USER DENSITY BASED SOFT FREQUENCY REUSE ALGORITHM FOR 5G CELLULAR NETWORKS

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ABSTRACT

Soft frequency reuse (SFR) techniques have been deployed to address the problem of interference experienced by users in cellular networks. In some of these techniques, resources allocations are based on the assumption that users are uniformly distributed.However, in a real network scenario where SFR is deployed for resource allocation, the distribution of users in the network regions is random. Analysis of the impact of random deployment of users in such network scenarios is essential for designing efficient networks. This research proposes a SFR algorithm (User-SFR), which intelligently adjusts resource allocation parameters according to the load distribution in the network. When compared with several results of a fixed SFR algorithm, the results for the proposed User-SFR outperforms the fixed SFR.The Signal to interference plus noise ratio (SINR) of the users at the edge region improved by about 3.2% and the Capacity improved by over 202%.This implies that a more realistic and enhanced network is achieved when random distribution of the users in a network is considered against the assumed uniform distribution of users.

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ABBREVIATIONS

Abbreviation	**Meaning**
SFR	Soft Frequency Reuse
SINR	Signal to interference plus noise ratio
5G	Fifth Generation of Cellular Communication Technologies
FFR	Fractional Frequency Reuse
FR	Frequency Reuse
ICI	Inter-cell interference
4G	Fourth Generation of Cellular Communication Technologies
LTE	Long Term Evolution
OFDMA	Orthogonal Frequency Division Multiple Access
D2D	Device to Device
MIMO	Massive Input Massive Output
ASE	Area Spectral Efficiency
eNB	e node B
ML – SFR	Multi – Level Soft Frequency Reuse
M-SFR	Modified Soft Frequency Reuse
HetNets	Heterogeneous Networks
SIR	Signal to Interference
SSFFR	Soft Sectored Fractional Frequency Reuse
SFFR	Sectored Fractional Frequency Reuse
DyCRA	Dynamic Cost/Reward based Allocation
IR	Inner Region
OR	Outer Region
SORA	Self Organising Resource Allocation
CDMA	Code Division Multiple Access
BSs	Base Stations
CIR	Carrier to Interference Ratio
UE	User Equipment
UEs	User Equipments

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Cellular communication has evolved tremendously and consistently for over five decades (Lopa, 2015).The use of large and cumbersome radios for communication was replaced with more portable but fixed devices. This was to be further replaced with compact, hand-held, wireless and mobile devices for the transmission and reception of speech, texts and media (Michael, 2019). The development of a more portable technology and better interconnection system came with notable advances in both the networking of wireless communication and sustenance in its usage.

Recently there has been a characteristic growth in the number of connected devices with the smartphone taking the centre stage. In order to differentiate advances made in network architecture as well as device hardware, the revolutions have been christened as Generations (G). From the first generation to the fifth generation of cellular communication technologies, specified band of frequencies and frequency reuse is employed (Mutabazi, 2019). This enables the provision of a service to a larger number of subscribers while increasing the effective use of the available bandwidth.

More so, the creation of a variety of communication networks is enabled by fully integrating the emerging capabilities of the mobile phone. The unprecedented increase in demand and consumption, as well as the development of different types of services accelerated the rapid technological expansion of advanced cellular communication networks, together with unceasing improvement of the cellular devices themselves (Zeng *et al.*,2018).

The development of the 5G network is to provide a solution to the high demand for more data rates occasioned by the exponential rise in the number of user equipment in modern

cellular networks. Such demand is beyond the theoretical upper cap of 200Mbps presently achieved by the 4G networks. The 5G network is envisaged to achieve a data rate of around 100 Gbps and a minimum latency of 1 ms as well an enhanced user Capacity (Qamar *et al*., 2019). According to Mumtaz *et al.* (2017), among the peculiar characteristics of 5G, flexibility is inherent. It supports several use cases in optimal manner using a spectrum < 6GHZ and > 6GHZ.

Among the many techniques that can be deployed to achieve high data rate and capacity in 5G is network densification. Densification is achieved by deploying more macro base stations (Macro Cellular densification).The goal is to increase user capacity and coverage. It can also be expanded to include the use of small cells with reduced coverage footprint. These small cells are easier to install and less costly to obtain. The deployment of more small (micro) base stations could be termed (Micro cellular densification) (Romanous *et al*., 2015).

However, increasing the number of randomly deployed cells in the network consequently leads to more challenges including inter-cell interference (ICI). ICI can be mitigated by intelligent spectrum allocation using frequency reuse techniques. Spectrum allocation has frequency reuse-1(FR-1), frequency reuse-3(FR-3), and Fractional frequency reuse (FFR).The FFR is usually considered under Strict Frequency reuse and Soft Frequency reuse(SFR), where the coverage region is divided into two parts (Adejo and Boussakta, 2016). Soft frequency reuse is selected because it gives a better relationship between interference management and bandwidth utilization (Elfadil *et al.,* 2015).

1.2 Statement of the Research Problem

As Cellular communication continues to evolve from one generation to another, new mobile terminals have also continued to emerge (Michael, 2019). The recent adoption of smart phones and other mobile Internet devices has boosted the cellular communication revolution resulting in enhanced user experience. This can be seen in the invention of high-bandwidth-consuming applications such as video streaming and mobile cloud. These have caused an exponential growth in data traffic requirement, exceeding the theoretical limits of network capacity and spectral efficiency of existing cellular systems (Qamar *et al*., 2019).

The launch of 4G cellular networks was thought to have the architecture to address this rise in data rate demand. This is achieved through massive deployment of base stations to form a dense network scenario. Coverage is improved as the number of base stations increase and the distance from users to the base station reduces (Adejo and Boussakta, 2016). However, the amount of interference in the network significantly increases and this causes serious degradation in the quality of service available to the user. Therefore, managing ICI has remained one of the major factors that limit the performance of current wireless cellular network systems.

Fractional frequency reuse (FFR) and Soft frequency reuse (SFR), with several of their variants have been introduced and are being improved as effective ways to optimize spectrum and control the ICI in developing 5G networks (AboulHassan *et al*., 2015). However, most of the previous works studied have not considered network load (the effect of the number, location and demand of users) in their frequency reuse algorithms. An improved Soft frequency reuse algorithm that takes into consideration the user‟s load demand in the network is hereby proposed.

1.3 Aim and Objectives of the Study

The aim of this research work is to develop a new resource allocation technique that adequately caters for varying load distribution in typical 5G networks.

This is achieved through set objectives. The objectives includes to:

i. develop an improved Soft frequency reuse algorithm that intelligently allocates resources according to load distribution (user demand) in a network.

ii. vary the number of users in various regions of the network adopted and modify it to include downlink interference probabilities under soft frequency reuse.

iii. implement the algorithm developed in (1) through simulations using Matlab.

iv. test the performance of the algorithm using cellular network performance metrics such as Signal-to-interference-plus-noise ratio (SINR) and Capacity.

1.4 Justification of the Study

It is impossible to have a cellular network that does not suffer interference. One of the most effective ways of managing interference is to effectively deploy frequency reuse in cellular networks. It has been widely researched leading to variants and modifications with accompanying reduction in interference levels in networks. However, several of these studies assumed uniform distribution of users in the network. This assumption is made for simplicity and does not depict a real network scenario. In this study a non-uniform distribution of users in various network regions is considered. This approach is novel and has not been seen in pervious works studied and is therefore justifiable as an area of interest for study.

1.5 Scope of the Study

Resource allocation for interference management in Cellular networks is a broad research area. It encompasses several models, innovations and technologies that drive mobile communication. For the purpose of this research, a single tier network of macro base stations is adopted. The base stations are restricted to the popular hexagonal network arrangement and the orthogonal frequency division multiple access (OFDMA) scheme is employed under the Long term evaluation (LTE) networks. Analysis is carried out by considering sectors of neighbouring base stations as they are arranged in clusters of three. Bandwidth allocation has different methods under the broad area of frequency reuse including full frequency reuse, frequency reuse-3, strict frequency reuse and soft frequency reuse where the coverage region is divided into two parts. Soft frequency reuse is selected because it guarantees a balance between interference management and bandwidth utilization. This work considers that the SINR depends on the distance between users and the base stations, without detailed analysis of the channel conditions. In the area of scheduling, it is therefore assumed that the network resources are uniformly assigned to users without any preference, as against several other existing scheduling methods.

1.6 Organisation of Thesis

The thesis is organised into five chapters. The remaining content is structured as Literature review and is contained in chapter two. In chapter three, the methods followed to achieve the results are logically presented while the discussions on the results obtained are done in chapter four. Chapter five is made up of the conclusion, recommendations as well as the contributions to knowledge.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview

The fifth generation (5G) Cellular networks have promised a remarkable increase in data rate to meet exponential rise in data traffic (Mumtaz *et al*., 2017). This is being achieved through the deployments of the 5G service around the globe, since it was first launched in South Korea on 3 April, 2019. More research, development and deployment of 5G systems is being expected. The 5G network is to offer an improvement over the existing network architectures. This is achieved through Ultra dense network, millimetre waves, device to device communication, and D2D/M2M networks and MIMO among many other technologies (Lopa ,2015;Mumtaz *et al*.,2017). The deployments of ultra-dense networks in 5G systems increases capacity but come with it more interference than existing networks . Interference in the communication networks arises as undesirable signal. Interference management and resource allocation problems become more challenging than in previous network systems (Hasan and Hossain, 2017).

