DEVELOPMENT OF A COMBINATIONAL USERS SELECTION SCHEME TO ENHANCE EFFICIENT RESOURCES ALLOCATION IN A FEMTOCELL

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Development of a Combinational Users Selection Scheme to Enhance Efficient Resources Allocation in a Femtocell

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DECLARATION

This thesis is my original work and has not been presented for a degree or any other University

Signature:…………………………… Date:…………………..

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TUK, Kenya

DEDICATION

I would like to dedicate this thesis to my parents, relatives and work place colleagues whose prayers, support and continuous encouragement made me to pursue this research to conclusion.

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First, I thank God the almighty for life and good health that enabled me to enroll and pursue this programme.

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LIST OF ABBREVIATIONS

ACG	Amplitude Craving Greedy
AMPS	Advanced Mobile Phone System
ANN	Artificial neural network
BPS	Bits per symbol
CDMA	Code Division Multiple Access.
DSL	Digital Subscriber Line
eMBB	Enhanced Mobile Broadband
EV-DO	Evolution-Data Optimized
FAP	Femtocell Access Point
FDD	Frequency-division duplexing
HeNB	Home eNodeB
LTE	Long Term Evolution Networks.
MAC	Media Access Control
MME	Mobile Management Entity
mMTC	Massive Machine-Type Communication
NAS	Non-Access Stratum
NTT	Nippon Telegraph and Telephone
OFDM	Orthogonal frequency-division multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
PSS	Primary Synchronization Signal
QAM	Quadrature Amplitude Modulation

QPSK	Quadrature Phase Shift Keying
RB	Resource Block
RCG	Rate Craving Greedy
RE	Resource Element
RLC	Radio Link Control
SC	Subcarrier
SC-FDMA	Single carrier - Frequency Division Multiple Access
S-GW	Serving Gateway
SIC	Successive Interference Cancellation
SINR	Signal to Interference plus Noise Ratio.
SMS	Short Message Service
SNR	Signal to Noise Ratio
SOM	Self Organizing Map
SSS	Secondary Synchronization signal
SY	Symbol
TACS	Total Access Communications System
TDD	Time Division Duplex
URLLC	Ultra-Reliable and Low Latency
VLC	visible light communications
WIMAX	Worldwide Interoperability for Microwave Access

ABSTRACT

Accessibility is one of the Key Performance Indicators (KPI) that is used by Long Term Evolution Mobile Networks to check on the quality of the services offered to mobile users. A number of techniques have been used to allocate resources to users. These methods have experienced challenges in terms of allocating multiple resources at high data rates due to the ever growing demands for mobile users within existing resources. This has prompted continuous research in optimization of resource allocation on the existing systems. Due to this, improving resource allocation techniques is a viable area of research in Orthogonal Frequency Division Multiple Access (OFDMA) networks. This is with reference to power levels, Signal to Interference plus Noise ratio (SINR) and limited resource availability to multiple users requesting for resources in a femtocell. A combinational resource allocation scheme is hereby presented in which the available resource blocks are taken into account alongside the users' resource requests. Signal to Interference plus Noise Ratio computation is then done per user. In addition, all possible arrangements of all users are evaluated to determine the highest SINR levels hence, the best combination of users in comparison to resource requests to allocate the resource blocks at the femtocell. Fairness is also utilized in situations where low SINR valued users have been left out of the femtocell resource allocation. In this case, a resource is reallocated from the next lowest SINR valued user to the user who has been left out to enable the user to communicate. The proposed combinational algorithm is tested in four scenarios. The first scenario tests the algorithm in a femtocell where six users need to only connect and synchronize to the femtocell. In this case, only one resource is required per user and there are only four available resources. The algorithm prioritizes the users with high SINR values and allocates each one of them a resource. The second scenario considers six users who are requesting for more than one resource for data transmission. When the users are allocated resources, one user is found to be left out. The fairness scheme reallocates a resource to the user who is left out and ensures that all users communicate in the femtocell. The third scenario compares the Combinational technique with the Global mobility prediction technique using eight users requesting for resources at eight intervals. The tests conclude that the Combinational technique achieves higher SINR total values for users allocated and also, when incorporated with fairness, all the low SINR valued users are able to be allocated resources in the femtocell. Therefore, all users can communicate. Finally, the fourth scenario tests the effectiveness of fairness in ensuring that all users are allocated resources. It determines that all users are allocated at least a resource to communicate with just a small compromise on the SINR total value in the femtocell.

CHAPTER ONE
INTRODUCTION

1.1 Background of the study

Accessibility to mobile services poses an ever growing demand in several countries. This makes it necessary to provide faster connectivity and higher bandwidth to users for the ever increasing need for the services. Challenges are always posed to network operators to provide effective resource allocation to users while taking into account Signal to Interference plus Noise ratios (SINRs) (Oyie, 2015). SINR among many other factors contributes to the overall quality of service of the network operator. A number of approaches have been used over the years to improve the SINRs and improve on the allocation. Despite this, they still face challenges in terms of reaching optimum levels to determine the best users to be allowed to communicate on the network (Farhana Afroz, 2015). This urge to accommodate as many users as possible has led to evolution of mobile networks from 1G to 5G with improvement being done on bandwidth and speed of access (Ariful Alam, 2013) (F. Afroz, November, 2014). 6G is the latest mobile technology that is currently under development and testing for deployment

In Global System for Mobile communications (GSM) networks, the early mobile technologies were mainly analog in terms of allocating user services. The technology used in the first Generation of networks was Advanced Mobile Phone System (AMPS). This was limited in terms of bandwidth and could connect very few users at a given time (Sapna Shukla, 2013). Some improvement was done in order to allow for an increase in allocation. This was done by introducing Frequency Division Multiple Access (FDMA). In FDMA, the bandwidth was split into a number of channels which were allocated to users to enable them to communicate. However, this was not very adequate in terms of allowing multiple users to access the network.

In the second generation, techniques of digital modulation such as Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) were introduced (Sapna Shukla, 2013). These encouraged the introduction of services such as Short

Messaging Services (SMS) and Circuit Switched Data (CSD) that enhanced the quality of voice and enabled text to be transmitted over the network (Sapna Shukla, 2013).

Furthermore, the third generation of GSM network introduced faster technologies such as Universal Mobile Telecommunications Service (UMTS). These technologies enhanced high speeds that enabled additional services such as high speed internet and video streaming (Ariful Alam, 2013).

The next technology is the Long Term Evolution (LTE) Networks (Anritsu Corporation, 2009). This was developed as an Internet Protocol network in the Next Generation Networks (NGN) scheme. All traffic is transmitted with the use of resources that are allocated and transmitted dynamically to various users (Sainju, 2012) (Imran, Jamal, & Qadeer, 2016). The key challenge that is posed by this network is the optimization of users' resources so as to accommodate as many users as possible within the bandwidth provided (Oyie, 2015) (Roy, 2015).

The new technology in mobile networks is 5G. This technology utilizes millimeter waves with frequencies reaching up to 60 GHz (Guerreiro, 2020). It utilizes Non Orthogonal Multiple Access (NOMA) technique with very high frequencies to allocate users flexible resource blocks that can be allocated to multiple users (Guerreiro, 2020).

6G is a technology that is under research and development. It will use Terahertz bands and have data rates of up to 1 Tbps (Guerreiro, 2020). It will also have higher spectral efficiencies, lower latencies and improved network capacities (Guerreiro, 2020).

1.2 Statement of the Problem

There is always need to make mobile radio resources available to as many users as possible in a femtocell at a given interval of time plus maintaining high levels of data transmission in the femtocell. A number of methods have been deployed to tackle accessibility of network resources to users so as to increase throughput in the network. These technologies have tried to improve accessibility by tackling issues such as: optimizing user data rates, power levels, mobility and so forth. There are also other techniques such as: maximum fairness, proportional rates constraints, mobility aware algorithm, and rate craving greedy schemes that have been used to allocate users on the basis of their data rates, mobility and signal power levels.

Despite this, quite a number of these techniques have had challenges in terms of determining the best users' combinations, given the huge resource requests that are normally experienced in femtocells from various users with varying network parameters. Therefore, it becomes necessary for radio resources allocation in femtocell networks to be improved so as to accommodate more users at higher throughput rates and SINR. This makes it necessary to further research in determining best users' combinations.

1.3. Objectives

1.3.1. Main Objective

To develop a combinational algorithm that efficiently allocates resources in a femtocell network.

