Inter-Cell Interference Mitigation in LTE Downlink Using Static Interference Coordination: Case of Addis Ababa

By

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A THESIS

Submitted to Addis Ababa University of the Addis Ababa Institute of Technology, School of Electrical and Computer Engineering in Partial Fulfillment of the Requirements for the Degree of

Master of Science

in

Communication Engineering

January 2016

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Approval by Board of Examiners

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Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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ABSTRACT

Recently, Long Term Evolution (LTE) has been deployed by many operators to address the growing data needs. Ethio telecom is among those operators that have deployed LTE in Addis Ababa. As other new emerging technologies, LTE uses orthogonal frequency division multiple access (OFDMA) technology to improve the system performance. However, the currently deployed LTE network has low average downlink throughput due to the deployment uses reuse factor of 1 in which every cell can provide services over the entire system band. Associated with reuse factor of 1, therefore, there will be inter-cell interference between neighbor eNodeBs when they try to use the same resource blocks to their user equipment. For cell-edge users (CEUs), the effect of inter-cell interference is especially severe. Therefore, to improve the throughput, inter-cell interference must be mitigated. Different methods have been proposed to mitigate this interference and interference coordination using static inter-cell interference coordination (ICIC) algorithm is the main one. Hence, this thesis focuses on the evaluation of static ICIC algorithms: hard fractional frequency reuse (Hard FFR), soft frequency reuse (SFR), partial frequency reuse (PFR) and soft fractional frequency reuse (SFFR) in already existed LTE network of Addis Ababa using simulation software. For this case study, sample sites around Gotera area of Addis Ababa are randomly selected. All these static ICIC algorithms are compared using the performance metrics such as peak throughput, the carrier to interference plus noise ratio (CINR) of the data channel and coverage probability. Simulation results shows that static ICIC schemes have better performance than reuse 1 scheme and from static ICIC algorithms, PFR algorithm has better average throughput and coverage probability of throughput.

Key words: Cell-edge user (CEU); Inter-cell Interference coordination (ICIC); Hard fractional frequency reuse; Partial frequency reuse (PFR); Soft frequency reuse (SFR); Soft fractional frequency reuse (SFFR).

ACKNOWLEDGEMENTS

This thesis is by far the most important achievement in my educational career. Firstly, I would like to express my gratitude and my sincere thanks to my advisor Dr.-Ing. Dereje Hailemariam for his valuable suggestion and guidance for finalizing my thesis. His comments boosted my work and motivated me to strive hard in my endeavor. It is my honor to be student under his supervision and his wise guidance. Secondly, I am very thankful to colleagues from Ethio telecom for providing me research materials and comments for my thesis work. Finally, I would like to extend my gratitude to my family and friends for supporting and encouraging me to finalize my thesis work.

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3GPP	3rd Generation Partnership Project
CCU	Cell Center User
CEU	Cell Edge User
CINR	Carrier to Interference plus Noise Ratio
CQI	Channel Quality Indication
eNodeB	Evolved NodeB
EPC	Evolved Packet Core
EPS	Evolved Packet System
EUTRAN	Evolved UTRAN
FFR	Fractional Frequency Reuse
GSM	Global System for Mobile Communication
HII	High Interference Indicator
ICI	Inter-cell Interference
ICIC	Inter-cell Interference Coordination
LTE	Long term evolution
MAC	Medium Access Control
MME	Mobility Management Entity
OFDMA	Orthogonal Frequency Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
OI	Overload Indicator
PF	Proportional Fair
PFR	Partial Frequency Reuse
PDCCH	Physical Downlink Control Channel

PDCP	Packet Data Convergence Protocol
PDSCH	Physical Downlink Shared Channel
P-GW	Packet Data Network Gateway
PLMN	Public Land Mobile Network
PRB	Physical Resource Block
PRS	Performance Report System
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RLC	Radio Link Control
RNC	Radio Network Controller
RR	Round Robin
RRC	Radio Resource Connection
RNTP	Relative Narrow Band Transmit Power
SFFR	Soft Fractional Frequency Reuse
SFR	Soft Frequency Reuse
S-GW	Serving Gateway
SINR	Signal to Interference Plus Noise Ratio
TDMA	Time Division Multiple Access
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
UTRAN	Universal Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

CHAPTER 1. INTRODUCTION

1.1 Background

In recent years, the demand for high data rate services is growing rapidly and this demand has motivated 3GPP to develop a new standard called Long Term Evolution (LTE). LTE is an all IP broadband internet system with voice and other services are built to ensure 3GPP's competitiveness over other cellular technologies. Therefore, in LTE Release 8, the peak data rate of 100 Mbps in the downlink and 50Mbps in the uplink with a radio network delay of less than 5 ms is achieved. Furthermore, LTE can support different bandwidths such as 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz and 20MHz and has improved spectrum efficiency [1]. In addition, LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) as the downlink multiple access technology and Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink. Besides, LTE supports frequency division duplex (FDD) and time division duplex (TDD) for simultaneous transmission [2]. Since the radio bandwidth is the scarce resource in wireless communications, many operators use frequency reuse one in their cellular networks. However, under this scenario, the system performance is severely degraded due to interference caused by neighboring cells [3]. Intra-cell interference and inter-cell interference are the two main categories of interference in cellular network. Since the LTE downlink system uses the OFDMA technology, intra-cell interference is not an issue because of the orthogonally among sub-carriers. However, the inter-cell interference which is caused by using the same frequency between the serving cell and the neighbor cell can reduce the LTE performance in terms of throughput and spectral efficiency, particularly for cell-edge users (CEU) [4]. Here, CEUs are user equipment in a cell which are far from the serving eNodeB while cell-center users (CCUs) are user equipment close to the serving eNodeB. Hence, inter-cell interference mitigation is a very important point to improve the performance of the LTE system. In this thesis, a static inter-cell interference mitigation based on fractional frequency reuse taking the case of LTE network of Addis Ababa is presented. Static inter-cell interference coordination usually classified into three broad categories: hard fractional frequency reuse, soft frequency reuse and partial frequency reuse [5]. In hard fractional frequency reuse, the whole bandwidth can be divided into three equal and orthogonal parts and is allocated to sectors so that adjacent sectors always use different resources in the bandwidth. This scheme is also called frequency reuse of 3 in some literatures. This clustering obviously leads to low inter-cell interference, with a cost of large capacity loss due to the restrictions imposed on the resources, where only one third of the resources are used in each sector. In soft frequency reuse, each cell transmits in the whole frequency band. Nevertheless, the cell uses high power in some frequency sub-bands while reduced power is used in the rest of the frequency band. In PFR, a common frequency band is used for cell-center users with a frequency reuse of 1 and with equal power and the remaining major bands is allocated edge users. Basically, the operator decides the power allocation of these sub-bands. In PFR, users at cell-edge are fully protected from cell-center users to avoid interference. So, the PFR scheme does not use the whole available frequency bandwidth, hence has limited bandwidth usage. Furthermore, although SFR can utilize the whole available bandwidth, it may lead to lower throughput than PFR because of interference between edge and center users. Thus, a variation of SFR which is SFFR scheme was proposed which has characteristics of both PFR and SFR. In SFFR, the resources which are allocated to cell-edge users are allowed to be used by the other cells center users with reduced power [6].

1.2 Statement of the Problem

In LTE Release 8, 100Mbps peak data rate is realized in downlink and 50Mbps is realized in uplink. It is confirmed that using 20 MHz bandwidth, a peak data rate of 150 Mbps in downlink can be achieved with 2x2 MIMO and 300 Mbps can be achieved if 4x4 MIMO is used also in uplink 75 Mbps can be reached with single transmit antenna in UE [7].

Ethio telecom has deployed LTE in Addis Ababa in 13 clusters. This deployment uses the 20MHz bandwidth and all eNodeBs with in the cluster will reuse the physical resource blocks of the 20MHz bandwidth. However, performance analysis shows that the average downlink data rate is very much lower than the maximum possible capacity. In other words, this implementation results in low system capacity and low throughput of the cellular network because of high interference from the neighbor eNodeBs as well as limits what a user can benefit from the LTE technology.

Since the current deployment of LTE of Addis Ababa uses reuse 1 technique, with increasing number of LTE subscribers there will be high probability of sharing the same resource blocks between cell-edge users in the serving cells and the neighbor cells. This condition results in slower data rate for services like video conferencing, video streaming especially for users at cell-edge areas because of degraded CINR. Thus, to improve the network performance we have to ensure that resource blocks are not shared between the cell-edge users of the serving cell and neighbor cells.

Thus, this thesis intends to indicate the benefits of using inter-cell interference mitigation techniques on LTE network of Addis Ababa.

1.3 Motivation

Because of its high data rate, LTE deployment gives us many benefits for the growth of data traffic. Also, OFDMA-based networks are suitable for practical deployment because of efficient usage of frequency resources. However, there are technical challenges on many operators LTE deployment such as low system performance. Ethio telecom is one of the operators that also have technical challenges in its LTE deployment. Reduced average downlink throughput is one of the challenges that persists on the currently deployed LTE network of Addis Ababa. Although there are many factors for this very low data rate, inter-cell interference plays significant role not to achieve high data rate and reduces user satisfaction. Consequently, mitigating inter cell interference will be one of the solutions for improving the system performance.

1.4 Objectives

1.4.1 General Objective

Ethio telecom has deployed LTE in Addis Ababa recently. However, this deployment has reduced downlink data rate. The main aim of this thesis is to investigate the downlink throughput of LTE network deployed in Addis Ababa and propose inter-cell interference mitigation method to enhance the network capacity and improves the downlink throughput.

1.4.2 Specific Objectives

The specific objectives of this thesis are to:

- Evaluate the system performance of currently deployed LTE network using performance metrics such as downlink throughput.
- Understand different inter-cell interference mitigation techniques in LTE networks.
- Compare the CINR and throughput of LTE network for no ICIC and static ICIC algorithms.
- Recommend which static ICIC method is better to implement in Addis Ababa LTE deployment scenario.

1.5 Methodology

Methodologies to be used in order to achieve the objectives of this research are:

- **Literature review:** includes reading books, journals, thesis and white papers about interference scenario and inter-cell interference coordination in LTE and how the static inter-cell interference algorithms such as hard fractional frequency reuse, soft frequency reuse and partial frequency reuse work.
- **Data Collection:** involves collecting the real network data of sample eNodeBs from Ethio telecom network management system. It includes global data such as duplex types and operating band and specific parameters such as cell parameters, transmitter parameters and antenna parameters.
- **Simulation Setup**: involves importing the digital map of Addis Ababa into Atoll software, its clutter class and clutter height. Then, configuration of the network parameters and static ICIC schemes on the selected sample 7 eNodeBs

are performed. Besides, resource blocks are configured for different sectors based on different static ICIC algorithms.

- **Simulation and interpretation of the result:** involves the simulation of the static ICIC algorithms in sample eNodeBs of Addis Ababa using peak RLC throughput, peak CINR and coverage probability. We will use Matlab for comparison of coverage probability between different ICIC algorithms. Then, the results are analyzed using those performance metrics.

1.6 Related Work

A. Daeinabi, K. Sandrasegaran and X.Zhu [8] proposed a joint resource block and transmit power allocation scheme in LTE downlink networks. In this paper, they tried to implement the idea first by calculating the priority of the user using QoS and interference level to schedule users into specified sub-bands in each cell. Then, eNodeBs dynamically control the transmit power using fuzzy logic system and by the exchange of interference information. Also in this paper, non-inter-cell coordination and inter-cell coordination schemes is surveyed. However, they had given the simulation of cell throughput and interference level only for reuse 1 and SFR schemes in which the SFR scheme outperforms the reuse 1 scheme.

Dai Kimura and Hiroyuki Seki [9] suggested the ICIC standardization and interference coordination method using user distribution in which LTE eNodeB automatically optimizes the cell-edge band by using received power distribution of user. In their simulations, they have evaluated the cell-edge performance by using only frequency reuse factor of 3 and 4 for cell-edge users without considering other static ICIC methods.

Chandra Thapa and Chandrasekhar.C [10] presented comparative evaluation on FFR and traditional frequency reuse system in LTE downlink. In their paper, they proposed FFR for interference management. They have evaluated the performance by creating a simulation environment of 15 eNodeBs without assuming real time scenario. In their simulation, they showed that FFR scheme have better performance than traditional frequency reuse scheme by using only two metrics i.e coverage probability and probability of acceptance.

Abdelbaset S. Hamza et.al [11] presented a survey on inter-cell interference coordination techniques in OFDMA-based cellular networks. This paper reviews the various ICIC avoidance schemes in the downlink of OFDMA-based cellular networks. In particular, the paper introduces new parameterized classifications of ICIC avoidance and uses these classifications to review and categories different static (frequency reuse-based) and dynamic (cell coordination-based) ICIC schemes. However, simulation results are not included in his paper.

