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A THESIS REPORT ON

MITIGATION OF INTER CELL INTERFERENCE IN MULTI CELL ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS SYSTEMS

By

SANUJ SHAKYA

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MITIGATION OF INTER CELL INTERFERENCE IN MULTI CELL ORTHOGONAL FREQUENCY DIVISION MULTIPLE ACCESS SYSTEMS

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A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Information and Communication Engineering

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Recommendation

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The thesis entitled **"Mitigation of Inter Cell Interference in Multi Cell Orthogonal Frequency Division Multiple Access Systems"**, submitted by **Mr. Sanuj Shakya** in partial fulfillment of the requirement for the award of the degree of **"Master of Science in Information and Communication Engineering"** has been accepted as a bona fide record of work independently carried out by him in the department.

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Abstract

Orthogonal Frequency Division Multiple Access (OFDMA) is the multi-user version of Orthogonal Frequency Division Multiplexing (OFDM). Due to the orthogonality of the sub-carriers, the interference between the sub-carriers is eliminated. However in multi-cell OFDMA system, if same sub-carriers are assigned to different users in neighboring cells, then inter-cell interference (ICI) occurs. ICI is more prominent for the users at cell boundaries due to which the cell edge users experience lower data rates compared to the users close to the base stations. During the thesis work, a dynamic radio resource allocation algorithm has been designed for mitigation of ICI. This algorithm assigns sub channels to the users and their transmission power based on the user location and sub channel assignment information from neighboring cells. The performance of Reuse 1, Reuse 3, Partial Frequency Reuse (PFR), Soft Frequency Reuse (SFR) and the dynamic resource allocation algorithm have been analyzed on the basis of change in Signal to Interference and Noise Ratio (SINR) values, system Bit Error Rate (BER), bandwidth efficiency and channel capacity with increase in distance of User Equipment (UE) from the center of cell. The dynamic resource allocation algorithm provides satisfactory levels of SINR values throughout the cell region and also maintains higher system capacity for users as compared to other resource allocation techniques.

Keywords: OFDMA, ICI, ICI mitigation, ICI coordination, resource allocation.

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List of Abbreviations

4G	Fourth Generations
BER	Bit Error Rate
BS	Base Station
CCU	Cell Centre User
CEU	Cell Edge User
DAB	Digital Audio Broadcast
DVB	Digital Video Broadcast
eNB	Evolved Node B
FDM	Frequency Division Multiplexing
FEC	Forward Error Correction
FFR	Fractional Frequency Reuse
FFT	Fast Fourier Transform
GSM	Global System for Mobile communications
HFR	Hard Frequency Reuse
ICI	Inter Cell Interference
ICIC	Inter Cell Interference Coordination
ISI	Inter Symbol Interference
LTE	Long Term Evolution
MATLAB	MATrix LABoratory
MS	Mobile Station
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PFR	Partial Frequency Reuse
PRB	Physical Resource Block
QoS	Quality of Service
RRM	Radio Resource Management
SFN	Single Frequency Network
SFR	Soft Frequency Reuse

SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
SSM	Spread Spectrum Multiplexing
TDM	Time Division Multiplexing
TRx	Transmit and Receive
UE	User Equipment
WiMAX	Worldwide Interoperability for Microwave Access

CHAPTER 1

INTRODUCTION

1. Introduction

1.1. Background

Orthogonal Frequency Division Multiplexing (OFDM) is a wideband multi-carrier multiplexing technique used in wide variety of applications such as Digital Audio Broadcast (DAB) systems, Digital Video Broadcast (DVB) systems, wireless networks, 4G mobile communication networks, etc. In OFDM, the overall wideband spectrum is divided into a large number of overlapping sub-carriers, which are orthogonal to each other. Due to the orthogonal property of the sub-carriers, the signals can be transmitted in parallel over a common channel and still be detected individually.

Orthogonal Frequency Division Multiple Access (OFDMA) utilizes OFDM multiplexing technique to allow multiple users to share a common wideband channel. Multiple access is achieved in OFDMA by assigning subsets of the sub-carriers to individual users over some time. The frequency and time resources in OFDMA systems are organized into physical resource blocks (PRBs) which are distributed to individual users.

The intra cell interference within a cell in an OFDMA system is negligibly small as the adjacent sub-carriers are orthogonal to each other. However in multi-cellular OFDMA wireless systems, the inter cell interference (ICI) from neighboring cells is a major problem for system engineers.

Generally, due to the availability of only a limited spectrum, the overall broadband spectrum is utilized in all cells in the system. This helps to maximize the total capacity in each of the cells. However, when two neighboring cells allocate the same sub-carriers to the different users in their regions, there may be interference in one cell due to the simultaneous transmission in same sub-channel from the neighboring cell and vice-versa. Thus the major source of interference in multi-cell OFDMA system is the Inter Cell Interference (ICI).

The effect of ICI is that the cell edge users (CEUs) experience lower data rates as compared to the cell centre users (CCUs).

1.2. Problem Statement

In multi-cell OFDMA system, the total available spectrum has to be reused at each cell in the entire network. Although the inter-carrier interference between the sub-carriers is eliminated due to the orthogonality of the sub-carriers, the OFDM signals may experience interference from neighboring cells.

Two or more OFDM signals in the same sub-carrier frequency transmitted from the neighboring cells will interfere with each other. The interference between the adjacent sub-carriers can be easily eliminated during the de-multiplexing process due to the inherent property of the OFDM technique. However, the interference between the signals at the same sub-carrier frequency cannot be eliminated and causes detrimental effects to the performance of the system. Since the interference levels are more prominent at the inter-cell boundary, CEUs are more affected by ICI than the CCUs. Due to ICI, CEUs are restricted to a significantly low data rates as compared to CCUs.

It is extremely important for the service providers to either eliminate or reduce ICI from adjacent cells in order to provide higher data rates to CEUs. Several approaches are available in order to mitigate ICI and thereby increase CEUs' data rates. The major approach to mitigate ICI is proper resource management between the neighboring cells. The sub-carriers must be assigned in such a way that the interference from neighboring cells doesn't affect CEUs and also the resource blocks assigned to CEUs do not affect the neighboring cells.

The basic methods for ICI mitigation are static in nature i.e. the resource allocation is performed by the network designer. In these methods, the sub-channels allocated in each cell are fixed and doesn't change even if the interference patterns change. Hence these static methods are not efficient in all cases. Due to the dynamic behavior of the user traffic and mobility, it would be efficient to adjust the allocated resources according to the traffic pattern. Hence it is significant to design a dynamic radio resource allocation algorithm that assigns the resource blocks and their power adapting to the changing user traffic patterns in the desired cell and its neighboring cells. Such algorithm must maintain an effective coordination between the adjacent cells.

1.3. Objectives

The major objective of this thesis work would be to design a dynamic radio resource allocation algorithm to mitigate ICI in multi-cell OFDMA systems and compare its performance with the basic ICI mitigation methods. The specific objectives of the thesis work are listed as follows:

i. To design a dynamic radio resource allocation algorithm for ICI mitigation in multi-cell OFDMA system

ii. To compare the performance of the designed algorithm with basic ICI mitigation methods

1.4. Scope

The scope of this thesis work is for a three-cell OFDMA based wireless communication system. The OFDMA system consists of three adjacent cells each consisting of an Evolved Node B (eNB) or Base Station (BS) at the center of the cell. Each eNB consists of a single omni-directional transmit and receive (TRx) antenna covering the whole cell region. The User Equipments (UE) or Mobile Stations (MS) are randomly distributed over the cells. The UEs are classified as CCUs and CEUs according to their distances from the center of the cell.

Although ICI is prominent in uplink (UE to eNB) as well as downlink (eNB to UE) transmissions, this thesis work considers the study of only the downlink transmission. This thesis focuses on the comparative performance analysis of various ICI mitigation measures based on the simulations carried out in above circumstances.

1.5. Organization of the Report

The remainder of the thesis report is organized as follows. The literature review of the thesis work is described in Chapter 2. It includes the brief review on the development of various ICI mitigation measures and description of the works related to the thesis. Chapter 3 provides the theoretical and technical background on ICI and its mitigation. It includes the detail descriptions on different resource block allocation techniques with ICI mitigation capabilities. This chapter also describes the proposed dynamic resource block allocation algorithm for mitigation of ICI. The methodology that has been used during the thesis work in order to study and compare different resource allocation methods has been described in Chapter 4. The simulation results for various resource allocation techniques are presented in Chapter 5. It also includes comparative analysis between the resource allocation techniques described in Chapter 3. Finally, the work performed during the thesis work and its results are summarized in Chapter 6. It also presents the limitations and possible future enhancements of the thesis work.

CHAPTER 2

LITERATURE REVIEW

2. Literature Review

In a multi-cell OFDMA system, ICI occurs if the same sub-carriers are assigned to different users in the neighboring cells. The signal transmission in one cell may interfere with the signal transmission in same sub-carrier frequency in the neighboring cells. ICI is particularly detrimental to CEUs and causes serious degradation of the users' throughput. In order to mitigate ICI, various resource allocation and management schemes as well as inter cell interference coordination (ICIC) techniques have been designed.

Hard Frequency Reuse (HFR) is the basic method for resource block allocation over multi-cell network. It allocates different sub-bands to neighboring cells in order to avoid ICI [1]. The total available wideband spectrum is divided into different groups, each consisting of a disjoint subset of total available sub-channels. Each of these disjoint groups is assigned to different neighboring cells. Since the neighboring cells are using sub-channels with different frequency bands, it is impossible for transmission in one cell to interfere with the transmission in a neighboring cell. However, with HFR, the capacity of the system is highly degraded as the total available wideband spectrum is divided into groups and only a portion of the total spectrum is assigned to each cell.

The performance of the OFDMA system was improved with Fractional Frequency Reuse (FFR) scheme in comparison to HFR scheme. In FFR, the bandwidth allocation over the cells depends on the proximity of the mobile station to the base station [2]. The bandwidth allocation for CCUs and CEUs are treated separately in FFR scheme.

Partial Frequency Reuse (PFR) and Soft Frequency Reuse (SFR) are the two major types of FFR. PFR allocates a sub-band of total available bandwidths to CCUs in all cells and a sub-band for CEUs, different from sub-bands used in adjacent cells [3]. Basically, the overall system bandwidth is divided into two groups; one for CCUs and remaining for CEUs. The bandwidth allocated for CEUs is further divided into sub-bands as in HFR scheme and each sub-band is allocated to different neighboring cells.

SFR utilizes the entire available wideband spectrum with low power transmission so as not to interfere with the neighboring cells. Only a portion of the available bandwidth is transmitted with high power for coverage towards the edge of the cells. The portion of the bandwidth which is transmitted in high power is different in different neighboring cells so as to avoid interferences among the neighboring cells. Thus in SFR, the CCUs can use all the bandwidth with low power transmission whereas CEUs are given a part of bandwidth with high power transmission [4]. The above static mitigation schemes are considered as conventional schemes for ICI mitigation.

A different class of ICI mitigation schemes is the dynamic interference coordination scheme. Dynamic interference coordination mechanisms do not require an a priori frequency planning, but achieve ICI mitigation by applying channel reuse avoidance techniques. Unlike static ICI mitigation measures, dynamic techniques are capable of adapting to the changing traffic and interference patterns. Li and Liu (2006) employed a semi-distributed resource allocation algorithm for interference mitigation in downlink of a multi-cell OFDMA system [5]. This algorithm was based on predetermined knowledge of all users' Signal to Interference and Noise Ratio (SINR). Rahman, Yanikomeroglu and Wong (2009) investigated a dynamic interference avoidance scheme that used inter cell coordination through X2 interface facilitated by LTE systems [6]. Quek, Lei and Sun (2009) proposed an adaptive algorithm for ICI mitigation that decomposed a multi-cell problem into a distributed optimization problem [7]. The proposed algorithm assigned a minimum number of sub-channels to cell-edge users arbitrarily and guaranteed a minimum service rate for them. Chen and Yuan (2009) discussed the FFR scheme in large networks with irregular patterns [8]. They concluded that two sub-bands always give better cell-edge performance. Triki and Nuaymi (2011) presented various inter cell interference coordination algorithms for OFDMA wireless systems [9]. They have performed comparative analysis of those algorithms. Finally, Dacinabi and Sandrasegaran (2013) proposed an inter cell interference coordination technique in LTE-A networks [10]. The ICI coordination technique is an enhanced algorithm for mitigation of ICI in heterogeneous networks in LTE-A.

CHAPTER 3

INTER CELL INTERFERENCE AND ITS MITIGATION

3. Inter Cell Interference and its Mitigation

3.1. Orthogonal Frequency Division Multiplexing

Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier multiplexing technique in which the overall wideband spectrum is divided into a large number of overlapping sub-carriers, which are orthogonal to each other. Due to the orthogonal property of the sub-carriers, the signals can be transmitted in parallel over a common channel and still be detected individually. The possibility of overlapping of the sub-carriers due to their orthogonal property results in less spectrum or bandwidth wastage.

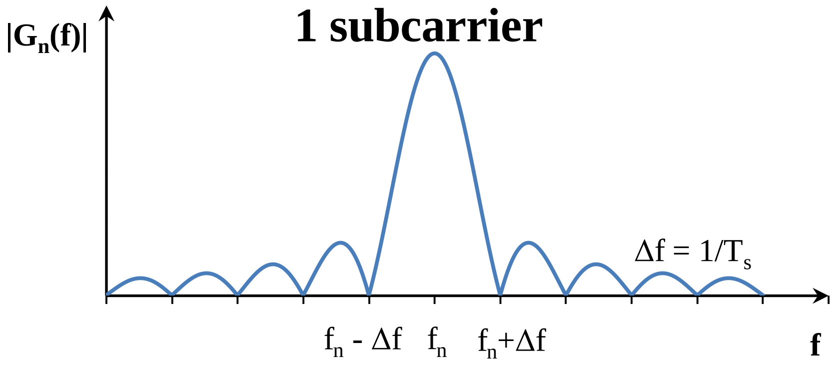

Figure 3.1 Single Carrier OFDM spectrum

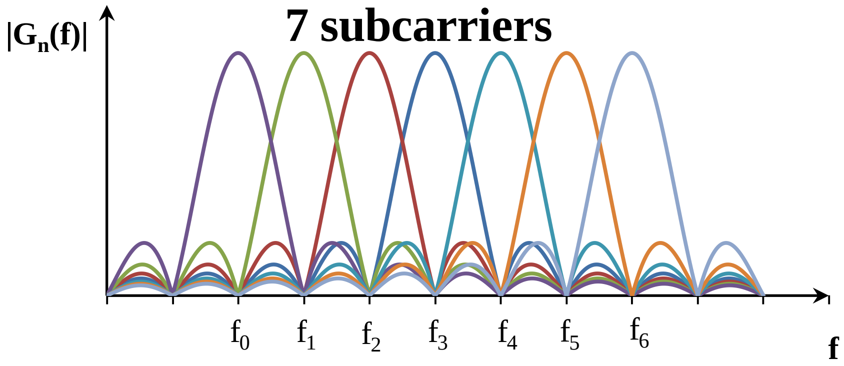

Figure 3.2 OFDM Spectrum with overlapping but orthogonal sub-carriers

Figure 3.1 shows the frequency spectrum of single subcarrier and Figure 3.2 shows the frequency spectrums for OFDM technique with seven subcarriers.

OFDM technique offers high spectral efficiency, improved inter symbol interference and is resistant to multipath fading. As a result, OFDM provides higher data rates, superior performance and other benefits over traditional multiplexing techniques such as Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM) and Spread Spectrum Multiplexing (SSM).

3.2. Orthogonal Frequency Division Multiple Access

Orthogonal Frequency Division Multiple Access (OFDMA) is a multi-user version of OFDM. Multiple access is achieved in OFDMA by assigning subsets of the sub-carriers to individual users over some time. In an OFDM system, the channel resources are available in the frequency domain through the use of overlapping orthogonal sub-carriers and in the time domain by means of fixed duration OFDM symbols. These frequency and time resources can be organized into resource blocks or scheduling blocks called Physical Resource Blocks (PRBs). The PRBs are allocated to individual users based on the bandwidth requirement of the users [11].

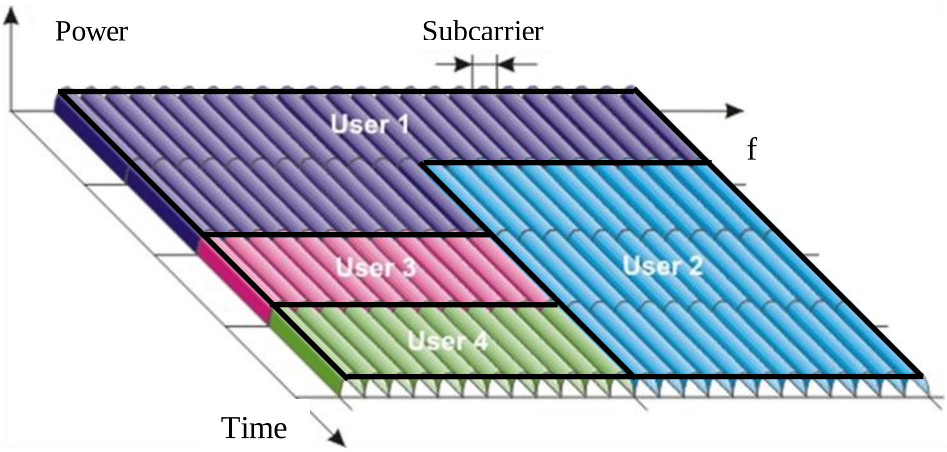

Figure 3.3 OFDMA Resource Allocation

(Source: http://www.enki.pl/images/ofdma.jpg)

There are several methods for allocating OFDMA resource blocks to the users. Figure 3.3 shows a typical frequency allocation pattern for four users. The three main user allocation methods are grouped carriers, spread out carriers and adaptive carrier allocation [12].