1.3.2. Specific Objectives

i). To determine the effectiveness of combinations as a users' arrangement technique

ii). To analyze combinations in terms of the resource requests types in comparison to resource availability in a femtocell.

iii). To investigate the effect of fairness on users' Signal to Interference plus Noise ratio while determining the most effective allocation of resources to users within a femtocell.

iv). To validate the combinational users' selection scheme as an improvement on resource allocation technique over the existing methods.

1.4 Justification

Mobile technologies have evolved in an attempt to address bandwidth requirements that keep on increasing. However there is always need to keep on granting resource requests to as many mobile applications as possible, while maintaining high spectrum parameters such as signal to noise ratio, so as to maintain high throughput. This has led researchers to seek ways of improving the quality of service being offered to cell phone users by enhancing the efficiency at which resources are allocated in a femtocell. The combinational algorithm aims to tackle this allocation challenge by obtaining all the possible group arrangement of users coupled with their SINRs totals. This will give a complete scenario of resource utilization in the femtocell and then the best group is selected from this algorithm. This is a good technique of determining the users to be allocated resources in a femtocell and hence improves the overall utilization and efficiency of the femtocell.

1.5 Scope

The scope of this research is limited to users within a femtocell in an LTE network. The femtocell is placed inside a building, and a number of users who are requesting for resources for connection and communication purposes are analyzed in different scenarios. A number of snapshots of users present in the femtocell are also analyzed with the users maintaining their SINR values, but are considered present at different intervals in the femtocell. The femtocell has limited number of resources compared to the ones being requested.

1.6 Organization of the study

This thesis is organized into the following: Chapter one is the introduction of the research. Chapter two gives the detailed background and similar methods reviewed in the literature. Chapter three outlines the proposed method to improve over the existing ones. Chapter four gives the results of the simulation of the proposed solution in different scenarios in the femtocell. Lastly, chapter five conclude the work done and recommends areas for improvement in future research out of issues noted while doing the research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Global System for Mobile Communications

GSM refers to Global System for Mobile communications. This was developed by the European Standards Institutes to outline global standardized protocols for cellular networks (Ariful Alam, 2013) (Stuhlfauth, 2015).

GSM offers the following services:

a) General mobile services which include: Voice and short message services (Ariful Alam, 2013).
b) Essential services which include: emergency service lines.
c) Supplementary services such as Internet.

GSM is subdivided into the following sectors to enable establishment of connections between users (Oyie, 2015):

a) Public Land Mobile Network service area. This refers to the service area covered by a particular network operator.
b) Mobile Switching Center service area. This subdivides the network into small areas and performs the task of setting up calls, obtains information concerning subscribers in terms of location, profile and performs the base level switching in a cellular network (Stuhlfauth, 2015).

A GSM system is made of the following sections:

a) Base Station Subsystem
b) Network and Switching subsystem
c) Network Management Subsystem

2.2 History of Evolution of Mobile Networks

Mobile networks have evolved from 1G to 5G cellular networks with an improvement in connectivity rates and the amount of data that is being transmitted (Sapna Shukla, 2013). 6G is currently under development and trial in some countries like China and USA. These technologies are briefly described below.

First Generation (1G) network operators were Nippon Telegraph and Telephone (NTT) commissioned in 1979 (Sousa, Vasco, & Tiago, 2016) and the Advanced Mobile Phone Systems (AMPS) used in United States of America and Australia. Others were: Total Access Communications Systems (TACS) used in the United Kingdom, C-450 in West Germany, Portugal and South Africa (Oyie, 2015). 1G technology was mainly analog in nature in terms of voice transmission. This system had limited capacity and mobility. It was limited in terms of frequency reuse in the cellular planning, security for mobile users and incompatibility between different mobile networks hence roaming was not possible (Ariful Alam, 2013).

Second Generation (2G) technology was mainly characterized by digital encoding. Voice would be encoded and multiplexed for transmission. In addition, there was improved bandwidth utilization by enabling voice to be transmitted on the same channel. Technologies such as Code Division Multiple Access (CDMA) and Time Division Multiple Access (TDMA) (Ariful Alam, 2013) were also incorporated. Short Messaging Service (SMS) was also developed in this generation.

The next generations to be developed were 2.5G and 2.75G cellular networks (Ariful Alam, 2013). Technology developed further from circuit switching mode of communication to packet switching mode of communication. Other aspects that were further developed were sharing of radio resources whereby, packet switching enabled multiuser support for available bandwidth. Packets have a routing header with the destination address indicated on it (Ariful Alam, 2013). This was also advancement on technologies such as TDMA.

The next technology was Third Generation (3G) communications. This was characterized by high data rates. This consisted of Universal Mobile

Telecommunications Service (UMTS) and Wideband Code Division Multiple Access (W-CDMA) (Chakraborty & Aditi, 2013). They enabled streaming capabilities of high data requirement such as Mobile television, Global Positioning systems, video-conferencing and Telemedicine among others (Chakraborty & Aditi, 2013).

The next generation is the fourth generation (4G) communications. Technologies used here are Long Term Evolution (LTE) networks and Worldwide Interoperability for Microwave Access (WiMAX). These are characterized by super-fast connectivity and high data rates (Sapna Shukla, 2013) (Chakraborty & Aditi, 2013). Speeds can reach up to 1 GB/s (Oyie, 2015). These provide support for high end services such as online 3D television, IP Television, IP telephone services, cloud computing among others (Chakraborty & Aditi, 2013). 4G communications is an all Internet Protocol (IP) network with packet switching being utilized in all aspects of communication from voice to data transmission (Sapna Shukla, 2013). This is an improvement from earlier technologies where circuit switching was used for voice communications (Chakraborty & Aditi, 2013).

5G is a new technology that utilizes millimeter waves which are transmitted in GHz bands. The frequency bands used reach up to 60 GHz (Technologies, 2018). 5G has three main use cases: Enhanced Mobile

Broadband (eMBB), Ultra-Reliable, Low Latency (URLLC) and Massive Machine-Type Communication (mMTC) (Guerreiro, 2020). 5G technologies utilize Non Orthogonal Multiple Access (NOMA) technology to accommodate many users in the same spectrum. It also deploys Successive Interference Cancellation (SIC) technologies to handle variations in power transmission and has a flexible Resource Block Numerology (Guerreiro, 2020).

6G is also a new technology that is currently under development and testing. It is expected to reach peak data rates of at least 1 Tbps. It will also utilize Terahertz band frequencies for transmission (Guerreiro, 2020). Technologies such as Visible Light Communications (VLC) will be supported by 6G. However, this technique is still vulnerable to interference by visible light. It is still under research and development to counter these challenges alongside the high speeds (Ahmet Yazar, 2020).

2.3 Long Term Evolution (LTE) Networks

LTE networks are built on the technology of Next Generation Networks that support a wide variety of services on an all IP platform (Sousa, Vasco, & Tiago, 2016). LTE speeds are 100Mbps for downlink and 50Mbps for the uplink channels (Sousa, Vasco, & Tiago, 2016). It also has high a spectral efficiency and network security for its users.

