring cells. The UE sends this measurement report to the eNodeB (source) in its serving cell. The UE performs L 3 filtering on the measurement report at its radio resource control layer (Sesia, Toufik and Baker 2012; ETSI 2012b). As discussed in previous section, the L 3 filtering is a recommended processing needed to ensure conformity of the measurement report to pre-defined criteria before it is used for decision. The handover decision is performed by the eNodeB. The overall handover procedure is illustrated in Figure 3.11 and is divided into initialization, preparation, execution and completion phases.

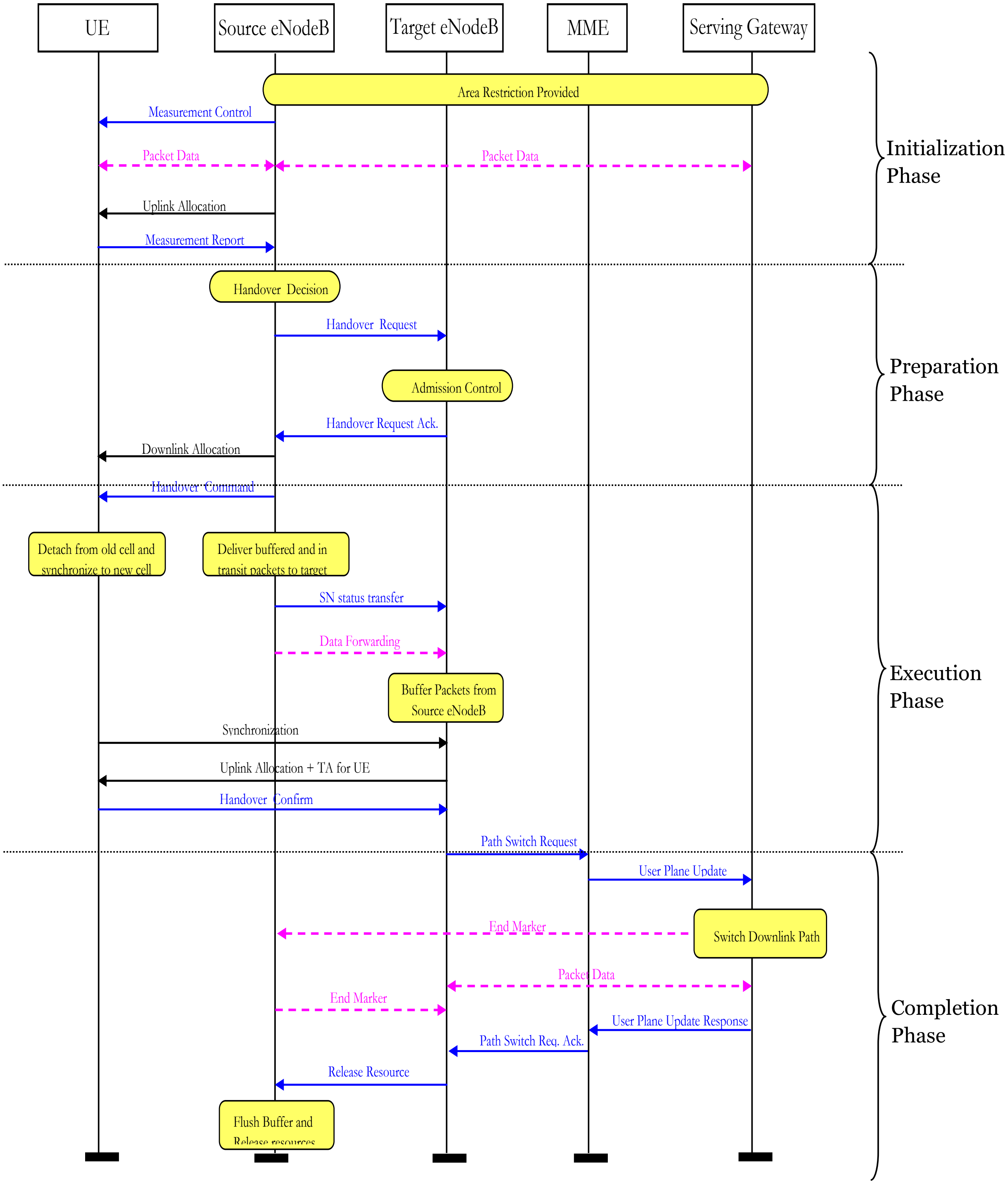


Figure 3.11: LTE handover procedure (ETSI 2012b)

### 3.5.1 HANDOVER INITIATION/PREPARATION

In handover preparation phase, the source eNodeB makes decision to handover the UE based on filtered measurement report and radio resource management information available. The source eNodeB sends handover request to target eNodeB. This is followed by exchange of necessary signaling information between source and target eNodeB over X2 interface (3GPP 2009). The target eNodeB performs admission control to guarantee that resource is available for the UE and sends handover request acknowledgement to the source eNodeB. The reception of handover request acknowledgement at the source eNodeB initiates handover execution

### 3.5.2 HANDOVER EXECUTION

In this phase, the source eNodeB issues handover command to the UE in downlink and begins data forwarding to the target eNodeB over X2 interface. The data forwarding is a necessary process to minimize amount of data loss during handover. Two modes that may be used for downlink packets data forwarding in LTE user plane are seamless and lossless (Lin *et al*. 2010; Sesia, Toufik and Baker 2012; Amin and Yla-Jaaski 2013). The mode is chosen based on bearer or sensitivity of UE downlink data packets to packet loss. The data forwarding is followed by the source eNodeB releasing its connection with the UE and sending status transfer message to the target eNodeB. Then, the UE synchronizes with the target eNodeB. The target eNodeB responds with uplink allocation and timing advance for the UE. This phase is finalized with the UE sending handover confirm message to the target eNodeB which in turns starts sending data to the UE.

### 3.5.3 HANDOVER COMPLETION

The handover completion phase is implemented after a successful handover execution. This phase involves processes to release all the resources used for handover. The phase is triggered by the target eNodeB informing the source eNodeB to release resources for the handover.