Grouping sub-carriers is the simplest resource allocation scheme. In this method, a group of adjacent sub-carriers is allocated to each user. In spread out carrier allocation scheme, the sub-carriers allocated to each user are spread out over the entire bandwidth. This improves the frequency diversity and helps to overcome the effects of frequency selective interferences. Adaptive carrier allocation technique is an advanced resource allocation technique where the resource block is frequently changed based on the channel conditions. Hence, the adaptive carrier allocation technique is a frequency hopping technique [12].

3.3. OFDMA Advantages and Challenges

The major advantage of OFDMA technique is its capability to spread the sub-carriers allocated to a particular user over the entire system spectrum. This provides frequency diversity to the signals that helps in eliminating or minimizing the effects of frequency selective fading. Moreover, OFDMA technique allows power control of individual resource blocks or individual sub-carriers, which helps to improve the performance of faded sub-channels without significantly raising the total transmission power. Since OFDM signals are robust to multipath fading, OFDMA systems can provide Single Frequency Network (SFN) coverage i.e. single frequency band can be used for all transmitters or cells in a multi-cell system [11] [12].

Although OFDMA technique is the preferred choice for today's broadband systems such as 4G mobile communication networks, wireless networks, DAB systems, DVB systems, etc., there are considerable challenges that can be encountered in this technique. Since the sub-carriers must be completely orthogonal to each other in order to eliminate the interferences among adjacent sub-carriers, the performance of OFDMA systems is highly sensitive to frequency offsets and phase noises. Another challenge of OFDMA technique is the system complexity due to the requirement of complex Fast Fourier Transform (FFT) algorithm, Inverse Fast Fourier Transform (IFFT) algorithm and Forward Error Correction (FEC) algorithms. Also, adaptive sub-carrier assignment based on fast channel feedback information accumulates more complexity to the system. An additional challenge in OFDMA technique implemented in a multi-cellular network is the co-channel interference from the neighboring cells. The interference from one OFDMA cell to a neighboring cell using same sub-channel(s) poses a critical challenge to the overall system performance. Such interference requires the system to implement complicated channel allocation techniques with advanced coordination among the neighboring base stations [11].

3.4. Inter Cell Interference

The main source of interference in multi-cell OFDMA systems is the inter-cell interference (ICI).

OFDMA system requires a large wideband spectrum for each transmission in order to effectively utilize the advantages of OFDMA technique. Thus, since radio spectrum is a scarce and expensive resource in wireless communication, the total available broadband spectrum has to be reused in each of the cells in a multi-cell OFDMA system. Due to the orthogonality between the sub-carriers in an OFDM spectrum, the interference between the sub-carriers within a cell is not possible. Also, since each sub-carrier is assigned to a single user at a time, the chances of intra-cell interference can be completely eliminated (at least theoretically).

However, interference may occur from the sub-carriers of same frequency in the neighboring cells when the same sub-carriers are assigned to different users in two or more neighboring cells. Since the signal transmission from a cell can't be completely blocked at its cell boundary, the transmitted signal (although of low power) can interfere with the signal transmission in same frequency sub-channels occurring in the neighboring cells. Thus a signal from one cell acts as noise or interference in other neighboring cells. This type of co-channel interference from the neighboring cells is called Inter Cell Interference (ICI). The effect of ICI is particularly more harmful to cell edge users (CEUs) which are closer to the neighboring base stations and receive interference with significantly higher power as compared to the cell centre users (CCUs). The CCUs which are deeper into the cell region receive less or negligible interference from the neighboring cells. Hence, CEUs experience lower data rates than CCUs.

3.5. ICI Mitigation Techniques

The inter cell interference in OFDMA systems causes degradation in Quality of Service (QoS) especially for the CEUs near the boundary between the adjacent cells. Due to ICI from neighboring cells, the CEUs experience lower SINR values as compared to that of the CCUs. The decrease in SINR values due to higher interference results in poorer throughput rates. In order to maintain comparable QoS between both CEUs and CCUs, either the inter cell interference must be avoided or its effect must be minimized.

Several approaches are available in order to mitigate ICI and to increase service quality (increase data rates) to CEUs [9]. One of the major ICI mitigation scheme is ICI coordination (ICIC) technique. It is one of the Radio Resource Management (RRM) functions. Its task is to manage the allocation of physical resource blocks (frequency and time) in a coordinated way between the adjacent cells such that ICI is kept under control. ICI coordination techniques manage the allocation of frequency of sub-bands and time of allocation to different users in each cell by considering the sub-bands allocated in the neighboring cells. Applications of ICIC techniques in multi-cell system minimize the probability of interfering with the transmission in nearby cells and the probability of getting interfered from the neighboring cells.

A very basic resource block allocation method is to reuse the overall available wideband spectrum in each of the cells in the system. This method provides the highest spectral efficiency among all other resource allocation schemes. However, this method is severely affected by inter cell interference. Since every sub-channel is utilized in all adjacent cells, the signal transmission in one cell interferes with the ongoing transmission in all neighboring cells. Thus this resource allocation scheme can't prevent ICI.

A simple method for resource block allocation over the cells with ICI mitigation capabilities is the Hard Frequency Reuse (HFR) method. In this method, the total bandwidth is divided into a disjoint sub-bands and each sub-band is assigned to different cells with dissimilar sub-bands in the adjacent cells. Since the adjacent cells use different frequency bands, the chances of interference from adjacent cells are completely removed. However, the interference may still occur from co-channel cells located in second and higher tier of cells. Also due to the allocation of only a portion of total available spectrum to each cell, the capacity of the system decreases drastically.

Another method of resource management that includes ICI mitigation capabilities is the Fractional Frequency Reuse (FFR) technique. In FFR, the bandwidth distribution over the cells depends on the proximity of the mobile users to the base station. It means the users in a particular cell are first classified as Cell Center Users (CCUs) and Cell Edge Users (CEUs). Then, CCUs and CEUs are allocated different frequency bands or same frequency bands with different power levels, such that the effect of interference from or to other neighboring cells is minimized. Partial Frequency Reuse (PFR) and Soft Frequency Reuse (SFR) are the two major types of FFR.

Partial Frequency Reuse scheme divides the overall system bandwidth into two groups; one for CCUs and remaining for CEUs. The bandwidth separated for CEUs is further divided into sub-bands and each of the sub-bands is allocated to different neighboring cells as in HFR scheme discussed above. The adjacent cells are allocated different sub-bands for CEUs in order to avoid the interferences from one cell to another [9].

Soft Frequency Reuse scheme allows the transmission of overall available wideband spectrum with low power so as not to interfere with the neighboring cells i.e. only for CCUs. Only a portion of the available bandwidth is transmitted with high power for coverage towards the edge of the cells i.e. for CEUs. The portion of the bandwidth which is transmitted in high power is different in different neighboring cells so as to avoid interferences among the neighboring cells [9].

Some of the resource blocks allocation techniques studied under this thesis work are described below.

3.5.1. Reuse 1 Technique

Reuse 1 technique or Frequency Reuse of One technique is the most basic form of resource block allocation. In this method, the overall sub-channels available in the wideband system spectrum are assigned to each of the cells in the network.

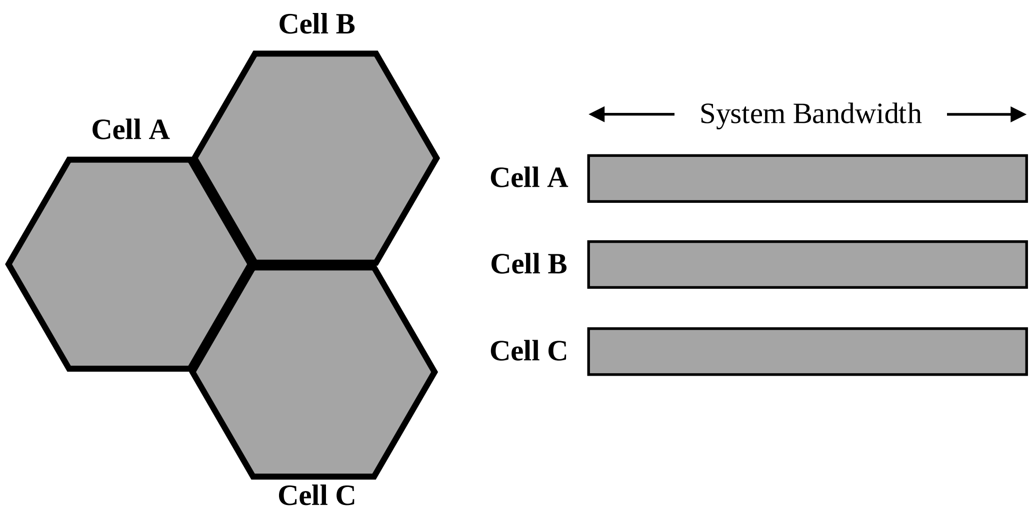

Figure 3.4 Illustration of Reuse 1 Technique

Figure 3.4 shows the illustration of Frequency Reuse 1 technique in a 3-cell network. Here, each of the cells A, B and C utilize the overall available system bandwidth.

The major advantage of using Reuse 1 technique of resource block allocation is that each cell is allocated the maximum possible number of channels. This results in high spectral efficiency of the entire system which is one of the requirements of broadband networking systems. However, Reuse 1 technique assigns all frequency channels to each of the cells. This means that each of the sub-channels in a particular cell has its co-channels in all of its adjacent cells as shown in Figure 3.4. The result is that when particular sub-channel(s) are being used in the adjacent cells, the transmission in one cell will create interference in another cell and vice-versa. Due to the nearness of the co-channel cells, the level of interference is high from all neighboring cells, which cause SINR levels to drop to a low value resulting in degradation of service quality.

Hence, although Reuse 1 technique provides high spectral efficiency, this method faces severe ICI problems. Thus, the use of Reuse 1 method is undesirable.

3.5.2. Reuse 3 Technique

Reuse 3 Technique or Frequency Reuse of Three Technique is another simple resource block allocation technique which uses HFR concept for spectrum allocation.

In this method, the total bandwidth available to the system is divided into three disjoint sub-bands of equal bandwidth each. The three sub-bands are allocated to three adjacent cells in such a way that each cell is surrounded by other cells which are assigned different sub-bands. Figure 3.5 illustrates Frequency Reuse 3 technique in a 3-cell network. Here, three adjacent cells, cell A, cell B and cell C, are allocated different sub-bands from the total available system bandwidth.

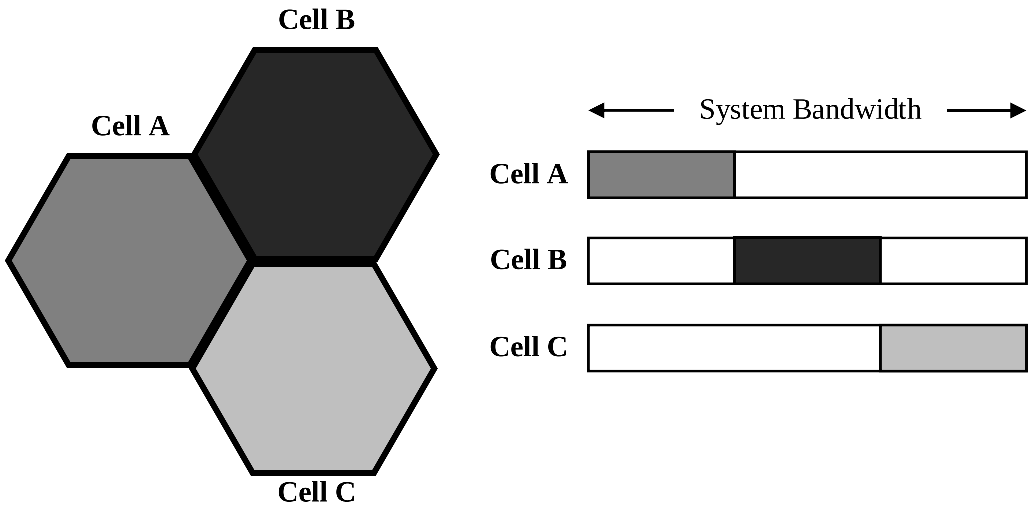

Figure 3.5 Illustration of Reuse 3 Technique

Reuse 3 technique eradicates the ICI problem in Reuse 1 technique by increasing the distance between the co-channel cells to at least two cells. The adjacent cells of a particular cell uses different group of channels as shown in Figure 3.5. Thus, a cell does not experience any interference from its adjacent cells. The only interference is from the co-channel cells which are at greater distances as compared to Reuse 1 technique. Thus the SINR levels are significantly improved in this technique.

However, since each cell is allocated only one-third of the total system bandwidth, the capacity of individual cells and that of the entire system is highly degraded. Thus, although Reuse 3 technique is highly successful in minimizing the ICI from neighboring cells, it is unable to maintain the high system capacity of Reuse 1 technique. Hence, the use of Reuse 3 method for resource block allocation and ICI mitigation is also undesirable.

3.5.3. PFR Technique

Partial Frequency Reuse (PFR) technique is a type of FFR scheme as described above. In FFR, the CCUs and CEUs are allocated different frequency bands or same frequency bands with different power levels, such that the effect of interference from or to other neighboring cells is minimized.

PFR scheme divides the overall system bandwidth into two groups; one for CCUs towards the center of the cell and remaining for CEUs towards the outer region of the cell. The bandwidth separated for CEUs is further divided into sub-bands and each of the sub-bands is allocated to different neighboring cells in order to avoid the interferences from one cell to another.

PFR utilizes the advantages of both Reuse 1 and Reuse 3 techniques of resource allocation. A particular group of frequency channels allocated to the CCUs are reuse at reuse ratio of 1 i.e. all cells use the same frequency channels for CCUs. However, for CEUs, the remaining frequency channels are divided into sub-groups as in Reuse 3 technique. These sub-groups of frequency channels are allocated to adjacent cells in such a way that the chances of interference from one cell to a neighboring cell is minimized, which is the same concept of Reuse 3 (or Reuse-n) technique.

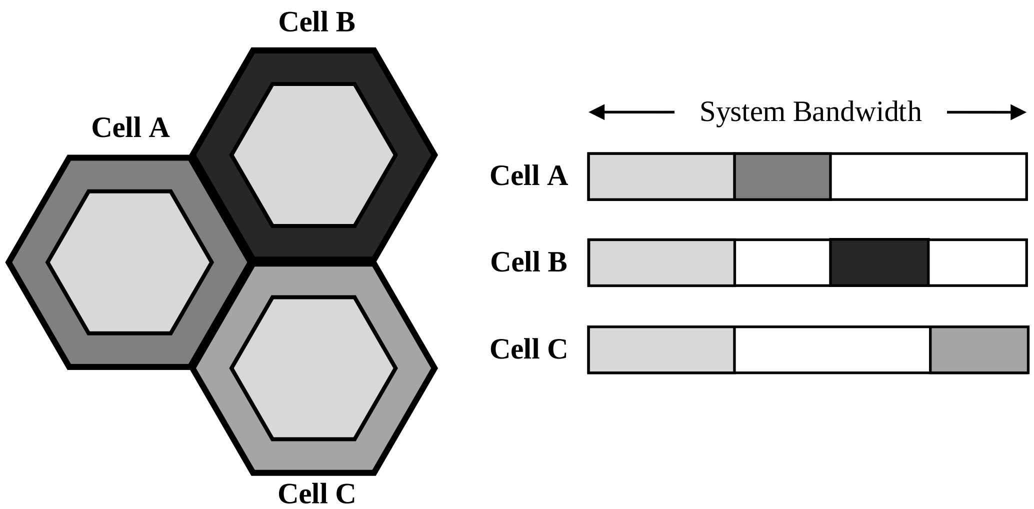

Figure 3.6 Illustration of PFR Technique

Figure 3.6 shows an illustration of PFR resource allocation technique in a 3-cell system. The inner parts of each of the three cells are allocated the same group of frequencies. The remaining spectrum is divided into three groups with equal bandwidths. Each of the sub-bands is allocated to different adjacent cells as shown in Figure 3.6 with different shades of grey. This method reduces the interference level at the edges of each cell, which results in increased quality of service in the region.

3.5.4. SFR Technique

Soft Frequency Reuse (SFR) is another type of FFR scheme for resource block allocation. In SFR, the CCUs can utilize the entire system bandwidth as in Reuse 1 scheme and CEUs are allocated a portion of system bandwidth, which is different from the bandwidths allocated by adjacent cells for their edge users. This is achieved by first dividing the available spectrum to two groups; one for CCUs and remaining for CEUs. The bandwidth which is especially dedicated for CCUs is transmitted with low power such that the coverage area is limited to the inner region of the cell. The portion of the bandwidth allocated for the CEUs is transmitted with high power such that the coverage area includes the outer region of the cell as well. The portion of the bandwidth which is transmitted at high power is made different for adjacent cells in order to wipe out the problems of ICI.