Zhang [12] proposed a classification for interference avoidance schemes with four categorizes that are static schemes, low level dynamic schemes, intermediate level dynamic scheme and high level dynamic scheme. A scheme is categorized to one of these four categories based on the flexibility to adjust to network environments. In his paper, Zhang only introduced the static interference avoidance schemes without providing the performance analysis.

Katzela *et al.* [13] surveyed the different channel allocation schemes and different channel reuse schemes without giving much emphasis on the problem of ICI. Katzela *et al.* divides the channel allocation schemes into the following three categories: fixed channel allocation, dynamic channel allocation and hybrid channel allocation. However, the methods discussed in the survey were evaluated on multi-cell traditional cellular networks like GSM but not on OFDMA systems such as LTE or LTE-Adv which make the methods doubtful to perform on these systems.

1.7 Scope and Limitation

This thesis addresses the importance of inter-cell interference mitigation for improving average downlink throughput of LTE deployment of Addis Ababa. It gives insight of different static inter-cell interference mitigation techniques of LTE network. The results are based on Atoll simulation software using the real LTE network data of Addis Ababa. In addition, due to the constraints of Atoll simulation software not having other static ICIC schemes, only four of them are evaluated in this thesis. Also, since Atoll will take more time for calculation of coverage predictions, only seven eNodeBs are used for the purpose of simulation.

1.8 Thesis Outline

The rest of the thesis is organized as follows:

- Chapter 2 gives the LTE system overview. In this chapter, the architecture of LTE, the LTE frame structure, LTE protocol structure, LTE communication channels, OFDMA technology and frequency reuse are overviewed.
- Chapter 3 describes about the interference scenario and mitigation techniques. Particularly, the static ICIC such as hard fractional frequency reuse (reuse 3), soft frequency reuse, partial frequency reuse and soft fractional frequency reuse is described in detail.
- Chapter 4 provides the system model used in this thesis with the focus of propagation path loss models, antenna models, shadowing models and types of schedulers.
- In Chapter 5, the performance analysis, the performance metrics and system simulation is described in details. The simulation setup and simulation parameters are also described here. In addition, simulation results are discussed in details. Besides, the performance comparison of throughput and CINR of the static ICIC algorithms are presented.
- Finally, the conclusions are drawn in Chapter 6. In addition, future work is presented in this thesis work in order to continue the research in this area.

CHAPTER 2. LTE SYSTEM OVERVEIW

Before discussing the interference scenarios and mitigation techniques of LTE deployment of Addis Ababa, the fundamental concept of LTE network with particular focuses on network architecture, protocol architecture, communication channel, frame structure, frequency reuse and OFDMA technology will be firstly overviewed in this chapter.

2.1 LTE Network Architecture

The LTE network architecture consists of four domains. These are user equipment (UE), evolved UTRAN (E-UTRAN), Evolved Packet Core Network (EPC) and Service domain. UE, E-UTRAN and EPC form Internet Protocol (IP) Connectivity Layer. These domains are also called as Evolved Packet System (EPS) [14].

USER EQUIPMENT (UE). User equipment (UE) is the device that is used for voice or data communication. The device could be a handheld device or a wireless data card or a modem. Each user is provided with Universal Subscriber Identity Module (USIM). USIM identifies one UE from other UEs and holds the authentication and security keys [15].

E-UTRAN NodeB (eNodeB). eNodeB is a base station that controls and manages all radio related functions of the EPS. All of the radio protocols from UE terminate at eNodeB. As a terminating node for the radio protocols, it sets Radio Resource Connection (RRC) and performs radio resource allocations to the users with QoS based prioritization. In addition, eNodeB is used for mobility management, encryption and decryption of user plane and control plane data and IP header compression and decompression of user plane data. Comparing with UTRAN, eNodeB has the functions of both NodeB and the Radio Network Controller (RNC). This function of eNodeB simplifies the network structure and reduces the latency in the network. The eNodeBs are connected to their neighboring eNodeBs with X2 interface which is used for handover and dynamic interference management [15].

Mobile Management Entity (MME). MME is a control plane element in EPC and is connected to eNodeBs with S1 interface and Home Subscription Server (HSS) via S6a interface as it is shown in Fig 2.1. MME performs user authentication and security related functions in the network with the help of HSS. MME also involves in the intra-system handover [16].

Serving Gateway (S-GW). It is a user plane element and is connected to eNodeB through S1 interface and has an important role in inter-frequency handover. During the handover, the MME commands the S-GW to switch data tunnel from current eNodeB to the target eNodeB. It is also used as a relay for data transmission between the serving eNodeB and P-GW. When the UE goes to IDLE mode from the CONNECTED mode while receiving the data packets from the P-GW for a data path, S-GW holds the data packet in buffer. In the meantime, it also requests MME to page the particular IDLE UE. Once the UE resumes to the CONNECTED mode, the buffered packets are delivered and S-GW starts to relay the data from P-GW. In addition, during handover, it performs the indirect forwarding of the downlink data, when direct inter-eNodeB connection is not available. It also acts as a tapping point for monitoring and security related issues. Moreover, the packet flow through S-GW can also be used for charging purposes [16].

Packet Data Network Gateway (P-GW). P-GW is the element of EPS that connects the EPS to the external data network. It can be considered as a router that connects EPS to external network. It allocates IP addresses to the UE attached to the EPS using the Dynamic Host Control Protocol (DHCP). In addition, P-GW interacts with the PCRF for appropriate policy control information. It also used as a bearer when the UE switches from one S-GW to another. Similar to S-GW, the P-GW can also be used for monitoring and charging purposes [17].

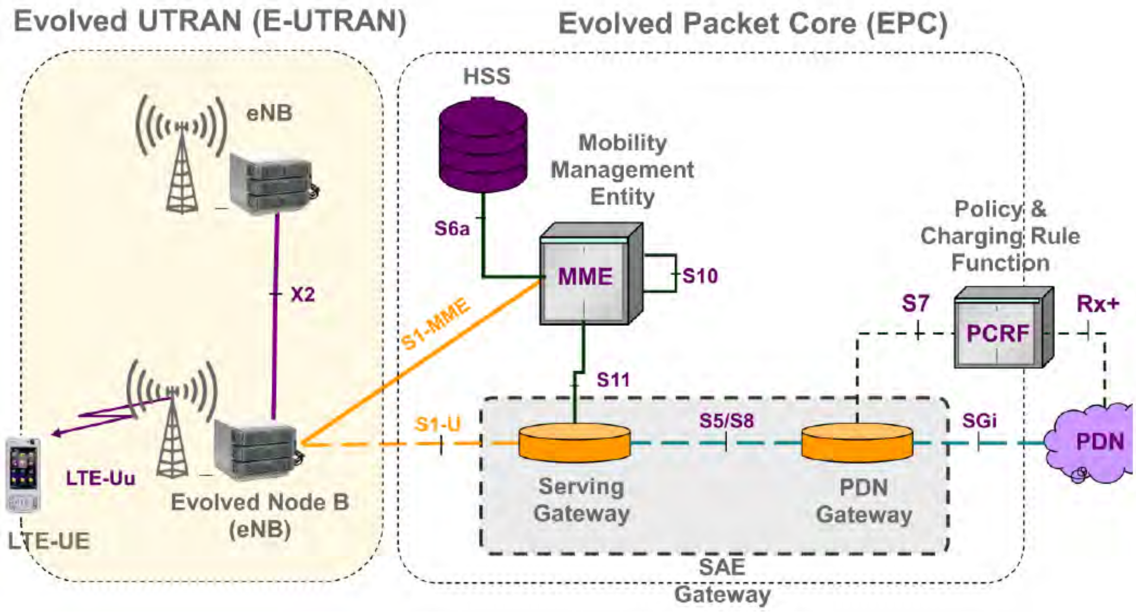


Fig 2.1: EPS network elements [18]

2.2 LTE Protocol Architecture

The radio interface protocols are needed to set up, reconfigure and release the radio bearer services which are used for communication between UE and network and maintain end to end connection. The protocol layers are physical layer (Layer 1), the data link layer (Layer 2) and the network layer (Layer 3). For control plane, Layer 2 contains Media Access Control (MAC) protocol, Radio Link Control (RLC) protocol and Packet Data Convergence Protocol (PDCP) and Layer 3 consists of one protocol called Radio Resource Control (RRC) which belongs to only to control plane [17].

Radio Resource Control (RRC). Radio Resource Control (RRC) messages comprise the major part of control signaling between UE and network core. RRC messages carry all parameters required to set up, modify and release Layer 2 and Layer 1 protocol entities (MAC, RLC and PDCP). In addition, RRC control all procedures related to establishment and release of connection including paging and configuration measurements and reporting for handovers [19].

Packet Data Convergence Control (PDCP). The PDCP layer is used for header compression and decompression for user plane data, ciphering and deciphering for user and control plane PDUs and reordering it in handover [20].

Radio Link Control (RLC). The RLC layer reformats PDCP PDU in order to fit MAC layer size. Thus, RLC segments and/or concatenates the PDCP PDUs and then reassembles the RLC PDUs to reconstruct PDCP PDUs [21].

Medium Access Layer (MAC). The Mac Layer maps logical channels and transport channels and selects appropriate transport format for each transport channel depending on the instantaneous data rate. It is also used for multiplexing and demultiplexing of RLC Payload Data Units (PDUs) [21].

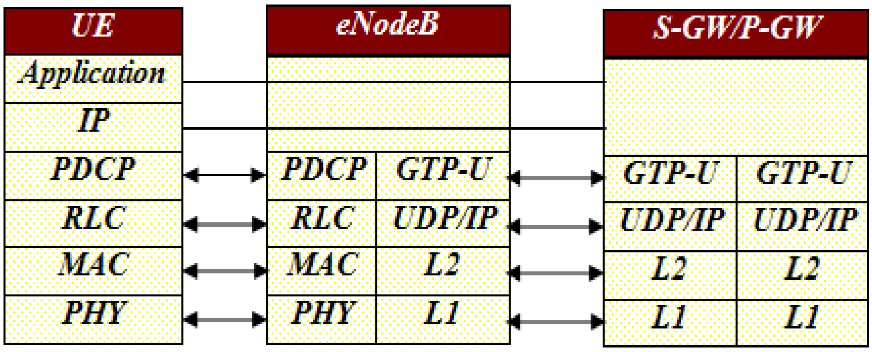


Fig 2.2: E-UTRAN protocol stack for user plane [22]

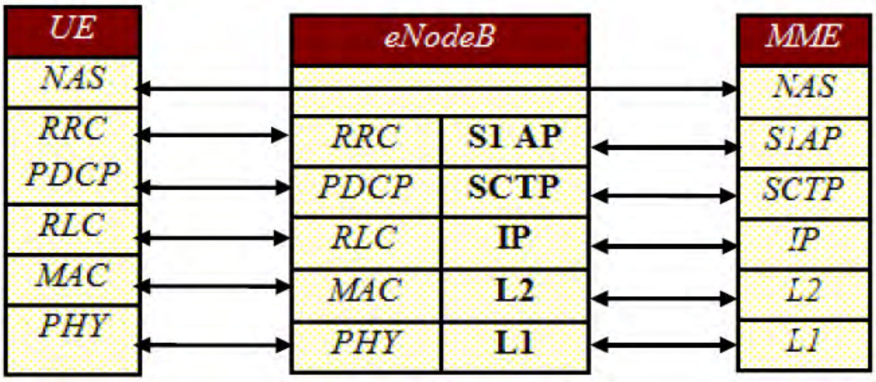


Fig 2.3: E-UTRAN protocol stack for control plane [22]

2.3 LTE Communication Channels

LTE uses several different types of logical, transport and physical channel which are identified by the kind of information they carry and by the way in which the information is processed.

2.3.1 Logical Channels

The logical channels are control channels which are located between MAC and RLC layers. These are:

Paging Control Channel (PCCH). It is a downlink control channel that is used for paging information when the network does not know the location of the UE [23].

Broadcast Control Channel (BCCH). It is a downlink Control channel for providing system control information all UE connected to the eNodeB [23].

Common Control Channel (CCCH). It is an uplink channel for transmitting control information between UEs and system which is used for random access information such as setting up a connection [23].

Dedicated Control Channel (DCCH). It is a dedicated point-to-point bi-directional control channel that transmits user-specific control information between a UE and the network [23].

2.3.2 Transport Channels

The transport channels are located between mac and physical layer to carry data and signaling messages. These channels are:

Paging Channel (PCH). It is a downlink channel used to carry PCCH. PCCH is used for discontinuous reception and for saving power of UE. It is broadcasted in the entire cell coverage area [23].

Broadcast Channel (BCH). It is a downlink channel with fixed and pre-defined transport format that is broadcasted with in the entire cellular coverage area and is mapped to BCCH [24].

