HANDOVER AND INTERCELL INTERFERENCE IN LTE ADVANCED AND BEYOND

BY

LUKONG ABDU JALIL [123407]
NASRATULLAH WALIZADA [123428]

Supervised By

Nafiz Imtiaz Bin Hamid

Assistant Professor

Dept. of Electrical and Electronic Engineering (EEE)

Islamic University of Technology (IUT)

The Organization of the Islamic Cooperation (OIC)

Gazipur-1704, Dhaka, Bangladesh

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Islamic University of Technology (IUT)
The Organization of the Islamic Cooperation (OIC)
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Declaration

This is to certify the project entitled "**HANDOVER AND INTERCELL INTERFERENCE IN LTE ADVANCED AND BEYOND "**is supervised by Mr Nafiz Imtiaz Bin Hamid. This project work has not been submitted anywhere for a degree or diploma.

Approved by

Nafiz Imtiaz Bin Hamid
Assistant Professor,

Project supervisor

Dept. of Electrical and Electronic Engineering (EEE)

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Date………………………….

Signature of Head of the Department

………………………………………………………………

Prof. Dr. Md. Shahid Ullah

Head

Date ……………………….

Lukong Abdu Jalil (123407)…………………………………….

Nasratullah Walizada (123428)…………………………………

Dedicated

To our parents

Abstract

This work provides an overview of handover and inter-cell interference in LTE/LTE-A. It gives handover techniques in LTE, some of the algorithm with it associated problems and proposed solutions in handover but focuses mostly on Inter-cell interference coordination mitigation (ICIC) techniques. It has been recognized however that inter-cell interference has become the limiting factor when trying to achieve not only high average user satisfaction, but a high degree of satisfaction for as many users as possible. Therefore, inter-cell interference coordination (ICIC) lies in the focus of researchers defining next generation mobile communication standards, such as LTE-A.

This thesis provides inter-cell interference mitigation techniques both in homogenous as well as heterogynous networks. It discusses the varied techniques used to mitigate ICI both in Rel 8/9 and Rel 10 of LTE_A, paying attention to the advantages and the disadvantages of each technique. Also various handover algorithms are examined. Lastly, as Performance of spatial multiplexing MIMO techniques degrades with the introduction of interference in the system. To choose optimum MIMO mode it is worthwhile to analyze the UE (user equipment) throughput under different interference scenarios before physical implementation of a system. A comparative study of MIMO technique performances in terms of UE throughput under two different UE speeds and interference scenarios has been examined.

Acknowledgement

First and foremost, we are very much indebted to Almighty Allah, the most Merciful without whose patronage and blessing this project report would not have been successfully completed.

We would like to express our sincere gratitude to our supervisor, Mr. Nafiz Imtiaz Bin Hamid Assistant Professor, Department of Electrical and Electronics Engineering (EEE) whose kind understanding, expertise, guidance, and patience, have considerably improved our graduate experience and know-how in our field of specialization. He provided us with immense guidance, technical support and constructive suggestions and in the course of time became more of a mentor than just a supervisor.

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Last but not the least; we would like to thank our parents who have given us tremendous inspiration and support. Without their constant moral and financial support we would not have been able to complete our project work.

Table of Contents

ABBREVIATIONS

OFDMA	Orthogonal frequency division multiple Access
CDMA	Code division Multiple Access
LTE	Long Term evolution
ICI	Inter cell interference
ICIC	Inter cell Interference Coordination
eICIC	enhance Inter cell Interference Coordination
3GPP	third Generation Partnership Project
FFR	Fractional frequency Reuse
SFR	Soft frequency reuse
IFR	Incremental frequency reuse
TDMA	Time Division Multiple Access
MIMO	Multiple Input Multiple Output
SISO	Single Input Single Output
RRM	Radio resource management
OPSM	Open Loop system multiplexing
CLSM	Closed loop system multiplexing
SINR	Signal to noise and interference ratio
Tx	Transmission diversity Clustering

MUD	Multiple user detection
FH	Frequency hoping
IDMA	Interleave division multiple access
ABS	Almost blank sub frame
EFFR	Enhanced fractional frequency reused
IFFR	Incremental fractional frequency reused
CCI	co channel interference
ITU	International Telecommunication union
IMT	International mobile Telecommunication
HO	Hand over
MME	mobility management entity
HOM	Handover margin
QoS	Quality of service
BBC	break before connect
CBB	Connect before break
TTT	Time to trigger
RSS	Received signal strength
SS	signal strength
RNC	Radio network controller

CHAPTER 1

Introduction

The long term evolution (LTE) standard defined in 3rd generation partnership project (3GPP) is a revolutionary step towards next generation communication technology. LTE includes features like multicarrier channel-dependent resource scheduling, fractional frequency reuse, adaptive modulation and coding, advanced MIMO techniques and support for both FDD and TDD. LTE ensures higher spectral efficiency, lower delay and better multiuser flexibility compared to currently deployed networks [11. The third generation of cellular radio technology was defined by the ITU-R through the International Mobile Telecommunications 2000 project (IMT-2000). The requirements for IMT 2000, defined in 1997, were expressed only in terms of peak user data rates. Of significance is that there was no requirement defined for spectral efficiency in 3G. The situation is quite different for IMT-Advanced

The key requirement that sets 4G apart from previous standards is Enhanced peak data rates to support advanced mobile services and applications (in the downlink, 100 Mbps for high mobility and 1 Gbps for low mobility) which gives the expectations for peak data rates that reach as high 1 Gbps for low mobility applications and 100 Mbps for high mobility. This is a huge increase from 3G, which specified a peak rate of 2 Mbps for indoor low mobility applications and 144 kbps vehicular. The peak rates targeted for 4G will have fundamental repercussions on system design.

Inter cell interference is one of the most limiting factor in the performance of the fourth generation (4G) networks which limit the achievable data rate. Basically there are two types of interference which limit the data rates, these are intra-cell and inter-cell interference. While intra-cell interference can be easily mitigated through the use of orthogonal resources (such as frequencies (in OFDM) or codes (in CDMA)), decreasing the inter-cell interference remains a difficult task that needs to be addressed. LTE allows for the total available spectrum to be in each cell (frequency reuse factor =1). This can be achieved since LTE provides intra-cell orthogonally between users in both uplink and downlink. Interference is mainly dominated by inter-cell interference due to users in neighboring cells using the same radio resources. Reducing this interference should result in significant enhancement in the achievable data rates particularly at the cell-edge. Part of the bandwidth can be allocated to the users at periphery of the cell through a frequency planning scheme with a reuse factor larger than 1. However, the gains due to less interference are typically larger than the loss due to reduced bandwidth. [1]

Inter-Cell Interference Coordination (ICIC) technique suggested by 3GPP LTE is a promising way to alleviate inter-cell interference, which may potentially attain significant performance improvements and has become very important in next generation wireless communication networks. ICIC provides tools for dynamic inter-cell-interference coordination of the scheduling in neighboring cells such that cell-edge users in different cells are preferably scheduled in complementary parts of the spectrum when required. In order to improve the cell-edge performance while retaining system spectrum efficiency of Reuse-1, several representative local ICIC approaches with static frequency resource partitioning are introduced in this paper, including the classical Fractional Frequency Reuse (FFR) scheme, the well-known Soft Frequency Reuse (SFR) scheme and the newly emerged Incremental Frequency Reuse (IFR) scheme.

The objective of this thesis is to improve cell-edge performance while retaining the maximum system capacity and highest spectral efficiency. Based on a thoroughly analyzing of several up to date prevailing ICI avoidance techniques, a new design called Enhanced inter-cell interference (EICIC) scheme is put forward in this paper. Which achieve not only ICI limitation at cell edge but also a great enhancement of overall cell capacity in OFDMA-based communication networks

In any cellular mobile communication system, two major classes of interference must be considered, namely: intra-cell interference, and inter-cell interference. In the former, interference is caused between frequency channels, within the same cell, due to adjacency of both frequencies and power leaked from one channel to an adjacent channel. In the latter, interference is caused by a frequency channel in one cell, on the same frequency channel used in an adjacent cell. Intra-cell interference can be mitigated by the use of OFDM and TDMA.

Inter-cell interference (ICI) mitigation on the other hand is a big challenge issue in cellular systems. Excessive ICI may lead to severe performance degradation or connection loss especially in the border area of cells. In order to efficiently reduce the ICI whilst not drastically reduce the utilization of the scarce frequency spectrum, suitable radio resource management (RRM) is desirable.

In 3GPP LTE systems, downlink makes use of Orthogonal Frequency Division Multiple Access (OFDMA). By orthogonal allocation of the OFDMA sub-carriers, intra-cell interference can be avoided. However, inter-cell interference (ICI) presents a great challenge that limits the system performance, especially for users located at the cell edge. Inter-cell interference coordination (ICIC) has been investigated as key technology to alleviate the impact of interference in LTE systems to improve system performance and increase bit rates at the cell edge. Several ICIC techniques have been proposed in the literature. Some of these techniques can be useful under particular network conditions and requirements.

As the user equipment (UE) moves away from the serving eNB, the degradation in its SINR can be attributed to two factors. On the one hand, the received signal strength decreases. On the other hand, ICI increases as the UE moves close to a neighboring eNB, as illustrated in Figure 1. The simple schematic shown in Figure (1) implies that the most susceptible users to the ICI are those located at the cell edge. Therefore, the cell-edge performance is of great interest for LTE-based system’s designers, as it represents an important aspect of design.

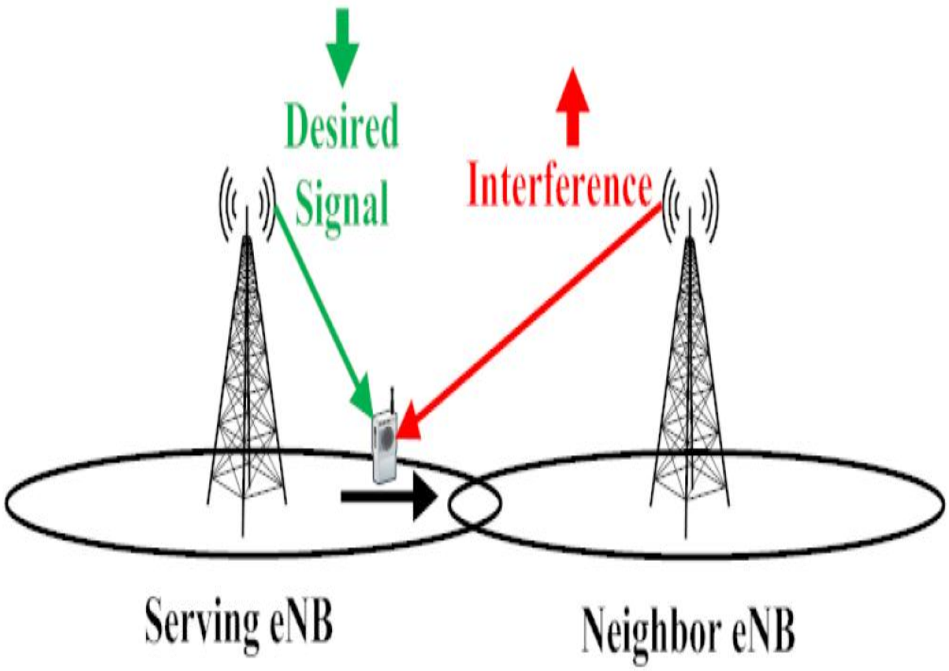

Figure 1.1: Illustration of UE moving away from serving eNodBs

CHAPTER 2

Handover

2.1.1 Introduction

The development in technology is really fast that sometimes we cannot imagine. If we look at them they need connection to internet to operate effectively, so from here we can say that being connected to the system is the need of every single human being in the earth who are browsing internet. But to be connected we higher quality of service. If we consider a mobile user who is connected and using several applications and services at a time so he/she does not want to have a disturbance with his connection if he is fixed at a position or moving from one cell to another. This is our job to provide a service that will be nonstop and here the idea of Handover comes that can make it possible. When we are taking about handover in LTE or LTE advanced, so we have to think of challenges and critical situations that we may face, so I am considering Handover as a big challenge in telecommunication because this handover is not an easy topic. I think when we are talking about handover we should start by its challenges and then we see the solutions for this. The biggest challenge that I am going to point out is Ping-Pong effect in Handover which in this thesis we are going to express some basic ideas about algorithms.

2.1.2 REQUIREMENTS FOR AN EFFICIENT HANDOVER

To provide an efficient handover there are several requirements and criteria that should be considered. They will help us to have a higher system performance and Quality of System (QoS). And I am suggesting these points as golden points toward a successful Telecommunication system.

2.1.3 Handover moment

One of the most important criteria for an efficient handover is the handover moment and location. To provide a handover without degrading the quality of service (QoS) the location of the handover moment should be carefully planned. The optimal point for a handover is at a spot where the old and the new access point have an overlap in coverage area. If a handover is not at a proper time and place so the UE will remain idle without connection to any eNodeB that will cause the battery failure of UE. Since UE always try to connect to any eNodeB and if it tries more than usual so the system will be busy and it causes the failure of system and lack of handover.

2.1.4 Unnecessary handovers

An important requirement for an efficient handover mechanism is the amount of necessary handovers. If the number of unnecessary handover goes lower than the efficiency of the system goes higher. To decide the handover moment, handover mechanisms use signal strength algorithms to determine the distance to the access point. Once the client comes near the border of the coverage area the algorithm starts determining the handover point. Then it will measure the distance and apply handover if it's necessary. Sometimes if the UE locates at the edge of the cell and we know that the interference is more at the cell edge so at these cell edges the number of handover is more so here we will have a lot of unnecessary handovers which will cause keeping the system busy and battery failure of UE. It happens that the UE will connect to a target eNodeB for a while and connects back to the source eNodeB which will cause Ping-Pong effect.