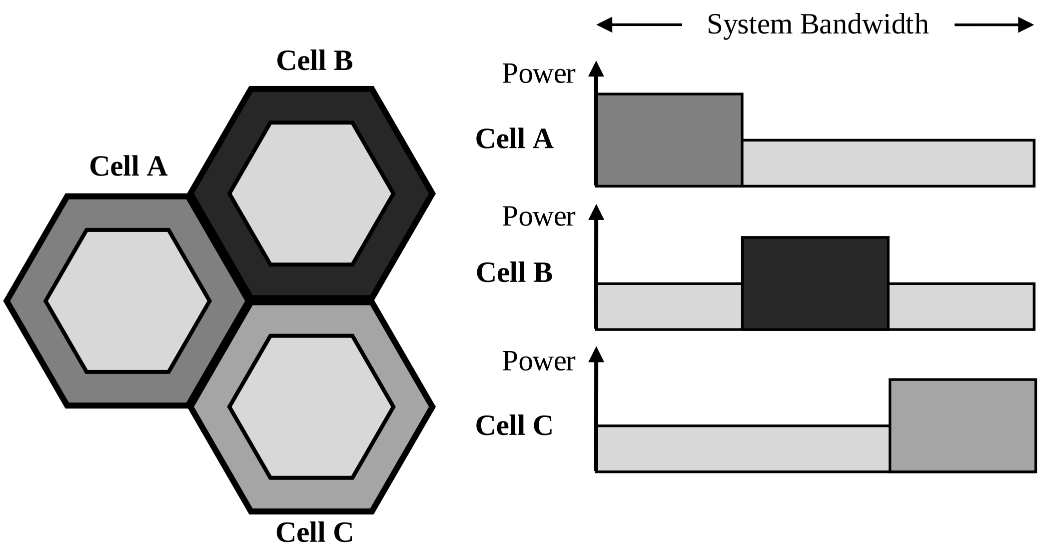

Figure 3.7 Illustration of SFR Technique

Figure 3.7 illustrates the SFR technique for 3-cell system. It shows that the inner regions of each cell can utilize the frequency channels of the entire system bandwidth. The three cells in Figure 3.7 have allocated one-third of the total available bandwidth for CEUs, which will be transmitted at high power level. But each of the cells has allocated different portions of the bandwidth to avoid interferences.

Although CCUs have access to both bands (one dedicated to CCUs and another dedicated to CEUs), the bandwidths allocated for CEUs are firstly prioritized for CEUs. CCUs can use those bandwidths for higher data rates only if they are unassigned. The CEUs, however, can only use the portion of the bandwidth especially allocated for them.

3.5.5. Proposed Algorithm

The basic resource allocation methods described in sections 3.5.1 to 3.5.4 are static allocation algorithms. In these algorithms, the resource allocation is performed by the network designers which remain unchanged till further changes are made manually. Thus, these algorithms are unaffected by the changes in the traffic and interference patterns. Due to the inability of these static algorithms to cope with the changing traffic and interference patterns, these static methods are not efficient.

In this section, a dynamic resource allocation algorithm is proposed that performs adaptive resource allocation as per the interference pattern in the adjacent cells. This algorithm requires each eNB to be provided with the information of resource allocation and power allocation in the neighboring cells. The coordination between the adjacent cells for information interchange can be performed through the X2 interface between the adjacent eNBs. The algorithm provides the sub-carrier and the transmission power for the sub-carrier to particular users in the cell region in such a way that the interference from the adjacent cells for the particular sub-carrier is minimized.

The proposed algorithm assigns each user in a cell with a sub channel which experiences the lowest interference from the adjacent cells. During this process, preference is given to the cell edge users as CEUs are more prone to ICI than CCUs. The algorithm also features collision avoidance technique which assures that the sub channels which are already in use in the cell are not reallocated to other users in the same cell.

The steps involved in the proposed scheme are described below:

1. Initialization

a. List all sub channels available in a cell and provide an identifier to each sub channel.

b. Collect sub channel assignment and power allocation information from adjacent cells.

c. Predict individual cell user location in the cell and calculate its distance from cell center.

d. Reset any sub channel assignments

e. Clear all sub channel assignment flags to null.

2. Exhaustive Search

a. For each cell, start with the user at farthest distance from the cell center.

b. Consider a sub channel from the list of all available sub channels. If the sub channel is already allocated i.e. if the corresponding channel assignment flag is marked, skip to step 2.c.

   Else,

   i. Calculate interference power to the particular sub channel from the adjacent channels based on neighboring sub channel assignment and power allocation information.

ii. Sum the interference levels from each of the adjacent cells to compute the total interference level.

iii. If the considered sub channel is the first sub channel, select this sub channel as candidate sub channel for assignment and skip to step 2.b.v.

iv. Compare the calculated total interference level with the stored minimum interference level. If the calculated value is greater than the stored value, skip to step 2.c.

Else, the particular sub channel is the new candidate for assignment. Continue to step 2.b.v.

v. Store the sub-channel identifier and sum of total interference level as candidate sub channel identifier and minimum interference level.

c. Update the new sub channel from the list of available sub channels and repeat step 2.b. until all sub channels are analyzed.

d. Finally, assign the sub channel to the user corresponding to the final candidate sub channel identifier.

e. Repeat steps 2.b. to 2.d. for the next farthest user in the cell until each of the users in the cell has been assigned unique sub channels.

3. Power Allocation

Assign transmission power levels to each sub channel according to the distance of the corresponding user from the cell center.

$$P_{ch} = P_{max} \times \frac{D_{user}}{D_{max}} \tag{3.1}$$

where, P_{ch} is the power allocated to particular sub channel, P_{max} is the maximum transmission power in the cell, D_{user} is the distance of the user from the center of the cell and D_{max} is the maximum cell radius.

CHAPTER 4

METHODOLOGY

4. Methodology

4.1. Development of Simulation Model

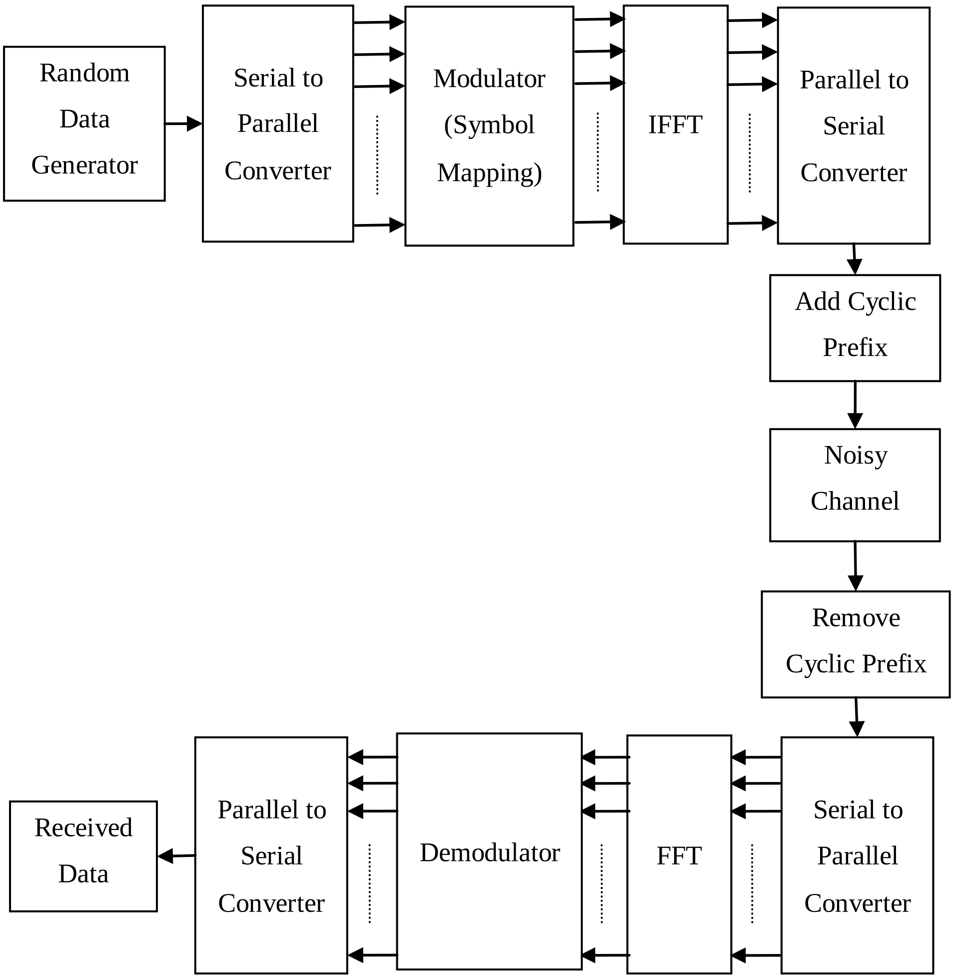

Figure 4.1 Block Diagram of OFDM Transmitter and Receiver

The block diagram for a basic OFDM communication system is shown in Figure 4.1. It consists of OFDM based transmitter and OFDM based receiver. The OFDM signal is transmitted through a noisy channel.

The random data generator generates a random sequence of binary digits (0 or 1) at a certain data rate. The serial data stream from the random data generator is converted into frames of certain size according to the number of data carriers in the OFDM signal, which would be transmitted in parallel.

The symbols (e.g. 1 bit/symbol for BPSK, 2 bits/symbol for QPSK, 4 bits/symbol for 16QAM etc.) in each parallel stream are mapped into a phase angle according to the modulation method. For example, in the case of QPSK mapping method , each symbol would constitute of 2 bits i.e. 2 bits/symbol and each symbol would be mapped to a phase angle of 0˚, 90˚, 180˚ or 270˚.

The Inverse Fast Fourier Transform (IFFT) of the modulated data frame then generates the corresponding time domain data frame. The IFFT procedure also ensures the orthogonality among the sub-carriers in the OFDM signal. The IFFT performs the transformation very efficiently and provides a simple way of ensuring that the sub-carrier signals produced are orthogonal to each other.

The time-domain output signals of the IFFT for each of the numerous sub-carriers of the system are linearly summed to form a single broadband signal. Then the cyclic prefix is appended at the start of each symbol. It is the repetition of the end of the symbol, added to the beginning of the symbol. It serves as a guard interval that minimizes the inter-symbol interference (ISI).

The resulting broadband signal is then transmitted through a communication channel model. The model determines the signal to noise ratio (SNR) in the channel. The output of the channel is the received signal at the receiver.

The receiver performs the opposite operation to the transmitter. The cyclic prefix is first removed from the received signal. The FFT operation then recovers the individual modulated signals. Due to the orthogonality of the sub-carriers, the recovered signals are free from adjacent sub-channel interferences. The signals are then demodulated using corresponding demodulation techniques to obtain the individual low-speed data streams. Finally, the multiple data streams can be re-accumulated to obtain the original high-speed message.

4.2. Implementation of Simulation Model

The simulation model of the OFDM communication system has been designed and modeled using Simulink software in MATLAB. Simulink is a software package integrated with the MATLAB environment which is used to model, simulate and analyze dynamic systems.

Figure 4.2 shows the OFDM system with 64-QAM digital modulation mapping implemented using Simulink in MATLAB.

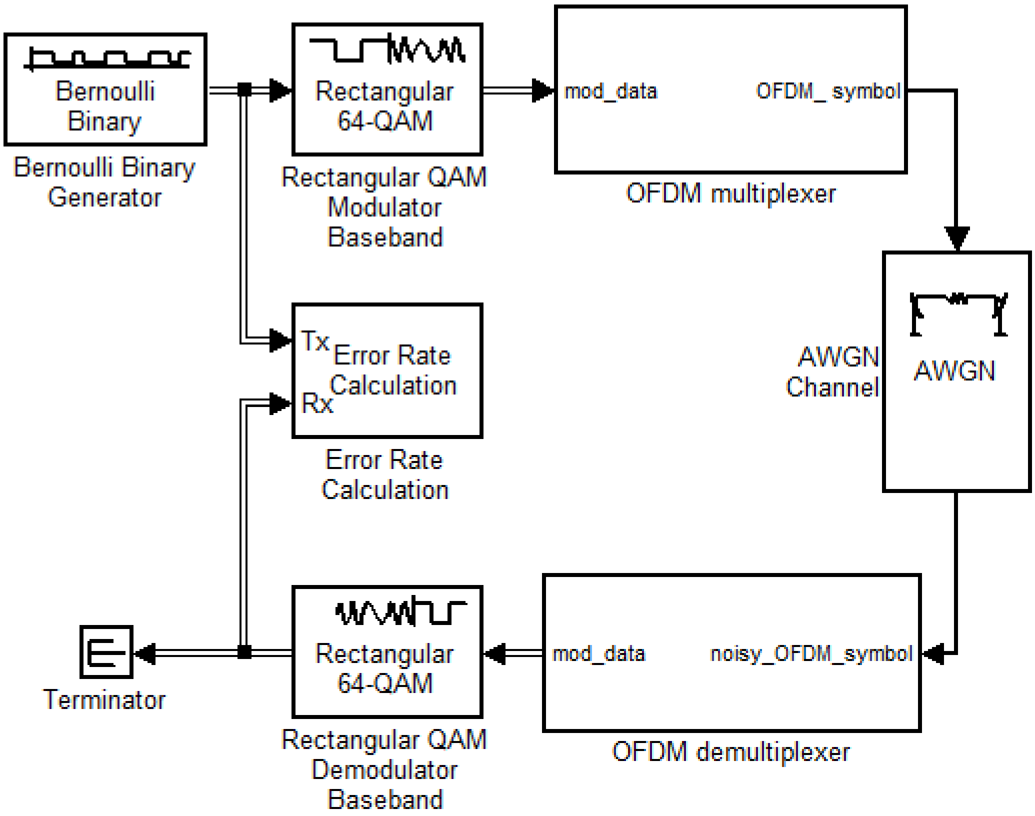

Figure 4.2 OFDM Simulation Model with 64 QAM Mapping

The Bernoulli random binary generator block generates random binary digits (0 or 1) at a constant data rate of 12 Mbps. Each consecutive six bits represent a single 64-QAM symbol. Thus, the Bernoulli binary random generator groups binary digits into frames of size 168 so as to produce 28 symbols each corresponding to a single sub-carrier in the OFDM symbol. This framing of 28 symbols into frames is equivalent to conversion of serial high-speed data stream into multiple parallel low-speed data streams. The 64-QAM modulator takes each symbol (group of 6 consecutive bits) and generates a baseband representation of the modulated signal. The output of the modulator is the frames with 28 modulated symbols.

This frequency domain data is fed to the OFDM multiplexer sub-system that constitutes of the blocks as shown in Figure 4.3. The pilot insertion and zero padding block in the OFDM multiplexer subsystem adds a number of zeros into each frame such that each frame constitutes of 32 symbols instead of 28 symbols. Thus the frame size is now matched with the consecutive IFFT size. The block diagram of the pilot insertion and zero padding block is shown in Figure 4.4.

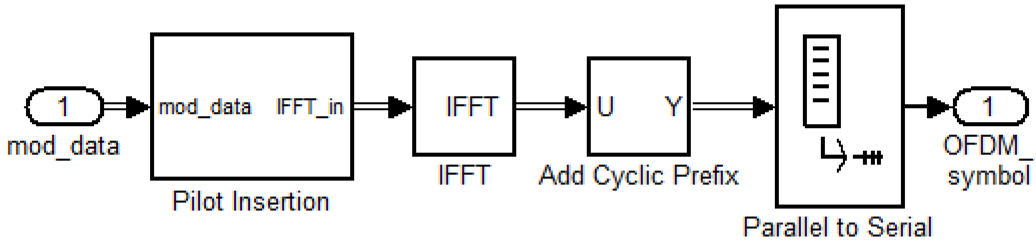

Figure 4.3 Block Diagram of OFDM Multiplexer

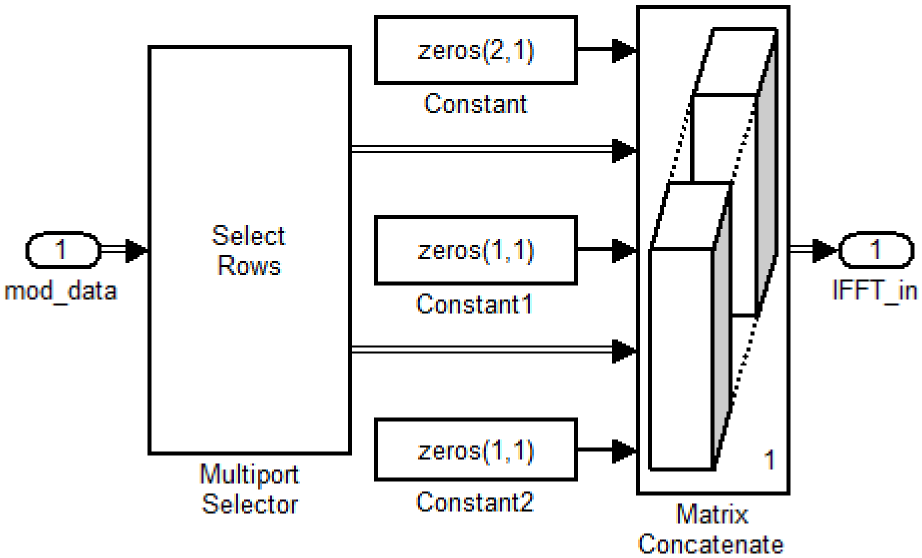

Figure 4.4 Block Diagram of Pilot Insertion and Zero Padding Block

The IFFT block converts the frequency domain data in each frame to time domain signals and also maintains the orthogonality among the sub-carriers. The output of the IFFT block is applied to a block that adds cyclic prefix to the overall symbol.