## 3.6 HANDOVER DESIGN GOAL

The design goal of most handover design is to maintain continuous connection, enhance capacity and quality of service perceived by mobile user. According to Pollini (1996) and Tripathi, Reed and VanLandingham (2001), the goals of handover design are as follows.

### 3.6.1 REDUCTION IN NUMBER OF HANDOVER FAILURE

The preservation of ongoing service is essential during handover. So, every handover design tries to ensure reduction in the number of service termination that occurs during handover.

### 3.6.2 REDUCTION IN OVERALL NUMBER OF HANDOVER INITIATED

Handover procedure is critical because of the need to select appropriate target among several neighbouring cells. The selection must ensure that resource of the new cell can support the new user (handover UE). Inappropriate selection may lead to the new user initiating handover after a little time in the new cell which is called ‘ping-pong’ handover. The ping-pong handover, which is switching between cells, degrades the overall performance of the cell and reduces perceived quality of the service by the user. Therefore from a design point of view, it is necessary to minimize the overall number of handover initiated.

### 3.6.3 REDUCTION IN HANDOVER DELAY

The transition of user from one cell to another should be fast to avoid degradation in quality of service. This is more important for handover in LTE which is hard handover with interruption in the user plane.

### 3.6.4 REDUCTION OF HANDOVER IMPACT ON SYSTEM AND SERVICE PERFORMANCE

The impact of handover on overall system should be minimized. Therefore, an efficient handover algorithm should achieve a balance between service quality and system performance which includes the overall cell throughput and spectral efficiency of the cell.

## 3.7 HANDOVER PERFORMANCE EVALUATION

The handover performance evaluation metrics are chosen according to system level performance and mobility related performance (Gora and Gouraud 2010; ETSI 2012b). The system level performance is analyzed in terms of peak user, average user and cell edge user throughput and spectral efficiency. The mobility related performance is evaluated as handover success rate and handover delay.

# CHAPTER 4

# MODEL IMPLEMENTATION

This chapter presents the implementation of the handover process of this research. The implementation is done using the LTE system level simulator. This is in accordance with specification for International Mobile Telecommunications Advanced (IMT-Advanced) that evaluation of radio technology be performed through simulation, analytical and inspection procedure (ITU-R 2009). The system level simulator helps perform holistic evaluation of mobility on the overall communication system with respect to several users. The users provide the channel state information of the downlink to the eNodeB to enable effective handover decision making. The channel model approach is used to allow for realistic modelling of the propagation condition experienced by the users while considering investigated scenarios.

## 4.1 SIMULATION TOOL

The system level simulator employed for this research work is developed with MATLAB® using object-oriented programming and allows for study of various aspects of the LTE network (Mehlführer *et al.* 2011). The simulator is adapted for the two LTE handover filtering investigated namely linear and local averaging. In order to examine the performance of each of the filtering techniques on handover, necessary changes were made to the physical layer and radio resource layer of the simulator. The simulation is performed in two phases. In the first phase, investigation of the suitability of the local average handover filtering technique is evaluated on the overall performance of the LTE system. Having seen improvement, the impact of the L 3 filtering on the handover decision is then carried out in the second phase. The simulation parameters and system configurations are ensured to be in conformity with recommendations in International Telecommunication Union Radiocommunication (ITU-R) and 3GPP standards.

## 4.2 KEY PERFORMANCE INDICATORS (KPI)

The KPI are the technically chosen characteristics in evaluating the performance of a communication system. A typical communication system involves several cells and performance of a radio communication link is influenced by other links from neighboring cells due to interference. Hence, the performance of the radio links and capacity achievable within the cells of a communication system needs to be evaluated. The system performance in terms of cell capacity is evaluated using normalized user throughput and cell spectral efficiency while the reliability of the radio links due to impact of interference and user mobility is evaluated using average handover failure (ITU-R 2009; Gora and Gouraud 2010; Guttman-McCabe 2011; ETSI 2012c; De la Roche and Allen 2012). The KPI are in accordance with the recommendation for system-level simulation evaluation for IMT-Advanced (ITU-R 2009; ETSI 2012c).

### 4.2.1 NORMALIZED USER THROUGHPUT

The normalized user throughput is the ratio of correctly delivered bits to active session time and the overall bandwidth available in the system. It is measured in bits per second per hertz (bps/Hz) and represented by equation 4.1. The throughput is measured separately for either downlink or uplink and can be performed using a single user or several users. Therefore, the overall cell throughput is the sum of the individual user throughputs as expressed by equation 4.2.

$$normalized\ user\ throughput = \frac{correctly\ delivered\ bits\ for\ a\ user}{active\ session\ time * available\ bandwidth} \tag{4.1}$$

$$cell\ throughput = \frac{transferred\ data\ volume}{transfer\ time} \tag{4.2}$$

### 4.2.2 CELL SPECTRAL EFFICIENCY

The cell spectral efficiency is the sum of the normalized user throughputs over a number of users divided by the number of cells. Assuming the number of users is $N_{UE}$ and there are $N_{CELL}$ numbers of cells then the cell spectral efficiency can be represented by the expression shown in equation 4.3. The Cumulative Distribution Function (CDF) of spectral efficiency, for a given number of users per cell, shows the distribution of capacity within the cell and the possible capacity to expect.

$$cell\ spectral\ efficiency = \sum_{UE=1}^{N_{UE}} \frac{normalized\ user\ throughput}{N_{CELL}} \tag{4.3}$$

Although it is known that other factors such as scheduler, modulation scheme affect the achievable spectral efficiency, the evaluation of each handover filtering technique within the cell coverage is performed to observe impact on overall cell capacity while these other factors are kept constant. It is worthy of note that cell spectral efficiency is a principal indicator that helps operator determine the capacity to expect in a cell (Guttman-McCabe 2011).

