TUNING OF HANDOVER PARAMETERS IN LTE-A HETEROGENEOUS NETWORKS

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EMRAH TUNÇEL

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submitted by **EMRAH TUNÇEL** in partial fulfillment of the requirements for the degree of **Master of Science in Computer Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Dean, Graduate School of **Natural and Applied Sciences** _______________

Prof. Dr. Adnan Yazıcı
Head of Department, **Computer Engineering** _______________

Dr. Cevat Şener
Supervisor, **Computer Engineering Department, METU** _______________

Examining Committee Members:

Prof. Dr. Ahmet Coşar
Computer Engineering Department, METU _______________

Dr. Cevat Şener
Computer Engineering Department, METU _______________

Assoc. Prof. Dr. Ertan Onur
Computer Engineering Department, METU _______________

Assist. Prof. Dr. Selim Temizer
Computer Engineering Department, METU _______________

Özgür Özuğur, M.Sc.
HAVELSAN _______________

Date: _______________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: EMRAH TUNÇEL

Signature :

ABSTRACT

TUNING OF HANDOVER PARAMETERS IN LTE-A HETEROGENEOUS NETWORKS

Tunçel, Emrah
M.S., Department of Computer Engineering
Supervisor : Dr. Cevat Şener

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In this work, a new handover parameter optimization algorithm for the LTE-A networks is presented. Most of the previous solutions that are proposed to solve the handover parameter optimization problem, optimize the handover parameters with considering all of the neighbor cells together. But with the introduction of heterogeneous networks to the LTE-A standards, the deployments are no longer homogeneous and the cell borders have different inter-cell interference conditions that changes according to the different cell types. To overcome this, the new algorithm optimizes the handover parameters for each of the neighbor cell separately. Since the hysteresis and time to trigger parameters cannot differentiate per neighbor cell, along with them, cell individual offset (CIO) values are tuned for providing different handover margins per neighbor cell. The proposed algorithm is tested on a simulation environment along with some of the important previous works. According to the results, the proposed algorithm performs better than the other algorithms while decreasing the handover failures.

Keywords: Mobile networks, 4G, LTE, LTE-A, Self Organizing Networks, Mobility Robustness Optimisation, Handover

ÖZ

HETEROJEN LTE-A AĞLARDA EL DEĞİŞTİRME PARAMETRELERİNİN AYARLANMASI

Tunçel, Emrah
Yüksek Lisans, Bilgisayar Mühendisliği Bölümü
Tez Yöneticisi : Dr. Cevat Şener

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Bu çalışmada LTE-A ağları için yeni bir el değiştirme parametreleri optimizasyonu algoritması sunulmuştur. Geçmişteki el değiştirme parametreleri optimizasyonu problemini çözmek için yapılan çalışmalara bakıldığında, optimizasyonun bütün komşu baz istasyonları birlikte ele alınarak çözüldüğü görülür. Fakat heterojen ağların LTE-A standartlarına eklenmesiyle birlikte, baz istasyonu yerleşimleri homojen olmaktan çıkmış ve farklı baz istasyonu tiplerine göre istasyonlar arası sınır girişimleri farklı özellikler gösterir duruma gelmiştir. Bunun üstesinden gelebilmek için, önerilen algoritma el değiştirme parametrelerini komşu baz istasyonlarını ayrı ele alarak iyileştirmektir. Gecikme ve tetikleme zamanı parametreleri komşu baz istasyonlarına göre farklı olarak belirlenemeyeceğinden dolayı, bunu sağlamak için, bu parametrelerin yanında baz istasyonu öteleme değerleri de ayarlanmıştır. Önerilen algoritma simülasyon ortamında konu üzerine daha önce yapılmış bazı önemli çalışmalarla karşılaştırılmıştır. Sonuçlara göre, el değiştirme hatalarını azaltmada önerilen algoritmanın diğer algoritmalara göre daha başarılı olduğu görülmüştür.

Anahtar Kelimeler: Mobil Ağlar, 4G, LTE, LTE-A, Kendini Düzenleyen Ağlar, Hareketliliğe Dayanıklılık Optimizasyonu, El Değiştirme

To my family...

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ALGORITHMS

LIST OF ABBREVIATIONS

3GPP	3rd Generation Partnership Project
4G	4th Generation
AMC	Adaptive Modulation and Coding
ANR	Automatic Neighbour Relation
ARIB	Association of Radio Industries and Businesses, Japan
ARQ	Automatic Repeat Request
ATIS	Alliance for Telecommunications Industry Solutions, USA
BCCH	Broadcast Control Channel
CC	Component Carrier
CCCH	Common Control Channel
CCSA	China Communications Standards Association
CGID	Cell Global ID
CIO	Cell Individual Offset
CoMP	Coordinated Multi Point
CSG	Closed Subscriber Group
CS/CB	Coordinated Scheduling/Beamforming
C-plane	Control-plane
C-RAN	Cloud Radio Access Network
DCCH	Dedicated Control Channel
DeNB	Donor eNB
DFT	Discrete Fourier Transform
DSL	Digital Subscriber Line
DTCH	Dedicated Traffic Channel
EMM	EPS Mobility Management
EMS	Element Management System
eNB	eNodeB
EPC	Evolved Packet Core
EPS	Evolved Packet System

ESM	EPS Session Management
ETSI	European Telecommunications Standards Institute
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
GERAN	GSM EDGE Radio Access Network
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GUTI	Global Unique Temporary ID
HARQ	Hybrid Automatic Repeat Request
HeNB	Home eNB
HeNB-GW	HeNB Gateway
HetNet	Heterogeneous Networks
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
IFI	Inter-frame Interference
IP	Internet Protocol
IPSec	Internet Protocol Security
ISI	Inter-symbol Interference
ITU-R	International Telecommunications Union - Radio Communications Sector
ITU-T	International Telecommunications Union - Telecommunication Standardization Sector
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
MAC	Medium Access Control
MBMS	Multimedia Broadcast and Multicast Services
MCCH	Multicast Control Channel
MIMO	Multiple Input Multiple Output

MME	Mobility Management Entity
MTCH	Multicast Traffic Channel
NAS	Non Access Stratum
NE	Network Element
NML	Network Management Layer
NMS	Network Management System
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OPEX	Operational Expenditure
PAPR	Peak-to-Average Power Ratio
PBCH	Physical Broadcast Channel
PCCH	Paging Control Channel
PCFICH	Physical Control Format Indicator Channel
PCI	Physical Cell Identity
PCRF	Policy Control and Charging Rules Functions
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
PHICH	Physical Hybrid ARQ Indicator Channel
PHY	Physical Layer
PMCH	Physical Multicast Channel
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
P-GW	Packet Data Network Gateway
QoS	Quality of Service
RACH	Random Access Channel
RE	Resource Element
RLC	Radio Link Control
RLF	Radio Link Failure
RRC	Radio Resource Control
RRH	Remote Radio Head

RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
SC-FDMA	Single Carrier Frequency Division Multiple Access
Se-GW	Security Gateway
SMS	Short Message Service
SON	Self Organizing Networks
S-GW	Serving Gateway
TAU	Tracking Area Update
TDD	Time Division Duplex
TMN	Telecommunications Management Network
TTA	Telecommunications Technology Association, Korea
TTC	Telecommunication Technology Committee, Japan
TTI	Transmission Time Interval
TTT	Time to Trigger
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
UTRAN	Universal Terrestrial Radio Access Network
U-plane	User-plane

CHAPTER 1

INTRODUCTION

Since its invention, cell phone usage is constantly growing in the world. To support the growing number of users, mobile network standards are constantly evolving. First generation mobile networks are introduced in the 1980s. These networks are analog networks and could only provide basic voice services. With the 1990s, second generation mobile networks are introduced. 2G mobile networks are designed to be digital and could provide data services with SMS messages beyond voice services. GSM was the most successful 2G mobile network standard. In the second half of the 1990s, cell phone usage increased rapidly along with the growing popularity of the Internet. To support the data services in the mobile networks, GPRS is introduced. To provide better data services for the users, third generation mobile networks are introduced in the late 1990s. 3G provided remarkable data rate improvements over the 2G mobile networks. 2000s saw explosion of data usages with the growing number of multimedia services on the Internet. To handle this growth on the mobile networks, fourth generation mobile networks are introduced.

LTE, which is introduced in 2008, is a 4G network standard. It provides better capacity and data rate over the previous mobile network standards and currently widely used in the world. To provide better service to the growing number of users and handle the increasing data, the LTE standard is constantly evolving. LTE-Advanced, which is a major update over LTE, is introduced in 2011.

LTE-Advanced has many improvements over the LTE. One of the major improvements is the introduction of heterogeneous networks. As the spectral efficiency of cellular networks approaches its theoretical limits, to improve network capacity, network topology can be changed. Traditionally, cellular networks are homogeneous networks which are consist of macrocells. In this type of networks, to improve network capacity and coverage, low power microcell, picocell, femtocells and relay stations could be deployed within the coverage of high power macrocells. This type of networks are called heterogeneous networks.

To support the growing number of users, the number of deployed cells is increased over the recent years. This number will be increased more with the introduction of heterogeneous networks. With the growing number of cells, operational expenditure (OPEX) of the network is constantly growing for the mobile network operators. To decrease the OPEX, self organizing networks (SON) is introduced to the LTE. SON tries to minimize the OPEX with automatizing the planning, management and configuration of the network.

While a user is in mobile state, if it goes out of the coverage of its serving cell, it needs to be switched to another neighbor cell without disrupting the user's session. This cell switching procedure is called handover. Handover is an important concept in the mobile networks. The system must switch the user's serving cell without dropping the user's session. Also, the system must not switch the user's serving cell unnecessarily since the handover operation is a costly procedure that uses the valuable radio resources.

To provide better service for the users in mobile state mobility robustness optimization is defined as a use case for the self organizing networks. Handover parameter optimization is a problem defined in the mobility robustness optimization use case. The handover parameter optimization problem tries to tune the parameters used in the handover procedure to increase the successful handover rate. Traditionally, these parameters are set manually by the network operators after analysis of the cell reports and logs. With the introduction of SON, this procedure could be automatized.

To solve the handover parameter optimization problem, several SON algorithms proposed in the literature. These problems generally gather the statistics of handover failures and unnecessary handovers from the cell reports and tune the handover parameters with using them. Generally most of these algorithms are proposed before the introduction of the heterogeneous networks and tested on homogeneous deployments. According to the technical reports [3], radio environment characteristics are different in the heterogeneous networks and because of this, handover performance drops significantly compared to homogeneous networks.

In this thesis, we propose a new handover parameter optimization algorithm for LTE-A networks. The proposed algorithm conforms the LTE standards and can be easily applied on a LTE network without major changes. The proposed algorithm is designed for the heterogeneous networks. In heterogeneous networks, different cell types has different inter-cell interference conditions on the cell edges. To solve this problem, handover margins must be differentiated per neighbor cell. To provide this, cell individual offset (CIO) values are tuned along with the hysteresis and time to trigger (TTT).

To test the proposed algorithm, the SON algorithm is implemented and tested on a simulation environment. ns-3, which is a discrete event network simulator, is used for the simulation. Before the implementation of the proposed solution, some of the missing parts in the simulator's implementation of the handover procedure are completed. To compare the results gathered from the implementation of the proposed algorithm, some of the previously proposed algorithms are also implemented and evaluated in the same environment. According to the results, the proposed algorithm performs better than the other algorithms while decreasing the handover failures.

The rest of the thesis is organized as follows. Chapter 2 gives some basic information about the LTE and includes some concepts in LTE, that is related to the thesis topic. Chapter 3 gives most of the academic works previously done on the mobility robustness optimization problem. The proposed SON solution is described in the Chapter 4. In Chapter 5, implementation of the proposed SON solution is explained with the improvements done on the simulation environment. In Chapter 6, the evaluation results of the proposed SON algorithm on the testing environment is presented and the results are compared with some of the previously proposed solutions. Finally, the thesis is concluded and the future works that can be done on the problem are mentioned in Chapter 7.

CHAPTER 2

BACKGROUND

In this chapter basics of LTE will be explained. Also, brief information will be given about some concepts in LTE, that needs to be known to understand the thesis work, are provided.

2.1 Overview of LTE

LTE, which is the acronym of Long Term Evolution, is a standard defined to provide high speed data for mobile phones and data terminals over wireless environment. It is designed to achieve the requirements of 4G, which is the fourth generation mobile telecommunication standards defined by International Telecommunications Union - Radio communications sector (ITU-R). The LTE specification is developed by the 3rd Generation Partnership Project (3GPP). The 3GPP unites six telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TTA, TTC), known as "Organizational Partners" and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies [1]. The 3GPP structures their standards as Releases. LTE is specified in Release 8, which is published in December 2008. Since then, the organization continuously evolve the LTE specification with publishing new Releases.

Much of the LTE standards are developed over previous generation UMTS/HSPA network technologies. The requirements of LTE are defined in [5]. Some of these requirements are:

- Peak data rate: System should support downlink peak data rate of 100Mb/s and uplink peak data rate of 50Mb/s within a 20 MHz spectrum.

- User throughput: An average user throughput per MHz must be 3-4 times Release 6 HSDPA in downlink and 2-3 times Release 6 HSUPA in uplink.

- Spectrum efficiency: In a loaded network, target for spectrum efficiency must be 3-4 times Release 6 HSDPA in downlink and 2-3 times Release 6 HSUPA in uplink.

- Mobility: System should support mobility up to 350 km/h, even up to 500 km/h depending on the frequency band.

- Coverage: Maximum cell range should be 100 km. The data rate, throughput and mobility clauses may not be met strictly after 30 km.

- C-plane capacity: System should be able to support 400 users per node.

- U-plane latency: System should provide less than 5 ms transfer latency over the network.

- Spectrum: System shall support different spectrum allocation sizes up to 20 MHz.

2.2 System Architecture

Unlike its predecessors, to simplify the architecture of the system, LTE is designed to be a fully packet switched network based on IP. The LTE system architecture is comprised of two main components; the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC). E-UTRAN is the air interface of the network. It's responsibilities include management of radio access and providing user and control-plane support to the users. EPC is the core part of the network and it is responsible for mobility management, policy management and security.

2.2.1 E-UTRAN

The E-UTRAN provides radio interface user and control-plane protocols for the users. The u-plane protocols provide management of user data transmission throughout the network, while the c-plane protocols control user data transmission and manage the connection between user and the network. Overall architecture of the E-UTRAN can be seen in figure 2.1.

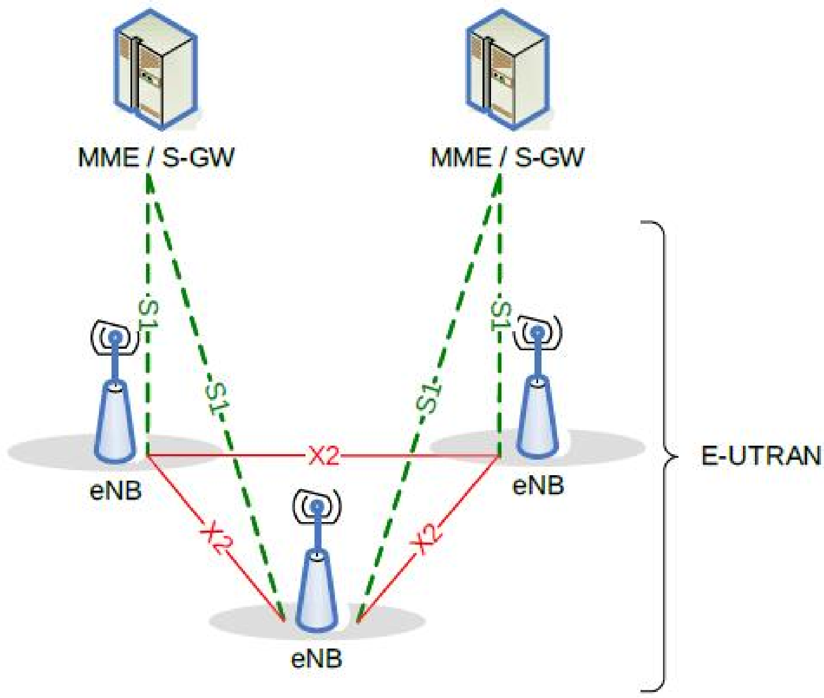

Figure 2.1: Overall Architecture of E-UTRAN

E-UTRAN consists of only one component, the evolved base stations called eNodeB or eNB. The responsibilities of eNodeB are listed in [7]. Some of these responsibilities are;

- Functions for Radio Resource Management; Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling)
- IP header compression and encryption of user data stream
- Selection of an MME at UE attachment

- Routing of User Plane data towards Serving Gateway
- Scheduling and transmission of paging messages
- Scheduling and transmission of broadcast information
- Measurement and measurement reporting configuration for mobility and scheduling

There are two main interfaces defined to connect the entities of LTE; X2 and S1 interfaces. The X2 interface provides communication between eNodeBs and used to transfer user and control-plane information. The S1 interface is used to connect the eNodeBs to EPC.

2.2.1.1 E-UTRAN Protocol Stack

The layers of E-UTRAN protocol stack and their responsibilities are [21];

- Physical Layer (PHY): The physical layer provides its services to MAC as transport channels and maps these channels to physical channels for transmission over the air interface. The physical layer's responsibilities include coding, modulation, mapping physical time-frequency resource to signals, scrambling, link adaptation (AMC), power control and physical HARQ processing.
- Medium Access Control (MAC): The MAC layer offers its services to RLC as logical channels and maps these channels to PHY transport channels. The responsibilities of MAC layer include uplink-downlink scheduling, HARQ retransmissions and priority handling.
- Radio Link Control (RLC): The RLC layer delivers PDCP's protocol data units (PDU) to MAC layer with using appropriate MAC logical channels. Its responsibilities include segmentation and concatenation, ARQ error connection, duplicate detection and in-sequence delivery of protocol data units.
- Packet Data Convergence Protocol (PDCP): The PDCP sublayer is responsible for delivering user PDUs to the RRC. It's responsibilities include IP header

compression/decompression, ciphering and integrity protection. It also provides duplicate detection and in-sequence delivery of PDUs during handover.

- Radio Resource Control (RRC): The RRC layer is a part of LTE c-plane air interface. It's responsibilities include connection management, mobility functions, system information broadcast, paging, security, radio bearer management and QoS management functions.

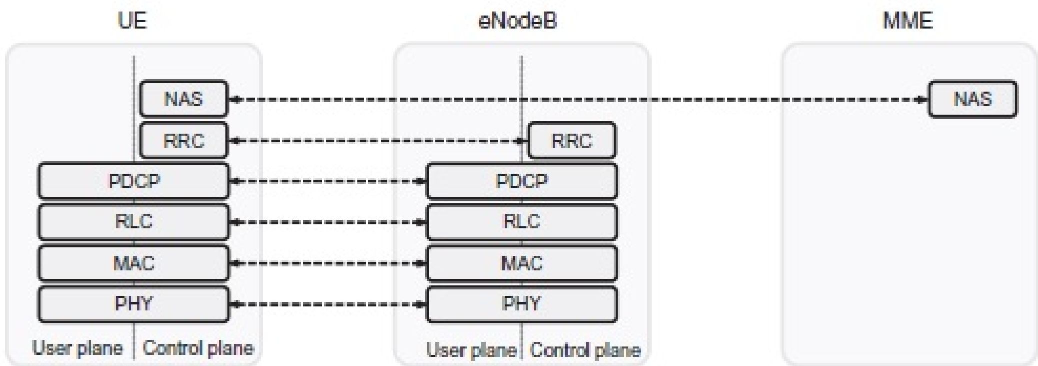

Figure 2.2: E-UTRAN Protocol Stack

Data transmissions between E-UTRAN and UEs are organized as radio bearers. u-plane data is sent over traffic radio bearers while c-plane data is sent over signaling radio bearers. Several radio bearers can be established for a UE depending on the characteristics of the transmission data. Every radio bearer has its own PDCP and RLC entity.

2.2.1.2 Logical Channels

The MAC layer offers its services as logical channels to RLC layer. Logical channels are named with the data type it relates; traffic channel for u-plane data and control channel for c-plane data. The logical channels defined in LTE are [17];

- Broadcast Control Channel (BCCH): The channel is used for the transmission of system information to all UEs connected to the eNodeB.

- Paging Control Channel (PCCH): The channel is used for paging information of a unit whose location on a cell level is not known to the network.

- Common Control Channel (CCCH):This channel is used for random access control information.
- Multicast Control Channel (MCCH): This channel is used for transmitting control information required for multicast reception.
- Dedicated Control Channel (DCCH): This channel is used for transmitting control information between eNodeB and an individual UE.
- Dedicated Traffic Channel (DTCH): This channel is used for transmitting user data between eNodeB and an individual UE.
- Multicast Traffic Channel (MTCH): This channel is used for the transmission of multicast data.

2.2.1.3 Transport Channels

The physical layer offers its services as transport channels to MAC layer. A transport layer is defined by different characteristics and requirements of data transmission over uplink and downlink. Data on a transport channel is organized as transport blocks. At most one transmission block can be transmitted in a Transmission Time Interval (TTI). The transport channels used in downlink are;

- Broadcast Channel (BCH): This channel is used for the transmission of BCCH information.
- Downlink Shared Channel (DL-SCH): This channel is the main transport channel used for transmission of downlink data.
- Paging Channel (PCH): This channel is used for the transmission of PCCH information.
- Multicast Channel (MCH): This channel is used for the transmission of MCCH information.

The transport channels used in uplink are;

- Uplink Shared Channel (UL-SCH): This channel is the main transport channel used for transmission of uplink data.
- Random Access Channel (RACH): This channel is used for random access requirements. It do not carry any transport channel related data.