2.1.5 Handover delay

The duration of the handover procedure is an important criterion of the efficiency of a handover mechanism. When a handover takes too long, service disruption can be experienced or connections can timeout and will be lost. For example, a real time video call could experience a temporary disruption when a handover takes longer than 400 ms. If the delay is even longer then the call could be terminated entirely.

2.1.6 Packet loss

An optimal handover mechanism provides handover without packet losses. No packet or/-data loss is almost impossible so the less packet loss a mechanism generates, the more efficient the mechanism is. The ITU has also got a (QoS) parameter for this and states that the probability for a packet loss shouldn’t be more than 1 × 10^–3.

2.1.7 Complexity of the Solution

The complexity of a handover procedure is very important when talking about mobile devices. These devices are all battery powered and have limited resources. If the handover mechanism takes too many resources, smaller mobile devices can’t use the handover. So the handover process should be as quick as possible and also in case of energy usage it should not use more energy that cause failure is UE or eNodeB.

2.1.8 Handover Techniques

Handover can be categorized as hard handover and soft handover also known as Break-Before-Connect (BBC) and Connect (Entry)-Before-Break (CBB) respectively. Soft and hard handover followed by handover in LTE are discussed in the following.

2.1.9 Soft Handover – Connect-Before-Break Handover

Soft handover is a category of handover procedures where the radio links are added and abandoned in such manner that the UE always keeps at least one radio link to the UTRAN. There is a centralized controller called Radio

Network Controller (RNC) to perform handover control for each UE in the architecture of WCDMA. A UE can be connected in to two or more cells during a call. In handover aspect, soft handover is suitable for maintaining an active session, preventing voice call dropping, and resetting a packet session. However, the soft handover requires much more complicated signaling, procedures and system architecture such as in the WCDMA network. As we can see below the UE will keep the connection alive with the source base station (BS1) and it connects to the target (BS2) till it's not sure that the connection with the target cell is secured then it will disconnect the S1 link with the (BS1) and keeps only one connection.

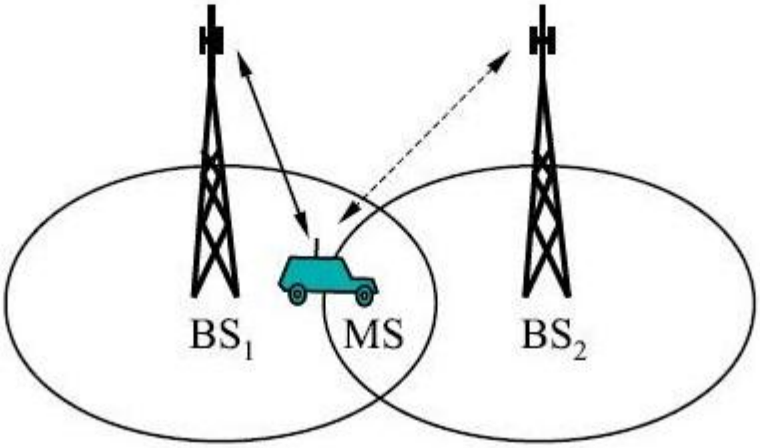

Fig: 2.1

2.2.1 Hard Handover – Break-Before-Connect Handover

Handover in LTE is purely hard handover (both S1 and X2 interface handover). The use of hard handover reduces the complexity of the LTE network architecture. Hard handover is a category of handover procedures where all the old radio links in the UE are abandoned before the new radio links are established. The hard handover is commonly used when dealing with handovers in the legacy wireless systems. The hard handover requires a user to break the existing connection with the current cell (source cell) and make a new connection to the target cell.

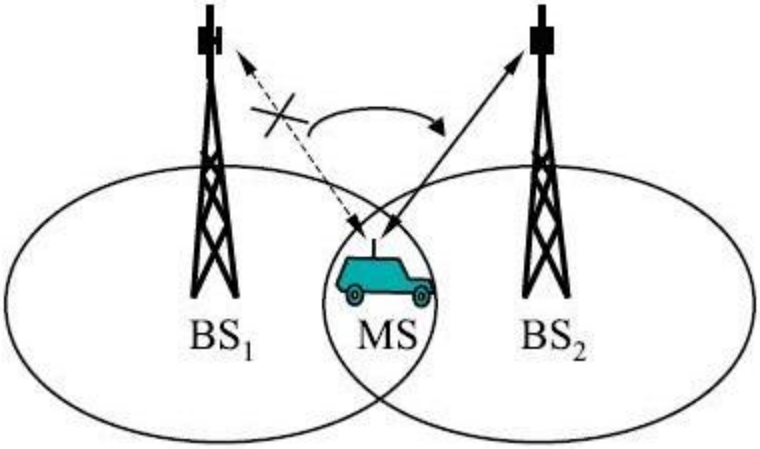

Fig 2.2

2.2.1Handover in LTE (LTE Intra EUTRAN Handover)

There are two types of handover procedure in downlink LTE for UEs in active mode which is the S1 and X2 handover procedures. The X2-handover procedure is normally used for the inter-eNodeB handover to balance network load and prevent interference. However, when there is no X2 interface between two eNodeBs, or if the source eNodeB has been configured to perform handover towards a particular target eNodeB via the S1 interface, then an S1-handover procedure will be triggered. And also S1 interface is a link between the UE and eNodB which all the data will be delivered to the UE via this interface.

There are three phases involved in both S1 and X2 handover procedures which are

- Preparation phase
- Execution phase
- Completion phase

In the preparation phase, the UE needs to send measurement reports periodically to the source eNodeB Based on these reports, the source eNodeB will decide to which target eNodeB the UE Should be handed over. Beside the measurement reports, other criteria are also considered by the source eNodeB before a control message is sent to the target eNodeB to prepare for the Handover. Upon receiving the control message requesting to prepare for handover, the target ENodeB will prepare a buffer for the UE. Once the preparation phase is completed, a handover command control message is sent by the Source eNodeB to the UE in the execution phase to notify the UE that it is going to be handed over to another eNodeB. Upon receiving the message, the UE will disconnect itself from the source eNodeB and request for connection with the target eNodeB. At the same time, the source NodeB forwards all packets of the UE to the target eNodeB. These packets are queued by the target eNodeB in the UE buffer. Once the UE has successfully connected to the target eNodeB, the target eNodeB transmits all the buffered packets of the UE followed by the incoming packets from the target gateway. The handover procedure moves to the completion phase after the UE sends to the target eNodeB a handover complete message that indicates this handover is Completed. The main purposes of the completion phase are to release all the resources used by the UE at the Source eNodeB and to notify the upper layer to switch the path of the packet to the target eNodeB. Therefore, the target eNodeB needs to inform the source eNodeB to release all resources of the UE and the target (MME) to execute path switching to the target eNodeB respectively.

2.2.3 LTE Inter RAT Handover

In here we have UE connected to a source eNodeB as a LTE client. A LTE client constantly reports signal measurements to the connected eNodeB. When the eNodeB determines the necessity to initiate a handover, the handover preparation procedure is initiated. This is done by sending the HANDOVER REQUIRED (HO-R) message to the Mobility Management Entity (MME) and MME will forward this request to the target eNodeB and target eNodeB will send a HANDOVER ACKNOWLEDGE (HO-ACK) to the MME. MME will prepare by starting the resource allocation procedure. This procedure is responsible for getting resource information from the access points in the vicinity. With this information the handover decision is made and the MME sends the HANDOVER COMMAND (HO-C) with the needed information to the eNodeB which sends it towards the client. At this point the client disconnects from the source eNodeB and connects to the target eNodeB. At this stage the target eNodeB will send a HANDOVER SUCCESSFUL (HO-S) message to the MME and MME will send a HANDOVER SUCCESSFUL (HO-S) message to the Source eNodeB.

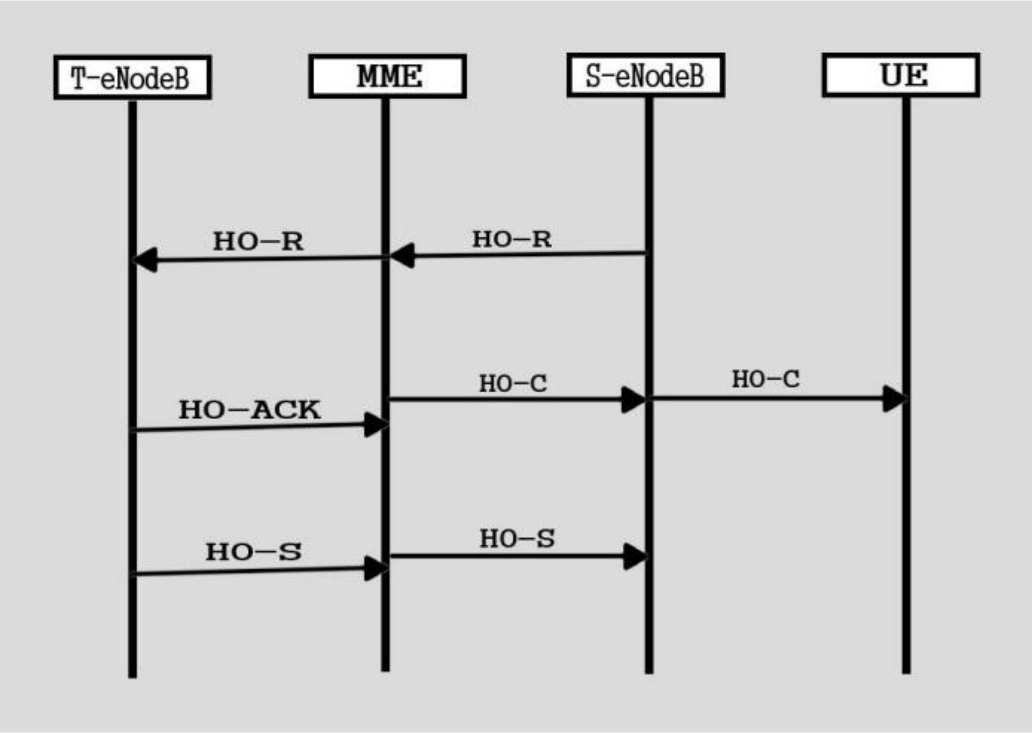

Fig 2.3

HANDOVER ALGORITHMS

2.2.4 LTE Hard Handover Algorithm

The LTE Hard Handover Algorithm, also known as “Power Budget Handover Algorithm”, is a basic but effective handover algorithm consisting of two variables, handover margin (HOM) and Time to Trigger (TTT) timer. HOM ensures the target cell is the most appropriate cell the mobile camps on during handover. A TTT value is the time interval that is required for satisfying HOM condition. Both HOM and TTT are used for reducing unnecessary handovers which is called “Ping-Pong effect”. When a mobile is experiencing this effect, it is handed over from a serving cell to a target cell and handed back to original serving cell again in a small period of time. This effect increases the required signaling resources, decreases system throughput, and increases data traffic delay caused by buffering the incoming traffic at the target cell when each handover occurs. Therefore effectively preventing unnecessary handovers is essential. TTT restricts the handover action from being triggered within certain time duration. A handover action can only be performed after the TTT condition has been satisfied. Figure 2.4 shows the basic concept of LTE hard handover algorithm.

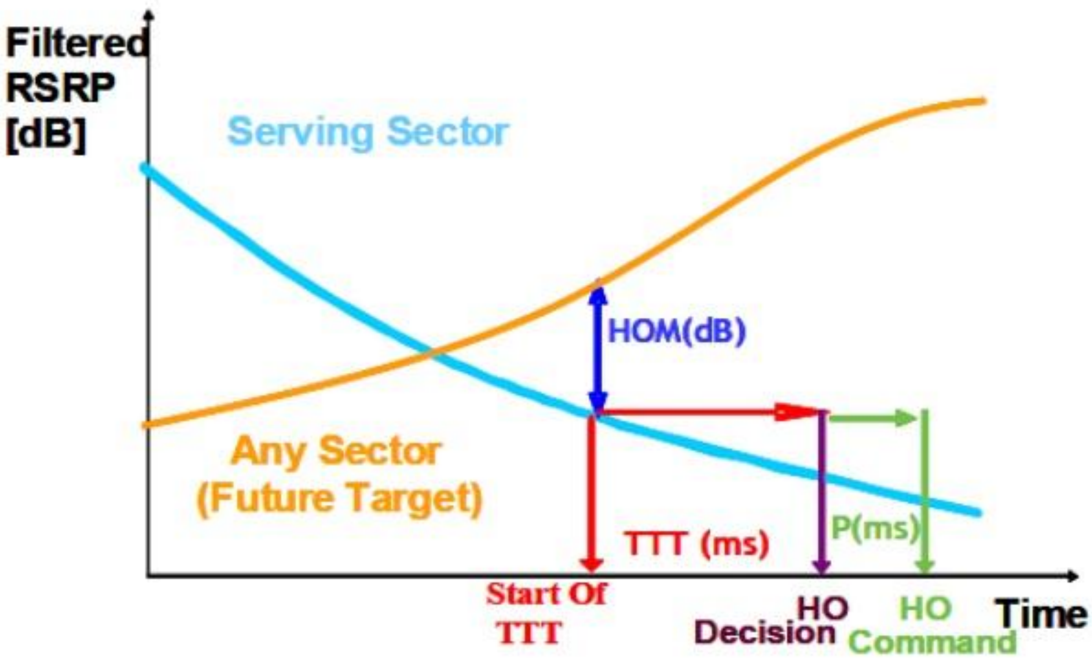

Fig 2.4

When a mobile is moving away from the serving cell, the RSRP which the mobile receives from the serving cell will degrade as time increases. Meanwhile, the mobile will move towards the target cell, therefore the RSRP the mobile receives from the target cell will increase as time increases. A handover process is going to be triggered if the below conditions are satisfied.