### 4.2.3 HANDOVER FAILURE

The handover failure is an indicator of mobility performance on the overall network. This is because of negative effect of multiple handovers on the system. After a failed handover, a new handover procedure is initiated to get the user connected to the system. This consequently impacts negatively on network performance due to increase in number of signaling overhead required for each handover procedure which involves re-routing of network resources between several network nodes. A handover failure is very likely to result in service failure or reduced QoS and should be avoided as possible to preserve continuous service provisioning. Hence, it is considered as one of the most important performance indicators for handover and user mobility.

Handover can fail due to a number of reasons. One being that the signal strength can drop below the minimum signal strength required for acceptable communication link quality which may lead to service disruption or termination. Another reason is that handover failure may be as a result of long handover delay due to error in UE measurement report which may cause deterioration of the radio link or loss in connection to the serving eNodeB. In the second case, the failure is due to the inefficient handover procedure which is mainly based on handover initiation. Therefore, the handover failure due to handover measurement and filtering is considered in this study. The average number of handover failure is as defined in equation 4.4.

$$Average\ handover\ failure = \frac{The\ amount\ of\ failed\ handover}{Total\ amount\ of\ triggered\ handover} \tag{4.4}$$

## 4.3 SIMULATION MODEL

A radio network layout with hexagonal grid using wraparound seven tri-sector (cell 0, cell 1, cell 2) sites are used for the system level simulation. Figure 4.1 shows the cell layout used for the simulation. A site hosts an eNodeB at its centre. The eNodeB provides coverage to the three adjacent cells that make up a site.

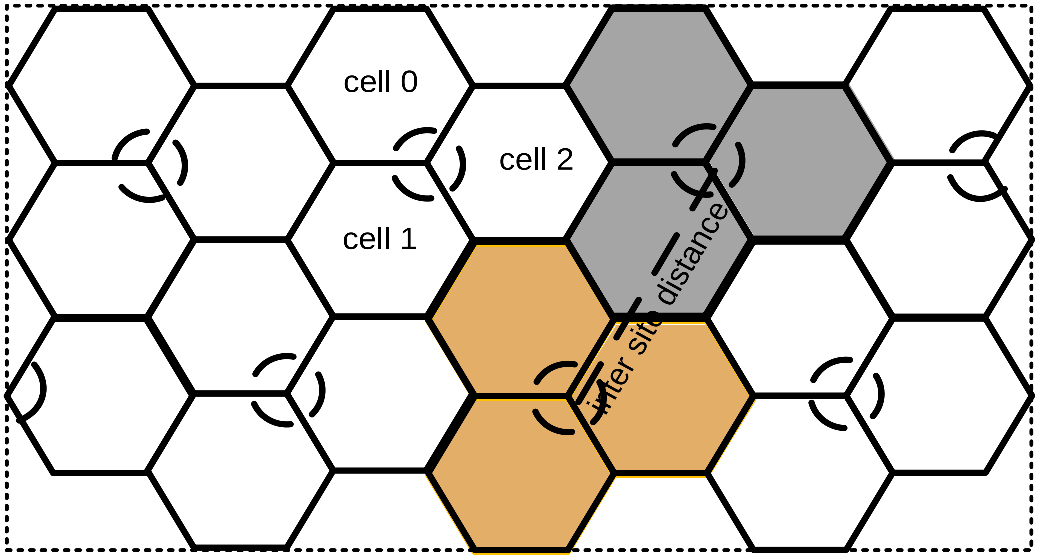


Figure 4.1: Network layout seven-site hexagonal grid

The system bandwidth for the simulation is 10 MHz. The bandwidth is divided into resource blocks of 180 kHz equal size. Each resource block consists of 12 subcarriers each with size 15 kHz and Transmission Time Interval (TTI) is 1 ms equivalent to two time slots. The number of user equipments at start of simulation is kept constant during the simulation period. The user equipments are uniformly distributed over the network coverage with random initial position chosen from the range [$0^o$, $360^o$]. The user equipments are moving with fixed speed in a random direction during the simulation. The speed of user equipment is chosen from 3 km/h, 30 km/h and 120 km/h depending on the scenario as recommended in (3GPP 2008b). The inter-site distance of each simulation scenario follows the specifications by guidelines for evaluation of radio interface technologies for IMT-Advanced (ITU-R 2009). The user equipments have active full-buffer traffic during the simulation. The channel estimation of the signal received at user equipment is dependent on the distance dependent path loss, shadow fading and fast fading. The path loss model used is as specified in (3GPP 2006). The shadow fading in Claussen (2005) with standard deviation of 8dB and 0 mean, and fast fading in Hentilä *et al.* (2007) are used for the simulation. The details of other simulator parameters are provided in Table 4.1.

Table 4.1: Parameters and assumption for simulation

| **Parameters** | **Assumption** |
|---|---|
| Cell Layout | Hexagonal grid – 7 sites, 3sectors per eNodeB |
| Carrier frequency | 2 GHz |
| Number of physical resource block (PRB) | 50 |
| Number of subcarrier per PRB | 12 |
| System Bandwidth | 10 MHz , 180 kHz per PRB |
| eNodeB Tx Power | 46 dBm |
| Number of UE per sector | 10 |
| Traffic Type | Full buffer |
| Handover Margin | 1 dB |
| L3 sampling interval | 200 TTI |
| L3 filter coefficient | 4 |
| Averaging window ($N_{av}$) | 5 and 6 |
| UE direction | Range [$0^o$,$360^o$] |
| UE speed | 3 km/h, 30 km/h,120 km/h |
| UE noise figure | 7 dB |
| UE position | Uniform distribution |
| Packet Scheduler | Proportional fair |
| Path loss | $128.1 + 37.6\log_{10}$ (R in km) dB |
| Shadow Fading | Standard deviation = 8 dB<br>Correlation mean = 0<br>Correlation between eNodeB = 0.5 |
| Fast fading | Winner channel Model |

## 4.4 SPECTRAL EFFICIENCY

The resource-limited nature of wireless radio access necessitates the efficient use of the spectrum. The knowledge of spectrum efficiency of a technology and radio-channel bandwidth enables estimation of capacity within a cell and makes spectral efficiency to be one of the major deployment factors of interest to operators. Due to the requirements of LTE system, enhanced capacity is vital as it allows operators to provide wider coverage for users. Also, high capacity within the cell will also bring about satisfying experiences of true mobile broadband when users are accessing mobile data-services and applications.