2.3.1. Long Term Evolution Structure

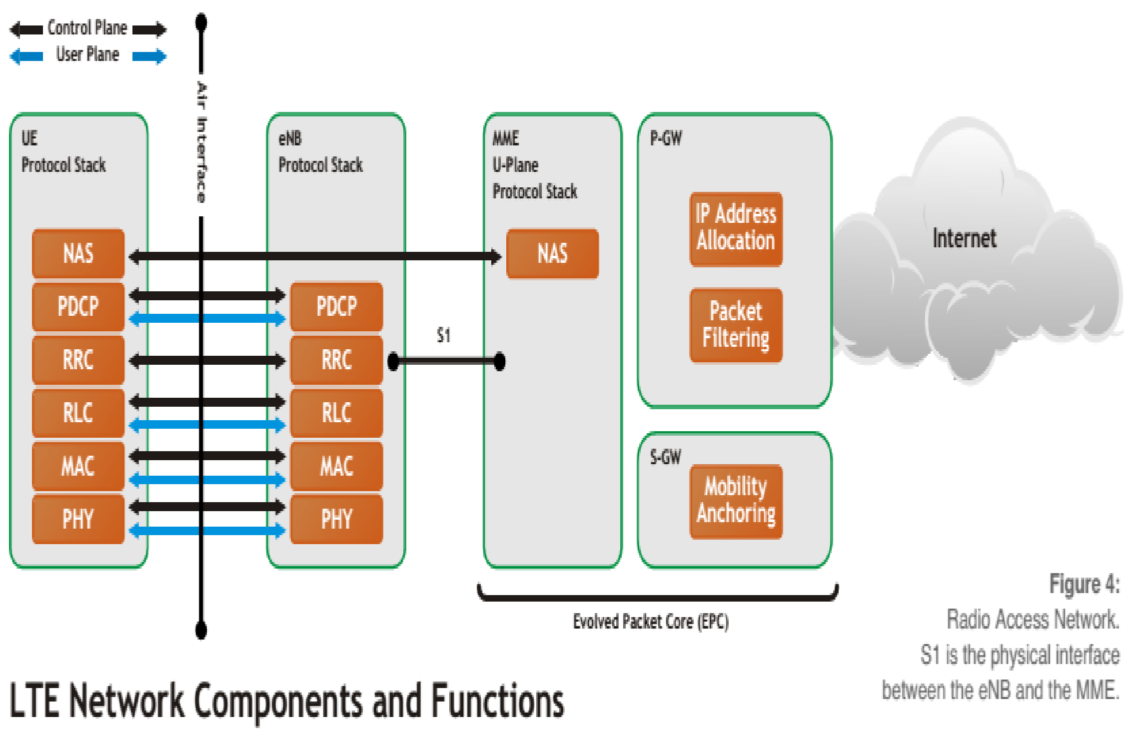


Figure 2.1: LTE Network Components (Anritsu Corporation, 2009)

An LTE network is made up of the following components (Martin, 2017) as shown in Figure 2.1

I. User Equipment
II. Enhanced NodeB
III. Packet Data Network Gateway.
IV. Mobility Management Entity
V. Serving Gateway

2.3.1.1 User Equipment

This refers to a handheld device that enables a user to access a network and provides network measurements that indicate channel conditions of the network (Anritsu, 2013).

2.3.1.2 Enhanced NodeB

This equipment contains the following components: Physical (PHY), Medium Access Control (MAC), Radio Link Control (RLC), and Packet Data Convergence Protocol (PDCP) layers (Anritsu, 2013). In addition it provides radio resource functionality, Radio Resource Management-admission control, scheduling, enforcement of negotiated uplink QOS and also cell information broadcast. (Anritsu, 2013). Furthermore, it also enhances load balancing between different simultaneous radios bearers. (Martin, 2017).

2.3.1.3 Packet Data Network Gateway.

This component is used to interconnect user equipment to the internet and to the external packet data networks (Martin, 2017). In addition, it is used to perform policy enforcement, packet filtering and screening for users. Furthermore, it anchors mobility between 3GPP and non-3GPP technologies such as Wi-Fi and 3GPP2 (CDMA2000 1xRTTand EV-DO) (Anritsu, 2013).

2.3.1.4 Mobility Management Entity (MME)

The MME is used for signaling exchanges between the base stations, the core network and between the users and the core network (Martin, 2017). Secondly, it acts as a unit over which data flows between the user and the Internet. Finally, it is important in user equipment tracking and paging procedures. (Anritsu, 2013). Figure 2.2 shows its location within the LTE network.

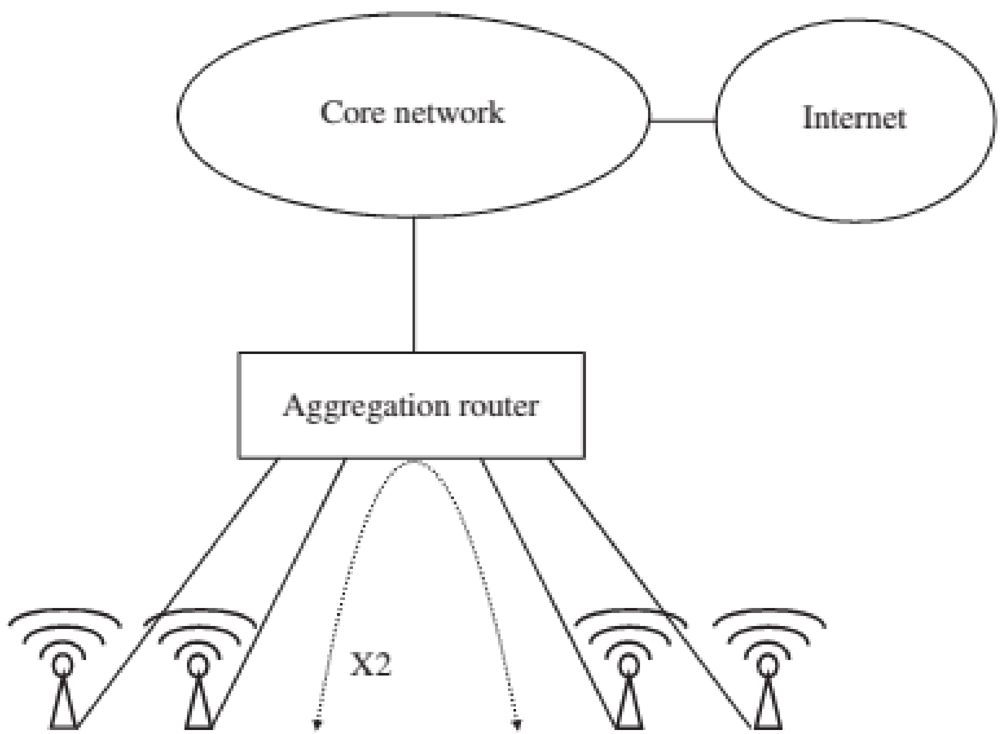


Figure 2.2: Routing on the MME. (Martin, 2017)

The MME also handles security key management functions and provides control plane function for mobility between LTE and other access networks (Anritsu, 2013). Furthermore, it acts as the termination point for the Non-Access Stratum (NAS) signaling (Anritsu, 2013).

In a nutshell, the MME does the following functions: Authentication, Establishment of bearers, Non-Access Stratum (NAS) mobility management, Handover support, SMS voice support and interworking with other radio networks (Martin, 2017).

2.3.1.5 Serving Gateway (S-GW)

The serving gateway manages user data tunnels between the eNode-B and the Packet Data Network Gateway (Martin, 2017). Secondly, it serves the function of routing and forwarding user data packets plus it also manages and stores user equipment contexts (Anritsu, 2013). Such parameters include: Network internal routing information and IP bearer services (Anritsu, 2013). Thirdly, the Serving Gateway is the mobility anchor during inter eNode-B handovers between LTE and other 3GPP technologies (Anritsu, 2013).

2.3.2. LTE Structures

LTE networks utilize the Time Division Duplex (TDD) and Frequency Division Duplex (FDD) methods in an orthogonal manner to enable users to be allocated channel resources in a dynamic manner (Oyie, 2015). LTE makes use of the Orthogonal Frequency Division Multiplex (OFDM) technology. It provides high robustness and scalability in the utilization of subcarriers in the spectrum. Since multiplexing is done in both the Time and Frequency domains, several closely spaced subcarriers are used to transmit several data packet steams to the receiver (Oyie, 2015).

OFDM checks on channel attenuation factors such as multipath and frequency selective fading, which used to occur due to reliance on single channel communication between the sender and the receiver of a message. Other factors that are controlled are as inter symbol interference and crosstalk.

2.3.3. Orthogonal Frequency-Division Multiple Access (OFDMA)

For OFDMA systems, multiple users are allocated radio resources within the network (Anritsu, 2013). These resources are subcarriers that come as a result of splitting of the frequency bandwidth into small sets of subcarriers spaced at 15 KHz. These resources are then allocated to users for modulation. This is shown in Figure 2.3. The modulation schemes normally used are QPSK, 16 – QAM and 64-QAM (Oyie, 2015).

