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OPTIMIZATION OF CELL LOAD IN LTE USING FRACTIONAL FREQUENCY REUSE METHOD

Ayodeji Oluwasola Daramola

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Engineering in Telecommunication Engineering

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OPTIMIZATION OF CELL LOAD IN LTE USING FRACTIONAL FREQUENCY REUSE METHOD

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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สำหรับเครือข่ายโทรศัพท์เคลื่อนที่แบบรังผึ้งในเร็วๆ นี้ การหาค่าที่เหมาะสมสำหรับเครือข่ายได้กลายเป็นปัจจัยที่สำคัญสำหรับผู้ให้บริการเพราะสามารถทำให้สมรรถนะของระบบดีขึ้น ส่งผลต่อการเพิ่มความจุของระบบและการลดปัญหาการแทรกสอดระหว่างเซลล์ ในเครือข่ายเอลทีอีการเพิ่มเซลล์โหลดเกิดขึ้นได้จากความต้องการใช้ทราฟฟิกเพิ่มขึ้นและการเกิดปัญหาการแทรกสอดระหว่างเซลล์มากขึ้น ทำให้ผู้ให้บริการต้องการวิธีการแก้ปัญหาด้วยการลงทุนที่ต่ำที่สุด จากการสำรวจปริทรรศน์วรรณกรรมพบว่ามีหลายวิธีที่เสนอแนวทางการลดผลกระทบจากปัญหาสัญญาณแทรกสอดนี้ แต่ที่นิยมมากที่สุดคือการใช้ความถี่ซ้ำ ซึ่งการใช้ความถี่ซ้ำนี้สามารถแบ่งได้หลายประเภทเช่น การซ้ำ 3 การซ้ำบางส่วน การซ้ำแบบซอฟต์ เป็นต้น วิทยานิพนธ์นี้นำเสนอเทคนิคที่ใช้ในการหาค่าเซลล์โหลดที่เหมาะสมผ่านกระบวนการใช้ความถี่ซ้ำในระบบเอลทีอี โดยวิทยานิพนธ์นี้เริ่มศึกษาการสร้างรูปแบบการคำนวณเซลล์โหลดสำหรับการใช้ความถี่ซ้ำบางส่วนอย่างมีหลักการ ก่อนจะนำไปเข้าสู่การใช้เทคนิคการหาค่าที่เหมาะสมที่สุด ผลจากการจำลองแบบแสดงให้เห็นว่าการใช้ความถี่ซ้ำแบบซอฟต์ให้ผลที่ดีที่สุด อย่างไรก็ตามวิทยานิพนธ์นี้ได้นำเสนอรูปแบบการประเมินและวิธีการหาค่าที่เหมาะสมสำหรับเครือข่ายซึ่งสามารถนำไปใช้กับเครือข่ายที่มีลักษณะแบบอื่นได้

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ปีการศึกษา 2557 ลายมือชื่ออาจารย์ที่ปรึกษา ____________

AYODEJI OLUWASOLA DARAMOLA : OPTIMIZATION OF CELL LOAD IN LTE USING FRACTIONAL FREQUENCY REUSE METHOD. THESIS ADVISOR : ASSOC. PROF. PEEREPONG UTHANSAKUL, Ph.D., 68 PP.

LTE/ OPTIMIZATION / FRACTIONAL FREQUENCY REUSE / CELL LOAD

Recently in cellular networks, optimization of network has become an important factor in system operations for better system performance, capacity improvement, and Inter-Cell Interference (ICI) mitigation. In LTE networks, the increase in cell load is due to never ending traffic demand and Inter-Cell Interference. The increase in cell load by ICI needs reliable solution, which is flexible in application with low cost of implementation. Since the rapid increase in cell load is badly affected by ICI, there have been various solution techniques in use today, such as reuse-3, Partial Frequency Reuse (PFR), Soft Frequency Reuse (SFR) and other ICI mitigation schemes. This thesis presents a technique for cell load optimization through the mathematical model of Fractional Frequency Reuse (FFR) Load Coupling Equation in LTE systems. This research investigates FFR as an optimization technique in LTE system. The practical application of this optimization technique provides a platform for LTE performance evaluation in terms of resource utilization and channel information carrying capacity. The simulation results which indicate more capacity for future increase in traffic demand reveal that SFR scheme is more

efficient than the PFR scheme for LTE cell load optimization in terms of maximum utilization of available resources and minimum cell load value.

School of Telecommunication Engineering Student's Signature____________________

Academic Year 2014 Advisor's Signature____________________

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Ayodeji Oluwasola Daramola

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SYMBOLS AND ABBREVIATIONS

BS	=	Base Station
CCU	=	Cell Center User
CEU	=	Cell Edge User
FFR	=	Fractional Frequency Reuse
FRB	=	Frequency Reuse Based
ICI	=	Inter Cell Interference
IR	=	Intelligent Reuse
LTE	=	Long Term Evolution
PFR	=	Partial Frequency Reuse
QoS	=	Quality-of-Service
SFR	=	Soft Frequency Reuse
SINR	=	Signal-to-Interference plus Noise Ratio
SNR	=	Signal-to-Noise Ratio
φ_i	=	Cell load
A_q	=	Pixel in the inner region of the cell (reference cell)
A_p	=	Pixel in the outer region of the cell (reference cell)
A_{ic}	=	Set of pixels in the cell inner region (reference cell)
A_{ie}	=	Set of pixels in the cell outer region (reference cell)

SYMBOLS AND ABBREVIATIONS (Continued)

dA_q	=	User demand of each pixel in the cell inner region (reference cell)
dA_p	=	User demand of each pixel in the cell outer region (reference cell)
S_1	=	Set of pixels in the inner region (neighboring cell)
Q	=	Total number of cells in the network system
S_3	=	Set of pixels in the outer region (neighboring cell)
A_m	=	Pixel in the inner region (neighboring cell)
A_w	=	Pixel in the outer region (neighboring cell)
Z_{inner}	=	Total Physical Resource Blocks (PRBs) for the cell inner region
Z_{outer}	=	Total Physical Resource Blocks (PRBs) for the cell outer region
B_{inner}	=	Set of pixels in the outer region (neighboring cell)
B_{outer}	=	Bandwidth per Physical Resource Block (PRB) for cell outer region
Z	=	Total available Physical Resource Blocks (PRBs) for the network system
H_l	=	Transmit power (reference cell)
H_m	=	Transmit power (neighboring cell) for inner region
H_w	=	Transmit power (neighboring cell) for outer region

SYMBOLS AND ABBREVIATIONS (Continued)

$n_{i\,A_q}$	=	Power gain between the Base Station (BS) and pixel in the cell inner region (reference cell)
$n_{i\,A_p}$	=	Power gain between the Base Station (BS) and pixel in the cell outer region (reference cell)
$n_{m\,A_m}$	=	Power gain between the Base Station (BS) and pixel in the cell inner region (neighboring cell)
$n_{w\,A_w}$	=	Power gain between the Base Station (BS) and pixel in the cell outer region (neighboring cell)
φ_m	=	User activity factor/Probability of receiving interference in the cell inner region/Cell load of neighboring cell (inner region)
φ_w	=	User activity factor/Probability of receiving interference in the cell outer region/Cell load of neighboring cell (outer region)
${\sigma^2}_1$	=	Noise power of the cell inner region
${\sigma^2}_3$	=	Noise power of the cell outer region
BS	=	Base Station
CCU	=	Cell Center User
CEU	=	Cell Edge User
FFR	=	Fractional Frequency Reuse
FRB	=	Frequency Reuse Based
ICI	=	Inter Cell Interference

SYMBOLS AND ABBREVIATIONS (Continued)

IR	=	Intelligent Reuse
LTE	=	Long Term Evolution
PFR	=	Partial Frequency Reuse
QoS	=	Quality-of-Service
SFR	=	Soft Frequency Reuse
SINR	=	Signal-to-Interference plus Noise Ratio
SNR	=	Signal-to-Noise Ratio
PRB	=	Physical Resource Block

CHAPTER I

INTRODUCTION

1.1 Background of problems

The LTE system provides high data rate, good Quality-of-Service (QoS) and better network capacity due to the adoption of reuse-1 scheme, which provides the total utilization of available resources in a cellular network. Nevertheless, Inter-Cell Interference (ICI) which increases the load of a cell has proven to be a challenge. There have been many research works on finding a lasting solution to this problem (Manli Q., et.al (2012) and Marko, P, et.al (2010)). Different frequency reuse schemes were proposed by different authors as solution techniques. The adoption of reuse-3 scheme to solve this problem of ICI was discussed in (S-E., et .al (2006). This technique reduces the impact of ICI and creates a platform for cell load optimization. The optimization technique based on reuse-3 scheme involves sharing of spectrum among cells. However, the problem of this scheme is the underutilization of spectrum. The Partial Frequency Reuse (PFR) scheme which is one of the Fractional Frequency Reuse Schemes was adopted to overcome the drawbacks of reuse-3 and also serves as an efficient mean of ICI mitigation (Nazmus S., et.al, (2013). This scheme involves the splitting of cell into two regions and allocation of the available bandwidth between these 2 regions (inner and outer). However, spectrum waste is still a concern, because only one third of the available resources can be used in the outer region

(Marko, P, et.al (2010). Another scheme of Fractional Frequency Reuse (FFR) is the Soft Frequency Reuse (SFR) scheme, and it is very efficient in terms of ICI mitigation according to works of some authors (Manli, Q., et.al (2012) and Yiwei, Y., et.al (2011). It involves the splitting of a cell into two regions, the inner and outer regions. Each cell is allowed to transmit in the whole frequency band available. The SFR scheme introduces the use of low transmit power over the frequency band in the inner region, while high transmit power is used in the rest of the frequency band for the outer region. The SFR scheme also allows users in the outer region to share the total available spectrum but with reuse factor of 3. However, there is still a problem of underutilization of spectrum but better off than in PFR scheme. Since the improvement of network system performance depends on various optimization techniques such as antenna height variation, cell splitting, sectoring, range extension, antenna down tilt and network parameters adjustment. Therefore, the optimization technique through ICI mitigation is adopted to minimize the total cell load in LTE system. The new mathematical model proposed is the Fractional Frequency Reuse nonlinear load coupling equation. This model creates a platform for resources allocation and management. In addition, it allows the comparison of different ICI schemes for cell load optimization with the objective of total cell load minimization in LTE network system.

1.2 Thesis objectives

(i) To mitigate the Inter-Cell Interference (ICI) originating from the neighboring cells.

(ii) To propose a mathematical model of LTE cell load optimization using Fractional Frequency Reuse (FFR) method.

(iii) To provide a constrained optimization that ensures feasibility of computational complexity of FFR load coupling equation.

(iv) To investigate the performances of different Fractional Frequency schemes for cell load optimization.

1.3 Scope of and limitation of the study

(i) This thesis presents numerical results analysis of different FFR schemes.

(ii) This thesis presents the mathematical model of FFR load coupling for cell load optimization in LTE systems.

(iii) Simulation results by MATLAB programming are also presented.

(iv) This thesis also shows the computational complexity of the system model.

1.4 Contributions

This thesis presents an optimization technique for LTE cell load using the FFR method. It provides the following contributions:

(i) Mathematical formulation based on of FFR schemes for LTE cell load optimization.

(ii) It provides a platform for resources utilization management.

(iii) It provides better LTE system performance through ICI mitigation.

(iv) It provides low cost of investment for LTE system optimization.

1.5 Thesis organization

The rest of this thesis is organized as follows. Chapter II presents the overview of LTE system, while the advantages and challenges of LTE system are also discussed. The impacts of ICI on cell resources utilization in cellular networks are presented. Furthermore, this chapter presents the Frequency Reuse Based Schemes. The subdivisions of Fractional Reuse Based Schemes (FRBS) which are Conventional Frequency Reuse (CFR) and FFR schemes are also critically analyzed in chapter II. Chapter III explains the background theory of LTE system and frequency allocations in wireless networks are discussed. The signal propagation model, network capacity and ICI are all discussed. Chapter IV presents the details of cell load optimization techniques and the mathematical model of Fractional Frequency Load Coupling equation for LTE systems. The simulation results of different ICI mitigation schemes for resources utilization management are graphically depicted.

Chapter V provides the conclusion of the research work and suggestions for further study.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The classifications of Frequency reuse based schemes (FRBS) are presented in this chapter. These classifications are Conventional Frequency Reuse (CFR) and Fractional Frequency Reuse (FFR). These schemes are also divided into sub-schemes. The classified schemes are presented in Figure 2.1.

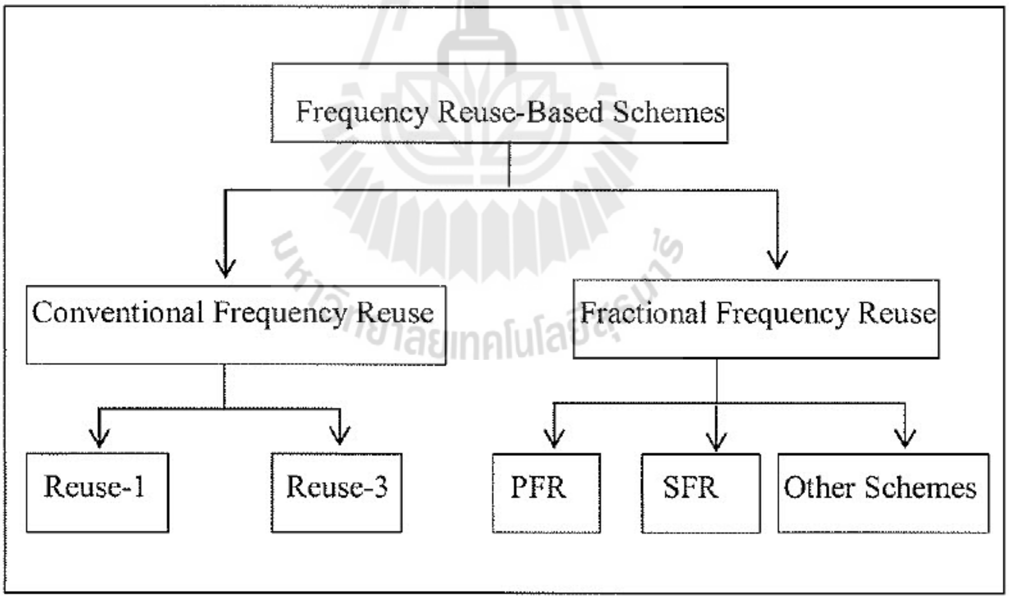

Figure 2.1 Classification of frequency reuse based scheme.

2.2 Frequency Reuse Based Schemes

The FFR of FRBS provides the platform for an improved network performance in terms of better QoS and interference mitigation. It presents the splitting of cells, which allows the allocation of resources among cells for ICI mitigation. The adoption of different schemes by various network systems has sparked interest in FRBS.

2.2.1 Conventional frequency reuse schemes

The network planning technically depends on frequency planning which involves the maximum use of frequencies with reuse-1 or frequency allocation with reuse-3 for ICI mitigation. Different network systems have been using the reuse-1 for capacity improvement, and a recent adoption of this method has shown an improved capacity in the LTE system (Nageen., et.al (2010)). Nevertheless, Inter-Cell Interference from neighboring cells using the same frequency channels poses a real threat to this network system. In search for a lasting solution technique, the reuse-3 was proposed (S-E. and B., et.al (2006)).

The two types of CFR are explained below.

- **Reuse-1 scheme**: It is a frequency reuse scheme that allows the available resources to be used in all cells without any spectrum coordination or transmit power control. This scheme achieves high data rate, high system capacity, spectrum efficiency and is commonly used in LTE system when network traffic is low. However, this scheme is always associated with very high value of ICI, mostly in the case of overloaded systems, where resources are more likely to be used by adjacent users in the neighboring cells. The scheme lacks cell coordination to deal with ICI. The problem of ICI in this scheme is that, it could lead to service outage, low throughput and call drops especially at the cell edges. The reuse-1 is shown in Figure 2.2.1(a).