The following sections present the results and discussion on cell spectral efficiency at different speeds when each of the handover filtering technique is applied by users in the system.

### 4.4.1 SPECTRAL EFFICIENCY AT 3 KM/H

The scenario presented in this section is with cell radius of 200 m and speed of 3 km/h. The channel is urban micro-cell model while other system simulation parameters are assumed constant. The evaluation methodology is applied to compare the system performances under the application of both handover filtering techniques when user equipments are moving at this speed.

In Figure 4.2, the empirical cumulative distribution function (ECDF) of average user equipment's spectral efficiency at speed of 3 km/h is presented. The empirical CDF shows a fair estimate of user equipments CDF and provides a consistent estimate of the real CDF at any given point (PSU 2013). It is observed that handover algorithm based on local averaging is slightly more spectral efficient than linear averaging technique in terms of the rate of information transmitted (number of bits per second per hertz). There is no remarkable difference in spectral efficiency for 10th to 30th percentile but average user spectral efficiency gradually increases from the 40th percentile to about 95th percentile. The result indicates that the capacity obtained within the cell is higher for average users and peak users when local averaging filtering is used at this speed.

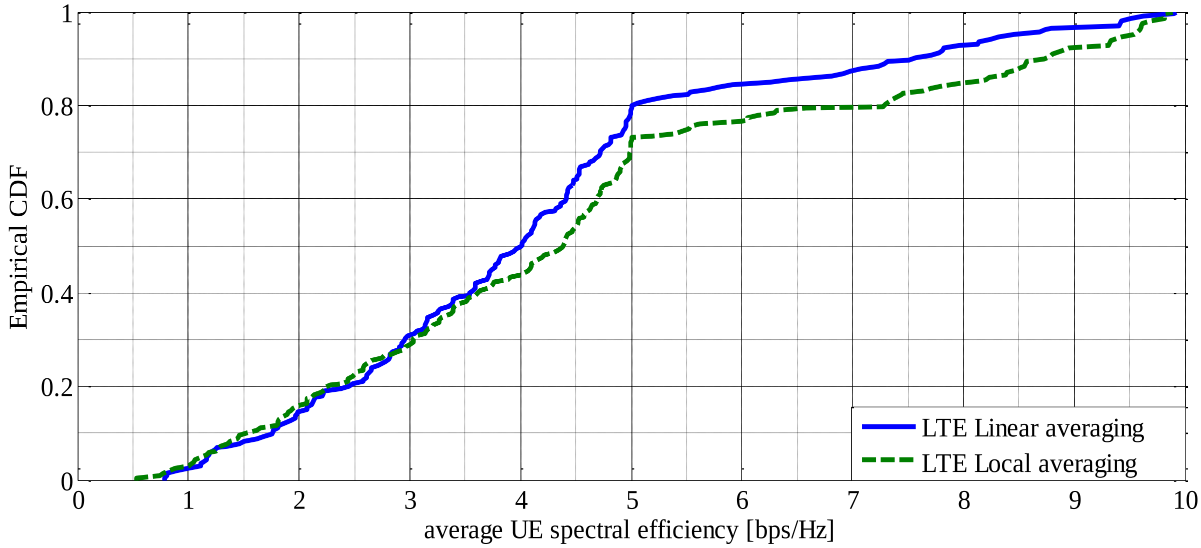


Figure 4.2: Empirical CDF of average UE spectral efficiency at speed of 3 km/h

### 4.4.2 SPECTRAL EFFICIENCY AT 30 KM/H

The analysis of the condition experienced in the system when the cell radius is 500m and user equipments are moving with speed of 30 km/h is presented in this section. The other system simulation parameters are kept constant. The KPI is used as an evaluation methodology to compare system performances under the application of both handover filtering techniques when user equipments are moving at this speed.

In Figure 4.3, the ECDF shows that the probability of average user equipment spectral efficiency is high when local averaging was used in the handover algorithm. This suggests that the number of bits transported within the bandwidth for this speed is higher for local averaging than linear averaging when used as filtering technique by the user equipment. It is observed from the result that there is a huge difference between linear averaging and local averaging in terms of the amount of information transmitted by an average user from about the 5th percentile to the 90th percentile. The local averaging technique produced higher average user spectral efficiency in bps/Hz or bit per channel use than linear averaging.