Downlink Shared Channel (DL-SCH). It is a downlink channel that supports Hybrid ARQ (Automatic Repeat Request) and dynamic link adaptation by changing the modulation, coding and transmit power. It also supports both dynamic and semi-static resource allocation and discontinuous reception of UE [24].

2.3.3 Physical Channels

Data and signaling messages are carried on physical channels between the different levels of the physical layer. Basically they are divided into physical data channels and control channels.

Physical control format indicator channel (PCFICH). PCFICH informs the UE about the format of the signal being received. It indicates the number of OFDM symbols used for the PDCCHs. The information within the PCFICH is also used to inform UEs about the size of the control region [24].

Physical downlink shared channel (PDSCH). PDSCH is the main data carrying channel which is dynamically assigned to users. These channel use QPSK, 16QAM, 64QAM as modulation types [25].

Physical downlink control channel (PDCCH). The main purpose of this physical channel is to carry mainly scheduling information such as downlink resource scheduling, uplink power control instructions and uplink resource grant indication for paging or system information [25].

2.4 LTE Frame Structure

A PRB is considered the smallest unit in a LTE frame. A PRB is allocated for time duration of 0.5 ms. A PRB can be considered as two dimensions of sub-carriers and symbol durations in which it contains a group of 12 sub-carriers and 6 to 7 symbols depending upon the CP length.

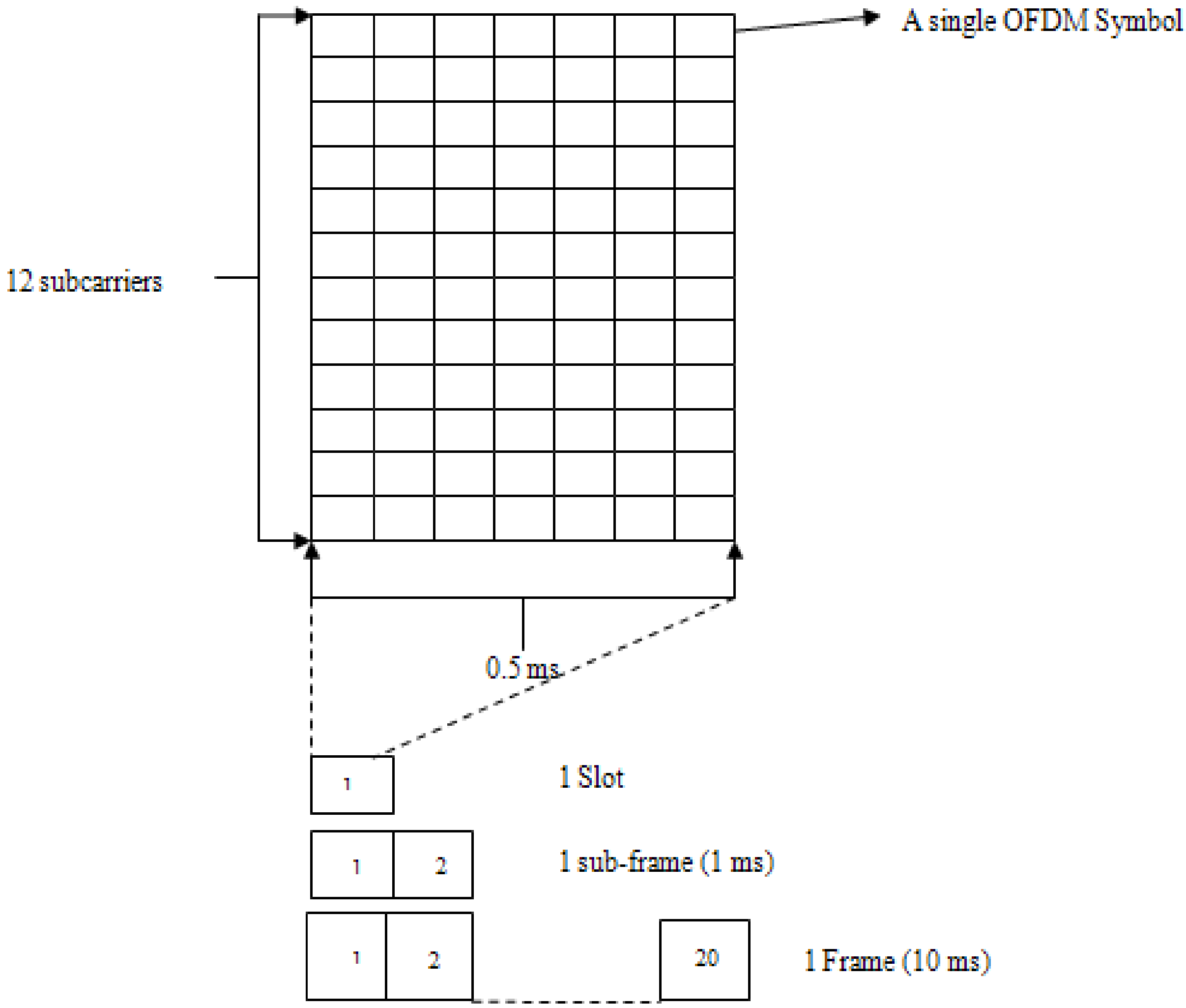


Fig 2.4: LTE frame structure [38]

In LTE frame structure, one PRB is called slot. Two slots make a sub-frame with duration of 1 ms. An LTE frame contains 20 slots which is 10 ms long. The frame structure is same for the downlink (OFDMA) and the uplink (SC-FDMA). The reference symbols are placed with specific pattern in the PRBs for the efficient channel estimation. Table 2.1 shows the list of resource block configuration for different allowable bandwidths in LTE [27].

Bandwidth	1.4MHz	3MHz	5MHz	10MHz	15MHz	20MHz
Sub-carriers	72	180	300	600	900	1200
Sampling Rate(MHz)	1.92	3.84	7.68	15.36	23.04	30.72
Samples per Slot	960	1920	3840	7680	11520	15360
Resource blocks	6	15	25	50	75	100

Table 2.1: Resource block configuration of different bandwidths [28]

2.5 OFDMA Technology

GSM technology uses the TDMA with frequency division multiplexing as multiple access whereas UMTS uses WCDMA as the multiple access technique. These technologies have their own advantages and disadvantages. Most of multiple access methods in the legacy network technologies have limitation on capacity (coverage) and throughput of the system. OFDMA technology is brought in due to necessity to modify the multiple access technology with 3GPP LTE specification requirements [29].

In frequency division multiplexing, users are separated from one another spectrally with each signal modulated onto a different carrier frequency using separate frequency channels and channel bandwidth being equal to the transmission bandwidth. Multiple frequency channels are arranged serially in simpler form of FDMA Organization. To prevent adjacent channel interference, the channels are separated by guard bands which are unused portions of the spectrum and ultimately increase the frequency range of the system and reduce the spectral efficiency [29].

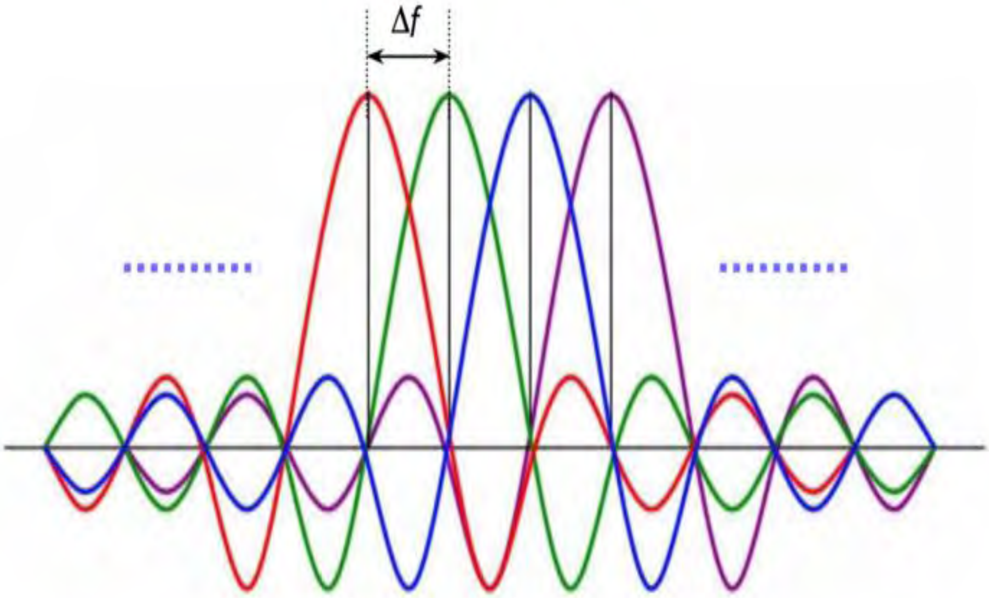


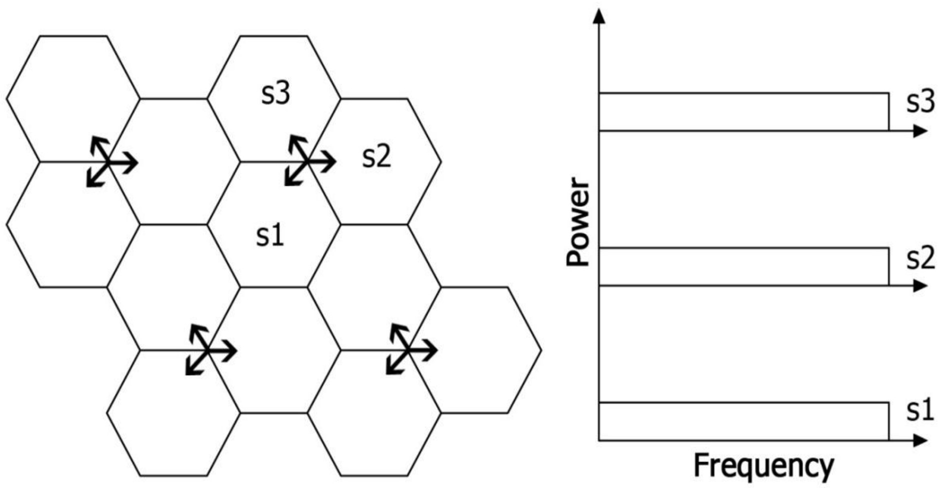
Fig 2.5: OFDMA sub-carrier in a single resource block [30]

The basic idea here is that OFDMA divides spectrum into large number of tightly packed narrowband sub-carriers. Figure 2.5 shows the orthogonal sub-carriers placed together overlapping each other in such way that the interference experienced in each sub-carrier due to the neighboring sub-carriers during the sampling is minimum. The sub-carrier spacing in the above figure is 15 kHz i.e. the spacing between the peaks of each sub-carrier and is the best found tradeoff at which sub-carrier interference is reduced. At the peak of each sub-carrier, all other sub-carriers have amplitude zero to avoid sub-carrier interference. For example, in LTE 20MHz, there are 1200 sub-carriers. Inter symbol interference is caused by multipath propagations which causes long channel delay spread. This causes the bits to interfere to each other and degrade the received signal. To prevent this, a Cyclic Prefix (CP) is added to the symbol which is a copy of the tail of the same symbol added at the start of the symbol. CP is a guard interval which separates the symbols in time domain to neutralize the delay spread caused by the multipath. This is because, with the use of guard interval, the receiver filter has to consider the delay added to the delay spread. Again, with the use of CP, the data stream becomes continuous and shortens the receiver filter delay. Based on their duration, there are two types of CP used; Extended CP with a duration of 16.67 µs which is used in large cells where there is long delay spread and Normal CP with a duration of 5.2 µs for the first symbol and 4.67 µs for the other symbols. The main advantages that make OFDMA a better choice for radio access such as LTE are:

- Better tolerance against frequency selective fading without the need of complex equalization filter due to the use of multiple sub-carriers;
- Link adaptation and frequency domain scheduling ;
- Simpler receiver architecture based on Digital Signal Processing (DSP) [30].

2.6 Frequency Reuse

The simplest scheme in frequency reuse is frequency reuse factor 1. In this scheme, every cell can use the whole system bandwidth. However, there is high inter-cell interference which in turn considerably limits the performance of users in LTE system. Thus, the overall spectral efficiency degrades and hence system capacity is reduced [31].



. Fig 2.6: Frequency reuse 1 scheme

CHAPTER 3. INTERFERENCE SCENARIOS AND MITIGATION TECHNIQUES

3.1 Interference Scenario

In LTE, a pair of RBS (in time domain) are allocated to a UE for data transmission in a TTI (Transmission Time Interval) of 1ms. Inter-cell interference is caused when several eNodeBs use the same RBs simultaneously. In other words, when different UEs located at adjacent cells use the same PRBs, it results in ICI. When a user moves away from serving eNodeB and becomes closer to adjacent eNodeB, the received SINR (Signal to Interference Plus Noise Ratio) degrades mainly because of two reasons. The first one is the received signal power from the serving eNodeB decreases and the other one is the interfering signal power from the neighbouring eNodeBs is becoming strong. The impact of inter-cell interference in LTE downlink can be analyzed by calculating the received SINR of UE m (User Equipment m) on RB n (Resource Block n) using Equation (3.1) [32].