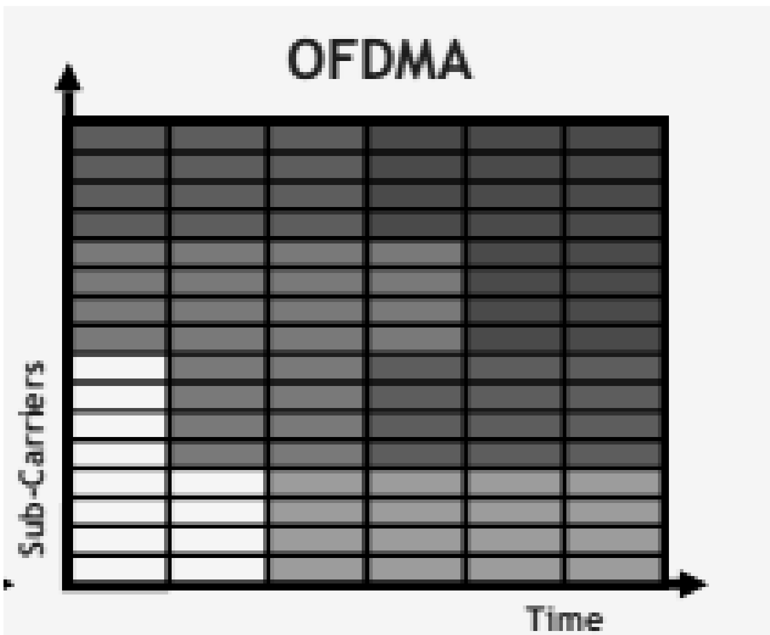


Figure 2.3: OFDMA (Anritsu, 2013)

During uplink, LTE utilizes Single Carrier – Frequency Division Multiple Access (SC-FDMA) due to low peak to average power ratio and hence, it tends to utilize less power (Anritsu, 2013). This is good for uplink since less battery power of the cell phone is required to upload data. In this scheme, data spreads across several subcarriers for several users which is indicated by the different colours (Anritsu, 2013). One colour indicates burst of data from a user.

2.3.4. LTE Frames

LTE spectrum has both uplink and downlink channels that utilize frames for these services.

In the time domain, LTE uses a Radio frame consisting of 20 slots with duration of 0.5 ms each. This is shown in Figure 2.4 (Anritsu, 2013).

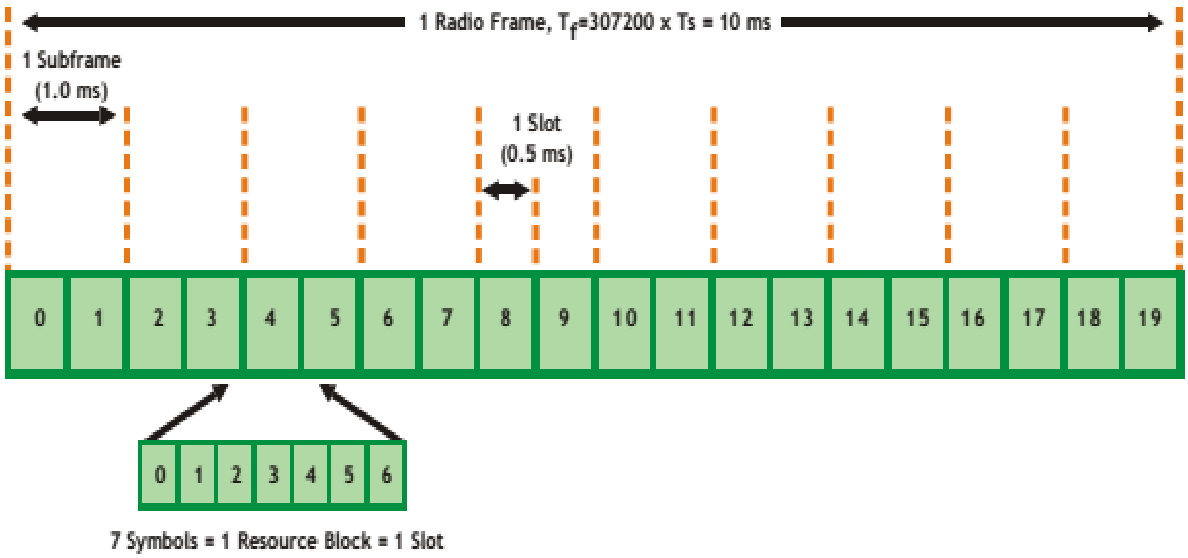


Figure 2.4: Radio Frame with slots in the TDD (Anritsu, 2013)

Each slot is made up of symbols. One slot can either have 7 symbols: a system known as *Normal Cyclic prefix* or, it can have 6 symbols: known as *Extended Cyclic prefix*.

2.3.5 Resource Block Size

In 4G networks, on the frequency domain or the FDD frame, one - 180 KHz subcarrier spacing forms a *Resource Block (RB).* A resource block is made up of subcarriers (SC) whose bandwidth is 15 KHz (Anritsu, 2013). Hence, it means that one resource block has 12 subcarriers.

When the two are incorporated into one frame, an orthogonal structure consisting of smaller units in the resource blocks in both the time and frequency domains is created. These smaller units are known as *Resource Elements* (Anritsu, 2013). This is shown in Figure 2.5.

The dimensions of a resource element are one symbol by 15 KHz subcarrier bandwidth. (Anritsu, 2013)

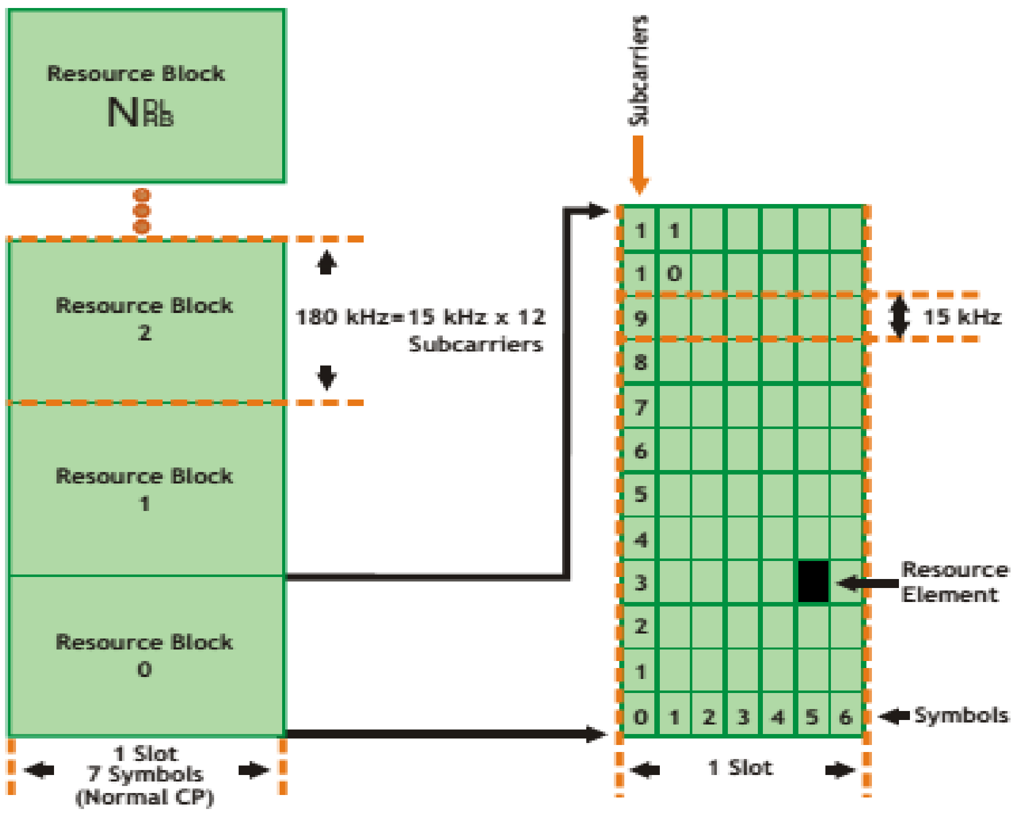


Figure 2.5: LTE Frame structure: Slots, Resource Blocks and Elements (Anritsu, 2013)

On the Time Division Duplex (TDD), a resource block is made up of 7 symbols (SY) in the normal cyclic prefix as shown in Figure 2.5 (Anritsu, 2013). The total number of resource elements is given by:

$$12\ SC \times 7\ SY = 84\ REs \qquad (2.1)$$

Where:

SC Refers to the number of subcarriers in a resource block

SY Refers to the number of symbols in a resource block

This makes the total number of resource elements in one resource block to be 84.

The numbers of resource blocks that can fit a given bandwidth vary directly with the given bandwidth of the LTE channel. The allocation of channels for LTE networks is shown in Table 2.1 (Anritsu Corporation, 2015).