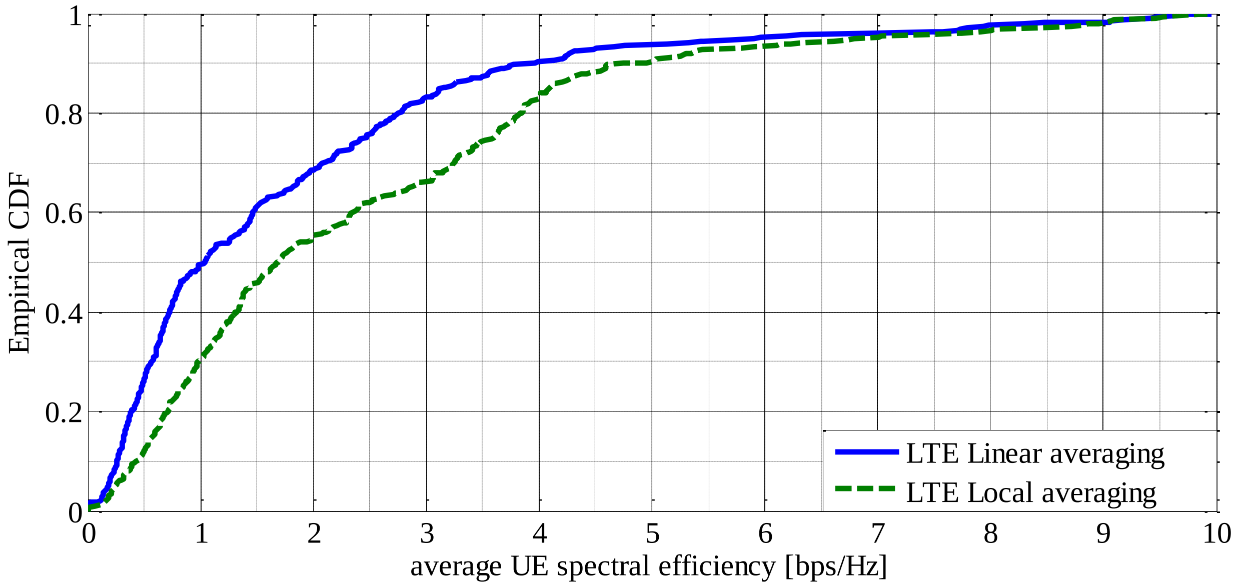


Figure 4.3: Empirical CDF of average UE spectral efficiency at speed of 30 km/h

### 4.4.3 SPECTRAL EFFICIENCY AT 120 KM/H

The section discusses the finding when the speed of the user equipment in the simulation environment is 120 km/h and cell radius is 1732 m. The effect of the handover filtering techniques used in the handover decision is investigated on system performance under the specified speed while other system parameters are kept the same.

The ECDF in Figure 4.4 shows the average user spectral efficiency in bit per second per hertz (bps/Hz) when the UE speed is 120 km/h. The result suggests that the limited frequency spectrum is more utilized when local averaging was employed than when linear averaging was used. It means that the average number of users accommodated to transmit simultaneously over the limited spectrum is high for local averaging. Although at about 95 percentile, there is a slight difference between the averaging techniques used. However, there is a clear indication of the impact of differences in the averaging technique employed on the spectral efficiency within the cell from 20 percentile to about 90 percentile.

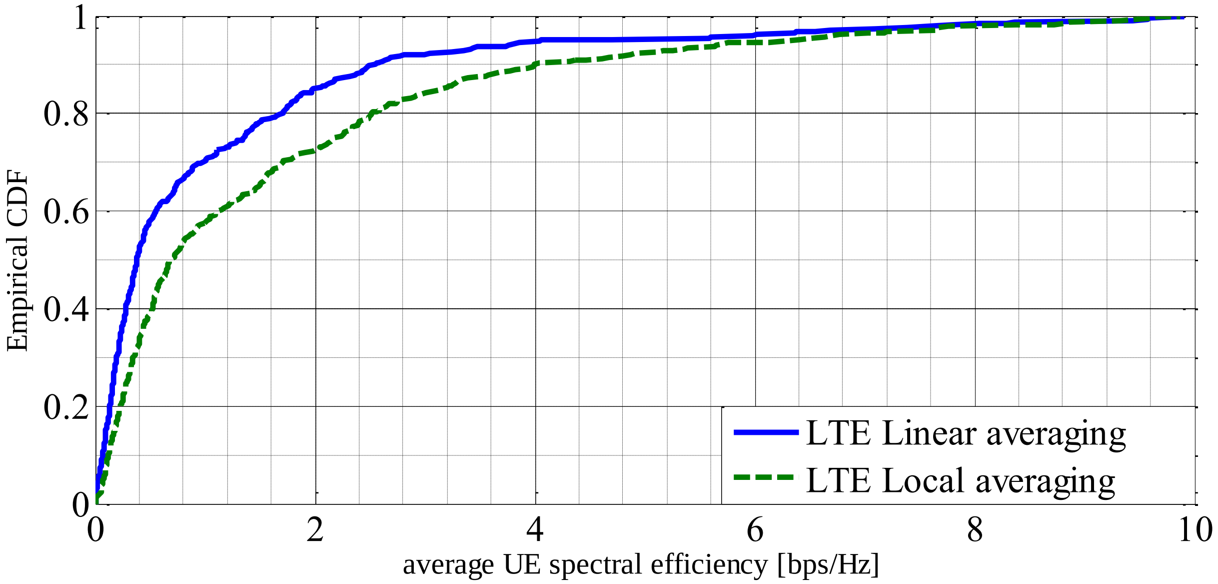


Figure 4.4: Empirical CDF of average UE spectral efficiency at speed of 120 km/h

## 4.5 USER THROUGHPUT

One of the major goals of handover in LTE like any communication system is to provide a seamless transition of UE from one cell to another without interruption to user's voice or data services while maintaining the quality of service (QoS). Maintaining the QoS is very essential and most operators use various sophisticated techniques to maximize the efficiency and performance of their networks to achieve best possible net data rates (user throughput). Therefore, the distribution of user throughput is a good indicator of the QoS and fairness achievable by users within the cell. It also shows the data rates experienced by users at different locations within the cell. For instance, ninety-five percent (95%) user throughput is considered as the peak throughput, mean user throughput is considered a typical data rate achievable within the coverage area of the network while the five percent (5%) user throughput is termed cell-edge user throughput. This explains the reason for using user throughput distribution as a metric for analysis of system level performance.

The following sections present the results of user throughput at different speeds when each of the handover filtering technique is applied by users in the system.

### 4.5.1 PEAK USER THROUGHPUT

This section presents the simulation results for peak throughput obtainable at user equipment speed of the simulated scenarios when handover filtering techniques based on linear averaging and local averaging are implemented in the system. This evaluation methodology is applied to compare system performances under the application of both handover filtering techniques when user equipments in the system are moving at these speeds.

It is observed from Figure 4.5 that effected of each filtering is not clearly distinguishable at relatively low speed of about 3 km/h. However, the handover algorithm based on local averaging filtering technique achieved a better performance in terms of peak throughput within the cell as the speed increases. It can be explained from the figure that resultant effect of averaged multiple independent spectra used by local averaging filtering is not clearly visible at low speed but gives a better estimate of the channel quality achievable by UE as the speed increases. The improved throughput experienced on the UE at higher speed when local averaging is employed is consequent upon the accuracy of the channel estimate that influences the choice of MCS which in turns increases the data rate achieved by the UE.