The cyclic prefix consists of 8 bits which increases the number of bits in each frame to 40 bits from 32 bits. The parallel data in each frame is then converted to serial data for transmission into the AWGN channel. The output of the OFDM multiplexer is the OFDM symbol that is transmitted serially into the noisy channel.

The AWGN channel block adds white Gaussian noise to the output of the OFDM multiplexer. The signal to noise ratio (SNR) of the AWGN channel can be set in the block parameters as required.

The OFDM demultiplexer sub-system in the receiver section of the system performs the reverse operation of the OFDM multiplexer. Various blocks in the OFDM demultiplexer sub-system are shown in Figure 4.5. First, the serial data obtained from the AWGN channel is converted to parallel data in the form of frames of size 40. Then the cyclic prefix is removed from each frame. The FFT operation is carried out next to recover the frequency domain data frame. Finally, the pilot data added into the frames as zero padding during the transmission process are removed to obtain the baseband representation of the modulated signal.

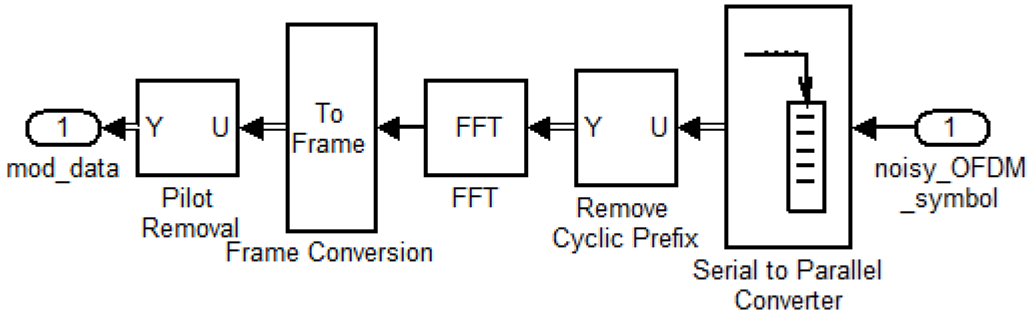

Figure 4.5 Block Diagram of OFDM Demultiplexer

The 64-QAM demodulator block in the receiver generates the original data by demodulating the baseband representation using 64-ary Quadrature Amplitude Modulation/Demodulation technique. The recovered data frames are transmitted to the terminator block which behaves as a sink.

The error rate calculation block in the simulation model is a comparison unit that compares the original data from the transmitter with the recovered data from the receiver. It calculates the running statistic of the error rate by dividing the total number of unmatched data pairs by the total number of input data pairs. The calculated error rate or the bit error rate (BER) serves as a performance metric for the OFDM system.

4.3. Performance Analysis of Resource Allocation Techniques

The performance analysis of different resource block allocation techniques can be performed on the basis of various performance parameters. These parameters can also be used to compare the performance of different allocation methods and ICI mitigation measures. The different performance parameters that are used in this thesis work in order to study the performance of different resource allocation methods are described in detail in the following sections.

4.3.1. Effect of Distance of UE on SINR

Signal to Interference and Noise Ratio (SINR) is a key parameter that can describe the performance of a resource block allocation technique. As a general rule, the received signal power level at a UE decreases as it moves away from the center of the serving cell. Thus, the SINR level of received signal decreases as the distance from the cell center increases. Furthermore, as a UE moves towards the cell edge from the center of the cell, the strength of the interference signals from the adjacent cells rises. Since, ICI levels are stronger at the edge of the cell, the SINR values of the actual transmitted signal is further reduced as the distance from the cell center increases.

The SINR at any point in a cell can be calculated by taking the ratio of actual signal strength and the strength of interferences from neighboring cells and noise (thermal noise) at that point.

The SINR in the l^{th} cell of a wireless communication system is given by the expression [13],

$$SINR = \frac{G_l P_l}{\sum_{i,i \neq l} G_i P_i + \sigma^2} \tag{4.1}$$

where, P_l is the transmission power of the signal from l^{th} cell, which is the actual signal power and P_i is the transmission power of the signal transmitted from the i^{th} interfering cell. G_i is the transmission gain between the i^{th} cell and the UE location. The transmission gain is mainly depends on the propagation path loss, shadow fading, fast fading, etc. during the propagation from respective eNB to the UE location. σ^2 is the additive white noise power given by,

$$\sigma^2 = N_o B \tag{4.2}$$

where, N_o is the noise power spectral density and B is the bandwidth of signal transmission.

For simplicity in the thesis work, a three cell OFDMA system has been considered as shown in Figure 4.6.

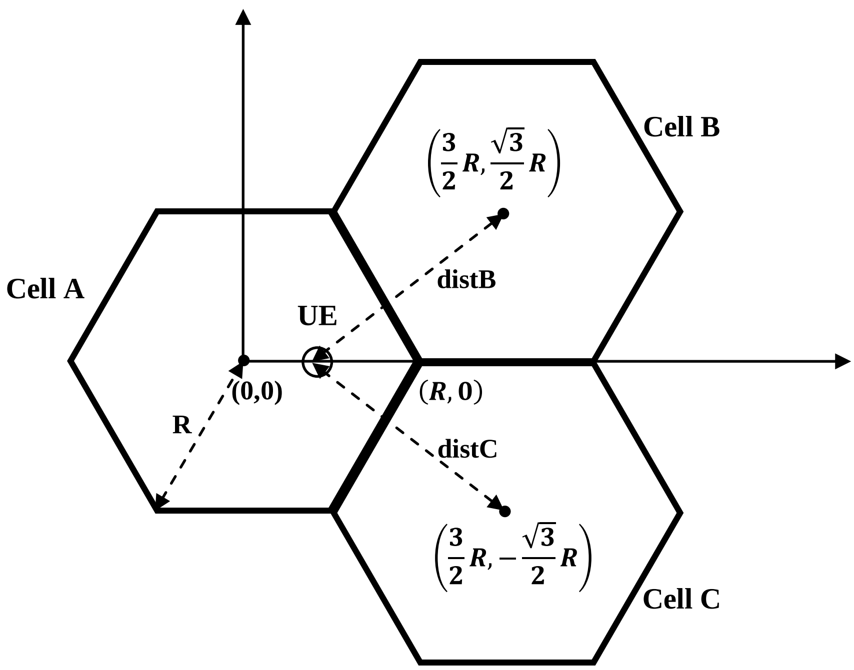

Figure 4.6 Three Cell Geometry

Three adjacent hexagonal cells each with equal radius R are considered in a two-dimensional coordinate system as shown in Figure 4.6. Cell A centered at the origin of the coordinate system. Then, according to the hexagonal geometry cell B and cell C would be centered at coordinates $\left(\frac{3}{2}R, \frac{\sqrt{3}}{2}R\right)$ and $\left(\frac{3}{2}R, -\frac{\sqrt{3}}{2}R\right)$ respectively.

The performance analysis is performed in cell A. Cell B and cell C act as interfering cells. The signal transmitted from eNB of cell A is the desired signal for the receiver UE located in cell A whereas the signal transmitted in same frequency channels from eNBs of cell B and cell C are interference for the receiver UE.

The SINR values at different locations in cell A for the model shown in Figure 4.6 can be calculated by modifying equation (4.1) as,

$$SINR = \frac{G_A P_A}{G_B P_B + G_C P_C + \sigma^2} \tag{4.3}$$

where, P_A, P_B and P_C are the signal transmission power from cell A, cell B and cell C respectively. G_A, G_B and G_C are the transmission gains between cell A and UE location, cell B and UE location and cell C and UE location respectively.

The SINR values at different locations in the cell can be obtained by varying the location of UE within the cell. For simplicity and uniformity, the receiver UE position in cell A is varied in equal steps along the x-axis from $(0,0)$ to $(R, 0)$ i.e. from cell center to cell boundary.

To model the propagation path loss, an empirical formula for LTE simulations suggested in [14] is used, which is given as,

$$L_P = 128.1 + 37.6\ log_{10}(d) \tag{4.4}$$

where, L_P is the path loss from transmitter to receiver in dB and d is the distance between transmitter and the receiver in km. Equation (4.4) is the distance dependent path loss equation defined for LTE macro-cell system simulations with operating frequency of 2 GHz. The path losses for signal transmitted by cell A, cell B and cell C for the given model are obtained by calculating the distance between the respective eNB and the UE location as indicated in Figure 4.6 and then using equation (4.4).

Finally, the transmission gains G_A, G_B and G_C required for equation (4.3) is obtained from the calculated path loses, using the formula given as,

$$G_P = 10^{-\frac{L_P}{10}} \tag{4.5}$$

If all cells in the system have constant and equal signal transmission power level i.e. $P_A = P_B = P_C = P$, then equation (4.3) is reduced to,

$$SINR = \frac{G_A P}{G_B P + G_C P + \sigma^2} \tag{4.6}$$

Furthermore, for UE locations with high ICI levels, the thermal noise can be neglected and the calculation of SINR value can be simplified as,

$$SINR = \frac{G_A}{G_B + G_C} \tag{4.7}$$

4.3.2. Effect of SINR on BER

Section 4.3.1 discusses the concept for obtaining the SINR values for different locations of UE in a cell. Once the SINR values are obtained, the simulation model of OFDMA system described in section 4.2 can be used to simulate the performance of the OFDMA system. Each of the calculated SINR values modifies the AWGN channel in the system model. The OFDMA system model then generates the BER in the OFDM transmission and reception for each value of SINR.

The BER values obtained for different values of SINR can be used to study the nature of change in error rate with change in SINR values. Also, the change in

BER for different UE distances from the cell center can be obtained using the relations between the distance of UE from the cell center and SINR values obtained in section 4.3.1.

4.3.3. Effect of SINR on Maximum Capacity

The effect of varying SINR can be used to estimate the maximum capacity of the channel. This can be done by using the Shannon's channel capacity theorem, which gives [13],

$$C = B\ log_2(1 + SINR) \tag{4.8}$$

where, C is the maximum capacity of the channel in bits/sec for the given SINR value. B is the total bandwidth of the channel in Hz.

Similarly, the maximum achievable bandwidth efficiency (γ) in bits/sec/Hz can be obtained using the following equation,

$$\gamma = \frac{C}{B} = log_2(1 + SINR) \tag{4.9}$$

Using equations (4.8) and (4.9), the effect of change SINR values in channel capacity or channel bandwidth efficiency can be obtained. Also, the relation between channel capacity or channel bandwidth efficiency with distance from the cell center can be achieved using the relations between the distance of UE from the cell center and SINR values obtained in section 4.3.1.

4.4. Performance Analysis of Reuse 1 Technique

According to the discussion in section 3.5.1, the Frequency Reuse 1 technique assigns the total available sub-channels in the system to each of the cells in the network. The Frequency Reuse 1 technique is implemented in three-cell OFDM system presented in section 4.3.1 (Figure 4.6). Then the performance analysis of the system with Reuse 1 technique is performed as discussed in following sections.

4.4.1. Effect of Distance of UE on SINR

As discussed earlier in section 4.3.1, the SINR values at different location in cell A of Figure 4.6 can be obtained by using equation (4.3). However, in Reuse 1 scheme all three cells use the same frequency channels. Hence the interference levels from cells B and C will be high and the thermal noise power can be neglected. Also, we assume that the transmission powers of all three cells are constant and equal. Hence, the SINR values for different UE locations can be obtained by using equation (4.7).

The transmission gain values G_A, G_B and G_C are obtained by using equations (4.4) and (4.5).

4.4.2. Effect of SINR on BER and Maximum Capacity

The SINR values at different UE locations obtained in section 4.4.1 are used to observe the effect on BER using the procedure described in section 4.3.2. Also, the maximum capacity and the maximum achievable bandwidth efficiency of the system for different SINR values are obtained using equations (4.8) and (4.9).

The relation between the BER and the UE location can also be observed using the corresponding values of UE locations for different SINR values.

4.5. Performance Analysis of Reuse 3 Technique

The Frequency Reuse 3 technique divides the total available system bandwidth into three disjoint sub-bands of equal bandwidths. Each of these sub-bands is assigned to three different adjacent cells. For simulation, the Reuse 3 technique is implemented in three-cell OFDM system presented in section 4.3.1 (Figure 4.6). The performance analysis of the system with Reuse 3 technique is performed as in previous sections, which is briefly described in following sections.

4.5.1. Effect of Distance of UE on SINR

The SINR values at different location in cell A of Figure 4.6 can be obtained by using equation (4.3). However, in Reuse 3 scheme all three cells use different sub-channel groups. Hence the interference from the adjacent cells B and C is zero. The only interference on the transmission signal in cell A is due to the thermal noise. Hence, equation (4.3) can be simplified for Reuse 3 technique as follows,

$$SINR = \frac{G_A P}{\sigma^2} \tag{4.10}$$

The transmission gain value G_A is obtained by using equations (4.4) and (4.5).

4.5.2. Effect of SINR on BER and Maximum Capacity

The effect of SINR values at different UE locations on BER performance of the OFDMA system model, described in section 4.2, is obtained by the simulation of the OFDMA system model using the procedure described in section 4.3.2. Also, the maximum capacity and the maximum achievable bandwidth efficiency of the system for different SINR values are obtained using equations (4.8) and (4.9). However, the bandwidth allocated for the system in Reuse 3 method will be only one-third of the total available bandwidth of the system, which results in reduced system capacity.

The relation between the BER and the UE location can also be observed using the corresponding values of UE locations for different SINR values, which can be obtained from section 4.5.1.

4.6. Performance Analysis of PFR Technique

From section 3.5.3, it can be seen that the Partial Frequency Reuse technique allocated different frequency bands for CCUs and CEUs. The implementation of PFR technique is done in the three-cell OFDM system presented in section 4.3.1 (Figure 4.6). Here, the CCUs of all three cells use the same band of frequencies, whereas the remaining spectrum is divided into three sub-groups, each for CEUs of single cell. The performance analysis of the system with PFR technique for ICI mitigation is performed with various parameters described below.

4.6.1. Effect of Distance of UE on SINR

The SINR values at different location in cell A of Figure 4.6 with PFR allocation method can be obtained by dividing the cell into two regions. The SINR values for CCUs are calculated in the inner region of the cell and that for CEUs are calculated in the outer region of the cell. For simulation purpose, the area within the two-third of the cell radius is considered for CCUs. The cell region outside the two-third of the cell radius is considered for CEUs. In both regions, the interference from the nearby cells B and C is almost zero. So, the SINR values are calculated using equation (4.10). The transmission gain value G_A is obtained by using equations (4.4) and (4.5).

4.6.2. Effect of SINR on BER and Maximum Capacity

The effect of SINR values at different UE locations on BER performance of the OFDMA system model, described in section 4.2, is obtained by the simulation of the OFDMA system model using the procedure described in section 4.3.2. Also, the maximum capacity and the maximum achievable bandwidth efficiency of the system for different SINR values are obtained using equations (4.8) and (4.9).

The relation between the BER and the UE location can also be observed using the corresponding values of UE locations for different SINR values, which can be obtained from section 4.6.1.

However, the bandwidth allocated in the system for CCUs and CEUs are different.

4.7. Performance Analysis of SFR Technique

The Soft Frequency Reuse technique, described in section 3.5.4, divides the overall users into CCUs and CEUs. The CCUs are allocated the entire system bandwidth whereas the CEUs are allocated only a portion of system bandwidth, different from those allocated in neighboring cells. The implementation of SFR technique, for the simulation purpose, is performed in the three-cell OFDM system presented in section 4.3.1 (Figure 4.6). The entire system bandwidth is divided into three equal but non-overlapping sub-groups, as in Reuse 3 technique. Each of these sub-bands is transmitted at high power in different adjacent cells. The remaining frequency bands in each cell are transmitted at low power so as to cover only the inner region of the cell. The performance analysis of the system with PFR technique implementation for ICI mitigation is performed with various parameters described in following sections.

4.7.1. Effect of Distance of UE on SINR

For simulation purpose, the area within the two-third of the cell radius is considered for CCUs. The cell region outside the two-third of the cell radius is considered for CEUs. In the inner region, the interference from the adjacent cells is negligible due to the large distance. Similarly in the outer region, the adjacent cells use different frequency bands. Hence in both regions, the interference from the nearby cells B and C is almost zero. Thus, the SINR values at different location in cell A of Figure 4.6 with SFR allocation method can be obtained by using equation (4.10).

The transmission gain value G_A is obtained by using equations (4.4) and (4.5).

4.7.2. Effect of SINR on BER and Maximum Capacity

The different SINR values at different UE locations on the cell cause varying BER performance along the cell. The simulation of the OFDMA system model, described in section 4.2, using the procedure described in section 4.3.2, gives the effect of change in UE location and corresponding change in SINR values on BER performance of the OFDMA system model.

The maximum capacity and the maximum achievable bandwidth efficiency of the system for different SINR values are obtained using equations (4.8) and (4.9). The relation between the maximum capacity or the maximum achievable bandwidth efficiency with the UE location can also be observed using the corresponding values of UE locations for different SINR values, which can be obtained from section 4.6.1.

It should be considered however that the entire system bandwidth is allocated for CCUs and only one-third of the available bandwidth is allocated for CEUs.

4.8. Performance Analysis of Proposed Algorithm

The proposed dynamic resource allocation algorithm has already been discussed in section 3.5.5. Each user in the cell can be allocated any sub channels from the entire system bandwidth. But the allocation is performed dynamically based on the information of interference pattern from the adjacent cells. The implementation of the proposed resource allocation algorithm, including power allocation, is performed in the three-cell OFDM system presented in section 4.3.1 (Figure 4.6). The performance analysis of the system implementing the proposed algorithm for ICI mitigation is performed with various parameters described in following sections.