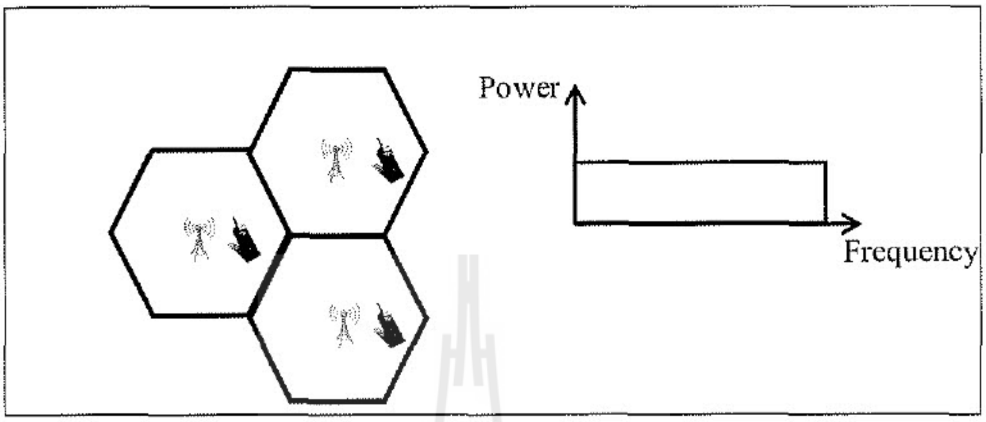

Figure 2.2.1 (a): Illustration of reuse-1

- **Reuse-3 scheme**: The scheme is adopted to overcome the problem of ICI resulting from the reuse-1 scheme. The available spectrum is divided into three-pattern of cells and repetition continues. This scheme tends to reduce ICI, nonetheless, it leads to underutilization of available spectrum, due to reuse restrictions of each channel in each cell. The reuse-3 allows only one - third of the available spectrum to be used in each cell, which seems uneconomical, considering the recent cellular network spectrum scarcity. The reuse-3 is also referred to as hard frequency reuse, due to allocation of its resources. Each cell is allocated one-third of the total spectrum. The resources allocation of reuse-3 is depicted in Figure 2.2.1 (b).

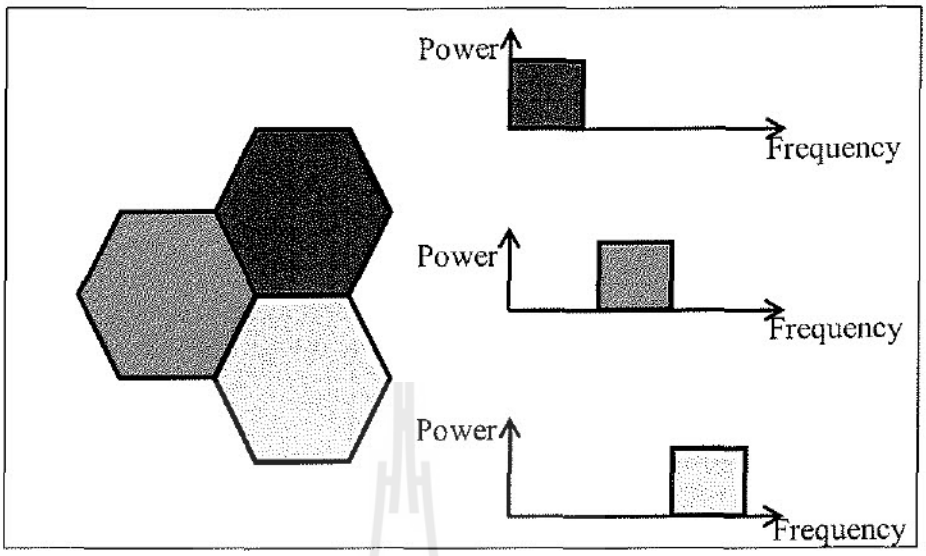

Figure 2.2.1 (b) Illustration of reuse-3

2.2.2 Fractional frequency reuse

The FFR is a frequency planning technique, in which the available spectrum is divided into different portions. Each portion is used for specific part of the cell in a coordinated manner for ICI mitigation. The main objective of FFR schemes is to strike a balance between the reuse-1 and reuse-3 schemes. The inner region users who typically do not suffer from ICI are allocated spectrum with the reuse-1, while the edge users who are subjected to ICI are allocated spectrum with the reuse-3. The two FFR schemes studied are explained below.

- **Partial Frequency Reuse (PFR) Scheme:** This scheme is an Inter-Cell Interference mitigation technique. In this scheme, the spectrum is divided into non overlapping bands referred to as inner and outer bands and each cell is also divided into inner and outer regions. The users near the center of the cell are served by the inner bands with reuse-1, while the cell edge users share the outer band with frequency reuse factor greater than 1, which is 3. In addition, the same transmit power is used in regions of all cells. The limitation of this scheme is the under-utilization of available spectrum, which could be a major problem where resources are limited. Figure 2.2.2(a) depicts PFR scheme.

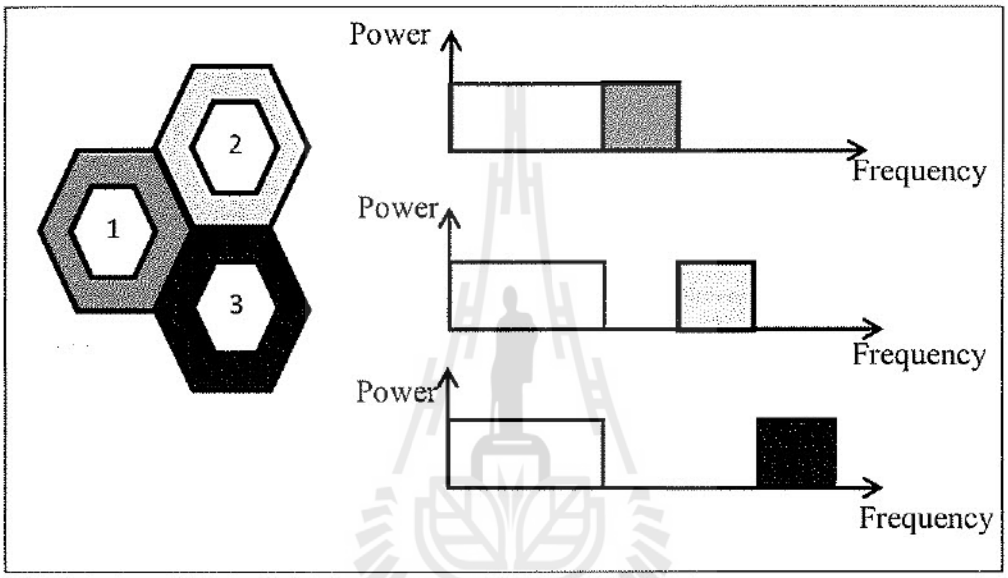

Figure 2.2.2 (a) Illustration of PFR

- **Soft Frequency Reuse (SFR) Scheme:** This scheme provides an alternative to PFR, because it allows the whole spectrum to be reused in all the cells. Each cell is also divided into two parts, the inner and outer regions. This scheme involves the variation of transmit power over spectrum, high transmit power is used over the spectrum allocated to the outer cell users because they are mostly affected by ICI, while low power is used over the spectrum allocated to inner region users that are subjected to low ICI. The reuse-1 is adopted for use by the inner cell users, while the reuse-3 scheme is used by outer cell users but with access to the total available spectrum. The SFR scheme is to strike a balance between the system capacity achieved by reuse-1 and the under-utilization of resources in PFR. The available resources allocated to the inner region users are reused in the inner regions of other cells, while outer cell users share total available spectrum among themselves with reuse-3. This is different from the PFR, because only the allocated resources to the outer cell users are shared with reuse-3.

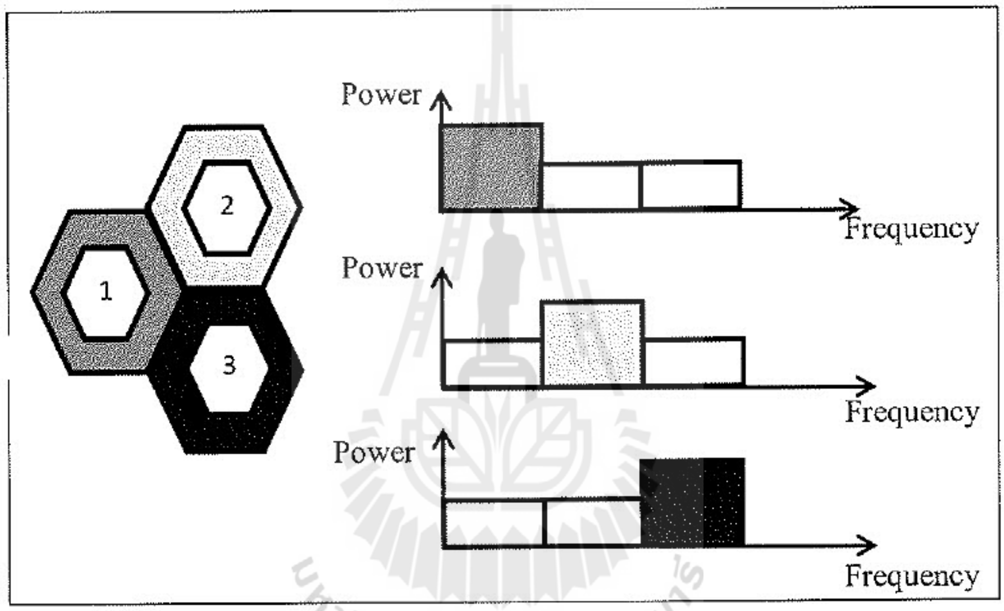

Figure 2.2.2 (b) Illustration of SFR

2.3 Literature review

2.3.1 LTE system

Recently, the LTE system has caught the attention of network operators. It is widely recognized as the fastest network system because of its capacity, data rate and low latency. Its commercialization is on the increase due to what it provides; from high peak data rate for the ever-growing users to the high system capacity and spectrum efficiency. The LTE system adopts reuse-1 to achieve the high system capacity. Nonetheless, ICI has been the demerit of this network system. The LTE system needs a solution technique that mitigates ICI. There have been various proposed techniques to control ICI, the ICI mitigation through coordination method was proposed by (Nazmus, S., et.al, (2013). The SINR estimation which is an essential tool for LTE performance improvement was also proposed. The improvement of cell-edge user throughput and capacity through the evaluation of SINR was proposed by (Subbarao, B., et.al (2010). This involves Probability Density Function (PDF) and Cumulative Density Function (CDF) analysis of cell edge users' throughput for different Inter Cell Interference Coordination (ICIC) schemes. Another ICI mitigation technique which is the interference avoidance was investigated by (S-E, E., et.al (2010). It was based on spectrum usage restrictions imposed by power and frequency planning. The Markov model for capacity calculation was used in the comparison of three frequency allocation schemes, the reuse-1, reuse-3 and the reuse-1/3, with sensitivity to ICI. It is thought-provoking to investigate the performance and impact of different ICI mitigating schemes for LTE cell load optimization, because it creates a platform for resources utilization management as a mean of preventing network traffic congestion that could result from high traffic demand and ICI. The existing ICI management techniques are explained below.

2.3.1.1 Inter-cell interference coordination

The ICIC technique is based on eradicating the degradation of network systems' performances caused by ICI and improving the throughput at the cell edges. The ICIC involves spectrum allocation methods for cellular system and the bandwidth that can be used in each cell is narrowed. The ICIC based on Fractional Frequency Reuse scheme is considered to be an effective technique for the LTE downlink. Nevertheless, the uplink is based on a principle, which is the shifting of bands by users in the locations where signal interference from an adjacent base station can occur could also be effective.

2.3.1.2 Inter-cell interference randomization

This technique randomizes the interfering signals, and also allows interference suppression. The techniques randomly hop between channels and it averages the interference on users. The interference randomization principle spreads the users' transmission over a distributed set of subcarrier in order to randomize the interference scenario and achieve frequency diversity gain.

2.3.1.3 Inter-cell interference cancellation

The interference cancellation can be explained as the class of techniques that demodulate desired information, while it uses the information along with channel estimate as a mean of canceling received interference from the received signal. It focuses on demodulating and canceling interference through multi-user detection methods so as to reduce and cancel interference at the receiver end. The two important techniques of interference cancellation are given and briefly explained below.

- **Successive interference cancellation**

The Home enhanced Node B (HeNB) is able to decode the stronger signal. In addition, it is capable of subtracting stronger signal from combined signals and also extracts the weaker signal from the combined signals. This process is step by step, the strongest received signal is detected first, then the next and so on.

- **Parallel interference cancellation**

This technique detects all users simultaneously, while it uses the initial estimate to cancel interference in near future. This technique is repeated on several stages.

2.4 Chapter summary

This chapter has presented the literature overview of LTE system in terms of its pros and cons. It explained the impacts of ICI on resources utilization in a cell. Different frequency reuse based schemes for ICI mitigation in LTE were criticized. The two categories of FRBS which are the CFR and FFR were also presented. These two categories were discussed and compared. The comparison was based on ICI mitigation and resource utilization efficiency. This thesis has focused on PFR and SFR as the effective and efficient techniques for ICI mitigation and minimization of spectrum waste that is experienced with reuse-3. The two schemes also allow channels allocation and coordination among cells of a particular network system.

CHAPTER III

BACKGROUND THEORY

3.1 Introduction

This chapter presents the LTE system which can be classified as the fastest developing system in wireless communication. It is widely recognized as the global standard for the fourth generation of mobile broadband among network operators. It offers the capacity and speed required to handle the explosive data traffic. The LTE standard is based on the use of OFDMA (Orthogonal Frequency Division Multiple Access) in the downlink and Single-Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink operations. These two platforms support great spectrum flexibility with a remarkable number of deployments from 1.4 MHz up to 20 MHz spectrum allocations. The LTE system uses the Time Division Duplex (TDD) and Frequency Division Duplex (FDD) methods in its spectrum allocations. In FDD, different frequency bands are used in UL and DL, while in TDD, the Uplink (UL) and Downlink (DL) transmissions are separated in time. One of the requirements of LTE is to provide downlink peak rate of at least 100 Mbps. Nevertheless, it also supports speed of more than 300 Mbps. The user latency achieved in LTE system is less than the existing 3G technology, thereby providing a good service advantage for highly interactive application environments such as; multi-player gaming and rich multimedia communication. The LTE provides a superior user experience when it comes to stability, throughput, latency and better system performance. The frame structure type 1 has the overall length of 10 ms and this is shown in Figure 3.1. This frame is divided into a total of 20 individual slots called sub frames. LTE sub frames consist of two slots, in order words there are ten LTE sub frames within a frame. The LTE frame structure type 2 is different from type 1. The 10 ms frame has two half frames, each of 5 ms. The LTE half-frames are also divided into five sub frames and each of 1 ms long. These sub frames are also divided into standard sub frames. These standard sub frames have three fields;

- DwPTS – Downlink Pilot Time Slot
- GP – Guard Period
- UpPTS – Uplink Pilot Time Slot.