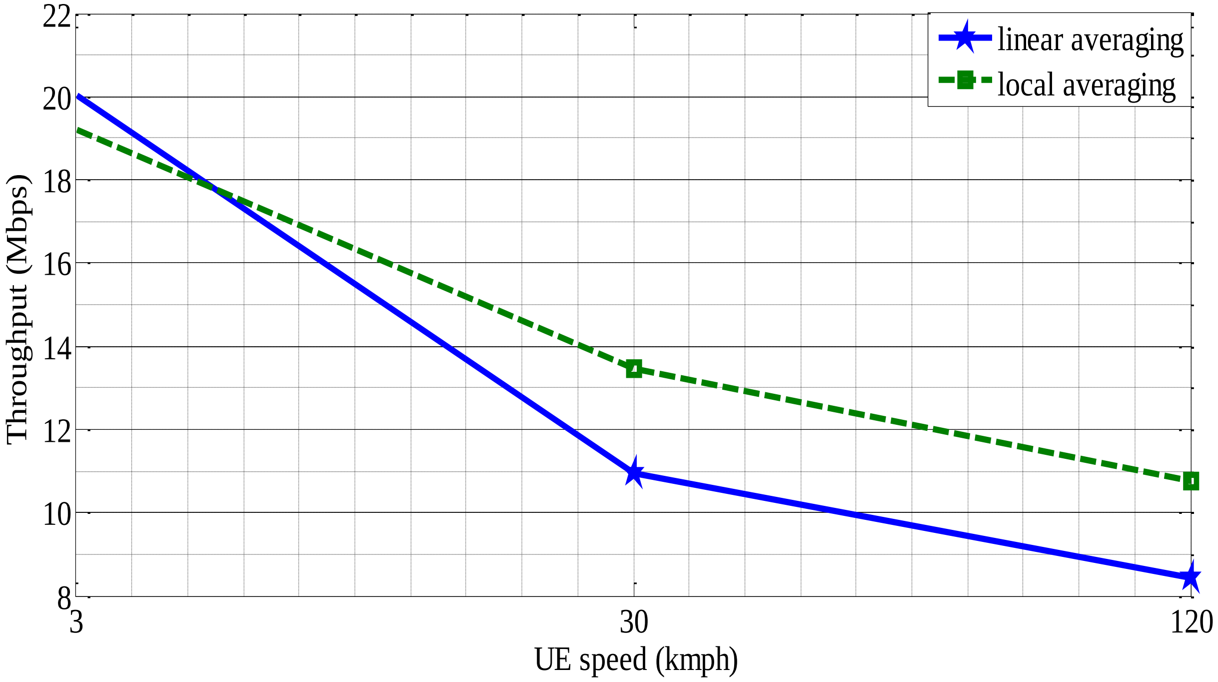


Figure 4.5: Peak user throughput at different UE speed

### 4.5.2 AVERAGE USER THROUGHPUT

The analysis of the simulation results for average throughput experienced by user in the system when the UE speeds of the simulated scenarios are varied is presented in this section. The handover filtering techniques for L 1 signal for handover decision are based on linear averaging and local averaging. This KPI is used to show comparative analysis of system performances under the application of both handover filtering techniques when user equipments are moving at these speeds.

It can be seen from Figure4.6 that the performances of the filtering techniques are almost the same for "typical" throughput experienced by the UEs. However, the average user throughput experienced when local averaging technique was employed is slightly higher than when linear averaging was employed in the handover algorithm for high mobility users. This is because at low speed the rate of change of radio channel condition experience by users is very low which makes estimation error of both filtering techniques to be negligibly small. At high speed, however, the radio channel changes at a fast rate and requires high accuracy of filtering technique to keep track of the channel condition.

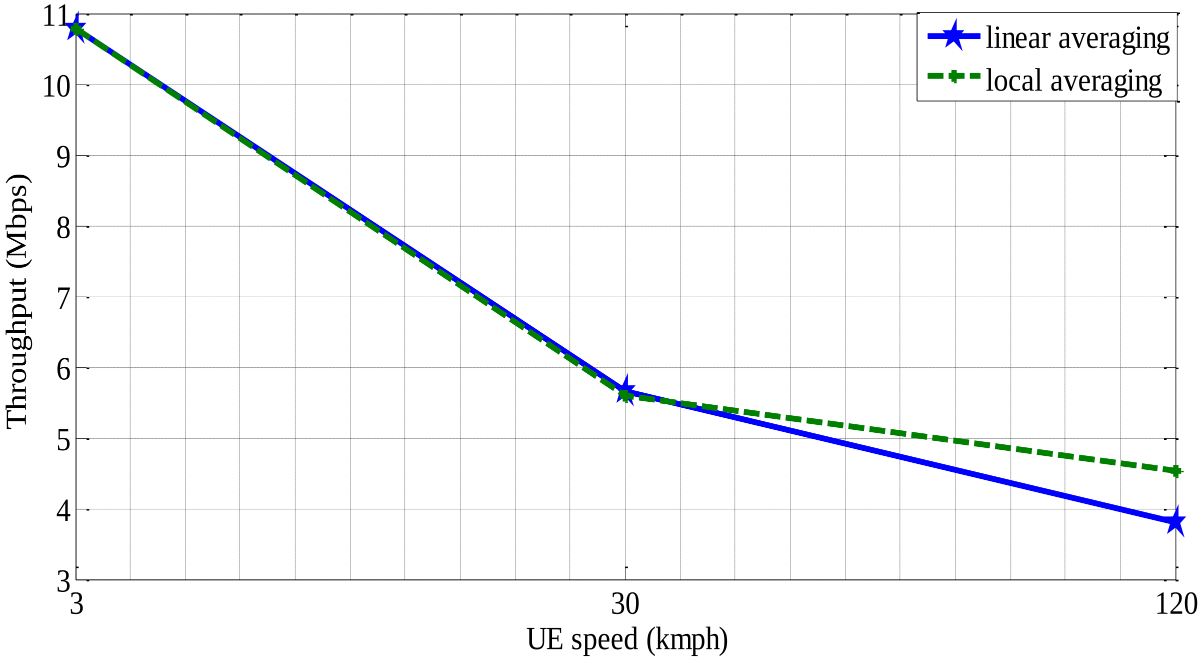


Figure 4.6: Average user throughput at different UE speed

### 4.5.3 CELL EDGE USER THROUGHPUT

This section presents the results for cell edge user throughput in the system at different UE speeds for the simulated scenarios. The handover filtering techniques for L 1 signal for handover decision are based on linear averaging and local averaging.