4.8.1. Effect of Distance of UE on SINR

The values of SINR at different locations in cell A of Figure 4.6 can be obtained by using equation (4.3). But the proposed algorithm assigns the sub channels and their transmission power levels in such a way that the interference levels are minimized. Hence, neglecting the interference from adjacent cells, the SINR values are calculated using equation (4.10).

The transmission gain value G_A is obtained by using the path loss equation described in equation (4.4) and path loss to path gain conversion equation given by equation (4.5).

4.8.2. Effect of SINR on BER and Maximum Capacity

The simulation of the OFDMA system model described in section 4.2, using the procedure described in section 4.3.2, gives the effect of SINR values at different UE locations on BER performance of the OFDMA system model. Also, the maximum capacity and the maximum achievable bandwidth efficiency of the system for different SINR values are obtained using equations (4.8) and (4.9).

The effect of UE location or distance of UE from the cell center on the BER performance of the simulation model, maximum capacity of the system and the maximum achievable bandwidth efficiency can be observed using the relation between the UE locations and the corresponding SINR values, which can be obtained from section 4.6.1.

CHAPTER 5

SIMULATION AND RESULTS

5. Simulation and Results

5.1. Simulation Parameters

The simulations are performed on three-cell OFDMA system described in section 4.3.1. The radius of each hexagonal cell is considered to be 500m and the area inside the two-third of the cell radius is considered for CCUs and the region outside the two-third of the cell radius is considered for CEUs. The simulations are performed every 25m, starting from 50m up to 500m from cell center.

To calculate channel capacity, a maximum of six PRBs are considered to be allocated for each user when total available bandwidth is allocated to each cell. If a cell is allocated only a portion of available bandwidth, then the user will get lesser number of PRBs proportional to the allocated bandwidth. The system parameters are derived from WiMAX system specifications described in [15]. The main simulation parameters are listed below.

Table 5.1 Main Simulation Parameters

Parameters	Value
Cell Radius	500 m
Max. Transmission Power	20 W
Thermal Noise Level	-174 dBm/Hz
Max. Number of PRBs per User	6
No. of sub-carriers per PRB	28
Sub-carrier Spacing	10 KHz

5.2. Simulation Results for Reuse 1 Technique

The results for the simulations of Reuse 1 resource block allocation technique as described in section 4.4 are shown below.

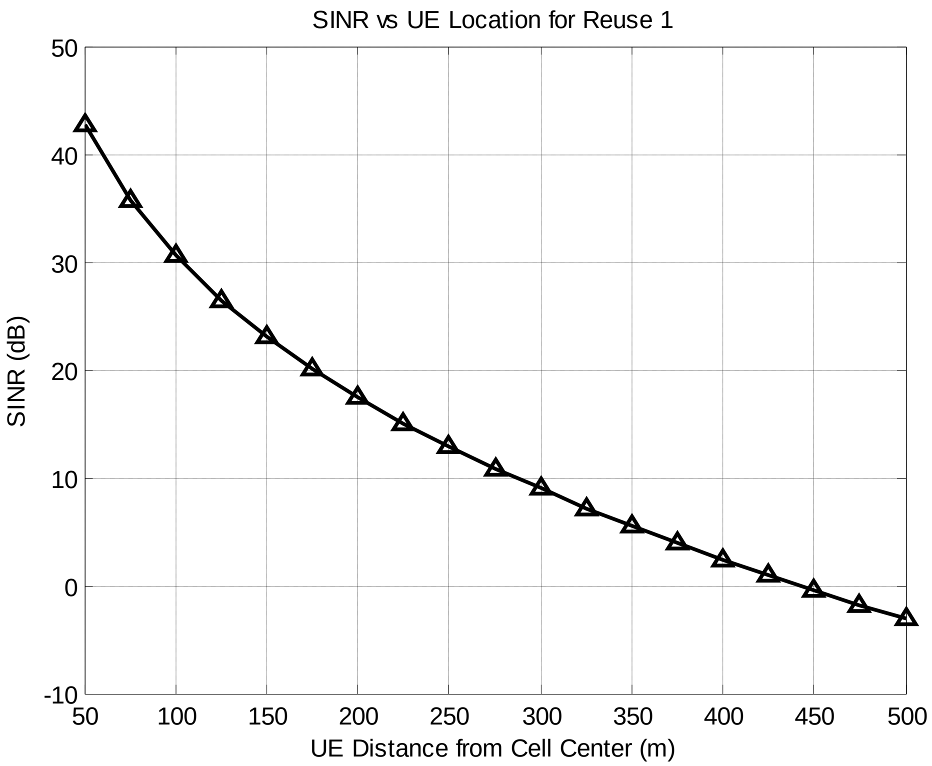

Figure 5.1 Change in SINR with distance from cell center for Reuse 1 technique

Figure 5.1 shows the effect of varying the UE distance from cell center on the SINR level of the transmitted signal. According to Figure 5.1, as the UE moves from cell center to the boundary of the cell, the SINR level decreases. The maximum SINR value is 42.73 dB at 50m from the center of the cell. Due to large ICI, SINR value is too low towards the cell edge. Signal level is less than interference level for UEs beyond 450m from the cell center.

Figure 5.2 and 5.3, shown below; present the change in BER for the change in SINR value and UE location respectively. As UE distance from the center of cell increases, SINR level decreases. This causes BER to increase with increase in distance from cell center. The BER is shown in logarithmic scale with respect to variation in SINR value and UE location. The BER is about 0.483 at the cell boundary (500m). The BER is low only for UEs located within 100m of the cell center. Beyond that, the BER is so high that the channel such that the QoS is highly degraded.

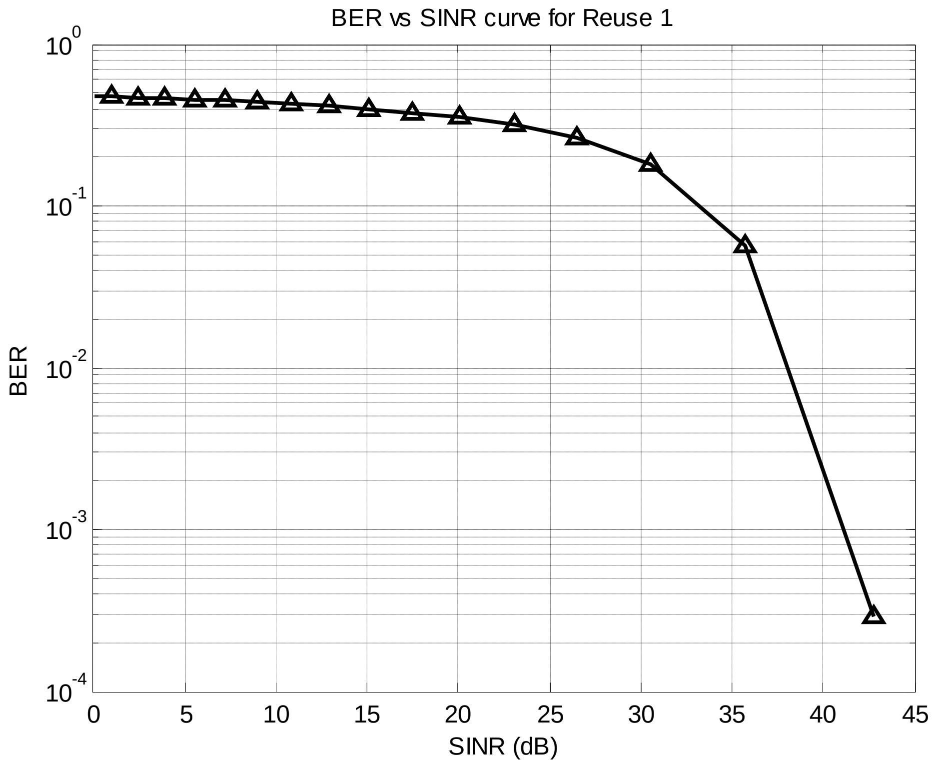

Figure 5.2 BER vs. SINR curve for OFDM System Model

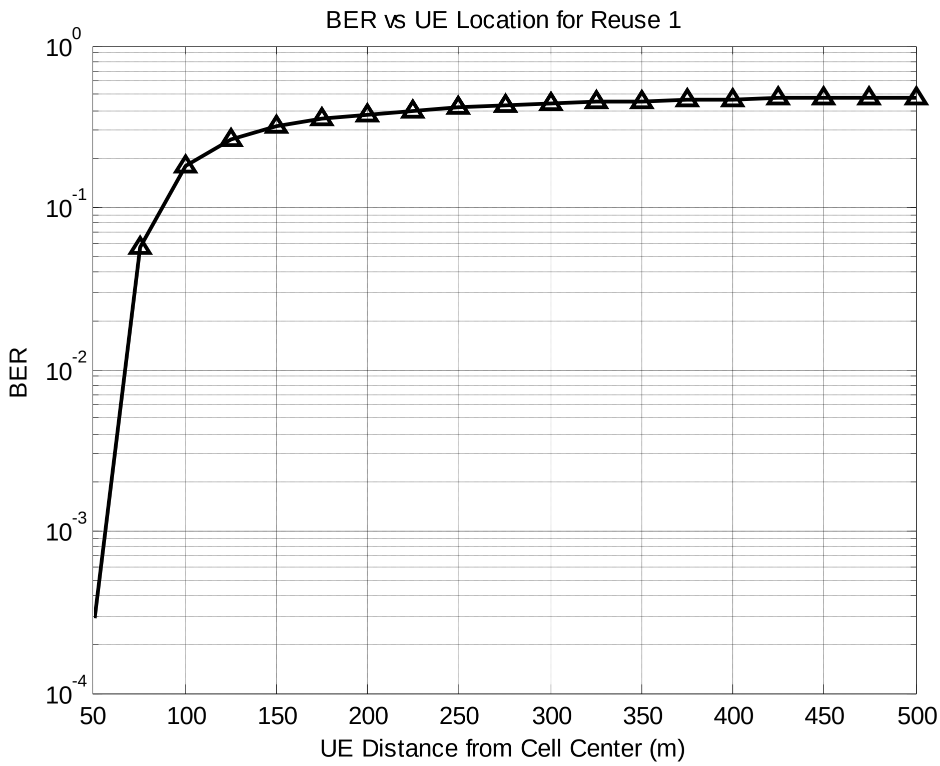

Figure 5.3 BER vs UE location for Reuse 1 technique

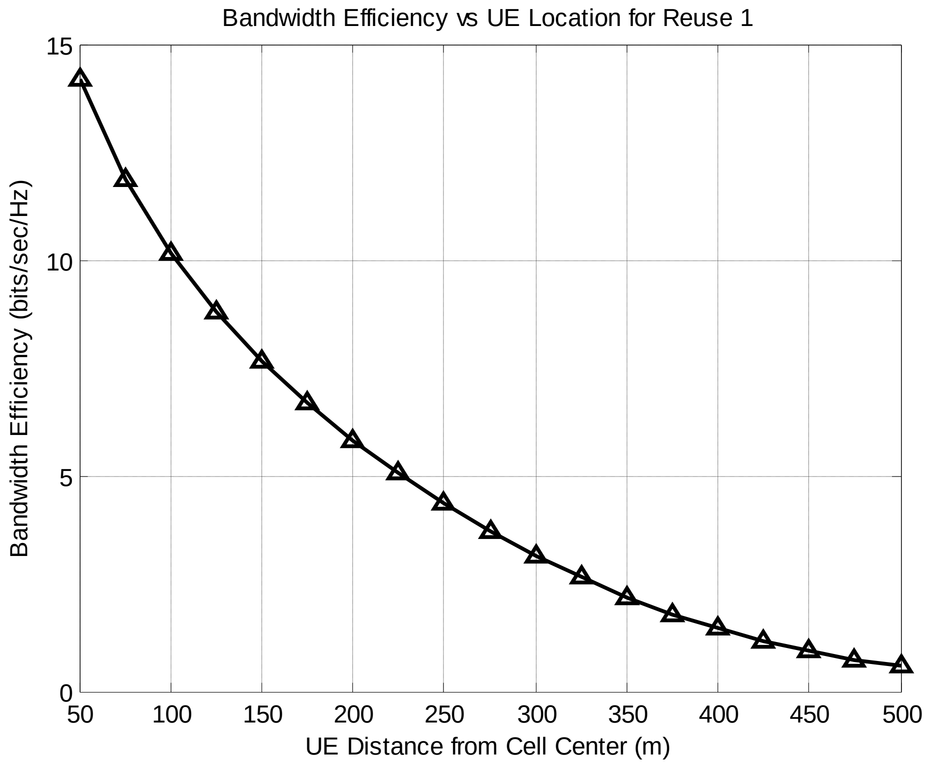

Figure 5.4 Bandwidth efficiency vs. distance from cell center for Reuse 1

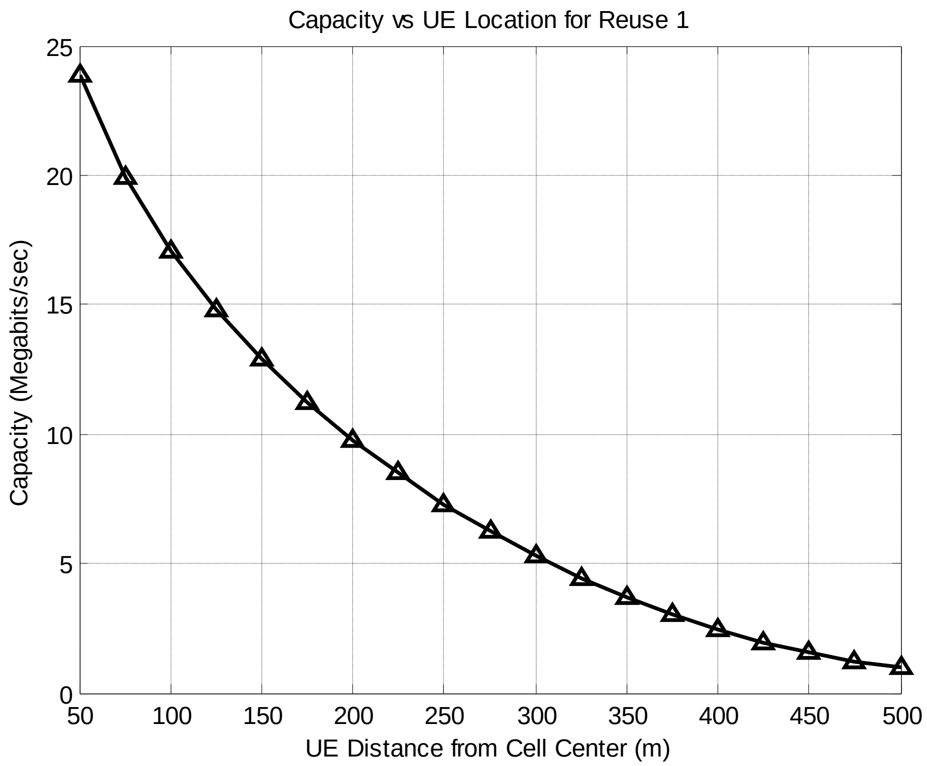

Figure 5.5 Capacity vs distance from cell center for Reuse 1

Figure 5.4 shows the variation in bandwidth efficiency for different UE locations. The bandwidth efficiency of the channel decreases with increase in spacing between the serving eNB and UE. Figure 5.5 presents the channel capacity vs UE distance from the cell center. In Reuse 1 technique, allocation of a total of six PRBs is considered. Thus a total of 168 subcarriers and 1.68 MHZ bandwidth is considered to be allocated for a user. According to Figure 5.5, a maximum of 23.85 Mbps data rate can be achieved for users at 50m from cell center, which decreases with increase in UE distance from cell center.

5.3. Simulation Results for Reuse 3 Technique

The performances of Reuse 3 technique based on various simulations, explained in section 4.5, are shown below.

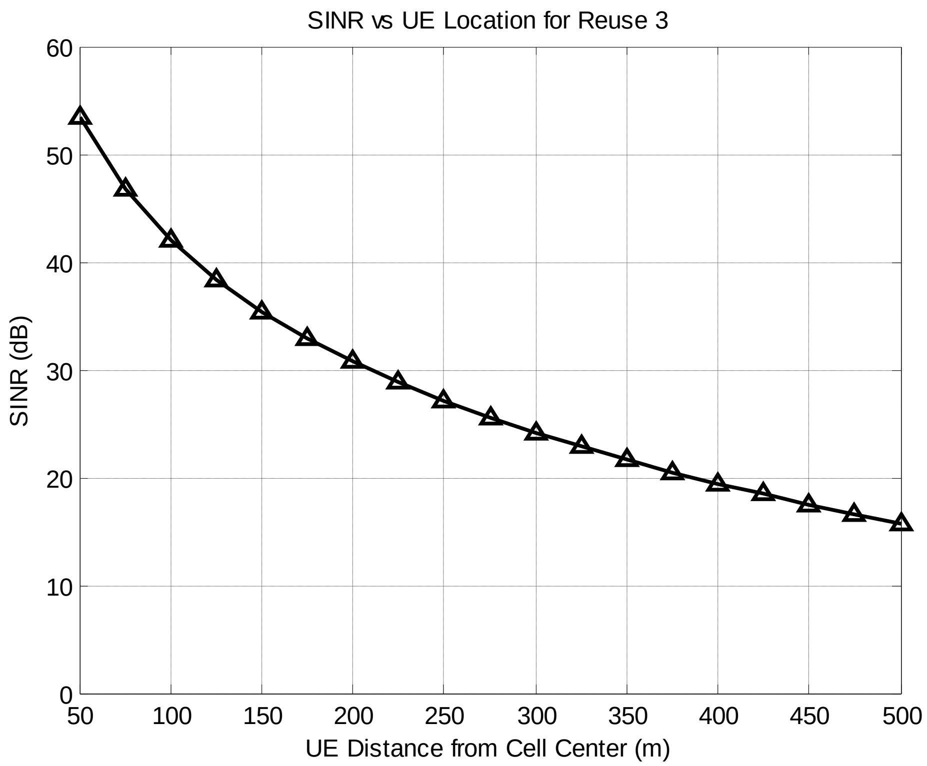

Figure 5.6 Change in SINR with distance from cell center for Reuse 3 technique

Figure 5.6 represents the effect of UE distance from cell center on the SINR level of the transmitted signal for Reuse 3 technique. UE at 50m distance from the cell center can receive signal level with SINR value of 53.38 dB. The SINR value decreases with increase in distance between the cell center and UE location. The minimum SINR value is 15.78 dB at cell boundary. In comparing Figure 5.1 and 5.6, it can be observed that the SINR level rises with the use of Reuse 3 technique.