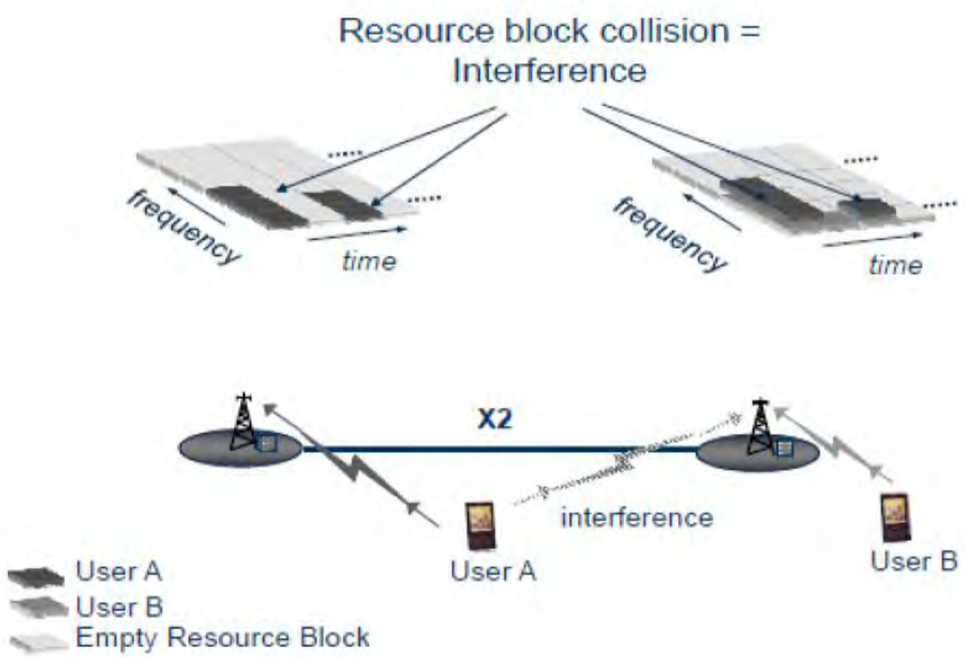


Fig 3.1: Inter-cell interference scenario in OFDMA system [33]

$$SINR_{m,n} = \frac{P_n^S G_{m,n}^S}{\sum_{K \neq S} P_n^k G_{m.n}^k \delta_n^k + P_N} \quad \text{.............................(3.1)}$$

Where, P_n^S is the received signal power of serving cell S on RB n, $G_{m,n}^S$ is the channel gain from serving cell S on user equipment m using resource block n, $G_{m,n}^k$ is the channel gain from neighbor cell K on user equipment m using resource block n, P_N is the noise power and δ_n^k is an indicator which is set to 1 or 0 to specify the neighboring cell k allocates RB n to UE m or not.

From Equation 3.1, it can be seen that there are three main factors named channel gain, transmit power and RB allocation scheme that affect the value of SINR of UE. In other words, the value of SINR can be decreased in three situations such as when UE moves far away from serving eNodeB which in turn decreases channel gain, when transmit power of neighboring eNodeB on a RB increases there by increase in interference and when the neighboring eNodeB assign the same RB to their UEs with the serving cell. Thus, the SINR of cell-center users (CCU) located nearer to their serving eNodeB are better as compared with users located at cell-edges.

3.2 Interference Coordination

Inter-cell interference coordination is a method of improving the signal quality at cell edges by using different resource blocks at cell-edge of potentially interfering cells. Power and frequency allocation strategies can be used for cell-center and cell-edge users to mitigate ICI. Though an increase in transmit power can improve the signal to interference and noise ratio, it may considerably increase the overall interference of the system. Therefore, for cell-edge user equipment, increasing transmit power may decrease the overall performance of the network. There are two main categories of inter-cell interference coordination techniques used in OFDMA systems: static and dynamic inter-cell interference coordination. In many ICI mitigation techniques, frequency reuse technique is taken as the main idea. Static interference coordination is implemented by using fractional frequency reuse techniques. Fractions of a channel are allocated to different sectors at cell-edges. This channel allocation does not change over time. On the other hand, in dynamic interference coordination or interference-aware scheduling, there is no fixed frequency allocation for each sector. Resources which are allocated to cell-edge users are determined by the schedulers based on network conditions dynamically. Dynamic ICIC is implemented by exchange of X2 messages, which carries interference information, with neighbor eNodeB after each ICIC periods. X2 interface is an interface between two neighbor eNodeBs. Then, the eNodeBs can learn the interference status of their neighbors from the messages and allocate radio resources such as frequency and transmission power to their UEs in such a way that would avoid inter-cell interference. These X2 messages are Relative Narrowband Tx Power (RNTP), High-Interference Indicator (HII) and Overload Indicator (OI) [34].

RNTP. Indicates resource blocks (RBs) that will have high transmission power for DL during the next ICIC time period. During the current ICIC period, power strength of each RB is measured and shown in bits i.e. 0 for low and 1 for high [35].

HII. Similar to RNTP, it also shows resource blocks (RBs) that will have high transmission power during the next ICIC time period. But, it is used for UL direction. To avoid interference with neighbor cells, UEs at cell-edge use RBs with high power. The power strength of each RB is measured and indicated by bits i.e. 0 for low and 1 for high [35].

OI. Indicates resource blocks (RBs) that had interference during the last ICIC period. The interference measured in each RB are marked as Low, Medium or High. RNTP and HII are information about interference to be caused by a cell to its neighbor cell. However, OI is information about interference that has already been caused by the neighbor cell [35].

3.2.1 Hard Fractional Frequency Reuse

In hard FFR, all the power is used on some resource blocks, while other resource blocks are not transmitted at all. In hard FFR scheme, the whole frequency band can be divided into three equal, orthogonal sub-bands, allocated to sectors so that adjacent sectors always use different frequency sub-bands. This setup is called reuse of 3 scheme or hard FFR scheme. However, due to only one third of frequency resources are used in each sector, it has reduced capacity [36].

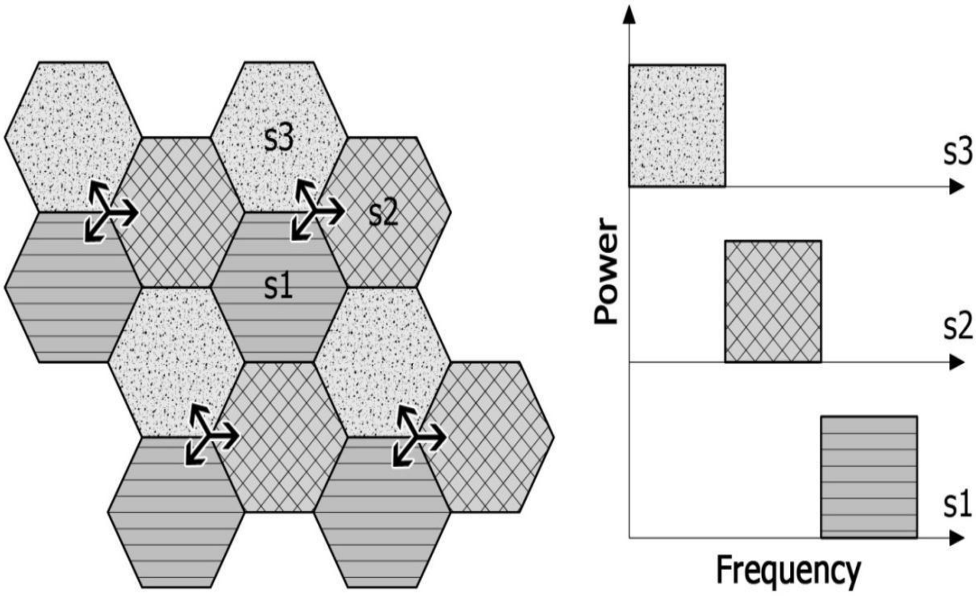


Fig 3.2: Hard fractional frequency reuse [37]

3.2.2 Partial Frequency Reuse (PFR)

There are different methods of improving cell-edge performance. One of the method is using different frequency reuse factor for cell-edge and cell-center users. For example, a FRF greater than one for the cell-edge regions and a FRF of one for the cell-center regions. In partial frequency reuse (PFR), some frequency resources are not used in some users at all. In this scheme (shown in Fig 3.3), total bandwidth is divided into four sub-bands. Cell-center UEs are allocated the frequency band using reuse factor of 1. Cell-edge UEs are allocated the remaining frequency bands using reuse factor of 3.
This scheme is also called FFR with full isolation as the cell-edge users cannot use the frequency band of cell-center users. This strategy highly reduces interference between cell-center and cell-edge uses at the expense of bandwidth usage [38].

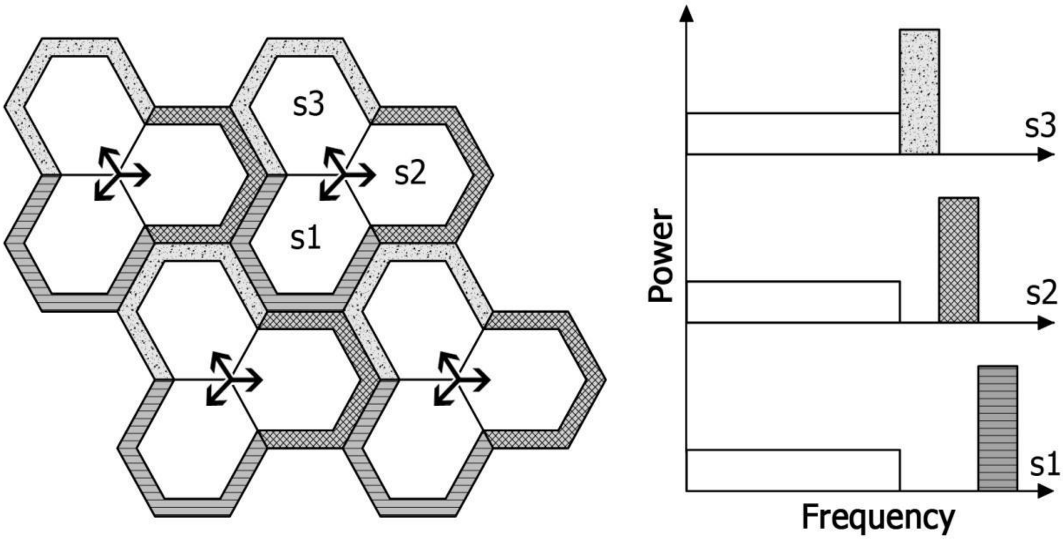


Fig 3.3: Partial frequency reuse [39]

3.2.3 Soft Frequency Reuse (SFR)

Since in PFR scheme cell-edge users does not share resources with center-users, it results in under utilization of available frequency resources. Therefore, soft frequency reuse (SFR) was proposed to compromise the available bandwidth between hard fractional frequency reuse and the PFR schemes. It avoids the high ICI associated with the unity FRF configurations, while providing more flexibility to the PFR scheme. SFR is implemented by adjusting and dividing the power between the frequencies used in the center and edge bands [40].

In SFR, a frequency reuse factor of 1 is used for the central users of a cell, while frequency reuse factor greater than 1 is used for cell-edge user. Unlike the PFR scheme, however, the frequency and transmission power used in SFR for cell-center and cell-edge users do not change. For example, in a 3-sector cell sites shown in Figure 3.4, the cell-edge band (major band) uses one third of the available resource which is orthogonal to those in the neighboring cells and form reuse factor of 3. The cell-center band (minor band) in any sector consists of the frequencies used in the cell-edge band of adjacent sectors. In other words, the minor band is allocated for center users only, but the major band can be used in the cell-center as well if it is not used by the cell-edge UE, resulting in a frequency reuse factor of 1 for cell-center user (Fig 3.4). Both major and minor band is assigned transmission power such that the power of major band group is higher than the power of the minor band while keeping the total transmission power fixed as shown in Fig 3.4. Consequently, a less ICI at the cell-edge is achieved at the expense of spectrum utilization [41].