2.2.1.4 Physical Channels

A physical channel is a physical time-frequency resource used for the transmission of control and user-plane messages. The physical layer maps transport channels to their corresponding physical channels. There are also physical channels that does not correspond to any transport channels. The physical channels used in downlink are;

- Physical Downlink Shared Channel (PDSCH): This channel is the main physical channel used for transmission of unicast downlink data. It is also used for the transmission of paging information.
- Physical Multicast Channel (PMCH): This channel is used for the transmission of Multimedia Broadcast and Multicast Services (MBMS).
- Physical Broadcast Channel (PBCH): This channel is used for the transmission of system information required by UEs within the cell.
- Physical Downlink Control Channel (PDCCH): This channel is used for the transmission of control information in downlink.
- Physical Control Format Indicator Channel (PCFICH): This channel is used for the transmission of the required information to decode the PDCCH data by UEs.
- Physical Hybrid ARQ Indicator Channel (PHICH): This channel is used for the transmission of he HARQ acknowledgement messages.

The physical channels used in uplink are;

- Physical Uplink Control Channel (PUCCH): This channel is used for the transmission of control information in uplink.

- Physical Uplink Shared Channel (PUSCH): This channel is the main physical channel used for transmission of uplink data.
- Physical Random Access Channel (PRACH): This channel is used for the random access procedure.

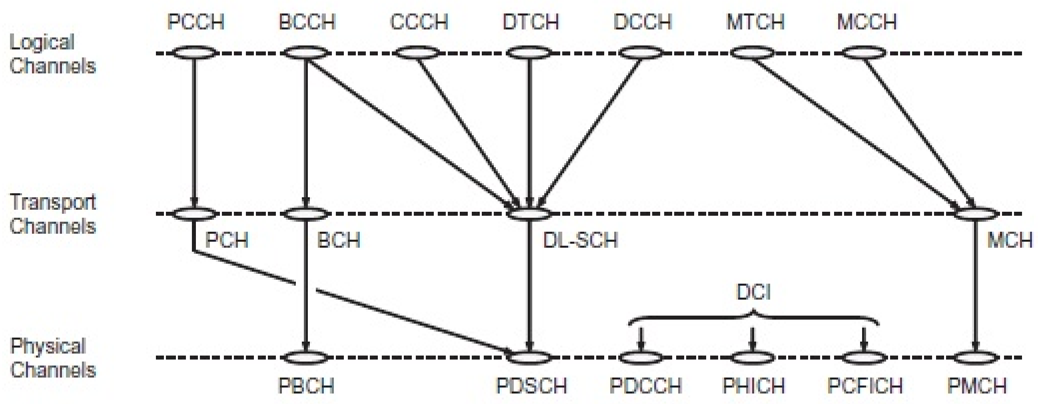

Figure 2.3: Downlink Channel Mapping

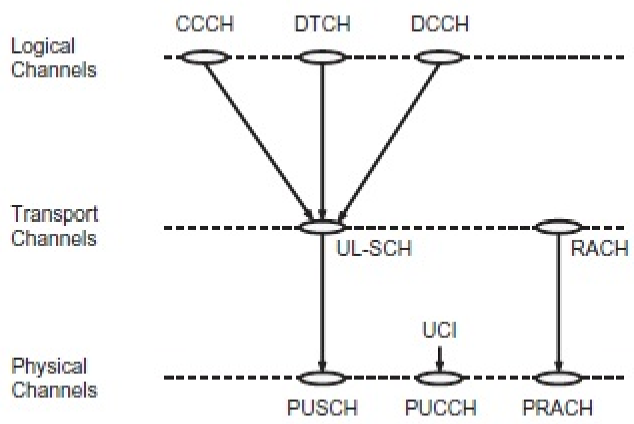

Figure 2.4: Uplink Channel Mapping

2.2.1.5 Physical Layer Design

E-UTRAN uses Orthogonal Frequency Division Multiplexing (OFDM) to provide multiple access schemes in uplink and downlink. OFDM is a Frequency Division Multiplexing Scheme (FDM) that uses large number of orthogonal signals on closely spaced subcarriers to carry data. OFDM has many advantages over other transmission schemes to support the requirements of the LTE. These advantages are:

- Robustness against severe channel conditions: The primary advantage of OFDM over single carries schemes is its robustness against severe channel conditions. It is more resistant to frequency selective fading than single carrier systems with dividing the channel into narrowband flat fading subchannels. Also, because of this, channel equalization can be made easily on the receiver side without using complex time-domain equalization. Usage of cyclic prefix eliminates inter-symbol interference (ISI) and inter-frame interference (IFI). With using adequate coding techniques and interleaving, lost symbols originated because of the frequency selectivity of the channel can be recovered. It also provides good protection against cochannel interference and impulsive parasitic noise.

- Usage of spectrum: Because of orthogonality between subcarriers, cross-talk between the sub-channels is eliminated, so inter-carrier guard bands are not required.

- Easy implementation: Orthogonality allows for efficient modulator and demodulator implementations on the sender and receiver side with using simple Fast Fourier Transform (FFT) techniques. Also, with using different bandwidths for subcarriers, multiple system bandwidth configurations can be easily supported.

LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) in downlink to provide multiple access. OFDMA is a multi-user version of OFDM digital modulation scheme. In OFDMA, multiple access is achieved by assigning different subcarriers to different users. Different number of subcarriers can be assigned to the users according to achieve QoS requirements. On the transmitter side, after mapping frequency domain resources, the signal is assigned to an Inverse Fast Fourier Transform (IFFT) to covert the frequency domain to the time domain. The signal can be transmitted after addition of a cyclic prefix. On the receiver side after receiving the signal, cyclic prefix is removed and with using FFT, time domain is converted to frequency domain. The data is constructed with combining the subcarriers assigned to the user and after equalization, it is passed for decoding.

Tu support full duplex communication, LTE standards support both of Frequency Dvision Duplex (FDD) and Time Division Duplex (TDD) methods. In FDD, different frequencies used in uplink and downlink to support simultaneous communication. In

TDD, same frequency can be used uplink and downlink but, the time of transmitting and receiving is different. Allocation of radio resources changes according to these methods.

In FDD, LTE physical layer organizes frequency-time resources as resource elements. In time domain a radio frame has a length of 10ms. Each frame is divided equally 1 ms length subframes. A subframe is divided into 0.5 ms length time slots. Each slot consists of seven or six OFDM symbols. The length of a OFDM symbol is approximately 66.7 μs. With using normal cyclic prefix, the length of cyclic prefix is approximately 4.7 μs, and seven symbol can be in a slot. With using extended cyclic prefix, the length of cyclic prefix is approximately 16.7 μs, and six symbol can be in a slot. The normal cyclic prefix is used in urban cells and high data rate applications, while the extended cyclic prefix is used in special cases like multi-cell broadcast and in very large cells [22].

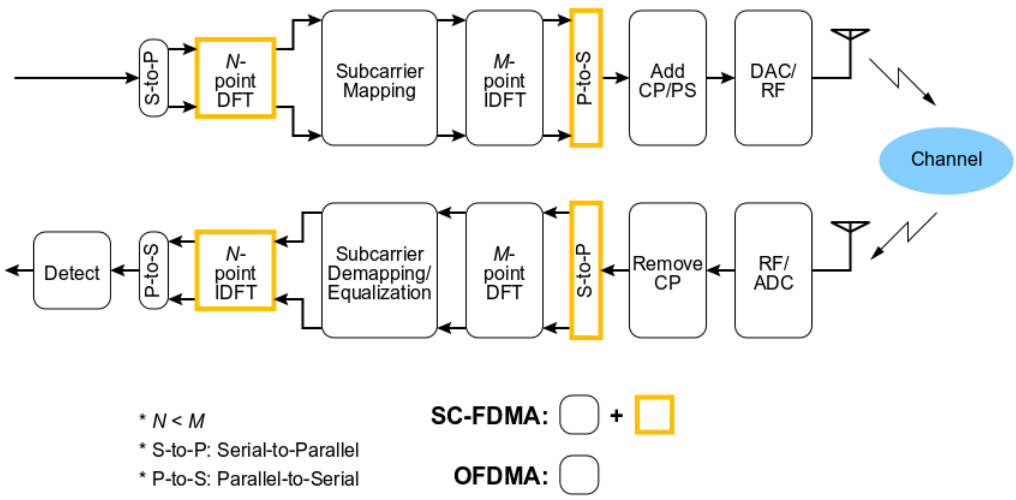

Figure 2.5: OFDMA and SC-FDMA Processing

In frequency domain, subcarriers are spaced 15 kHz apart from each other. The supported bandwidths in LTE are; 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz. The number of subcarriers differs according to the bandwidth. Not all subcarriers are used in a given bandwidth. Approximately %10 of sub-carriers are used as guard carriers. The frequency domain parameters that differs with the canwidth can be seen in table 2.1. A Resource Element (RE) is the smallest defined unit which consists of one OFDM subcarrier during one OFDM symbol interval. The transmission can be scheduled as physical resource blocks (PRB), each of which consist of 12 consecutive subcarriers (180MHz) in a time slot.

In TDD, the radio frame has divided into two 5ms half frames. Each half-frame is divided into five subframes with 1 ms duration. Beyond uplink and downlink, some of these subframes are used to coordinate the uplink and downlink. The specification defines 7 uplink-downlink configurations for the LTE TDD mode. These configurations can be seen in table 2.2.

In uplink, LTE uses Single Carrier Frequency Division Multiple Access (SC-FDMA) to provide multiple access. While having most of the advantages of OFDMA, SC-FDMA also provides lower peak-to-average power ratio (PAPR). With low PAPR, transmit power efficiency and coverage is increased and cost of the power amplifier used in UE is reduced. The transmission processing of SC-FDMA is almost similar to the OFDMA. The only difference is the application of N-point Discrete Fourier Transform (DFT) before the subcarrier mapping. N-Point DFT is used to provide frequency-domain precoding. To preserve the single-carrier property, an SC-FDMA symbol must be either contiguous or evenly distributed in the frequency domain. After transmission, on the receiver side, N-Point Inverse Discrete Fourier Transform (IDFT) is performed after subcarrier demapping and equalization. The transmission and reception processing in OFDMA and SC-FDMA can be seen in figure 2.5

The transmission structure of uplink is similar to the downlink. Instead of OFDM symbols, SC-FDMA symbols are defined in uplink.

2.2.2 EPC

Evolved Packet Core (EPC) is the core part of the LTE network. EPC is a radical evolution over previous 2G and 3G core network standards. In GSM, the core network is a circuit switched network. In GPRS, while data are transmitted with packet switching, circuit switching is used for voice and SMS messages. In 3G, this concept is kept on the core network. Instead of using both of packet and circuit switching, to simplify the architecture, LTE is designed to be a fully IP based packet switching network. The responsibilities of EPC are mobility management, security management,

Table 2.1: Parameters for Downlink Transmission

Transmission bandwidth [MHz]	1.4	3	5	10	15	20
Occupied bandwidth [MHz]	1.08	2.7	4.5	9.0	13.5	18.0
Guardband [MHz]	0.32	0.3	0.5	1.0	1.5	2.0
Guardband, % of total	23	10	10	10	10	10
Sampling frequency [MHz]	1.921/2 x 3.84	3.84	7.682 x 3.84	15.364 x 3.84	23.046 x 3.84	30.728 x 3.84
FFT size	128	256	512	1024	1536	2048
Number of occupied subcarriers	72	180	300	600	900	1200
Number of resource blocks	6	15	25	50	75	100
Number of CP samples (normal)	9 x 610 x 1	18 x 620 x 1	36 x 640 x 1	72 x 680 x 1	108 x 6120 x 1	144 x 6160 x 1
Number of CP samples (extended)	32	64	128	256	384	512

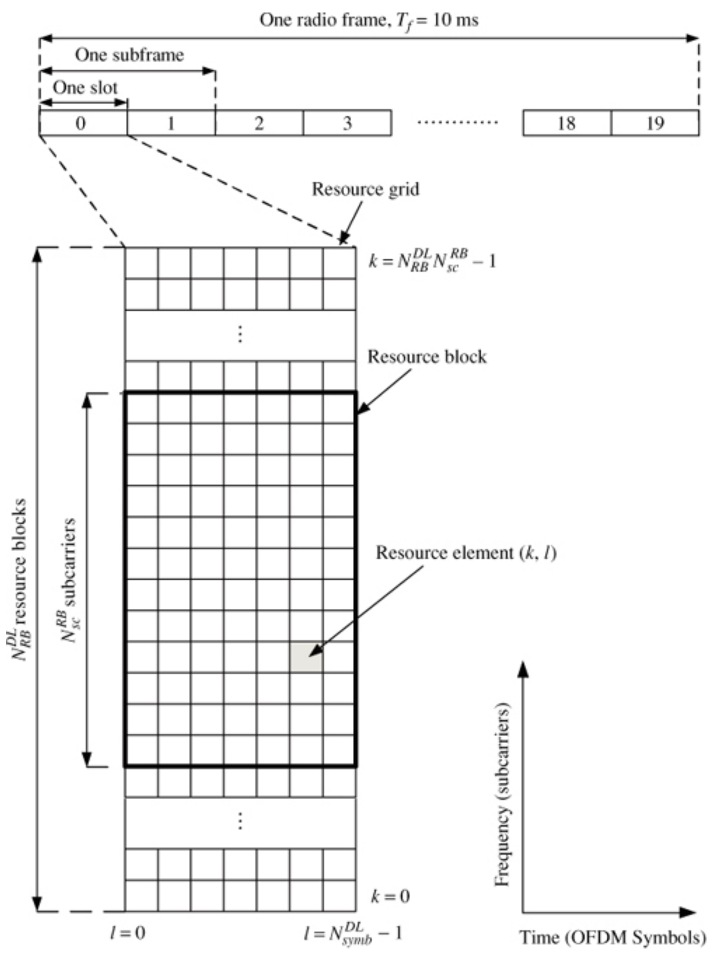

Figure 2.6: OFDM Downlink Resource Grid

Table 2.2: LTE TDD Configuration Schemes

Uplink-Downlink Configuration	Downlink-to-Uplink Switch-Point Periodicity	Subframe Number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

session management and policy control and charging. Overall architecture of the EPC can be seen in figure 2.7. The basic logical EPC network elements are;

- Mobility Management Entity (MME): The MME is the key control element for the LTE network. It is responsible for the tracking and the paging of UE in idle mode. Other responsibilities of MME include bearer activation/deactivation, P-GW and S-GW selection, user authentication and roaming support.
- Serving Gateway (S-GW): The S-GW manages user data between eNodeB and P-GW. It routes and forwards user data packets. Also S-GW is the anchor point that ensures continuous data connection for the u-plane during S1 based and Inter RAT handovers.
- Packet Data Network Gateway (P-GW): The P-GW connects the EPC to other external networks. Functions of the P-GW include packet filtering and routing, policy enforcement, charging support and IP address allocation for the user.
- Home Subscriber Server (HSS): HSS is a database that holds user and subscriber related information. It also provides support for user authentication and access authorization, mobility management and call and session setup.

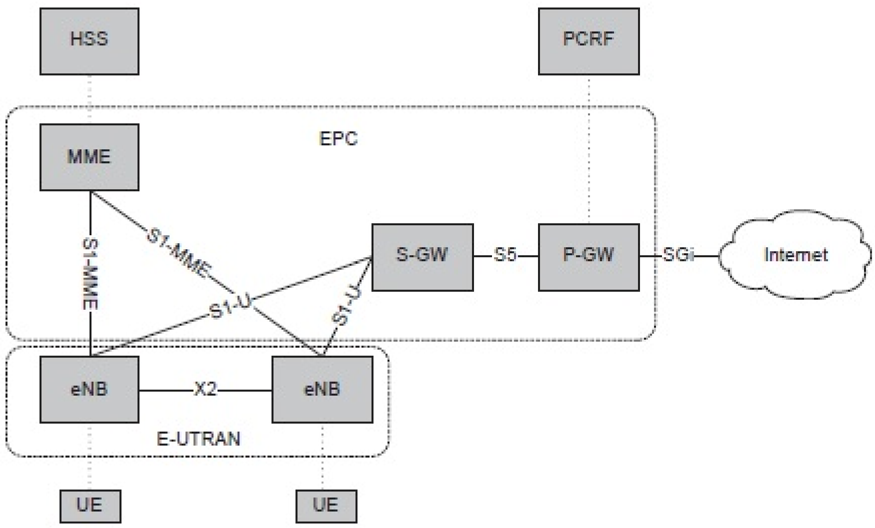

Figure 2.7: Overall EPC Architecture

- Policy Control and Charging Rules Functions (PCRF): PCRF is responsible for QoS handling and charging. It defines the rules and policy associated with this work.

EPC interfaces E-UTRAN with two protocol layers; Non Access Stratum (NAS) on the c-plane and IP on the u-plane. NAS, which is the highest layer of the c-plane, is a set of protocols between UE and MME. The protocol definition of NAS is defined in [4] The responsibility of NAS is supporting the mobility of the UE and the session management procedures between the UE and a P-GW. These responsibilities can be grouped into two categories:

- EPS Mobility Management (EMM): EPS Mobility Management includes protocols related to mobility over E-UTRAN, authentication and security. EMM procedures can be grouped into three. EMM common procedures include GUTI (Global Unique Temporary ID) reallocation, authentication, security mode control, identification and EMM information. EMM specific procedures define attach/detach and Tracking Area Update (TAU) mechanisms. EMM connection management procedures include service requests, paging and transport of NAS messages.

- EPS Session Management (ESM): EPS Session Management protocol offers support to the establishment and handling of user data in the NAS. It provides protocols to support the activation, deactivation and modification of EPS bearer contexts and the request for resources by the UE.

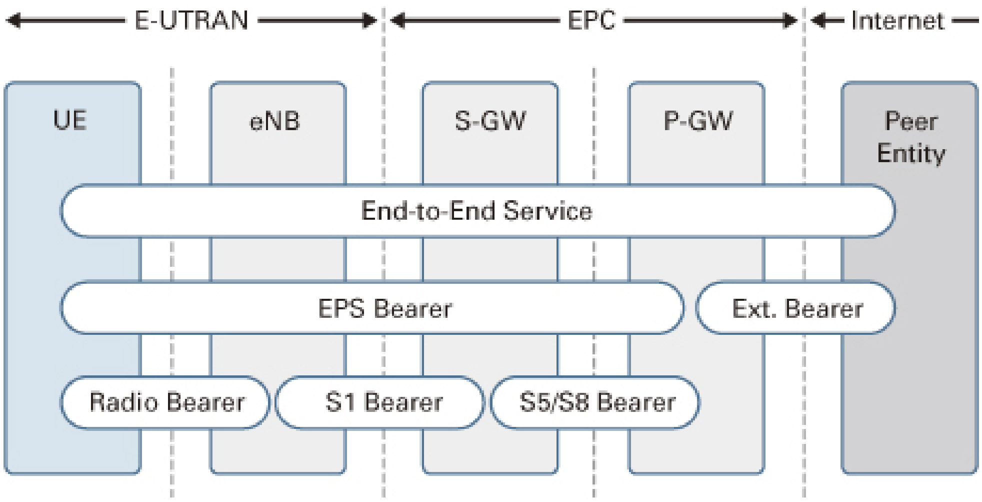

Figure 2.8: Bearer Services in LTE

2.3 LTE-Advanced

After release of the LTE specification with Release 8 document in December 2008, 3GPP continued to work on new requirements to define a specification with more enhanced capabilities. This new specifications gave birth to LTE Advanced (LTE-A) and the final specification is published with Release 10 in March 2011. LTE-A is a continual improvement over LTE with providing strict backward compatibility. Requirements of LTE-A are defined in [10]. Some of these requirements that changed over LTE requirements are:

- Peak data rate: System should support downlink peak data rate of 1 Gbps and uplink peak data rate of 500 Mbps.
- Peak spectrum efficiency: System should support downlink peak spectrum efficiency of 30 bps/Hz with assuming 8x8 antenna configuration and uplink peak spectrum efficiency of 15 bps/Hz with assuming 4x4 antenna configuration.
- Average spectrum efficiency: System should support downlink peak spectrum efficiency of 3.7 bps/Hz with assuming 4x4 antenna configuration and uplink

peak spectrum efficiency of 2.0 bps/Hz with assuming 2x4 antenna configuration.

- Cell edge spectrum efficiency: System should support downlink peak spectrum efficiency of 0.12 bps/Hz with assuming 4x4 antenna configuration and uplink peak spectrum efficiency of 0.07 bps/Hz with assuming 2x4 antenna configuration.

To achieve this requirements, some physical layer enhancements have been introduced in LTE-A. These enhancements are:

- Carrier aggregation: With carrier aggregation, more than one Component Carrier (CC) can be assigned to a specific UE in order to increase bandwidth on uplink or downlink. Maximum five component carrier can be assigned to a UE, so total bandwidth of a user can go up to 100 MHz. Total number of aggregated carriers can be different for uplink and downlink. Also, the aggregated carriers need not to be equally sized. Three types of aggregation can be arranged on frequency spectrum. In intra-band contiguous allocation, contiguous component carriers within the same operating frequency band are used in aggregation. In intra-band non-contiguous allocation, any carrier within the same operating frequency band can be used in aggregation. In inter-band non-contiguous allocation, carriers on different operating frequency bands can be used in aggregation.

- Multiple Input Multiple Output (MIMO): MIMO is used to increase bitrate with transmitting multiple different data streams over multiple antennas. MIMO provides transmission of different data streams with same physical time-frequency resources. The data streams are separated with using different reference signals. With MIMO, multiple transport blocks can be transmitted per TTI.

- Heterogeneous networks (HetNet): Traditionally, cellular network deployments provide coverage with using high powered nodes called macro-cells. In order to increase network capacity and coverage, low powered micro-cell, pico-cell, femto-cells and relay stations could be deployed within the umbrella coverage of high power macro-cells. This type of networks are called heterogeneous networks.

- Coordinated Multipoint (CoMP): CoMP allows transmission and reception from multiple distribution points in a coordinated way. CoMP is introduced to LTE-A in Release 11, published in June 2013. The main reason to introduce CoMP is to improve network performance over cell edge users. There are two techniques of CoMP. In Joint Transmission, more than one distribution point transmit the same subframe on the same frequency. In Coordinated Scheduling/Beamforming (CS/CB), the data is available on more than one distribution point and the data is only transmitted from a single distribution point at the time. In this type of technique, distribution points are connected with each other in order to exchange scheduling and beamforming information.