These fields are used in LTE TDD (TD-LTE) for path upgrade. The length of these fields are configured individually, while the total length of all these fields must be 1 ms. The frame structure type 2 is presented in Figure 3.2

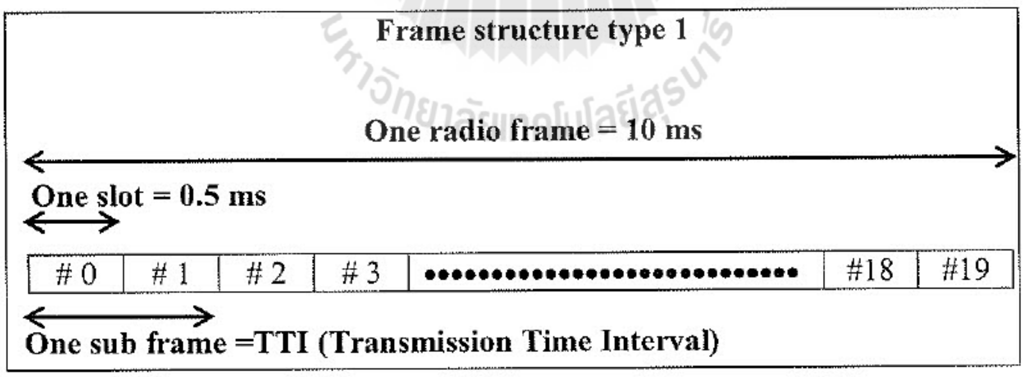

Figure 3.1 LTE OFDMA FDD Frame Structure

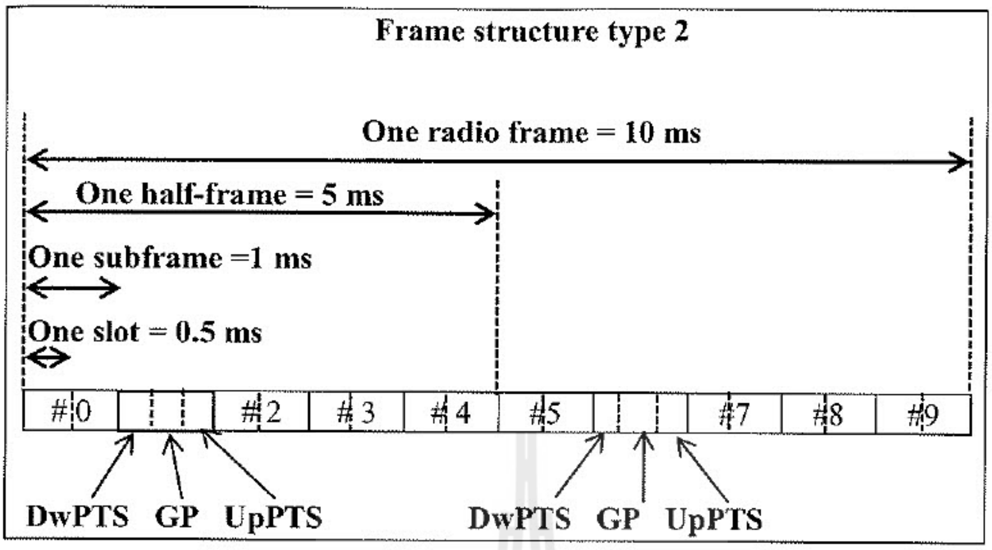

Figure 3.2 LTE OFDMA FDD Frame Structure (Type 2)

The increased capacity of LTE system has brought new and better service to users. The network delivery capacity, user experience and throughput of LTE have created new business, opportunities and revenues for network operators. The LTE system offers low long-term capital and operational costs. Nonetheless, the impact of ICI on cell edge users due to frequency reuse in LTE has led to the adoption of FFR techniques as ICI mitigating tools. Different authors have proposed various FFR schemes for ICI mitigation. The main concept of FFR techniques is the allocation of spectrum resources known in LTE as Physical Resource Blocks (PRBs). The LTE physical layer supports any bandwidth from 1.4 MHz to 20 MHz in form of resource blocks. The LTE specification supports a subset of 6 different system bandwidths and these bandwidths are presented in Table 3.1. The PRBs in LTE are shown in Figure 3.1. The FFR techniques provide the platform for ICI mitigation as a mean of LTE resources optimization. The mathematics of the system model in this chapter involves different theories.

Table 3.1 Resource allocation

Channel BW [MHz]	**1.4**	**3**	**5**	**10**	**15**	**20**
Number of PRBs	6	15	25	50	75	100

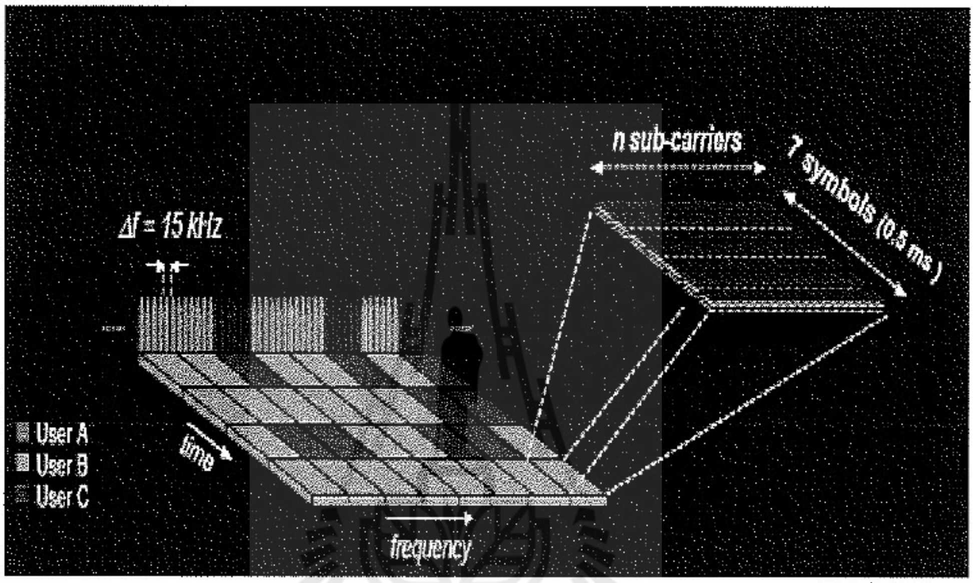

Figure 3.3 LTE physical resource block

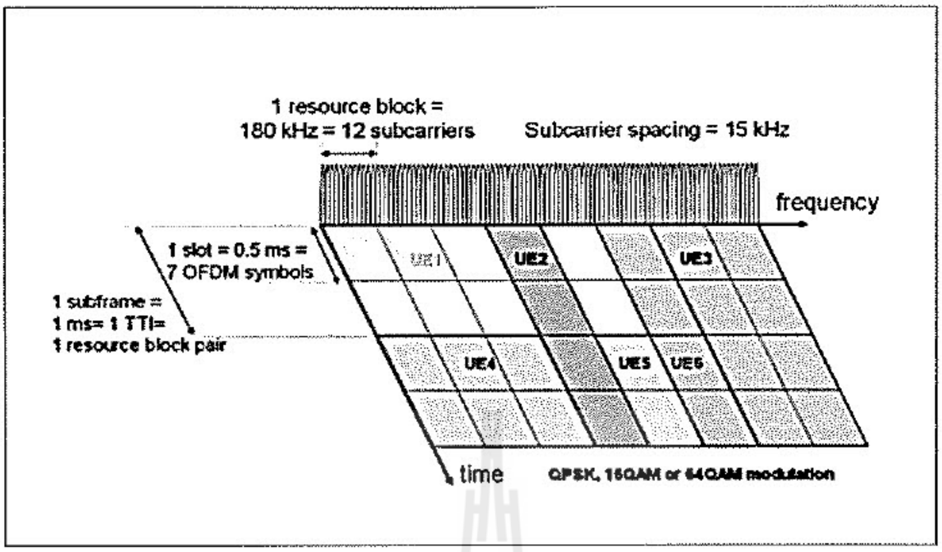

Figure 3.4 OFDMA time-frequency multiplexing

3.2 LTE cellular system

LTE adopts the reuse of the same channel at different locations. This method is termed frequency reuse-1 and it is depicted in Figure 3.5. The network coverage areas are also divided into non overlapping cells with the reuse of spectrum. In addition, it provides more capacity for cellular systems due to the reuse of spectrum.

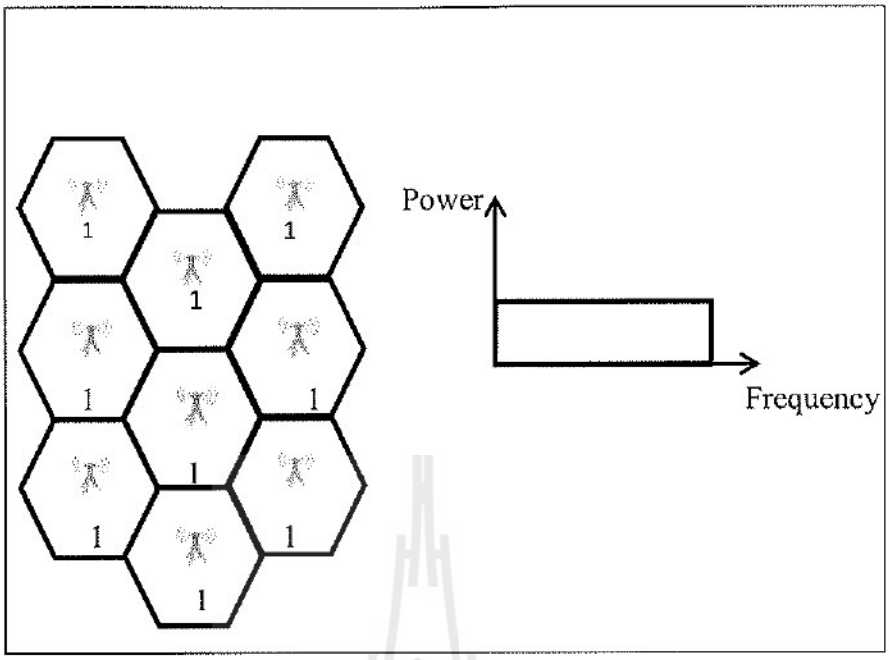

Figure 3.5 Frequency reuse-1

3.3 LTE cell size

This is an important design parameter in LTE cellular system. It determines the number of users that can be achieved within a system by reducing the size of the cell. It also leads to constant SINR of each user. There are various cell sizes in today's cellular system such as Macro, Micro, Pico and Femto cells. The size of a cell is a function of its radius. The determination of cell radius depends on, thermal noise, Signal to Interference plus Noise Ratio (SINR), path loss (L), and coverage area. The thermal noise equation is given in (3.1)

$$P = kTB\ [Watts] = 10 * \log_{10}(1000 * k * T * B) + 30\ [dBm] \qquad (3.1)$$

$$\text{SINR} = \frac{Power\ gain * Transmitter\ power}{Thermal\ Noise + Interference} \tag{3.2}$$

The cell radius which is related to path loss can be calculated using the Okumura-Hata model (L) and the cell radius (d) is in km.

$$\text{L}\ (dB) = 15.3 + 37.6 * \log_{10} d \tag{3.3}$$

Table 3.2 Cell radius for LTE different terrains

	Area	**Cell Radius d (km)**
Uplink (2000 MHz)	Urban	1.58
	Suburban	1.93
Downlink (2000 MHz)	Urban	2.28
	Suburban	2.79

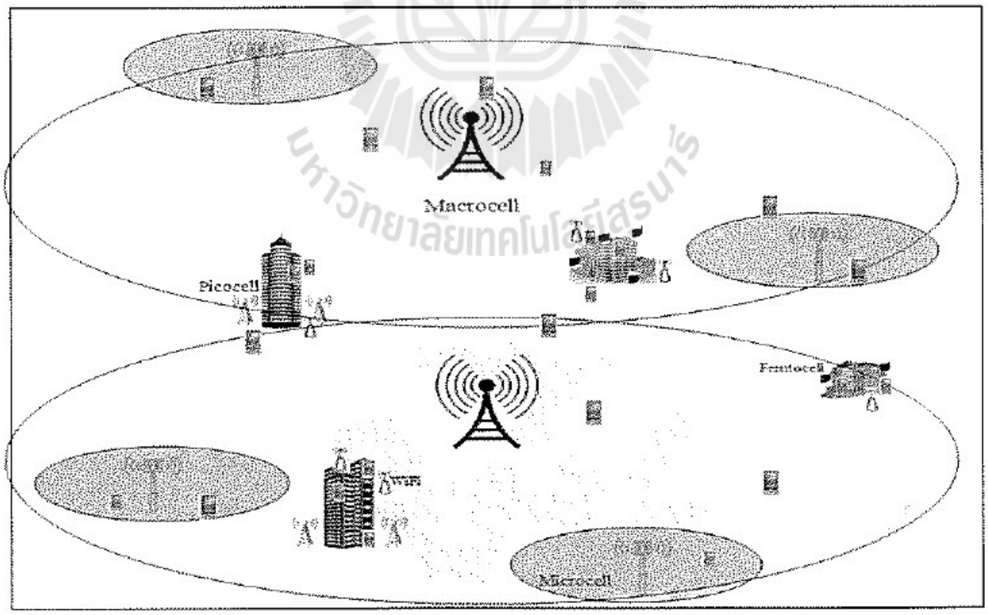

Figure 3.6 LTE advanced heterogeneous network

3.4 LTE channel reuse distance

This is used in determining the users' ICI, system performance and capacity. Since the received signal power is related to desired signal, therefore the inter-cell interference and intra-cell interference are determined by LTE channel characteristics between the desired or interfering transmitters and desired receiver. The reuse distance between cells using the same channel is denoted by D, which serves as an important parameter in determining the average ICI power. D is the distance between the centers of the cells that use the same channels. The mathematical representation of reuse distance (D) is given by.

$$D = \sqrt{3C} \tag{3.4}$$

The cluster size for hexagonal cells is given as C, and it's shown in Figure 3.7

$$C = i^2 + ij + j^2 \tag{3.5}$$

The integers i and j determine the relative location of co-channel cells

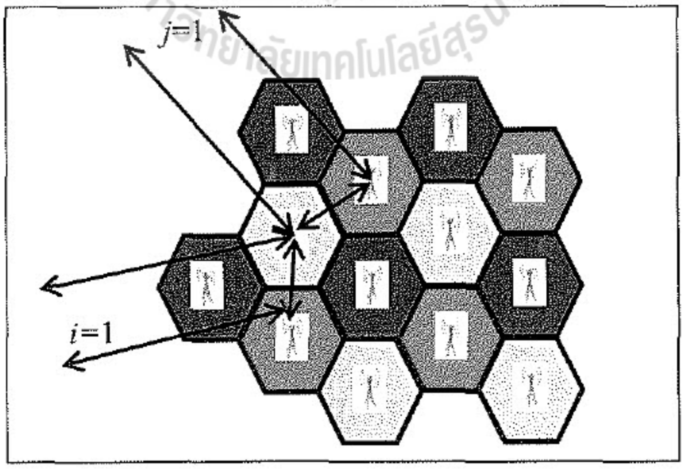

Figure 3.7 Cluster size for hexagonal cells

3.5 LTE channel capacity

It is the information carrying capacity, which is based on the noisy-channel coding theorem. The channel capacity of a particular channel is the information per unit-time that can be achieved with small error probability. The mathematical model is given as:

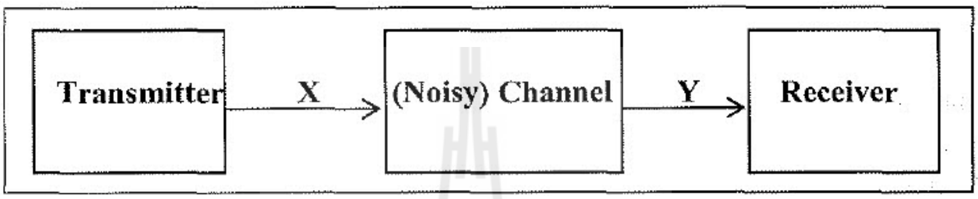

Figure 3.8 Information carrying channel

The random variables X and Y represent the input and output of the channel. The conditioning distribution function of Y that gives X is given as $p_{Y|X}(y|x)$. It is a fundamental fixed property of the communication channel. The joint distribution $p_{X,Y}(x,y)$ is determined by marginal distribution $p_X(x)$ due to the identity presented below.

$$p_{X,Y}(x,y) = p_{Y|X}(y|x)\, p_X(x) \tag{3.6}$$

The mutual information I $(X;Y)$ is induced by the equation above. Therefore, the channel capacity is given as;

$$C = \sup_{p_X(x)} I(X;Y) \qquad (3$$

3.5.1 Shannon Hartley theorem

The maximum rate at which information can be transmitted over a channel of a particular bandwidth with noise is known as Shannon's theorem. The theorem states the channel capacity C to be;

$$C = B\log_2\left(1 + \frac{S}{N}\right) \tag{3.8}$$

The channel capacity C is in bits per second (bps), the bandwidth of the channel in hertz (Hz) is represented by B, the average received signal power over the bandwidth is S and it is measured in watts (W). While N is the interference power over the bandwidth (it is measured in watts). S/N is the signal-to-noise ratio of the communication signal to the Gaussian noise interference, and it is expressed as a linear power ratio.