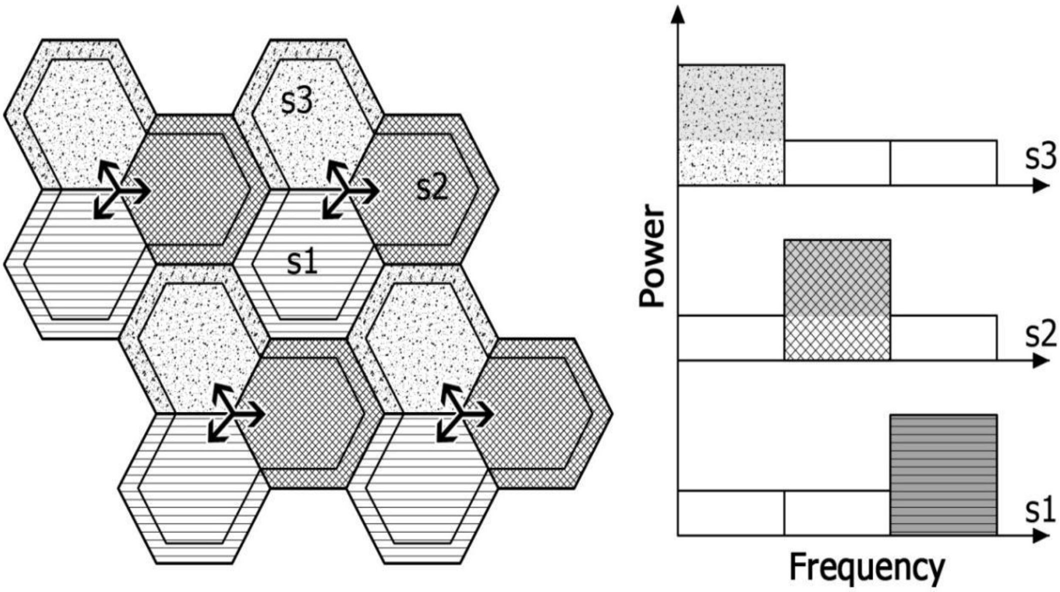


Fig 3.4: Soft frequency reuse [42]

3.2.4 Soft Fractional Frequency Reuse (SFFR)

The static PFR and SFR algorithms can improve the throughput of cell-edge users by minimizing the ICI occurring in users in that region. The static PFR algorithm does not use the whole available frequency bandwidth and may leads to reduced spectrum efficiency. Moreover, although SFR can use the whole bandwidth available in the cell, and therefore have better spectrum efficiency compared to that of the PFR algorithm; however, the overall cell throughput of SFR scheme may be lower than that of PFR. Unlike PFR scheme, SFFR uses the sub-bands allocated to the outer region in the adjacent cells. It uses these sub-bands for center-users but with low power levels as shown in Fig 3.5. Therefore, SFFR is similar to SFR in that they both use high power levels for some sub-bands and low power levels for other sub-bands. However, the SFFR uses the common sub-band to increase the throughput of center users [43].

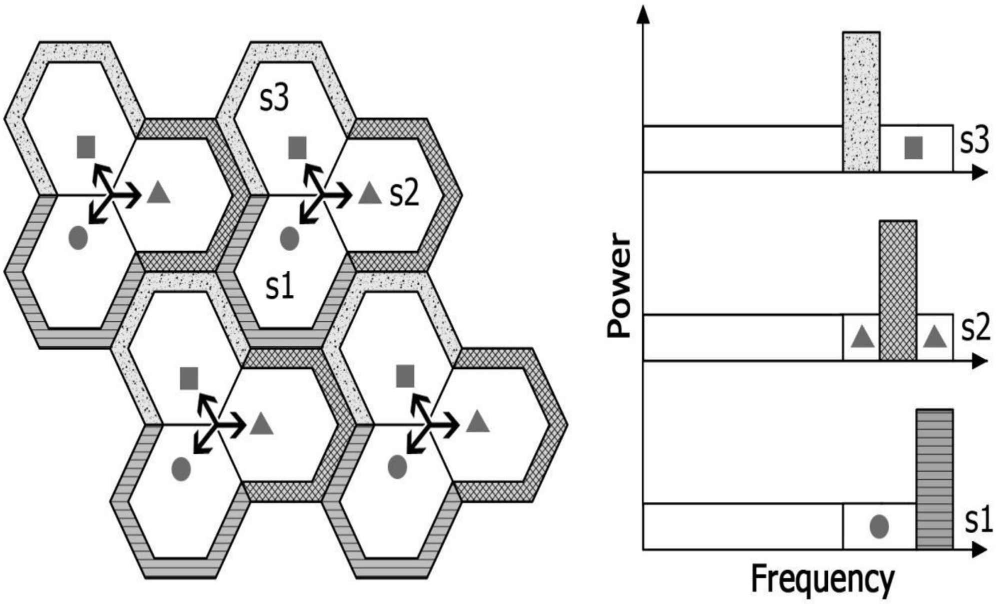


Fig 3.5: Soft fractional frequency reuse [44]

CHAPTER 4. SYSTEM MODEL

4.1 Propagation Path Loss (PL) Models

Propagation path loss (PL) models are the reference formulas used to describe the propagation loss encountered in the downlink between transmitter (eNodeB) and receiver (MUE). Path loss (PL) models can be summarized as follows:

4.1.1 Standard Propagation Model

Standard Propagation Model in a propagation model based on Okumura-Hata models which support frequencies higher than 1500 MHz. It is used in Asset and Atoll softwares. Standard Propagation Model (SPM) is based on empirical formulas and the parameters are set to their default values [45]. However, it is possible to tune the parameters of SPM according to the actual propagation conditions. In this thesis, also, this PL model is used. SPM is formulated as

$$L_{model} = K_1 + K_2 logd + K_3 log\ (H_{Txeff} x) + K_4 * Diffraction\ loss + K_5\ (logd * log\ H_{Txeff} + K_6\ H_{Txeff}\ + K_{clutter} f_{clutter} \quad (4.1)$$

Where, K_1 is frequency constant (dB), K_2 is distance attenuation constant, d is the distance between the receiver and transmitter (m), K_3 and K_4 are correction coefficient of height of mobile station antenna, K_5 and K_6 are correction coefficient of height of base station antenna, $K_{clutter}$ is correction coefficient of clutter attenuation, $f_{clutter}$ is average of weighted losses due to clutter, H_{Txeff} is the effective antenna height of a mobile. Diffraction loss is loss due to diffraction over an obstructed path (dB).

4.1.2 Stanford University Interim (SUI) Model

Stanford University Interim (SUI) model is developed jointly by IEEE 802.16 group and Stanford University. It is used for WiMAX application and for frequencies above 1900MHz. In this propagation model, three different groups of terrains are considered. Terrain A represents an area with maximum path loss and it can be a highly dense populated and heavy tree while terrain B denotes an area with moderate path loss (sub-urban environment). Terrain C represents a rural or flat area i.e the least path loss areas. The SUI model is formulated as:

PL= A+ 10 γ log (d/do) +X_f+X_h+S…………………………………………….. (4.2)

Where, PL represents Path Loss in dBs, d is the distance between the transmitter and receiver, do is the reference distance taken as 100, X_f is the frequency correction factor, X_h is the correction factor for base station height, S represents shadowing and γ represents the path loss component [46].

4.1.3 Cost -231 Hata Model

The COST-Hata model which is also known as the COST-231 models [47] is a radio propagation model that extends the Hata-Okumura model to cover a more extended range of frequencies. It supports a range of frequency of 1500 MHz to 2000 MHz, a base station antenna height from 30m to 200m, a mobile station antenna height from 1 to 10m and a link distance of 1 to 30km. The COST-Hata model is formulated as:

Path Loss (L) = 46.3 + 33.9 $log_{10} f$ – 13.82 $log_{10}(h_b)$ –a(h_m) + (44.9 - 6.55 log(h_m)log10(d) + C [dB]……………. ……………………………………… (4.3)

Where, L is path loss in decibel (dB), f is a frequency of transmission in MHz, h_b is the base station antenna effective height in meter (m), d is the link distance in killo meter (km), h_m is mobile station antenna effective height (m) and a(h_m) is a mobile station antenna height correction factor as described in the Hata model for urban areas.

4.2 Antenna Model

There are various antenna models which are used in mobile communications. In this thesis, 1800MHz antenna with horizontal beam width of 65 degree with gain of 17dbi is used.

4.3 Shadowing Models

Shadowing or slow fading is signal loss along a path that is caused by obstructions in the surrounding and it is not taken into consideration by the propagation model. Even when a receiver remains in the same location or in the same clutter class, there are variations in reception due to the surrounding environment.

The Atoll simulation software uses a standard deviation with the cell-edge coverage probability to model shadowing and thereby generate coverage predictions that are reliable more than fifty percent of the time. The additional losses or gains caused by shadowing called shadowing margin. The shadowing margin is added to the path losses calculated by the propagation model. In this thesis, a cell-edge coverage probability of 75 percent with standard deviation of 4.72 for all models are used.

4.4 Scheduling Types

4.4.1. Round Robin (RR)

In RR scheduling, UEs are assigned the resource blocks in round fashion (one after another) without considering Channel Quality Indication (CQI). It is a simple procedure of giving the best fairness. Fairness is achieved in this scheduling by providing an equal share of packet transmission time to each user. However, cell throughput significantly decreased as the scheduler does not depend on the instantaneous downlink SNR values for determining the number of bits to be transmitted [48].

4.4.2. Proportional Fair (PF)

The main aim of Proportional Fair algorithm is to balance between throughput and fairness among all UEs. This algorithm tries to maximize total cell throughput while at the same time it provides minimal level of service for all UEs. Proportional Fair (PF) scheduling is performed by allocating more resources to a user with better channel quality. This is done by giving a scheduling priority to each data flow that is inversely proportional to its predicted resource consumption. Therefore, PF scheduling may be the best option [48].

4.4.3. Best CQI

This scheduling algorithm is used to assign resource blocks to the user with the best radio link conditions. The resource blocks assigned by this scheduler to the user will have the highest CQI on that RB. To perform best CQI calculations, the UEs must send the CQI to the BS. Basically in the downlink, the BS transmits downlink reference signal to UEs which is used by UEs for the calculation of the CQI. A higher CQI value means better channel condition [48].

CHAPER 5. SIMULATION ANALYSIS AND RESULTS

5.1 Performance Analysis

Table 5.1 is taken from Huawei iManager PRS (Performance Report System) which is used for performance analysis of different network element (GSM, UMTS and LTE). It shows that the Key Performance Index (KPI) of the whole eNodeBs of Addis Ababa on one specific day for each hour interval. According to the data, the average downlink throughput is far more less than the theoretical LTE network capacity which is 100Mbps and requires improvement.

Time	Whole Network	Cell Traffic Volume_DL(Gbits)	DL Average Throughput(Kbps)	DL Cell PDCP Layer Average Throughput(kbit/s)	L.Thrp.Time.Cell.DL(s)
05/26/2015 00:00	Whole Network	102.4388	18917.0779	533.4633	192026
05/26/2015 01:00	Whole Network	63.3245	19620.9139	486.3636	130200
05/26/2015 02:00	Whole Network	31.9075	17368.3111	357.0747	89358
05/26/2015 03:00	Whole Network	10.8678	9158.211	157.7054	68912
05/26/2015 04:00	Whole Network	18.1222	12664.0061	211.4409	85708
05/26/2015 05:00	Whole Network	24.1978	14771.3534	219.3335	110324
05/26/2015 06:00	Whole Network	58.447	18254.2116	411.7057	141963
05/26/2015 07:00	Whole Network	82.6091	18294.9702	414.2362	199425
05/26/2015 08:00	Whole Network	127.0893	20472.7473	486.0588	261469
05/26/2015 09:00	Whole Network	237.2771	24180.6146	750.25	316264
05/26/2015 10:00	Whole Network	234.2764	21748.0811	672.8542	348183
05/26/2015 11:00	Whole Network	227.7513	22407.7036	674.6308	337594
05/26/2015 12:00	Whole Network	194.8376	22684.3743	607.1977	320880
05/26/2015 13:00	Whole Network	252.379	21805.6547	796.8923	316704
05/26/2015 14:00	Whole Network	218.4929	19650.6017	628.9212	347409
05/26/2015 15:00	Whole Network	225.3506	18602.0879	590.8401	381407
05/26/2015 16:00	Whole Network	148.6987	17448.7749	467.7942	317872
05/26/2015 17:00	Whole Network	169.0046	17155.9187	473.7779	356717
05/26/2015 18:00	Whole Network	187.1798	20205.6367	588.3031	318169
05/26/2015 19:00	Whole Network	210.1441	21620.8119	629.4416	333858
05/26/2015 20:00	Whole Network	208.8884	19402.4926	541.4127	385821
05/26/2015 21:00	Whole Network	279.6679	19327.1403	701.6536	398584
05/26/2015 22:00	Whole Network	214.0266	18446.6404	623.4644	343286
05/26/2015 23:00	Whole Network	190.8066	20289.6578	719.9761	265018

Table 5.1: KPI of whole LTE network on day May 26 2015

5.2 Performance Metrics

5.2.1 PDSCH Carrier to Interference Plus Noise Ratio

LTE is designed to work on environments where there are peripheral interferences. System performance reduces as the PDSCH C/I (i.e. Carrier interference ratio) is decreased. However, it may be acceptable in places where there is zero or negative C/I. In reuse 1, every site and sector in LTE systems can use the same resource block. As the result, there will be interference from other sectors within the system. As the result, in the border areas where there is overlapping coverage between sectors there will be 0 dB CINR or below. The carrier to interference plus noise (CINR) is the ratio of the carrier signal of best serving eNodeB for a user among neighbor eNodeBs and all the interference plus noise.

$$CINR_{m,k} = \frac{P_{M,k}\, G_{m,M,k}}{N_0 \Delta f + \sum_{M'} P_{M',k} G_{m,M',k}} \quad \text{..................................... (5.1)}$$

Where, $P_{M,k}$ and $P_{M',k}$ are transmit power of serving eNodeB M and neighboring eNodeB M′ on sub-carrier k respectively. $G_{m,M,k}$ is channel gain between macro user m and serving eNodeB M on sub-carrier k. Channel gain from neighboring eNodeBs are denoted by $G_{m,M',k}$. N_0 is white noise spectral density and Δf is sub-carrier spacing.