More so, the causes and effects of interference are made difficult to understand because of different preferences in channel access and the provision of Peer to Peer communication. Nevertheless, the adoption of multiple tiers in the cellular network architecture will provide better performance in terms of capacity, spectral efficiency, coverage, and power consumption (Hossain *et al.*, 2015), provided that there exists an efficient inter-tier and intra-tier interference management scheme .

The improvement of the Area Spectral Efficiency (ASE), especially at the cell edges is of utmost importance to the design and management of network systems. This is however often hindered by ICI caused by the use of the same frequency band in adjacent cells (Wu *et al.*, 2017). It also can limit the performance of wireless cellular network systems when left unmitigated (Lam *et al*., 2015).

2.2 Inter-cell Interference Management

Inter-cell interference management techniques are widely researched. The techniques are widely divided into two schemes: inter-cell interference mitigation and inter-cell interference coordination/avoidance schemes (Hamza *et al.*, 2013).

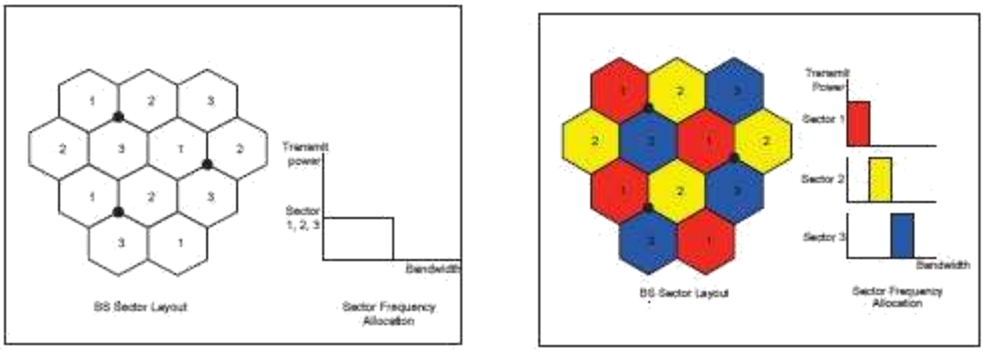
The use of Interference mitigation causes a decrease or suppression in the inter-cell interference during transmission or at the instant of reception. In Lam *et al*. (2015), the interference mitigation techniques are classified into randomization (interference averaging), interference cancelation and adaptive beam forming. These techniques come with either inability to meet requirements of widely used communication standards, inability to improve signal strength or can improve signal strength but are too complex (Hashima *et al.*, 2013).

2.3 Interference avoidance (Frequency Reuse Techniques)

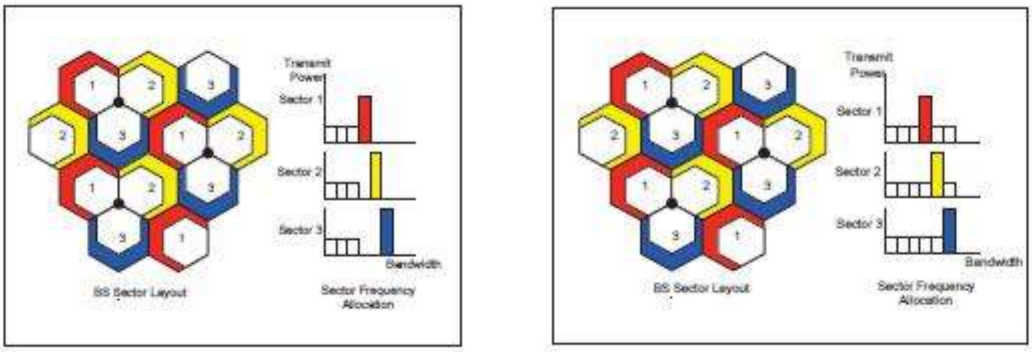
Interference avoidance schemes focuses on the frequency reuse planning algorithms used by the network elements for allocation or restriction of certain resources (in both frequency and time domains) and power levels among users in different cells. The objective of these frequency reuse planning algorithms is to increase the SINR, and hence, increase the capacity of the system. These frequency reuse planning algorithms must satisfy the power constraint in each cell by ensuring that the allocated transmission power of an e node B (eNB) does not exceed the maximum allowable power. A fundamental concept common to most interference avoidance schemes is to classify users in the cell based on their average SINR to a number of users‟ classes (also known as “cell regions”).Interference avoidance schemes then apply different reuse factors to the frequency band used by the different classes of users (to different cell regions). This scheme is simple, having less computation and does not impose any additional cost on extra hardware element on the user"s device. Hence, it has often been used as the most effective technique for LTE network to provide high quality of services to cell edge users without compromising cell centre performance (Lam *et al.*, 2015). Sustained studies have been carried out on these techniques: the Fractional frequency reuse(FRR) in Figure 1(c),Soft frequency reuse(SFR) in Figure 1(d) and the Modified Soft frequency reuse(M-SFR) which have been used extensively for effective spectrum allocation in order to increase system throughput(Qian *et al.*,2015).

2.4 Soft Frequency Reuse

In SFR, each cell is divided into a centre zone and a cell edge zone. For the cell centre zone of each cell, frequency reuse -1 is used. However, in the cell edge zone, only a small portion of the spectrum is made available in such a way that the spectrum allocated to the cell edge zones of the neighbouring cells are incompatible. This ensures that the users in the cell edge zone will experience lower ICI compared to the conventional frequency reuse scheme as illustrated in Figure 1(d) (Adejo *et al*., 2016). The quantity of bandwidth available at the cell edge is directly proportional to the capacity for the cell edge users. However, since the spectra are incompatible, the high power carriers are allocated to the users in this zone and thereby improving the overall ASE of the system (Qian *et al*., 2015).



(a) FR1 (b) FR3



(c) Strict FR (d) SFR

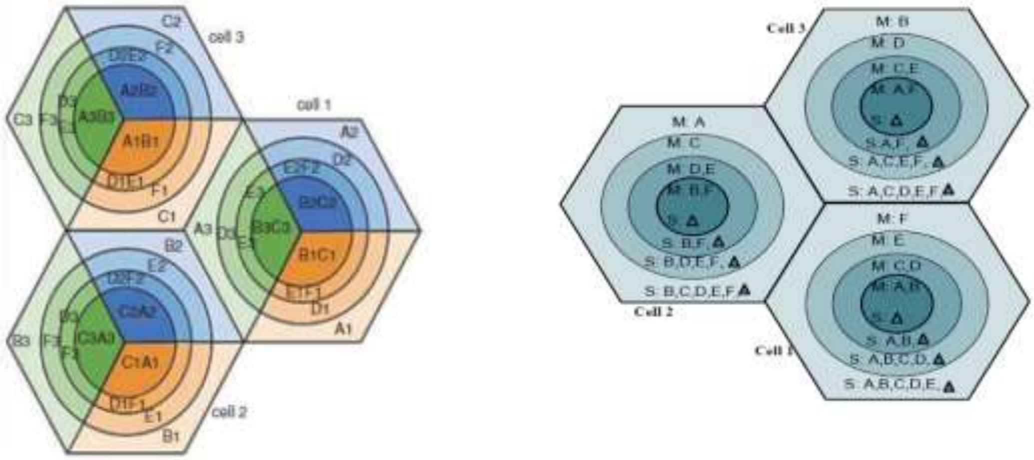
Figure 1.0: Frequency and power assignments for different FR schemes

2.5 Review of Past Research

In order to meet the fifth-generation (5G) high data rate requirements, more robust resource allocation strategies have been proposed. They come in form of modifications over the conventional SFR discussed in section 2.4 (Hashima *et al*., 2013; Adejo *et al*., 2016).

In Yang (2013), a Multi-level SFR (ML-SFR) is proposed. As in a conventional SFR, each cell is divided into centre and edge regions. These are further divided; thereby having at least two SFRs with the transmit power level also divided accordingly. The author however assumed a uniform load distribution.

A further modification on the technique is proposed as ML-SFR for sectored macro cell in Hossain *et al.*(2015) in Figure 2(a). The authors established an increase in the Spectral Efficiency (SE), obtained by trading off reduced spectrum reuse, resulting in a limited gain in terms of the system capacity considering a single tier network. The author also assumed uniform load distribution.



(a) ML-SFR Macro BS(Sectored)

(b) ML-SFR Hetnets

Figure 2.0: Bandwidth allocation for different ML-SFR schemes

More so, in Hossain *et al*.(2017), a new resource allocation scheme for Heterogeneous Networks (HetNets), called multi-level soft frequency reuse for HetNets (ML-SFR HetNets) in Figure 2 (b), is proposed. From the performance analysis the authors achieved significant increase in the throughput several folds.

Abdullah *et al*.(2020) proposed an enhanced fractional frequency reuse algorithm to attenuate the interference in femtocell networks. The service area is partitioned into three regions and the spectrum is also partitioned into three sets. Each bandwidth set is allocated to different region. The femtocell is then located and assigned bandwidth as may be needed by the region. The approach leads to a reduction in the interference. It also boosts the signal to interference plus noise (SINR), and enhances the throughput.

According to Eman *et al*. (2019), a higher Signal to interference (SIR) is achieved in the outer sector when the proposed hybrid Soft Sectored Fractional Frequency Reuse (SSFFR) is compared with sectored FFR (SFFR) through simulation. The SSFFR examines the uplink worst case Signal to Interference power Ratio (SIR). The outcome of power control exponent, path loss exponent and inner radius are also studied. Overall the cell edge transmission is enhanced through interference management.