2.4 Heterogeneous Networks

Heterogeneous networks are the type of networks that consist of multiple tiers with different cell sizes and/or multiple radio access technologies. Traditionally, cellular network deployments are planned with a homogeneous deployment approach that consist of base stations with similar transmit power and backhaul connectivity. This base stations are deployed with considering user demand and they are configured to maximize coverage and minimize inter-cell interference. With the explosion of data demand in recent years, to overcome this problem, cell splitting and addition of more carriers can be considered. However, this process is costly and difficult in especially already dense urban areas. To overcome this problem, a new deployment model is needed.

Heterogeneous networks brings a different approach to the traditional deployment model. In heterogeneous networks low powered micro-cell, pico-cell, femto-cell, relay nodes and remote radio heads (RRH) can be deployed within the umbrella coverage of the macro-cell. Micro-cell and pico-cells can provide better coverage within the coverage holes and increase the capacity of the network within the places where traffic demand is high, with low cost. Femto-cells can provide better service for the users in indoor areas. Also, relay nodes can be deployed in places where backhaul wireline is not accessible or economically viable.

2.4.1 Small Cell

Small cells are basic eNodeBs that have lower transmit power than macro-cells. According to their transmit powers and deployment characteristics, small cells can be grouped as micro-cells and pico-cells. Small cells can deployed in indoor or outdoor areas with a dedicated backhaul line to the network. Also instead of using sectored antennas like macro-cells, small cells generally have omnidirectional antennas.

2.4.2 Femto-Cell

Femto-cells are low powered network nodes that are deployed by the consumer to provide indoor coverage. Their transmit power is generally less than 100 mW and they are equipped with omnidirectional antennas. They can be connected to the core network with using user's broadband connection.

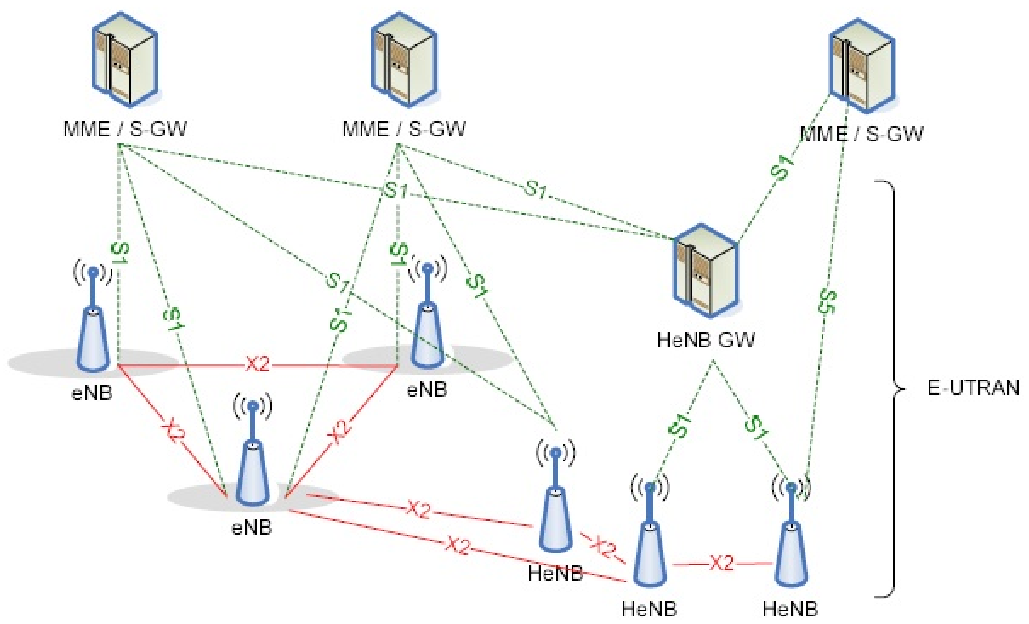

Figure 2.9: Overall Architecture of E-UTRAN with HeNB

Femto-cells are privately owned and can provide access to only a limited number of terminals. They can be grouped into two according to their restriction policies. Open femto-cells can provide access to all terminals. Closed femto-cells only provide access to a group of terminals within the Closed Subscriber Group (CSG). Beyond these, hybrid femto-cells can provide access to all users with giving higher priority to the terminals in the Closed Subscriber Group.

Femto-cell is introduced to LTE in Release 9 and named as Home eNodeB (HeNB). HeNB does not support X2 interface to communicate with other cells over air interface. It connects to the EPC with S1 interface over user's broadband connection. In EPC, Security Gateways (Se-GW) establish IPSec tunnels with the HeNB. Also, HeNB Gateways (HeNB-GW) manage and connect the HeNB traffic to the core network.

2.4.3 Relay Nodes

Relay node is a network node that connects to the network without a wired backhaul. Instead of a wired backhaul, relay nodes connect to a donor eNB (DeNb) over the air interface. The interface between relay node and DeNB is called as LTE-Un. LTE-Un is based on LTE-Uu, which is the interface between eNB and UE. Relay nodes generally use directional antennas in backhaul link and omnidirectional antennas in access link. In backhaul, if a relay node uses the same frequency as the link between eNB and UE, it is called as an in-band relay. An out-of-band relay use a different frequency from the link between eNB and UE. There are two types of relay nodes defined in LTE-A. These are:

- Type-I: A Type-I relay node controls its own cells and serves the purpose of extending the coverage to UEs beyond the DeNBs effective coverage. Type-I relay nodes work in in-band half duplex mode. There are also two variations of Type-I relay node. A Type-I.a relay node works in out-of-band full duplex mode, while a Type-I.b relay node works in in-band full duplex mode.
- Type-II: A Type-II relay node does not provide an identity and looks like the DeNB. It only serves as to increase capacity within the coverage of DeNB. Type-II relay nodes work in in-band full duplex mode.

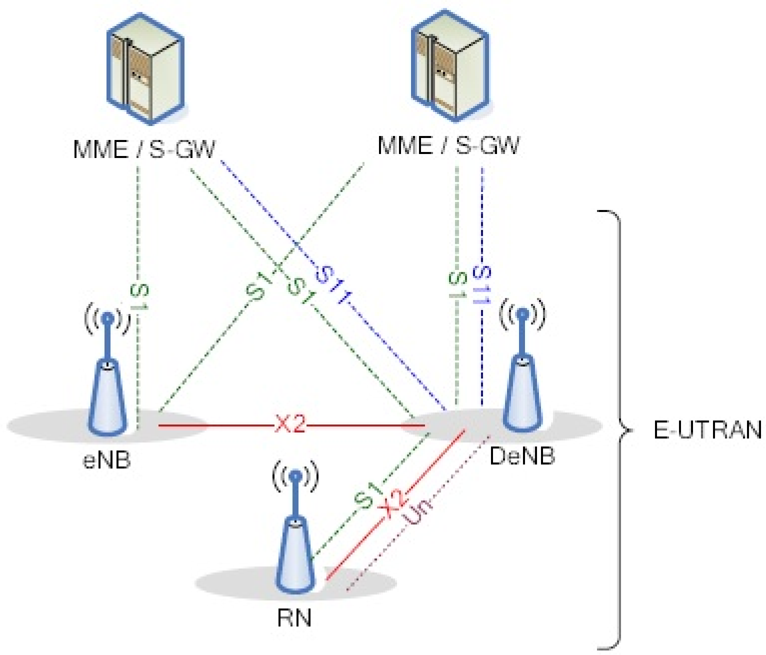

Figure 2.10: Overall Architecture of E-UTRAN with relay nodes

2.5 Self Organizing Networks

Self Organizing Networks (SON) is a concept that is introduced to automatize the planning, management, configuration, optimization and healing efforts in mobile networks. The main motivations behind the self organizing networks are:

- Fixed legacy systems cannot adapt to the chaotic nature of mobile systems, due to the mobility of users and varying conditions of wireless channels. This leads to over or under utilization of wireless resources under different conditions.
- With the growing complexity and scale of mobile networks, periodical manually optimization methods with human labor become inefficient and error prone. Autonomous methods can help decreasing human labor and operational expenditure (OPEX).
- With the introduction of the concept of heterogeneous networks, with traditional management methods, it will be impossible to manage the network nodes with so many numbers and different characteristics. Especially, configuration and optimization of privately owned femto-cells cannot be managed by network

operators.

In LTE, self optimizing efforts are introduced with Release 8. The use cases of self optimizing networks are defined in [9]. Most of these use cases can be summarized under the following 9 specific categories: Coverage and capacity optimization, energy saving, interference reduction, automated configuration of physical cell identity, mobility robustness optimization, mobility load balancing optimization, random access channel (RACH) optimization, automatic neighbor relation function, inter-cell interference coordination [12]. These use cases are generally grouped into categories as self configuration, self optimization and self healing functions.

Self organizing networks can be divided into three according to their architectures. These are:

- Distributed SON: In distributed architecture, self organization functions are executed on the edge network elements, generally eNodeBs.
- Centralized SON: In centralized architecture, self organization functions are generally executed on the core network elements.
- Hybrid SON: Hybrid architecture combines distributed and centralized architectures with distributing self organization functions over both core and edge network elements.

2.5.1 Self Configuration

The self configuration process includes configuring the new deployed nodes, integration of these nodes to the network and putting them to operational state automatically. The basic self configuration use cases are:

- Auto Connectivity and Commissioning: In this use case, a newly deployed node must add itself to the backhaul network without manual intervention. To make this, firstly the new node must get an IP address and establish a secure connection to the network with identifying itself as a valid node. Secondly, the new node must identify its site to the network to update the network topology database. After the new node is identified, the network can send the required parameters to the node to configure itself. The auto commissioning phase also include automatic allocation of Physical Cell Identity (PCI) and Cell Global ID (CGID). There are 504 PCI numbers in LTE and assignment of these numbers to the nodes within an area must be made without collision and confusion. To make these operations easier, the deployed node must prepare the list of its neighbors with using Automatic Neighbor Relation (ANR) procedure. The ANR procedure creates the neighbor list after configuration and manages this list during operation.

- Dynamic Radio Configuration: After auto connection and commissioning phases, the node must configure its radio access settings. The node must allocate its frequency resources with considering the required bandwidth to the users and interference from neighbor cells. Also, it must set its transmission power and antenna configuration.

2.5.2 Self Optimization

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

- Mobility Robustness Optimization: The purpose of mobility robustness optimization is to provide better service to the mobile users. In mobile state, the user needs to do handover in connected mode and cell re-selection in idle mode after entering to the coverage area of a new cell. While doing the cell change, the user can encounter some problems like call drops, radio link failures (RLF), unnecessary handovers and unnecessary cell re-selections. Mobility robustness optimization tries to minimize this problems with tuning the required configuration parameters.

- Mobility Load Balancing: The purpose of mobility load balancing is to direct the traffic to the other suitable nodes on heavy load conditions or beacuse of the factors like QoS or energy consumption.

- Energy Saving: The purpose of energy saving is to reduce the carbon footprint and operational cost of the nodes while maintaining the service quality. To save energy, some cells can be switched off during low load conditions and on again when the load on the system is increased. Also, power consumption of a node can be reduced with decreasing the active carriers during off-peak times.
- Coverage and Capacity Optimization: A node can change its coverage with changing its transmit power or antenna configuration. While increasing its coverage, a node also needs to observe its capacity and the interference from neighbor cells.
- RACH Optimization: The use of RACH needs to be optimized to provide sufficient number of random access opportunities to the users while keeping the required resources for random access minimum.

2.5.3 Self Healing

The self healing process includes diagnosing and healing the failures in the network with changing the required parameters and algorithms in the system to minimize the impact. After diagnosing and reporting the failure, the system can trigger recovery and compensation actions. While the compensation actions try to minimize the effect of the failure, with changing the required configuration parameters on the associated cells, the recovery actions try to recover the affected cell from the failure.

2.6 LTE Handover Procedures

The handover procedure provides transferring a connected user's session from a base station to another base station without disconnecting the session. Handover is an important concept in mobile networks. The system must provide mobility to the users reliably and without dropping any of their calls. In mobile networks, there are two types of handover. In hard handover, the user disconnects from the source cell before connecting to the target cell. The duration between disconnection and connection is so short that the user does not notice the disruption. In soft handover, the user connects to the target cell before disconnecting from the source cell. In LTE, only hard handover is supported.

According to the characteristics of the source and target cells, there are two types of handover defined in LTE. These are:

- Intra E-UTRAN: In Intra E-UTRAN handover, handovers are performed between eNodeBs in LTE network.
- Inter RAT: In Inter RAT Handover, handovers are performed between E-UTRAN and other 3GPP radio access technologies like UTRAN and GERAN or different radio access technologies like CDMA2000.

2.6.1 Intra E-UTRAN Handover

Intra E-UTRAN handovers can be done over S1 or X2 interface. The MME and S-GW that serves the the UE can be changed during the handover. This changes alter the handover procedure. Both of serving MME and S-GW can be changed with S1 based handover, while only serving S-GW can be changed with X2 based handover. The handover procedure can be generalized in three phases. These phases are; handover preparation, handover execution and handover completion.

2.6.1.1 Handover Preparation

The steps of the handover preparation phase are;

1. The UE sends a measurement report to its serving cell.
2. The serving cell decides if the user needs to do handover based on the measurement reports and identifies the target cell if a handover is needed.
3. The serving cell decides the interface that will be used in handover. In X2 based handover, the serving cell sends Handover Request message directly to

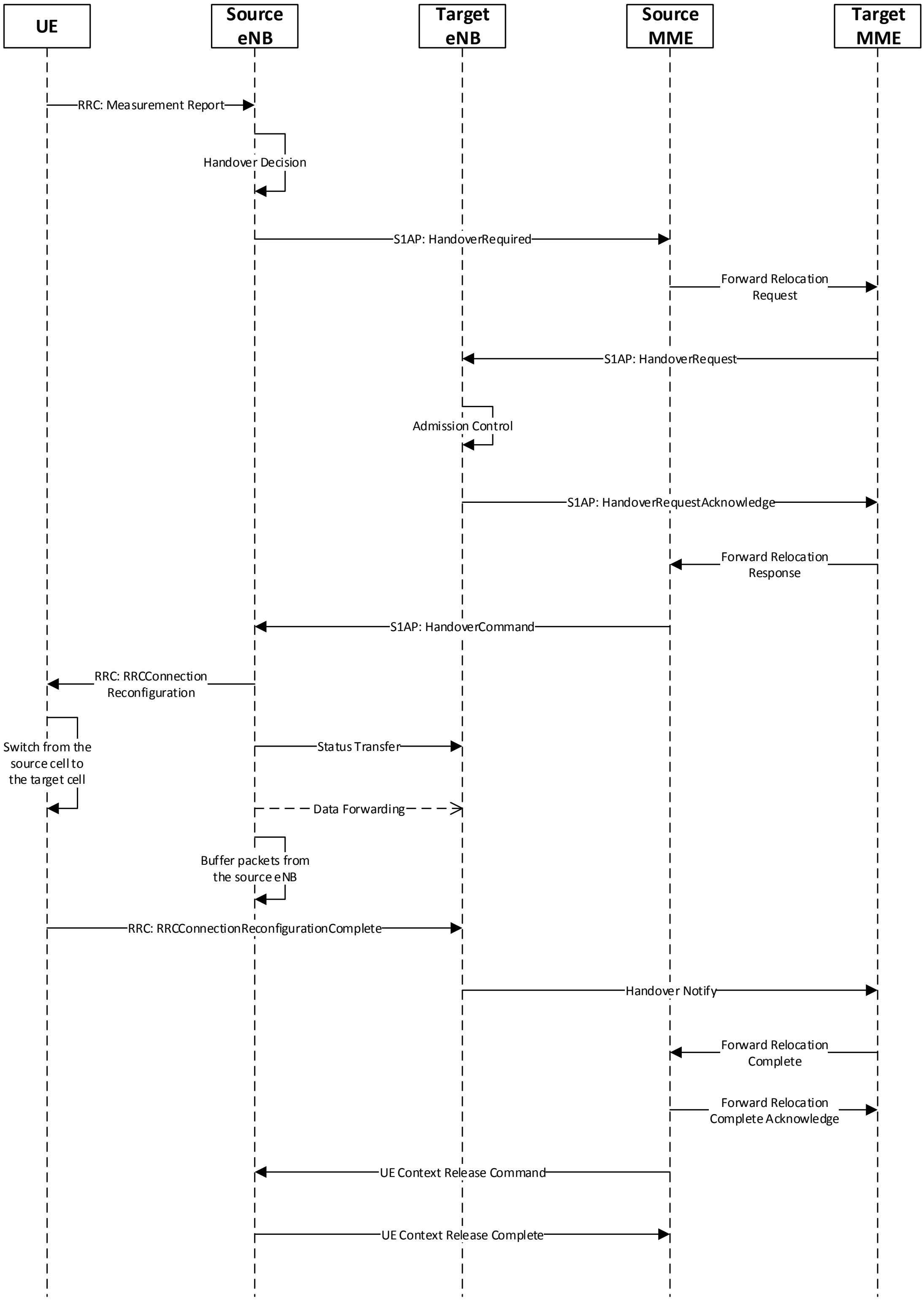

Figure 2.11: S1 Based Handover Procedure

the target cell. In S1 based handover, the serving cell sends Handover Required message to its MME. If the MMEs of the source and target cells are different, the source cell's MME forwards the message to the target cell's MME with using Forward Relocation Request message. After, the target MME sends a Handover Request message to the target cell. The Handover Request message includes capability information of the UE, RRC configurations of the source cell, QoS and bearer information of the UE and security information that will be used while forming the link between target cell and UE.

4. After receiving the Handover Request message, the target cell performs access control based on the contents of the message. If the target cell accepts the request, it allocates the required resources for the UE and sends a Handover Request Acknowledge message to the source cell over MMEs in S1 based handover or directly in X2 based handover. The Handover Request Acknowledge message includes a *RRCConnectionReconfiguration* message generated by the target cell that holds the configurations that will be used by the UE at the target cell.

2.6.1.2 Handover Execution

The steps of the handover execution phase are;

1. The source cell forwards the *RRCConnectionReconfiguration* message inside the Handover Request Acknowledge message to the UE.
2. The source cell can send Status Transfer message to the target cell that holds the downlink PDCP transmitter status and the uplink PDCP receiver status to support SDU reordering in the PDCP layer.
3. The source cell forwards user data packets to the target cell over GTN tunnels with using X2 or S1 interface according to the interface used in the handover.
4. After receiving the *RRCConnectionReconfiguration* message, the UE releases the resources of the source cell, synchronizes with the downlink of the target cell and tries to access the target cell with using the random access procedure.

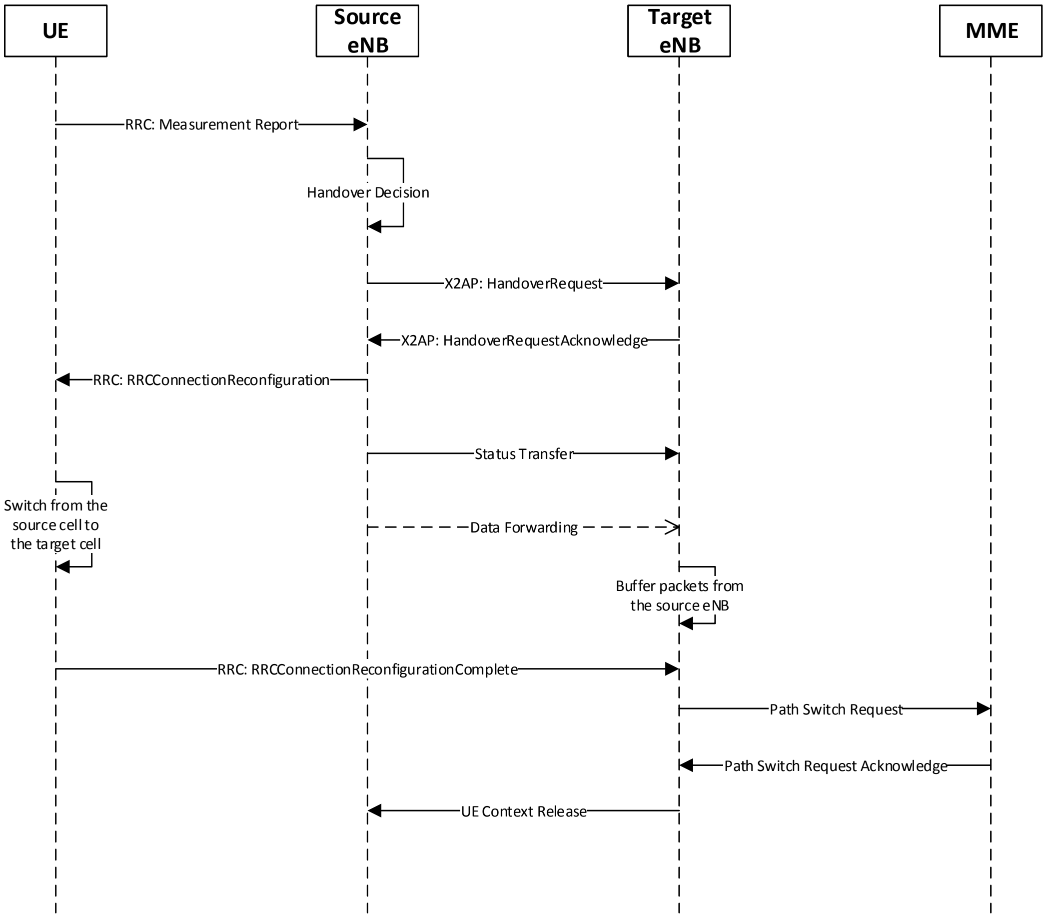

Figure 2.12: X2 Based Handover Procedure

The random access procedure can be contention-free if a dedicated RACH preamble is indicated in the mobilityControlInformation in *RRCConnection-Reconfiguration* message. Else, contention-based random access procedure is used.

5. If the UE can access the target cell, it sets a secure link and sends a *RRC-ConnectionReconfigurationComplete* message to the target cell to confirm the handover.