3.5.2 AWGN channel

Additive White Gaussian noise (AWGN) is an elemental noise model used in information theory to mimic the effect of many random processes that occur in nature. The AWGN channel capacity is given as;

$$C_{awgn} = \mathrm{W}\log_2\left(1 + \frac{\overline{P}}{N_0W}\right)_{[\mathrm{bits/s}]} \tag{3.9}$$

The average received power is $\overline{P}$ [W], and the noise power spectral density is N_0 [W/Hz]. The received signal-to-noise ratio (SNR) is $\frac{\overline{P}}{N_0W}$ and when the (SNR >> 0 dB), the capacity becomes

$$C \approx W \log_2\left(1 + \frac{\overline{P}}{N_0 W}\right) \tag{3.10}$$

The capacity is logarithmic in power and approximately linear in bandwidth, and it is known as **bandwidth-limited regime**. When the (SNR << 0 dB), the capacity $C \approx \frac{\overline{P}}{N_0}$ $\log_2 e$ is linear in power but insensitive to bandwidth because capacity is proportional to the total power received across the total bandwidth. Increasing the bandwidth has a limited impact on capacity. Moreover, increasing power has a significant effect. This is called **power-limited regime**.

3.5.3 Signal – to –interference plus noise ratio (SINR)

The SINR is defined as the power of a certain signal of interest divided by the sum of the interference power (from all the other interfering signals) and the power of background noise. The SINR is reduced to the signal-to-interference ratio (SIR), when the noise power is zero. Contrarily, when interference value is zero, the SINR is reduced to the signal-to-noise ratio (SNR). The quality of wireless connection is usually measured by SINR. The SINR of a user located at some point x on a site is given as

$$\text{SINR}(x) = \frac{P}{I+N} \tag{3.11}$$

P is the power of the receiving signal, I is the interference power of the other (interfering) signals in the network and N is noise power which is a random signal with equal power over a range of frequencies.

3.5.4 Signal – to – noise ratio (SNR or S/N)

It is defined as the ratio of signal power to the noise power, it is often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise. The signal-to-noise ratio, bandwidth, and channel capacity of a communication channel are connected by the Shannon–Hartley theorem.

$$\text{SNR} = \frac{P_{signal}}{P_{noise}} \tag{3.12}$$

3.6 LTE signal propagation

The Hata model for urban areas is a developed version of *Okumura model* and it is known as the *Okumura–Hata model*. It is the most widely used radio frequency propagation model for predicting the behavior of cellular transmissions in built up areas. This model explains the effects of diffraction, reflection and scattering of signal caused by city structures. The other common propagation models for LTE are depicted in Table 3.3

Table 3.3 Signal propagation models

No	Propagation model	Frequency Band [MHz]	Base Station Height [m]	Distance between Transmitter and Receiver [km]
1.	Cost-231	1500-2000	30-200	1 < d < 20
2.	ITU-529	300-1500	30-200	1 < d < 100
3.	Okumura-Hata	150-2200	30-100	1 < d < 100

The frequency band of *Okumura–Hata model* is from 150-2200 MHz, but it could be extended to 3 GHz which makes it suitable for today's LTE working frequencies of 2.3 -2.6 GHz.

3.7 Antenna gain

This describes how much power is transmitted by an antenna from a far –field source on the antenna's beam axis to that of hypothetical lossless isotropic antenna, with equal sensitivity to signals from all directions. Antenna gain can be expressed as a function of angle, but when a single number is quoted, the gain becomes the 'peak gain' over all directions. Antenna gain (G) is related to directivity (D), while ε_R is the radiation efficiency. The Antenna gain is given by the equation below

$$G = \varepsilon_R D \tag{3.13}$$

However, the peak gain of an antenna can be extremely low because of losses or low efficiency.

3.8 Noise power

The noise power depends on thermal noise at the input of the system along with system gain and noise figure. Thermal noise usually spreads over a very wide spectrum which means that noise power is proportional to bandwidth. A generalized noise voltage equation within a given bandwidth is defined as below.

$$V^2 = 4\mathrm{kT} \int_{f1}^{f2} R \; dF \tag{3.14}$$

Where:

V = integrated RMS voltage between frequencies f1 and f2.

R = resistive component of the impedance (or resistance) Ω.

T = temperature in degrees Kelvin (Kelvin is absolute zero scale).

f1 & f2 = lower and upper limits of required bandwidth.

B = bandwidth in Hz.

k= Boltzmann constant $= 1.3807 * 10^{-23} \left\{\frac{J}{K}\right\}$

Mostly, the resistive component of the impedance remains constant over the required bandwidth which allows the simplification of noise voltage equation (3.14) to (3.15)

$$V = \sqrt{4kTBR} \qquad (3.15)$$

3.8.1 Thermal noise power

While the above thermal noise equations are expressed in terms of voltage, it is also important to express the thermal noise in terms of power level. The thermal noise power modeling considers a noisy resistor as an ideal resistor. The noise power which is independent on the resistance but bandwidth is given below.

$$P = \frac{V^2}{4R} \tag{3.16}$$

$$P = \frac{\left(\sqrt{4kTBR}\right)^2}{4R} \tag{3.17}$$

$$P = kTB\ [Watts] \tag{3.18}$$

k = Boltzmann constant $= 1.3807 * 10^{-23} \left\{\frac{J}{K}\right\}$

T = Ambient temperature $\{K\}$

B = Bandwidth {Hz}

It is easy to relate this to other bandwidths, because the power level is proportional to the bandwidth. Which means, ten times the bandwidth gives ten times the power level (+10dB). The noise power is normally expressed in dBm.

$$P\ [dBm] = 10 * \log_{10}(1000 * k * T * B) + 30 \tag{3.19}$$

Thermal noise in a 50 Ω system at room temperature is -174 dBm / Hz.

$$P_{Noise\ @\ Output}[dBm] = P_{Noise\ @\ Input} + Gain_{system} + NF_{system} \tag{3.20}$$

NF_{system} (Noise Figure) is the additional noise by the system.

3.9 Chapter summary

In this chapter, the background theory of LTE system was explained and the frequency allocation of resources in cellular networks was considered. The LTE channel capacity which depends on Shannon-Hartley model was also discussed. The AWGN channel, SINR and propagation model (Okumura–Hata model) were critically discussed. In general, the LTE systems have adopted the reuse-1 for better coverage and capacity. Nevertheless, ICI remains a major concern. The parameters and necessary mathematical formulations for LTE cell load optimization were explained in this chapter. The knowledge of this chapter would be essential for LTE cell load optimization in the next chapter.

CHAPTER IV

CELL LOAD OPTIMIZATION

4.1 Introduction

This chapter describes the technique of cell load optimization, which is vital for cellular network performance improvement because it allows the management of resources utilization and mitigation of ICI that affects available resources. There have been many optimization techniques for ICI mitigation in this study. The reuse-3 technique provides a unique way of ICI mitigation through resources allocation among cells. This allocation is coordinated in such a manner that no cell uses the same spectrum as its neighboring cells, and this reduces the effect of ICI that increases the load of a cell. Moreover, the reuse-3 scheme often leads to underutilization of resources. In order to overcome this limitation of reuse-3, the PFR was proposed. This technique allows the splitting of cells into regions (inner and outer), with coordinated resources allocation. The users in the inner region are called Cell Center Users (CCUs), while those in the outer region are Cell Edge User (CEUs). PFR adopts the frequency reuse-1 for the inner region, in order to maintain the maximum system capacity achieved by this scheme, while it adopts the reuse-3 at the cell edge for ICI mitigation. PFR seems to perform better than reuse-3 in terms of resources utilization and ICI mitigation, but due to the fact that users in both regions have no access to the total bandwidth usage, underutilization of resources remains a great challenge. The SFR was proposed as an efficient technique of alleviating the underutilization of resources which is common in both reuse-3 and PFR. It allows the total utilization of the available bandwidth by the users in the inner and outer regions. It is a flexible technique, because it varies power over bandwidth. This thesis has proposed a technique of ICI mitigation as a tool for cell load optimization. The proposed technique offers an efficient and low cost platform for resources utilization management in LTE system.

4.2 Cell Load optimization technique

The set of cells for a particular cellular site is given as (Q),

$$Q = \{1,2,3,4 \ldots\ldots, \infty\} \tag{4.1}$$

Each cell has pixels, which could be termed as users in the cell and each pixel is represented by (r). The position of each pixel from the base station antenna is usually determined by the path loss model adopted for this study, which also depends on the distance of the pixel from the Base Station (BS). The power gain between a pixel and the base station which is crucial in signal transmission is represented by n_{ir}, (i) represents the base station and (r) the position of the pixel, while the value of i is infinite. In addition, the transmit power in cell i is represented by (H_i), while the noise power from base station equipment is σ^2. The amount of resources utilization in a cell (i) that is referred to as cell load in this thesis is expressed as φ_i. Another important factors in network planning which is the load vector is given as $(\boldsymbol{\varphi})$ in equation (4.2)

$$\boldsymbol{\varphi} = (\varphi_1, \varphi_2, \dots \varphi_n)^T, \tag{4.2}$$

The cell load optimization involves the performance modeling that is technically based on SINR of a particular pixel and this performance model is given in equation (4.3)

$$SINR_r\ (\varphi) = \frac{H_i\, n_{ir}}{\sum_{m \in S \setminus \{i\}} H_m\, n_{mr}\, \varphi_m + \sigma^2} \tag{4.3}$$

- **Fractional frequency load–coupling model**

This thesis considers the non-linear system modeling of fractional frequency reuse. First, each cell is divided into two parts, the inner and outer regions. The pixel in the inner region is denoted by A_q, while the total number of pixels in the inner region is A_{ic}. The outer pixel is denoted by A_p and the total number of pixels is denoted by A_{ie}. B represents the bandwidth per Physical Resources Block (PRB) in LTE, which is constant. The capacities of the inner and outer regions are given as C_{inner} and C_{outer}.

$$C_{inner} = B_{inner} \log_2 \left(1 + SINR_{Aq}\ (\varphi_i)\right) \tag{4.4}$$

$$C_{outer} = B_{outer} \log_2 \left(1 + SINR_{Ap}\ (\varphi_i)\right) \tag{4.5}$$

The demand requirement of pixel at the inner region is denoted by $d_{k\ inner}$ and it is given below.

$$d_{k\ inner} = \frac{dA_q}{B_{inner}\ \log_2\left(1+SINR_{Aq}\left(\varphi_i\right)\right)} \tag{4.6}$$

While dA_q is the demand of each pixel in the inner region, the demand requirement of pixel in the outer region is denoted by $d_{k\ outer}$.

$$d_{k\ outer} = \frac{dA_p}{B_{inner}\ \log_2\left(1+SINR_{Ap}\left(\varphi_i\right)\right)} \tag{4.7}$$

The dA_p is the demand of each pixel in the outer region.

In LTE, PRBs represent the available bandwidth. In this model, the available PRBs for the inner region are denoted by Z_{inner} , while PRBs for the outer region are given as Z_{outer}. Z is the total PRBs available in the network. The cell load of a cell i is given as $0 \leq \varphi_i \leq 1$. The proportion of resource utilization by the pixels in the inner region of cell i is given as φ_{innerA_q} and the proportion of resource consumption of cell i due to serving outer region pixels is given as φ_{outerA_p} .

$$\varphi_{innerA_q} = \frac{dA_q}{Z_{inner}B_{inner}\ \log_2\left(1+SINR_{Aq}\left(\varphi_i\right)\right)} \tag{4.8}$$

$$\varphi_{outerA_p} = \frac{dA_p}{Z_{outer}B_{outer}\ \log_2\left(1+SINR_{A_p}\,(\varphi_i)\right)} \tag{4.9}$$

The SINR for the inner region pixel in cell i $\left(SINR_{A_q}\,(\varphi_i)\right)$ is given below as;

$$SINR_{A_q}\,(\varphi_i) = \frac{H_i\ n_{iA_q}}{\sum_{A_m \in S_1 \setminus \{i\}}\ H_m\ n_{mA_m}\ \varphi_m + \ \sigma^2{}_1} \tag{4.10}$$

The pixel in the inner region is denoted by A_q (reference cell), while the set of pixels in the inner region is denoted by S_1.

The SINR for the outer region pixel in cell i $\left(SINR_{A_p}\,(\varphi_i)\right)$ is given below as:

$$SINR_{A_p}\,(\varphi_i) = \frac{H_i\ n_{iA_p}}{\sum_{A_w \in S_3 \setminus \{i\}}\ H_w\ n_{wA_w}\ \varphi_w + \ \sigma^2{}_3} \tag{4.11}$$

The pixel in the outer region is denoted by A_p (reference cell), while the set of pixels in the outer region is denoted by S_3.

The total amount of resource consumption of the entire pixels in the inner region of cell i is denoted by φ_{inner} while the total amount of resources consumption of the entire pixels in the outer region of cell i is φ_{outer}

$$\varphi_{inner} = \sum_{A_{q \in A_{ic}}} \varphi_{innerA_q} \tag{4.12}$$

Substituting equation (4.8) into (4.12)

$$\varphi_{inner} = \ \sum_{A_{q \in A_{ic}}} \frac{dA_q}{Z_{inner}B_{inner}\ \log_2\left(1+SINR_{Aq}\,(\varphi_i)\right)} \tag{4.13}$$

Substituting equation (4.10) into (4.13), it becomes

$$\varphi_{inner} = \sum_{A_q \in A_{ic}} \frac{dA_q}{Z_{inner}\, B_{inner}\, \log_2\left(1 + \frac{H_i\, n_{iA_q}}{\sum_{A_m \in S_1 \setminus \{i\}} H_m\, n_{mA_m}\, \varphi_m + \sigma^2{}_1}\right)} \quad (4.14)$$

$$\varphi_{outer} = \sum_{A_p \in A_{ie}} \varphi_{outerA_p} \quad (4.15)$$

Substituting equation (4.9) into (4.15) gives (4.16)

$$\varphi_{outer} = \sum_{A_p \in A_{ie}} \frac{dA_p}{Z_{outer}\, B_{outer}\, \log_2\left(1 + SINR_{A_p}\,(\varphi_i)\right)} \quad (4.16)$$

Also substituting equation (4.11) into (4.16), it becomes;

$$\varphi_{outer} = \sum_{A_p \in A_{ie}} \frac{dA_p}{Z_{outer}\, B_{outer}\, \log_2\left(1 + \frac{H_i\, n_{iA_p}}{\sum_{A_w \in S_3 \setminus \{i\}} H_w\, n_{wA_w}\, \varphi_w + \sigma^2{}_3}\right)} \quad (4.17)$$

$$\varphi_i = \varphi_{inner} + \varphi_{outer} \quad (4.18)$$

Putting equations (4.14) and (4.17) together leads to equation (4.19).

$$\varphi_i = \sum_{A_q \in A_{ic}} \frac{dA_q}{Z_{inner}\, B_{inner}\, \log_2\left(1 + \frac{H_i\, n_{iA_q}}{\sum_{A_m \in S_1 \setminus \{i\}} H_m\, n_{mA_m}\, \varphi_m + \sigma^2{}_1}\right)} + \qquad (4.19)$$

$$\sum_{A_p \in A_{ie}} \frac{dA_p}{Z_{outer}\, B_{outer}\, \log_2\left(1 + \frac{H_i\, n_{iA_p}}{\sum_{A_w \in S_3 \setminus \{i\}} H_w\, n_{wA_w}\, \varphi_w + \sigma^2{}_3}\right)}$$

Equation (4.19) is known as nonlinear Fractional Frequency Load Coupling equation. However, the optimization formulation in this thesis is the minimization of total cell load of cellular LTE network. The formulation is given as;

$$\min \sum_{i \in Q} \varphi_i \qquad (4.20)$$

Subject to $Z_{outer} + Z_{inner} = Z$

Equation (4.19) is used for the analysis and comparison of cell load optimization with different ICI mitigation schemes.