Post *et al*. (2019) introduced „"A dynamic Cost/Reward based Allocation (DyCRA), for dense cellular networks. The scheme considers users bandwidth demands and is self-adapting. Decisions are made depending on cost-reward trade-offs: while rewards are viewed in the form of capacity improvement, costs considered in the form of interference. The costs and rewards were quantified based on SINR, and use periodic load estimates to determine if access points are in need of bandwidth, or can offload same. Considerable simulation results show that the DyCRA scheme provides efficient resource allocations that adjust to changing traffic conditions and yields significant performance.

In a related study Lam *et al*. (2020) presented a general case of FFR where the users are divided into zones with each zone allocated a serving power level. The mathematical model of the general FFR is introduced and studied using a stochastic geometry technique. The average coverage probability obtained through analysis can be covered by all the related well-known results in the literature.

Ilhak *et al*. (2020) proposed a novel fractional frequency reuse (FFR) based on dynamic user distribution. According to the authors, a macro cell is usually divided into two regions, i.e., the inner region (IR) and outer region (OR). The criterion for dividing the IR and OR is the distance ratio of the radius. Attenuation phenomena such as shadowing, path loss and wall penetration make these distance -based criteria less reliable in measuring user performance.

The new technique considers SINR of macro users in place of distance ratio of the radius, and the FFR is partitioned into two new regions. Simulation results show that the proposed scheme has better performance than the conventional FFR in terms of SINR and throughput of macro cell users.

In this study, Karthika and Indumathi. (2020) proposed Self-organized resource allocation (SORA) framework that selects the reuse factors randomly. The result of the simulation of the Approach using Matlab was compared with selected reuse factor arrays .The results from simulation showed improved efficiency for Cell edge Users.

In another research, three non-uniform user density models are developed and used to analyse system performance in typical Code division multiple access (CDMA) (Ganesh and Joseph .,1997). According to the authors, the intra-cell interference among multiple users in a network contributes more to the total interference levels in most networks. Based on the study, Gaussian user density model provided the most significant improvements in performance with cell-splitting when compared to linear or exponential user density models. The outcomes of the study provide more depth into the performance of CDMA systems, and are useful for the objectives of network planning and resource allocation.

To account for the differences in the user densities of different network tiers in a network, Li *et al.*(2016) proposed a non-uniform user distribution model in which the user density depends on the distance to the associated base stations (BSs).The model covers many possible combination and an accurate performance analysis of the downlink coverage probability obtained. The numerical evaluations show that our analysis can produce results that closely match the simulation results.

Jain *et al*. (2005) implemented a model for simulating a CDMA system with clustered and uniform user distributions. Some subsisting studies relevant to CDMA systems on trade-off between throughput and interference power, decreasing carrier to interference ratio (CIR) are corroborated. The authors also studied the outcomes of these user distributions through spatial analysis and two different data rates using higher order moments. The two distributions are shown to have similar mean values for CIR and Outage but the standard deviation for the clustered distribution is significantly higher than that for the uniform distribution.

Dhillon *et al*.(2013) propose a new tractable method of sampling User equipment (UEs) by conditionally thinning the BS point process .This is to overcome the inability to model non-uniform UE distributions in random spatial models, especially when there is dependence in the UE and the base station (BS) locations. The new framework can be used as a tractable generative model to evaluate existing capacity based deployments, where the UEs are more likely to lie closer to the BSs.

A summary of some reviewed works is attached on page 44 as an appendix A.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

This Chapter contains the complete methods followed in the course of the research work, with details of the proposed resource allocation algorithm based on Soft Frequency Reuse (SFR) technique.

3.1 Cellular Network Model

The first objective of this research is to develop an improved Soft frequency reuse algorithm that intelligently allocates resources according to load distribution (user demand) in a network. To achieve this, a network model in Figure 3.1, where SFR is deployed for resource allocation is adopted (AboulHassan *et al.*,2015). A study of the characteristics of the model is done in the sections that follows.

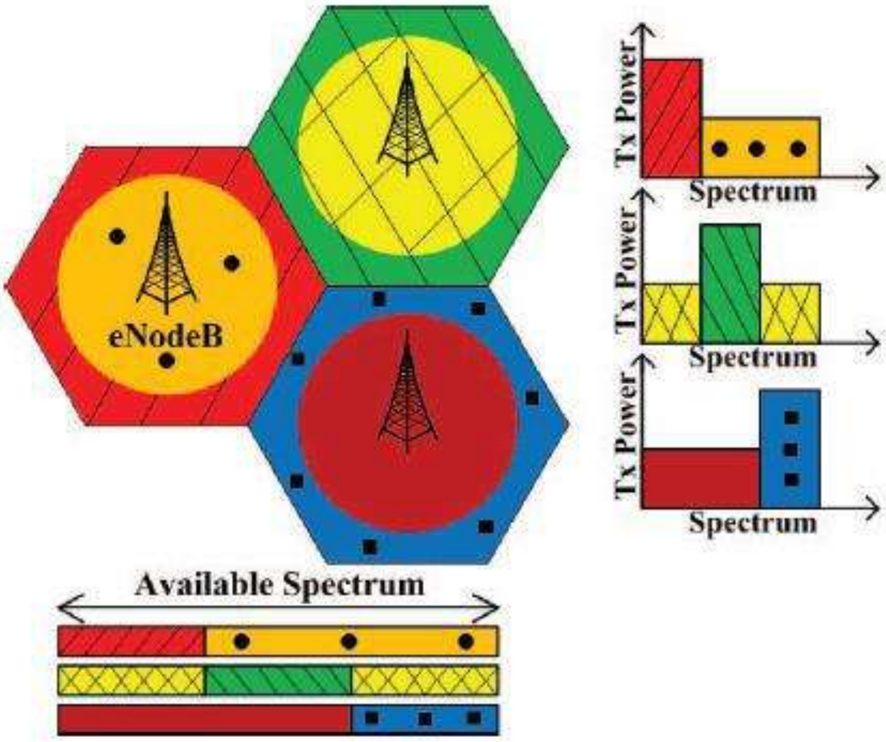


Figure 3.1: Frequency and power assignments for SFR scheme

Source: (AboulHassan *et al.*,2015)

3.1.1 Base Station Description

The model consists of several base stations arranged regularly to provide cellular network coverage for users in a defined geographical area as shown in Figure 3.2. A base station is centrally placed as the reference base station. It is surrounded by six base stations, offering interference to it and each other during transmission of signals in the downlink transmission channel.

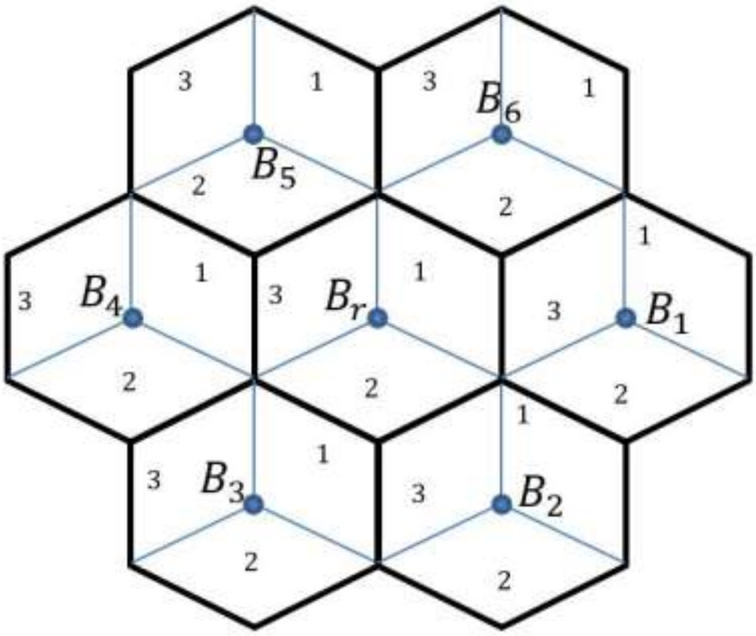


Figure 3.2: Typical cellular network depicting base stations

All base stations used in this model are Macro base stations. The coverage area of each of the base stations is designed to be hexagonal for simplicity of analysis. In order to study the behaviour of the network, the coverage area of each base station is divided into three sectors as seen in Figure 3.2. The base stations are separated from each other based on their coverage radius.

3.1.2 Cellular User Description

The deployment of the cellular users is assumed to be random across the entire coverage area. This depicts a practical network architecture where user positions change at different moments. More so, each user connects to the base station with the highest signal strength.

3.1.3 Basic Soft Frequency Reuse

In a conventional Soft frequency reuse (SFR) algorithm, a resource allocation technique is described on how the bandwidth in a base station is shared among its users. The SFR algorithm is usually carried out on three close sectors from three neighbouring macro base stations. For example, Figure 3.2 shows Sector from , from and from .

3.1.4 Coverage division and User classification

The base station is divided into centre and edge regions using the dotted circle in the reference base station in Figure 3.2. Consequently, users found in the central region are classified as central users ( ) while those in the edge region are called edge users ( ).

For effective utilization of the scarce network resources (bandwidth and power), SFR is deployed. A sector of the reference base station is used to illustrate how SFR technique is applied in the network.