5.2.2 Peak RLC Throughput

One of the performance metrics used in this thesis is the peak RLC throughput and it is defined as

$$R_{RLC\ max} = \frac{RWIN\ (N_{RLC\ PDU} - N_{RLC\ header})}{RTT + TSP} \quad \text{........................... (5.2)}$$

Where, RWIN is RLC window size in number of RLC PDUs, $N_{RLC\ PDU}$ is the size of the RLC PDU, $N_{RLC\ header}$ is the size of the RLC PDU header, RTT is the round trip time and TSP is the timer status prohibit. By increasing RLC PDU size, the maximum RLC data rate can be increased. However, for cell-edge users if the UE has a reduced power, this large PDU may not be transmitted.

5.2.3 Coverage Probability

The coverage probability is the probability that a mobile user is able to achieve some SINR threshold, i.e. it is the complementary cumulative distribution function (CCDF).

$$P = P(SINR > H)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5.3)$$

Where, the right-hand side denotes the coverage probability that the SINR is greater than some SINR threshold H.

5.3 Simulation Setup

For the simulation purpose, 7 eNodeBs around Gotera area of Addis Ababa with total area of 3.758 km square is randomly selected which is our focus zone. Each eNodeB consists of 3 hexagonal sectors such that each hexagonal sector is served by a different directional antenna. The static inter-cell interference coordination algorithms are tested in this selected eNodeBs.

Site Name	Site ID	Longitude	Latitude
112077	AA TEP049	38.7521	8.98418
111217	AA 286G	38.7582	8.98703
111047	AA ZTEG 240	38.76465	8.98293
111127	AA 279G	38.7526	8.98006
111099	AA ZTEG027E	38.75836	8.97971
111206	AA 304G	38.74688	8.98028
111203	AA 301G	38.74963	8.97113

Table 5.2: Sample eNodeBs position in Gotera area used for simulation

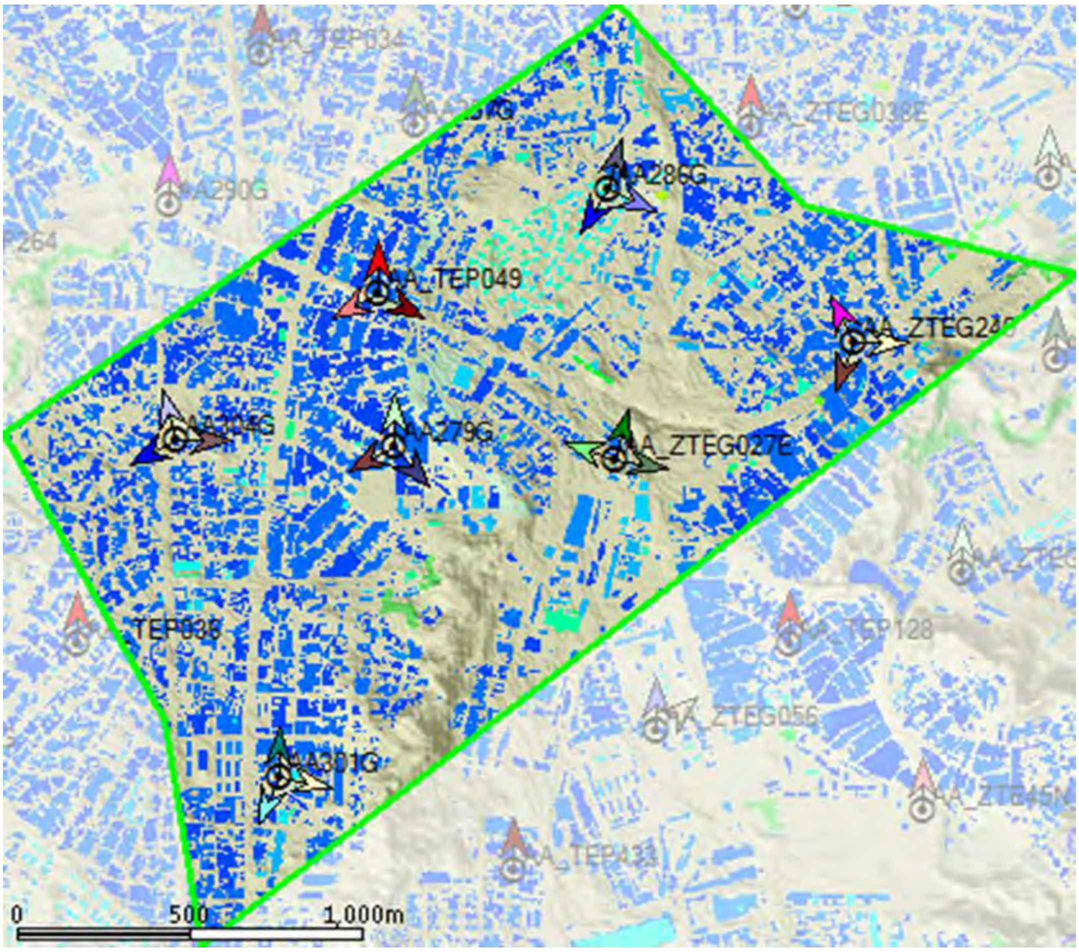


Fig 5.1: Antenna location of eNodeBs (Gotera area) used in the simulation (Atoll snapshot)

5.4 Simulation Results

General simulation parameters are presented in Table 5.3. The simulation is run on Atoll software by using the network parameters eNodeBs around Gotera area. In addition, it is assumed that proportional fair algorithm is used as a scheduler type, PDCCH overload is taken as 1 symbol duration per sub-frame and standard propagation model is taken as a propagation model for all eNodeBs in the simulation. Moreover, the simulation is performed taking the assumption of Mobile user which is fixed and is using high speed internet. The eNodeBs calculate the difference in path loss for cell to consider the user as the cell-edge and it is taken as 5dB in this simulation.

Number of eNodeBs		**7**
Sector per eNodeBs		**3**
Channel Number		**1765**
E-UTRA Band		**3**
Power (dbm)		**43**
Antenna model		**65deg17dbi1800MHZ**
Channel bandwidth		**20 MHz**
Number of resource blocks		**100**
Spectrum of resource blocks		**180 kHz**
Number of sub-channels		**1200**
Subcarrier spacing		**15 KHz**
Noise figure (DB)		**5**
Number of Antenna port	**Transmission**	**2**
	Reception	**2**

Table 5. 3: General network parameters of eNodeBs in Addis Ababa to be used for the simulation

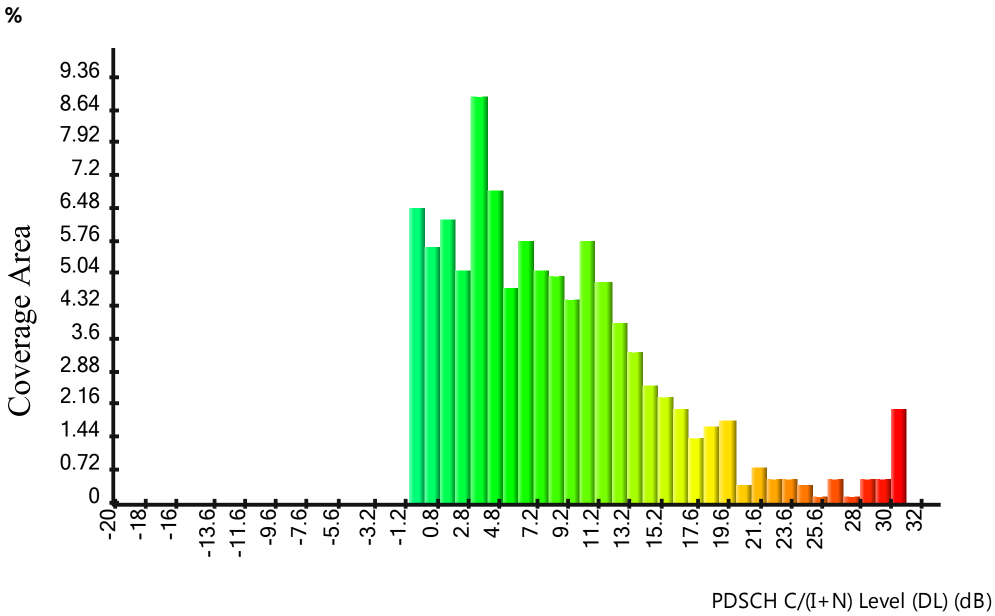
The table below shows the resource block configuration of different static ICIC algorithms for the data channel (PDSCH) used in the simulation.

ICIC Mode	Frequency Blocks	Group 0	Group 1	Group 2
Hard FFR	100	1-34	35-67	68-100
SFR	100	1-34	35-67	68-100
PFR	100	51-67	68-84	85-100
SFFR	100	51-67	68-84	85-100

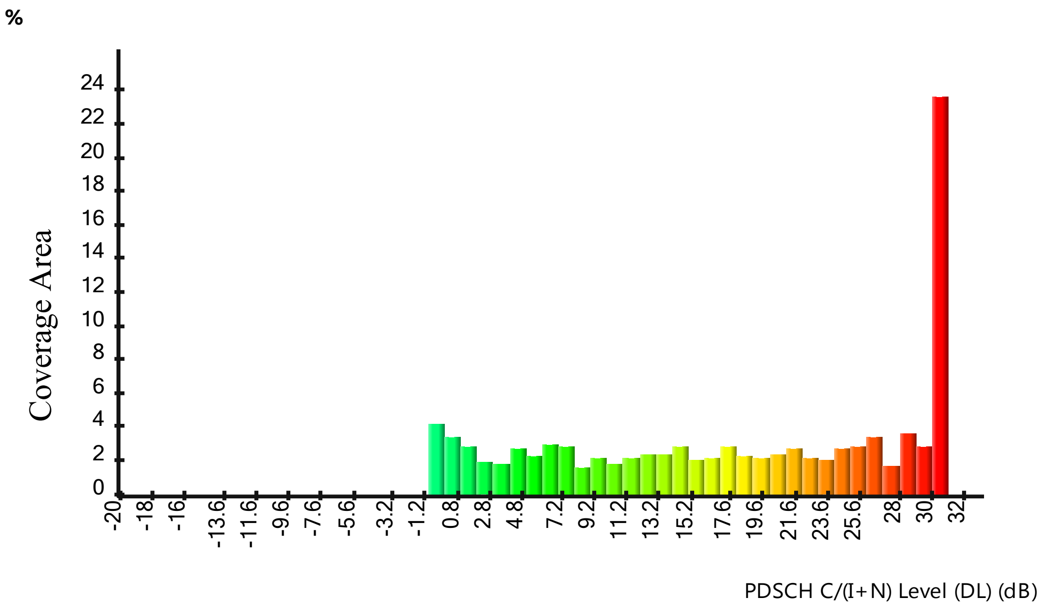
Table 5.4 Resource block configuration for different static ICIC

5.4.1 Simulation by CINR level

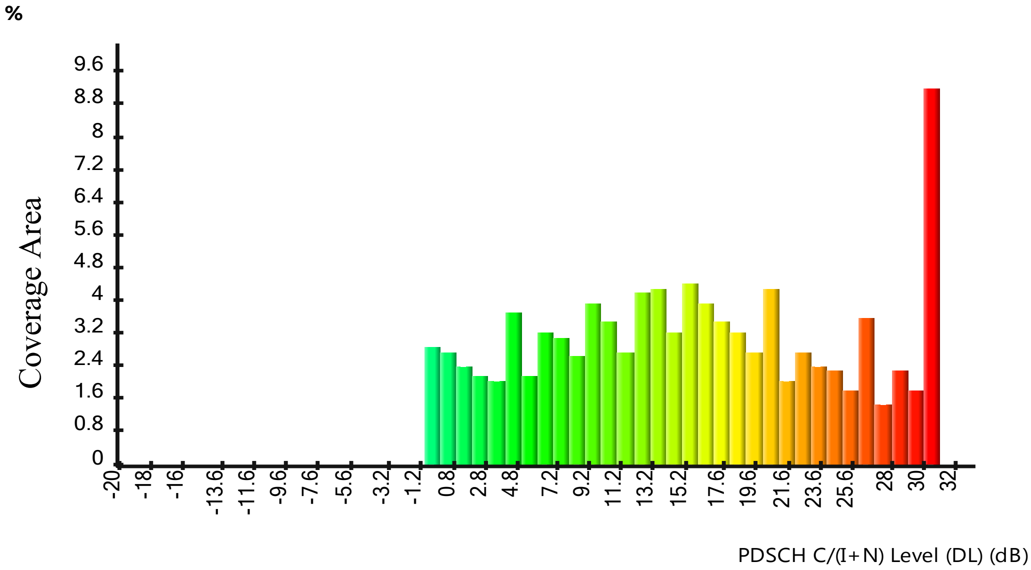
This simulation result shows different PDSCH C/ (I+N) levels in the downlink and their respective percentage in the coverage area for different static ICIC schemes i.e No ICIC, Hard FFR, PFR, SFR, and SFFR.