RSRPs + HOM < RSRPt ……………………………………...…. (1)

Where RSRPs means Reference Signal Received Power from Source cell and RSRPt is Reference Signal Received Power from Target cell. And

Handover Trigger >TTT ……………………………………….. (2)

2.2.5 Received Signal Strength based TTT Window Algorithm

There are 3 steps involved in Received Signal Strength based on TTT Window Algorithm. It collects required information during processing step, and then performs the comparison based on this information during decision step followed by the execution step. By the help of following equation it will process the data and sends it to the next step.

$$RSS_F(nT_m) = \beta RSS(nT_m) + (1-\beta)RSS((n-1)T_m)$$

Where RSSF is the filtered received signal strength (RSS, same as RSRP) measured at every handover measurement period (Tm) where n and (n-1) is the nth and (n-1) the time instant, respectively. Beta is a proposed fractional number called "forgetting factor" and

Beta = Tu / Tm

Where Tu is an integer multiple of Tm.

And the comparison step will be done with the help of the following equation.

$$RSS_F(nT_u)_{TS} \geq RSS_F(nT_u)_{SS} + HOM$$

Where HOM is a constant threshold value, RSSF (nTu) TS and RSSF (nTu) SS are the filtered RSS of the target sector (TS) and the filtered RSS of the serving sector (SS) at (n Tu) the interval. This algorithm tracks the RSS value from each eNodeB and stores the instantaneous RSS value. Filtered RSS value at each instant is calculated using historical data (previously filtered RSS) by applying the forgetting factor variable. The closer the forgetting factor gets to 0, the higher the proportion that the current RSS depends on the filtered RSS in previous time instant. On the other hand, the closer the forgetting factor gets to 1, the higher the proportion that the current filtered RSS depends on the current RSS value. A handover decision will be made if the following condition is satisfied for duration of whole Tu window.

$$\beta = \frac{T_u}{T_m}$$

2.2.6 Integrator Handover Algorithm

Integrator Handover Algorithm is a LTE handover algorithm proposed in 2008. The main concept is to make the handover decision by the historical signal strength differences. The idea of historical data is similar to what Received Signal Strength based TTT Window Algorithm has. There are 3 parts in integrator handover algorithm, RSRP difference calculation, filtered RSRP difference computation, and handover decision. The RSRP difference calculation is presented as following.

$$DIF_{s\_j}(t) = RSRP_T(t) - RSRP_S(t)$$

Where RSRPT (t) and RSRPS (t) represent the RSRP received from the target cell and serving cell at time t, respectively. DIFs_j (t) is the RSRP difference of the user j at serving cell sat time t. And the computation will be done by the following equation. Where α is a proposed variable with constraint $0 \le \alpha \le 1$. FDIFs_j (t) is the filtered RSRP difference value of user_j at serving cell sat time t, and DIFs_j (t) is the RSRP difference value.

$$FDIF_{s\_j}(t) = (1-\alpha)FDIF_{s\_j}(t-1) + \alpha DIF_{s\_j}(t)$$

A filtered RSRP difference value will depend on the proportion between current RSRP difference and historical filtered RSRP difference in previous time instant by changing the variable. The closer they go to 1, the higher the chance that filtered RSRP difference will have a heavier portion on the current RSRP difference. In the other way, the closer the goes 0, the filtered RSRP difference will have a heavier portion on the previous historical filtered RSRP difference then on the current RSRP difference. Once the filtered difference has been computed, the handover decision will be made if the following condition is satisfied.

$$FDIF_{s\_j}(t) > FDIFThreshold$$

Where FDIF Thresholds a constant value equivalent to HOM. And it has one disadvantage, since there is no TTT mechanism involved we may have “Ping-Pong” effect in our system.

2.2.7 PING-PONG DETECTION ALGORITHM FOR INTRA LTE HANDOVER

The whole Handover movements are divided in to two parts.

- General movement
- Ping-Pong movement

By the help of a timer we can differentiate between these two movements. If the received Signal Strength (SS) form the target eNodeB (SS-target) is stronger than that received from the source (SS-source), then the timer can be set and the HO preparation and execution part may be performed by both the source and the target eNodeB. If the difference between the SS-target and SS-source always shows that the SS-target is sufficiently strong than the SS-source, and the timer is expired then the movement is general (no Ping-Pong movement). The operator in this case can immediately release the resources along the old path (MME/SGW-source eNB) and finish the completion HO part. If the difference between the SS-target and SS-source does not show that the SS-target is sufficiently stronger than the RSS-source then there is a Ping-Pong type of movement. In this case, the operator can keep the old path (MME/SGW-source eNodeB) during the Ping-Pong duration and only the completion part of the HO procedure can be delayed to avoid the swinging between releasing and initiating of the paths between the MME/SGW and eNodeBs.

Flow char of Ping-Pong detection algorithm

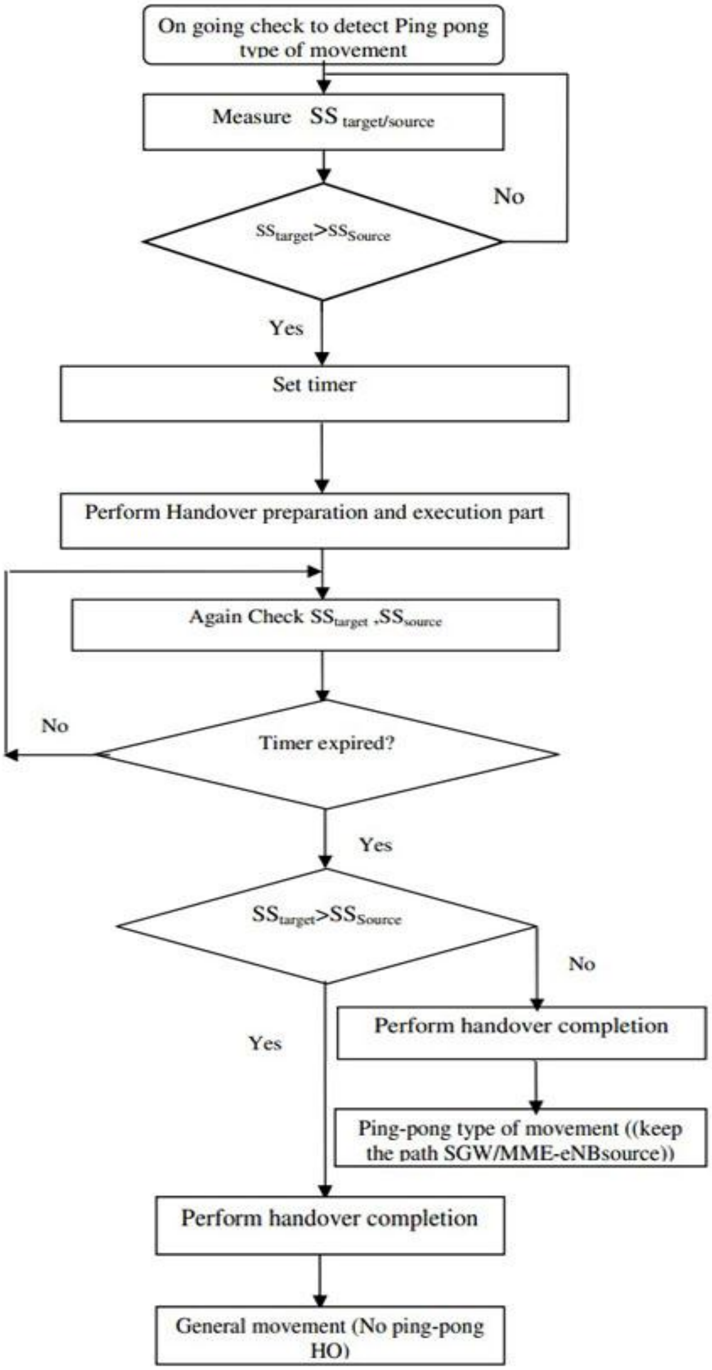

Figure 2.5: shows the Ping-Pong detection algorithm that reduces the number of Ping-Pong HOs in LTE networks.

This algorithm has 2 phases as explained below. As it can be seen in the figure 2.6, the preparation and execution HO phase means that the new connection between the UE and the target is made but the old S1 interface is still in use (dark line in figure 6). For the HO completion part there is completely new connection path via new S1 interface as it is shown in figure 2.6 below.

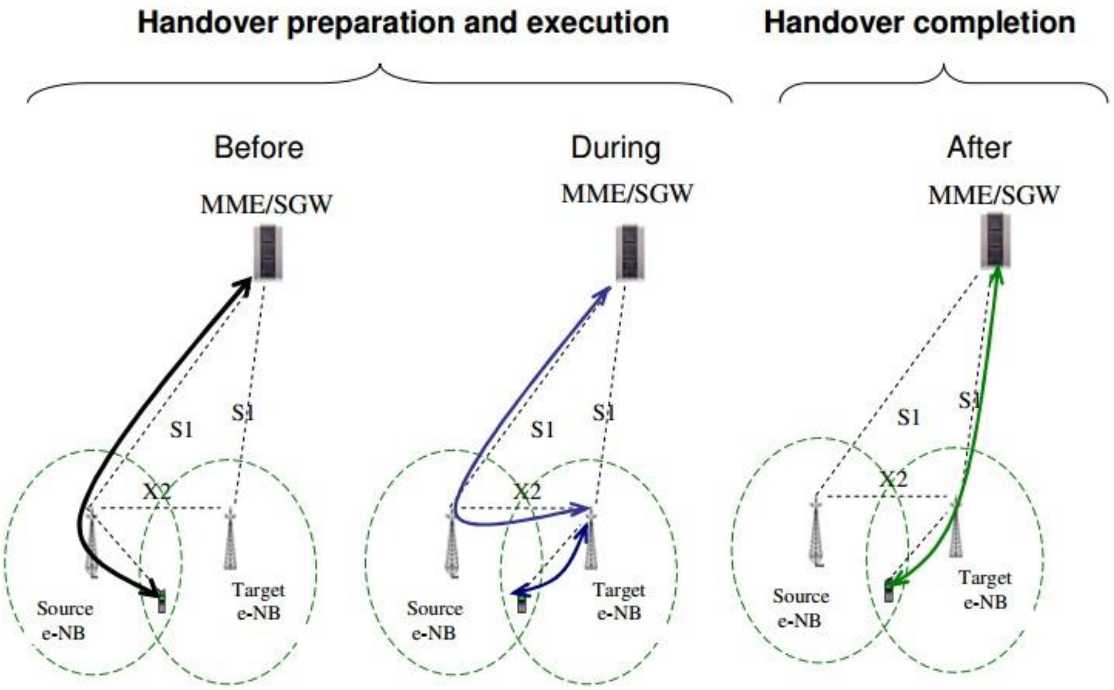

Figure 2.6: Two phases of Ping-Pong detection algorithm.

2.2.8 LTE Hard Handover Algorithm with Average RSRP Constraint

LTE Hard Handover Algorithm with Average RSRP Constraint is proposed based on LTE Hard Handover Algorithm with an extra average RSRP condition for more efficient handover performance. In this algorithm we will take the average of received signal and compare it with previous signal. The concept of this algorithm is to narrow down the possibility of handovers to minimize unnecessary handovers and ensure the channel quality of the target cell a user can have is not only higher than the current RSRP of serving cell with a certain threshold, but also better than the average RSRP received from the serving cell from the first handover measurement period till the last. The average RSRP can be calculated as following

$$\mathrm{RSRP}_{\mathrm{avgS\_j}} = \frac{\sum_{n=1}^{N} \mathrm{RSRP}_{\mathrm{s\_j}}(n T_m)}{N}$$

Where RSRPS_j (nTm) is the RSRP received by user j from serving cell Sat n-th handover measurement period of Tm and N is the total number of periods of duration Tm. An average RSRP of cell S received by user j (RSRPavgS_j) can be calculated by a sum of each n-th handover measurement period (Tm) up to N divided by N times. An average RSRP constraint can be found with the help of below condition.

RSRPT (t) > RSRP avgs_j………………………… (1)

Where RSRPT (t) is the current RSRP received from target cell T and RSRPavgS_j is the average RSRP computed by the first equation. The handover decision will be made by satisfying above condition and followed by the same conditions as in LTE Hard Handover Algorithm. Let’s have again a glance at them below

RSRPt > RSRPs +HOM…………………………….. (2)

HO Trigger >=TTT ………………………………….. (3)

A handover will be triggered if and only if equation (1), (2), and (3) are all satisfied. And also remember that RSRPavgS_j will be reset to 0 each time due to serving cell changes when a handover is successfully performed

CHAPTER 3

INTERCELL INTERFERENCE

3.1 Inter-cell Interference Mitigation Techniques

3.1.1 ICI Cancelation

ICI cancelation techniques have been investigated and deployed with varying degrees of success in terrestrial mobile networks for more than 20 years. The basic principle of ICI cancelation techniques is to regenerate the interfering signals and subsequently subtract them from the desired signal. Good overviews of historical approaches can be found in [8] and the references contained therein. It has been successfully applied to both CDMA systems and TDMA systems, as well as proposed within the 3GPP-LTE standardization.