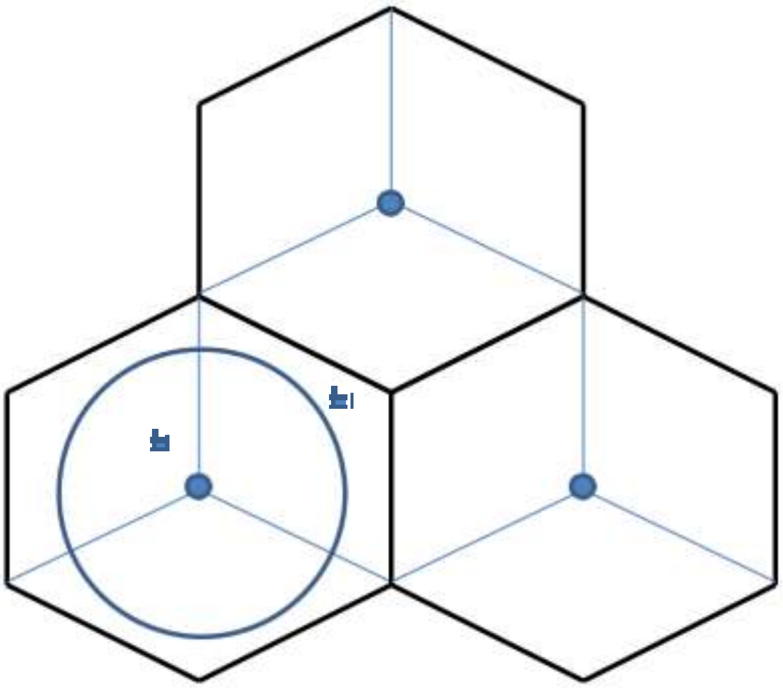


Figure 3.3: Soft Frequency Reuse for three sectors including a Reference sector

From the SFR technique described in Figure 3.3, the following parameters are defined:

1. Reference base station,
2. Interfering base stations,
3. Central cellular users in the reference sector, }
4. Edge Cellular users in the reference sector, }

3.1.5 Bandwidth allocation in SFR

To illustrate the sector-by-sector allocation of bandwidth and power to cellular users, the locations of the users are considered. The users could be at the centre or the edge.

Considering a sector, of the reference base station and sectors and of two interfering base stations, the allocations of the resources of the sectors are presented in Figure 3.4

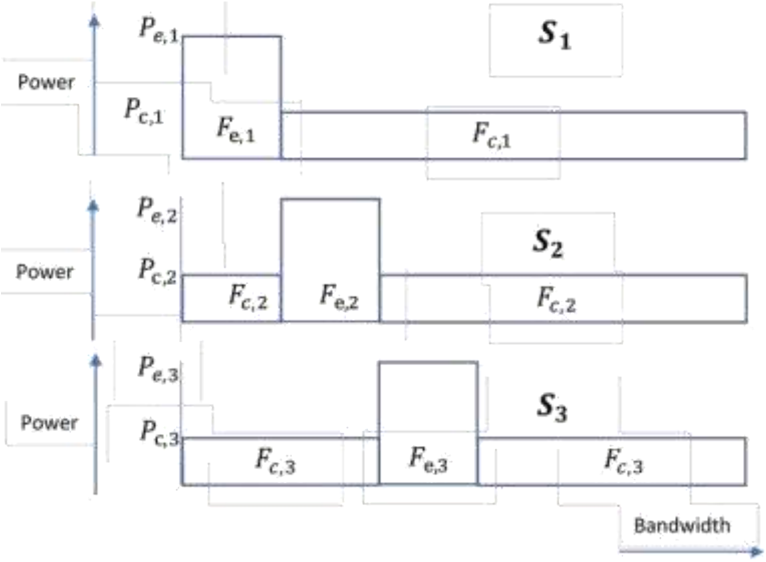


Figure 3.4: Standard Downlink Resource allocation for Sectors , and

Each base station coverage area is divided into three sectors. Each sector is occupied by centre users and edge users. The available bandwidth and power resources are therefore deployed randomly among the users.

If the total bandwidth at each sector is denoted by .

(3.1)

where is the total bandwidth for edge users in Sector 1 and is the total bandwidth for center users in Sector 1.

The total power budget at each sector is denoted as .

(3.2)

where is the total number of edge users in Sector 1, is the total number of center users in Sector 1, is the transmitted power to each edge user in Sector 1 and is the transmitted power to each center user in Sector 1.

and are related by the power ratio constant μ

$$= \qquad (3.3)$$

3.2 Modification of the adopted Network Model

3.2.1 Interference factor in SFR

The amount of attenuation caused in a signal due to interference needs to be quantified. This can be achieved by determining the interference factor of the bandwidth in a particular base station area caused by an area from an interfering base station. The factor is used to calculate the signal to interference plus noise ratio (SINR) of a system. For a standard SFR illustrated in Figure 3.4, the following bandwidth interference factors are derived and presented in Table 3.1. The rows indicate the source of the interference while the columns shows where the interference is felt.

Table 3.1: Interference factors

To From	Central area of	Central area of	Central area of	Edge area of	Edge area of	Edge area of
Central area of		—	—			
Central area of	—		—			
Central area of	—	—				
Edge area of		—	—			
Edge area of	—		—			
Edge area of	—	—				

3.2.2 Performance Evaluation Equations

In order to analyse the performance of the network model under consideration, equations are derived. The equations are used to characterize and quantify the behaviour of the critical network elements.

In this study the most critical elements are bandwidth and power which changes as the users‟ locations changes. To account for the changes in power available for the users at any instant, an expression for the power of a desired signal in relation to the power available for undesired signals that may be transmitting simultaneously is found. This relationship gives us the Signal to interference plus noise ratio (SINR). It may be defined for a user as:

SINR for each centre Cellular user in : An expression for SINR of any user located at the central part of any sector of the reference base station is derived as follows:

( )

where is the fading component, is the distance between the user and the reference base station , is the distance between the user and the interfering base station and is the distance between the user and the interfering base station .

SINR for each edge Cellular user in : An expression for SINR of any user located at the edge part of any sector of the reference base station is derived as follows:

Capacity of Users: Another performance parameter very useful for the analysis of this network model is the network Capacity. It gives how much information can be transmitted in a communication channel. With a known bandwidth and SINR values, the Capacity of the base stations at any instant can be determined using the Shannon Capacity equation;

(3.7)

where C = Capacity (bits/sec), W = bandwidth (Hz), SINR = Signal to noise and interference ratio.

3.2.3 Variation in the number of users in the regions of the network

The network model where user distribution is assumed to be uniform is hypothetical. To establish a real network scenario where users are randomly deployed, the distribution of users in the various network regions is varied as can be seen in the Figure 3.4.

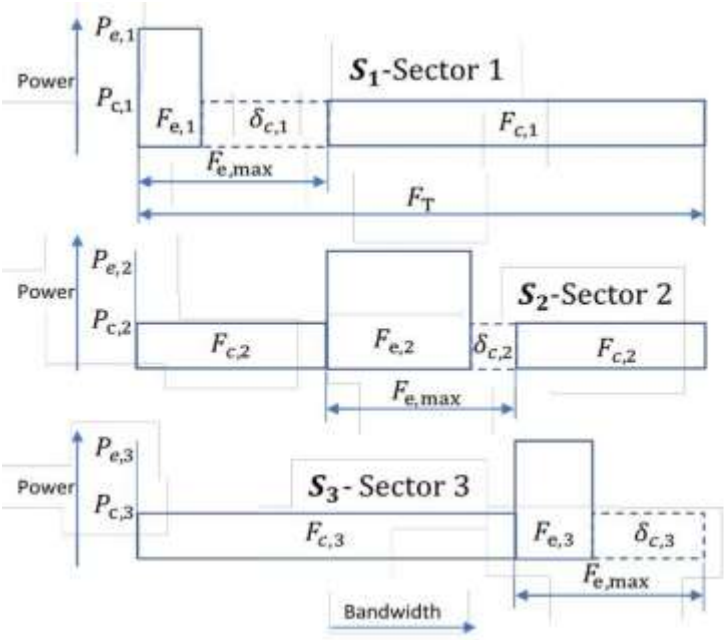


Figure 3.5: Improved Downlink Resource Allocation for Sectors , and

3.3 Assumptions in the Standard (Fixed) SFR Algorithm

In the standard resource allocation algorithm shown in Figure 3.4, the following assumptions were made which limits the application of the algorithm when user deployment is random:

1. The size of the total centre bandwidth in each of the sectors , and is the same,

2. The size of the total edge bandwidth in each of the sectors , and is the same,

3. The algorithm assumes that the number of users in Sectors , and and within their various central and edge regions are assumed to be uniform which may not always be guaranteed. There could be situations in which the spread of users to the regions may differ significantly.

3.4 Improved SFR Algorithm for Intelligent Resource Allocation

This is an enhanced SFR Algorithm that considers user deployment. The key principle of the algorithm is to perform intelligent bandwidth allocation based on the user distribution in the reference sector.

In order to account for the random redeployment of users in the various sectors of the base stations, this resource allocation algorithm in Figure 3.5 is proposed. The following improvements have been implemented in the new SFR algorithm:

1. A new parameter ( ) has been added to make the sharing of the total bandwidth in each sector more flexible to the user distribution. Each Sector of a base station has its total bandwidth, available for reuse given as:

(3.8)

2. Each sector has a maximum bandwidth allowed for the edge regions, – .

   NB: The bandwidth available to edge users in any part of the sector must be less or equal to the maximum bandwidth, , also depicted in Figure 3.5.

3. Any change in the number of users in any part of each of the sectors causes a corresponding change in the bandwidth available for reuse in that part of the sector, . is intelligently allocated to the Central region based on the number of users in these areas. The information obtained from the distribution of the users are used to adjust the bandwidth allocation more intelligently thereby reducing interference.