The mathematical model parameters of this thesis are shown in Table 4.1

The number of cells considered in this thesis is 9, while the cell layouts represent cell sites with conventional reuse frequency and fractional frequency reuse. The two cell layouts are depicted in Figure 4.1. Figure 4.1 (a) represents the cellular layout without frequency coordination because each cell uses the same frequency channel, while Figure 4.2 (b) represents layout with FFR which involves frequency coordination among cells. The position of each pixel in both layouts is considered constant and could also be varied. The transmit power from base station to each pixel in both layouts is assumed to be constant.

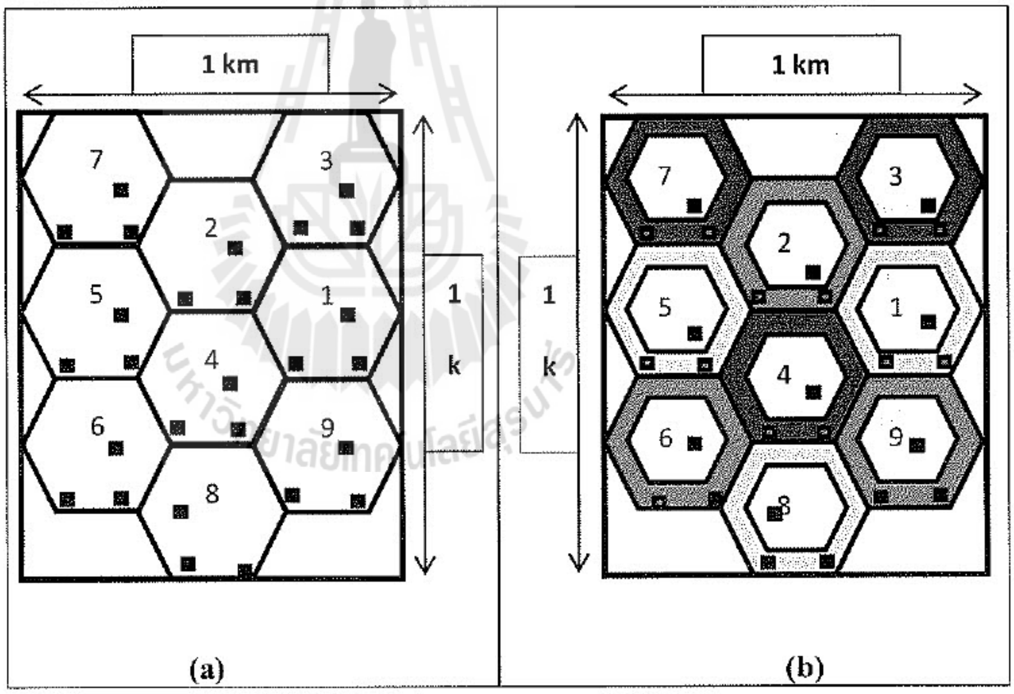

Figure 4.1 Cell layouts

4.3 Simulation results

The simulations were executed using the MATLAB optimization toolbox. The cell load of each cell was evaluated using equation (4.19) with different ICI mitigation schemes. In this thesis, the feasible solution within the network capacity is regarded to be below 1, while beyond 1 is regarded as feasible solution beyond the network capacity. It must be stated that the solution to nonlinear FFR load coupling equation is considered to be of (positive values) and simulation results beyond the network capacity do indicate the lack of resources with respect to demand or the amount of interference. These two conditions play an important role in network planning and management. The simulation system considered LTE network layouts with a site area of 1 km. The LTE site layouts were equipped with down tilt directional antenna of 14 dBi, User Equipment (UE) with Omni-directional antenna but with antenna gain of 0 dBi. Each cell had a total number of 9 cells with 36 users/pixels. The transmit power used was 46 dBm, while the power gain of each pixel was determined by the propagation environments and distance from the base station. The locations of pixels in the LTE system layouts were assumed to be the same for logical analysis. The distribution of users was uniform and the propagation model adopted was the Okumura-Hata urban model with shadow fading of 8 dB. The available spectrum for this simulation was 10 MHz (50 PRBs for LTE system). The traffic demand of 400 Kbps was used for each user/pixel. It must be stated that an increase in load of a cell affects the load of another cell because of the wrap around technique adopted in this thesis.

This technique allows cell layouts to be folded, which means cells are connected suitably. The simulation parameters for each scheme's analysis are given in Table 4.2. Figure 4.2 shows the cell load solution of each cell with reuse-1 scheme and solution follows the cellular layout without frequency coordination and cell splitting. The constraint for each cell's capacity is given as 1 in this thesis. The results show that most of the load values are below the network capacity. Nevertheless, cell 4 and cell 7 have load values beyond 1. The increase in cell loads of these cells is due to the impact of ICI originating from the neighboring cells using the same PRBs. The analysis of these results considers the same traffic demand, number of users and propagation conditions for all cells in layout (a). The cell load values of cell 4 and 7 that are beyond the network capacity indicate the shortage of resources in these cells. This shortage of resources presents an important information for future's network planning. Since the cells of layout (a) are folded, an increase in cell loads of cells (4 and 7) causes an increase in cell loads of other cells especially the neighboring cells.

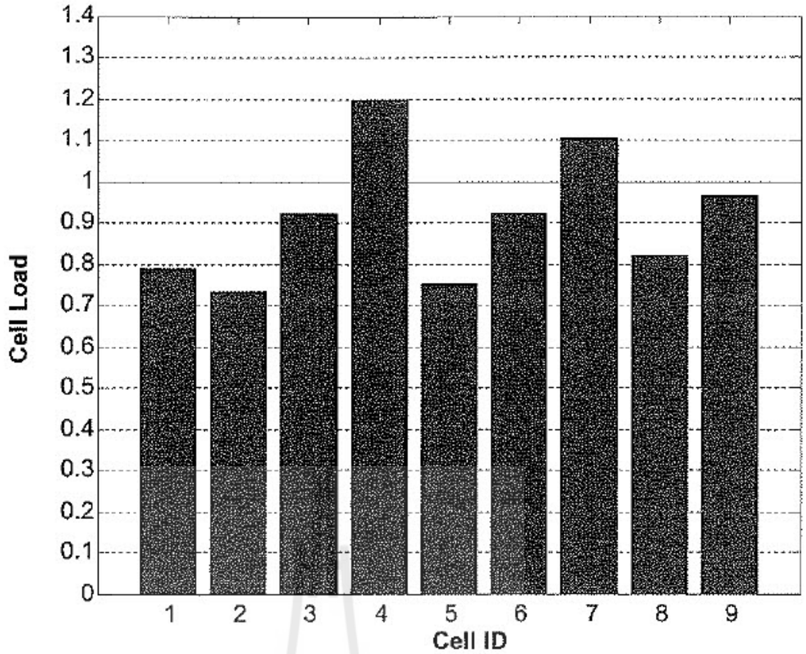

Figure 4.2 Cell load solution to equation (4.19) of reuse-1 scheme

Figure 4.3 indicates the simulation results of reuse-3, which shows three cells with cell load values beyond the network capacity. The cell load of cell 4 continues to increase, while cell load values of cell 1 and cell 8 have also increased. The reuse-3 scheme offers limited resources but with high strength of ICI mitigation. The continuous increase of these cell load values could be attributed to shortage of resources in network system under the same simulation conditions as reuse-1. Since each scheme has the same amount of resources, it means that the shortage of resources could be attributed to under-utilization of reuse-3. Moreover, reuse-3 mitigates ICI, but today's spectrum limitation has made its application expensive.

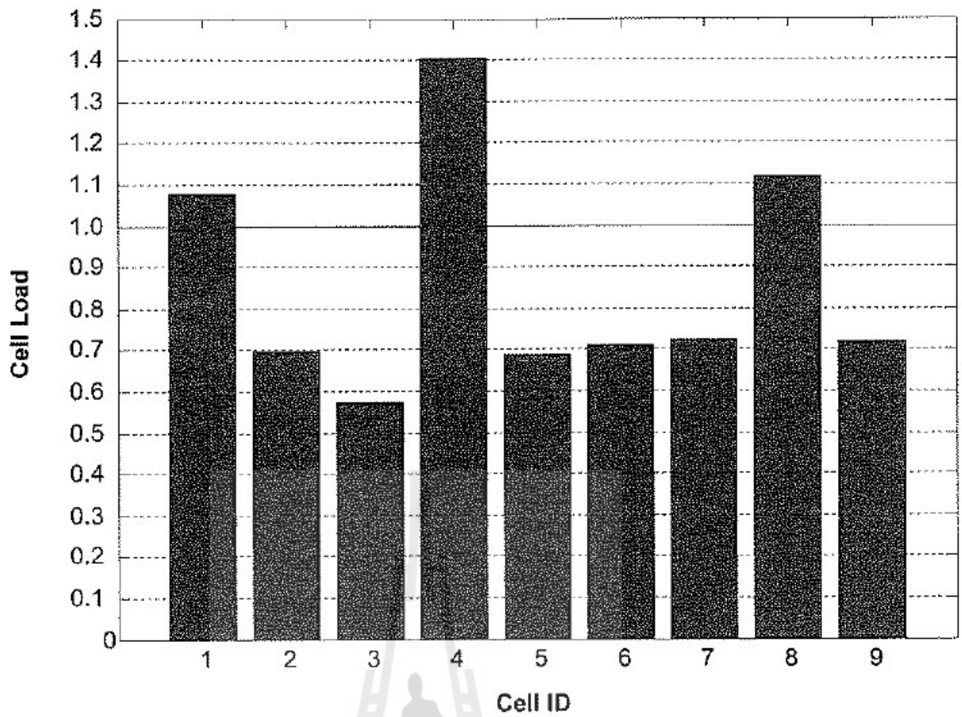

Figure 4.3 Cell load solution to equation (4.19) of reuse-3 scheme

Figure 4.4 shows the cell load values of PFR schemes, the graph shows that six cell load values are below the network capacity and the cell loads of cell 1, cell 4, and cell 8 have decreased. The decrease in cell loads could be attributed to allocation of resources in the inner and outer regions of a cell. Nevertheless, underutilization of available resources remains a problem.

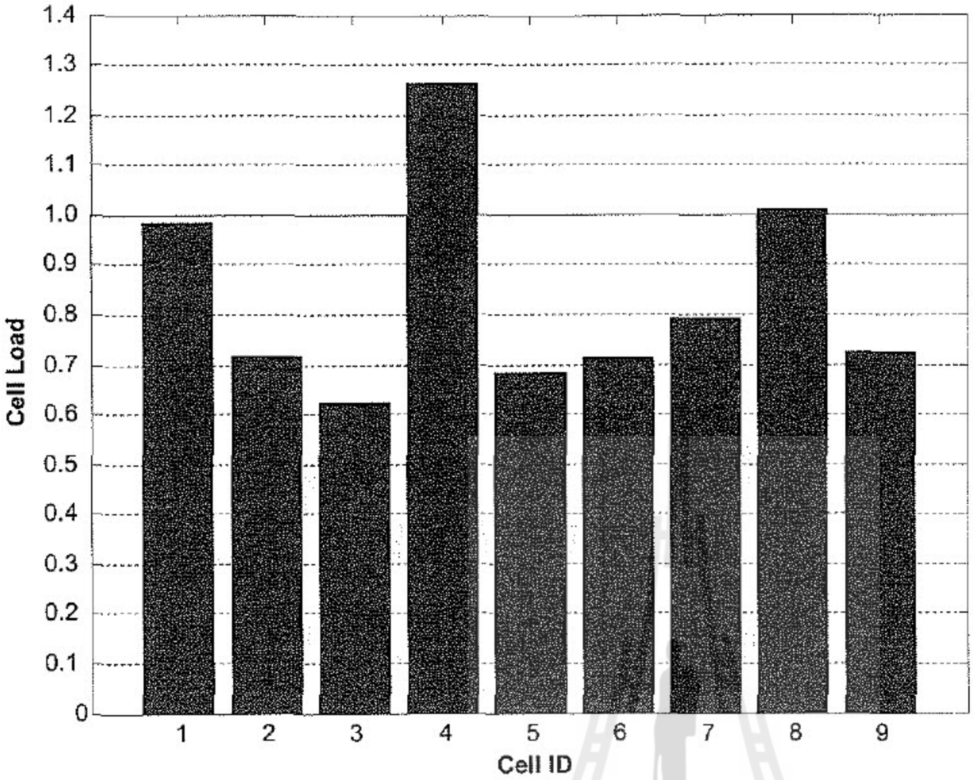

Figure 4.4 Cell load solution to equation (4.19) of PFR scheme

The cell load values of SFR scheme are depicted in Figure 4.5 and it shows that most of load values are within the network capacity. This indicates that the available resources are enough for the cellular network system. The high cell load values of cell 1, cell 4, cell 7 and cell 8 that were evident in the previous schemes have significantly reduced. In addition, this scheme creates more capacity for future traffic demand. The results of SFR scheme have shown that the capacity achieved by reuse-1, the under-utilization of resources of reuse-3 and PFR could be managed by SFR scheme.

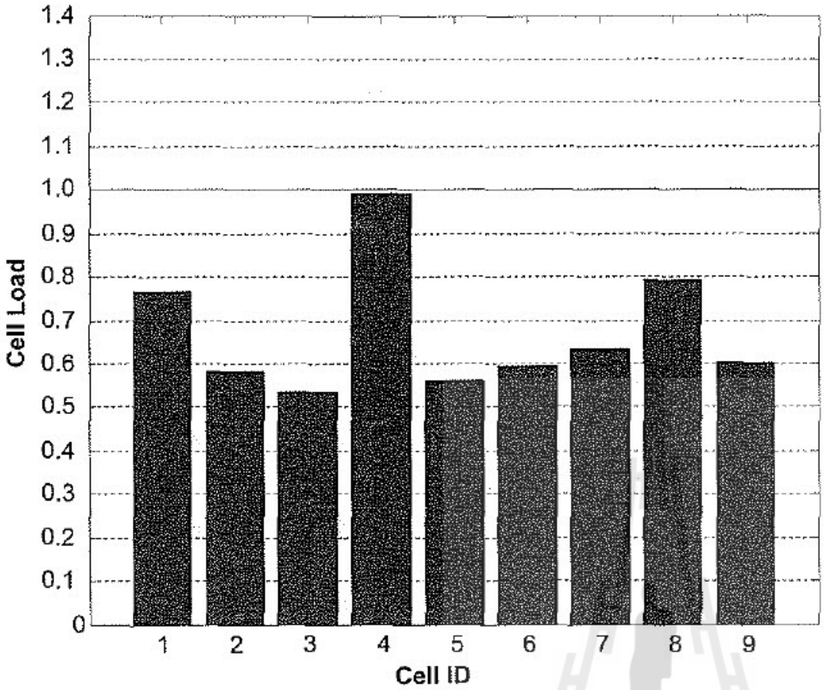

Figure 4.5 Cell load solution to equation (4.19) of SFR scheme

The focus of this thesis is to optimize cell load in LTE system. The total cell load of each scheme with the minimization tool of $Z_{outer} + Z_{inner} = Z$ is shown in Figure 4.6. The SFR scheme shows the lowest total cell load, which means more capacity for future traffic demand. Comparing the total cell load of reuse-1 with SFR scheme shows that the capacity achieved by reuse-1 could be achieved with SFR schemes, while the ICI with reuse-1 could be mitigated by SFR. The simulation results have shown that the impact of SFR scheme on cell load optimization should not be overlooked.