In 5G networks, resource blocks are defined by a flexible numerology which makes the subcarrier spacing scales range from 15 kHz to 240 kHz (Technologies, 2018). In addition, the slots per sub-frame range from 1 to 16 in number (Technologies, 2018). These different numerologies on the 5G resource block structure have brought a challenge of interference between the different subcarriers. This is an area of research that has to be pursued under the SIC technologies (DeTomasi, 2018). 6G utilizes Terahertz bands: 1THz to 10THz that are also susceptible to light interference.

This research is only limited to the 4G technology which utilizes LTE networks. In LTE networks, a user is allocated an OFDMA resource block directly without blending with any other technology in the process (DeTomasi, 2018).

Table 2.1: LTE Transmission bandwidth configuration.

Channel bandwidth in MHz	Max no of resource blocks that can be transmitted	Maximum occupied bandwidth (MHZ)
1.4	6	1.08
3	15	2.7
5	25	4.5
10	50	9
15	75	13.5
20	100	18

2.4 Adaptive Modulation and Coding (AMC)

The AMC of an LTE network determines the modulation schemes and the coding rate to be used in the transmission of data over the network. This is based on the radio frequency reports from the user equipment sent to the base station in the form of Measurement reports (Anritsu, 2013). This is used to calculate the number of bits per symbol that can be transmitted by a symbol inside a resource block.

There are 3 modulation schemes used in LTE networks (Anritsu, 2013).

a) QPSK (4-QAM). This scheme transmits 2 bits per symbol.
b) 16- QAM – This scheme transmits 4 bits per symbol.
c) 64- QAM – This scheme transmits 6 bits per symbol.

The Adaptive Modulation and Coding scheme is used to determine the number of bits transmitted by each symbol in the resource block. This in turn determines the transmission bandwidth.

$$RE_{(per\ RB)} \times AMC_{BITS/SY} = BITS_{(per\ RB)} \qquad (2.2)$$

Where:

$RE_{(per\ RB)}$ Refers to the number of resource elements per resource block. This is normally 84 as per equation 2.1

$AMC_{(BITS/SY)}$ Refers to the number of bits transmitted per symbol depending on the modulation scheme allocated by the Adaptive Modulation Scheme (AMC)

$BITS_{(per\ RB)}$ Refers to the total bits transmitted by a resource block depending on the modulation scheme used.

This research wishes to pursue the maximum possible allocation to users using the maximum bits that can be allocated to a user for the best case comparison. For this reason, the modulation scheme that will be used is 64-QAM. The numbers of bits transmitted by a resource block using 64 QAM are 6 bits per symbol. This translates to the following data transmission.

$$84 \times 6 = 504 \text{ bits/RB} \tag{2.3}$$

There are 84 resource elements in a resource block and each resource block is carrying 6 symbols. This gives a total of 504 bits to be transmitted by a resource block.

On the Time Division Duplex (TDD) frame, a resource block occupies 0.5 milliseconds. Therefore the data transmission rate is given as follows:

$$\text{Tx rate}_{(per\ RB-64QAM)} = \frac{504 \text{ bits}}{0.5 \text{ ms}} = 1.008 \text{ Mbps} \tag{2.4}$$

Where:

$\text{Tx rate}_{(per\ RB)}$ Refers to the transmission rate per resource block per second (*in this case using 64-QAM scheme*)

2.5 Resource Block Requests

The number of resource block requests is determined by the bandwidth requirements of the users' cellphone applications. The requirements for resource blocks for communication are described in Sections 2.5.1 and 2.5.2 respectively.

2.5.1 Resource Request for Data Streaming

In this instance, the bandwidth requirements are high. This is because of the classification based - call admission control mechanism described in (AlQahtani, 2015) whereby, the applications of the phone request for multiple resource blocks simultaneously. This results in a high number of resource block requirements resulting in huge bandwidth requirements. Such instances include: Video streaming, video conferencing and so forth (Stefanis, Issam, & Mathew, 2011).

The number of resource blocks required is calculated with the aid of the data transmission rate in equation 2.5 as follows

$$RB_{REQ} = \frac{\mathrm{TP}^{\mathrm{REQ}}}{\mathrm{Tx\ rate}_{(PER\ RB)}} \tag{2.5}$$

Where:

RB_{REQ} Refers to the number of resource blocks required

$\mathrm{TP}^{\mathrm{REQ}}$ Refers to the throughput required

$\mathrm{Tx\ rate}_{(PER\ RB)}$ Refers to the transmission rate per resource block per second

2.5.2 Resource Request for Synchronization

This is an event that normally takes place when a user switches on a cell phone. The cell phone starts to search for resources to connect to the femtocell. This is a process that is achieved with the use of the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS). These two signals occur at two intervals of 5 milliseconds in the radio frame as shown in Figure 2.6. The resource blocks utilized for this function are at Subframe ‘0’ and Subframe ‘5’ (Stefanis, Issam, & Mathew, 2011). Therefore, it can be stated that only one resource block is used to perform the primary and the secondary synchronization sequences. Hence, only one resource block is used in this operation. This forms the basis of single resource requests as demonstrated in chapter 3 and chapter 4.

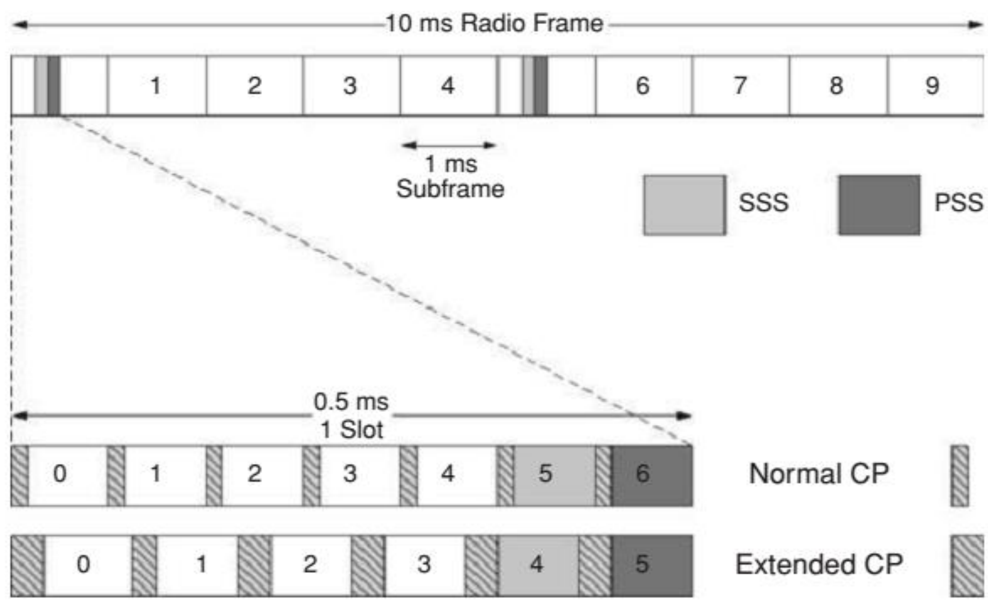


Figure 2.6: The PSS and SSS in the radio frame structure in the TDD frame (Sesia, Toufik, & Baker, 2011).

2.6 Femtocells

Femtocells refer to low powered base stations that are stationed indoors for mobile services provision in residential or enterprise use in workplaces (Oyie, 2015). They are typically deployed in places that have very little or no cell phone coverage from outer macrocells. They are installed indoors as Femtocell Access Points (FAPs) and are connected back to the mobile network operator via either: broadband connection, optical fibre cables or Digital Subscriber Lines (DSL) (Oyie, 2015). The need to have femtocells emanated from an overall survey that puts indoor and in-building mobile services use at around 70%. Out of these, up to 40% of the users in building and residential areas experience mobile access coverage problems. They can also be referred to as Home eNodeB (HeNB) (M. Arif, 2013). A femtocell can support up to 32 active calls depending on configuration at the point it is stationed, whether residential or in a commercial building. This is because femtocells are designed according to the 3GPP: LTE release 9 standards. They are designed for indoor environments to operate with a maximum output power of 17 dBm (Telesys, 2015). They also transmit at frequencies of 2.4 GHz and 5 GHz. This power level is only ideal for indoor environments and has little penetration across a few walls similar to Wi-Fi. With high speed connection like fiber optics to the macro cells outside, the numbers of users that they can support can reach a maximum of 32. The normal operating range is 8 to 16 users (M. Arif, 2013).