However, the following assumptions are maintained from the standard SFR algorithm:

The power allocation per user in all the edge regions, , as well as all the Central regions, are assumed to be the same. The centre ratios which are used for the classification of cellular users as centre or edge users are also held constant.

Details of the Algorithm are presented in Algorithm 1 and Figure 3.6.

Algorithm 1

INPUT

Three sectors (),
Total System Bandwidth ( ),
Maximum allowable edge bandwidth (),
Number of edge and centre users per sector ( )

OUTPUT

Bandwidth to edge and centre users, (,, , , ,)

Stage 1: First allocation of Edge bandwidth for macro network

01 Divide the total bandwidth into 3 and assign each portion to the edge region of each of the three sectors,

i.e / ∪ /+ / + /+ / ∪ /+ /+/+

02 Find the fraction of edge users in each sector, $\frac{}{+}$, for each sector

03 Compare the fraction of edge users to the maximum allocated edge bandwidth and note the remaining (unused) bandwidth if any, $\frac{}{+}$.is then calculated and bandwidth assignment is made to the edge region accordingly.

Stage 2: Final allocation of Edge and Centre band widths based on

04 Determine the total remainder bandwidth across all sectors

05 Usingand Consider the sectors with under allocated edge bandwidth and find the fraction of under allocation.

06 Allocate more bandwidth to under allocated edge regions based on fraction of under allocation, and available remainder bandwidth.

07 Perform edge and centre bandwidth allocation (, , , , ,).

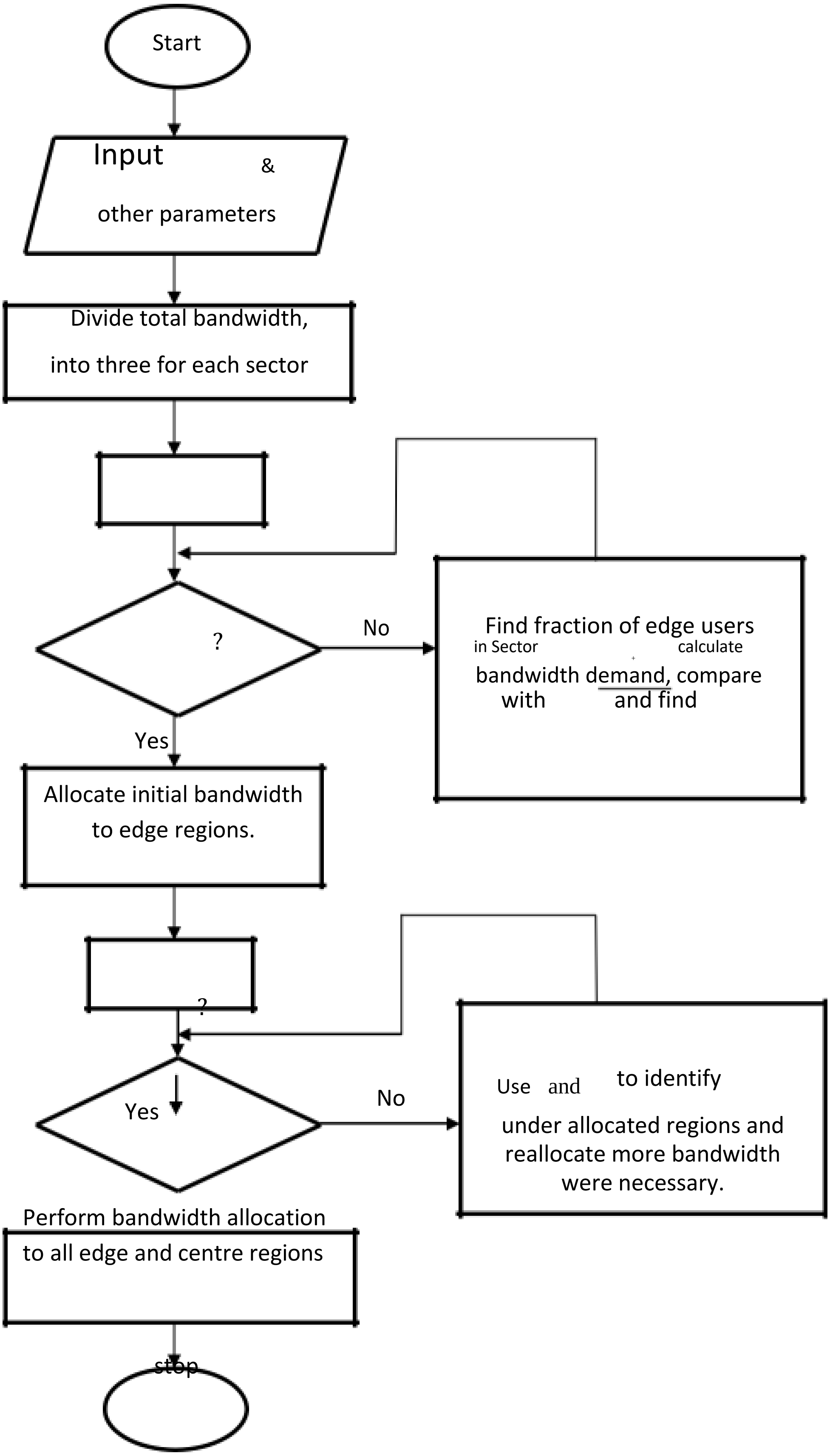


Figure 3.6: Flowchart of the Improved Downlink Resource Allocation for , and

3.5 Simulation tool

The software used for simulation of the network scenario is Matrix Laboratory (Matlab R2015b, 2015). It was used to define the network environment including the layout of the base stations and network users and running the bandwidth allocation algorithm.

3.6 Base station configuration

In this network, macro base stations were used for the entire system simulation. The base stations were arranged in hexagonal format. The reference base station was assumed to be placed at the origin (0,0), surrounded by six interfering base stations. The coordinate location for the interfering base stations are therefore [(0.433,0.75), (0.866,0), (0.433,-0.75), (-0.433,--0.75), (-0.866,0), (-0.433,0.75)], based on an assumed coverage radius of 0.5km. Table 3.2 has details of other base station parameters selected.

Table 3.2: Summary of Base station parameters

Parameter	**Value**
Base station type	Macro base station
Base station radius	0.5km
Number of sectors	3
Number of users per sector	49 (full user deployment)
Number of bandwidth slots per base station	48
Power threshold	1.2W
Edge User bandwidth for fixed SFR	[7,10,13,16]
Power budget	43dBm
Power ratio	2.5

Edge User bandwidth for fixed SFR: For the case of the standard (Fixed) user SFR, several fixed number of bandwidth slots for the edge users were used, [7,10,13,16] as shown in the Table. Results obtained in each case were used to compare with the proposed algorithm where bandwidth assignment to edge users is intelligently performed.

3.7 Cellular User parameters:

User variation (random user deployment is the major feature of this project). The simulation of the user variation was achieved based on the following description:

1. The same number of users is assumed for each simulation.
2. However, the user classification into centre and edge changes randomly.

Using a base station coverage radius of 0.5km (r = 0.5km), the centre user classification was varied 9 times between 0.5r to 0.9r: (0.250,0.272,0.294,0.317,0.339,0.361,0.383,0.406,0.428) km. This corresponds to the following percentage of edge users [69.4, 67.3, 51.0, 49.0, 36.7, 28.6, 18.4, 10.2, 2.0]%.

3.8 Network Assumptions

The following assumptions were made for the network simulation:

1. Only the dominant interfering base stations were considered, the closest base station neighbours to the sector under consideration.
2. The scheduling assumption is fair scheduling, the channel conditions are not considered when allocating bandwidth to users. This guarantees a baseline testing of the algorithm performance without any external influence.
3. Dense user deployment with centre and edge users available in all cases of simulation.
4. No antenna beamwidth considered
5. Same power parameters used in all macro base stations, power ratio and threshold