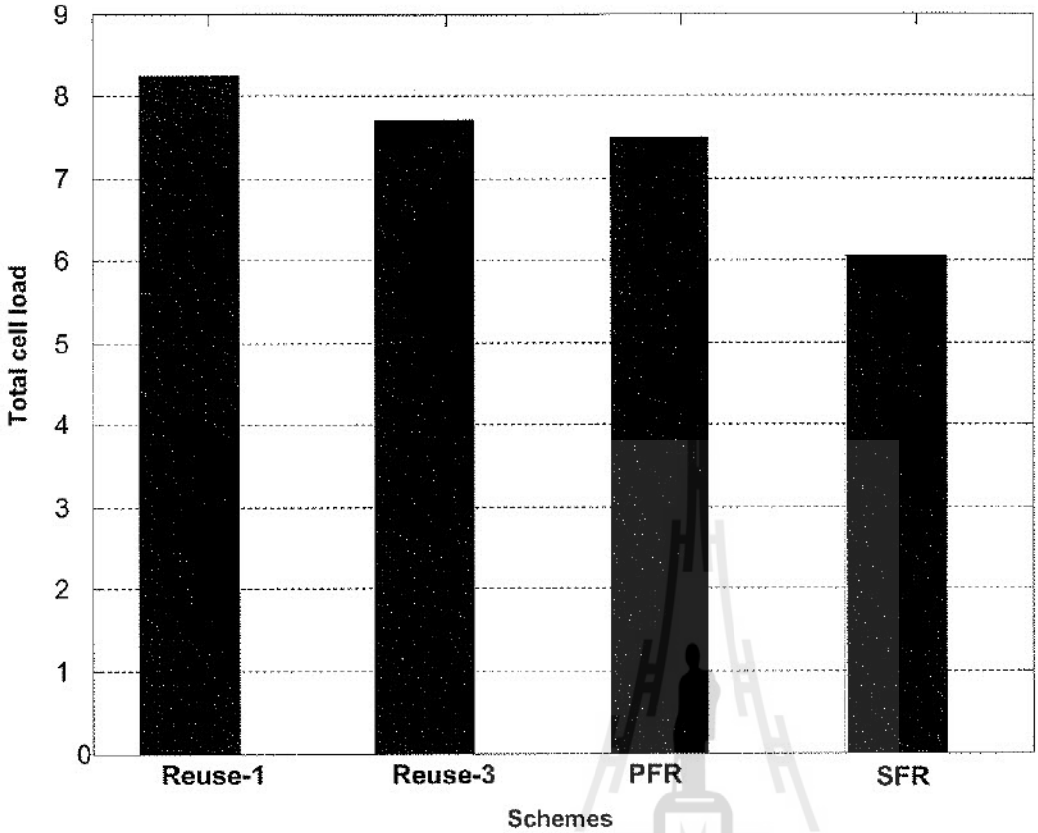

Figure 4.6 Total cell load solution to equation (4.20) of different schemes

Figure 4.7 shows the cell edge performance of FFR schemes. It has been analyzed and criticized that cell edge users are seriously affected by ICI. This ICI causes abnormal increase in cell load. It is clearly seen that the cell edge performance of SFR scheme is higher than PFR scheme with respect to cell loads of both schemes. Figure 4.8 presents the cell loads of PFR and SFR inner regions. The inner load value of each cell of PFR scheme is slightly higher than that of SFR. This could be attributed to resource allocation in both schemes and also variation of power over spectrum in SFR. Nevertheless, the inner loads of SFR and PFR are so close that it could be related to reuse-1 in the inner regions of both schemes. The results have shown that the performance of cell edge users in LTE cellular networks can be improved through SFR scheme using the mathematical model presented in this thesis. Figure 4.9 presents the percentage decrease in cell load of reuse-3, PFR and SFR schemes.

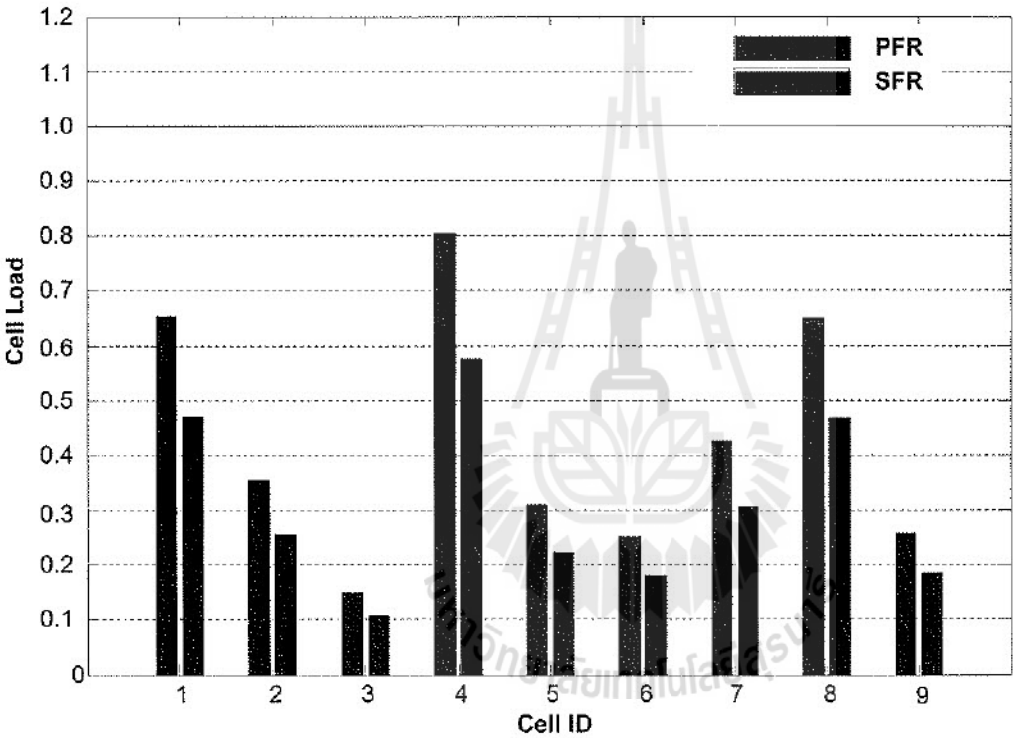

Figure 4.7 Comparison of outer cell load solution to equation (4.19)

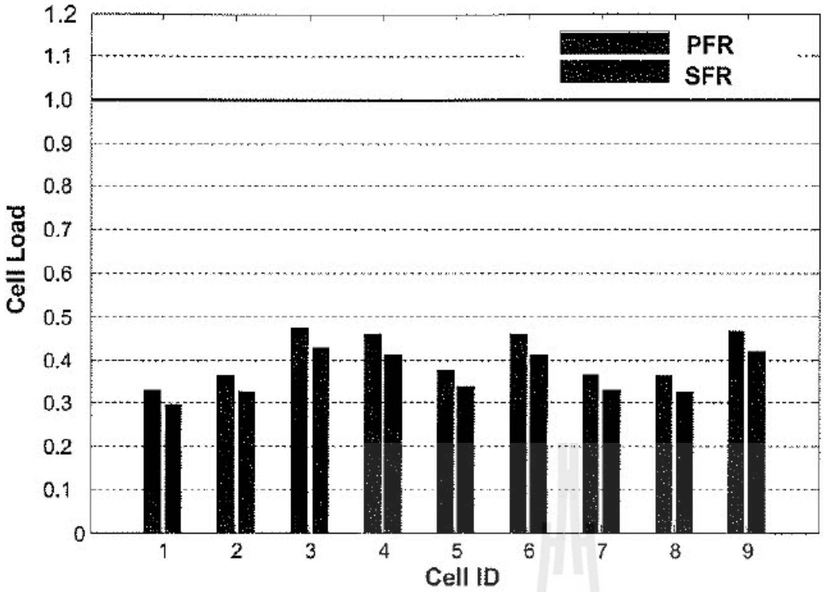

Figure 4.8 Comparison of inner cell load solution to equation (4.19)

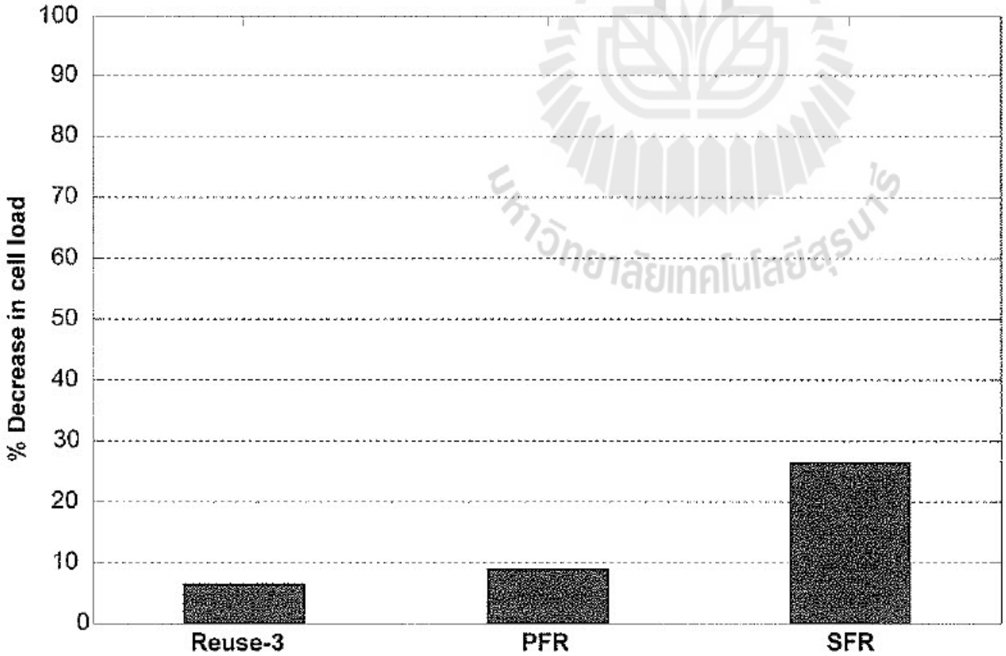

Figure 4.9 Decrease in cell load of reuse schemes

Table 4.2 Simulation parameters

No	Parameter	Value	Unit
1.	Carrier frequency	2	GHz
2.	Channel bandwidth	10	MHz
3.	Transmit power	46	dBm
4.	User demand	400	Kbps
5.	Number of PRBs	50	-
6.	Bandwidth per PRB	180	KHz
7.	Site area	1	km
8.	Noise power	-174	dBm/Hz
9.	Shadow fading	8	dB
10.	Cell radius	400	m
11.	Number of cells	9	-
12.	Users per cell	36	-
13.	Users per inner region	28	-
14.	Users per outer region	10	-
15.	Propagation model	Okumura-Hata	-
16.	Path loss model	$15.3 + 37.6 * \log_{10} d$ d = distance (km)	dB

PRB = Physical Resource Block

The resource allocations of each scheme and power variation of SFR scheme are shown in Table 4.3.

Table 4.3 Resource allocation and power variation summary

Schemes	Reuse-1	Reuse-3	PFR	SFR	Unit
Z_{inner}	50	16.7	20	33.3	PRBs
Z_{outer}	–	–	10	16.7	PRBs
Transmit power (inner region)	46	46	46	23	dB
Transmit power (outer region)	46	46	46	46	dB

SFR = Soft Frequency Reuse

PFR = Partial Frequency Reuse

PRB = Physical Resource Block

It must be stated that the values of allocated resources and power variations in these schemes depend on cellular network planning and objectives of cellular operators.

4.4 Trend analysis of simulations

Though variation of parameters was considered during the simulation of the system model, the validity of the model for all cellular networks is beyond the scope of this thesis. Nevertheless, the trend analysis of model simulations with respect to parameters variation provides the platform for an adoption by cellular networks. The five main parameters varied during model simulations are explained below.

4.4.1 Resource allocation

The allocation of available PRBs in LTE within a cell depend on the mechanisms adopted by network operators, number of users and frequency reuse schemes adopted for users in the inner and outer regions. Different allocations of resources for users in the inner and outer regions of PFR and SFR schemes were considered during simulations of the system model. The simulation results showed similar trends as the PFR and SFR graphs presented in this thesis.

4.4.2 User demand

The cell load of a particular cell increases with the level of user demands of that cell. This parameter was varied during simulation of the mathematical model. The results of this parameter variation showed the same trend as the graphs presented in this thesis.

4.4.3 Power gain

The location of each user within a cell for the schemes adopted in this thesis was varied. This variation of users' locations brought about changes in path loss calculations and values of power gain. The variation of this parameter produced different simulation results, but with similar trends to those results presented in this thesis.

4.4.4 Transmit power

The transmit power variation over spectrum was observed in SFR scheme. Low transmit power was considered for users close to the base station and high transmit power was considered for user at the outer region of the SFR scheme.

4.4.5 Number of users

Different numbers of users were considered during the simulation of the mathematical model. The results showed similar trends to all graphs presented in this thesis.

In conclusion, the similar trend in results of the above varied parameters for PFR and SFR schemes showed the flexibility of the mathematical model for cell load optimization in LTE. The trends of simulations have shown that the model could be adopted by other cellular networks.

4.5 Chapter summary

This chapter has shown the step-by-step mathematical formulation of fractional frequency reuse load coupling equation. The results of MATLAB programming simulation of different reuse schemes for ICI mitigation and cell load optimization were presented. The effects of these FFR schemes on ICI were also discussed. It was clearly seen that the SFR scheme performances in terms of cell load minimization and system capacity improvement were outstanding in comparison with other FFR schemes. The most important aim of this thesis was achieved through SFR scheme. Nevertheless, the contributions of other frequency reuse schemes should also be considered.

CHAPTER V

THESIS CONCLUSION

5.1 Conclusion

The LTE systems use reuse-1 for better cellular capacity, coverage and resource utilization. Moreover, ICI has been the bottleneck of this technology because it usually causes an increase in cell load of a network system. When this ICI is left uncontrolled, it leads to congestion or service outage. This thesis has discussed different ICI mitigation techniques; the Conventional Reuse Based (CRB) scheme and the Fractional Frequency Reuse (FFR) schemes with focus on reuse-3, PFR and the SFR schemes. The pros and cons of each scheme were discussed and their impacts on ICI mitigation were verified with the mathematical system model presented in this thesis. The reuse-3 has been studied as an ideal solution to ICI originating from neighboring cells with reuse-1 scheme. Nevertheless, the underutilization of frequency resources has undermined its ICI mitigating strength. Furthermore, PFR scheme was proposed to overcome this shortcoming of reuse-3.

The theoretical explanations of PFR scheme as a mean of cell load optimization are presented in thesis. Though PFR is the combination of reuse-1 and reuse-3 schemes, nonetheless, the problem of underutilization of resources remains a major concern. The SFR scheme was proposed as an efficient ICI mitigation scheme that minimizes the problem of underutilization of resources which has undermined the application of reuse-3 and PFR. This thesis presents the performance of resources utilization in each cell using reuse-3, PFR and SFR schemes based on simulations. The simulation results revealed the mitigating strength of SFR. The results have also revealed that SFR scheme can be practically implemented because it is of low application complexity.

This thesis has presented the mathematical model of non-linear Fractional Frequency Reuse load coupling equation, and this model considers cell splitting, resources allocation for ICI mitigation, and cell load coupling method. The cell load optimization performances of reuse-1, resuse-3, PFR and SFR schemes were compared, while the simulation results have shown that SFR performed better than PFR in terms of resources utilization minimization through ICI mitigation. The high system capacity of reuse-1 could also be maintained by SFR.

In summary, this thesis has presented three outstanding novel contributions in the field of research. Firstly, it has provided the mitigation of ICI that eats up spectrum in LTE systems. Secondly, it has created a suitable platform for resources utilization management which leads to better spectra efficiency, system performance and capacity improvement. Thirdly, it has opened up novel thinking on future schemes that could be adopted for ICI mitigation with the focus on cell load optimization in LTE system.