With the assistance of Self Organizing Networks technologies, femtocells can be configured and deployed so as not to cause interferences (Oyie, 2015) (R. Saadatdoost, 2011), with the macrocells outside. This is also used to enhance seamless handover of users during their mobility, in and out of areas covered by the femtocells (Alliance, 2015).

2.7 LTE System Parameters

2.7.1 Channel Quality Indicator (CQI)

The CQI is a measure of the channel's worth in terms of transmitting information from the user equipment to the femtocell and vice versa (Sapna Shukla, 2013). It is used as a determining factor while making a decision on which resource to allocate a user to transmit data on. The following are useful factors that are used in CQI measurement (Sapna Shukla, 2013).

i). Signal-to-noise ratio (SNR)

ii). Signal-to-interference plus noise ratio (SINR)

iii). Signal-to-noise plus distortion ratio (SNDR)

For LTE systems, 15 different values of CQI levels are set with comparisons made with various modulation schemes and transport block sizes (Hur, 2012) (Sushruth N. Donthi and Neelesh B. Mehta, 2011). This is outlined in Table 2.2.

Table 2.2: 4 – Bit CQI table (Mohammad T. Kawser, 2012).

CQI INDEX	MODULATION	CODE RATE X 1024	EFFICIENCY
0	OUT OF RANGE		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

The values in the efficiency column are used to give a figure of merit for the quality of the resource block for transmission of data (Sushruth N. Donthi and Neelesh B. Mehta, 2011).

2.7.2 Signal to Noise Ratio

This refers to the ratio of meaningful useful power in a signal in comparison to background noise or interfering power in the signal. (Mohammad T. Kawser, 2012). It is mathematically expressed as follows.

$$SNR = \frac{P_{SIGNAL}}{P_{NOISE}} \tag{2.6}$$

$$SNR_{dB} = 10\log(P_{SIGNAL}) - 10log\ (P_{NOISE}) \tag{2.7}$$

Where:

P_{SIGNAL} refers to the signal power

P_{NOISE} refers to the noise power in the signal from undesired sources

SNR refers to the signal to noise ratio

2.7.3 Signal to Interference plus Noise Ratio (SINR)

The SINR refers to the ratio of the power in a signal to the sum of the average of the interference power from adjacent cells plus noise power. It is normally reflected in the channel quality indicator by the user equipment per every resource block and sent to the femtocell. (Guowang Miao, 2016) (Ferreira, 2018).

SINR is also a measure of the signal quality with relation to the radio frequency conditions of the LTE network and also in relation to the throughput. It is calculated using equation 2.8 (Anritsu Corporation, 2009) (Ferreira, 2018).

$$SINR = \frac{P_{SIGNAL}}{P_{INTERFERENCE}+P_{NOISE}} \tag{2.8}$$

Where

P_{SIGNAL} is the average signal power

$P_{INTERFERENCE}$ is the interference power in the signal from co-channel and adjacent channels

P_{NOISE} is the Noise power from undesired sources in the signal.

Signal to Interference plus Noise ratio calculations are also calculated in terms of the channel bandwidth and the resource throughput in bits per second (bps). This is given by the formula stated in 2.9 (Anritsu Corporation, 2009).

$$C = Blog_2(1 + SINR) \tag{2.9}$$

Where:

C = Capacity of the channel or throughput (bps)

B = Bandwidth of the channel (Hz)

SINR = Signal to Interference plus Noise Ratio (Anritsu Corporation, 2009).

When derived further, this would give equations 2.10 and 2.11,

$$Log_2(1 + SINR) = {}^{C}/_{B} \tag{2.10}$$

$$SINR = 2^{[C/B]} - 1 \tag{2.11}$$

The SINR in equation 2.11 can be further expressed in terms of dB as shown in equation 2.12

$$SINR_{dB} = 10\log(SINR) \tag{2.12}$$

2.8 Self-Organizing Maps (SOM)

SOM are used in Artificial neural networks (ANN) to produce a representation of the variables presented to them at the input in a two dimensional pictorial format (Anritsu Corporation, 2009). They are usually independent from external input and reorganize data internally with the use of common features. They are able to categorize the data with reference to these features despite the varying versions of inputs (Anritsu Corporation, 2009) (Shah-Hosseini, 2011). They are also trained and built in terms of biological neural models made up of nodes or neurons known as Kohonen Maps or networks. In addition, they are useful in representing data presented in high order inputs and dimensions into simple two dimensional clusters of map space in the Kohonen maps (Shah-Hosseini, 2011).

The process of implementing the SOM algorithm involves the following stages: Initialization, Sampling, Matching, Updating then redoing the second stage of sampling until the map stops changing (Anritsu Corporation, 2009).

2.9 Resources Allocation Schemes

There are quite a number of resource allocation schemes that dynamically allocate resources to users on both the downlink and uplink channels. Research is continuously being done to optimize on both powers, which are transmitted to the user so as to make it as minimal as possible. This reduces power transmission losses (Oyie, 2015). On the other hand, it is meant to make the channel gains for transmission as high as possible (Oyie, 2015).

2.9.1 Rate Craving Greedy (RCG) and Amplitude Craving Greedy (ACG)

The rate craving algorithm checks for users with the highest transmission rate then allocates the available subcarrier to that user (Oyie, 2015). The amplitude craving greedy technique checks for users who have high channel gain then it allocates the subcarrier to that user (Oyie, 2015). The target in the above methods usually is to get as much data through the system as possible (Sudhir B. Lande, 2012), so that maximum throughput in each subcarrier is achieved (Sudhir B. Lande, 2012) (Yaramasu, Qureshi, & Lande, 2014).

2.9.2 Maximum Fairness Algorithm

The aim in Maximum fairness algorithm is to allocate subcarriers in a technique that ensures the minimum user's data rate is maximized. (Sudhir B. Lande, 2012). An assumption is normally done at the beginning, where by, all users are allocated equal power. Next, optimal water filling power allocation algorithm is then carried out to distribute power to users with low power levels and low data transmission rates (Sudhir B. Lande, 2012) . An exhaustive search for the best joint power allocation is then achieved (Sudhir B. Lande, 2012).

2.9.3 Proportional Rate Constraints Algorithm

This algorithm's objective is to maximize sum throughput through the transmission system (Sudhir B. Lande, 2012) (Yaramasu, Qureshi, & Lande, 2014). In this method, a predetermined system parameter βk, is introduced as a constraint to each user's data rate of transmission (Sudhir B. Lande, 2012). Given that each user's data rate is given by Rk, proportional data rates constraints can be expressed as shown in equation 2.13:

$$\frac{R_1}{\beta_1} = \frac{R_2}{\beta_2} = \cdots \dots \dots \dots \dots .. \frac{R_K}{\beta_k} \tag{2.13}$$

A merit of this approach is that data rates can be achieved at any level by varying the β values. On the contrary, optimization is normally difficult to achieve since it entails considering both the Binary and continuous variables.

2.9.4 Proportional Fairness Scheduling

This method takes the assumption that users have the same average channels in the long term and no constraint exists with regards to latency (Sudhir B. Lande, 2012). A common type of framework used in this scheduling is Proportional Fairness (PF) scheduling (Yaramasu, Qureshi, & Lande, 2014). This scheduler takes advantage of multiuser diversity and continues to maintain good levels of throughput for all users.

2.9.5 Mobility Aware Resource Algorithm

This method involves an appropriate hybrid centralized/distributed resource allocation algorithm with the following stages involved: Cluster formation, Cluster-head resource allocation with user mobility awareness and Resource contention resolution (Oyie, 2015).

In cluster formation, a femtocell has its list of interfering neighboring femtocells. Femtocell access points are realized with the numbers of interfering femtocell of each of its neighbours (Oyie, 2015). Based on this information, a cluster head is chosen with the other femtocells being cluster members. Time synchronization is an important factor in determining resource allocation in the clusters (Oyie, 2015) (Yaramasu, Qureshi, & Lande, 2014).

Resources consisting of LTE tiles made up of 0.5ms and 180 KHz band are the resources that are allocated to users corresponding to their required bandwidth, achieved through allocation of a given number of tiles (Oyie, 2015)

This requirement can be expressed in terms of required number of tiles 'Di', throughput requirement 'TP^{req}' and '*eff*' which is the efficiency (bits/symbol) of the Modulation and Coding Scheme (MCS) used (Oyie, 2015).