The flowchart for the Simulation procedure is presented in Figure 3.7

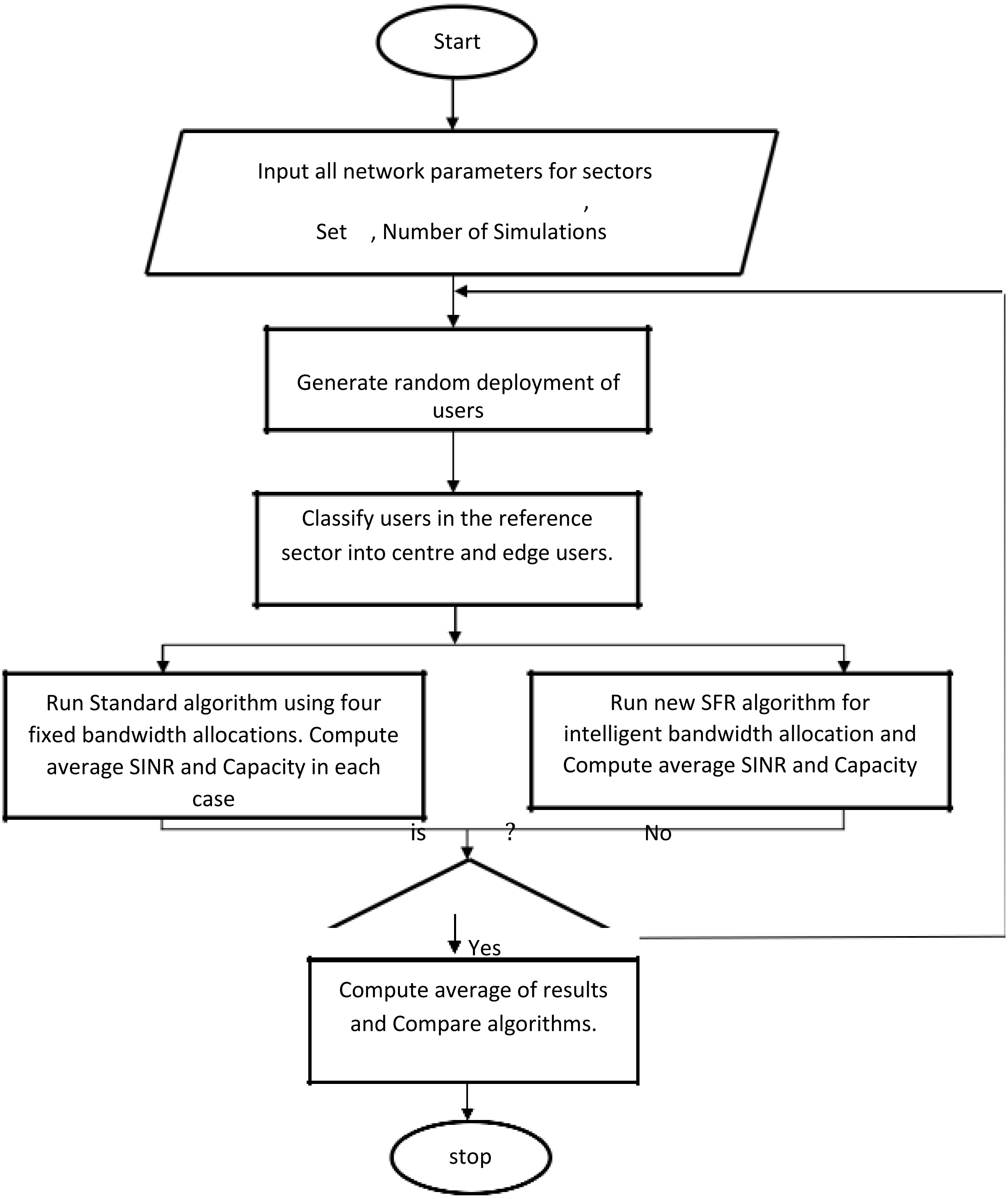


Figure 3.7: Simulation Flowchart for testing the fixed SFR and Improved SFR algorithms

3.9 Testing the performance of the improved algorithm

To test the performance of the algorithm using cellular network performance metrics: Signal-to-interference-plus-noise ratio (SINR) and Capacity.

The results of the performance of the Improved SFR algorithm is compared with the results of the performance of the fixed (conventional) SFR algorithm and presented in chapter four of this work.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

In this Chapter, results are presented showing the performance of the proposed SFR algorithm in different user deployment environments. The simulation parameters and the simulation environment were defined. For each of the algorithms, simulations were ran severally and averages taken for each of the performance metrics. The simulation process of the network was done using Matlab R2015b. A flowchart detailing all procedures followed during the simulation is also presented.

Finally, the results of the simulations are presented as plots for SINR and capacity. These results are discussed here in details.

4.1 Proof of Interference Factor

Interference factors were derived from the relationships of users across different regions of the base stations in the network. The downlink interference probabilities were integrated into the SINR equations for the adopted network model. The equations are tested for accuracy and efficiency.

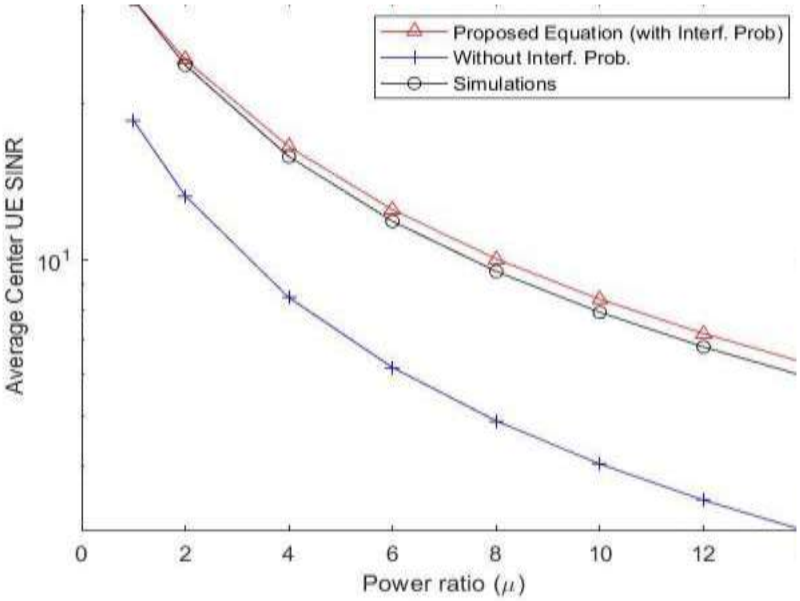


Figure 4.1: Testing accuracy of Equations with Interference factors

This objective was achieved in the model and equations presented in Sections 3.1.5 and 3.2..2 respectively. Specifically, the parameters derived in Table 3.1 for the Interference factors under soft frequency reuse were applied to the SINR equations derived in equations (3.5) and (3.6).

Figure 4.1 shows the comparison of the average SINR for centre users based on equation (3.5), without interference probabilities and as obtained through simulations. Each of the three cases in the result represents a different value of power ratio, (μ). Power ratio is the ratio of the power transmitted to an edge user, to the power transmitted to a centre user. As expected, the center user SINR drops as the power ratio increases. It can also be observed that the results obtained from the modified model are closer to the actual simulation results than the case where the model is not modified. This verifies that a more accurate model was achieved.

4.2 Edge User Performance

In this section, the results for average performance (SINR and Capacity) for edge users are presented. The proposed algorithm described in Section 3.4 and Algorithm 1 was simulated, and the results compared with results of several fixed soft frequency reuse algorithm.

4.2.1 Results for Average Edge User SINR

The result for average SINR for edge users is shown in Figure 4.2. It can be observed that when the percentage of edge users is low, there is no difference in the results across all the algorithms. In addition, the results for all the fixed soft frequency reuse cases are the same always. However, the proposed algorithm (user-SFR in the Figure) outperforms the fixed cases when the number of edge users increases to more than 30% of the total users in the sector.

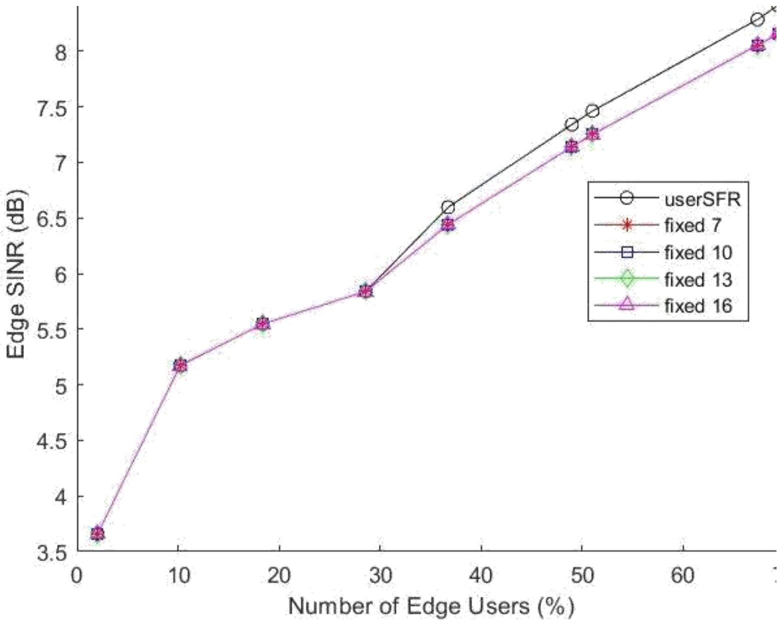


Figure 4.2: Average Edge User SINR performance

4.2.2 Results for Average Edge User Capacity

The result for average capacity for edge users is shown in Figure 4.3. It can be observed that the proposed algorithm (user-SFR in the Figure 4.3) gives a better result in capacity of edge users than the fixed algorithm cases and this is especially when the number of edge users increases to more than 30% of the total users in the sector, similar to the case of SINR.