Various ICI cancelation techniques have been proposed in literature and they are mainly categorized into two classes, *filter-based approaches* and *Multi-User Detection* (MUD) [6]. Filter-based approaches try to mitigate ICI by means of linear filters and interference models. In contrast, MUD directly includes the interfering signals in the decoding process. This is done by jointly decoding the signal of interest and the interfering signals, or by decoding and subtracting the interfering signals from the signal of interest. ICI-cancelation techniques can also be jointly used with MU - Multiple-Input Multiple-Output (MIMO) technique if the mobile terminals are equipped with multiple-receive antennas.

From an implementation standpoint, interference cancelation does not require any modifications of the system standard, making it an attractive technique. Although ICI cancelation promises significant gains and its algorithms are mature, it is considered mostly as a technique for the UL due to processing complexity (scales exponentially with number of mobiles served at the BS) [5]. Furthermore, it requires exchange of information in real time between BSs about every *msec* to maximize the system gain.

3.1.2 ICI Randomization

In contrast to ICI cancelation, which tries to eliminate interfering signals in the received signal, ICI randomization, which is also known as *ICI whitening* or *ICI averaging*, aiming at making ICI appear like background noise, i.e., it averages the interference across the data symbols of a data block or the whole frequency band. The approaches include *Frequency Hopping* (FH) and *Interleave Division Multiple Access* (IDMA). FH ensures User Equipment (UEs) to access a range of channels rather than a narrow set in a specific pattern so that interference effect is averaged out for all UEs. It is widely applied in CDMA systems. Both FH and IDMA-based schemes have also been proposed within the 3GPP-LTE standardization. Nevertheless, these methods randomize the interference into White Gaussian Noise‖, which cannot reduce interference in nature. Thereby, these approaches can hardly achieve a substantial performance

3.1.3 Adaptive beam forming:

It is also a mitigation technique where the antenna can dynamically change its radiation pattern depending on the interference levels.

3.1.4 Inter-cell Interference *avoidance* techniques (Frequency reuse schemes)

Interference *avoidance* techniques: Also known as ICI coordination techniques, on the other hand Controls the allocation of the various resources (time/frequency and/or power) to users with the objective of increasing the SINR (and thus, the throughput) experienced by the users at the cell edge, and to ensure that the ICI remains within acceptable limits. Various avoidance (allocation) techniques have been studied in the literature under various traffic conditions and/or network structures. Techniques under this category can be classified along several orthogonal dimensions to differentiate mainly between static vs. dynamic and central vs. distributed techniques. Moreover, techniques under this category also differ with respect to the resources that are being allocated/ coordinated between users, and whether various power levels need to be used at different locations in the cell.

This report studies the inter-cell interference avoidance in downlink. The common theme of Inter-cell interference coordination/avoidance is to apply restrictions to the usage of downlink resources e.g. time/frequency resources and/or transmit power resources. Such coordination of restrictions will provide an opportunity to effect on interference generation in the cellular network area. It thus has potential to improve the signal to interference ratio (SIR) experienced at the receivers in the coverage area, this will provide potential for increased (cell-edge) data-rates over the coverage area, or increased coverage for given data-rates. As the coordination of restrictions applies between different cells of the same site and cells of different sites, the impact is expected to be the largest at the cell edges and cell borders, which are the most critical for the 95% coverage target set for the LTE evaluation

In order to improve the performance of the cell-edge users, the Fractional Frequency Reuse (FFR) scheme was proposed. In this scheme, part of the total available resources is used for cell-edge users‟ transmission. This will result in reducing the interference for cell-edge users [1]. However, clearly this improvement comes at the cost of reducing bandwidth utilization. Several research efforts have focused on improving the performance of the FFR by introducing several variations of the basic scheme. The concepts of FFR and its variants are discussed in greater details in the following section.

Frequency reuse-based schemes are relatively easy to implement as they require no frequent interaction among involved eNBs. However, since it is considered to be static frequency reuse, once this allocation scheme is used, it is not easy to perform modifications to the major frequency distributions [1]. Thus, this scheme is not adaptive to dynamic demand changes per sector as it adapts to the cell loads only by changing power used over different sub-carriers.

To avoid the above problem, cell coordination based schemes were proposed. As the name suggests, this scheme involves coordination among neighboring eNBs, on both sub-carriers and power levels. Accordingly, it can efficiently adapt to the variations in cell loads.

According [1], inter-cell interference avoidance technique can be broadly divided into two. These are the Fractional frequency reuse base scheme and the cell coordination base schemes. They are discus as follows. To proceed with the different schemes, it is better to understand the concept of frequency reuse.

3.1.5 Frequency Reuse

The main feature in cellular network is frequency reused. The whole available bandwidth for a system is divided into several narrower sub bands, each of which is assigned once to a cell of each cluster consisting of several adjacent cells. The number of subbands should equal the size of cell-cluster, termed as Frequency Reuse Factor (FRF). This way, all directly neighboring cells in the system use different subbands to avoid heavy CCI among them; and the entire available system bandwidth can be *reused* in all cell-clusters distributed over the network covered area so that the utilization of valuable spectrum resources can be ensured to some extent. [5]

Therefore according to [1], the simplest scheme to allocate frequencies in a cellular network is to use a FRF of 1, i.e. available frequency spectrum is reused in each sector without imposing any restriction to frequency resource usage or power allocation leading to high peak data rate and thus increasing the performance of the system. However, this case presents the worst inter-cell interference scenario, where high inter-cell interference is observed especially at cell edges.

The most important thing is to determine the value of FRF δ, which is another essential parameter in radio network planning. With a bigger FRF value, the distance between adjacent cells becomes larger. There by reducing the ICI, which will bring about better cell/system coverage? However, when a smaller FRF value is used, more bandwidth is available per cell. Since the same frequency resources are then reused within a short distance, the CCI in the system is increased limiting the number of UEs that can be served. The question is to answer what FRF value would be the best choice to gain the maximum cell capacity. Figure 3.1 illustrates cellular systems using a FRF of 1, 3, and 7, respectively. The higher the FRF the smaller will be the CCI which will result in an increase in SINR and thus the performance of the system [1]. Attention is given to cell in the middle of each system, and is surrounded by 3 tiers of cells. Using the single frequency deployment (FRF = 1), as shown in Figure 3.1a, all 3 tiers have a total of 36—surrounding cells are co-channel cells and originate heavy CCI. Yet, each cell in the system has the whole available bandwidth to utilize. When the FRF increases to 3 (see Figure 3.1b), there is no from the 1st-tier, and only 6 co-channel cells from the 2nd- and 3rd-tier exist, respectively. Correspondingly, each cell is assigned 1/3 of the whole available bandwidth for serving its traffic. Figure 3.1c gives a cellular network with a FRF of 7, where the number of co-channel interfering cells is reduced to 6 in total from the 3rd-tier. However, in this case, only 1/7 of the whole system bandwidth is available for each cell, which fundamentally limits the cell capacity. Hence, an optimal assignment of resources to cells with a tradeoff between maximum spectrum utilization efficiency and optimal cell coverage in terms of CCI needs to be found during the network planning process, which is also the main target of this monograph. [5]

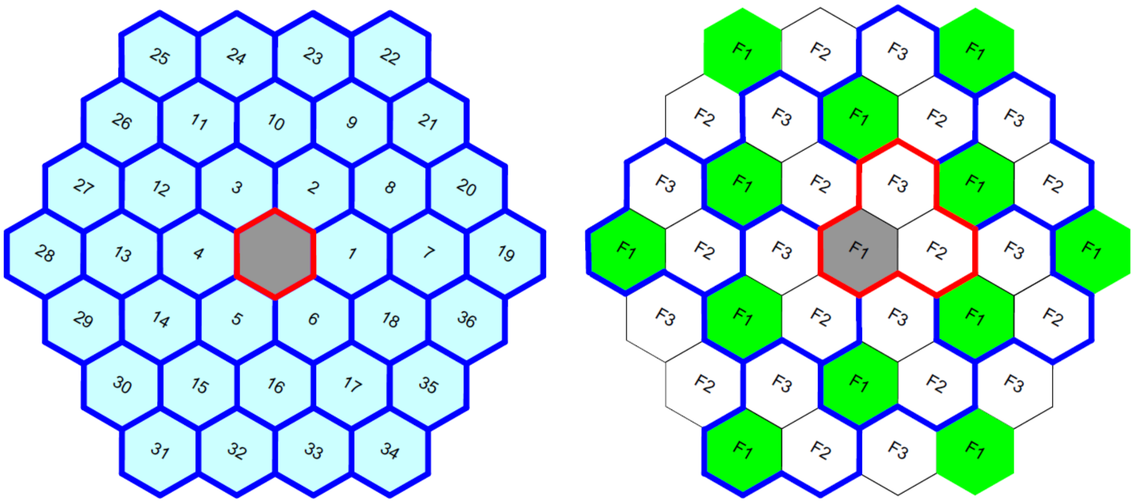

Figure 3.1

(a) FRF of 1 cellular system (b) FRF of 3 cellular system

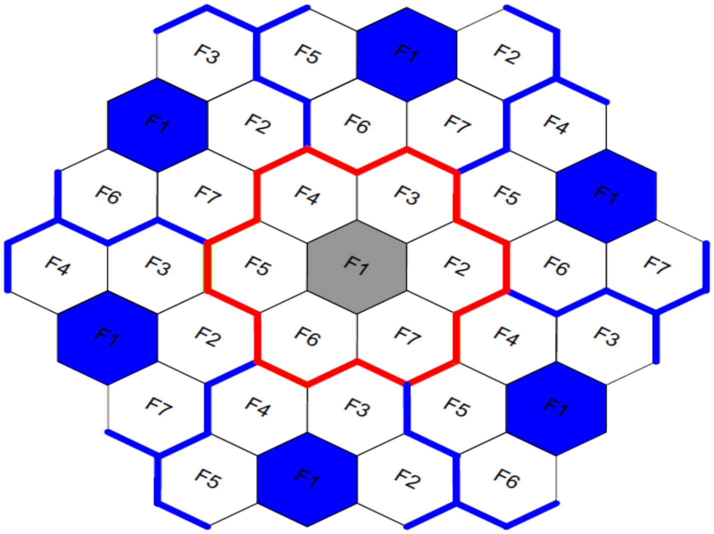

Figure 3.2: FRF of 7 cellular system

Figure 3.1.: Cellular networks using different size cell-clusters, in each of which the middle located cell is surrounded by 3 tiers of neighboring cells. (a) When FRF =1, the cell in the center is interfered by in total 36 co-channel cells in the near neighborhood; (b) When FRF =3, the cell in the center is interfered by 12 co-channel neighboring cells; (c) When FRF =7, the cell in the center is just interfered by 6 co-channel cells located on the relatively farther 3rd –tier.

3.1.6 Conventional frequency reuse:

The simplest scheme to allocate frequencies in a cellular network is to use a FRF of 1, i.e. available frequency spectrum is reused in each sector without imposing any restriction to frequency resource usage or power allocation (figure 4.1a) , leading thus to high peak data rate. However, this case presents the worst inter-cell interference scenario, where high inter-cell interference is observed especially at cell edges.

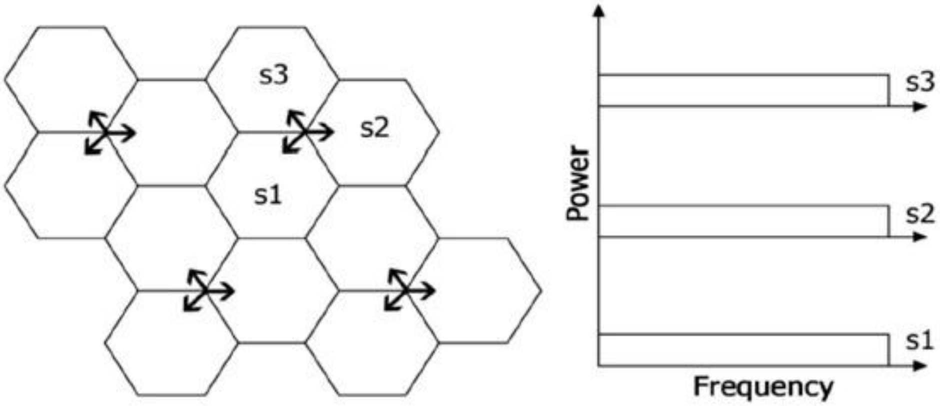

Fig 3.3: Conventional Frequency Planning with Reuse factor of 1.

On the other hand, the whole frequency band can be divided into three equal, orthogonal sub-bands, allocated to sectors so that adjacent sectors always use different frequencies. This setup is called reuse of 3 scheme. This clustering obviously leads to an improved a decrease in inter-cell interference, with a price to a large capacity loss due to the restrictions imposed on the resources, where only one third of the resources are used in each sector. In conventional frequency planning two extremes are presented. While reuse 1 does not employ any interference coordination, reuse 3 can be regarded as an extreme case of partition based static interference coordination.

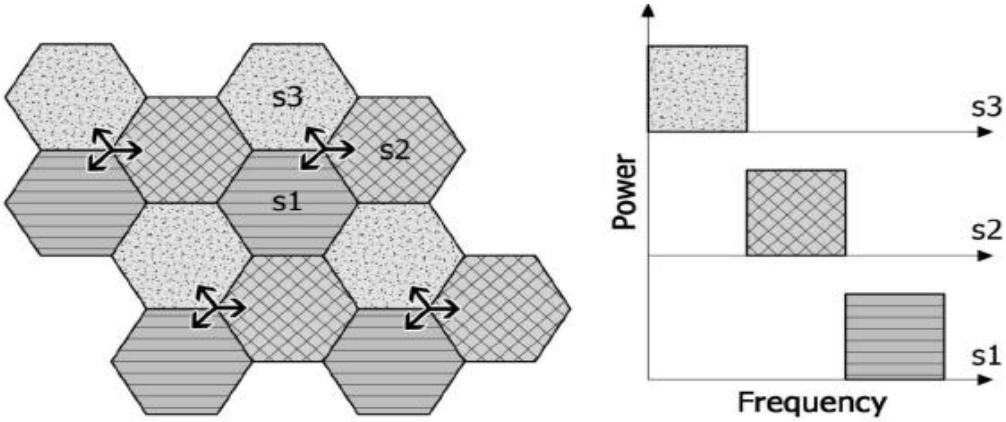

Figure 3.4 Conventional Frequency Planning with Reuse factor of 3.