2.6.1.3 Handover Completion

The steps of the handover completion phase are;

1. After receiving the *RRCConnectionReconfigurationComplete* message, the target cell sends Path Switch Request message in X2 based handover or Handover Notify message in S1 based handover to the MME.

2. After receiving the Path Switch Request or Handover Notify message, the MME informs the S-GW about the change in the data path of the UE. The MME sends Path Switch Request Acknowledge message to the target cell in X2 based handover. If the MMEs of the source and target cells are different, the target cell's MME sends an Forward Relocation Complete message to the source cell's MME. The source cell's MME responds to it with Forward Relocation Complete Acknowledge messsage.

3. The source UE receives UE Context Release message in X2 based handover or UE Context Release Command message in S1 based handover. Upon receiving these messages the source cell can release the resources for the UE. After releasing the resources, the source cell sends UE Context Release Complete message to it's MME in S1 based handover.

2.6.2 Measurement Reporting

In LTE, the responsibility of the handover decision is on the serving cell. To assist these decisions, UEs can send measurement reports on specific conditions. These measurement reports can be classified as;

- Intra-frequency: These measurements are made over the downlink frequency of the serving cell.

- Inter-frequency: These measurements are made over the frequencies different from the downlink frequency of the serving cell.

- Inter-RAT: These measurements are made over the frequencies used by other radio access technologies like UTRA, GERAN and CDMA2000.

The responsibility of collecting the measurements is on the Physical Layer. After collecting the measurements, the Physical Layer can perform Layer 1 Filtering. The filtering procedure is not defined in the standard and left for implementation. After Layer 1 Filtering, the measurements are sent to RRC Layer for Layer 3 Filtering. Layer 3 Filtering is configured according to the measurement configurations sent by the serving cell. After Layer 3 Filtering, the measurements are evaluated for reporting. The evaluation procedure is also configured according to the measurement configurations. If the reporting criteria is met, the measurements are sent to the serving cell within a measurement report.

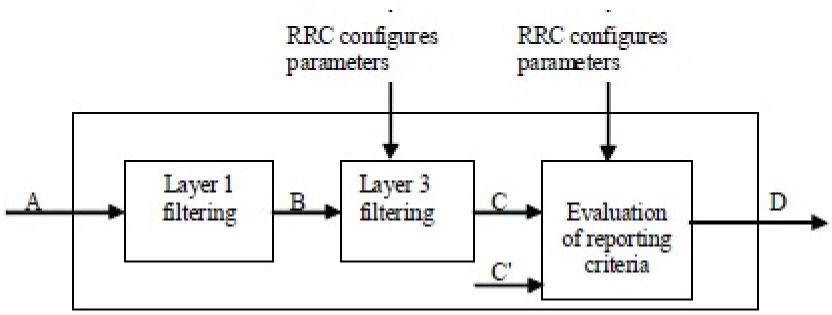

Figure 2.13: Measurement Model

The measurement configurations are defined in *RRCConnectionReconfiguration* message sent by the serving cell. A measurement configuration includes the following elements [38]:

- Measurement objects: The measurement objects are the frequencies or cells that need to be monitored by the UE. The serving cell can also send the list of the blacklisted cells.
- Reporting configurations: The reporting configurations include the reporting criterion and reporting format. The reporting criterion shows when the UE needs to send a measurement report and the reporting format shows which quantities must be included in the measurement report.
- Measurement identities: Measurement identities show the links between measurement objects and reporting configurations.
- Quantity configurations: The quantity configurations include the quantity of the parameters used by filtering and evaluation procedures.

- Measurement gap: Measurement gaps are defined to help the UE for their inter-frequency and inter-RAT measurements. During the defined measurement gaps the serving UE does not schedule a transmission towards the UE.

```
-- ASN1START

MeasConfig ::=                      SEQUENCE {
    -- Measurement objects
    measObjectToRemoveList              MeasObjectToRemoveList              OPTIONAL,   -- Need ON
    measObjectToAddModList              MeasObjectToAddModList              OPTIONAL,   -- Need ON
    -- Reporting configurations
    reportConfigToRemoveList            ReportConfigToRemoveList            OPTIONAL,   -- Need ON
    reportConfigToAddModList            ReportConfigToAddModList            OPTIONAL,   -- Need ON
    -- Measurement identities
    measIdToRemoveList                  MeasIdToRemoveList                  OPTIONAL,   -- Need ON
    measIdToAddModList                  MeasIdToAddModList                  OPTIONAL,   -- Need ON
    -- Other parameters
    quantityConfig                      QuantityConfig                      OPTIONAL,   -- Need ON
    measGapConfig                       MeasGapConfig                       OPTIONAL,   -- Need ON
    s-Measure                           RSRP-Range                          OPTIONAL,   -- Need ON
    preRegistrationInfoHRPD             PreRegistrationInfoHRPD             OPTIONAL,   -- Need OP
    speedStatePars              CHOICE {
        release                             NULL,
        setup                               SEQUENCE {
            mobilityStateParameters             MobilityStateParameters,
            timeToTrigger-SF                    SpeedStateScaleFactors
        }
    }                                                                       OPTIONAL,   -- Need ON
    ...,
    [[  measObjectToAddModList-v9e0         MeasObjectToAddModList-v9e0     OPTIONAL    -- Need ON
    ]]
}

MeasIdToRemoveList ::=              SEQUENCE (SIZE (1..maxMeasId)) OF MeasId

MeasObjectToRemoveList ::=          SEQUENCE (SIZE (1..maxObjectId)) OF MeasObjectId

ReportConfigToRemoveList ::=        SEQUENCE (SIZE (1..maxReportConfigId)) OF ReportConfigId

-- ASN1STOP
```

Figure 2.14: Structure of a MeasConfig Object

There are two measurement metrics defined in LTE. These metrics are [6];

- Reference Signal Received Power (RSRP): RSRP is defined as the average received power of all resource elements that carry cell specific reference signal within the considered bandwidth.

- Reference Signal Received Quality (RSRQ): RSRQ is defined as the quality of the signal and calculated with the formula (2.1). In this formula, Received Signal Strength Indicator (RSSI) is defined as the average of the total received power observed only in OFDM symbols containing reference symbols within the measured bandwidth, over N number of resource blocks by the UE from all sources, including interference and noise.

$$\frac{N \times RSRP}{RSSI} \tag{2.1}$$

The reporting criterion can be event triggered, periodic or event triggered periodic. For event based triggers, the events defined in the specification are [8];

- Event A1: Serving becomes better than threshold.
- Event A2: Serving becomes worse than threshold.
- Event A3: Neighbor becomes offset better than serving.
- Event A4: Neighbor becomes better than threshold.
- Event A5: Serving becomes worse than one threshold and neighbor becomes better than another threshold.
- Event B1: Inter-RAT neighbor becomes better than threshold.
- Event B2: Serving becomes worse than one threshold and inter-RAT neighbor becomes better than another threshold.

The threshold and offset values are set according to the measurement configurations sent by the serving cell. After an event is happened, before sending the measurement report, the event condition must be preserved within a given duration. This duration is called time to trigger (TTT) and it's value is also included in the measurement configurations.

2.6.3 Handover Parameter Optimization

Handover parameter optimization is a procedure that tunes the handover configuration parameters to provide better mobility for the users in connected mode. Incorrect setting of handover parameters can cause handover failures and unnecessary handovers. Handover failures occur when a Radio Link Failure (RLF) occurs between the UE and the source or the target cell during the handover procedure. Handover failures degrade the system performance with using the system resources to recover from the failure and also can cause call drops if they cannot be recovered. After a handover failure is occurred, the UE can try to re-establish its connection with the strongest cell. Call drops occur if the re-establishment procedure is failed. The scenarios that cause handover failures are listed below [25]:

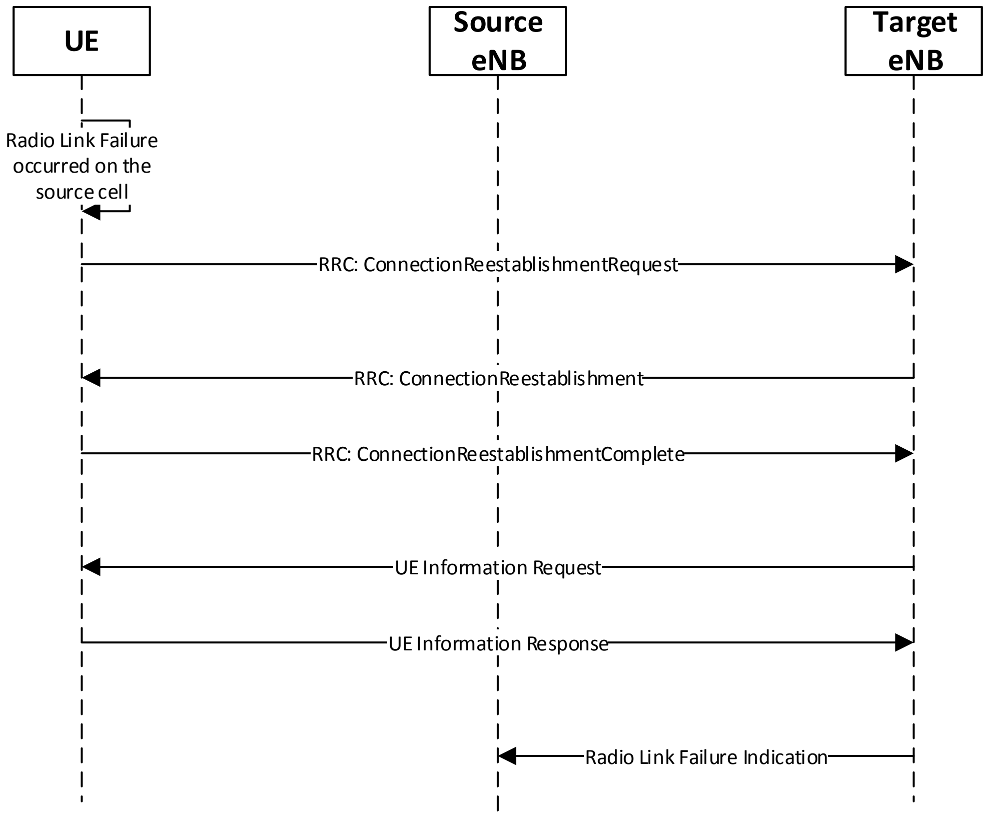

Figure 2.15: Connection Re-establishment After Handover Too Late

- Handover too late: In this situation, before or during the handover procedure, RLF occurs in the source cell and the UE tries to re-establish a connection with the target cell. After the connection re-establishment, the target cell can send a RLF Indication message to the source cell.

- Handover too early: In this situation, during or after the handover procedure, RLF occurs in the target cell and the UE tries to re-establish a connection with the source cell. After the connection re-establishment, the source cell can send a RLF Indication message to the target cell. To inform the source cell about the failure, the target cell can send a Handover Report message with setting Handover Report Type as Handover Too Early.

- Handover to the wrong cell: In this situation, during or after the handover procedure, RLF occurs in the target cell and the UE tries to re-establish a connection with another cell. After the connection re-establishment, the third cell can send a RLF Indication message to the target cell. To inform the source cell about the failure, the target cell can send a Handover Report message with setting Handover Report Type as Handover To Wrong Cell.

Unnecessary handovers also degrade the system performance with using the system resources unnecessarily. Unnecessary handovers can be grouped into two categories:

- Continuous handover: In this situation, the UE tries to switch to another cell shortly after a successful handover to the target cell.
- Ping-pong handover: In this situation, the UE tries to switch to the source cell again shortly after a successful handover to the target cell.

Traditionally, handover parameter optimization is made by system operators with using drive testing and log processing. With the introduction of SON, this problem can be solved autonomously under the mobility robustness optimization use case.

CHAPTER 3

RELATED WORK

Mobility Robustness Optimization is one of the most important use cases in self optimization. Since the specifications does not provide a direct solution for this problem, there are many mobility robustness optimization solutions offered in the literature.

To solve this problem, some authors propose solutions that optimize the handover and measurement parameters. In [24], the authors propose a solution that tunes the hysteresis and TTT values. In this solution, the authors define a cost function that takes ping-pong handover, call drop and handover error rates as parameters with assigning each of them a weight coefficient.

$$HP = w_1 \cdot HPI_{HOF} + w_2 \cdot HPI_{HPP} + w_3 \cdot HPI_{DC} \tag{3.1}$$

The optimization algorithm works in an iterative way. For each iteration the algorithm checks the result of the cost function with a predefined threshold value. If the result of the cost function is bigger than the threshold value for a given number of iteration, the algorithm changes the hysteresis and TTT values according to the reference measurements previously made. The algorithm also tunes the threshold value with looking the consecutive number of iterations below or above the threshold value. In [14], the authors enhance this algorithm with offering a new algorithm to find the optimum handover parameters. The enhanced algorithm looks to the results of the previous iteration and computes the change rate. If only this rate is bigger than a value called Performance Degradation Percentage value, the algorithm changes the direction of the optimization. In [31], the authors also try to enhance the solution in [24]. In this work, the algorithm looks for the last three iterations' results and makes the decision to change the direction of the optimization. When one parameter reaches its limits with this way, the algorithm passes to other parameters. The limits of a parameter is calculated with using the statistics from its previous usages.

In [18], the authors propose a distributed SON solution that, the base stations optimize their handover parameters individually. In this solution, the base stations keeps their handover statistics individually. The base stations gather the statistics of ping-pong handovers, too late handovers with using RLF Indication messages, too early handovers with using handover too early SON messages and handover to wrong cell with using hadover to wrong cell SON messages. After a predefined threshold is passed, the base station starts an optimization cycle. In optimization cycle, the base station firstly looks for the statistics gathered from all of the neighbors. If an optimization is needed, the algorithm changes hysteresis and TTT values. After, the algorithm looks for the statistics per neighbor and if an optimization is needed, the algorithm changes the cell individual offset (CIO) value with the neighbour.

In [26], the authors propose a solution that finds the optimization direction of the SON algorithm with comparing the previous statistics. The solutions gather the statistics of too late handovers, too early handovers, handover to wrong cell and ping-pong handovers. If the number of too late handovers is bigger, the solution increases the handover parameters. If the total number of too early handovers, handover to wrong cell and ping-pong handovers is bigger, the solution decreases the handover parameters.

In [19], the authors propose a solution that divides the coverage area of the cell as handover areas. While calculating too early handover, too late handover and ping-pong handover ratios, the algorithm can use different weight values for different handover areas. After calculating these ratios, if they are over predefined thresholds, the algorithm tunes the hysteresis and TTT values.

With the introduction of the heterogeneous networks, mobility robustness optimization algorithms needs to be revised to support the characteristics of the heterogeneous topologies. In [42], the authors propose a solution that optimizes the handover parameters in femto-cell networks. The solution defines a cost function with taking numbers of ping-pong handover, continuous handover, too late handover, too early handover and wrong handover as parameters. After, the optimization algorithm tries to minimize this cost function with using gradient method. The hysteresis and TTT values are changed according to the result of the optimization algorithm. Some of these algorithms also proposes some changes in the LTE specification. In [35], the indoor femto-cell learns from previous handovers by looking their locations and creates a self organizing map. After, with using this map, it decides whether to permit or prohibit future handover attempts from that locations. [40] also tries to solve this problem. In this solution, the algorithm takes the speed and service type of the user as input. The handover from a femto-cell to a macro-cell is only done if the UE is in high mobile state or in medium mobile state with real time QoS.

Some heterogeneous network solutions try to optimize handover parameters between macro-cell and pico-cells. In [33], the authors propose setting lower hysteresis and TTT values for handover between macro and pico-cells. While lowering hysteresis and TTT values, the authors also propose a method to decrease the number of unnecessary handovers. In this method, the UE calculates the degree between its moving direction and line between itself and the pico-cell. If the degree is bigger than a given threshold, the UE ignores the cell. In [28], the authors take speed of the user and types of the source and target cell as parameters to find the optimum TTT values. The authors accept %2 RLF rate as threshold and find the optimum TTT values with different reference speed values with considering macro-to-macro and macro-to-pico handovers. After, they group the speed values as normal, medium and high classes according to the LTE specification.

User mobility is one of the most important parameter for mobility robustness optimization. The LTE specification defines three speed classes, normal, medium and high. According to these mobility classes, the UE can alter the TTT value with multiplying it with a coefficient. Lots of mobility robustness optimization solutions take speed as parameter and use it also to adapt the other handover parameters. In [37], the authors propose to use different hysteresis values for different speed values. In [26], the authors propose to adapt the CIO values according to the velocity of the users. In this solution the system proposes using different CIO values for different speed classes. If a ping-pong or too early handover occurs, the CIO value between the serving and neighbor cell is increased with looking the velocity of the user. If a too late handover occurs, the CIO value is decreased.

User mobility can be measured with using different ways. In [39], the authors propose a solution that changes the TTT, threshold and hysteresis values with looking the number of cell boundary crossings of the UE. The authors also add the velocity of the UE as a parameter to the L3 filtering phase. To find the number of cell boundary crossings, the authors propose a probabilistic model that calculates the value over two parameters, velocity of the UE and diameter of the serving cell. In [36], the authors calculate the number of cell boundary crossings with counting the number of cell identity changes.

Since high speed trains have higher mobility, some solutions try to optimize the handover parameters specifically for high speed railway environments. In [30], the authors propose to use different hysteresis and TTT values according to the speed of the train. In [41], the authors replace the TTT value with a threshold value. In this solution, the L3 filtering works periodically according to a given period T_u. The handover criteria are only met when number of successful L3 filtering reaches to a given predefined threshold value $S_{threshold}$. The solution defines different threshold values for different speed classes.

In [27], the authors propose a solution that calculates the hysteresis value adaptively with using input parameters like load, velocity and service type. The hysteresis value is calculated with using the formula;

$$H = H_{default} + \alpha \cdot (w_l \cdot N_l + w_v \cdot N_v + w_s \cdot N_s) \tag{3.2}$$

Every cost parameter in the formula has a weight and the total value of the weights must be equal to 1. The first cost parameter is the load difference between the serving and neighbor cell. The hysteresis must be increased if the load of the neighbor cell is greater than the serving cell's load. The second parameter is the velocity. The hysteresis must be increased with the user's velocity. The third parameter is the service type. The UEs with higher QoS classes need to have lower hysteresis value.

In [15], the authors propose a method to decrease handover oscillations. In this solution, instead of only using the last measurement, the authors propose to use the average of last N measurements while evaluating the handover decisions. With this way handover oscillations because of unusual changes in measurement results could be prevented. In [34], the authors extend this solution with calculating the N adaptively. The solution adapts the number of measurements that will be used in the algorithm with using the velocity and moving direction of the user. In [13], also the authors try to minimize the handover oscillations. The algorithm works in iterations and compares the previous iterations' results with the current iteration's with calculating oscillation ratio each iteration. According to the results, the algorithm changes the handover parameters between the two cells.

Some solutions try to add extensions to the handover procedure in the network. In [23], after the serving cell receives the measurement report, it monitors the downlink SINR of the UE. When the SINR drops below a given threshold, the serving cell starts the handover preparation.

Since self optimization use cases generally confront with each other, some authors propose solutions that deal the problem with considering other use cases. In [29], the authors propose a solution that coordinates mobility load balancing and mobility robustness optimization algorithms. For mobility load balancing, CIO values can be changed to offload some users in cell border to neighbor cells. For mobility robustness optimization, the algorithm proposed in [24] could be used. In this solution, the authors try to coordinate these two solutions with using a coordinator mechanism.

If we look these previous studies, we can see that in practice, most of the solutions can only be implemented with addition of new parameters to the RRC procedures in LTE specification. This changes need excessive work and an agreement. Also, the implementations must provide backward compatibility. Beyond these works, some of the previous works offer the optimization of handover parameters defined in the standard and these solutions can be easily applied to current LTE networks. These works generally tune hysteresis and TTT parameters. Since these values can only be adjusted for all of the neighbor cells, this approach has some limitations. In this thesis, we plan to offer a handover parameter optimization algorithm which is easily applicable, conforms to the LTE standards and works better in heterogeneous networks.

CHAPTER 4

PROPOSED SOLUTION TO THE HANDOVER PARAMETER OPTIMIZATION PROBLEM

With the advancements in the LTE specifications, previous solutions that are offered to solve the handover parameter optimization problem need to be revised. In this chapter our proposed solution to the problem is explained briefly with mentioning the mechanisms that the solution is implemented in.

4.1 A3 Event

For Intra E-UTRAN handovers, generally A3 event is used by the UE to send measurement report to the serving cell. An A3 event is triggered when the power of a neighbor cell becomes offset better than the serving cell's. The entry condition for the A3 event can be seen in formula 4.1.

$$mn + ofn + ocn - hys > mp + ofp + ocp + off \tag{4.1}$$

The definition of the values in the equation are:

- *mn*: This value shows the measurement report of the neighbor cell.
- *ofn*: This value shows the frequency specific offset defined for the frequency of the measured cell. It can be used in inter-frequency measurements.
- *ocn*: This value shows the CIO value defined for the measured cell.
- *hys*: The hysteresis value shows the difference needed between the measurements of the serving and the neighbor cells to trigger the A3 event.

- *mp*: This value shows the measurement report of the serving cell.

- *ofp*: This value shows the frequency specific offset defined for the serving cell's frequency. It can be used in inter-frequency measurements.

- *ocp*: This value shows the CIO value defined for the serving cell.

- *off*: This value shows the offset parameter for the A3 event.

The *mn* and *mp* values are RSRP or RSRQ of the measured cell. These values are expressed in dBm for RSRP and db for RSRQ. The other parameters, hysteresis and offset values, are expressed in dB. Also, hysteresis value must be positive, while offset values can also be negative.