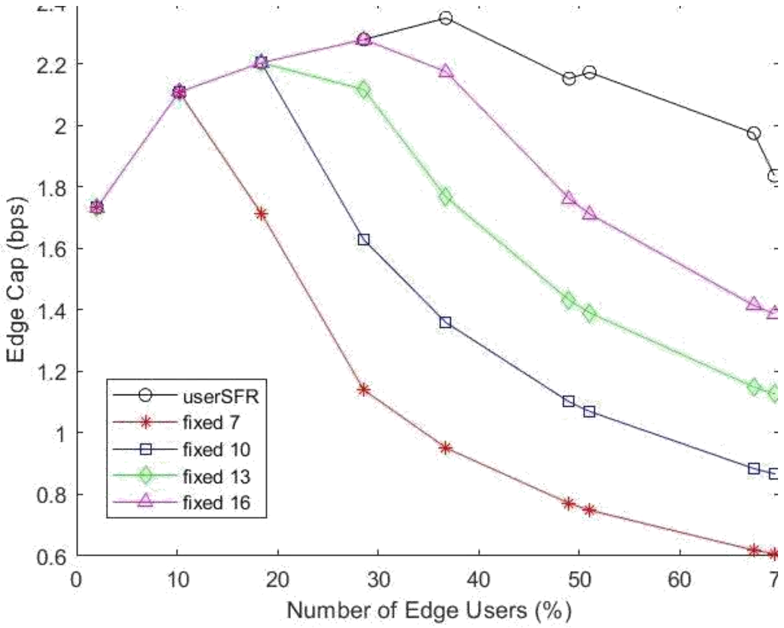


Figure 4.3: Average Edge User Capacity performance

4.3 Centre User Performance

In this section, the results for average performance (SINR and Capacity) for centre users are presented. The proposed algorithm described in Sections 3.4 and Algorithm 1 was simulated, and the results compared with the results of several fixed soft frequency reuse algorithms

4.3.1 Results for Average Centre User SINR and Capacity

The results for average performance (SINR and Capacity) for centre users are presented in Figure 4.4 and Figure 4.5. It can be observed that the best performance for most cases is the fixed-7 algorithm. The fixed-7 SFR has the lowest edge bandwidth allocation and the highest centre bandwidth allocation. The proposed algorithm performs averagely for SINR and Capacity compared to the fixed cases. The proposed algorithm however performs as the best algorithm for SINR, but the worst algorithm for Capacity when the number of edge users is very high. It is important to note that even though the performance for Centre users is not the best; the gap in performance is not very significant since the focus of the proposed algorithm is mainly to improve the performance of edge users who are the most affected by interference.

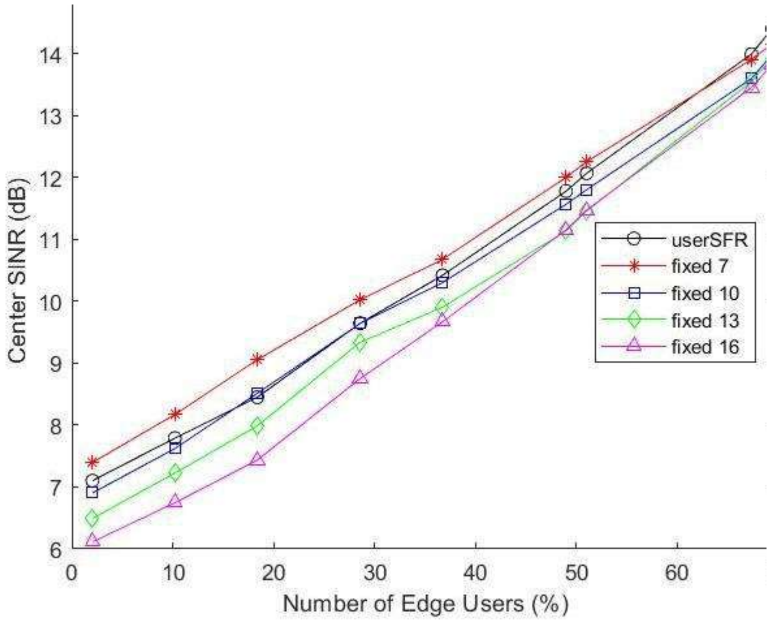


Figure 4.4: Average Centre User SINR performance

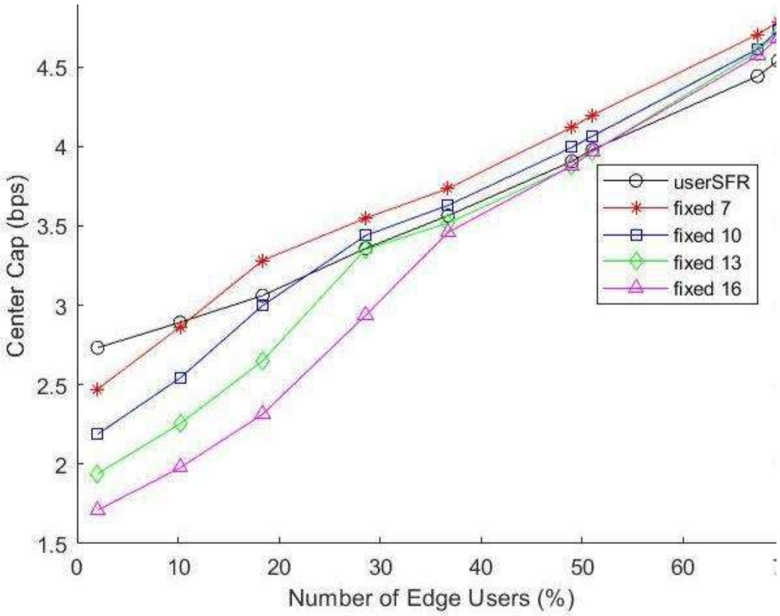


Figure 4.5: Average Centre User Capacity performance

4.4 Power Ratio

The final set of results presented in this section shows a deeper analysis of the algorithm based on observed SINR and Capacity according to variation in the power ratio.

4.4.1 The effect of Power ratio on SINR performance

From Figure 4.6, it can be observed that the higher the power ratio, the better the SINR performance for edge users. Similarly, in Figure 4.7, the higher the power ratio, the lower the SINR performance for centre users.

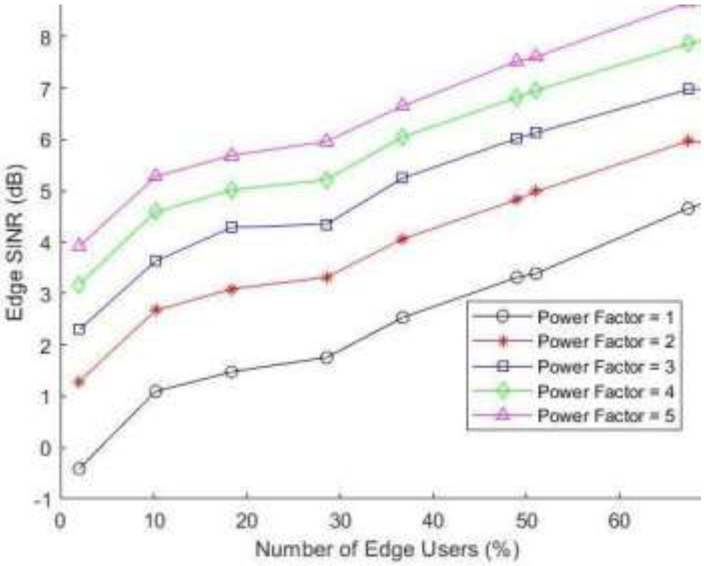


Figure 4.6: Impact of Power ratio on Average Edge SINR performance

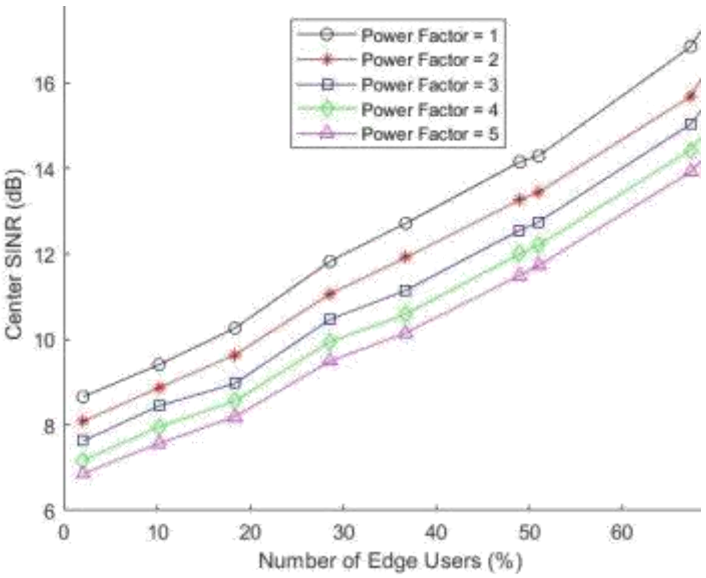


Figure 4.7: Impact of Power ratio on Average Centre SINR performance

4.4.2 The effect of Power ratio on Capacity performance

Similar to the case of SINR from Figure 4.7, it can be observed that the higher the power ratio, the better the capacity performance for edge users. This is due to the fact that they are farther from the transmitter at the centre of the base station and hence need more power to boast the signals being delivered to the edge of the cell. Similarly, from Figure 4.8, the higher the power ratio, the lower the capacity performance for centre users. When the edge users have more access to network resources due to increase in power allocated to the edge region, resource allocation between the centre and edge users become more competing. This may lead to a reduction in the capacity performance to centre users.

In Figure 4.9, it is further demonstrated that the maximum Capacity for Edge users occurs when the percentage of edge users is between 30% and 40%. This may be due to network design or implementation challenges.