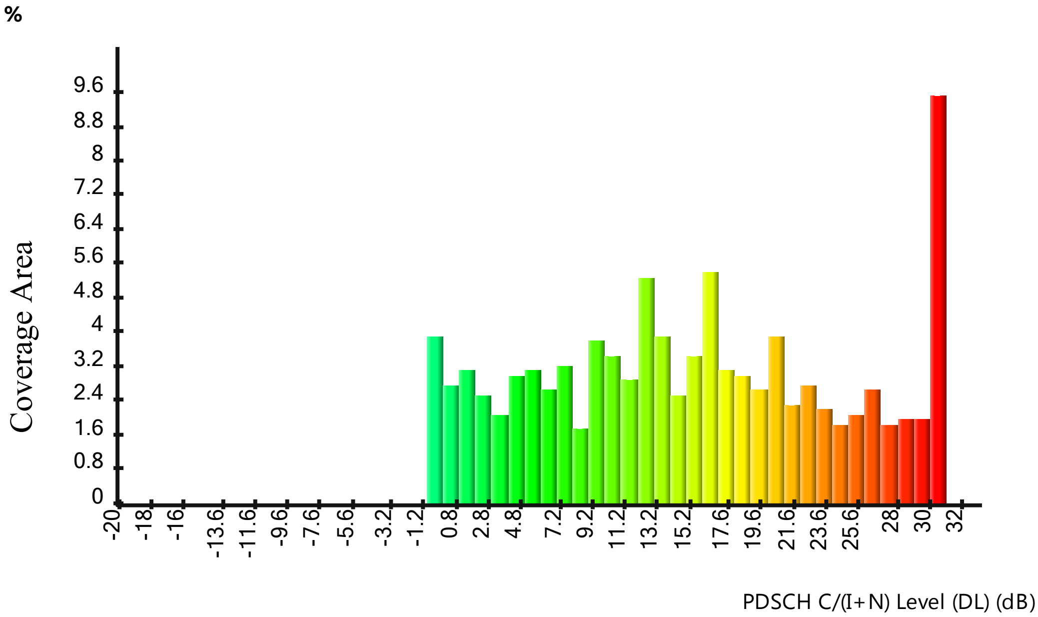
(i) No ICIC



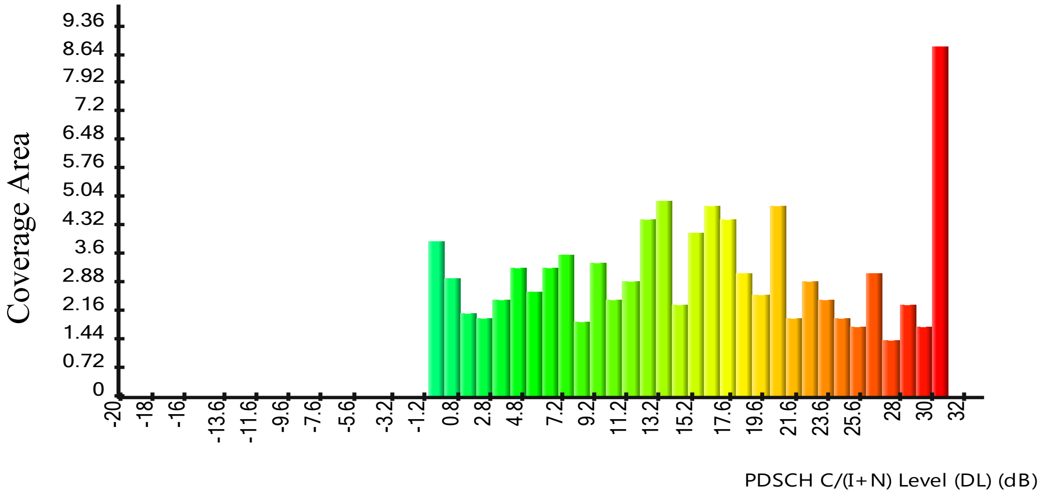
(ii) Hard FFR



(iii) PFR



(iv) SFR

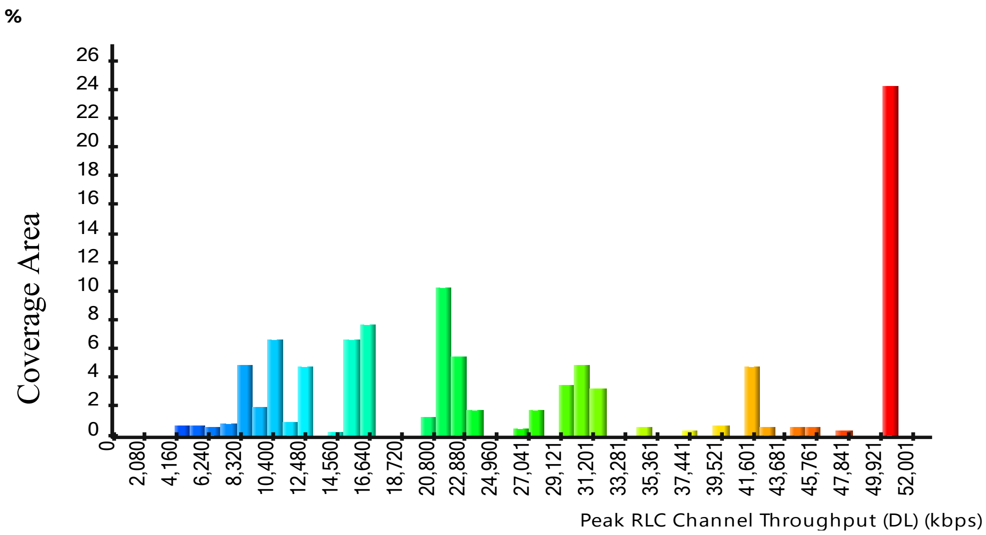


(v) SFFR

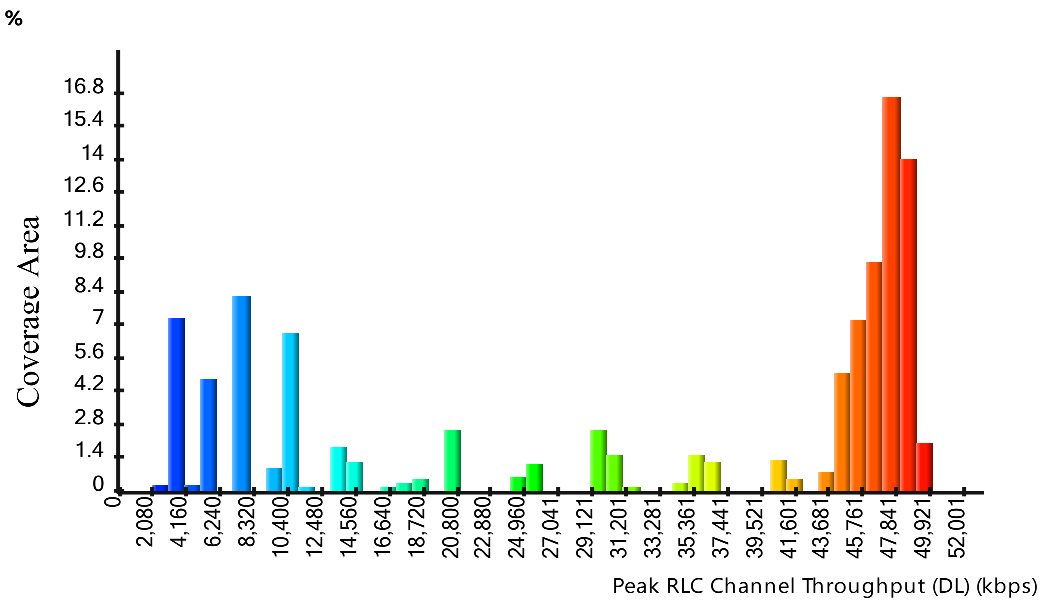
Fig 5.2: Coverage prediction vs PDSCH C/ (I+N) level of static ICIC schemes.

According to Figure 5.2, about 24 percent of the area under the study is predicted to have 30dB CINR when we are using Hard FFR whereas about only 1 percent of it can get 30dB CINR when we are using no ICIC techniques. Similarly, for this CINR the figure is about 9.4, 9.5, and 9.5 percent for SFR, PFR and SFFR respectively. This result implies that using static ICIC algorithms more percentage of the area can get better CINR than using No ICIC algorithms and it is particularly high for Hard FFR algorithm since in this algorithm the center and edge-users of one sector does not share resources with another sector users, hence reducing interference.