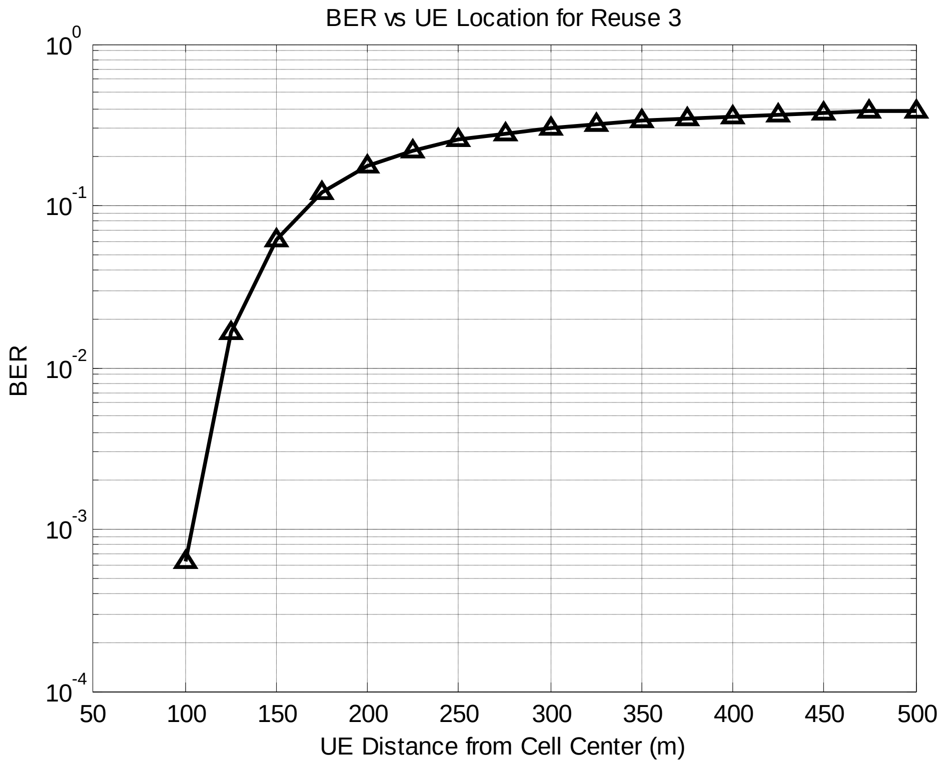

Figure 5.7 BER vs. UE location for Reuse 3 technique

Figure 5.7 shows the change in BER for the change in UE distance. Since, the SINR value for Reuse 3 technique is higher than that for Reuse 1 technique; the BER for Reuse 3 is lower in comparison to the BER distribution in Reuse 1 technique.

Figure 5.8 and 5.9 show the change in bandwidth efficiency and channel capacity with increase in UE distance from the cell center.

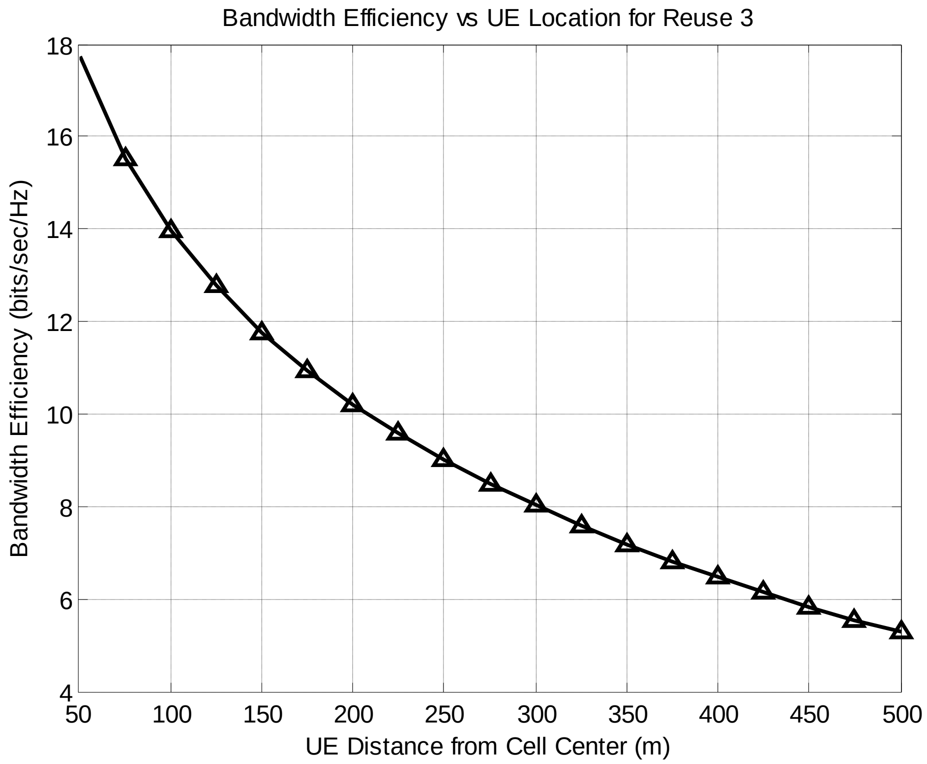

Figure 5.8 Bandwidth efficiency vs. distance from cell center for Reuse 3

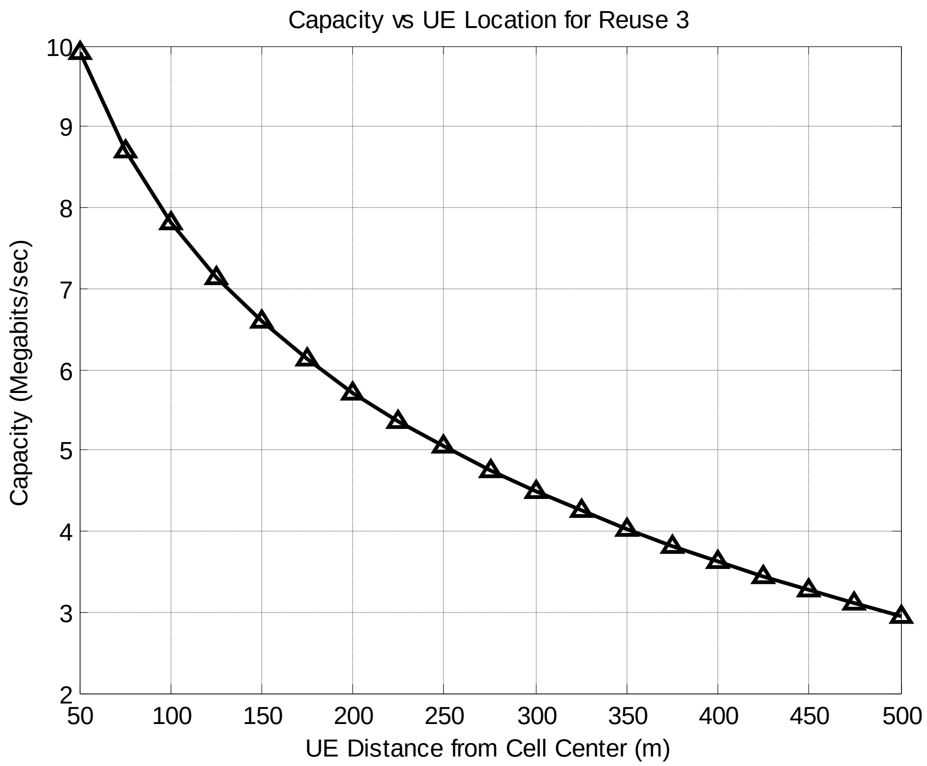

Figure 5.9 Capacity vs. distance from cell center for Reuse

According to Figure 5.8 and 5.9, the bandwidth efficiency or the channel capacity of the channel decreases with the increase in distance between the eNB and UE. Since, the total system bandwidth is equally divided and allocated into three adjacent cells; the channel capacity is reduced in Reuse 3 technique. For simulation, only two PRBs are allocated to a user. Thus only 56 subcarriers with a total of 560 KHz bandwidth are allocated to a user. Figure 5.9 shows that UE at 50m from the cell center can have maximum data rate of 9.929Mbps, which decreases with the increase in UE distance from cell center.

5.4. Simulation Results for PFR Technique

The interference pattern in PFR technique is similar to that of Reuse 3 technique. So, the SINR vs UE location curve and BER vs UE location curve for PFR technique are same as that of Reuse 3 technique. The bandwidth efficiency and channel capacity vs UE locations for PFR are shown below.

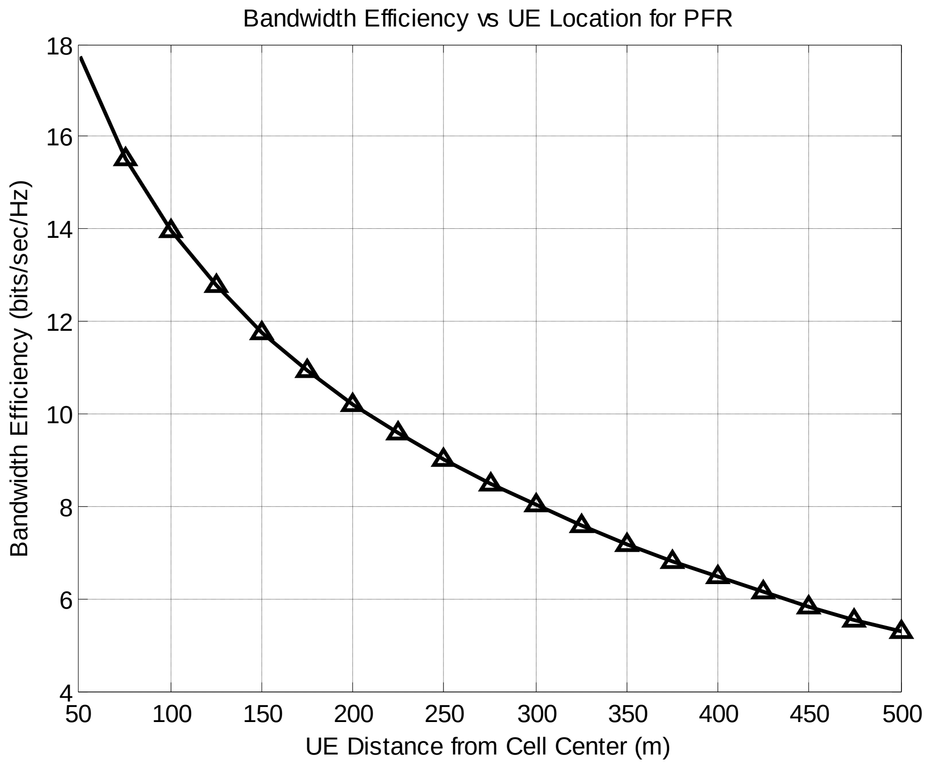

Figure 5.10 Bandwidth efficiency vs. distance from cell center for PFR

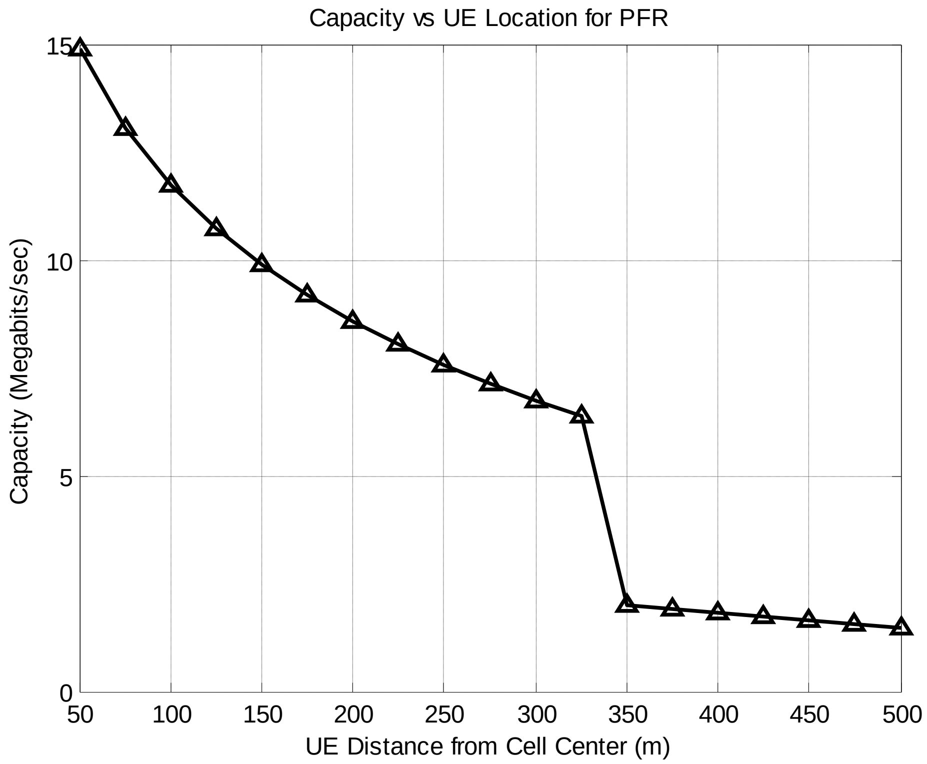

Figure 5.11 Capacity vs. distance from cell center for PFR

Figure 5.10 shows the bandwidth efficiency vs. user distance curve. The bandwidth efficiency is also similar to that of Reuse 3 technique. Figure 5.11 presents the maximum capacity for varying distances from the center of the cell. For simulation purpose, the CCUs are allocated three PRBs per user with 840 KHz and CEUs are allocated single PRB with 280 KHz bandwidth. Thus, the CCUs within 333m (two-third of cell radius) have higher channel capacity in comparison to CEUs located farther than 333m.

5.5. Simulation Results for SFR Technique

The interference pattern in SFR technique is also similar to that of Reuse 3 technique and PFR technique. So, the SINR vs UE location curve and BER vs UE location curve for SFR technique are same as that for Reuse 3 technique, as shown in Figure 5.6 and Figure 5.7.

The bandwidth efficiency vs UE locations and channel capacity vs UE locations for SFR technique are shown below.

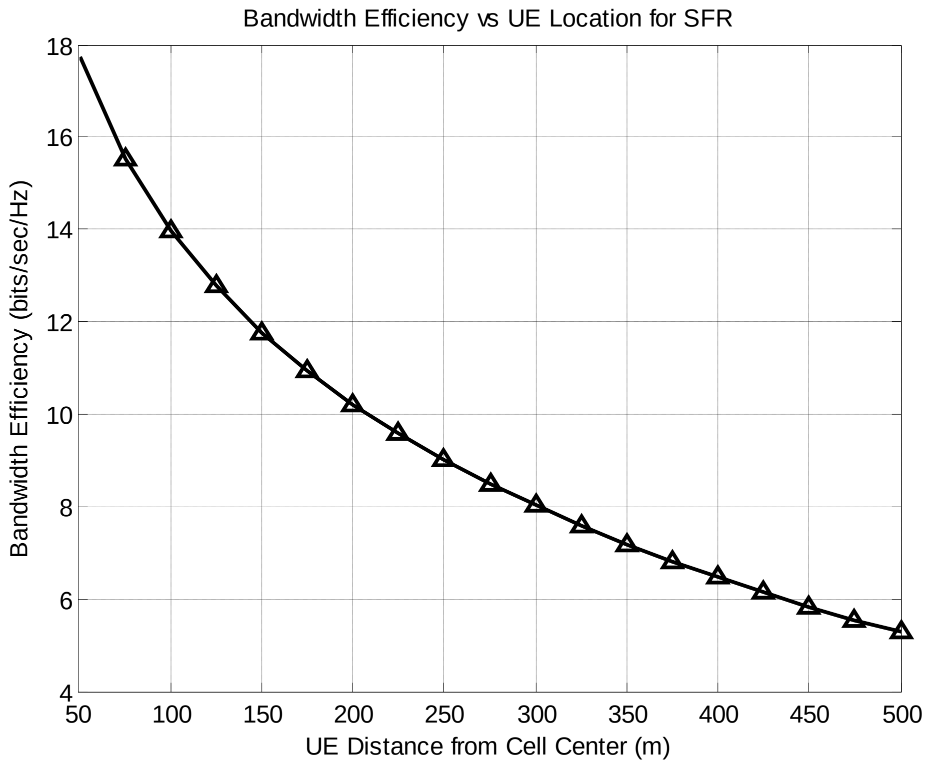

Figure 5.12 Bandwidth efficiency vs. distance from cell center for SFR

Figure 5.12 shows the bandwidth efficiency vs. user distance curve. The bandwidth efficiency curve for SFR technique is also similar to that of Reuse 3 technique and PFR technique due to the similar interference pattern.