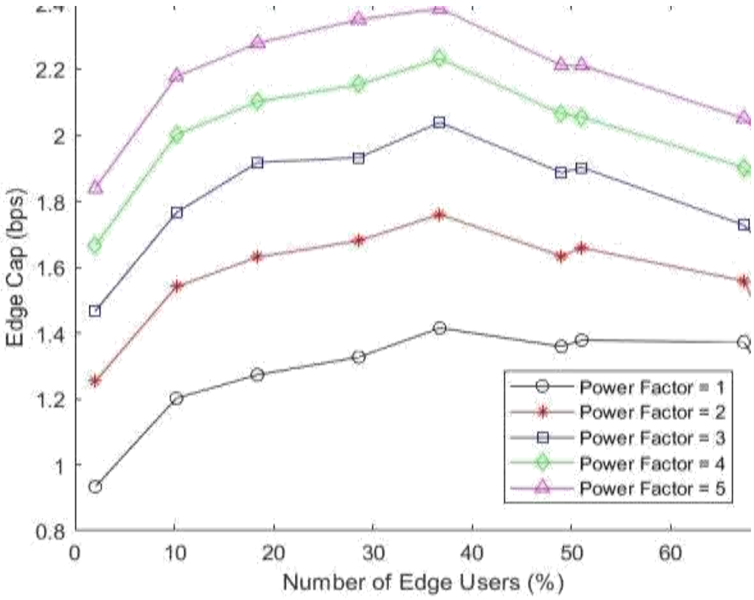


Figure 4.8: Impact of Power ratio on Average Edge Capacity performance

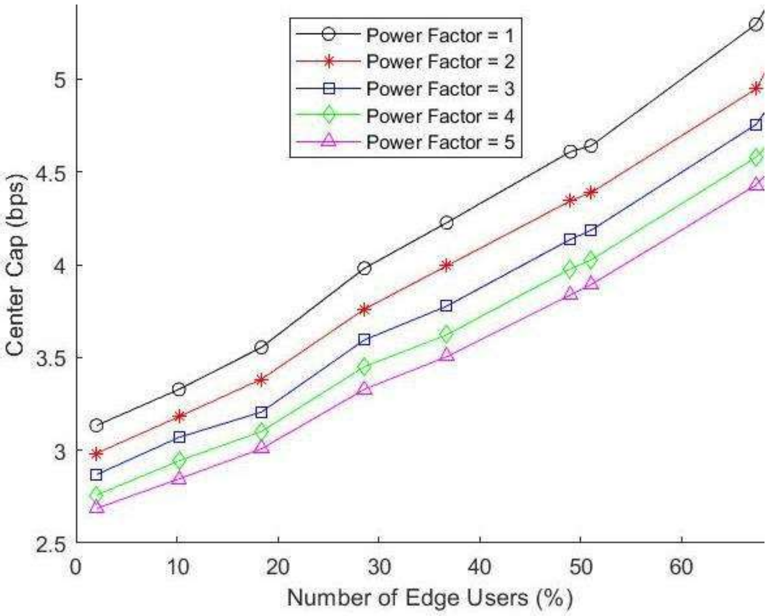


Figure 4.9: Impact of Power ratio on Average Centre Capacity performance

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A modified network model that captures interference in networks deploying SFR was achieved and performance equations on SINR and capacity derived.

The average SINR for Centre users based on equations without interference probabilities was realized. The average SINR for centre users based on the modified model was also realized. Through simulations the average SINR for centre users was also obtained. These three different results were compared. It was observed that the result obtained from the modified model is closer to the actual simulation results than the case where the model is not adopted, verifying that a more accurate model is achieved.

Relatively, an improved SFR algorithm called User-SFR has been developed. It intelligently adjusts resource allocation parameters according to the load distribution in the network regions. When compared with several results of a fixed SFR algorithm, the results for the proposed User-SFR outperforms the fixed SFR, especially in Edge user‟s SINR (which improved by about 3.2%) and Capacity(which improved by over 202%).

5.2 Recommendations

In many of the approaches employed in the deployment of SFR to minimize interference in cellular networks, uniform distribution of users was assumed. This assumption may be to enable researchers achieve some results. In this approach, the random deployment of users was considered and good performance was achieved in the SINR and Capacity of the edge users. However, more significant results were obtained when the number of the edge users exceeded 30% of the total number of users in the sector under consideration.

Future works should explore improving the SINR and the Capacity of the edge users even when there are less than 30% of edge users in a sector. This will enhance the accuracy of the User-SFR.

5.3 Contributions to Knowledge

The outcome of the research efforts of this project has led to the development of an intelligent algorithm based on improved soft frequency reuse that allocates bandwidth to cellular regions according to the load distribution at different regions within the network. The results for the proposed Algorithm outperforms previous algorithm (the fixed SFR), especially in Edge user‟s SINR (which improved by about 3.2%) and Capacity(which improved by over 202%).

5.4 Publications

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2. Asaka, O. T., Adejo, A., Salawu, N., Onumanyi, A. J., Bello-salau, H.,& Oluwamotemi, F. T.(2021). Load-Driven Resource Allocation for enhanced Interference mitigation in Cellular Networks. *A paper presented at the 1st International Conference on Multidisciplinary Engineering and Applied Sciences* held on 15th – 16th July, 2021, at Nile University, Abuja.Nigeria.

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APPENDIX A (Summary of some research works reviewed)

Author/Title of paper	**Strength**	**Weakness**
Hossain et al.(2015) Enhancing cell-edge performance using multi-layer soft frequency reuse scheme	A generic expression for power allocation in different regions along with the SINR of ML- SFR in sectored cell is derived**.** Spectral efficiency at cell-edge area improves by approximately 10% when simulated.	Uniform load distribution assumed.
Kumar and Sani. (2019) Implementation of Fractional Frequency Reuse Schemes in LTE-A Network.	FFR, SFR and conventional frequency reuse technique are compared. Simulation carried out showed an improvement in performance metrics: SINR, throughput and Spectral efficiency of the cell edge users when FFR schemes were used over the conventional FR technique.	Uniform load distribution assumed.
Abdullah et al. (2020) Enhanced fractional frequency reuse approach for interference mitigation in femtocell networks.	An algorithm to mitigate the interference in femtocell networks is developed. It involves dividing the coverage area into three regions rather than two used in the fractional frequency reuse approach. The proposed algorithm has minimised the interference, enhanced the SINR, and improved the throughput of the system as compared to the previous approaches considered.	Uniform load distribution assumed.
Veancy and Yogesh.(2021) Fractional Frequency Reuse with Enhanced Scheduling Strategies .	FFR with enhanced scheduling strategies and inter-cell interference coordination (ICIC) using expectation maximization algorithm are proposed. This enhances capacity, good user experience and improved spectral efficiency through the mitigation of the effects of the CCI. The resource allocation in FFR is done relying on the optimum post processing SINR threshold with different schedulers in the two regions. It is shown that a particular combination shows the best throughput performance for the proposed enhanced FFR scheme.	Users are assumed to be distributed evenly in various network regions.

Author/Title of paper	Strength	Weakness
Hossain et al.(2017)Multi Layer Soft Frequency Reuse Scheme for 5G Heterogeneous Cellular Networks.	A new resource allocation scheme for HetNet, called multi-level soft frequency reuse for HetNet (ML-SFR HetNet), is proposed. Bandwidth is allocated for macro cell users, small cell users and cell edge users among the various cells in the reuse system. Results of simulations shows that the throughput improved by around 3.5 times and outage probability reduces almost 5 times compared to traditional SFR system.	load distribution assumed.
Temaneh-Nyah et al.(2015) Computation of Users" Density in a Mobile Wireless Communication Network.	Subscriber"s density distribution for a wireless network based on the actual subscribers" traffic data obtained using a new algorithm.	Network regions not considered
Zhu *et al*.(2018) An Adaptive Spectrum Allocation Algorithm in Ultra-Dense Network,	A new technique introduced where the optimal parameter threshold is adaptively adjusted according to distribution of the users. Results show improvement in the SINR performance of users and the cell throughput. .	Network regions not considered
Hossain and Becvar .(2020) Flexible Soft Frequency Reuse for Interference Management in the Networks with Flying Base Stations	An SFR graph theory based algorithm for allocation of bandwidth and power is presented. It is flexible, self-organising and can handle incalculable and a dynamic layout of the networks with Flying base stations. The results of F-SFR showed improvement in the throughput of the cell-edge users and improves the satisfaction of the cell-edge users up to 25% compared to the state of the art SFR solutions. It also demonstrates that the proposed scheme ensures a higher fairness in throughput among the users.	Distribution of users is assumed to be uniform
Temoa *et al*. (2019) A Reinforcement Learning Based Intercell Interference Coordination in LTE Networks	A full dynamic ICIC approach where there is no bandwidth partitioning for downlink Long Term Evolution networks. The scheme is a joint resource allocation that uses reinforced learning strategy as well as power allocation scheme. Performances of proposed scheme shows improvement in SINR, packet loss and delay compared to other algorithms.	Downlink bandwithth not allocated in regions

Author/Title of paper	Strength	Weakness
Zhou *et al.,* (2019) The design of load balancing mechanism under Fractional Frequency Reuse for heterogeneous Cellular Networks	A technique to reduce interference in heterogeneous networks is introduced. It considers partitioning of network resource and balancing of load. The result is an enhanced performance of edge users while maintaining the fidelity of the overall throughput.	User association among cells considered but not within the sectors of the cells
Shamma and Mustafa. (2018) An Analysis of User Mobility in Cellular Networks.	The probability distribution function of the path length that a user will be associated with the same base station is derived. It is assumed that the user travels along a straight path and it is associated to the nearest base station. We make the stochastic geometry assumption that the base stations are distributed over the area according to a Poisson point process. We provide simulation results as further evidence that the analysis is correct. The results of this paper may be useful in the design of cellular networks.	Base stations are assumed to be uniformly distributed.
Mardani *et al*.(2020). A User-Centric Frequency Reuse in Non-full Interference Cellular Networks	A resource block (RB) allocated to a specific user in a cell is divided into multiple sub-channels. One of the sub-channel is used by the intended user while the unused RB reduce interference in other cells. The interfering BS depends on the coverage probability of the typical user. When compared with a known FFR, the scheme increases coverage probability and spectral efficiency.	Users are assumed to be uniformly distributed in a voronoi cell