3.1.7 Fractional Frequency Reuse

A type of ICI coordination techniques, called *Fractional Frequency Reuse (FFR)* or *Reuse Partitioning (RUP)*, aims at effectively mitigating ICI by applying various FRFs to EUs situated in different regions in each cell. From [5] [9]. The basic idea on which the FFR schemes rely is to divide the whole available resources into two subsets or groups: major group, and minor group. The major group will be used to serve the cell-edge users with a fraction of the available resources, while the minor groups are used to cover the cell-center users.

However, if we consider the way in which spectrum are shared among different FRF-zones in each cell, FFR schemes presented in [5]-[9] can be distinguished into two classes, namely, *exclusive* and *inclusive* reuse partitioning (RUP). Figure 4.2 gives an example to compare the spectrum partitioning of both FFR schemes. Exclusive FFR split the bandwidth *B* into two or more subsets (different-color blocks in the figure: *B_reuse7*, *B_reuse3* and *B_reuse1*). Each subset serves the requirements from a specific FRF-zone. Unlike exclusive FFR, the whole spectrum band *B* in inclusive design is allowed to be used by all different FRF-zones, which results in an overlapping reuse effect, as depicted in figure 4.2b. It should be noted from the figure that the whole system that bandwidth *B* is available for all cells, while on the other hand with FFR only a fraction of the bandwidth is available to the users as shown in figure (3.3)

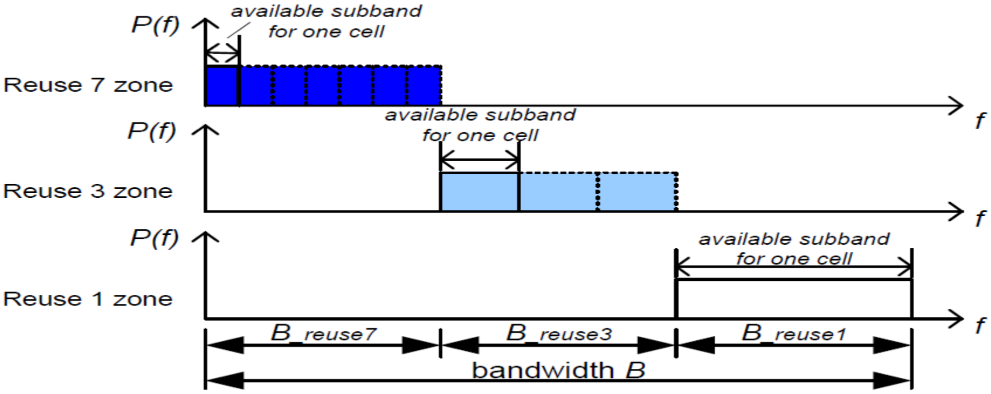

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Figure 3.5 Exclusive FFR

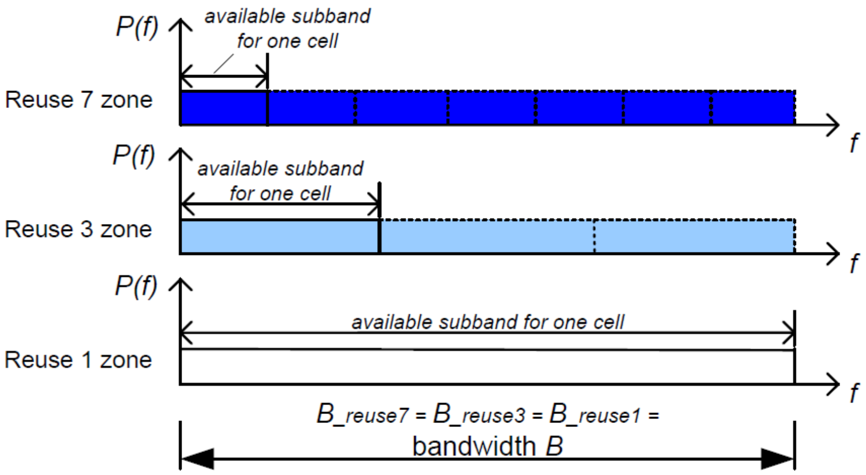
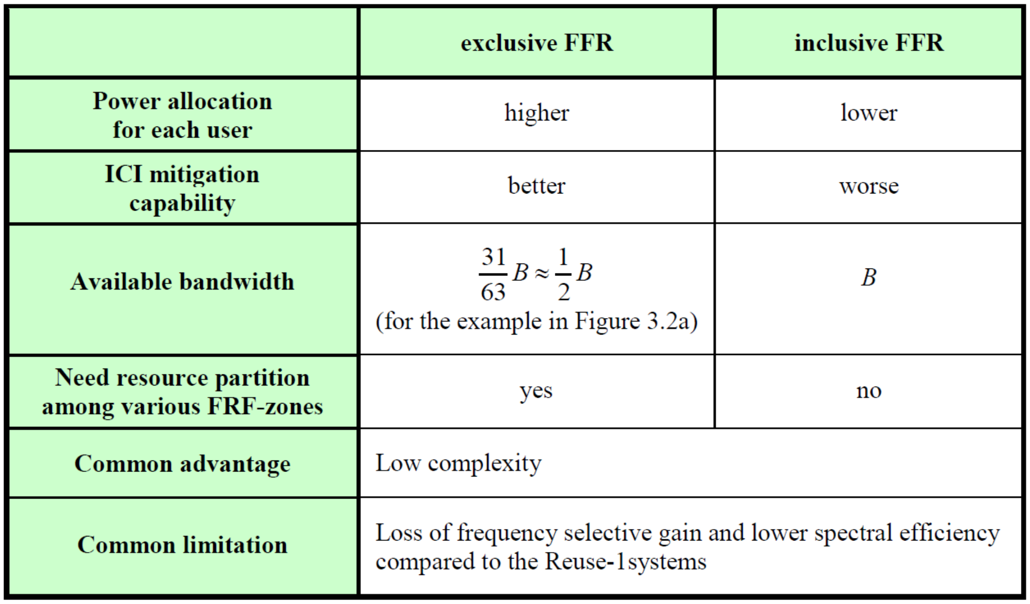


Figure 3.6 Inclusive FFR

Figure 3.6.: Frequency partitioning example for comparing exclusive and inclusive FFR scheme in a cellular system based on FRF =7 for cell-edge users, FRF =3 for cell-middle users and FRF =1 for cell centered users

Power adaptation mechanism is not considered for different FRF zones. All transmissions in a system are applied with equal transmission power. In DL, each BS evenly distributes its total power over the available sub bands of its cell. As exclusive FFR owns less bandwidth than inclusive FFR to utilize, packets in exclusive FFR can be delivered with higher transmission power than in inclusive FFR. Table (1) present the comparison between exclusive and inclusive FFR reused schemes.

Table 1 Comparison between exclusive and inclusive FFR schemes



	exclusive FFR	inclusive FFR
Power allocation for each user	higher	lower
ICI mitigation capability	better	worse
Available bandwidth	$\frac{31}{63}B \approx \frac{1}{2}B$ (for the example in Figure 3.2a)	B
Need resource partition among various FRF-zones	yes	no
Common advantage	Low complexity	
Common limitation	Loss of frequency selective gain and lower spectral efficiency compared to the Reuse-1systems	

Table 3.1

3.1.8 Soft Frequency Reuse

The FFR scheme may result in under-utilization of available frequency resources due to its strict no-sharing policy. Because of this Soft Frequency Reuse (SFR) was proposed in 2005 as a solution to avoid the high ICI levels associated with the unity FRF configurations, while providing more flexibility to the PFR scheme. The term *soft reuse* is due to the fact that effective reuse of the scheme can be adjusted by the division of powers between the frequencies used in the center and edge bands.

According to [1][5]the basic idea on which the SFR scheme depend is to apply a FRF of 1 to Cell-Centre Users (CCUs) and FRF of 3 to Cell-Edge Users (CEUs). This is shown in figure (4.3).Only one third of the whole available bandwidth named *Major Segment* can be used by CEUs. Yet on this Major Segment, packets are sent with higher transmission power. To actualize bigger FRF for CEUs, Major Segments among directly adjoining cells should be orthogonal. In opposite to CEUs, CCUs may access the entire frequency resources, however, with lower transmission power to avoid yielding too much ICI to

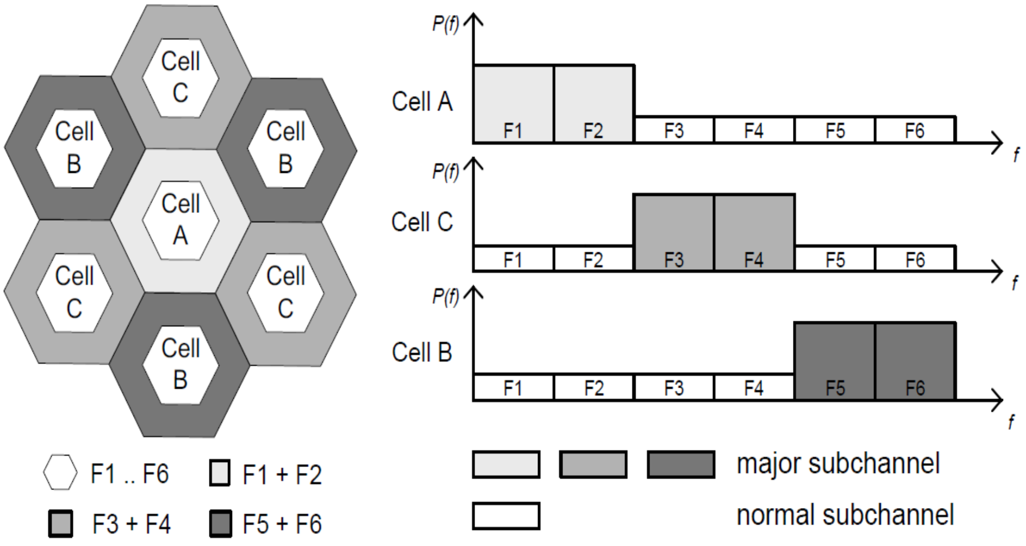


Figure 3.7 Concept of the SFR scheme in a cellular system based on FRF =3 for CEUs and FRF

3.1.9 Soft Fractional Frequency Reuse (SFFR)

The throughputs for the cell-edge users can be improved by using FFR which will intend reduce the ICI experienced by users at the periphery of the cell. However, both schemes may lead to a lower cell throughput as compared to the conventional reuse of one scheme. The PFR scheme does not utilize the whole available frequency bandwidth, and thus, it has a lower cell throughput as compared to reuse of one scheme. Furthermore, although SFR can make use of the overall frequency band available in the cell, and thus, increase the overall system capacity compared to that of the PFR; however, the overall system capacity of SFR maybe lower than that of reuse one scheme.

Soft FFR (SFFR) scheme has been proposed as a way to improve the overall cell throughput of FFR [14]. Unlike the PFR that does not make use of the sub-bands allocated to the outer region in the adjacent cells, the Soft FFR scheme utilizes these sub-bands for the inner UEs, but with low power levels (figure 4.5). As a result, the SFFR is similar to the SFR in that both adopt a non-uniform power profile (it uses high power levels for some sub-bands and low power levels for others). Unlike the SFR;

however, the Soft FFR uses the common sub-band which can enhance the throughput of the inner

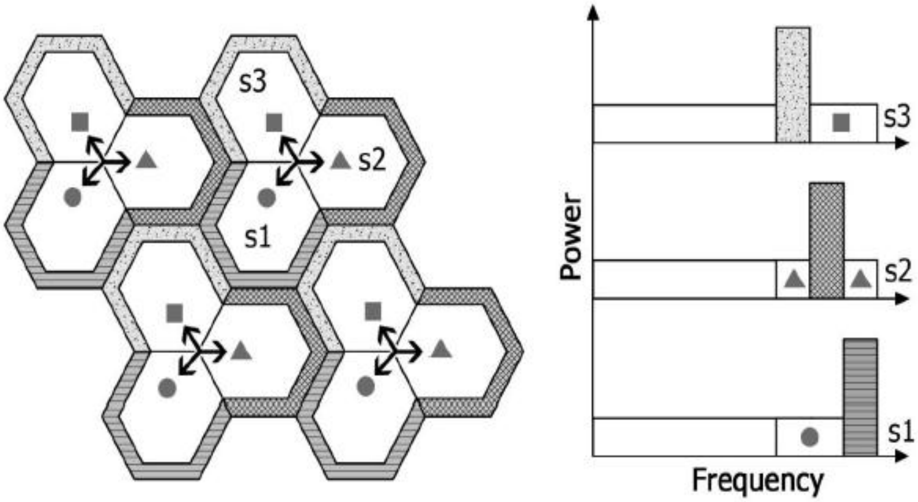


Figure 3.8 Soft Fractional Frequency Reuse (SFFR)

3.2.1 Incremental Frequency Reuse

As a result of the drawbacks of the SFR scheme, that is low spectrum efficiency and co channel neighbor which may still increase under low load conditions, Ki Tae Kim et al. came up with a new design referred as *Incremental Frequency Reuse (IFR)* scheme [11], which can reduce the ICI effectively in the case of a low-offered traffic, and thereby betters the overall system capacity. All these are due to the fact that under the SFR scheme, cell edge users have a maximum of one third of the entire bandwidth to utilize. But; typically, cellular systems have more cell edge users than cell center users.