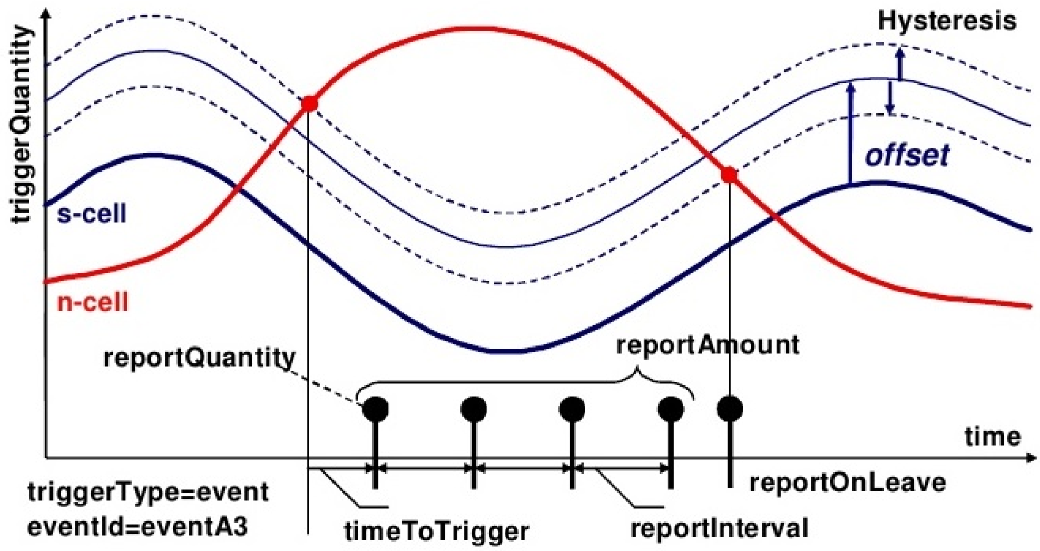

Figure 4.1: A3 Event

After the event triggering, the UE continues to measure the environment for a duration called time to trigger (TTT). The values that can be assigned to the TTT are defined in the LTE specification. These values are; 0, 40, 64, 80, 100, 128, 160, 256, 320, 480, 512, 640, 1024, 1280, 2560 and 5120 ms. During the TTT duration, if the leaving condition is satisfied, the UE leaves the event triggering. The leaving condition for the A3 event can be seen in formula 4.2.

$$mn + ofn + ocn + hys < mp + ofp + ocp + off \tag{4.2}$$

If the leaving condition does not satisfied during the TTT duration, A3 event is triggered and the UE sends a measurement report to the serving cell to request a handover.

According to the formulas, it can be clearly seen that different parameter settings change the time of the measurement report triggering. Since the serving cell starts the handover procedure after receiving the measurement report, incorrect setting of handover parameters can end with handover failures or unnecessary handovers due to untimely handover attempts. The offset values also effects the measurement report triggering with changing the hysteresis value positive or negative.

4.2 Optimization Algorithm

To find the proper set of handover parameters, previous statistics gathered from the handover events can be used. The metrics that can be used in the optimization algorithm are:

- Handover too early ratio: This metric shows the ratio of the too early handover events to all of the handover events. The handover failures can be detected with using the RLF Indication messages sent to the target cell.

$$HTER = \frac{N_{HOte}}{N_{HO}} \tag{4.3}$$

- Handover too late ratio: This metric shows the ratio of the too late handover events to all of the handover events. The handover failures can be detected with using the RLF Indication messages sent to the source cell.

$$HTLR = \frac{N_{HOtl}}{N_{HO}} \tag{4.4}$$

- Ping-pong ratio: This metric shows the ratio of the ping-pong handover events to all of the handover events. A ping-pong event can be detected with looking consecutive handovers of a UE. If the first handover's serving cell is the second handover's target cell and the difference between the starting time of these handover events is smaller than the critical ping-pong handover time, this can be called as a ping-pong handover.

$$PPR = \frac{N_{HOpp}}{N_{HO}} \tag{4.5}$$

To solve these handover problems, different changes could be made on the handover parameters. These changed are listed below.

- Handover too early: Handover too early events occur when RLF occurs between the UE and the target cell during or after the handover. RLF can be occurred because of the channel quality degradation caused by the high inter-cell interference from the source cell. To solve this problem, the handover procedure could be started later, when the UE moves closer to the target cell. So, to decrease the handover too early events, handover parameters could be increased.
- Handover too late: Handover too late events occur when RLF occurs between the UE and the source cell before or during the handover. RLF can be occurred because of the channel quality degradation caused by the high inter-cell interference from the target cell. To solve this problem, the handover procedure could be started earlier, when the UE is closer to the source cell. So, to decrease the handover too late events, handover parameters could be decreased.
- Ping-pong handover: Ping-pong handovers occur when the UE switches back to its serving cell after a successful handover to a neighbor cell. The ping-pong handover can occur because of the instantaneous increases in the measurements of a neighbor cell. If the UE sends a measurement report during these increases, the serving cell can initiate a handover procedure with the neighbor cell. When the measurements of the serving cell get better again, the UE can send a measurement report and the new serving cell could start a handover procedure with the previous serving cell of the UE. In A3 event, if the hysteresis and TTT values are too low, instantaneous increases in the measurements can trigger the measurement reporting. So, to prevent ping-pong handovers, handover parameters could be increased.

If we look to the changes that needs to be done to solve these problems, we can see that the solutions contradict with each other. To decrease handover too early and ping-pong handover events, the handover parameters must be increased while to decrease handover too late events, the parameters must be decreased. According to these, the handover parameter optimization problem could be categorized as a multi-objective decision making problem.

There are multiple ways to solve a multi-objective decision making problem. The simplest method is the weighted sum method. In weighted sum method, the parameters of the optimization function is multiplied with weight values. Since there are multiple solutions for the multi-objective decision making problem, these weight values help giving different priorities for the different parameters. With this method, for the handover parameter optimization problem, the goal of the problem can be defined as minimizing the following equation;

$$HPI = w_{HTER} \cdot HTER + w_{PPR} \cdot PPR + w_{HTLR} \cdot HTLR \tag{4.6}$$

If we look to the previous studies on handover parameter optimization problem, we can see that most of the solutions use this method with same or different parameters while calculating the handover performance. These previous studies generally differ on the finding of the optimization direction according to the result of the function.

Another approach to solve the multi-objective decision making problem is to use a utility function that helps the decision making. The weighted sum method is a simple method that works on the uncertainty. If the system is known enough to define a utility function that helps the decision making, this can work better than using the weighted sum method.

In handover parameter optimization problem, it can be said that if the numbers of handover too early and ping-pong handover events are bigger than the number of handover too late events, the handover parameters are above the optimum. Vice versa, the handover parameters are below the optimum. According to these, two decision functions can be defined. These decision functions can be defined as up and down cost functions. The formula of the up cost function can be defined as;

$$HPI_{up} = w_{HTER} \cdot HTER + w_{PPR} \cdot PPR \tag{4.7}$$

The up cost function consist of the sum of handover too early ratio and ping-pong ratio after multiplying them with weight values. The other function, the down cost function is only consist of handover too late ratio after multiplying it with its weight value. The formula of the down cost function is;

$$HPI_{down} = w_{HTLR} \cdot HTLR \tag{4.8}$$

The weight values can be assigned by the network operators to give priority to the different parameters according to the network policy. For example, priority of the handover too late events can be increased with assigning a bigger value to w_{HTLR} over other weight values. With this way, the optimization direction can be changed to down even if the sum of $HTER$ and PPR is bigger than $HTLR$. The values of the weights must not be extreme or too different from each other, since this can affect the operation of the optimization algorithm negatively. Also, to normalize the results of the cost functions, a restriction can be added that the sum of the weight values must be equal to 1.

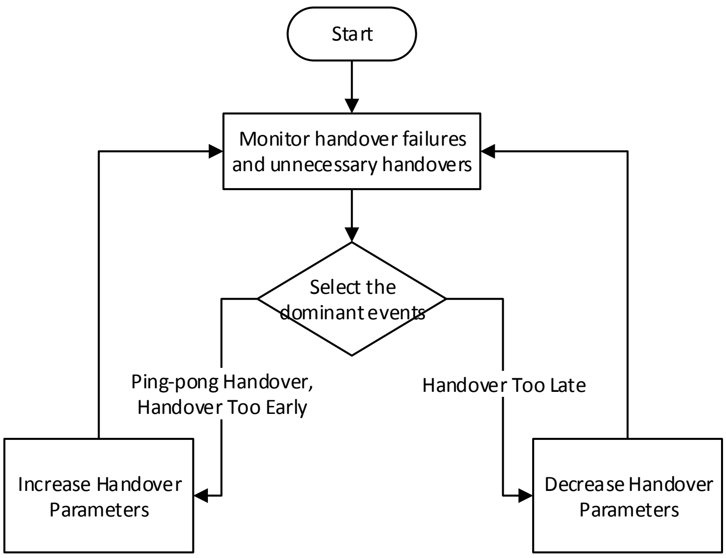

Figure 4.2: Flowchart of the Optimization Direction Finding Approach

The optimization algorithm also defines a threshold value, T, for the cost functions. This value is necessary to prevent the unnecessary oscillations between up and down for so small ratios. Therefore, to change the handover parameters, HPI_{up} or HPI_{down} must be bigger than T.

The value of the threshold can be defined with considering stability and reactivity of the algorithm. If the threshold value is set too low, the handover parameters cannot converge and change up and down around the optimized values. If the threshold value is set too high, the handover parameters cannot find better handover parameter values after the cost functions dropped below the threshold.

To sum up these definitions, the optimization direction finding algorithm works as follows:

```
Compare HPI_up with HPI_down
if HPI_up is bigger than HPI_down and T then
    Change the optimization direction to up
else if HPI_down is bigger than or equal to HPI_up and bigger than T then
    Change the optimization direction to down
end
```

Algorithm 4.1: Optimization Direction Finding Algorithm

After finding the optimization direction, the handover parameters that will be changed needs to be found. In most of the related works, hysteresis and TTT values are tuned. But, this approach brings some limitations. Hysteresis and TTT parameters cannot be adjusted independently per neighbor cell. This can be acceptable for homogeneous networks which all of the handover attempts are between macro-cells. For heterogeneous networks, the handover parameters need to be tuned with considering the different characteristics of the neighbor cells.

In heterogeneous networks, the handovers between macro-cells and small cells have different characteristics compared to handovers between macro-cells. For handovers from small cells to macro-cells, the power of the small cell drops dramatically compared to macro-cells. So, the UE suffers inter-cell interference from the macro-cell earlier. If the handover parameters are high, too late handovers can occur. Handovers from macro-cells to small cells are also problematic. Since the power of the small cell increases dramatically compared to macro-cells, the UE suffers inter-cell interference from the small cell earlier. Like the small cell to macro-cell scenario, too late handovers can occur if the handover parameters are high.

To handle the different conditions for neighbor cells, CIO values could be changed. With this way, handover margins can be differentiated per neighbor cell. According to the equation in 4.1, it can be said that, to increase the handover margin, CIO value of the neighbor cell must be decreased while to decrease the handover margin, CIO value must be increased.

Since tuning of the hysteresis or TTT effects the handovers for all neighbors, it can be defined as global optimization while tuning of the CIO can be defined as local optimization. The global direction finding algorithm can also be used for the local direction finding algorithm with changing weight and threshold values. Since the local optimization comes after the global optimization, the threshold value must be big enough to prevent the change of the local values after global values for near optimal parameters. For local direction finding algorithm, the handover too late ratio, handover too early ratio and ping-pong ratio are calculated per neighbor and the cost functions are calculated with using them. So the local cost functions can be defined as;

$$HPI_{upl} = w_{HTERl} \cdot HTER_l + w_{PPRl} \cdot PPR_l \tag{4.9}$$

$$HPI_{downl} = w_{HTLRl} \cdot HTLR_l \tag{4.10}$$

According to the proposed algorithm, it can be seen that the change that must be made in the handover margin is determined by the global and local threshold values. If only one of the conditions is satisfied, the handover margin changes one step. If both of the conditions are satisfied, the handover margin can change two steps if the optimization directions are the same. According to the different handover parameters, the changes that can be made on a parameter are:

- TTT: The values that can be used as a TTT are defined in the LTE specification. These values are; 0, 40, 64, 80, 100, 128, 160, 256, 320, 480, 512, 640, 1024, 1280, 2560 and 5120 ms. If the proposed algorithm needs to change TTT value, it increases or decreases the TTT value one step at a time.
- Hysteresis: According to the LTE specification hysteresis value can be a positive number between 0 and 15. In the solution the maximum hysteresis value

is set to 10 dB. If the proposed algorithm needs to change hysteresis value it increases or decreases the hysteresis value 0.5 dB at a time.

- CIO: According to the LTE specification hysteresis value can be a positive number between -24 and 24 dB. In the solution these values are set to -5 and 5 dB. If the proposed algorithm needs to change CIO value it increases or decreases the CIO value 0.5 dB at a time.

According to these, the flow of the optimization algorithm is;

```
Calculate the HPI_upg and HPI_downg
Compare HPI_upg with HPI_downg
if HPI_upg is bigger than HPI_downg and T_g then
    Increase the hysteresis or TTT
else if HPI_downg is bigger than or equal to HPI_upg and bigger than T_g then
    Decrease the hysteresis or TTT
end
for each neighbor cells do
    Calculate the HPI_upl and HPI_downl
    Compare HPI_upl with HPI_downl
    if HPI_upl is bigger than HPI_downl and T_l then
        Decrease the CIO
    else if HPI_downl is bigger than or equal to HPI_upl and bigger than T_l then
        Increase the CIO
    end
end
```

Algorithm 4.2: The Proposed Handover Parameter Optimization Algorithm

For the global optimization, hysteresis and TTT are the values that can be changed. So before the parameter changes, firstly the parameter that will be changed needs to be found. There are three approaches used when selecting hysteresis or TTT. These approaches are;

- Diagonal: In diagonal approach, both of the hysteresis and TTT can change in an iteration [14].

- Zig-zag: In zig-zag approach, only one parameter can change in an iteration. The parameters change in order. If a parameter is changed in the previous iteration, the other parameter changes [14].

- Single: In single approach, only one parameter can change in an iteration. A parameter changes until it reaches its limits. If the parameter reaches its limits, the other parameter changes [31].

In these approaches, the diagonal approach is better in extreme parameter values since it can change the handover parameters faster. But it performs poorly in near optimal parameter values since its search space is very narrow. In single approach, the algorithm looks for the previous results to find its limits. With the introduction of CIO, this approach is not possible since the handover margins can differ even if the same hysteresis and TTT are used. So, the zig-zag approach is preferred in the proposed solution.

4.3 Archtitecture of the Proposed Solution

SON functions can be divided into three according to their architectures, distributed, centralized and hybrid. In this solution centralized architecture is preferred. In centralized architecture, SON functions are executed on the core elements of the network, generally on the Element Management System (EMS) or Network Management System (NMS).

NMS and EMS are defined in Telecommunications Management Network (TMN) which is a open framework defined by ITU-T to provide a standard for managing telecommunications networks. EMS consists of systems and applications that manages telecommunications network elements (NE) and defined on the Element Management Layer (EML) of the framework which is the layer that is responsible of managing network elements. NMS is defined on the Network Management Layer (NML), which is the layer that is responsible of control and configuration supervision of the network. In centralised SON architecture, the NMS receives the reports, measurement data etc. from the ENodeBs over EML and after applying the SON algorithms, it sends the commands, parameters etc. back to the eNodeBs over EML.

The centralized SON functions work in a periodical way and can be divided in three phases. These phases are [11]:

- Collection Interval: In this interval, the eNodeBs gathers the required metrics that will be used as a input to the SON algorithm. After gathering the eNodeB sends the metrics to the EMS. In this solution, this interval is named as a window.
- Analysis Interval: In this interval, after gathering the inputs, the SON algorithm analyse the inputs and decide the output. The analysis can be made over the last 1 or N windows.
- Change Interval: In this interval, after the decision, the EMS sends the results to the eNodeBs. After receiving the results, the eNodeBs update their configuration.

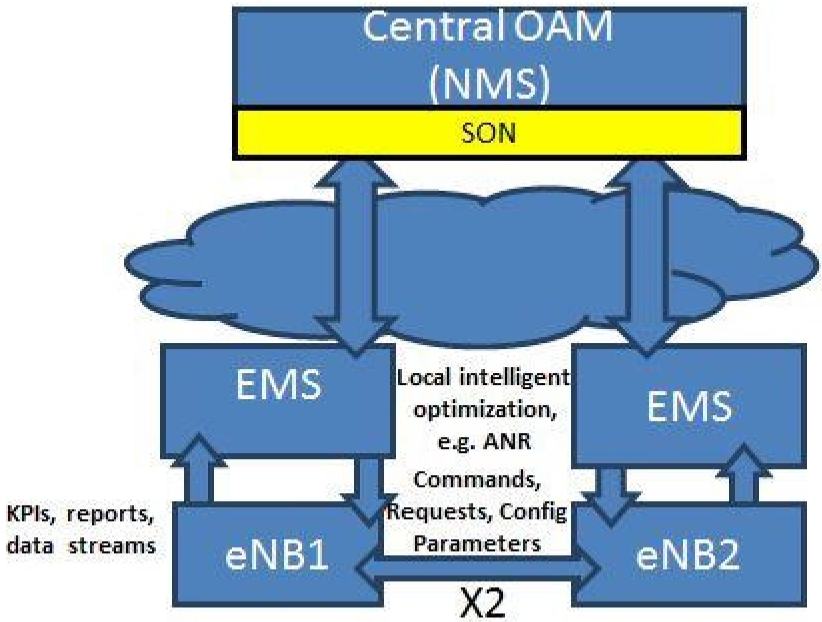

Figure 4.3: Centralized SON Architecture

The centralised architecture have many advantages over distributed architecture. Firstly, the same SON algorithms can work same for all eNodeBs without considering vendor differences. Secondly, the SON algorithm can easily consider the reports from other eNodeBs while analysing the reports of an eNodeB and can jointly optimise the network parameters. Thirdly, the SON algorithm can easily consider the other SON algorithms and made the optimisation with considering conflicted goals.

The centralised architecture also have some disadvantages over distributed architecture. The first disadvantage is the delay caused by the forwarding of inputs to a centralised location for processing. The EMS must scalable to support the load caused by the maintained eNodeBs. The second disadvantage is the usage of excessive network resources used while sending the measurements and reports to the EMS.

Centralized architecture is preferred over the distributed architecture in the proposed solution. One of the main concerns considered while proposing the handover parameter optimization algorithm is the simplicity. In centralized architecture, complexity caused by the vendor differences is nearly eliminated. Also, the centralized architecture does not need a coordination between the eNodeBs for SON purposes. Beyond these the downside of the centralized architecture is negligible while people are considering technologies like Cloud Radio Access Network (C-RAN).

CHAPTER 5

IMPLEMENTATION

In this chapter, implementation of the proposed solution is explained. The implementation of the LTE network is over a simulation environment. Since the simulation environment does not provide the full standards of the LTE specifications, some improvements need to be done on the simulator. In first part of this chapter, these improvements are explained. Beyond the simulation environment, the SON algorithm is implemented as a secondary application. In second part, this application and its coordination with the simulation environment is explained.

5.1 Simulation Environment

There are only a handful of open or proprietary simulation environments that support simulating the LTE networks. The choices are:

- OPNET: OPNET is a proprietary network simulation solution that is developed by Riverbed. It is a complete simulation environment solution that provides a graphical user interface to create the simulation environment. OPNET supports various network technologies including LTE. The implementation of the LTE covers most aspects of the LTE specification including complete support of the handover procedure. Since OPNET is a proprietary solution with high licensing fees, it could not be used in this thesis work.
- LTE-Sim: LTE-Sim, which is developed by Telematics Lab of Politecnico di Bari, Italy, is a open source simulation framework that is specifically designed

for simulating LTE networks. It is developed with C++. LTE-Sim fulfills the basic requirements for this thesis work with providing basic support for heterogeneous network environments, mobility and handover procedures. But while providing the basic requirements for these aspects, it lacks the detailed implementation according to the LTE specifications. For example for handover procedure, it lacks the implementation of measurement events. Also its documentation is very poor with only providing a tutorial. Since excessive work needs to be done to implement the incomplete parts, LTE-Sim is not preferred for this thesis work.

- ns-3: ns-3 is a discrete-event network simulator that provides support for various network technologies including LTE [32]. It is a open source free software and generally used for teaching and academic purposes. ns-3 is a part of ns network simulator series and the successor of ns-1 and ns-2. ns-3 is developed with C++ and also provides bindings for Python. Since being the generally preferred free network simulation choice, ns-3 has a wide community and its documentation is very good. The LTE module of the ns-3 is developed by Centre Tecnològic de Telecomunicacions de Catalunya, Spain with LENA project [16]. ns-3 supports various aspects of the LTE with providing support for heterogeneous networks, mobility and handover procedures. With comparing the LTE-Sim, ns-3 implementations of these aspects are more complete than LTE-Sim's implementations. So, ns-3 is preferred as a simulation environment for this thesis work.

Beyond these simulators, telecommunications corporations generally develop their own LTE simulators.

5.2 Improvements Over the Simulation Environment

To use the ns-3 as a simulation environment, some problems need to be solved. Firstly, ns-3 does not support RLF. So, to catch the handover failures, it needs to be implemented or a workaround mechanism is needed. Secondly, the CIO is not implemented in ns-3 and in A3 Event, it is always assigned as 0. Thirdly, while ns-3 provides helper functions for creating the network topology easier, it does not provide helper functions for creating heterogeneous networks. The modifications that need to be made over ns-3 to solve these problems are explained below.

5.2.1 Detection of Handover Failures

The proposed SON algorithm uses too early and too late handover reports to tune the handover parameters. In LTE specification, after these events, the UE tries to re-establish a connection to source, target or another neighbor cell. After connection re-establishment, the UE sends a RLF Indication message that includes the detailed information about the event. Normally, these messages are used to identify the RLF events.

Since ns-3 does not support RLF, to detect the handover failures, it must be implemented or a workaround solution is needed. At current stage, ns-3 provides limited support for the RRC Idle mode. The UEs start the simulation with Idle mode and after cell selection, they change to RRC Connected mode. After this transition, a UE cannot go back to Idle mode even it goes out of the cell's coverage. To implement the RLF, a proper implementation of RRC Idle mode is needed since the UE must go to Idle mode when connection re-establishment attempts are failed. Since this require excessive work, implementation of the RLF option is not considered.