Where

$$D_i = \left[\frac{TP^{req}}{\varphi.eff}\right] \tag{2.14}$$

Given that:

$$\varphi = \frac{SC \times SY}{T_{Sub}} \tag{2.15}$$

φ – A constant that is dependent on the network configuration given the other factors in the above equation.

SC – Number of subcarriers

SY – Number of symbols per tile

Tsub–Slot duration in the time domain (Oyie, 2015).

For the given specifications in LTE network, SC = 12, SY = 7 and Tsub = 0.5. When computed this gives φ = 168 (Oyie, 2015).

In the case of mobility prediction, certain algorithms are used to determine the most probable position of the user with mobility dynamics being taken into consideration. Two approaches used in this prediction are: Global prediction and Local prediction algorithms (Oyie, 2015).

The *Global prediction* approach takes into account the users previous patterns. This entails listing the cells previously visited by the mobile user. It also tries to estimate the next move basing on the users precedence of movement. The formula is given in equation 2.16 below:

$$P_e = \frac{M(F_f, F_{f+1})}{N(F_{f-1}, F_f)} \tag{2.16}$$

Where:

Pe is the transition probability between previous and future femtocells

F_1, F_2, F_3……..F_{f-1}, F_f is the sequence of the mobility history trace of a mobile user (N. O. Oyie, 2013).

$F_{f-1}F_f$ is the sequence of the previously visited femtocells to the current femtocell

F_fF_{f+1} is the sequence of the current femtocell and the future femtocell to be visited.

M and N are sequences of elements of variables outlined in the equations determined by the users' movements in the femtocells

These sequences can be illustrated in Figure 2.7 where the user mobility is traced from cell 34 to cell 24 as described in (Oyie, 2015).

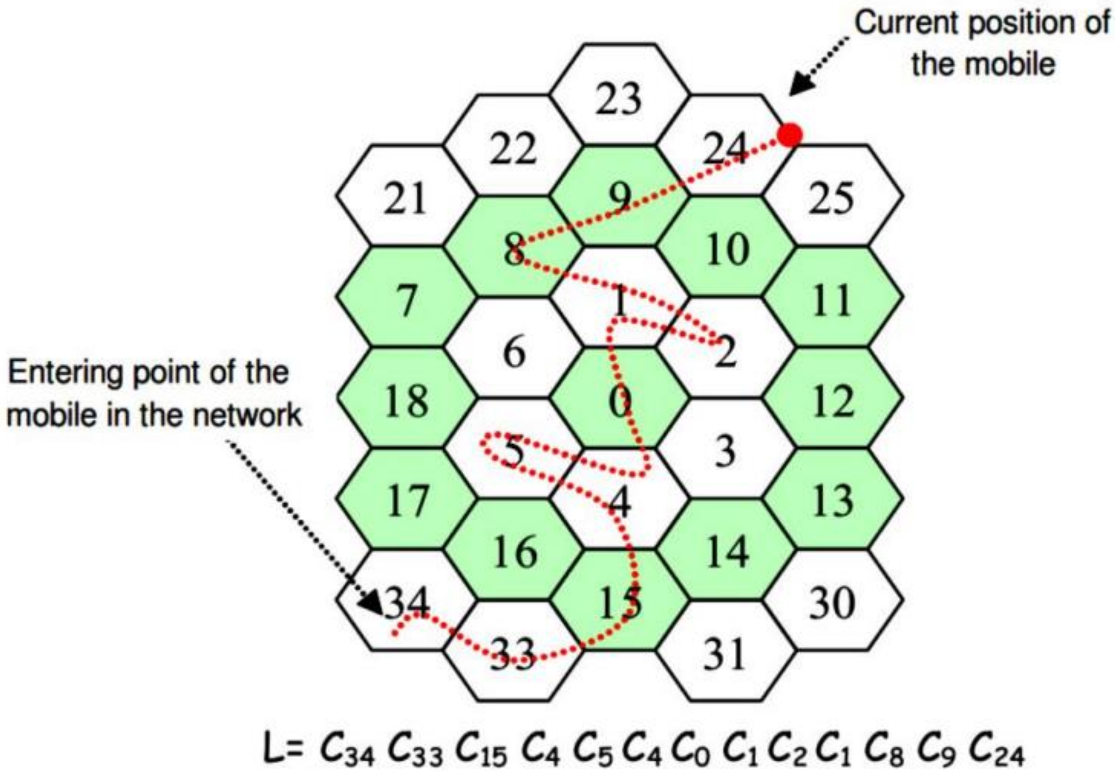


Figure 2.7: User Mobility trace (Oyie, 2015).

Figure 2.7 displays the movement of a user in a series of femtocells. This is recorded in a sequence L. The user enters a region at femtocell 34 and moves through femtocells: 33, 15, 4, 5, 4, 0, 1, 2, 1, 8, 9 and finally stops in femtocell 24.

Under the *local prediction* approach, the algorithm checks for the transition probability of the user from the current femtocell to the adjacent ones. It checks all the neighboring femtocells and analyses the Signal to Interference plus Noise ratio (Nicholas O. Oyie, 2014).

With the aid of this information, the mobility aware algorithm uses the minimization-maximization (min-max) optimization approach to determine the resource allocation prediction. This entails minimizing the maximum gap between the number of allocated and capacity tiles and taking into account the users' mobility actions (Oyie, 2015).

2.10 Artificial Intelligence Techniques

2.10.1 Genetic Algorithm

Genetic algorithm is a technique of selecting individuals through a process of natural selection. This involves checking their individual traits and determining which individuals are to be retained to be carried over to the next stages. This algorithm bases its operation on evolutionary biology that involves the following stages (Jacobson & Kanber, 2015) (Ting, 2005).

First of all: Selection. The users with the best traits are chosen at this stage to be used in the subsequent stages with reference to fitness function based on their properties.

The second stage is crossover. This entails maintaining similar good traits that are common among the ones chosen in the selection stage and carried over to the mutation stage (Jacobson & Kanber, 2015).

Third, we have the mutation stage. This involves altering the traits of the children from the parent users from the crossover stage in order to achieve the best traits. The traits can also be an improvement over the inherited traits so as to avoid just maintaining the constraints inherited from the parents (Ting, 2005).

2.10.2 Ant Colony Algorithm

This optimization imitates ants that wander randomly in search of food from their nest. In their movement, they drop pheromone trails along the paths that they follow. The future ants then follow these trails to the food destination (Burchill & Moreau, 2016). These pheromone trails signify the distances covered and are of different lengths (X Hu, 2008). The longer the trail the higher the chances of the pheromone trail to evaporate hence removing the trace of movement of ants in that direction. This means that the shortest paths leave trails and enhance optimization in terms of finding the fastest way of reaching the food destination for the latter groups of ants. This is useful in networking and smart grid systems in terms of determining the best routing paths to enhance throughput of systems (X Hu, 2008).

2.10.3 Particle Swarm Algorithm

This method uses a group of particles that are commonly referred to as a swarm. These particles usually move around a given area that they have been stationed, commonly known as search space (Oliveira, Pinheiro, Andrade, Bastos-Filho, & Menezes, 2016) (Walker, 2017). Their individual mission is to find the best position in the space provided or in terms of algorithm, to obtain the best solution to a problem (Walker, 2017). These particles have individual positions and velocities and hence move around iteratively in search of the next best position. This way, they keep on improving their position or the solution to a problem (Oliveira, Pinheiro, Andrade, Bastos-Filho, & Menezes, 2016).

2.11 Combinations

Combination refers to a mathematical evaluation of arranging objects in several manners in a given space (Brualdi & Richard, 2010) (Pintea, 2014). Given that ‘x’ is a subset sample from a population of ‘n’, then expression: ${}^{n}C_{x}$ is the number of distinct ‘x’ samples that can be obtained from the population of ‘n’ elements. This is normally referred to as the possible combinations of ‘x’ samples from ‘n’ and is expressed as shown in equation 2.17 (Brualdi & Richard, 2010):

$$ {}^{n}C_{x} = \frac{n!}{x!(n-x)!} \tag{2.17} $$

Where:

${}^{n}C_{x}$ refers to the number of different ways of arranging ‘n’ items in a space of ‘x’ items without regard to order.

n! Denotes the factorial of n

x! Denotes the factorial of x

(n-x)! Denotes the factorial of (n-x).