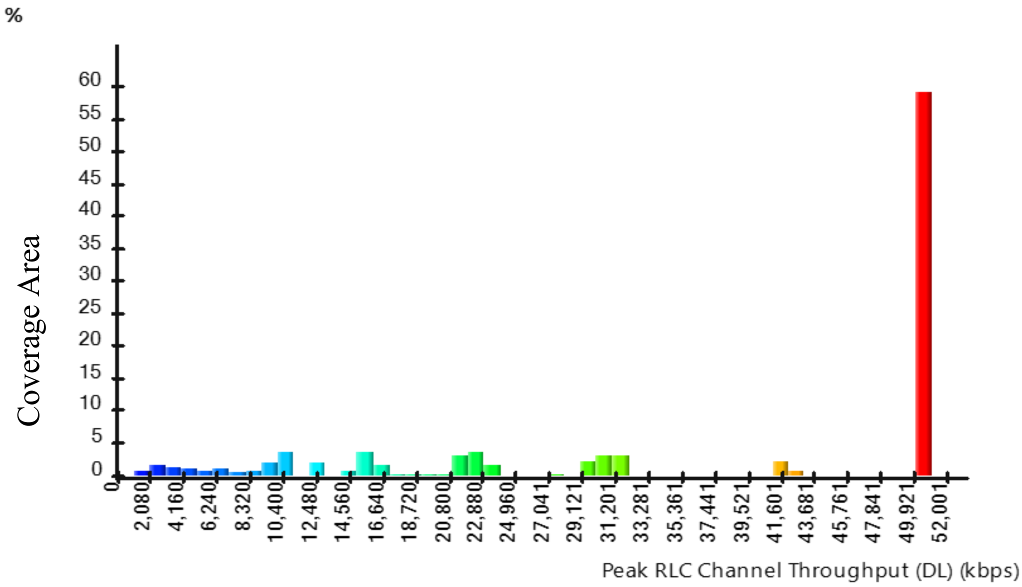
5.4.2 Simulation by Throughput



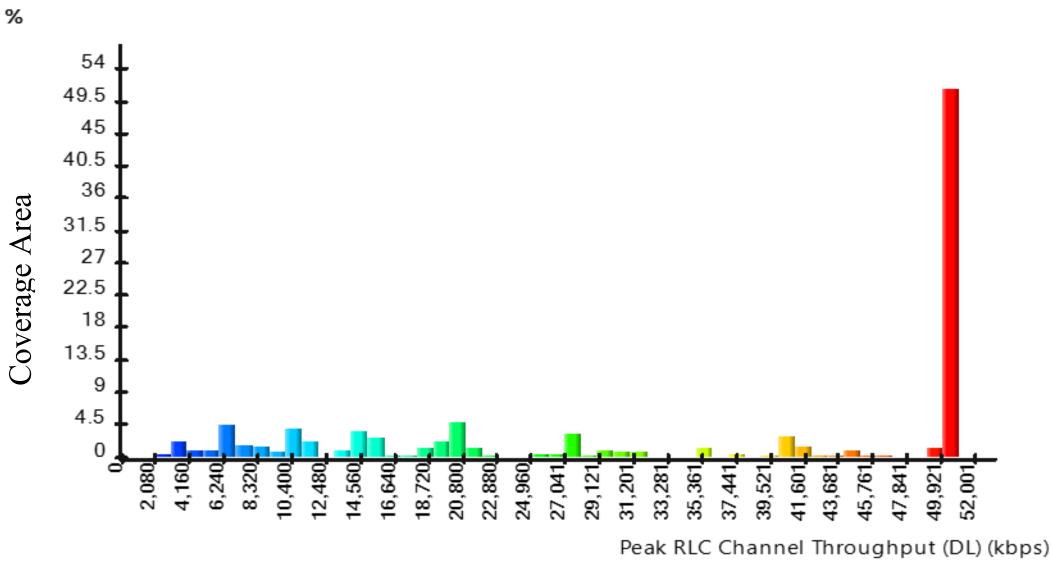
i) No ICIC



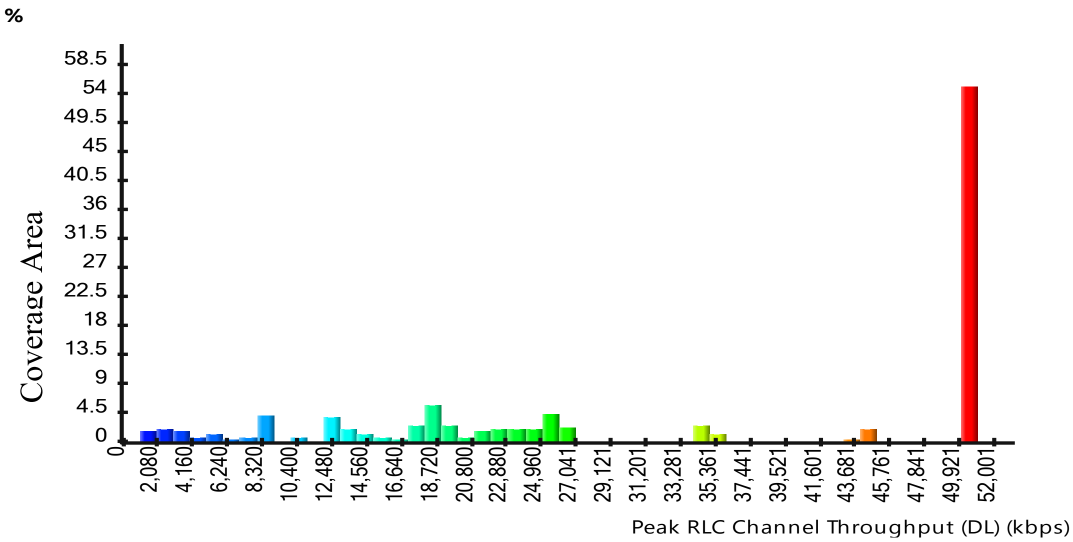
(ii) Hard FFR



(iii) PFR



(iv) SFR



(v) SFFR

Fig 5.3: Coverage prediction vs peak RLC channel throughput (DL) of different static ICIC schemes.

Figure 5.3 depicts the coverage prediction by Peak RLC channel throughput of 7 eNodeBs (Gotera area) when the eNodeBs use different static ICIC algorithms. From the figure it can be shown that 89 % of the area under the study have the peak RLC channel throughput of about 10Mbps when we are using no inter-cell interference mitigation techniques (No ICIC). Also under No ICIC, 64% of it is predicted to get a throughput of 20Mbps. In contrast, for Hard FFR algorithm the coverage prediction to receive the throughput of 10Mbps and 20Mbps accounts for 78 and 67 percent respectively. In addition, for SFR, SFFR and PFR algorithms, it is shown that for receiving 10Mbps, the figure is about 87, 89 and 90 percent respectively. Similarly, the coverage prediction for the throughput of 20Mbps is about 71, 72 and 78 percent for SFR, SFFR and PFR respectively. The result implies that using ICIC schemes decreases inter-cell interference because different groups of resource block are allocated to each sectors of the eNodeB depending on the ICIC types used which in turn increases the throughput.

From the figure 5.2 which describes the peak RLC throughput of the area under the study, the average RLC throughput can be calculated.

ICIC Schemes	Average throughput (Mbps)
NO ICIC	26.5
Hard FFR	31.4
SFR	34.5
SFFR	34
PFR	37

Table 5.5: Average RLC throughput of the area under the study

As can be seen from the table, when we use no ICIC, the area is predicted to have an average throughput of about 26.5 Mbps. However, the average throughput is 31.4, 34.5, 34 and 37 Mbps for Hard FFR, SFR, SFFR and PFR respectively. This result indicates that PFR scheme has improved the average downlink throughput by 10.5 Mbps when compared to No ICIC case and by 5.6Mbps compared to Hard FFR scheme.

5.4.3 Simulation by Coverage Probability

The Figure 5.4 below shows the coverage probability of the area at different DL PDSCH CINR level for different static ICIC algorithms.

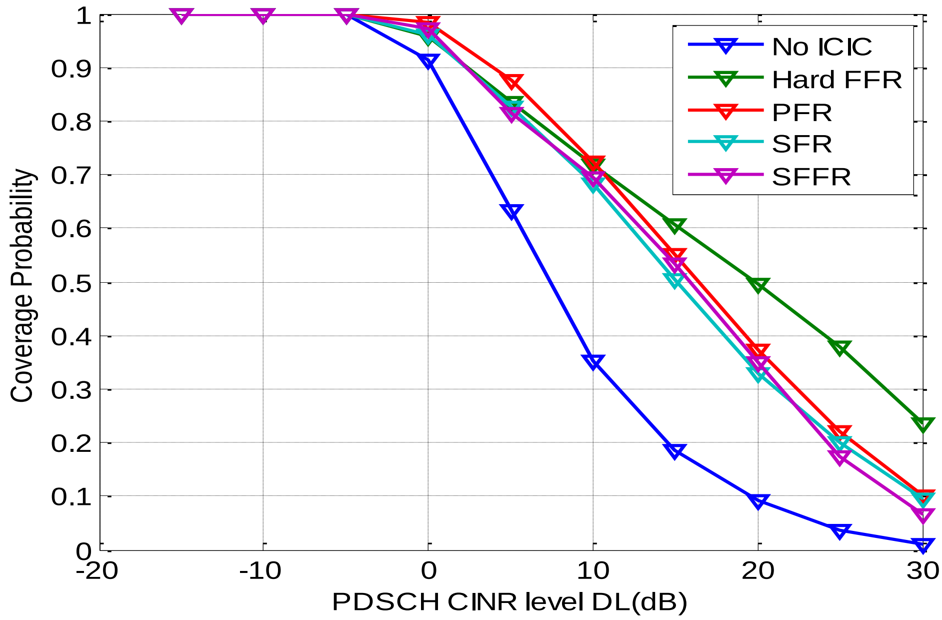


Fig 5.4: Coverage probability vs PDSCH C/ (I+N) threshold

According to the Figure 5.4, for 10dB downlink PDSCH CINR threshold, the coverage probability value is 0.35 for No ICIC. However, this value is 0.71 for Hard FFR, 0.68 for SFR, 0.69 for SFFR and 0.72 for PFR. This implies that 72 percent of the coverage area receive greater than 10dB CINR under PFR algorithm. As the result, when CINR is decreasing (close to cell-edge), using PFR algorithm is more preferable compared to other algorithms. However, the figure also shows that for 20dB downlink CINR threshold, Hard FFR (reuse 3) algorithm has the coverage probability of 0.49 whereas the values are 0.37 for PFR, 0.32 for SFR and 0.35 for SFFR. This indicates that under Hard FFR algorithm, more percentage of areas near the center have more than 20DB CINR compared to other algorithms. This is due to considerable decrease of interference for center-users in neighboring sectors because Hard FFR algorithm totally divides the whole cell into three sector and no sharing of resources blocks between users of neighbor sectors.

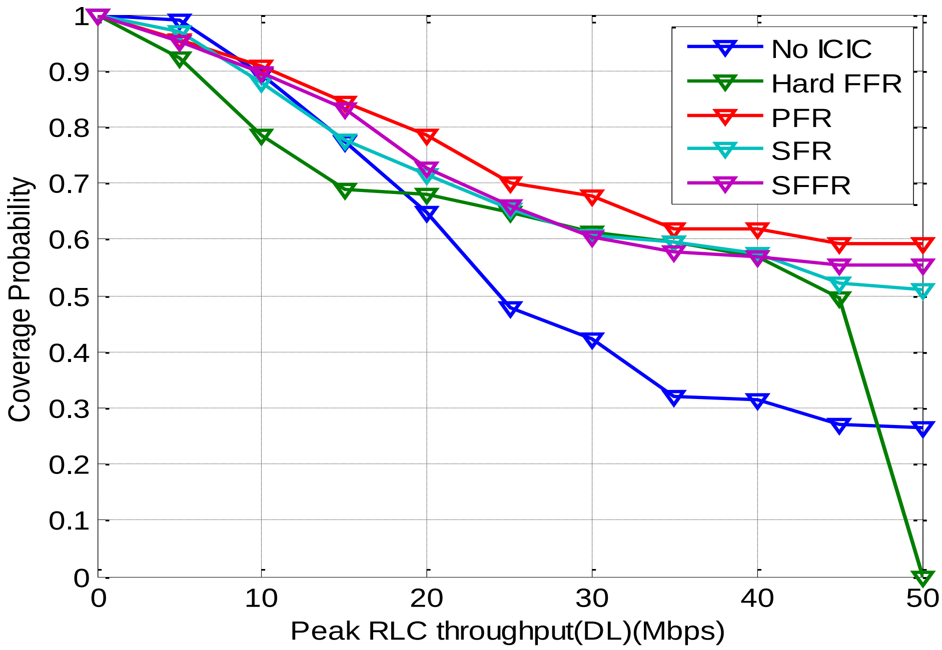


Fig 5.5: Coverage probability vs peak RLC channel throughput

In Figure 5.5, the probability of coverage by peak RLC channel throughput under different static interference coordination algorithms is compared. If we consider a point where peak RLC channel throughput is 20Mbps, the probability of coverage for SFR is at 0.71, for Hard FFR it is at 0.65, for SFFR it is at 0.72, for No ICIC it is at 0.64 and for PFR it is at 0.78 which is more compared to others. This implies that using PFR algorithm the coverage has a probability of 78 percent for receiving more than 20Mbps. Basically, this result is due to the fact that under PFR algorithm cell-edge users cannot use resources of center-users and also edge-users of neighbor cells use different resource blocks helping for reducing interference thereby increase in throughput.

CHAPTER 6. CONCLUTION AND FUTURE WORK

6.1 Conclusion

This thesis addressed a research topic which is inter-cell interference mitigation in LTE downlink network considering the case of Addis Ababa using static inter-cell interference coordination algorithms to increase the data rate specially for cell-edge users. It is indicated previously that the currently deployed LTE network of Addis Ababa uses reuse 1 techniques and has low average downlink throughput. In this thesis, we have created a simulation environment in Atoll simulation software by taking the real network (eNodeB) data of Addis Ababa and we have used Matlab software for performance comparison. Different algorithms of the static ICIC techniques which is based on frequency domain are analyzed and interpreted. As can be seen from the result of case study, the following conclusions are drawn:

- Using the static ICIC algorithms have better CINR coverage than using no ICIC algorithm (reuse 1) and among the static inter-cell interference algorithms PFR algorithm has better CINR coverage for low CINR values (near cell-edge) and Hard FFR algorithm (reuse 3) will give us better probability of coverage for high CINR values(near center region).
- Using PFR algorithm as a static ICIC technique can provide considerably better average throughput than the other static ICIC techniques because PFR scheme balances the requirements of interference reduction and resource utilization efficiently.
- From a practical perspective, static ICIC techniques are a very attractive alternative for currently deployed LTE network of Addis Ababa since it is not complex to implement because it is based on managing the resource blocks and it doesn't involve signaling massage exchange.
- Implementing the static ICIC schemes on currently deployed LTE network of Addis Ababa can improve the average downlink throughput.

6.2 Future Work

The following points have been proposed as a future work to further complete and investigate this important thesis work.

- Studying and implementing other proposed FFR schemes such as Incremental frequency reuse (IFR) for reducing ICI.
- Studying the enhanced inter-cell interference coordination algorithm to mitigate interference in LTE-Advanced heterogeneous networks.
- Studying the impact of changing the power level of resource blocks for cell-edge users relative to cell-center users.
- Studying and implementing dynamic interference coordination which uses real time cell coordination to allocate resources on LTE deployment of Addis Ababa.
- Studying the uplink static and dynamic inter-cell interference coordination techniques.
- Studying and implementing time domain based inter-cell interference coordination techniques in LTE deployment of Addis Ababa.

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