Instead of, to detect the handover too early and too late events, timers defined in the source and target cells are used. The ns-3 implementation of LTE defines two timers for the handover event on an eNodeB. These timers are;

- Handover Leaving Timer: After the source cell receives Handover Request Acknowledge message from the target cell, it starts the Handover Leaving Timer. The timer stops when the UE Context Release message received from the target cell. If timeout occurs, the source cell destroy the UE's context.
- Handover Joining Timer: After sending the Handover Request Acknowledge message, the target cell starts the Handover Joining Timer. The timer stops when the *RRCConnectionReconfigurationComplete* message is received from the UE. If timeout occurs, the target cell destroy the UE's context.

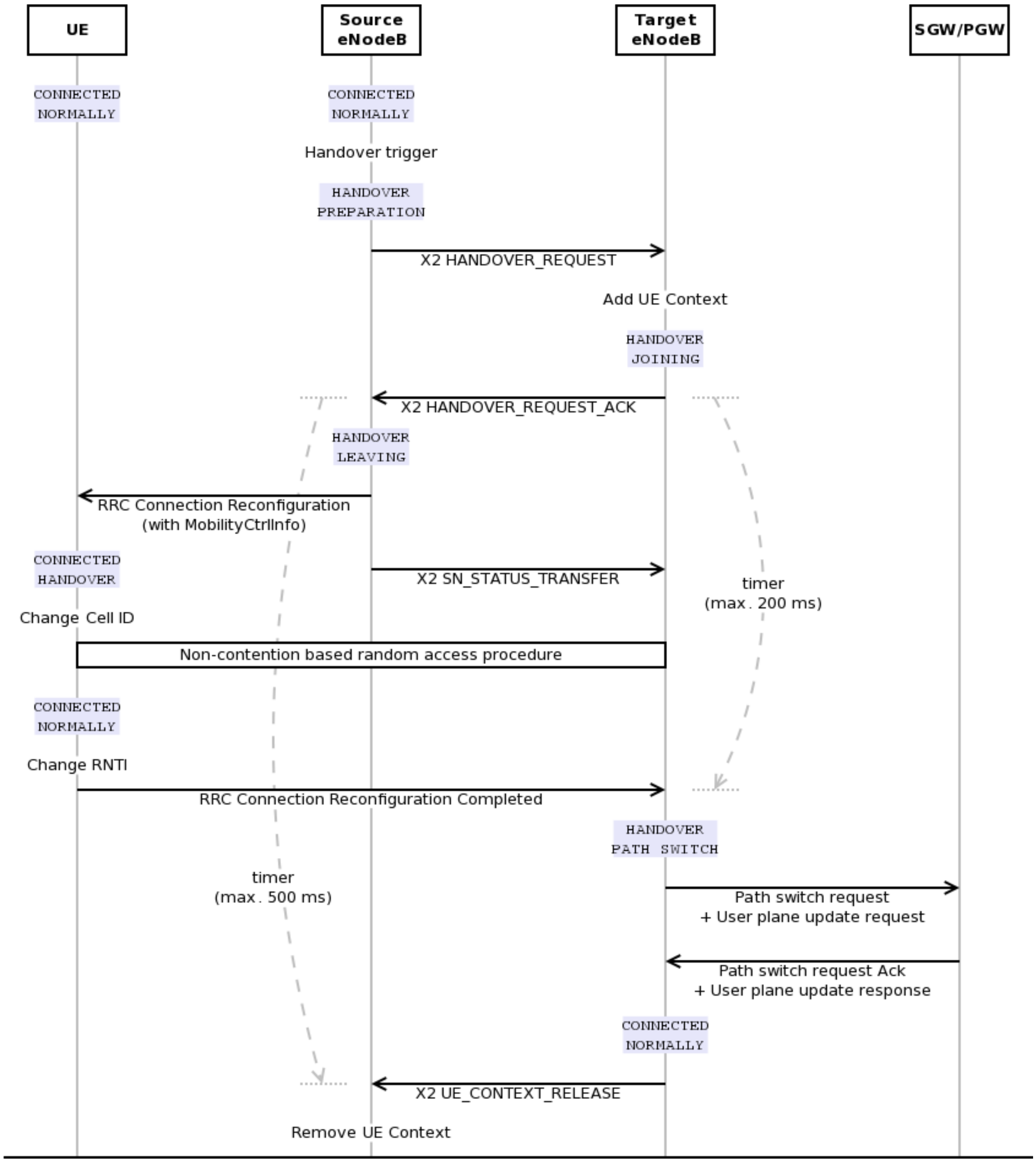

Figure 5.1: Implementation of the Handover Procedure in ns-3

With using these timers, handover failures can be detected. The causes of the detected handover failures can also be found with looking the messages sent and received after the timers' starts. A timeout can occur because of the following situations;

- After receiving the Handover Request Acknowledge Message, the source cell sends the *RRCConnectionReconfiguration* message to the UE. If the UE cannot receive this message, timeout occurs and this can be labeled as handover too late.
- After receiving the *RRCConnectionReconfiguration* message, the UE starts a

random access procedure with the UE. If this procedure is failed, timeout occurs and this can be labeled as handover too early.

- If the random access procedure is successful, the UE sends *RRCConnectionReconfigurationComplete* message to the UE. If the target cell cannot receive this message, timeout occurs and this can be labeled as handover too early.

With looking these situations in simulation logs, handover too early and too late events can be detected. Since this solution is not a proper implementation, it has some downsides. Firstly, it cannot detect handover too late events occurred before the handover and handover too early events occurred after the handover. Also, the UE cannot start a connection re-establishment procedure for all cases.

The connection re-establishment procedure is only implemented for the handover too early events caused by the connection failures in random access procedure. ns-3 does not support connection re-establishment because its procedure is not implemented fully in UE RRC layer. In UE RRC Layer's code, connection re-establishment messages and their functions are defined but the procedure is not fully integrated to the RRC state machine. So, for a basic support of connection re-establishment, some of the dummy functions defined for the connection re-establishment procedure are filled. In first filled function, after a random access failure is occurred during the handover, the UE sends a *RrcConnectionReestablishmentRequest* message to the target cell and changes to CONNECTED REESTABLISHING state. In second filled function, after receiving the *RrcConnectionReestablishment* message from the target cell, the UE sends a *RrcConnectionReestablishmentComplete* message and changes to CONNECTED NORMALLY state. This solution does not provide the full implementation of connection re-establishment procedure but in cases without failure, the UE can connect to the target cell again.

5.2.2 Implementation of Cell Individual Offset

In LTE, CIO values are sent to the UEs with measurement objects in measurement configurations. ns-3 does not support using CIO in measurement events. In order to implement the solution properly, CIO values must be sent to the UEs and they must be used in event condition inequalities according to the equations. The implementation is done with the following way.

```
-- ASN1START

MeasObjectEUTRA ::=                 SEQUENCE {
    carrierFreq                         ARFCN-ValueEUTRA,
    allowedMeasBandwidth                AllowedMeasBandwidth,
    presenceAntennaPort1                PresenceAntennaPort1,
    neighCellConfig                     NeighCellConfig,
    offsetFreq                          Q-OffsetRange              DEFAULT dB0,
    -- Cell list
    cellsToRemoveList                   CellIndexList              OPTIONAL,       -- Need ON
    cellsToAddModList                   CellsToAddModList          OPTIONAL,       -- Need ON
    -- Black list
    blackCellsToRemoveList              CellIndexList              OPTIONAL,       -- Need ON
    blackCellsToAddModList              BlackCellsToAddModList     OPTIONAL,       -- Need ON
    cellForWhichToReportCGI             PhysCellId                 OPTIONAL,       -- Need ON
    ...,
    [[measCycleSCell-r10                MeasCycleSCell-r10     OPTIONAL,       -- Need ON
        measSubframePatternConfigNeigh-r10  MeasSubframePatternConfigNeigh-r10  OPTIONAL
                -- Need ON
    ]],
    [[widebandRSRQ-Meas-r11             BOOLEAN OPTIONAL        -- Cond WB-RSRQ
    ]]
}

MeasObjectEUTRA-v9e0 ::=            SEQUENCE {
    carrierFreq-v9e0                    ARFCN-ValueEUTRA-v9e0
}

CellsToAddModList ::=               SEQUENCE (SIZE (1..maxCellMeas)) OF CellsToAddMod

CellsToAddMod ::=   SEQUENCE {
    cellIndex                           INTEGER (1..maxCellMeas),
    physCellId                          PhysCellId,
    cellIndividualOffset                Q-OffsetRange
}

BlackCellsToAddModList ::=          SEQUENCE (SIZE (1..maxCellMeas)) OF BlackCellsToAddMod

BlackCellsToAddMod ::=  SEQUENCE {
    cellIndex                           INTEGER (1..maxCellMeas),
    physCellIdRange                     PhysCellIdRange
}

MeasCycleSCell-r10 ::=              ENUMERATED {sf160, sf256, sf320, sf512,
                                        sf640, sf1024, sf1280, spare1}

MeasSubframePatternConfigNeigh-r10 ::=  CHOICE {
    release                             NULL,
    setup                               SEQUENCE {
        measSubframePatternNeigh-r10        MeasSubframePattern-r10,
        measSubframeCellList-r10            MeasSubframeCellList-r10    OPTIONAL    -- Cond
always
    }
}

MeasSubframeCellList-r10 ::=    SEQUENCE (SIZE (1..maxCellMeas)) OF PhysCellIdRange

-- ASN1STOP
```

Figure 5.2: Structure of a MeasConfigEUTRA Object

1. The simulation environment receives the CIO values as a sparse matrix from a input file. In this matrix, a value's row number represent the source cell id and column number represents the target cell id.

2. After reading the input file, while creating an eNodeB, the required row from the input matrix is sent to the eNodeB's RRC layer object in an array.

3. In LTE RRC specification, *MeasConfig* objects defined in *RRCConnectionReconfiguration* message holds the measurement objects. E-UTRAN measure-

ment objects are named as *MeasObjectEUTRA*. A *MeasObjectEUTRA* holds the *cellsToAddModList*, which is the list of eNodeBs that the UE will measure. The CIO values are hold in *CellsToAddMod* objects in this list with their cell ids. The simulation environment implements this structure, but while creating a *CellsToAddMod* object, the CIO values are always set to zero. So, to send the CIO values to UEs, while creating a *CellsToAddMod* object, the CIO value is set with using the CIO array with looking the cell id in the object.

4. After the UE receives the *RRCConnectionReconfiguration*, it extracts the *CellsToAddMod* objects from the *MeasObjectEUTRA* and updates its measurement list.

5. In simulation environment, the CIO values are always set to zero in event entry and leaving condition inequalities. So, to use the CIO values in event condition inequalities, the values are read from the measurement list of the UE according to the measured cell's id.

5.2.3 Implementing Heterogeneous Networks

With the absence of a user interface, forming a network topology and configuring the nodes is a complex task in ns-3. To overcome this problem, helper classes are defined in ns-3. The helper classes generally want some required parameters from the user and forms a generic network topology that can be extended. For LTE implementation, *LteHelper* class guides the user to form a LTE network. The *LteHelper* gets some basic parameters from the user and creates the nodes and their network layers with setting the required parameters.

To help the deployment of the eNodeBs, ns-3 defines the *LteHexGridEnbTopologyHelper* class. This class receives the number of the eNodeBs and after forming the topology on a hexagonal grid, it creates and installs the nodes. In hexagonal grid, base stations are deployed on the centre of the hexagons. A base station consist of three eNodeBs. A eNodeB is deployed with a parabolic antenna and covers the one third of the hexagon. This deployment forms a macro-cell.

To implement a heterogeneous network, a new helper class is implemented called

LTEHeterogeneousDeploymentHelper that extends the *LteHexGridEnbTopologyHelper* class. In *LTEHeterogeneousDeploymentHelper* class, after the macro-cells are installed on a hexagonal grid, small cells are installed randomly within the hexagons. The class receives the following configurations from the user; total number of eNodeBs, number of small cells per hexagon, transmit power of the macro-cells, transmit power of the small cells, handover parameters of the cells in an array and CIO matrix. After receiving the configurations, the class installs the eNodeBs according to the following way.

1. The algorithm assigns a index number that is smaller than the total number of eNodeBs to a eNodeB and finds the row and column of the eNodeB in the hexagonal grid with using this index.

2. If the remainder of the division of index number by the number of eNodeBs that must be deployed in a hexagon is smaller than 3, the eNodeB is a macro-cell. Else it is a small cell.

3. After creating the eNodeB, its handover parameters and CIO values are set.

4. After setting the eNodeB's transmit power according to its cell type, if the eNodeB is a macro-cell, the eNodeB is installed in the center of the hexagon after its sector is assigned. Else, the eNodeB is installed after finding a position within the hexagon randomly.

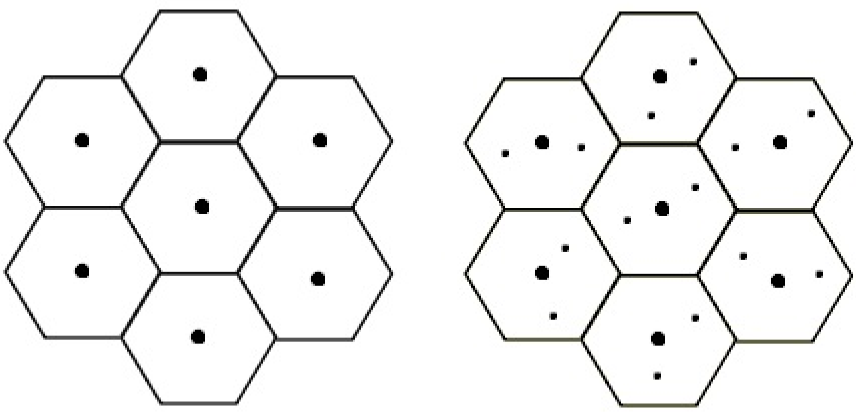

Figure 5.3: Macro-cells in a Hexagonal Grid and Macro-cells with Small Cells

5.3 Generating Mobility Models for the UEs

Since we are proposing an algorithm for the mobility robustness optimization problem, to prepare a testing environment, proper mobility models must be generated for the mobile users. To generate mobility models for the users, traffic simulation environments can be used.

To simulate the mobility of the users, a traffic simulation environment called SUMO (Simulation of Urban MObility) is used. SUMO is is an open source, highly portable, microscopic road traffic simulation package designed to handle large road networks [20]. SUMO takes the road network, definitions and routes of the vehicles as input and simulates the traffic environment for a given time. During the simulation, it generates an output file that has the information about the vehicles, their positions and their speeds during the simulation.

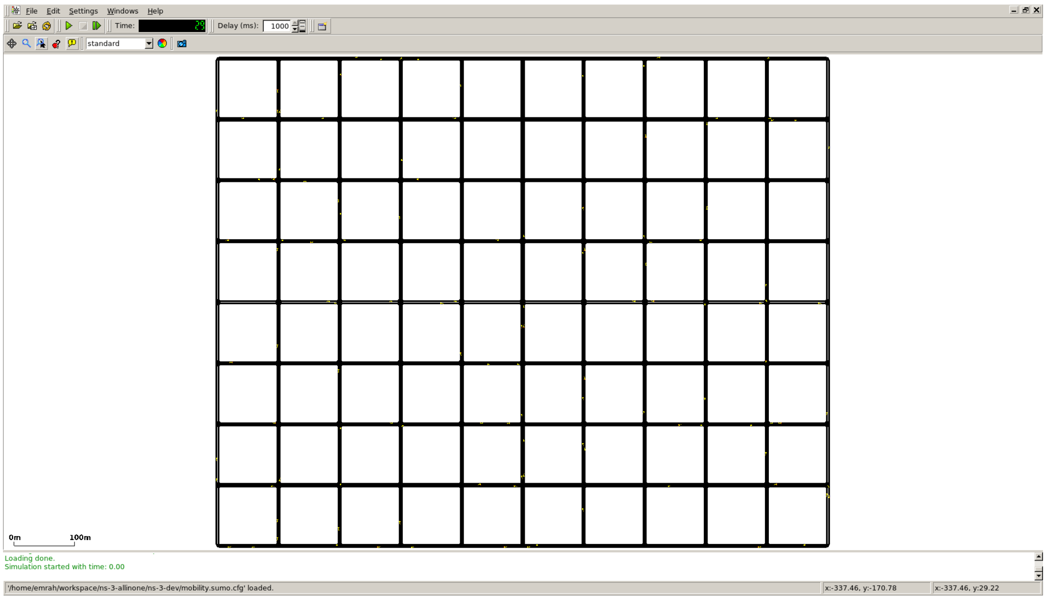

Figure 5.4: A simple Manhattan model road network displayed in SUMO GUI Tool

The output of the SUMO can be used as an input for the ns-3 simulator. SUMO provides a script called *traceExporter* to generate a ns-2 mobility file with using the output of the simulation. The ns-2 mobility files can be used in ns-3 with using a helper class called *Ns2MobilityHelper*. With using it, the simulation can read the ns-2 mobility file and assign mobility models for the UEs.

5.4 Handover Analyzer

To simplify the implementation, the SON algorithm is implemented in a separate application. This application is named as Handover Analyzer and beyond applying the SON algorithm it also manages the simulation environment. The Handover Analyzer application receives the simulation environment configurations, maintains the running of the simulation, applies the SON algorithm according to the output of the simulation and reports the results to the user. The application works according to the following flow:

1. The application reads the input files that have the list of eNodeBs and UEs. These files can be generated by the simulator. The simulation code provides an option for generating the radio environment map. If this option is set to true, the simulator does not run the simulation and only generates the radio environment map with the lists of eNodeBs and UEs.

2. The application reads an input file that has the configurations. This configuration file includes the following information; number of windows, default hysteresis, TTT and CIO values.

3. After reading the configuration file, the application creates a handover parameter list and CIO matrix for the eNodeBs. They are filled with the default values from the configuration file.

4. The application creates a *Window* object per eNodeB. A window represents a collection interval. The handover parameters of the windows are copied from the handover parameter list and CIO matrix.

5. The application creates three input files for the simulation. The first file includes the handover parameters of eNodeBs and the second one includes the CIO matrix. The third one includes some parameters for the simulation.

6. The application creates a route file for the traffic simulation environment. After, it runs the traffic simulation and creates the mobility models of the UEs in a ns-2 mobility file with using the output of it.

7. The application runs the simulator. The simulator reads some of the network configurations from the input files. Beyond these, some of the configurations are provided in the simulation code directly. After creating the network, the simulator runs the simulation.

8. The application waits for the simulator to finish. While running, the simulator creates a log file. The simulator only traces the required events and writes the details of the events to the log file when they are occurred. These traced events are; eNodeB Connection Established, UE Connection Established, eNodeB Handover Start, UE Handover Start, eNodeB Handover End, UE Handover End, UE Handover Error, eNodeB Handover Leaving Timeout and eNodeB Handover Joining Timeout.

9. When the simulation finishes, the application reads the log file and creates *Event* objects with analyzing it. These objects hold the detailed information about the events gathered from the log file. The event types defined in the application are *ConnectionEvent*, *HandoverEvent* and *ConnectionFailureEvent*. A *ConnectionFailureEvent* also holds the cause of the handover failure with *HandoverTooEarly*, *HandoverTooLate* and *RandomAccessError* values.

10. The application analyses the *Event* object lists of the UEs and calculates some statistics with considering cell pairs. The first statistic shows the number of handovers and it is calculated with looking the number of *HandoverEvent* objects. Second statistic shows the number of handover too early events and it is calculated with looking the *ConnectionFailureEvent* objects labelled with *HandoverTooEarly*. Third statistic shows the number of handover too late events and it is calculated with looking the *ConnectionFailureEvent* objects labelled with *HandoverTooLate*. Fourth statistic shows the number of ping-pong handovers and it is calculated with looking the number of consecutive *HandoverEvent* objects which the source cell of the first object is the same as the target cell of the second object.

11. The application also holds *CumulativeWindow* objects that holds the sum of previous windows' statistics. After the calculation of the statistics, they are also added to this objects.

12. The application applies the SON algorithm and updates the handover parameters list and CIO matrix.

13. If the window index does not reached the number of windows, the application continues with the next window. Else, the application writes the statistics hold in the *Window* and *CumulativeWindow* objects to an output file and exits.

CHAPTER 6

TESTING

The proposed SON algorithm is implemented and evaluated in the testing environment. In this chapter, firstly, the testing environment is presented. After, the results gathered from the evaluation of the algorithm are presented. Some of the other handover parameter optimization algorithms also implemented in the simulation environment to compare the results gathered from the implementation of the proposed solution.

6.1 Topology

A heterogeneous network topology is formed to evaluate the SON algorithms. The topology consist of high powered macro-cells and low powered pico-cells. The macro-cells are deployed within a hexagonal grid and the low powered pico-cells are uniformly distributed in the hexagons.

The testing topology consist of 5 macro-cell sites. The distance between two adjacent macro-cell sites are 500 m. The number of macro-cells are 15 and the number of pico-cells are 10. Pico-cells are distributed randomly with 2 pico-cells per a macro-cell site ratio. Macro-cells are deployed with parabolic antennas and their transmit powers are 46 dBm. Pico-cells are deployed with omnidirectional antennas and their transmit powers are 30 dBm. The radio environment map of the testing environment can be seen in figure 6.1.