As mention above, SFR may result in low spectral efficiency as shown in figure 4.6, where the co channel neighbor increases even under low load conditions, while there are still sub channels in idle and underutilized in the system. This is due to the fact that resource allocation of all cells under the SFR scheme starts always from the first sub channel up. Again, this may reduce the spectrum utilization efficiency.

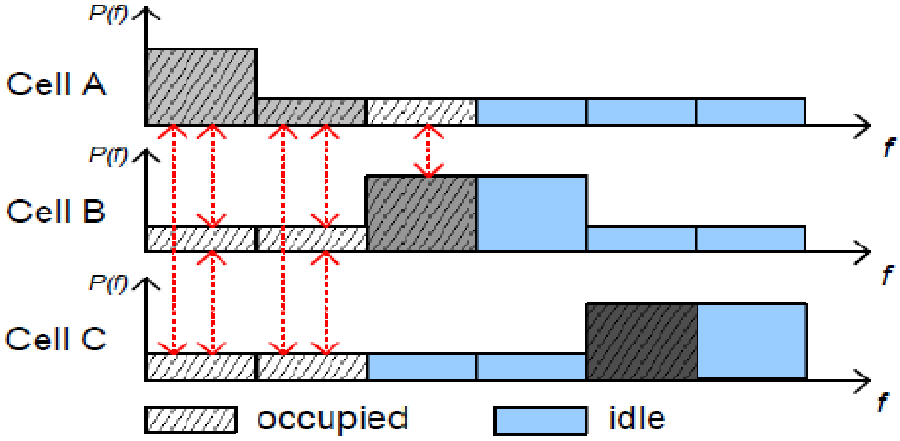


Figure 3.9 Low spectrum efficiency problem in SFR.

The only difference between the IFR design and the Reuse-1 is that adjacent cells in an IFR system start dispensing resources to their users from *different points* of the available bandwidth, whereas the Reuse-1 and the SFR allocate resources always from the first sub channel.

Ki Tae Kim et al, proposed the concept of incremental frequency reuse as was to overcome the shortcomings of the conventional SFR scheme discussed above (low spectrum efficiency, increased co-channel interferences at low loading traffic, and loss of cell capacity system when system is over half-full loaded), in [11], IFR attempts to reduce the ICI effectively under low offered traffic, while maintaining the overall system capacity as shown in figure 4.7.As shown in figure 4.7, the operation method of the IFR scheme for a cellular system with 3 various types of neighboring cells. Cells of type-A occupy resources from the first sub channel, whilst cells of type-B from the one-third point of the whole bandwidth, and cells of type-C from the two-thirds point of the bandwidth. They allocate consecutive sub channels successively along with increasing traffic load until the entire bandwidth is used up

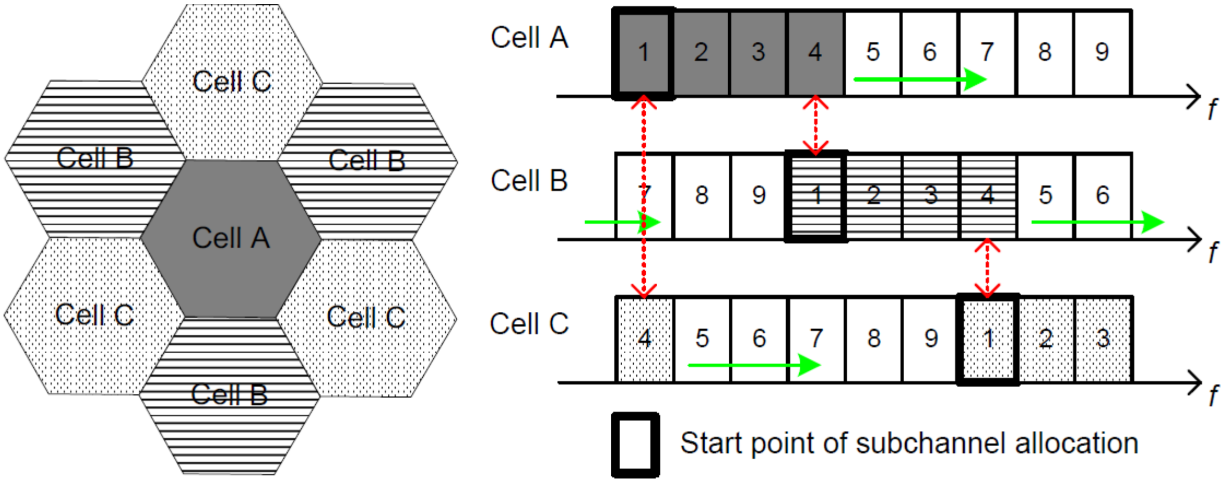


Figure 3.10 IFR scheme in a tri-sector cell system

The ICI generated by directly adjoining cells can be avoided completely at low traffic situation, since frequency reuse of the first tier neighboring cells doesn't occur when loading factor below 0.3, and the whole system operates as in the classical reuse-3 system. Effectively, under the IFR scheme, the system operates with increasing traffic load like moving from a reuse-3 system to a reuse-1 system.

Regardless of the fact that the IFR scheme can overcome most of the shortcomings inherited in the SFR scheme; the IFR scheme performs better only under low traffic. When the loading factor in the system is above 0.3, the IFR performance is lower than that of the SFR. According, it is clear that IFR scheme do not perform better than classical reuse-1 scheme over middle load or full load situation. The SFR scheme even performs worse than the reuse-1 system. Accordingly, it is concluded that the system capacity cannot be substantively improved by the IFR and the SFR schemes. To further improve the performance of the IFR and the SFR schemes and overcome their limitations, a scheme called Enhanced Fractional Frequency Reuse (EFFR) was proposed. EFFR attempts to enhance the system capacity especially under overload situations.

3.2.2 Enhanced Inter-Cell Interference Coordination (eICIC)

Enhanced Inter-Cell Interference Coordination (eICIC) in heterogeneous networks is one of the techniques to mitigate ICI that is introduced in LTE-Advanced. This is due to the fact that without an efficient inter-cell interference scheme the range extension area concept loses its advantage and efficiency. The problem with ICIC schemes in releases 8 and 9 was that they were only considering data channels and did not focus on the interference between control channels, so LTE release 10 solves this problem with the solutions in the following subsections. To understand the concept of eICIC, it is therefore helpful to understand the Range extension area concept.

3.2.3 Range Extension

According to [13], Range extension is an approach in which an offset is added to the Pico cell Received Signal Strength (RSS) in order to increase its DL coverage footprint. But however Cell selection in LTE is based on terminal measurements of the received power of the downlink signal or more specifically the cell specific reference (CRS) downlink signaling. This approach for cell selection would be unfair to the low power nodes (Pico-eNBs) as most probably the terminal will choose the higher power base stations (Macro-eNBs) even if the path loss to the Pico-eNB is smaller and this will not be optimal in terms of **Uplink coverage** (as the terminal has a lower path loss to the Pico-eNB but instead it will select the Macro-eNB.), **Downlink capacity** (Pico-eNBs will be under-utilized as fewer users are connected to them while the Macro-eNBs could be overloaded even if Macro-eNBs and Pico-eNBs are using the same resources in terms of spectrum, so the cell-splitting gain is not large and the resources are not well utilized) and **interferenc**e (due to high interference of the macro-eNBs).

As a solution to the Uplink coverage and Downlink capacity, cell selection could be dependent on estimates of the uplink path loss, which in practice can be done by applying a cell-specific offset to the received power measurements used. . This offset would somehow compensate for the transmitting power differences between the Macro-eNBs and Pico-eNBs; it would also extend the coverage area of the Pico-eNB, or in other words extend the area where the Pico-eNB is selected. This area is called "**Range Extension**" is illustrated in Figure (3.12)

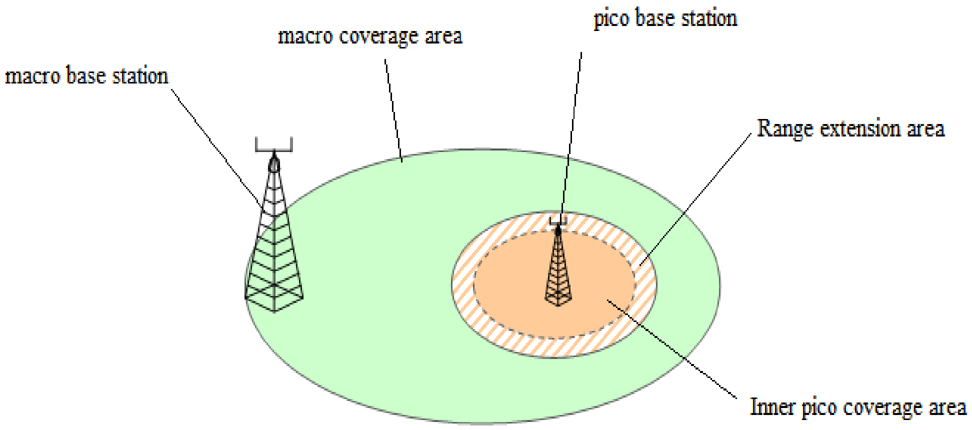


Figure 3.11 range extension area illustration

3.2.4 Advantages of the Range Extension area

1. The Range extension area brings about an increase in the SNIR in the uplink. This will maximize the uplink data rate and thus the performance of the system.
2. The terminal transmit power would be reduced as the path loss to the Pico-eNB is lower than the one to the Macro-eNB so the interference to other cells would be reduced and the uplink system efficiency would be improved.
3. It also allows more users to be connected to the Pico-eNB, thus increasing the cell splitting gain.
4. Since the Macro-eNB transmits to fewer users then the interference it applies on the Pico-eNB is reduced and the Pico-eNBs can reuse the resources more efficiently so the downlink system efficiency is maximized as well.

Though the Range extension come about with numerous advantages as seen above, it also has one main disadvantage due to the fact that users located in the range extension are prone to more inter cell interference which is undesirable. This ICI is due to the difference in transmission powers of the Macro-eNBs and the Pico-eNBs, in the range extension area as seen in figure 3.13 the effect of ICI in the range extension is illustrated in figure 3.13

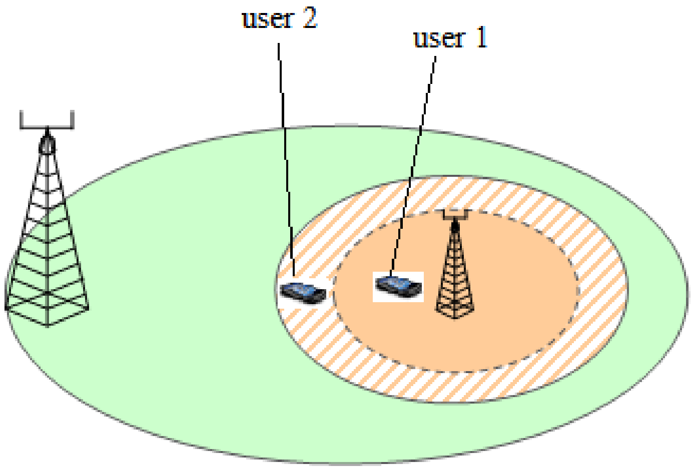


Figure 3.12 Range extension area interference

As depicted in figure (3.12), User 1 is placed close to the Pico-eNB so we will call it "center Pico user", the Pico user is not affected very much by the Macro-eNB interference as the downlink received power from the Pico-eNB is higher than the one received from the Macro-eNB. Furthermore User 2 is placed some distance away from the Pico-eNB, in the range extension area, and as discussed before this user experiences a severe interference from Macro-eNB.

Our objective in this section is to get rid of or reduces this ICI as much as we can to improve the system performance. This can be achieved using eICIC. The problem with ICIC schemes in releases 8 and 9 was that they were only considering data channels and did not focus on the interference between control channels. LTE solves this problem by using a technique known as eICIC. Here, the solutions are mainly divided into frequency domain solutions such as carrier aggregation and time domain solutions such as almost blank sub frames (ABS), [3] however according to [1], there is a third technique known as the power technique. All these techniques are discussed as follows.

3.2.5 Frequency domain multiplexing inter-cell interference coordination scheme.

Carrier aggregation allows resource allocation across carriers and also allows scheduler based on fast switching between carriers without time consuming handovers. That

means that a node can schedule its control information on a carrier and its data information on another carrier. In the example provided bellow we have 2 component carriers' f1 and f2 where 5 sub frames are shown in each carrier. There are 2 cases, the case of Macro layer usage and the case of Pico layer usage; the sub frames are distributed in control part, the blue part, and data part. The control part in the example only illustrates the PDCCH, PCFICH and PHICH11 at the beginning of the sub frames.
As shown in the Figure (3.13) the Macro layer can schedule its control information on f1 but can still schedule its users on both f1 and f2 so by scheduling control and data information for both Macro and Pico layers on different component carriers, interference on control and data channels can be avoided. The disadvantage of carrier aggregation with cross carrier scheduling is that it is only supported by release 10 terminals and onwards so this feature cannot be used by release 8 and 9 terminals.