However, Figure 5.11 shows that the maximum capacity of system with SFR technique is improved in comparison to that of the PFR technique. It represents the maximum capacity for varying distances from the center of the cell. Since the CCUs can occupy the entire system bandwidth, the CCUs within 333m (two-third of cell radius) are allocated maximum possible number of PRBs i.e. six PRBs per user. Thus, each user is allocated a total bandwidth of 1.68 MHz. Similarly, the CEUs located farther than 333m are allocated two PRBs per user with 560 KHz bandwidth.

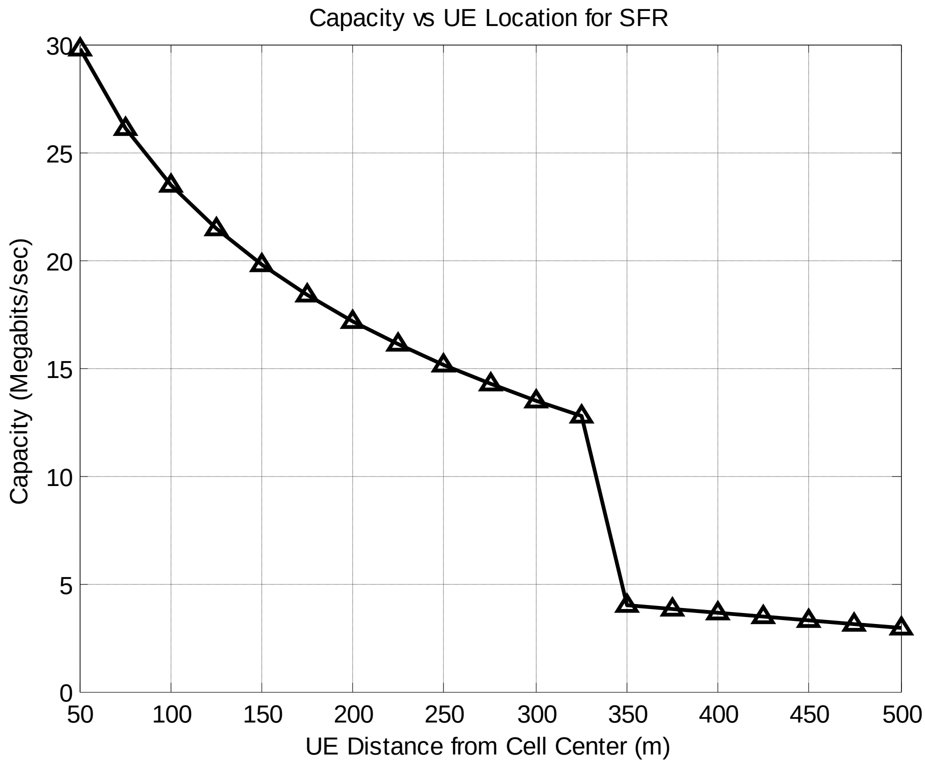

Figure 5.13 Capacity vs. distance from cell center for SFR

5.6. Simulation Results of Proposed Algorithm

This section describes the results of the implementation and simulation of the proposed dynamic resource allocation algorithm. The simulation of the proposed algorithm is performed based on the description given in section 4.8.

Figure 5.14 below shows the variation of SINR values at different UE locations. The SINR value decreases from 43.38 dB at 50 m from cell center to 15.78 dB at cell boundary. Unlike in previous resource allocation techniques, the system provides strong SINR values throughout the cell region and maintains smaller variation between the strongest and weakest transmission signals.

Figure 5.15 presents the change in BER for different UE locations. As the location of UE becomes farther from the cell center, SINR value decreases as shown in Figure 5.14. This causes the BER to increase with increase in UE distance.

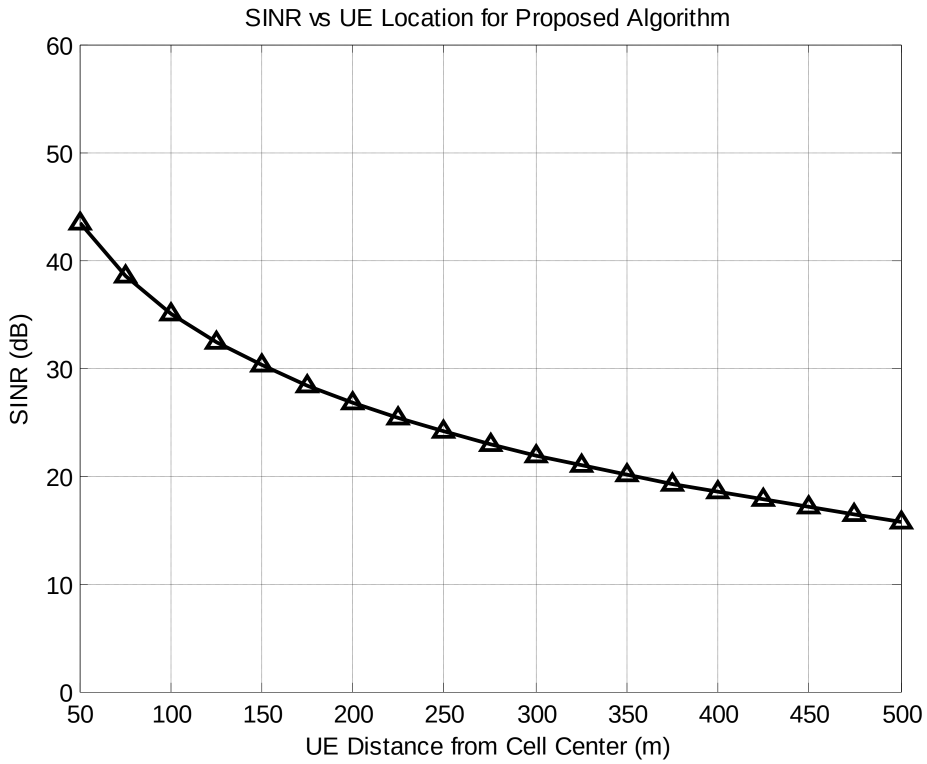

Figure 5.14 Change in SINR with UE distance for Proposed Algorithm

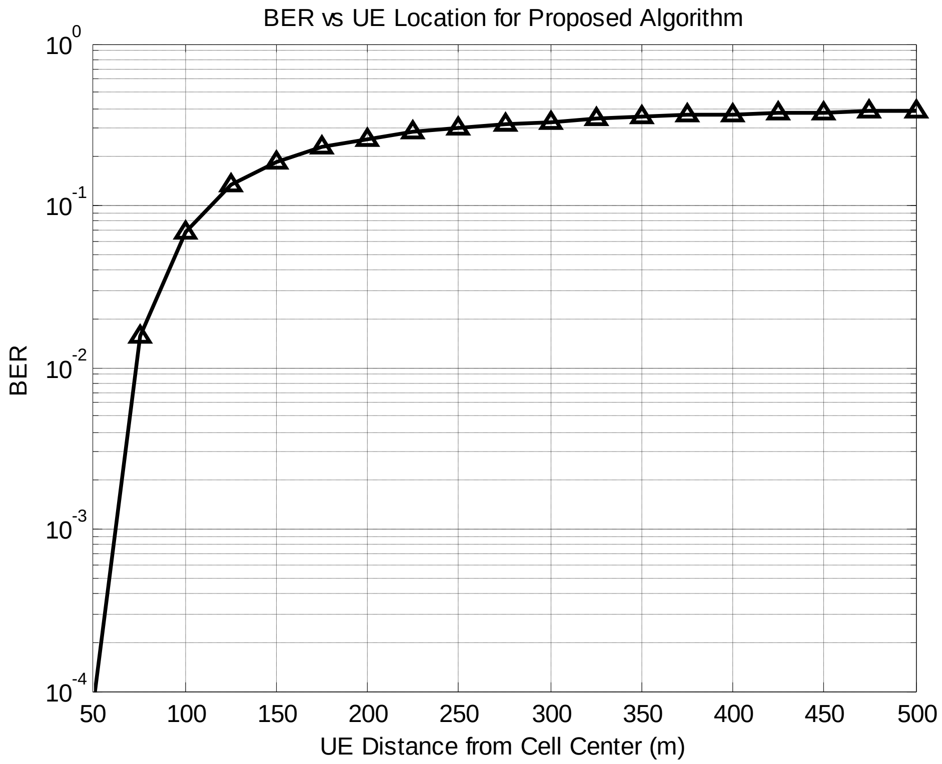

Figure 5.15 BER vs UE location for Proposed Algorithm

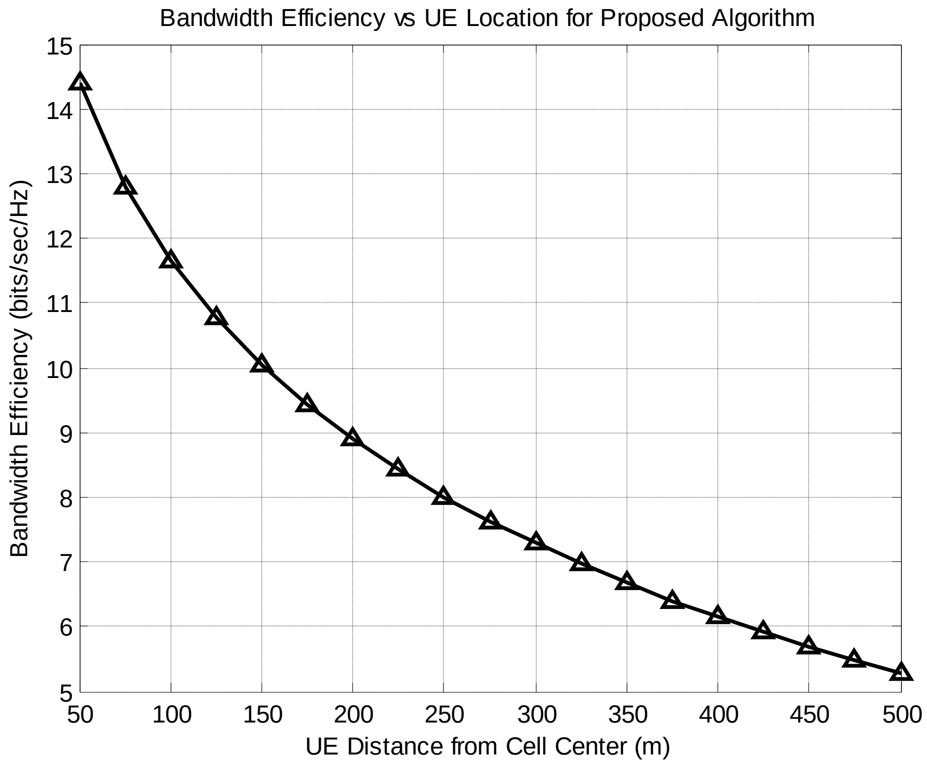

Figure 5.16 Bandwidth efficiency vs. UE distance for Proposed Algorithm

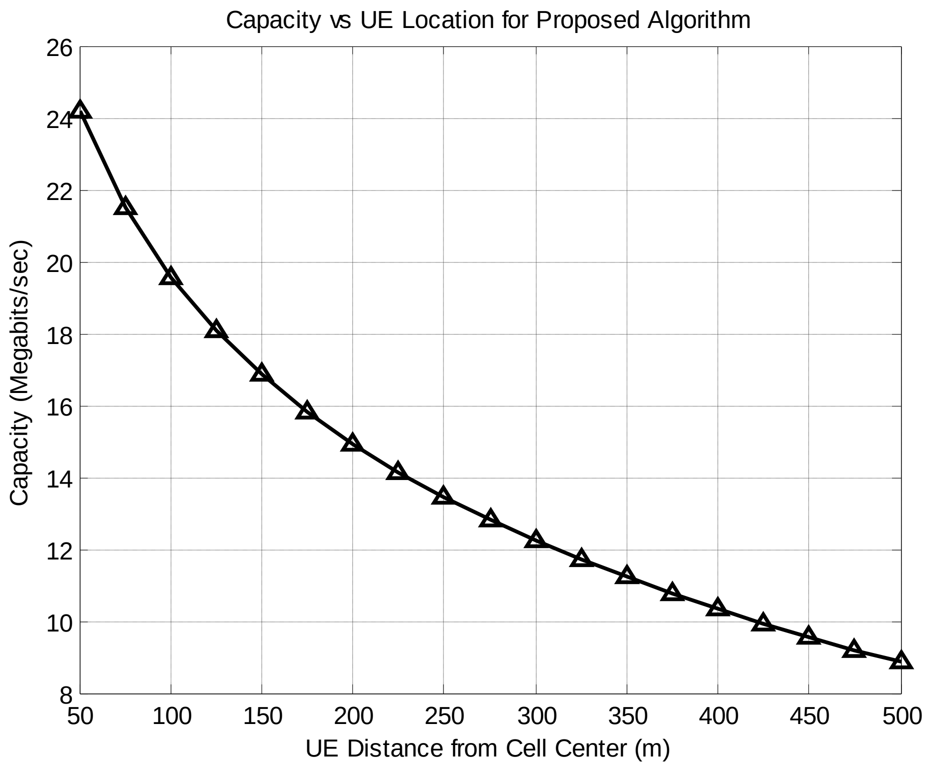

Figure 5.17 Capacity vs. distance from cell center for Proposed Algorithm

The variation in bandwidth efficiency with respect to different UE locations for the system utilizing the proposed algorithm is shown in Figure 5.16. Figure 5.16 presents that the bandwidth efficiency of the channel decreases with increase in spacing between the serving eNB and UE.

Figure 5.17 shows the channel capacity vs. UE location curve for the system with the application of the proposed algorithm. In this algorithm, each user is allocated with a total of six PRBs (maximum possible no. of PRBs). Thus a total of 168 subcarriers and 1.68 MHZ bandwidth is considered to be allocated for each user. This results in the increased capacity performance for all users, both CCUs and CEUs. According to Figure 5.17, a maximum of 24.21 Mbps data rate can be achieved for users at 50m from cell center, which gradually decreases to a minimum of 8.867 Mbps data rate at the cell boundary. However, unlike PFR and SFR techniques, the huge variation of system capacity for the CCUs and CEUs does not exist for users in the system utilizing the proposed algorithm.

5.7. Comparative Performance Analysis

This section presents the comparative analysis between the basic resource allocation techniques (Reuse 1, Reuse 3, PFR and SFR techniques) and the proposed dynamic resource allocation algorithm.

Figure 5.18 shows the SINR vs. UE location curves for the OFDMA system with Reuse 1, Reuse 3, PFR, SFR and proposed resource allocation techniques. Since the Reuse 1 technique cannot mitigate ICI, this system experiences the highest ICI values. Thus, SINR levels for the system with Reuse 1 technique are poorest. Reuse 3, PFR and SFR techniques have similar interference patterns. Hence, these techniques have same SINR vs. UE location curves. Due to the use of ICI mitigation techniques, these methods provide higher SINR levels in comparison to the Reuse 1 technique. The SINR vs. UE location curve for the proposed algorithm lies in between that of Reuse 1 technique and other techniques. The proposed algorithm provides much stable SINR values throughout the cell region.