5.2 Future studies

The knowledge acquired over the course of this research enables some recommendations for future research in the field of wireless communication. In this thesis, the cell load optimization has adopted the use of FFR with proper investigation on different schemes of FFR. It was found out that SFR scheme outperforms the other FFR scheme. Nevertheless, there are still problems of resources allocation with increase in cell resources, and variation of transmit power over spectrum. The future wireless technology is expected to present higher data-rate and capacity than the existing ones for never-ending traffic demands. Therefore, the future work on ICI mitigation and resources utilization management as techniques for cell load optimization in cellular networks, will adopt an Intelligent Reuse (IR) scheme. In this scheme, the band allocated to different cells expatiates based on the existing workloads. The scheme adopts the reuse-3 scheme at low workloads, while it can be changed when workloads increase to become PFR, SFR or reuse-1.

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APPENDIX A

PUBLICATIONS

List of Publications

International Conference Paper

Daramola, A., Uthansakul P., (2014). **LTE Cell Load Optimization through FFR Scheme.** Proceedings of the 29th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC), June 1-4, pp. 1-4.

Daramola, A., Uthansakul P., (2014). **Evaluation of Various FFR Schemes for LTE System.** Proceedings of the 29th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC), Thailand June 1-4, pp. 1-4.

LTE Cell Load Optimization through FFR Scheme

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Abstract*—In cellular network, never-ending traffic demand, capacity improvement, network coverage and Inter-Cell Interference (ICI) need reliable solution that exhibits flexibility in application with low cost of implementation. Nevertheless, there are various solution techniques in use today, such as; the use of the same frequency, ICI mitigation schemes and cellular network parameters adjustment. This paper proffers a new and reliable technique to these challenges. It introduces the management of LTE network in terms of cell resource utilization and Inter-Cell Interference mitigation, by solving the mathematical model of Fractional Frequency Reuse (FFR) load coupling equation. The simulation results indicate that the new technique improves the LTE system performance.

***Keywords*— Cell Resource Utilization; LTE; Fractional Frequency Reuse; Inter-Cell Interference.**

I. INTRODUCTION

The limitless increase in traffic demand, better Quality of Service (QoS), system performance, and spectrum efficiency led to LTE system. Notwithstanding, Inter-Cell Interference (ICI) has been a major concern. It is widely known that the negative effect of ICI on network system has been tremendous. The ICI mitigation scheme adopted for analysis is similar to that of authors in [3]-[5]. In order to improve Quality of Service (QoS), spectrum efficiency and ICI mitigation, network providers and service operators have embarked on network system optimization, but finding a solution to an optimization problem, is of a critical issue. Many authors have criticized ICI mitigation and LTE optimization, using various techniques [1]-[9], this paper provides LTE system performance model, which unquestionably accounts for traffic demands and ICI mitigation. The performance model in this paper is referred to as Fractional Frequency Reuse (FFR) load coupling equation. This model clearly represents the relationship between cells in term of resources utilization components. It must be stated that lesser value of resource utilization in the system analysis, means that the network system has enough capacity to meet the endless demand, while higher value of resource utilization leads to poor performance and potential service outage. When this happens, optimization is required. The optimization model in this paper is similar to [2], while the ICI mitigation scheme

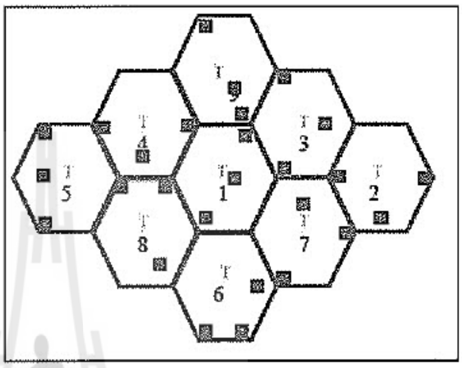

Fig. 1. LTE network layout without FFR.

adopted is similar to [4]. It must be stated that our model is different from [2], because ICI mitigation scheme is incorporated in the system model. It is also different from [4], which focused more on interference calculation. The rest of this paper is coordinated as follows; Section II is the system model, Section III provides numerical analysis, Section IV presents validation, and Section V gives conclusion.

II. SYTEM MODEL

The set of cells in the model is given as $H = \{1,\ldots, n\}$. R denotes the set of pixels, and each cell is divided into inner region r_q and outer region r_p, due to FFR scheme (inner region with reuse of 1, and outer region with reuse of 3). The power gains between antenna i, inner pixel r_q and outer pixel r_p are given as n_{ir_q} *and* n_{ir_p}. The serving areas of cell i are denoted by R_{ic} *and* $R_{ie} \subset R$. The total pixels at the center and edges are R_{ic} and R_{ie}. In this paper, Υ_i is defined as the level of resource utilization in cell i, and also referred to as Cell load. In this paper, an appropriate solution is denoted by Υ^*, it is considered as the one with values within defined boundaries. The user demand in pixels r_q and r_p are d_{r_q} *and* d_{r_p}. A_i is the transmit power, while σ^2_{r1} is the noise power for users at the center, and σ^2_{r2} is for users at the center, and σ^2_{r3} is for users at the edges, which are considered

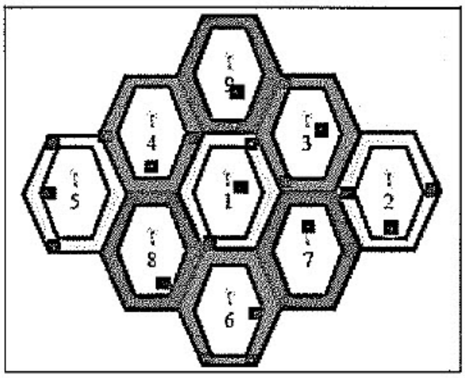

Fig. 3. LTE network layout without FFR.

to be the same value. The bandwidth per Physical Resource Block (PRB) at the center is denoted by B_{r1} and B_{r2} is the bandwidth per Physical Resource Block (PRB) at the edges. The probabilities of receiving interference from the centers and edges of neighboring cells are ρ_m and ρ_w. K_1 and K_2 represent the total number of (PRBs), at the center and edges of a cell.

A. Model derivation

The performance modeling of any network system also depends on load vector. The load vector for the model is given below;

$$\Upsilon = (\Upsilon_1, \Upsilon_2, \Upsilon_3, \dots\dots, \Upsilon_n)^T \quad (1)$$

The Signal to Interference plus Noise Ratio (SINR) in the pixels of the inner region is presented in (2) and that of the outer region is presented in (3), both are really important in the modeling.

$$SINR_{r_q}(\Upsilon) = \frac{A_i n_{ir_q}}{\sum_{m \in H_{r1} \setminus \{i\}} A_m n_{mr_q} \rho_m + \sigma^2_{r1}} \quad (2)$$

$$SINR_{r_p}(\Upsilon) = \frac{A_i n_{ir_p}}{\sum_{w \in H_{r2} \setminus \{i\}} A_w n_{wr_p} \rho_w + \sigma^2_{r2}} \quad (3)$$

The resource blocks needed to serve demand of pixels in the inner region is given as d_{r1} in (4).

$$d_{r1} = \frac{d_{a_p}}{B_1 \log_2 \left(1 + SINR_{a_p}(\Upsilon)\right)} \quad (4)$$

The Physical Resource Blocks needed to provide service to pixels in the outer region is presented as d_{r3} in (5).

$$d_{r3} = \frac{d_{a_q}}{B_2 \log_2 \left(1 + SINR_{a_q}(\Upsilon)\right)} \quad (5)$$

The resource consumption of a pixel of the pixels in the inner region $\Upsilon_{i_{a_q}}$ is given as

$$\Upsilon_{i_{a_q}} = \frac{d_{a_Q}}{K_1 B_1 \log_2 \left(1 + SINR_{a_q}(\Upsilon)\right)} \quad (6)$$

The resource consumption of a pixel of the pixels in the inner region $\Upsilon_{i_{a_p}}$ is given as;

$$\Upsilon_{i_{a_p}} = \frac{d_{a_p}}{K_2 B_2 \log_2 \left(1 + SINR_{a_p}(\Upsilon)\right)} \quad (7)$$

The cell resources utilization of pixels in the inner region Υ_{in} is given in (8), while that of the outer region Υ_{io} is presented in (9)

$$\Upsilon_{in} = \sum_{a_q \in A_{in}} \Upsilon_{i_{a_q}} \quad (8)$$

$$\Upsilon_{io} = \sum_{a_p \in A_{io}} \Upsilon_{i_{a_p}} \quad (9)$$

The cell resources utilization of in cell i is represented mathematical in (11).

$$\Upsilon_i = \Upsilon_{in} + \Upsilon_{io} \quad (10)$$

$$\Upsilon_i = \sum_{r_q \in R_{in}} \frac{d_{r_q}}{K_1 B_{r1} \log_2 \left(1 + \frac{A_i n_{ir_q}}{\sum_{m \in H_{r1} \setminus \{i\}} A_m n_{mr_q} \rho_m + \sigma^2_{r1}}\right)} + \sum_{r_p \in R_{io}} \frac{d_{r_p}}{K_2 B_{r2} \log_2 \left(1 + \frac{A_i n_{ir_p}}{\sum_{w \in H_{r2} \setminus \{i\}} A_w n_{wr_p} \rho_w + \sigma^2_{r2}}\right)} \quad (11)$$

The optimization formulation for (1) is the minimization of total cell load.

$$\min \sum_{i \in H} \Upsilon_i \quad (12)$$

Subject to $0 \leq \Upsilon_i \leq 1$

B. Analysis of LTE system layouts

In this paper, two LTE network layouts are presented. One of the optimization techniques is the cell splitting. The use FFR scheme in ICI mitigation involves the splitting of cell into two parts for different reuse factors. In Fig. 2, each cell is divided into inner and outer regions, and it is assumed that the positions of users in both layouts are constant. In Fig. 1, the cells are not divided, and reuse of 1 is adopted for the network layout. Each cell is divided into two parts, for inner users, and outer users. The outer users are classified as users at the edge of the cell, while inner users are at the center of the cell. The differentiations between Fig. 1, and Fig. 2 are shown in Table I. The reuse-1 in Fig. 1, indicates higher system capacity than Layout 2, because each user in a cell has access to the available bandwidth, nevertheless, there is high probability that the same frequency channels in a cell are used by neighboring cells, which results to high value of interference. In Fig. 2, the resource usage in a cell varies with different frequency reuse from inner region to outer region.

TABLE I.

LTE system layouts	LTE Layout Schemes		
	Reuse-1	*Reuse-3*	*Color configuration*
Layout 1	✓	-	☐
Layout 2 Inner region	✓		☐
Layout 2 Outer region		✓	☐ ▩ ▩

C. *Optimization Analysis*

One of the cellular optimization is the parameters adjustment such as power level, handoff parameters, and bandwidth allocation. The minimization of (2) depends on variables in (1) such as; the Physical Resource Blocks (PRBs) at the inner region K_1 and K_2 for the outer region; probabilities of receiving interference from neighboring cells ρ_{IR} and ρ_{O} for both users at the center and edge and the power gains between base station i and the pixels in each cell. The total number of pixels in a cell could also impact the resource utilization of that cell.

III. NUMERICAL ANALYSIS

The numerical analysis assumes LTE network layouts, and each layout has 9 cells. The propagation model adopted in the analysis is Okumura-Hata, while the propagation environment follows the 3GPP specification [10]. Each Base Station has antenna gain of 14 dBi, and the User Equipment has Omni-directional antenna of 0 dBi gain. The traffic demand is 400 Kbps for each user, and users are distributed uniformly across the layouts. The locations of the users from in each layout are assumed to be the same. The power gain in each pixel depends on the propagation environment and distance from the antenna. In this paper, since the received power in the pixel decreases with distance and signal strength drops faster, the power gain for the analysis is considered to be from 0-1 dB, but higher values are achievable. Fig. 3 shows that most of load values from layout 1 are above 50% of the network capacity, while layout 2 has load values below 30%. The high load values of layout 1 could be attributed to ICI received from neighboring

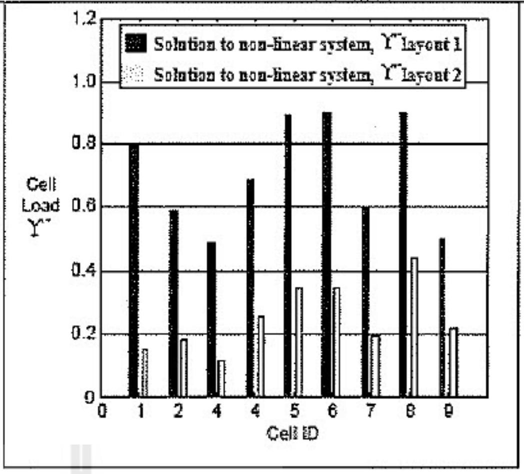

Fig. 3. Resource utilization solution within the network capacity.

cells. The purpose of (2) involves minimization of total cell load. The total cell load of 70.5% is from layout 1, while that of layout 2 is 24.5%; this verifies the formulation (12). The mathematical model presented in (1) is solved using the non-linear MATLAB optimization toolbox. The introduction of FFR schemes in layout 2 has shown significant reduction in high load values that could be attributed to ICI impact. The percentage decrease in ICI through FFR scheme adopted in the model is shown in Fig. 4.

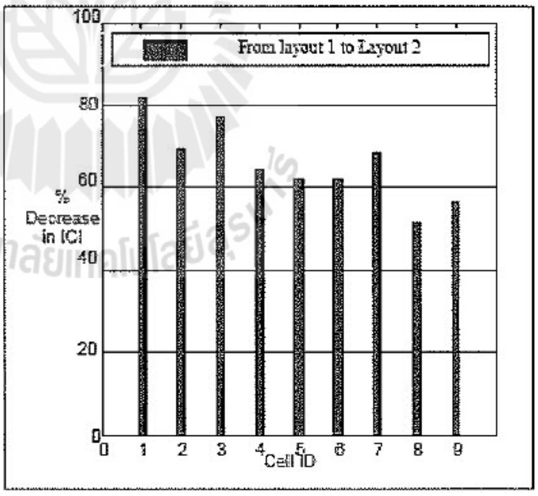

Fig. 4. Inter-cell interference mitigation with FFR.

TABLE II

Main Simulation Parameters	Simulation Parameter assumptions	
	Value	*Unit*
Number of User per cell	3	-
Channel Bandwidth	10	MHz
Carrier Frequency	2	GHz
Transmit Power per cell	46	dBm
Thermal Noise	-174	dBm/Hz
Propagation Model	Okumura–Hata, Urban macro	-
Shadow fading	8	dB
Path Loss Model	$15.3 + 37.6 * \log_{10} d$	d in (m)
Inter-site distance	500	m

IV. VALIDATION OF NUMERICAL RESULTS

There have been so many optimization techniques adopted for network system modeling; either for performance improvement or Inter-Cell Interference (ICI) mitigation. Nevertheless, the comprehensive assessment of any system model validity includes validating the numerical results from the model against the results of real deployment, which is not considered in this paper. Moreover, the ICI mitigation and optimization techniques adopted, as well as the numerical results from the model presented in (11) could be validated through comparison with model and numerical results of related works.

V. CONCLUSION

The provision of new system applications for mobile users demands for better network system performance and Quality of Service (QoS), especially in real time situations. The rapid growth in cellular industries has continued to eat up the available bandwidth. Therefore, continuous upgrade and optimization of cellular network system are required. The focus of this paper is on the new optimization technique as a contribution to the existing techniques for LTE downlink system. The simulation results from the mathematical model indicate that this technique is effective. In addition, the model provides a platform for better LTE system performance. There are assumptions adopted in the system model analysis, which could be of interest in future research works.