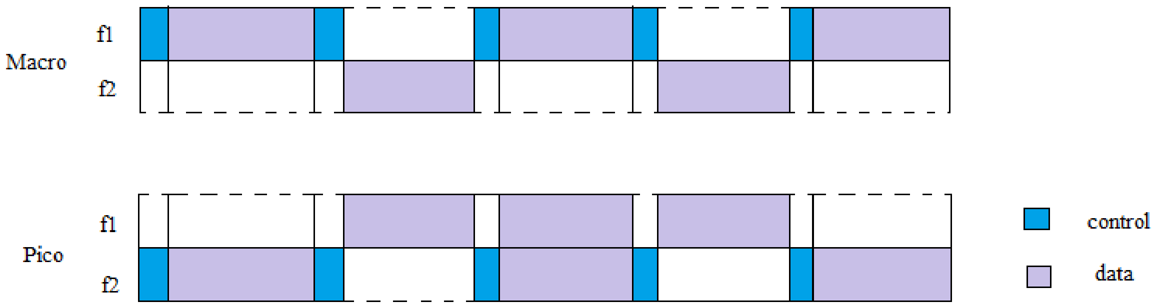


Figure 3.13 Illustration of eIIC based on carrier aggregation

3.2.6 Time domain multiplexing inter-cell interference coordination scheme (Almost Blank Sub frames)

In this approach transmissions from Macro-eNBs causing high interference onto Pico-eNBs users are periodically muted (stopped) during entire sub frames, this way the Pico-eNB users that are suffering from a high level of interference from the aggressor Macro-eNB have a chance to be served. However this muting is not complete as certain control signals are still transmitted .As shown in Figure (3.11) TDM ICIC using ABS causes a lot of variation in terms of interference between the sub frames, this fact can be used in the sense that the users that suffer from a high level of interference should be served during these ABS while the users that are closer to the transmitting node or that are not very much affected by interference can be served during the non-ABS sub frames. [3]

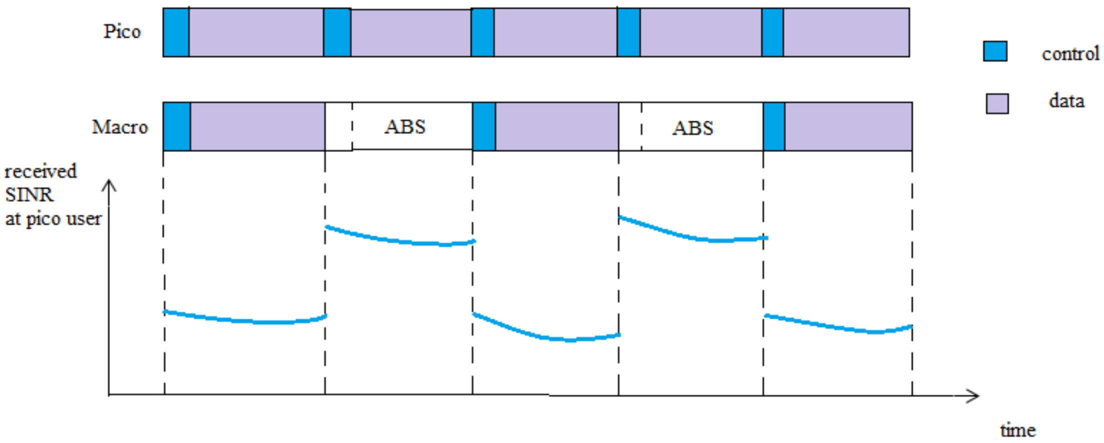


Figure: 3.14 Illustration of TDMICIC

3.2.7 Power setting based on HeNB Measurements

Power setting of the HeNB is another approach to limit the interference between the MeNBs and HeNBs. The main concept of this approach is to control the radiated power of the HeNB to limit its coverage to the premises boundary of the owner of that HeNB as shown in Figure (3.16). Different proposals are discussed in 3GPP for this purpose where all of them depend on measurements performed locally by the HeNB.

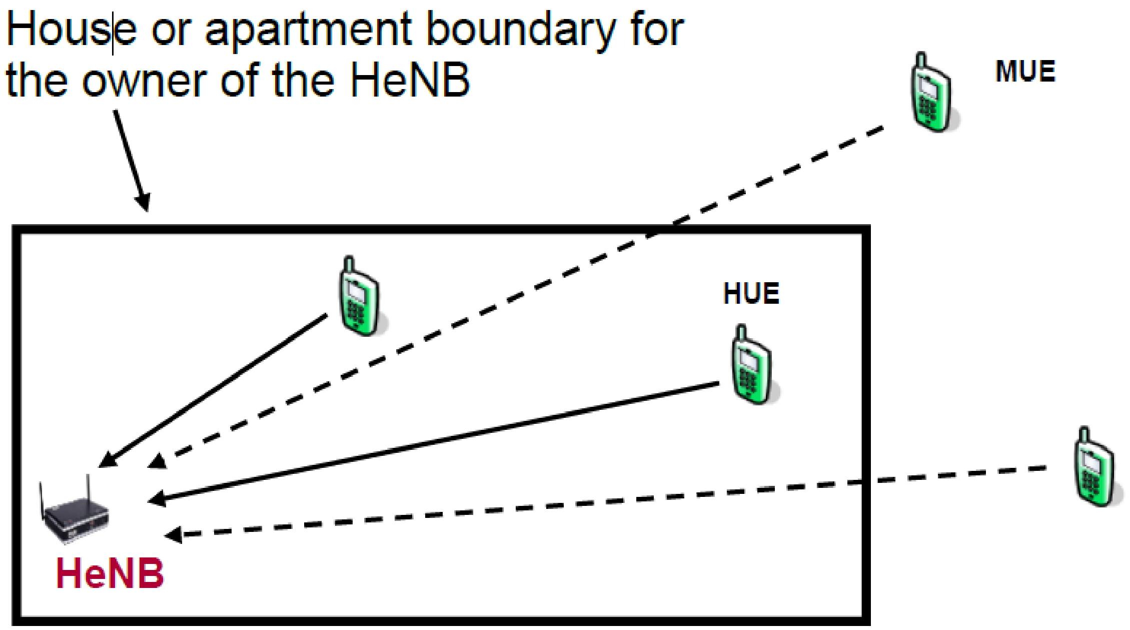


Figure: 3.15 Power Setting of HeNB

CHAPTER 4

Simulations and Results

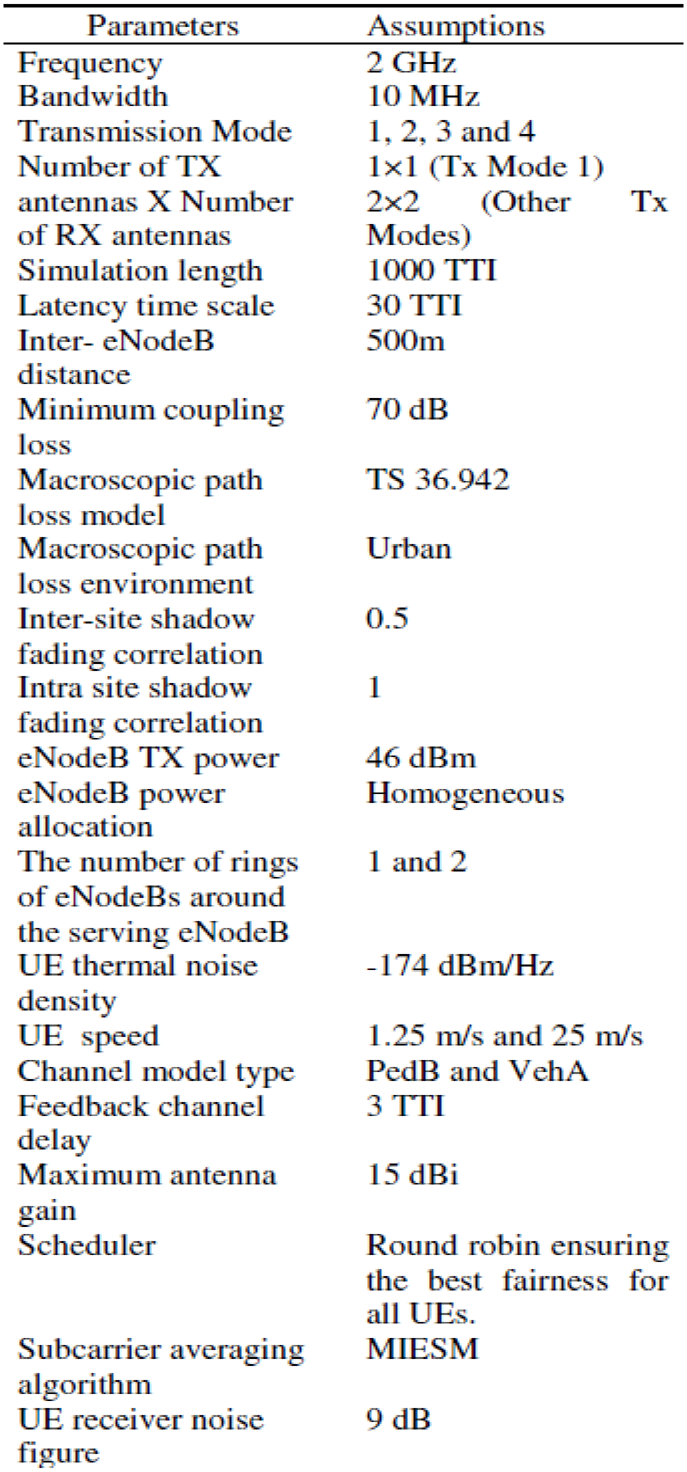
4.1 Transmission Modes:

During dynamic resource scheduling, suitable transmission mode can be adapted semi-statically according to various channel conditions. The PDSCH channel employs different transmission modes utilizing multiple antennas in both transmitting and receiving sides. Till now nine transmission modes have been released but only first four have been implemented [2]. The nine transmission modes are:

1. Single antenna; port 0,
2. Transmit diversity,
3. Open loop spatial multiplexing,
4. Closed loop spatial multiplexing,
5. MU-MIMO,
6. Closed loop rank=1 preceding,
7. Single antenna; port 5,
8. Dual layer transmission; port 7 and 8 and
9. Up to 8 layer transmission; port 7-14.

Simulation was performed using LTE system level simulator v1.3_r427 [1]. A number of different UEs operating under a central serving eNodeB were used in the simulation. One or two rings of eNodeBs around the serving eNodeB were used for the purpose of creating two different levels of interference. The same UE locations were used in all simulations and the UE locations are shown in the (Fig.4. 1). The central eNodeB numbered 5 is the serving eNodeB when one ring of eNodeBs around the serving eNodeB was used. The central eNodeB numbered 11 is the serving eNodeB when two rings of eNodeBs around the serving eNodeB were used.

Table: 2. Simulation Parameters



Parameters	Assumptions
Frequency	2 GHz
Bandwidth	10 MHz
Transmission Mode	1, 2, 3 and 4
Number of TX antennas X Number of RX antennas	1×1 (Tx Mode 1) 2×2 (Other Tx Modes)
Simulation length	1000 TTI
Latency time scale	30 TTI
Inter- eNodeB distance	500m
Minimum coupling loss	70 dB
Macroscopic path loss model	TS 36.942
Macroscopic path loss environment	Urban
Inter-site shadow fading correlation	0.5
Intra site shadow fading correlation	1
eNodeB TX power	46 dBm
eNodeB power allocation	Homogeneous
The number of rings of eNodeBs around the serving eNodeB	1 and 2
UE thermal noise density	-174 dBm/Hz
UE speed	1.25 m/s and 25 m/s
Channel model type	PedB and VehA
Feedback channel delay	3 TTI
Maximum antenna gain	15 dBi
Scheduler	Round robin ensuring the best fairness for all UEs.
Subcarrier averaging algorithm	MIESM
UE receiver noise figure	9 dB