In Figure 4.7, the cell edge user throughput performance is observed in local averaging technique to be slightly better than linear averaging at higher user speed. Although, the cell edge user throughput for linear averaging is not as high as local averaging for low user speed but the rate of change is not as remarkable as in local averaging. However, the rate of change for cell edge throughput based on local averaging is better than linear averaging for high speed user equipments. This translates to the perceived QoS experienced by cell edge users as the speed increases. The low speed users might experience a sharp change in quality of service when local averaging technique is used while this might not be the case for UE that employs linear filtering. However, the experience is reversed for the UEs at high speed.

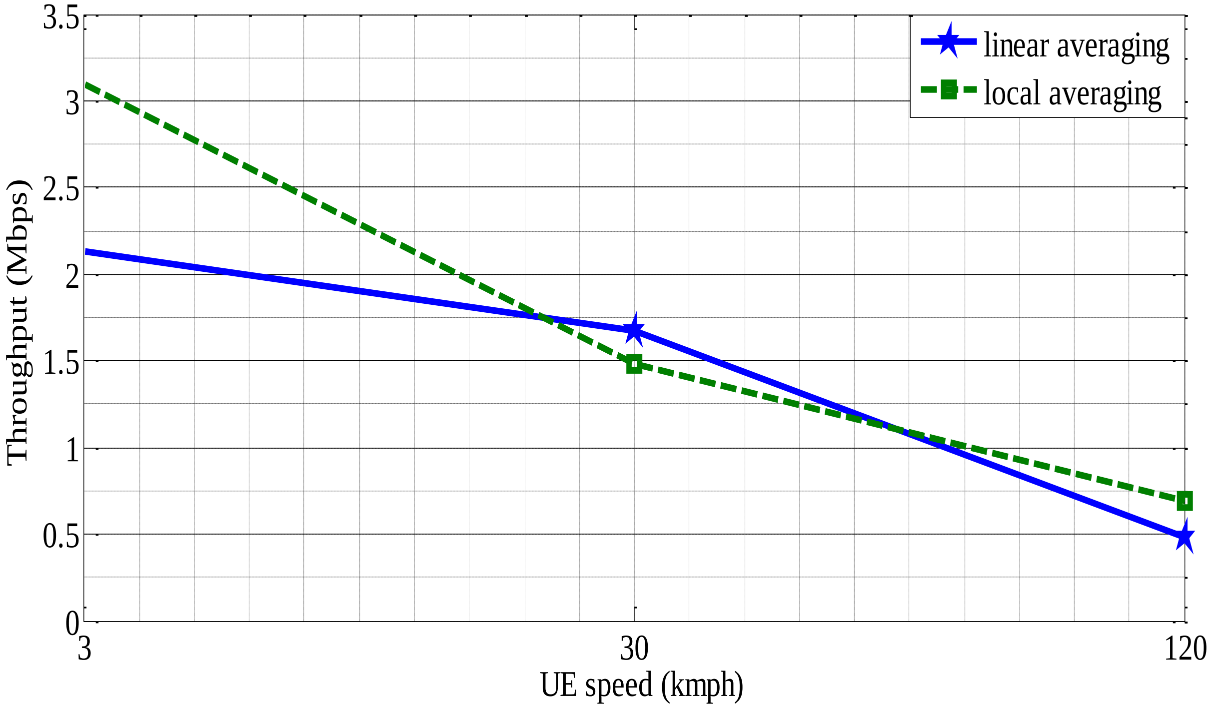


Figure 4.7: Cell edge user throughput at different UE speed

## 4.6 HANDOVER FAILURE

Handover is essential for continuous service provision and is a key to maintain the quality of service (QoS) requirement of the users. Maintaining handover is important to most operators because it is a reflection of QoS to the users. Hence like spectral efficiency, handover performance is always of interest to operators. In this section we investigate the performance of the filtering technique on handover performance using the average number of handover failure. Handover failure is one of the important KPI to evaluate LTE mobility performance because it links directly to QoS achievable on the network (ETSI 2012c). In LTE, different mobility performance is required for each scenario as stated in the standard. For instance, the low speed users (stationary or pedestrians) are expected to have continuous connectivity with fairly high data rate, while high speed users (vehicular) must be ensured to stay connected. These requirements dictate difference level of QoS among user within the cell coverage area. Therefore, the effect of the filtering technique on average number of handover failure is investigated for each of the scenarios.

Figure 4.8 shows the average number of handover failure per user equipment speed. When the speed is as low as 3 km/h, the rate of handover failure obtained is low for both handover filtering techniques with handover failure in linear averaging as low as less than 1.5%. The average number of handover failure observed is also remarkably low for local averaging with a value less than 1%.