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Evaluation of various FFR Schemes for LTE System

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***Abstract*—Advancement in cellular technology has caused rapid growth in network capacity; moreover, Inter-Cell Interference (ICI) has undermined this development. The introduction of LTE system has provided better network capacity, data rate and Quality of Service (QoS) for never-ending user demand. The downlink performance of LTE system is strongly limited by ICI. There have been different schemes proposed by various authors, either for capacity improvement, better system performance or ICI mitigation. This paper has investigated and criticized different schemes, with aim of evaluating cell resources utilization in LTE network system. The simulation model adopted for the analysis is based on performance modeling of Signal to Interference and Noise Ratio (SINR) for Cell Center Users (CCUs) and Cell Edge Users (CEUs). The simulation results for the analysis show an optimal scheme for LTE system; in terms of system performance and resources utilization.**

Keywords*—*Evaluationt; FFR schemes; LTE; Inter-Cell Interference and Cell Resource Utilization.

I. Introduction

The introduction of frequency reuse in cellular network system led to capacity improvement in different network system, from GSM to LTE-A. It is widely known that higher system capacity is more pronounced with reuse-1 (LTE-system). Nevertheless, Inter-Cell Interference (ICI) remains an obstacle. In order to solve this problem, reuse-3 was introduced, but with little impact. Notwithstanding, ICI continues to impose limitations on system capacity, Quality of Service (QoS) and cellular system performance. In order to combat the effect of ICI, different schemes have been criticized by various authors [1]-[13]. The assignment of bandwidth to inner and outer regions and optimal reuse factor, as a technique of mitigating ICI was investigated in [1]. In [11], another scheme of ICI mitigation was proposed, which involved varying subcarriers and power adjustment of each cell. The technique of improving ICI reduction through PFR (Partial Frequency Reuse) was criticized, with a Flexible Bandwidth Allocation (FBA) scheme which depends on network load was proposed in [2]. In [6], it is made known that ICI experienced by users in their own cells was lower when using the Fractional Frequency Reuse, instead of Universal Frequency Reuse. There was a significant decrease

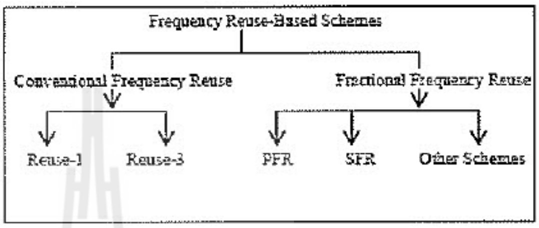

Fig. 1. Reuse planning schemes

in outage probability when compared to Universal Frequency Reuse. The relationship between throughput and distance; which plays a key role in LTE optimization was investigated in [7]. In this paper, the focus is on an efficient ICI mitigation scheme, which gives a significant application in LTE system; in terms of resources utilization management, cell capacity, QoS and congestion control. The remaining parts of this paper are organized as follows; Section II presents the system model, the model platform is presented in Section III. Section IV gives the performance analysis, while the paper is concluded in Section V.

II. System Model

In many literatures, there have been classifications of different frequency reuse based schemes; but this paper has focused on schemes classified in Fig.1.

A. Frequency reuse-1

The reuse-1 is for capacity maximization in cellular network system, which means the same frequency channels are used by all neighboring cells. The high system capacity is achieved with limited or without cell planning, resource utilization management or power control to deal with the interference challenges. There is also a degradation of Signal to Interference plus Noise Ratio (SINR) due to ICI. The high probability that the resource blocks scheduled to a cell are used by neighboring cells; could lead to low throughput or service outage due to high inter-cell interference It must be stated that the reuse-1scheme adopted by LTE system achieves

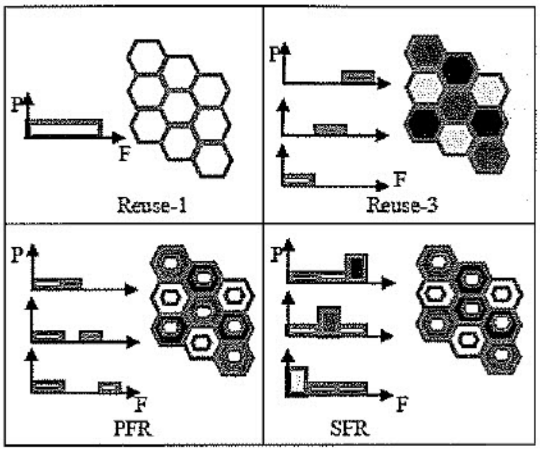

Fig. 2. Frequency allocation of reuse schemes.

the highest data rate; nevertheless, it shows high values of ICI especially in the case of overloaded systems.

B. *Frequency reuse-3*

In reuse-3, the system bandwidth is divided into 3 equal parts. These parts are allocated to cells; in such a way that no neighboring cell is using the same sub-band. This scheme enhances the system capacity, and reduces the effect of ICI from neighboring cells. However, the disadvantage is the under-utilization of spectrum with restriction on the reuse of each channel in each cell. The scheme only allows the use of one third of resource, which might not be good in situation where there is scarcity of frequency resources.

C. *Partial Frequency Reuse (PFR)*

It is an Inter-Cell Interference (ICI) mitigation technique, which involves the sharing of spectrum, while the same transmit power is maintained among cells. Each cell is divided into inner region and outer regions. The reuse factor of 1 is adopted for usage by users at the inner region, and reuse of 3 for users at the outer region. The allocation of spectrum involves larger portion to inner users, while the remaining one-third is for the outer users. The defect of PFR is also the under-utilization of available frequency bandwidth

D. *Soft Frequency Reuse (SFR)*

SFR is the variation of transmit power over spectrum, with total usage of available resource. It mitigates high ICI level associated with Conventional Frequency Reuse (CFR) configurations, while providing more flexibility to the Partial Frequency Reuse (PFR) scheme. Each cell is also divided into two parts, inner region and outer regions. The reuse-1 is used by users in the inner region, and the reuse-3 is used by users at the edge of the cell. The SFR is an effective reuse scheme which can be adjusted by the division of powers between the frequencies used in the center and edge bands.

III. MODEL PLATFORM

The network site is made up of cells equipped with base stations. The resuse-1, resure-3, PFR and SFR schemes are adopted in the model presented in this paper for critical analysis. In each cell, there are pixels which represent the area of network coverage; it is denoted by A, and each pixel is represented by a. The set of cell is given as $M = \{1,\ldots\ldots, n\}$, $l=1,\ldots\ldots, n$, and $l \in M$. The capacity of the system is denoted by C. In this paper, we denote B as the bandwidth per Physical Resource Block (PRB) in LTE system. The serving region of cell l is represented by $a \in A_l$. The Signal to Interference plus Noise Ratio (SINR) in pixel $a \in A_l$ is denoted by $SINR_a$. The network resource utilization vector, which is a key factor in performance modeling, is given as

$$\mathcal{V}=(\mathcal{V}_1, \mathcal{V}_2, \mathcal{V}_3, \ldots\ldots\ldots, \mathcal{V}_n)^T \tag{1}$$

The channel capacity which is important in cell planning and performance improvement is presented below;

$$C = B\log_2\left(1 + SINR_a(\mathcal{V})\right) \tag{2}$$

The modeling of PFR and SFR involves the splitting of each cell into two parts; the inner and outer regions. The capacity of the inner region is represented by C_i, while that of the outer region is denoted by C_o. The pixel in the inner region is a_q, and that of the outer is represented by a_p. For the sake of proper assessment of ICI schemes, the total number of pixels in the inner and outer regions are denoted by A_{li} and A_{lo}. In (3), the capacity of the inner region is given as;

$$C_i = B\log_2\left(1 + SINR_{z_q}(\mathcal{V})\right) \tag{3}$$

$$C_o = B\log_2\left(1 + SINR_{z_p}(\mathcal{V})\right) \tag{4}$$

$$C_T = C_i + C_o \tag{5}$$

The capacity of the outer region is also represented in (4), while the total channel capacity in cell l is given in (5). For the purpose of resource utilization and ICI mitigation evaluation, the SINRs of each pixel in the inner region and outer region are given as;

$$SINR_{a_q}(\mathcal{V}) = \frac{X_l P_{la_q}}{\sum_{r \in M_{r1} \setminus \{l\}} X_r P_{ra_q} \rho_r + \sigma^2_{r1}} \tag{6}$$

$$SINR_{a_p}(\mathcal{V}) = \frac{X_l P_{la_p}}{\sum_{w \in M_{r3} \setminus \{l\}} X_w P_{wa_p} \rho_w + \sigma^2_{r3}} \tag{7}$$

X_l is the transmit power and it is assumed to be the same for all cells, at the same time, the power gains between the base station l, the inner pixel a_q and outer pixel a_p are given as

$n_{i a_q}$ and $n_{i a_p}$. The probabilities of receiving interference from the inner and outer are ρ_r and ρ_w. The user demands in both the inner and outer regions of each cell are given as; d_{a_q} and d_{a_p}. The available resources in LTE system are represented by PRBs; for each cell, the available resources in the inner and outer regions are Z_i and Z_o . The resource consumption of pixels at the inner is given as ϑ_{l_i}, while that of the outer region as ϑ_{l_o}. The bandwidth per Physical Resource Blocks (PRBs) at the inner region is denoted by B_1, and the bandwidth per Physical Resources Block at the outer region is B_2. This paper presents the noise power for the inner and outer region as $\sigma^2{}_1$ and $\sigma^2{}_{r3}$, both are assumed to be the same. The serving areas of cell l are A_{li} and $A_{lo} \subset A$. The set of cells in the inner and outer regions are presented in this paper as M_{r1} and M_{r3}. It must be stated that the reuse-1 is adopted for bandwidth allocation in the inner region and reuse-3 for the outer region.

$$\vartheta_{l_i} = \sum_{a_q \in A_{li}} \frac{d_{a_q}}{z_i B_1 \log_2\left(1 + \frac{x_l\, n_{l a_q}}{\sum_{r \in M_{r1} \setminus \{l\}} x_r n_{r a_q} \rho_r + \sigma^2{}_1}\right)} \quad (8)$$

$$\vartheta_{l_o} = \sum_{a_p \in A_{lo}} \frac{d_{a_p}}{z_k B_3 \log_2\left(1 + \frac{x_l n_{l a_p}}{\sum_{w \in M_{r3} \setminus \{l\}} x_w n_{w a_p} \rho_w + \sigma^2{}_{r3}}\right)} \quad (9)$$

The total resource utilization ϑ_l in cell l is given as

$$\vartheta_l = \vartheta_{l_i} + \vartheta_{l_o} \quad (10)$$

IV. PERFORMANCE ANALYSIS

This paper has investigated the performance evaluation of each scheme. The traffic demand for each user is assumed to be 500 Kbps; for total available spectrum of 10 MHz and with Carrier Frequency of 2 GHz. The transmit power to users at the inner and outer regions is 46 dBm, and it is assumed to be the same for all cells. The propagation environment follows the Okumura-Hata model urban macro cells [14] with shadow fading of 8dB, and Noise Figure of 7dB. The analysis is done for inter-site distance of 500 m, with radius of 250 m. The analysis assumed static positions of users for all schemes, which has proved to be essential in power gain calculation. The analysis includes the comparison of resources utilization management and Inter-Cell Interference of each cell. Fig. 3, depicts the high levels of resource utilization with reuse-1 in each cell. There is a significant reduction in interference with reuse-3, which presents ICI mitigation value of 20%, though ICI is still a major limitation to system performance. Since the scheme could not prevent the under-utilization of resource, it is considered as an inefficient scheme in this paper. The Partial Frequency Reuse indicates a substantial reduction in interference, with less than 50% of system capacity used, with

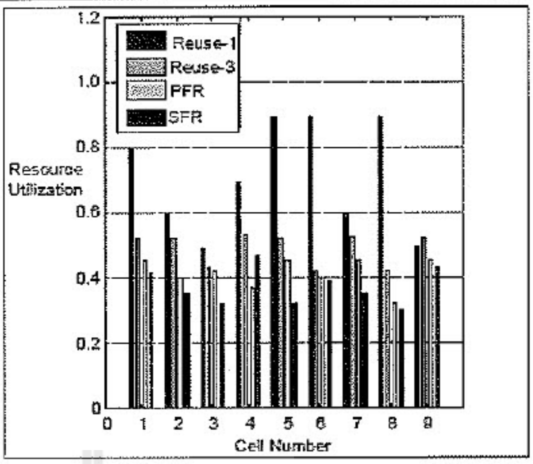

Fig. 3. Resource utilization solution within the network capacity.

level of interference mitigation value of is 32.0%. The variation of transmit power over spectrum with SFR scheme has proven to be the most effective, with interference percentage mitigation of 42.6%. The SFR scheme has also shown that under-utilization of resources could be avoided, with sharing of total resources in term of PRBs by the outer cell region. In the analysis of SFR, the power ratio is set to 1/2; which means the transmit power to outer region in twice that of the inner region. The effect of different schemes on ICI mitigation with reference to resources utilization of reuse-1 is shown in Fig. 4. In this paper, it is assumed that ICI impact of reuse-1 is 100%. In Fig 5, decrease in the level of resource utilization of cell 8 is shown, because it has the highest value in the reference scheme (reuse-1). It is clearly evident that if the

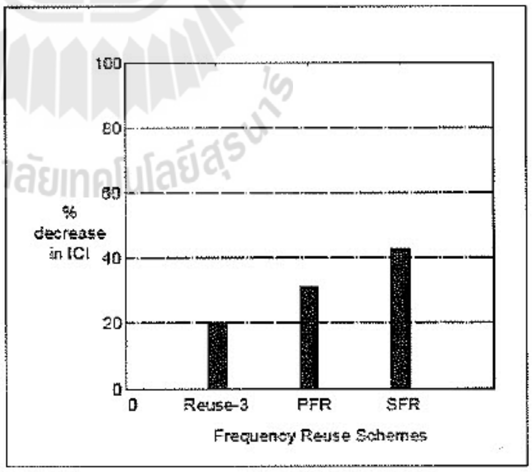

Fig. 4. Reduction in inter-cell interference impact by schemes.

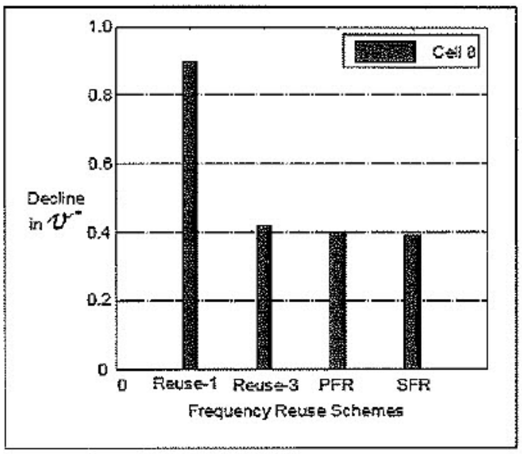

Fig. 5. Decline in resource utilization of schemes with reference to cell 8

Inter-Cell Interference (ICI) evolving from neighboring cells could be mitigated, there would be enough capacity for the ever-increasing user demands. The schemes investigated are for LTE downlink, but could be adopted for uplink. The model for the schemes is solved using MATLAB toolbox. It must be stated that the validation of the results should be against real deployment, which is not the priority of this paper.

TABLE I.

Main Simulation Parameters	Simulation Parameter assumptions	
	Value	*Unit*
Number of User per cell	5	-
Channel Bandwidth	10	MHz
Carrier Frequency	2	GHz
Transmit Power per cell	46	dBm
Thermal Noise	-174	dBm/Hz
Propagation Model	Okumura–Hata, Urban macro	-
Shadow fading	8	dB
Path Loss Model	$15.3 + 37.6 * \log_{10} d$	d in (m)
Inter-site distance	500	m

V. CONCLUSION

Recent works on ICI mitigation, resources management, capacity improvement and optimization have opened doors to different approaches and techniques. This paper presents a unique approach for an effective evaluation of Frequency Reuse Based Schemes (FRBS) in LTE system. It presents the results from the investigation of different schemes, with proper focus on SFR as an optimal scheme. The evaluation of these schemes with the system model shows flexibility of its application in LTE system. Nevertheless, this paper does not rule out the possibilities of better scheme in the nearest future.

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BIOGRAPHY

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