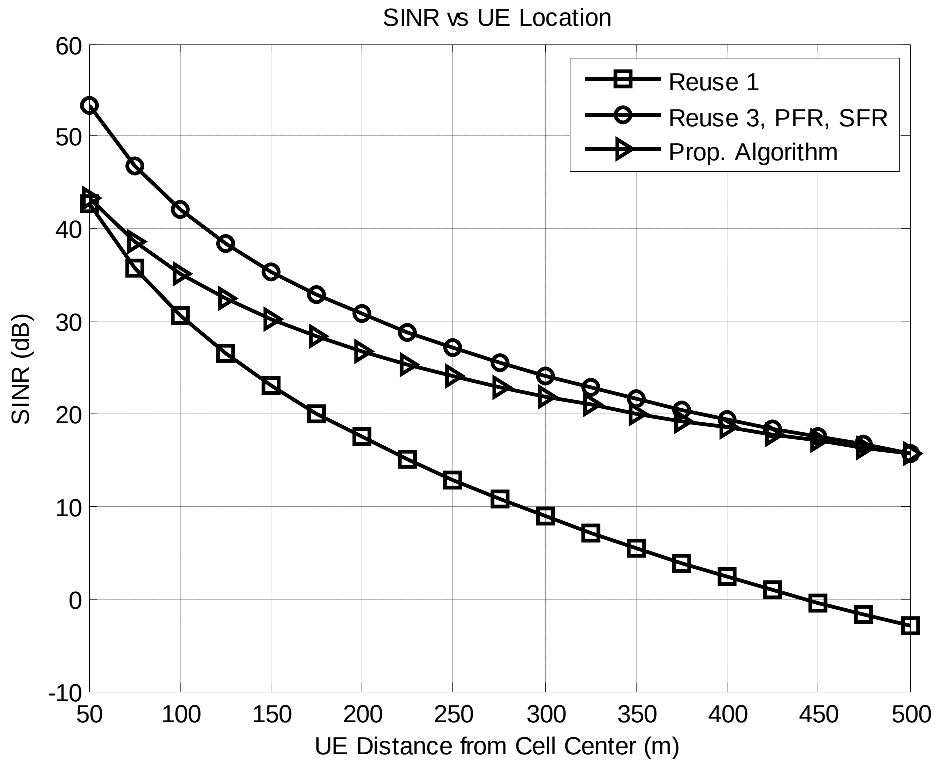

Figure 5.18 Comparative Analysis of SINR vs. UE Location

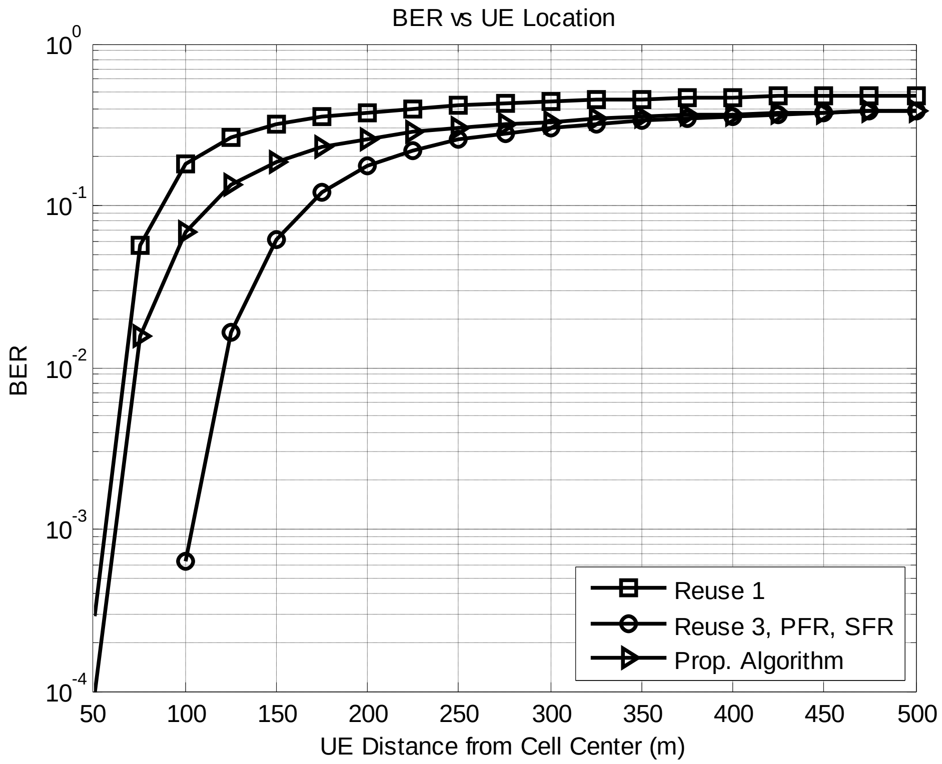

Figure 5.19 Comparative Analysis of BER vs. UE Location

The comparative analysis of BER vs. UE location for Reuse1, Reuse 3, PFR, SFR and proposed dynamic resource allocation techniques is shown in Figure 5.19. For a particular location in a cell, the BER in Reuse 1 technique is highest due to the lack of ICI mitigation techniques. Similarly, the BER in Reuse 3, PFR and SFR techniques is the lowest at any particular cell location. The BER for the proposed algorithm at any particular cell location lies in between that of Reuse 1 technique and other techniques. The BER for the proposed algorithm towards the boundary of the cell is similar to that for Reuse 3, PFR or SFR techniques.

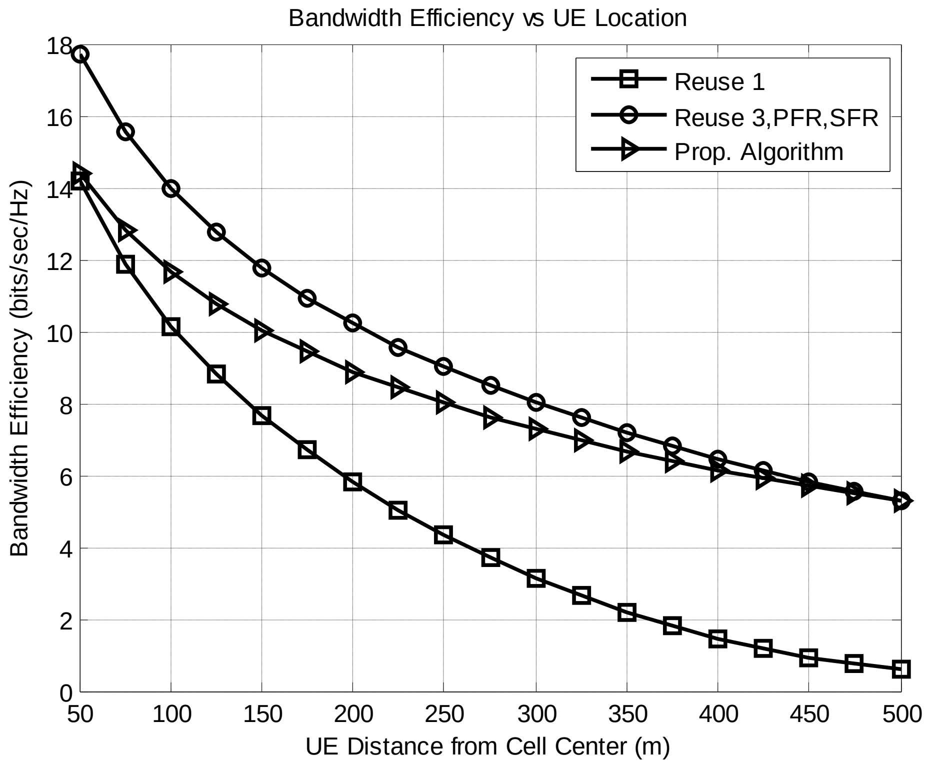

Figure 5.20 Comparative Analysis of Bandwidth Efficiency vs. UE location

The comparison between Reuse 1, Reuse 3, PFR, SFR and proposed resource allocation algorithms on the basis of bandwidth efficiency vs. UE location curves is shown in Figure 5.20. The natures of these curves are similar to the SINR vs. UE location curves. Due to the highest levels of ICI in Reuse 1 technique, the bandwidth efficiency of the channels for this technique is lowest. The implementation of ICI mitigation measures in Reuse 3, PFR and SFR techniques causes less interference from adjacent cells. Also, the interference patterns or levels in Reuse 3, PFR and SFR techniques are similar. Hence, these techniques have same bandwidth efficiency vs. UE location curves. The bandwidth efficiency for Reuse 3, PFR or SFR techniques are considerably higher than Reuse 1 technique. The bandwidth efficiency for CEUs is highly increased with the use of these ICI mitigation techniques. The bandwidth efficiency vs. UE location curve for the proposed algorithm shows that the variation between the bandwidth efficiency for CCUs and CEUs is reduced. The bandwidth efficiency of the channels in the system utilizing the proposed algorithm lies in between that of Reuse 1 and other techniques.

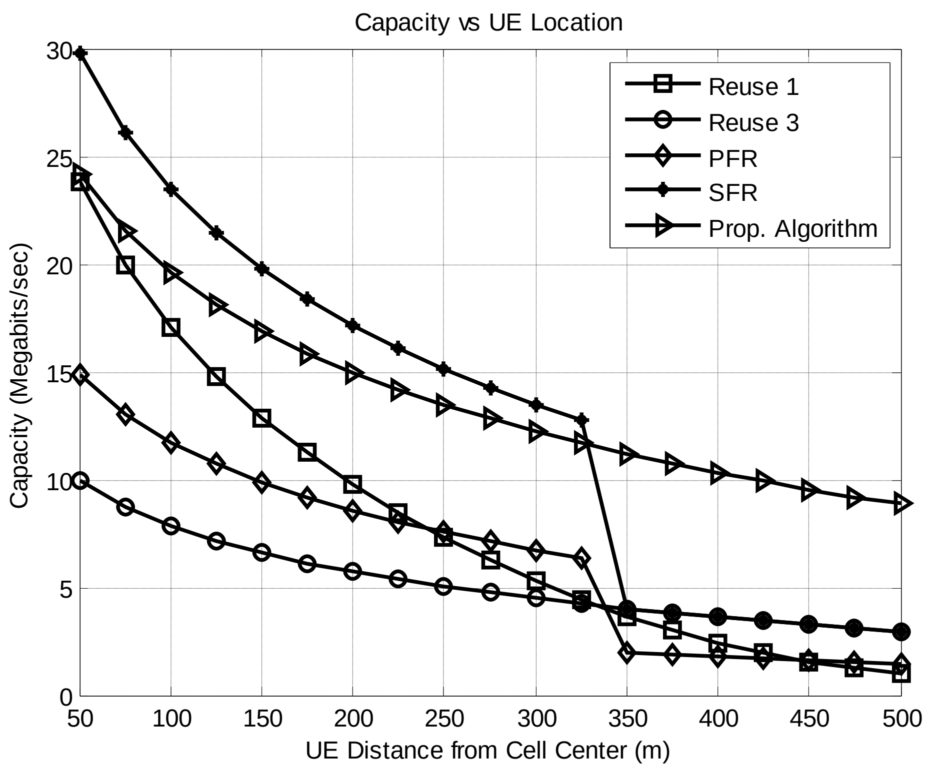

Figure 5.21 Comparative Analysis of Capacity vs. UE Location

Figure 5.21 provides the comparative analysis between Reuse 1, Reuse 3, PFR, SFR and the proposed resource allocation algorithms on the basis of maximum capacity per user. The result is based on the assumption that each user is provided a maximum of six PRBs containing 28 sub carriers each, which leads to the total of 1.68 MHz bandwidth. Figure 5.21 shows that, for Reuse 1 technique, the system capacity for CCUs is high but decreases rapidly as the users move towards the boundary of the cell. Thus, the system capacity for CEUs is very low. The Reuse 3 technique provides almost uniform system capacity for the users throughout the cell region. But the system capacity is very small.

The system capacity vs. UE location curves for PFR and SFR techniques show that there is wide variation between the capacities for CEUs and CCUs. The PFR technique provides higher capacity for CCUs in comparison to the Reuse 3 technique but the capacity for CEUs is further degraded. SFR technique provides the highest system capacity for CCUs in comparison to other techniques. But the system capacity for CEUs is only as that for Reuse 3 technique. Thus, the CEUs experience highly diminished QoS in comparison to the CCUs in cases of PFR and SFR techniques.

The proposed algorithm provides the most efficient distribution of system capacity for all users throughout the cell region. The capacity for the proposed algorithm is higher than all other techniques except for the SFR technique in case of CCUs. In case of CEUs, the proposed algorithm provides the highest capacity compared to all other techniques. Also, the proposed algorithm causes only a narrow variation in system capacity for CEUs and CCUs, unlike in PFR and SFR techniques.

CHAPTER 6

CONCLUSIONS AND FUTURE RECOMMENDATIONS

6. Conclusions and Future Recommendations

6.1. Conclusions

In this thesis work, a dynamic radio resource allocation algorithm has been designed for a multi cell OFDMA system in order to mitigate the problems of ICI interferences from neighboring cells. The performance of the dynamic resource allocation algorithm has been compared with that of the basic resource allocation techniques that include Reuse 1, Reuse 3, PFR and SFR techniques. These basic resource allocation techniques are static in nature i.e. once the resource allocation has been performed, it does not change with change in interference patterns. However, in the dynamic resource allocation algorithm, the resource blocks are allocated to the users in a cell, based on sub channel assignment information from neighboring cells. Thus, this algorithm utilizes the coordination between the adjacent cells for ICI mitigation.

The performance of Reuse 1, Reuse 3, PFR, SFR and the dynamic resource allocation algorithm have been analyzed on the basis of change in SINR values, system Bit Error Rate (BER), bandwidth efficiency and channel capacity with increase in distance of User Equipment (UE) from the center of cell. The Reuse 1 technique does not provide any ICI mitigation measures which results in highest levels of interference from the neighboring cells. Hence, although the entire system bandwidth is reused in each cell, the capacity of the system decreases drastically towards the boundary of the cell. The Reuse 3 technique provides improved SINR and BER in comparison to Reuse 1 technique but the system capacity diminishes due to the reduced bandwidth in each cell.

The PFR and SFR techniques divide the users in a cell into CCUs and CEUs based on their location in the cell. The SINR and BER patterns in PFR and SFR techniques are similar to that in Reuse 3 technique. However, both PFR and SFR techniques present wide variations in system capacity for CCUs and CEUs. The

PFR technique provides higher capacity for CCUs in comparison to the Reuse 3 technique but the capacity for CEUs is further degraded. Similarly, SFR technique provides the highest system capacity for CCUs in comparison to other techniques but the system capacity for CEUs is comparatively poor.

The SINR values in case of the dynamic resource allocation algorithm are higher than the SINR values in case of Reuse 1 technique. Also, this algorithm provides only a small difference in SINR values for users towards the center and towards the boundary of the cell. The capacity for this algorithm is higher than all other techniques except for the SFR technique in case of CCUs. In case of CEUs, the dynamic resource allocation algorithm provides the highest capacity compared to all other techniques. Also, this algorithm causes only a narrow variation in system capacity for CEUs and CCUs, unlike in PFR and SFR techniques.

6.2. Limitations

The major limitation of this thesis work is that its scope is limited only for a three-cell OFDMA system. The study of the performances of different resource allocation techniques have been performed only for OFDMA system consisting of three adjacent hexagonal cells.

Although ICI is prominent in uplink as well as downlink transmissions, the study of the thesis work is limited to the downlink transmission only. In the thesis work, only the signals from neighboring eNBs have been considered as the sources of interferences in the system. Other sources of interference such as multipath fading, Doppler's shift, non-cellular interferences etc. are not considered.

6.3. Future Recommendations

In the future, the scope of the thesis work can be extended for real networks with larger number of cells. Also, the performance of different resource allocation techniques can be analyzed for heterogeneous systems consisting of macro cells cooperating with pico and femto cells. Further studies can be made for ICI mitigation in both uplink and downlink transmissions. Also, more accurate analysis of the resource allocation algorithms can be achieved by considering interferences from multipath fading, Doppler's shift, non-cellular interferences etc. as well.

Moreover, the improvement of the dynamic resource allocation algorithm can be considered as a future work for possible improvements in ICI mitigation and system capacity.

References

[1] S. Kumar, G. Monghal, J. Nin *et al.*, "Autonomous Inter Cell Interference Avoidance under Fractional Load for Downlink Long Term Evolution," *69th Vehicular Technology Conference VTC, IEEE,* Spring 2009.

[2] K. Begain, G. I. Rozsa, A. Pfening *et al.*, "Performance Analysis of GSM networks with intelligent underlay-overlay," *International Symposium on Computers and Communications, IEEE,* 2002.

[3] Siemens, "Interference mitigation considerations and results on frequency reuse," 3GPP Contribution R1-050599, 2005.

[4] Ericsson, "Intercell Interference handling for E-UTRA," 3GPP Contribution R1-050764, 2005.

[5] G. Li and H. Liu, "Downlink Radio Resource Allocation for Multi-Cell OFDMA System," *IEEE Tran. Wireless. Commun.*, vol. 5, no 12, pp. 3451-3459, Dec. 2006.

[6] M. Rahman, H. Yanikomeroglu and W. Wong, "Interference avoidance with dynamic inter-cell coordination for downlink LTE system," in *Proc. IEEE Wireless Commun. Netw. Conf (WCNC),* Apr. 2009.

[7] T. Q. S Quek, Z. Lei and S. Sun, "Adaptive Interference Coordination in Multi-cell OFDMA Systems," in *Proc. 20th IEEE Intern. Sympos. On Personal Indoor & Mobile Radio Commun. (PIMRC)*, Sept. 2009.

[8] L. Chen and D. Yuan, "Soft Frequency Reuse in Large Networks with Irregular Cell Pattern: How Much Gain To Expect?," in *Proc. 20th IEEE Intern. Sympos. On Personal Indoor & Mobile Radio Commun. (PIMRC),* Sept. 2009.

[9] A. Triki and L. Nuaymi, “Inter Cell Interference Coordination Algorithms in OFDMA wireless systems,” *IEEE Vehicular Tech. Conf.*, 2011.

[10] A. Dacinabi and K. Sandrasegaran, “A Proposal for an Enhanced Inter-Cell Interference Coordination Scheme with Cell Range Expansion in LTE-A Heterogeneous Networks,” in *Workshop on Advances in Real-Time Information Networks*, 2013.

[11] H. Yin and S. Alamouti, “OFDMA: A Broadband Wireless Access Technology,” in *Proc. IEEE Sarnoff Symposium,* Mar. 2006.

[12] E. Lawrey, “Multiuser OFDM,” in *Proc. IEEE International Symposium on Signal Processing and its Applications,* vol. 2, pp. 761-764, Aug. 1999.

[13] X. Xu, H. Zhang and Q. Wang, “Inter-cell Interference Mitigation for Mobile Communication System,” in *Advances in Vehicular Networking Tecchnologies*, Dr. M. Almeida, Ed. InTech, 2011, pp. 357-388.

[14] M. Bohge, J. Gross and A. Wolisz, “Optimal soft frequency reuse and dynamic sub-carrier assignments in cellular OFDMA networks,” *Eur. Trans. Telecomms.*, 2010.

[15] L. Jorguseski, T. M. H. Le, E. R. Fledderus *et al.*, “Downlink Resource Allocation for Evolved UTRAN and WiMAX Cellular System,” *IEEE PIMRC 2008*, September 2008.