Table 4.1

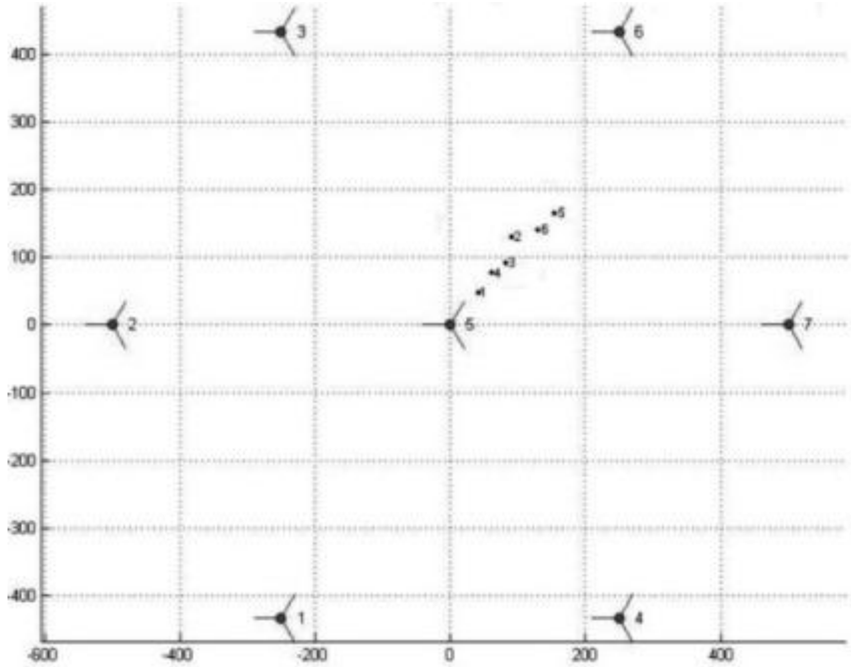


Figure: 4.1 UE position for one ring of eNodeBs around the serving eNodeB

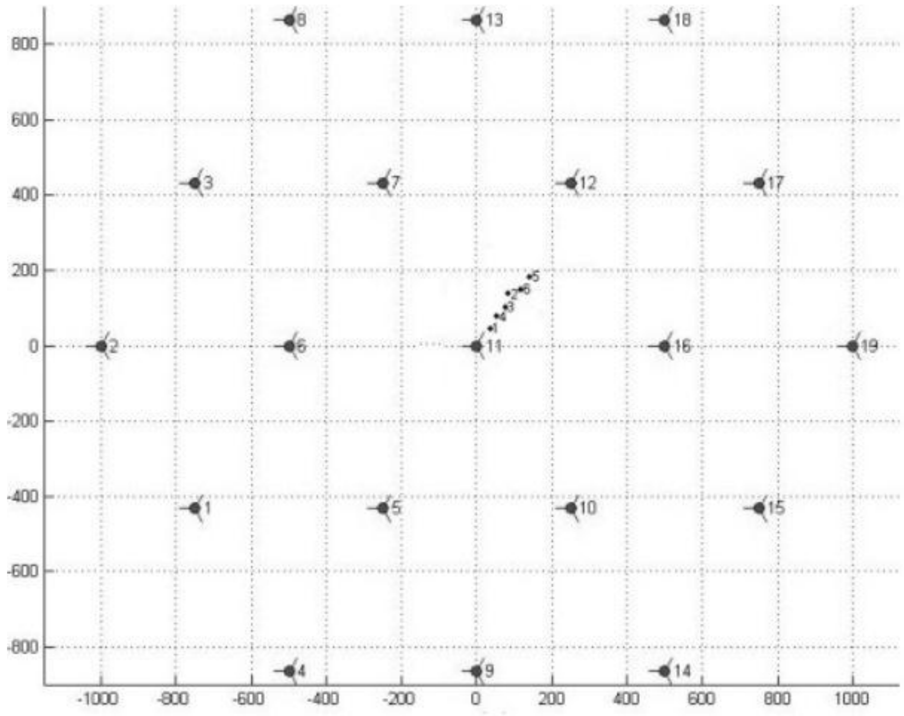


Figure 4.2UE position for two rings of eNodeBs around the serving eNodeB

4.2 Simulation Results

After execution of the simulations, the UE throughput is plotted against the distance of UEs form the serving eNodeB. The plot is shown in Fig. (4.3) for UE speed 1.25 m/s and in Fig. (4. 5) for UE speed 25 m/s, respectively. The throughput falls off for greater distance of the UE because of increased path loss. Fig (4.4) and Fig.(4.5) demonstrate the amount of degradation in throughput for all Transmission modes when interference from the second ring of eNodeBs around the serving eNodeB was introduced. SISO is generally found to have lower data rate compared to all MIMO techniques as expected. The transmit diversity achieves much better throughput compared to other transmission modes for UEs very far away from the serving eNodeB. CLSM performs better than OLSM in case of pedestrian but performs almost equally in case user in a high speed vehicle.

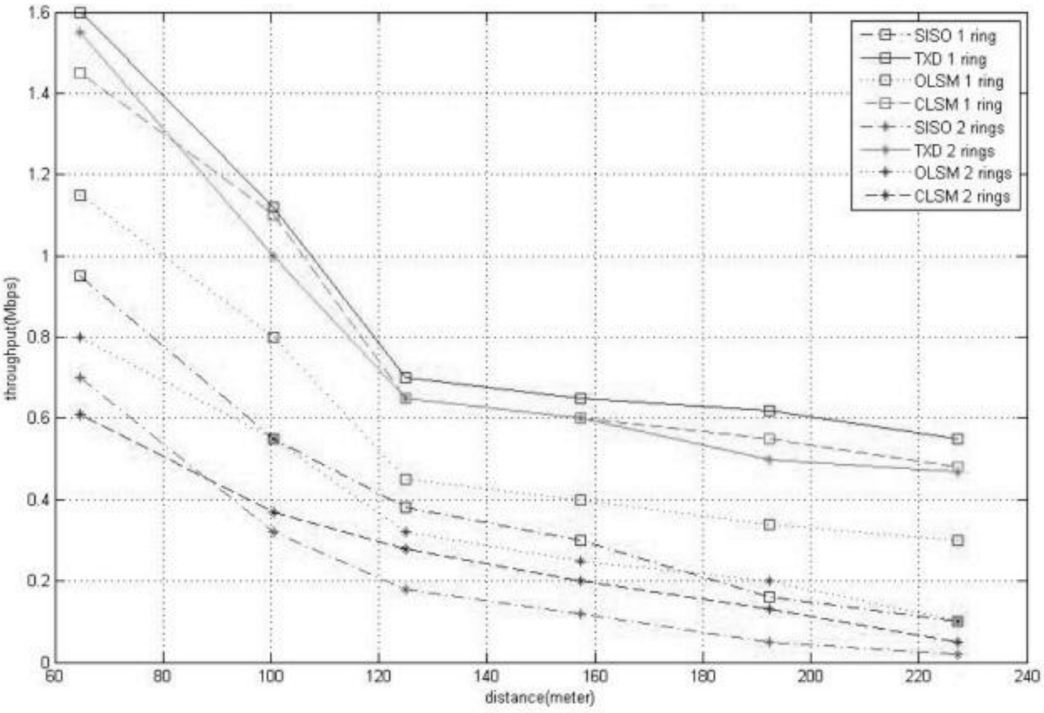


Figure 4.3 Throughput for UE speed 1.25 m/s

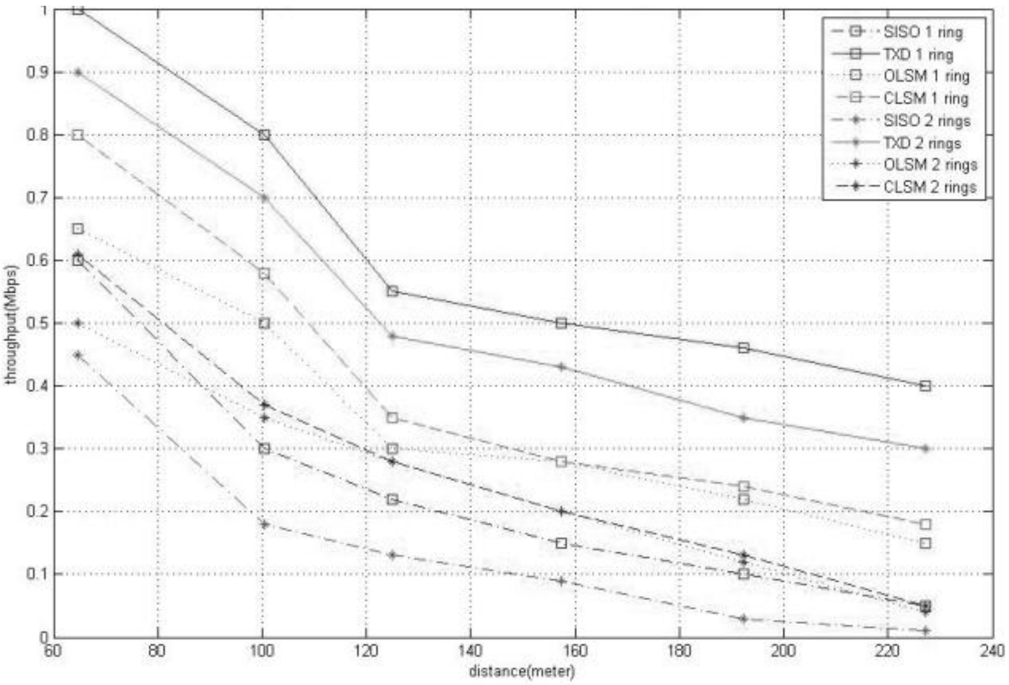


Figure 4.4 Throughput for UE speed 25 m/s

CHAPTER 5

Conclusion

In this thesis we have provided a study of different ICI avoidance techniques. These techniques are classifies in to two; that is the frequency reuse base scheme and the coordination base scheme. FFR schemes and the IFR scheme for ICI mitigation in cellular OFDMA networks are outlined and discussed. Also various coordination schemes are equally discussed. The coordination schemes are suitable for heterogeneous network unlike FFR schemes which are suitable for homogenous networks. All the above schemes have their unique advantages and disadvantages. However a common advantage in frequency scheme is that they don't need global coordination among neighboring cell and thereby can reap significant complexity reduction benefits.

The idea of the range extension area is also introduce in this monograph in order to have a good understanding of the recent ICI mitigation technique known as enhanced Inter-Cell Interference Coordination (eICIC) in heterogeneous networks that has been introduce in LTE-Advanced.
The Range extension come about with numerous advantages but however, it also has one main disadvantage due to the fact that users located in the range extension are prone to more inter cell interference which is undesirable. Because of this eICIC is discussed which came along with the possible solutions to ICI in heterogeneous in LTE-Advance and beyond. These coordination techniques include: time domain inter cell interference coordination scheme also known as almost blank sub frame (ABS) and frequency domain multiplexing coordination scheme. A mix between two or approaches may be of better effect on the performance of HetNets. Considering the scenarios that apply time-domain and power control techniques may give performance boosting that can be considerable.

For the stimulation, the performances of different MIMO Techniques under different interference levels and mobility have been analyzed. Transmit diversity achieves better performance for UEs far away because the signal combining technique in transmit diversity reduces fading variation and increases the signal-to-noise ratio at the receiver side. This provides for robustness of data transmission. When the UE speed was only 1.25 m/s, CLSM offered better throughput compared to OLSM. This is because the UE indicate the precede that would result in a transmission with an effective SNR by choosing most closely the largest singular values of its estimated channel matrix in case of CLSM. However, CLSM had much more decline in throughput compared to OLSM when the UE speed was increased from 1.25 m/s to 25 m/s. This is because the Preceding Matrix Indicator (PMI) fails to indicate optimum use of preceding matrix for high-speed UEs and then the fixed preceding can achieve better performance. CLSM and OLSM were actually expected to provide better throughput than the results obtained. This poorer performance was probably due to the fact that system level simulator had not used very rich multipath environment.

References

[1] Abdel-Baset Hamza, Abdel-Rahman Hanafy, Ahmad Abdel-Karim, Ahmed Zahran, Haitham Hamza, Hussain Elsaid, Khaled Elsayed, Mahmoud Ismail, Mahmoud Kamel, Mostafa Elkhamy” 4G++: Advanced Performance Boosting Techniques in 4Th Generation Wireless Systems”

[2] Volker Pauli, Eiko Seidel Nomor Research GmbH, Munich, Germany September, 2011

[3] Interference Management In LTE-Advanced Heterogeneous Networks Using Almost Blank SubframesHisham El Shaer March 2012

[4] G´abor Fodor, Chrysostomos Koutsimanis, Andr´as R´acz, Norbert Reider, Arne Simonsson and Walter M¨uller Ericsson Research JOURNAL OF COMMUNICATIONS, VOL. 4, NO. 7, AUGUST 2009

[5] Tag der mündlichen Prüfung: 22. Dezember 2011

[6] M. Porjazoski and B. Popovski, "Analysis of Intercell interference coordination by Fractional frequency reuse in LTE," in *Proc. Int Software, Telecommunications and Computer Networks (SoftCOM) Conf.*, 2010, pp. 160-164.

[7] Lei Chen and Di Yuan, "Soft frequency reuse in large networks with irregular cell pattern: How much gain to expect?," in *Proc. IEEE 20th Int Personal, Indoor and Mobile Radio Communications Symp.*, 2009, pp. 1467-1471

[8] M. Porjazoski and B. Popovski, "Contribution to analysis of Intercell interference coordination in LTE: A fractional frequency reuse case," in *Proc. Global Mobile Congress (GMC).*, 2010, pp. 1-4

[9] I. Katzela, and M. Naghshineh. Channel Assignment Schemes for Cellular Mobile Telecommunication Systems: A Comprehensive Survey. *IEEE Personal Communications*, 3(3):10–31, June 1996.

[10] 3GPP TS 36.300 V8.4.0, "E-UTRA and E-UTRAN Overall description;
Stage 2 (Release 8),' March 2008

[11] T.-h. Kim et al. (Eds.): FGCN 2011, Part I, CCIS 265, pp. 103–110, 2011.
© Springer-Verlag Berlin Heidelberg 2011

[12] T.F.M Hendrixen " UMTS and LTE /SAE handover solotions and their comparision" Faculty of Governance University of Twente, the Netherlands

[13] 1 Cheng-Chung Lin, 2Kumbesan Sandrasegaran, 3 Huda Adibah Mohd Ramli, and 4Riyaj Basukala "OPTIMIZED PERFORMANCE EVALUATION OF LTE HARD HANDOVER ALGORITHM WITH AVERAGE RSRP CONSTRAINT" Sydney, Australia

[14] Banerjee, N.; Wei Wu; Das S.K, "Mobility support I wireless internet" vol.10, no.5, pp.54-61, Oct 2003

[15] 3GPP TS 36.300 V8.7.0 (2008-12) "Evolved Universal

Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN)" December 2008

[16] Dr. Hayan Alradwan, Dr.Adnan Motermawy, Kinan Ghanem "Reducing Ping-Pong Handover Effect in LTE Mobile Networks Using TRIAS"

[17] 3GPP 36.214 "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements", March 2009.

[18] ANASM., F. CALABRESE, P OSTLING, K. PEDERSEN, P. Mogensen. "Performance Analysis of Handover Measurements and Layer 3Filtering for UTRAN LTE," PIMRC2007.

[19] 3GPP, "Technical Specification Group Services and System Aspects; General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access (Release 8) TS 23.401 V8.7.0," 09-2009.