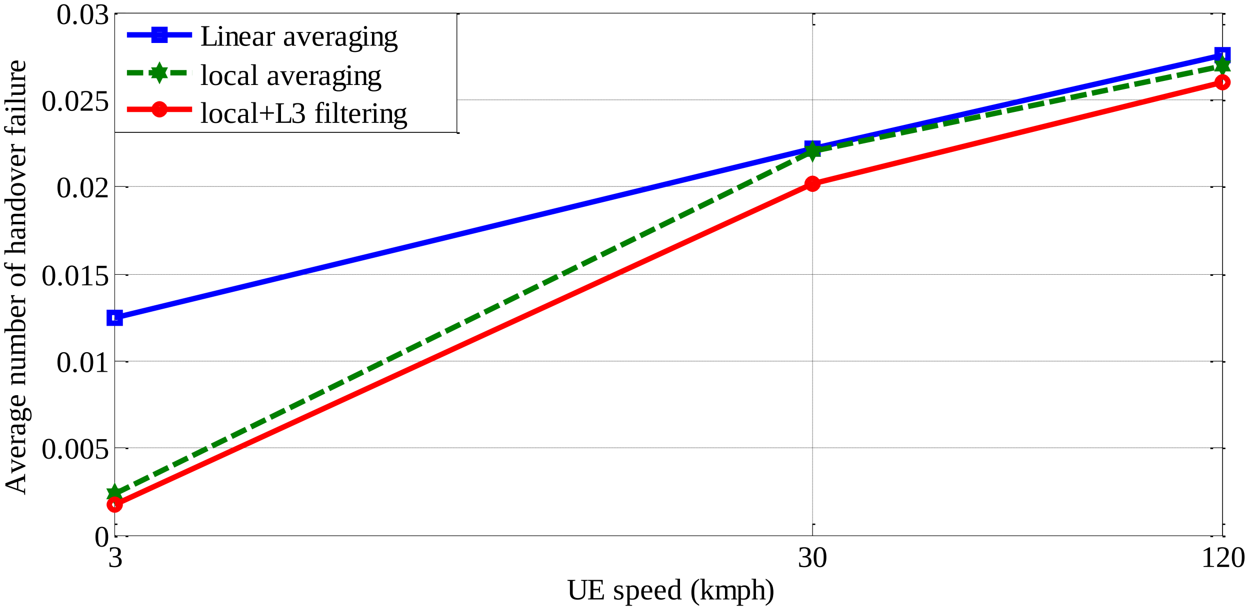


Figure 4.8: Effect of UE speed on average number of handover failure

As expected, the average number of handover failure increases as the user speed increases. At high speed, the difference in performance of both handover filtering techniques is not too significant. However, the effect of L3 filtering on handover failure becomes clearly visible at high speed. This is because L 3 filtered output that is used for triggering the handover decision reduces the L 1 measurement and estimation error that becomes high as user speed increases due to the high uncorrelated nature of the time-varying channel between user equipments and base stations.

# CHAPTER 5

# CONCLUSION AND FUTURE WORK

This chapter presents a summary of the research study documented in this thesis. The synopsis of the research task and the final result is presented first. Then, insights into possible future work and improvement are stated.

## 5.1 CONCLUSION

In order to handle the data explosion on mobile telecommunication, several proposals were presented on how well they could address this demand. Out of the numerous propositions, the 3GPP is observed to be the likely possible solution that will help achieve the goal of mobile broadband. Then 3GPP comes up with a technology that will help maintain a competitive edge for the future mobile network. This technology is LTE of UMTS. Like any mobile communication system, mobility of user presents a serious challenge to LTE. This is because of high QoS demand of mobile user. The possibility of achieving the high QoS demand is further jeopardized as a user moves across cells due to interference from the neighbouring cells. This is why the handover of user between base stations is considered as a major aspect of mobile cellular networks because it impacts on the capacity within the cell and the achievable QoS by users. Hence, the work in this thesis is based on handover in downlink LTE. The research focuses on how to ensure accuracy of the downlink measurement needed to enhance promptness and accurate handover decision that is required for high QoS demands of mobile users. Two types of handover filtering techniques are investigated. Handover decisions based on each filtering technique are implemented in a dynamic LTE system-level simulator. The simulator helps to analyze the performance of each technique on the overall LTE system and mobility. The result of the analysis shows the effect of each handover filtering techniques on achievable capacity within the system in terms of spectral efficiency and user throughput while mobility related performance is presented in terms of average number of handover failure.

The spectral efficiency for pedestrian speed (3 km/h) user equipment for local averaging with respect to linear averaging produces an increase of 9.1%, 10.8% and 15.1% for cell-edge, average and peak users respectively. From the result obtained at UE speed of 30 km/h, the comparison between the linear averaging and local averaging technique shows increased capacity of 31.6%, 37.9% and 15.3% for cell-edge, average and peak user respectively when local averaging is used as filtering technique by the user equipment. Likewise, the spectral efficiency of high speed (120 km/h) UE also produces 52.1%, 68.7% and 40.8% increase for cell-edge, average and peak user respectively when local averaging is compared with linear averaging technique in the simulation environment.

The system throughput for cell-edge users shows 44.8%, 11.7% and 42.8% improvement for UE speed of 3 km/h, 30 km/h and 120 km/h respectively when local averaging filtering was employed. The peak user throughput for linear averaging is 4.1% better than local averaging. However, the local averaging shows better performance of about 23.1% and 27.4% for UE speed of 30 km/h and 120 km/h respectively.

Finally, the result obtained from comparison of average number of handover failure between the L 1 filtering techniques shows that there is a significant reduction in average number of handover of about 80.9% for pedestrian users (3 km/h) when local averaging is employed. The result for the UE speed of 30 km/h and 120 km/h show reduction of about 0.5% and 4.6% respectively in average number of handover failure for local averaging filtering technique. The application of L 3 filtering on local averaging further improved the performance by 26.9%, 8.6% and 0.8% for UE speed of 3 km/h, 30 km/h and 120 km/h.

## 5.2 FUTURE WORK

This research work considers how handover downlink measurement used for handover decision impact on the performance achievable on the whole LTE system. This work like any worthwhile project provides direction for further improvements. The work in this thesis covers the handover filtering techniques used by a user equipment to estimate the downlink channel quality for making handover decision. Since the measurement report is an effective way to improve quality of handover decision, considering several filtering techniques are vitally important. Thanks to 3GPP for not raising the bar on the particular filtering technique to employ in LTE system. It then behooves us to try many possible filtering techniques until desired results are achieved. Some of the techniques proposed in Kalakech *et al*. (2012), Dai *et al*. (2012), Chin, Ward and Constantinides (2007) and Van de Beek *et al*. (1995) can be investigated, compared and implemented in the LTE system to see how they improve quality of handover decision.

# CHAPTER 6

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