To simulate the EPC, MME and S-GW/P-GW nodes are deployed. These two nodes

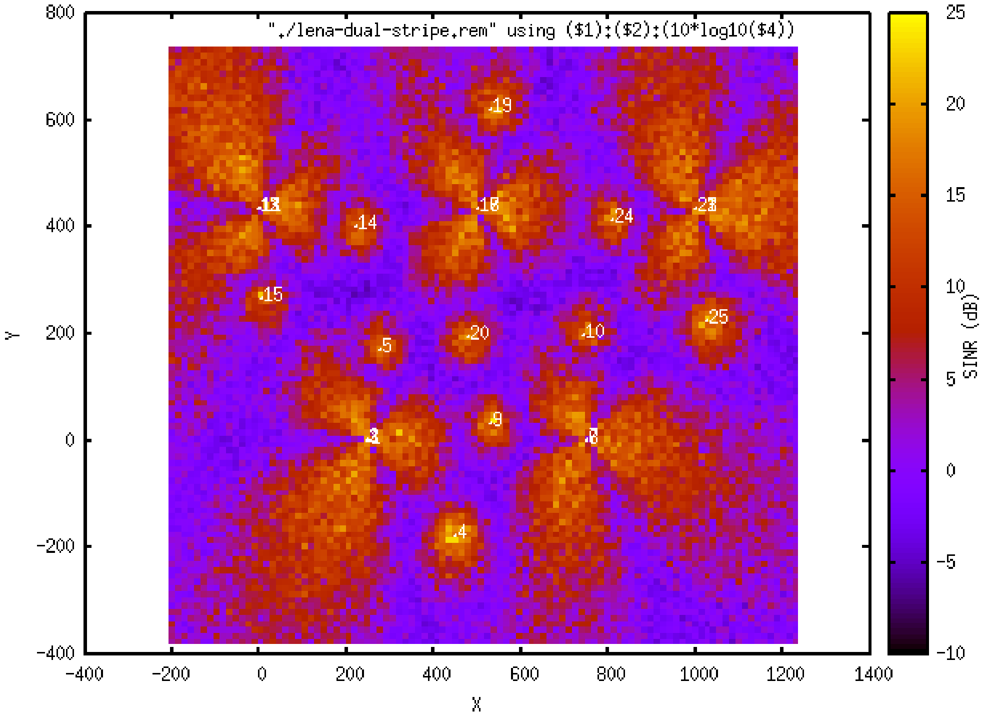

Figure 6.1: Deployment Positions of the eNodeBs

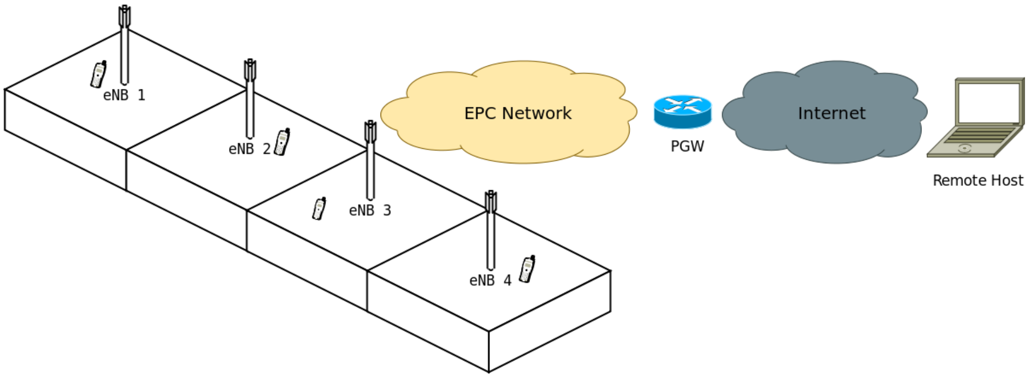

Figure 6.2: End-to-End Network Topology

are connected to the eNodeBs. The S-GW/P-GW node is also connected to a remote host over the Internet. For simulating the data communication, applications are deployed on the remote host and the UEs. To simulate the UE downlink, an application that sends UDP packets to the UEs is deployed on the remote host. The application sends 1024 byte UDP packets to the UEs during the simulation with 0.5 s periods. To simulate the UE uplink, an application that sends UDP packets to the remote host is deployed on the UEs. The application sends 1024 byte UDP packets to the remote host during the simulation with 0.5 s periods.

6.2 Parameters Used In Simulation

Some of the default eNodeB parameters are changed in the simulation environment. These parameters can be seen in the table 6.1

Table 6.1: Simulation Parameters

Macro-cell transmit power	46 dBm
Macro-cell antenna	Parabolic
Pico-cell transmit power	30 dBm
Pico-cell antenna	Omnidirectional
Path Loss Model	$15.3 + 37.6 \cdot log_{10}R$, R in m [2]
Shadowing Model	Log-normal shadowing
eNodeB downlink bandwidth	5 MHz
eNodeB uplink bandwidth	5 MHz
Downlink Channel	2120 MHz
Uplink Channel	1930 MHz

Beyond these parameters, proportional fair scheduler is used as the downlink scheduler. HARQ is disabled because of the problems encountered during the simulation.

The number of UEs used in the simulation is 120. The mobility model of the UEs are provided in a ns-2 mobility file generated with using the SUMO traffic simulator. The road network of the simulation, which is a Manhattan model road network with 11 lanes in X axis and 9 lanes in Y axis, can be seen in figure 5.4. The speed limit in a lane is 13.9 m/s. All of the UEs are in mobile state during the simulation and the routes of the users are generated randomly in the Handover Analyzer application.

6.3 Simulation Results

In this section, results gathered from the simulation environment are presented. Beyond the proposed solution, handover parameter optimization algorithms proposed in [26], [14] and [18] are also implemented. In first part of the section, results gathered from the proposed algorithm are compared with the algorithms that only do global optimization which are [26] and [14]. In second part of the section, results gathered from the proposed algorithm are compared with an algorithm that do global and local optimization which is [18].In third part, the proposed algorithm is implemented with different local threshold values and the results are compared with each other.

To make these comparisons, the simulation is ran for each of the implementation during 20 windows where each window's length is 125 s. Four metrics are collected for each window; handover too early ratio, handover too late ratio, handover failure ratio, which is the sum of previous two ratios, and ping-pong ratio. The simulations are done with three independent samples per window. After getting the results of these samples, average handover too early ratio, handover too late ratio, and ping-pong handover ratio are calculated for the window and these results are given to the optimization algorithm.

6.3.1 Comparison of the Proposed Algorithm with the Algorithms that Do Global Optimization

In the first comparison, beyond the proposed solution, two algorithms proposed in [14] and [26] are implemented. These algorithms only do global optimization and tune hysteresis and TTT parameters.

In [14], the authors propose to use a cost function to calculate the handover performance. The cost function can be summarized as;

$$HP = w_{RLF} \cdot RLF + w_{HOF} \cdot HOF + w_{HPP} \cdot HPP \tag{6.1}$$

According to the formula, the cost function includes RLF ratio, handover failure ratio and ping-pong ratio as parameters. After applying the cost function, the algorithm finds the optimization direction. The optimization direction finding algorithm can be seen in algorithm 6.1.

collect HPIs for the previous interval
calculate HP weighted sum
if current HP value is PDP% worse than previous HP value **then**
    switch optimization direction
else
    maintain current optimization direction
end
change current HOP

Algorithm 6.1: Optimization Direction Finding Algorithm Proposed by Bălan et al.

The implementation parameters of this algorithm could be seen in table 6.2. In the implementation, zig-zag approach is preferred to choose the parameter that needs be changed, hysteresis or TTT.

Table 6.2: Parameters Used In the Implementation of the Algorithm Proposed by Bălan et al.

w_{RLF}	1.0
w_{HOF}	1.0
w_{HPP}	0.5
PDP	20%

The second implemented algorithm is the solution proposed in [26]. In this solution, the authors propose to change the direction of the optimization according to the different causes of handover failures and unnecessary handovers. The algorithm gather handover too early ratio, handover too late ratio, handover to the wrong cell ratio and ping-pong ratio from the previous collection interval to calculate the optimization direction. The direction finding algorithm can be seen in algorithm 6.2.

In the implementation of this algorithm, handover to the wrong cell ratio is not used since this event cannot be detected directly in the simulation environment. In both of the handover too early and handover to the wrong cell events, RLF occurs between the target cell and the UE. Since RLF Indication is not implemented in the simulation

collect HTLR, HTER, HTWCR, PPR for the previous interval
if HTER + HTWCR + PPR > HTLR **then**
  change the optimization direction to up
else if HTER + HTWCR + PPR < HTLR **then**
  change the optimization direction to down
end
change current HOP

Algorithm 6.2: Optimization Direction Finding Algorithm Proposed by Kitagawa et al.

environment, both of these events are detected as handover too early events. Beyond this, the zig-zag approach is also selected for the implementation of this algorithm.

After these two previously proposed algorithms, the algorithm proposed in this work is implemented. The following parameters are used in the implementation of the algorithm.

Table 6.3: Parameters Used In the Implementation of the Proposed Algorithm

w_{HTERg}	1.0
w_{HTLRg}	1.0
w_{PPRg}	0.5
T_g	0.01
w_{HTERl}	1.0
w_{HTLRl}	1.0
w_{PPRl}	1.0
T_l	0.5

After running these implementations, the results gathered for each window and the average results are listed below. The reference value shows the results when a handover parameter optimization algorithm is not used.

According to the results in figure 6.3, 6.4, 6.5 and table 6.4, 6.5, 6.6, it can be said that the proposed algorithm performs better than the other algorithms with a %28.9 decrease in the handover failures. After the proposed algorithm, Bălan's algorithm performs better than the Kitagawa's algorithm with %22.3 decrease over %18.4 decrease in the handover failures.

With looking to the handover failure figures, it can be said that, the Bălan's algorithm is more stable compared to the other algorithms. While this brings some advantages, it has also some downsides. With the stability increase, the algorithm respond slower to the changes in the environment. This can be seen clearly in figure 6.4. After window 15, the other algorithms look for better handover parameter values after reaching a near optimum value and because of this consecutive increases and decreases can be seen in the handover too late ratio. But for the Bălan's algorithm, it shows a stable line after finding a near optimum value.

While the Kitagawa's algorithm changes its optimization direction faster when it is needed, it has a downside compared to the proposed algorithm. The Kitagawa's algorithm only compares the handover too early ratio with the sum of handover too late and ping-pong handover ratio. So, if one of these ratios is dominant to the others, the algorithm can continuously choose the same direction until the other events increase too much. This situation can be clearly seen in the simulation results. The handover too late ratio is generally bigger than the sum of handover too early and ping-pong handover ratios. To prevent this, the proposed algorithm uses weight values in the direction finding algorithm. While setting this weight values, beyond setting the priorities of the parameters, also average ratios of the parameters must be considered.

Table 6.4: Average Handover Too Early Ratio of the Proposed Algorithm with the Algorithms that Do Global Optimization

Proposed Algorithm	0.0425
Kitagawa's Algorithm	0.0493
Balan's Algorithm	0.0481
Reference	0.0596

According to the results in figure 6.6 and table 6.7, the proposed algorithm performs worse than the other algorithms while decreasing the ping-pong ratio. The proposed algorithm show %56.6 increase in the ping-pong handovers while the Kitagawa's algorithm show %22.2 increase and the Bălan's algorithm show %20.1 increase. In the simulation environment, the weight value of the ping-pong handover ratio is set

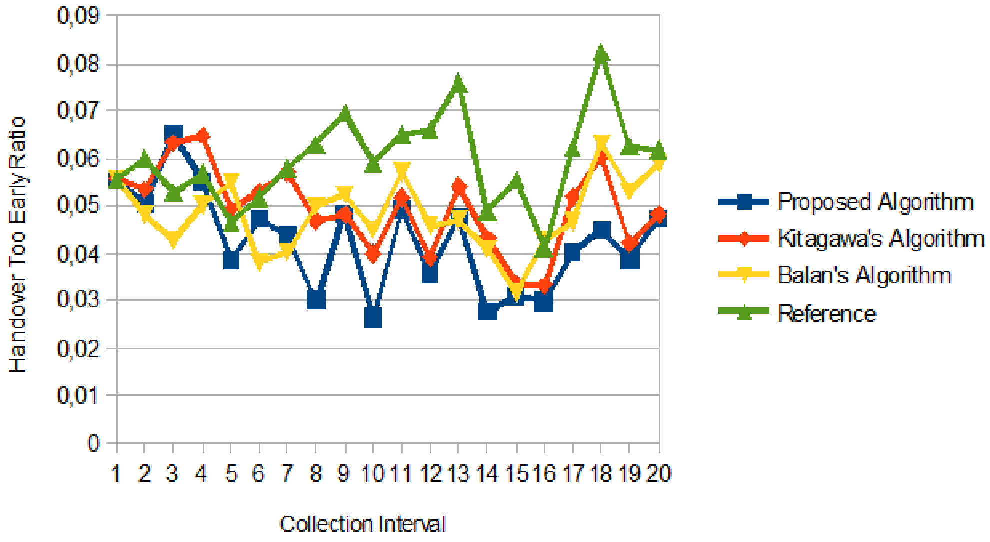

Figure 6.3: Comparison of Handover Too Early Ratio with the Algorithms that Do Global Optimization

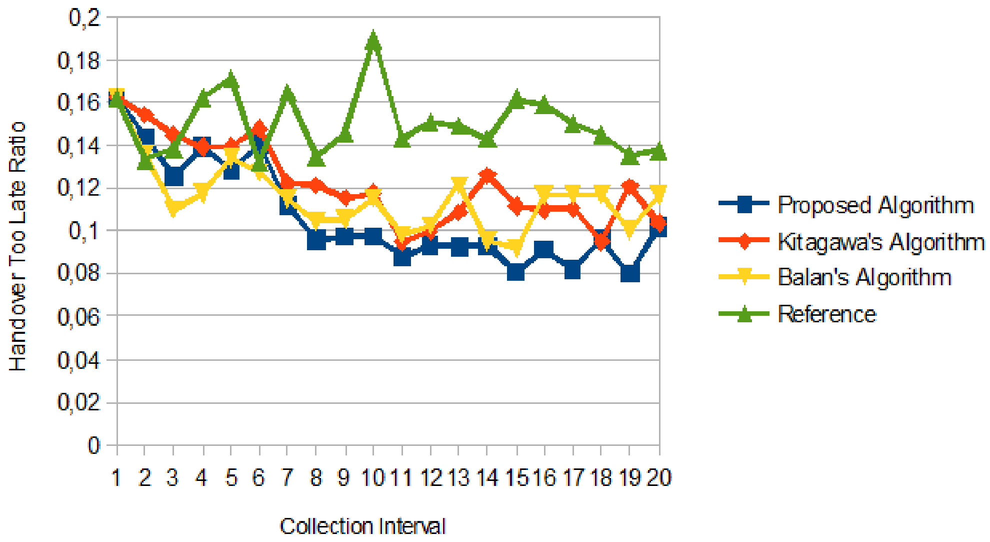

Figure 6.4: Comparison of Handover Too Late Ratio with the Algorithms that Do Global Optimization

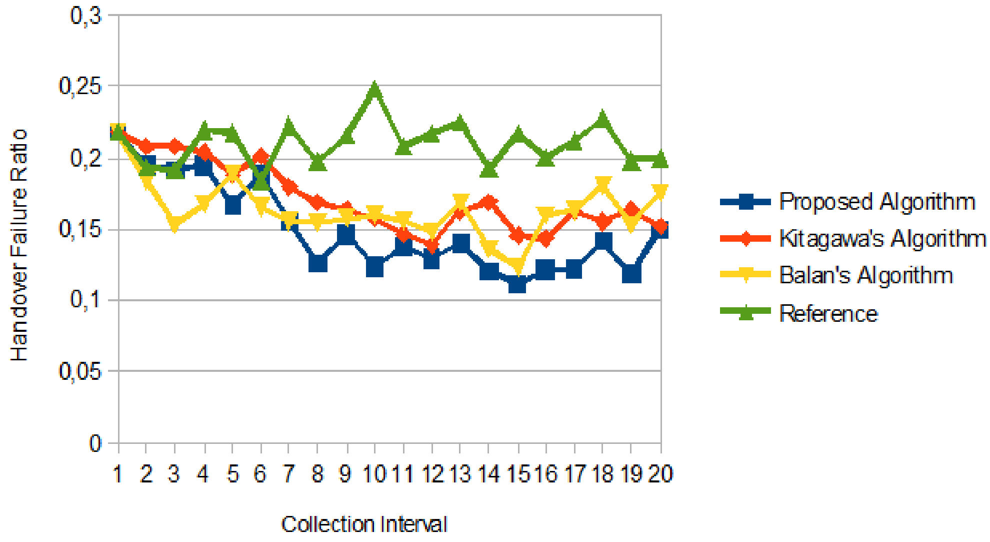

Figure 6.5: Comparison of Total Handover Failure Ratio with the Algorithms that Do Global Optimization

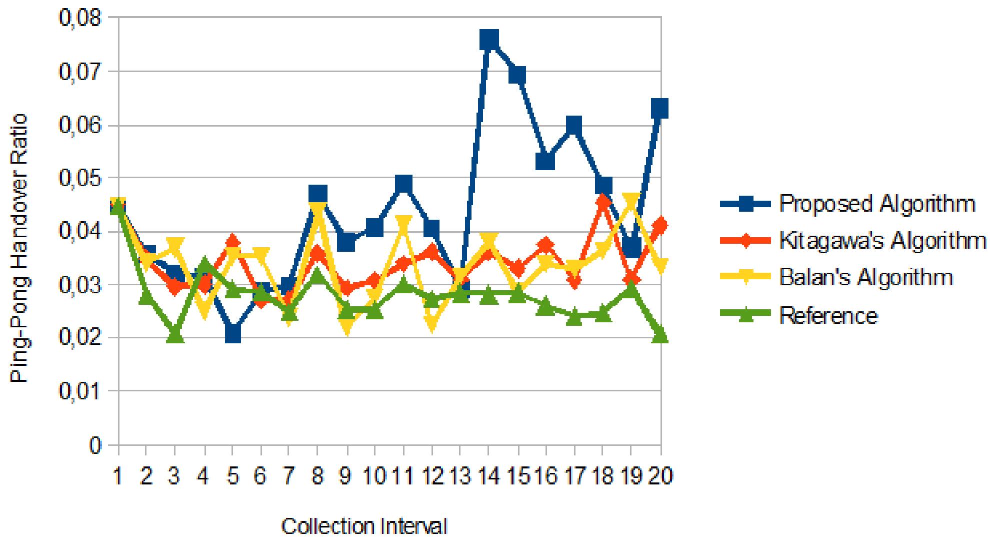

Figure 6.6: Comparison of Ping-Pong Handover Ratio with the Algorithms that Do Global Optimization

Table 6.5: Average Handover Too Late Ratio of the Proposed Algorithm with the Algorithms that Do Global Optimization

Proposed Algorithm	0.1072
Kitagawa's Algorithm	0.1224
Balan's Algorithm	0.1153
Reference	0.1507

Table 6.6: Average Handover Failure Ratio of the Proposed Algorithm with the Algorithms that Do Global Optimization

Proposed Algorithm	0.1496
Kitagawa's Algorithm	0.1717
Balan's Algorithm	0.1634
Reference	0.2103

to 0.5, lower than the handover failure ratios. So, because of this, the ping-pong ratio effects the direction finding algorithms less than the handover failure ratios. The performance of the proposed algorithm is worse than the other algorithms and this is caused by the introduction of local optimization. Beyond the algorithms that change hysteresis and TTT, the proposed algorithm also change CIO. If both of the global and local optimization conditions are satisfied for a neighbor cell, the algorithm changes CIO and one of the hysteresis or TTT at the same interval. This can create low performance near optimum values since the CIO value can increase or decrease too much before reaching the near optimum values. After reaching the near optimum values, these CIO values must be decreased for too large CIO values and increased for too small CIO values. This situation can be seen in figure 6.6 after window 15. This problem can be solved with tuning local threshold and weight values. The problem is investigated with different local threshold values later in this chapter.

6.3.2 Comparison of the Proposed Algorithm with the Algorithms that Do Global and Local Optimization

In the second comparison, the proposed algorithm is compared with the algorithm proposed in [18]. Beyond the global optimization, this algorithm also do local optimization with changing CIO values like the proposed algorithm.

Table 6.7: Average Ping-Pong Handover Ratio of the Proposed Algorithm with the Algorithms that Do Global Optimization

Proposed Algorithm	0.0437
Kitagawa's Algorithm	0.0341
Balan's Algorithm	0.0335
Reference	0.0279

In [18], the authors propose a distributed handover parameter optimization scheme. According to the solution, the cells can gather handover too early, handover too late and handover to the wrong cell informations with the RLF Indication and Handover Report messages from the neighbor cells. Also, the cell can detect ping-pong handovers itself. When the analysis interval reached, the algorithm firstly try to tune hysteresis and TTT with looking the statistics for all of the neighbors. After, if the threshold is reached with a neighbor cell, the algorithm try to tune the CIO value per neighbor cell.

The Ewe's algorithm use the Bălan's algorithm while finding the global and local optimization direction. The implementation parameters of the algorithm could be seen in table 6.8. In the implementation, zig-zag approach is preferred to choose the parameter that needs be changed, hysteresis or TTT.

Table 6.8: Parameters Used In the Implementation of the Algorithm Proposed by Ewe et al.

w_{RLF}	1.0
w_{HOF}	1.0
w_{HPP}	0.5
T_l	0.5
PDP	10%

For the implementation of the proposed algorithm, the results gathered from the previous comparison are used.

According to the results in figure 6.7, 6.8, 6.9 and table 6.9, 6.10, 6.11, the proposed algorithm works better than the Ewe's solution while decreasing handover failures. While the proposed algorithm shows %28.9 decrease, the Ewe's algorithm only show %10.7 decrease in the handover failures. Since the Ewe's algorithm use Bălan's algorithm, it has also the weaknesses of it, which is the slow response to the optimization direction change.

Table 6.9: Average Handover Too Early Ratio of the Proposed Algorithm with the Algorithms that Do Global and Local Optimization

Proposed Algorithm	0.0425
Ewe's Algorithm	0.0497
Reference	0.0596

Table 6.10: Average Handover Too Late Ratio of the Proposed Algorithm with the Algorithms that Do Global and Local Optimization

Proposed Algorithm	0.1072
Ewe's Algorithm	0.1381
Reference	0.1507

Table 6.11: Average Handover Failure Ratio of the Proposed Algorithm with the Algorithms that Do Global and Local Optimization

Proposed Algorithm	0.1496
Ewe's Algorithm	0.1878
Reference	0.2103

Table 6.12: Average Ping-Pong Handover Ratio of the Proposed Algorithm with the Algorithms that Do Global and Local Optimization

Proposed Algorithm	0.0437
Ewe's Algorithm	0.0321
Reference	0.0279

Beyond the handover failures, both of the algorithms show an increase in the ping-pong handover ratio over the reference according to the figure 6.10 and table 6.12. While the proposed algorithm show %56.6 increase, the Ewe's algorithm show %15.1 increase in the ping-pong handovers. Since both of the algorithms do local optimization per neighbor, their response could be slower than the algorithms that only do global optimization in near optimum values. The same results could also be seen the simulation results in [18]. According to the authors, assigning low threshold values cause reactivity while high values cause stability. A suitable trade-off must be found with setting the local threshold and weight values.

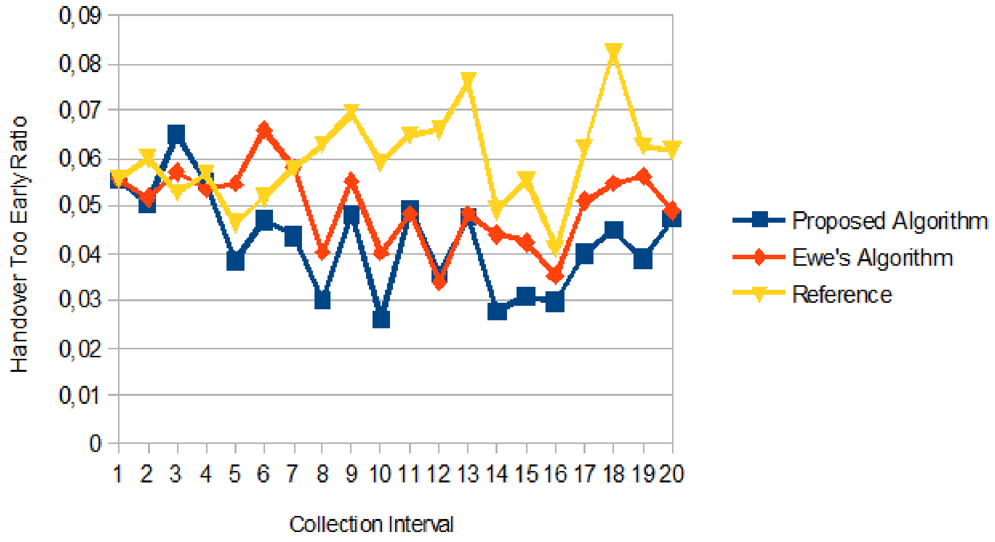

Figure 6.7: Comparison of Handover Too Early Ratio with the Algorithms that Do Global and Local Optimization

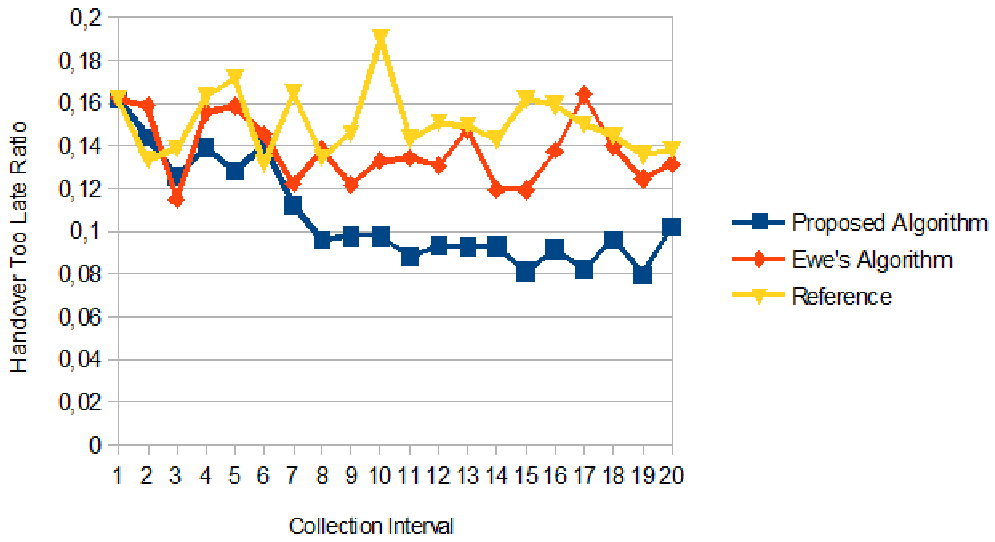

Figure 6.8: Comparison of Handover Too Late Ratio with the Algorithms that Do Global and Local Optimization

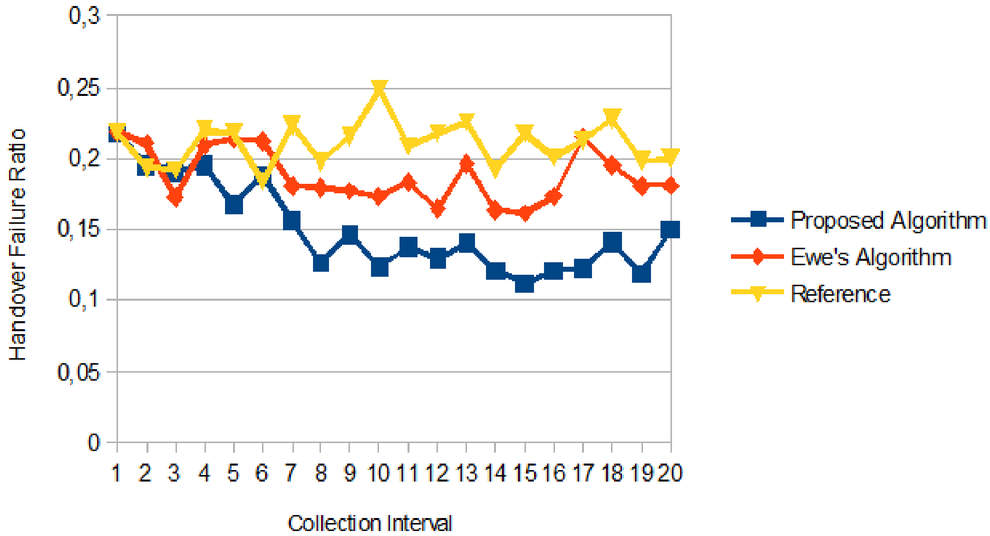

Figure 6.9: Comparison of Total Handover Failure Ratio with the Algorithms that Do Global and Local Optimization

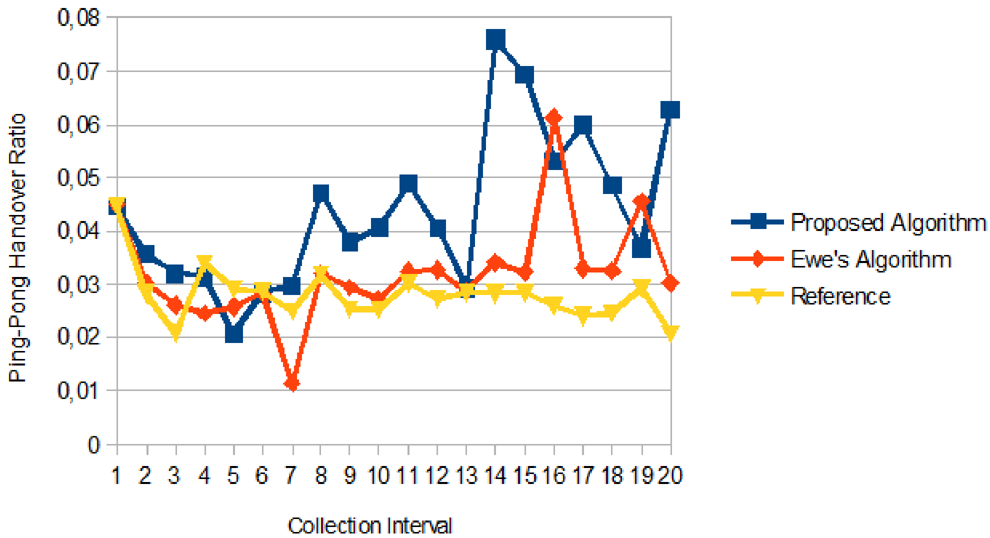

Figure 6.10: Comparison of Ping-Pong Handover Ratio with the Algorithms that Do Global and Local Optimization

6.3.3 Comparison of the Proposed Algorithm with Different Local Threshold Values

In the third comparison, the proposed algorithm is implemented with different local threshold values. For this comparison local threshold is set to 0.25, 0,50 and 0,75 while keeping other simulation parameters as the same.

According to the results in figure 6.11, 6.12, 6.13 and tables 6.13, 6.14, 6.15, the algorithm performs better when the local threshold is set to 0.50. The algorithm shows %25.7 decrease when the local threshold is set to 0.25, %28.9 decrease when the local threshold is set to 0.50 and %24.3 decrease when the local threshold is set to 0.75 in the handover failure ratio compared to the reference value. When the local threshold is set to 0.25, the local optimization condition is satisfied more and this decreases the performance of the algorithm since local optimization may not be necessary for some neighbors after the global optimization. When the local threshold is set to 0.75, local optimization condition is satisfied less and this decreases the performance of the algorithm since optimization per neighbor cell cannot be done in some conditions when it is necessary. According to these, the local threshold value must be set with considering these situations.

With the results in figure 6.14 and table 6.16, we can say that increasing the local threshold value decreases the ping-pong handover rate. The algorithm show %134.1 increase when the local threshold is set to 0.25, %56.6 increase when the local threshold is set to 0.50 and %20.1 increase when the local threshold is set to 0.75 in the ping-pong handover ratio compared to the reference value. If the local threshold is too low, the algorithm does local optimization more and the negative effects of the local optimization on the ping-pong handovers could be seen more. If the local threshold is too high, the algorithm does local optimization less and the negative effects of the local optimization on the ping-pong handovers could be seen less. But, with the increase of the local threshold, the algorithm gets closer to the algorithms that only do global optimization and this increases the handover failure rate. The solution to this problem is to find good local weight values while keeping the local threshold average.

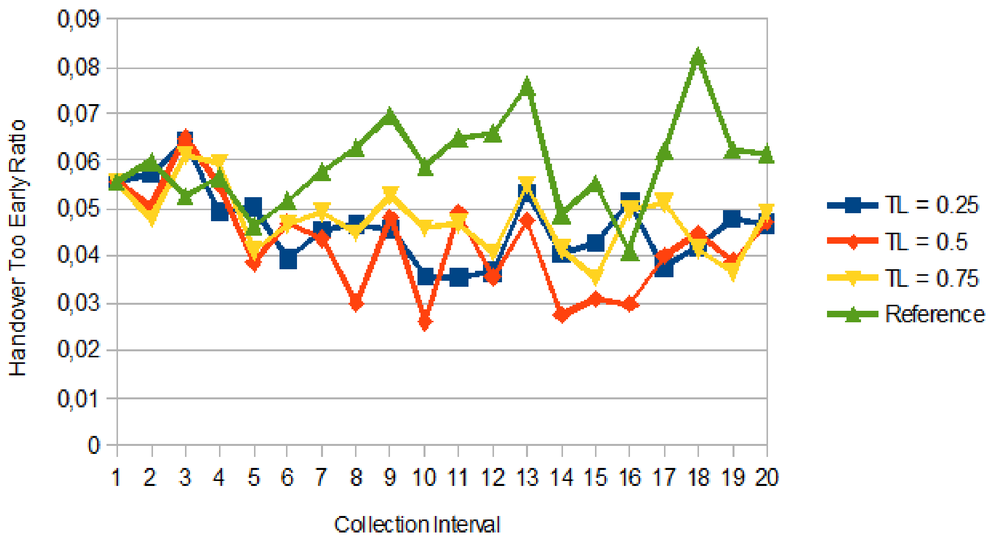

Figure 6.11: Comparison of Handover Too Early Ratio with Different Local Threshold Values

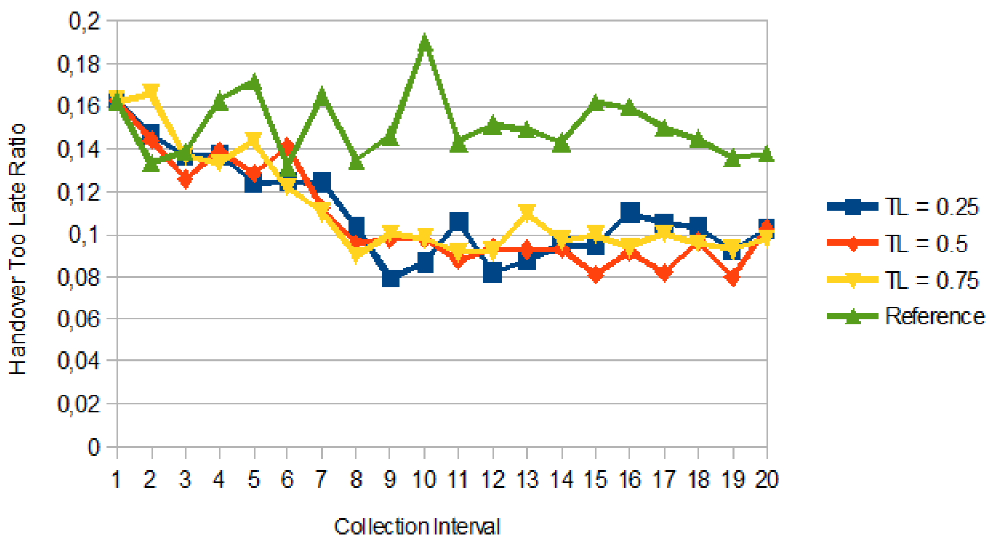

Figure 6.12: Comparison of Handover Too Late Ratio with Different Local Threshold Values

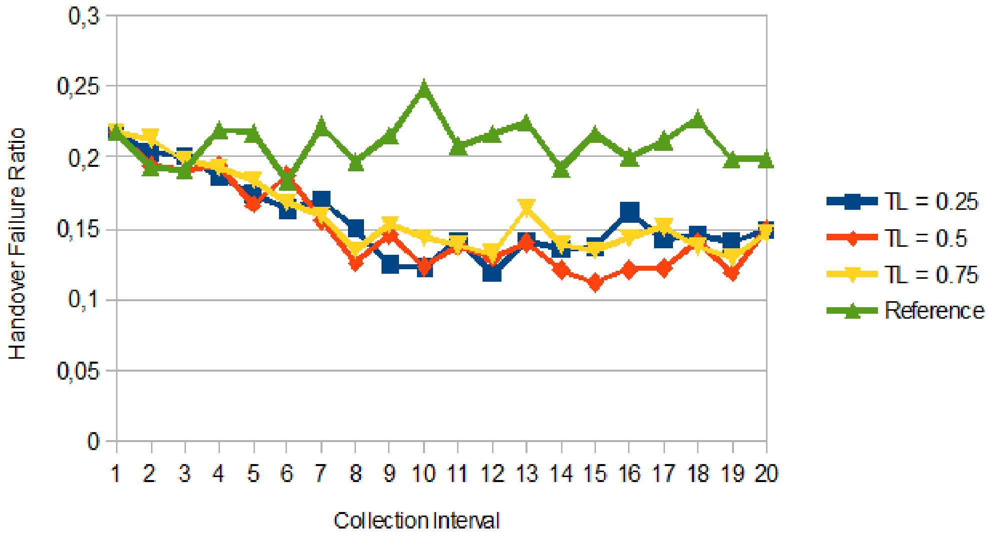

Figure 6.13: Comparison of Total Handover Failure Ratio with Different Local Threshold Values

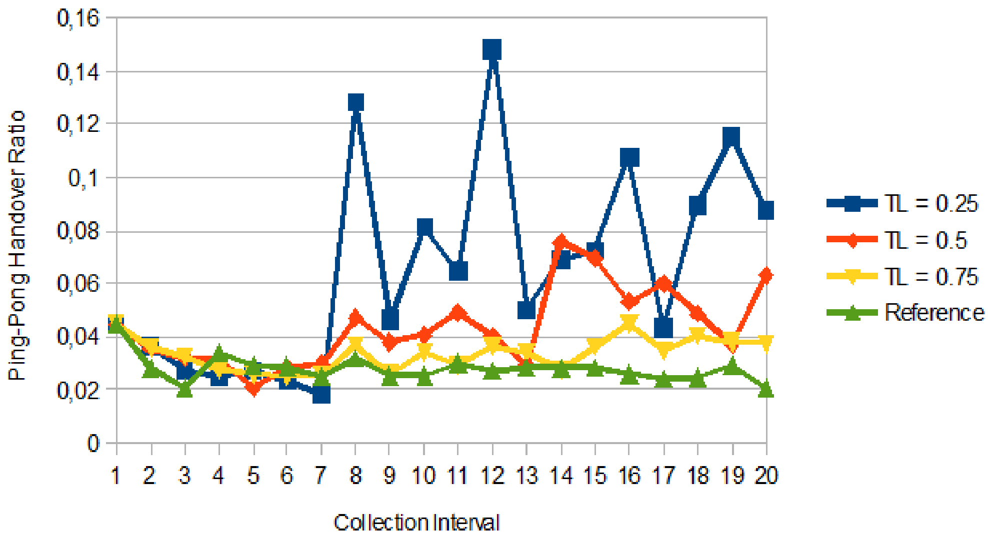

Figure 6.14: Comparison of Ping-Pong Handover Ratio with Different Local Threshold Values

Table 6.13: Average Handover Too Early Ratio of the Proposed Algorithm with Different Local Threshold Values

$T_l = 0.25$	0.0462
$T_l = 0.50$	0.0425
$T_l = 0.75$	0.0476
Reference	0.0596

Table 6.14: Average Handover Too Late Ratio of the Proposed Algorithm with Different Local Threshold Values

$T_l = 0.25$	0.1102
$T_l = 0.50$	0.1072
$T_l = 0.75$	0.1116
Reference	0.1507

Table 6.15: Average Handover Failure Ratio of the Proposed Algorithm with Different Local Threshold Values

$T_l = 0.25$	0.1563
$T_l = 0.50$	0.1496
$T_l = 0.75$	0.1591
Reference	0.2103

Table 6.16: Average Ping-Pong Handover Ratio of the Proposed Algorithm with Different Local Threshold Values

$T_l = 0.25$	0.0653
$T_l = 0.50$	0.0437
$T_l = 0.75$	0.0335
Reference	0.0279

CHAPTER 7

CONCLUSION

The main aim of this thesis is to improve the handover performance and decrease handover failures and unnecessary handovers. To achieve this, a new handover parameter optimization algorithm is proposed. The proposed algorithm conforms the current LTE-A standard and can be implemented easily. Beyond this, the proposed algorithm provides some improvements over the previous algorithms. Firstly, it can optimize the handover margin different for each of the neighbor cells. With this way, performance of the algorithm could be increased in heterogeneous networks. Secondly, the algorithm can be tuned according to the different needs of the network operators. With using different weight values, different priorities could be assigned to events or with using different threshold values the flow of the algorithm can be differentiated easily.

According to the results gathered from the simulation environment, the proposed algorithm provides great gains while decreasing the handover failures compared to other algorithms implemented in the simulation environment. Handover failures are the most important problem in mobility robustness optimization since they can result with call drops. Call drops directly effect the service quality of the network, while other handover problems effect the service quality indirectly. Therefore, generally decreasing handover failures has the top priority in the mobility robustness optimization.

However, while decreasing the handover failures, the proposed algorithm increased the number of ping-pong handovers in the simulation environment. Beyond the proposed solution, the other algorithms also perform poorly while decreasing the ping-pong handovers. This is caused by the priority of the ping-pong handovers which is lower than the priorities of the handover failures. According to the previous studies on the handover parameter optimization problem, the ping-pong ratio can be increased while the handover failure ratio is being decreased. This is generally caused by the dominant reason of the handover failures, which is the handover too late event. This can be seen clearly in the testing results where most of the time, the number of handover too late events is bigger than the number of handover too early or ping-pong handover events. To control the ping-pong handovers while decreasing the handover failures, the threshold and weight parameters of the algorithm must be set properly. To test this in the simulation environment, the algorithm is ran with different local threshold values, which is the most important parameter in the algorithm. According to the results, the ping-pong handovers can be decreased with changing the local threshold value, while keeping the number of handover failures.

While the weight and threshold values give flexibility to the algorithm, setting these parameters is the most difficult part in the implementation of the algorithm. The global and local threshold values must be set with considering the trade-off between stability and reactivity. The weight values must be set with considering the differences in the number of the events, beyond their priorities. In this work, we do not propose a proper solution to solve this problem. Finding of proper values for these parameters could be studied in a future work. Instead of setting the parameters at the start of the algorithm, dynamically changing the threshold and weight values during the simulation with considering priorities of the parameters and previous results could be an approach that can be considered.

Beyond this, as a future work, speed of the user can be included in the solution. With the current version of the LTE-A specification, this cannot be done since the UE does not inform any cell about its speed. Since the optimization is done with the cells' reports and logs, the optimization algorithm cannot know the user's speed while optimizing the handover parameters. Also, with heterogeneous networks, the way that the user's speed is calculated needs to be changed. With current specification, the UE calculates its speed class with looking the number of its previous handovers. This could be used in homogeneous networks but for the heterogeneous networks, cell coverages change according to their types because of this the speed of the UE cannot be calculated right with looking the number of previous handovers.

Also, this algorithm only considers the mobility robustness optimization use case while optimizing the handover parameters. Different SON use cases can also optimize the handover parameters according to their needs. For example, mobility load balancing can change CIO parameter to offload some of the users in the cell border to a neighbor cell to decrease the traffic of the cell. To support the other SON use cases, a framework could be offered that changes the handover parameters according to different needs of the SON use cases.

In the future, the handover procedure of the LTE can be changed. Currently, LTE only supports hard handover which the UE breaks its connection with the source cell before connecting to the target cell. But, with the introduction of CoMP, a UE can connect to multiple cells at the same time. With using this, soft handover procedure can be defined in the LTE specification. Since the soft handover procedure is different from the hard handover procedure, with this change, different mobility robustness optimization solutions can be considered.

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