The areas that have applied combinations before include:

a) Job scheduling problem (Mirshekarian & Šormaz, 2016): In this technique, a number of tasks are given to a group of machines with varying machine power. The main task is to minimize the span of completing tasks (Mirshekarian & Šormaz, 2016). This can be compared to arrangement of resource blocks to achieve the highest group of a given parameter such as SINR to achieve high throughput.
b) Travelling Salesman problem (Jones & Adamatzky, 2014): In this technique, a list of cities are given with stated distances. A salesman is required to determine the best route to take between the cities so as to return as fast as possible to the original city (Jones & Adamatzky, 2014). This can also be compared to finding the best possible arrangement of resource blocks in order to determine the best allocation to users so as to achieve high LTE parameter values such as SINR.
c) Assignment problem (Burkard, Dell'Amico, & Martello, 2012): This is a challenge given to a group of agents with a certain number of tasks. They are required to perform the tasks within a given time with a balance of the tasks so as to minimize the costs for all the agents (Burkard, Dell'Amico, & Martello, 2012). This can be compared to allocation of resources so as to maximize the throughput of the entire channel.

This research seeks to utilize combinations as the main mathematical technique of arranging users' resource requests against the available resources in a femtocell. The users' SINR values are used to prioritize the users from the highest to the lowest value (Pintea, 2014) (Bóna, 2010). The combinational allocation technique is compared to other resource allocation methods as described in section 2.12.

The reason for using Combinations, which is an arrangement technique, is that it can directly relate to arrangement of resource blocks that make up the basic structure of an OFDMA in an LTE network. Resource blocks can be dynamically allocated to users on the Downlink and Uplink channels in all scenarios from a shared channel to control channels. Hence, this makes combinations an appropriate technique to apply as an allocation scheme.

Therefore, this research tends to pursue allocation of a group of 12 subcarriers of a resource block to an individual mobile user without need of other overlapping technologies.

2.12 Comparison of Combinations Allocation with other Resource Allocation Schemes.

2.12.1 Mobility Aware Resource Allocation Algorithm

This method is predictive in terms of movements of a mobile user in a set of Femtocells based on the previous movements of the user, and is used to predict the next probable cell that the user will enter. This is explained in the Global prediction algorithm (Oyie, 2015). It also checks on all adjacent cells and makes an assumption that the user will enter either of the cells as explained in the Local Prediction Algorithm (Oyie, 2015).

This scheme predicts the position of a user at a particular femtocell which may not be very accurate at times. This scheme may have problems when the users are many due to crisscrossing mobility paths taken by many users, and may have problems allocating resources to users of these nature. This is because the Mobility aware scheme makes use of the mobility dynamics of the users which is stored in a sequence. A transitional probability is then derived as per formula 2.15 (Oyie Nicholas, 2014). Therefore crisscrossing paths will make this method complex to make accurate predictions for future movements. Also, mobility of users is not always predictive for all users.

The proposed combinational approach in this research takes into account several users who are trying to access resource blocks regardless of their mobility status and does all possible arrangements of users who are trying to access the femtocell resources. This is demonstrated in the combinational formula where all the users' resource requests and SINR values are tabulated as described in section 2.11. Therefore, it is able to come up with all possible arrangements for combinations to take place. It also considers their

SINRs that may be affected by their movements which are not addressed by the mobility solutions scheme.

2.12.2 Maximum Sum Rate Algorithm

The maximum sum rate algorithm tends to try and send as much data through the system as possible by maximizing the rate of data transmitted through the system (Sudhir B. Lande, 2012). It also bases its data transmission rate on the power constraints of the user equipment.

However, this algorithm does not take into account the number of resources requests alongside the available resources together with the interference levels. It tends to allocate with respect to power levels only, hence, the algorithm will give priority to the users near the femtocell who receive high power levels (Sudhir B. Lande, 2012).

The proposed combinational approach does take into consideration the interference levels vis-à-vis the requests made and the available resources (Bóna, 2010). It also arranges them with a view to award the best combination of users with the best SINRs given the fact that the number of resource requests and available ones are dynamic and subject to change at given intervals.

2.12.3 Maximum Fairness Algorithm

This algorithm tries to equalize data rates for all users as much as possible. A min-max approach is used whereby; it maximizes the minimum data rate (Sudhir B. Lande, 2012) as described earlier. One of its problems is that it assumes that equal power is allocated to each subcarrier, then; an iterative power water filling algorithm is used to assign power to the low rate users. This leads to improper allocation of resources since the low rate users have low signal to noise ratio and tend to get the most resource allocation. This makes this approach not appropriate for improved throughput of the system.

An appropriate approach would be to allocate resources dynamically considering the rapid changing environment of the users' properties such as SINR levels, the resource requests and also the available resources in place (Macharia A. R, 2017). This makes the proposed combinational allocation method to be better than this method since it considers the varying conditions of the users in the femtocell network. It also allocates resources to the best combinations of users with the best SINR levels against the available resources. The low SINR level users can just be allocated a small number of resources for them to utilize interchangeably in given timeslots so as not to cut them off completely which is better than withdrawing resources from the high SINR users.

2.12.4 Genetic Algorithm

The Genetic algorithm approach assumes the natural biological way of selecting population in stages based on their traits. The process involves main selection, crossover of similar good traits and mutation of traits so as to improve their properties (Ting, 2005).

However, in femtocell scenarios, users' properties are not inherited but are individual based with reference to their properties such as SINR and resource requests cases as compared to the combinational allocation technique. Hence the Genetic algorithm as described in (Jacobson & Kanber, 2015) cannot be applicable in this case due to the nature of users' individual independent attributes as stated above.

2.12.5 Ant Colony Algorithm

In this technique, the optimized path to give the best channel between the source and destination is determined after quite a number of searches are done across several paths, covered by previous packets en route the destination from the source (Burchill & Moreau, 2016). This method is not directly applicable in a femtocell resource allocation because it is not practical for a user to move around a cell in search of resources for communication (Burchill & Moreau, 2016). The resources are supposed to be availed to the user at any position within the range of the femtocell. This is done effectively with the combinational scheme that considers the resources requested per user then carries out the algorithm against the available ones to determine the best allocation.

2.12.6 Particle Swarm Algorithm

In this approach, a swarm of particles or in mobile application terms, a group of users move around in search of the best position for resources. They keep on moving at individual basis with individual velocities, each time, trying to achieve better positions and solutions to their current status (Oliveira, Pinheiro, Andrade, Bastos-Filho, & Menezes, 2016).

In comparison to the proposed combinational technique, this method can be slower in less robust systems since many users are involved and much iteration may be required to determine the best position and solution for resource allocation (Walker, 2017). In addition, this technique may not be directly applicable to mobile applications since users may not only be in motion nor their movements pegged on search for best network coverage only, but also, many other factors need to be considered.

2.12.7 Proportional rates Constraints algorithm.

In this method, allocation of resources is done proportional to the users' data rates and set of predetermined system parameters defined by a variable parameter as described in equation 2.1. This is a good approach since it takes care of the throughput (Sudhir B. Lande, 2012).

However, an additional parameter of considering the resources requests against the present ones compared to the throughput of the given resources is presented in this proposed research using an approach of the best combination of users, to allocate the resources with priority given to best SINR levels. This is an improvement on the proportional rates algorithm (Macharia A. R, 2017).

2.12.8 Identified research gap

Having reviewed the methods above and highlighting their drawbacks, it is emerging that previous methods have been allocating users requests arbitrarily. This is where, resources are either allocated directly in the order of the sequence of requests from user, or a system parameter is introduced to take care of the throughput. Others have not been applicable directly in a femtocell by requiring users to move in search of resources whereas it is the femtocell that should avail resources where they are.

Therefore, the research gap identified is the need to consider all users' resource requests and check on the available resources then do a computation of all possible arrangement of resource allocation. Finally, give priority to the higher SINR valued users for allocation then reallocate a resource to low SINR valued users left out on fairness basis.

In this research, the main comparison will be done with the Global mobility prediction since it is also based on a femtocell. It also allocates in the order of sequence of resource requests from users as described in the transitional sequence in equation 2.16.

The reviewed methods are summarized as shown in table 2.3

Table 2.3: Summary of research gaps identified from reviewed schemes

Ref	Method used	Major findings related to this work	Strengths of the method	Weaknesses of the method and gaps identified
(Oyie, 2015)	Mobility aware resource allocation	Allocation of resources is based on the mobility dynamics of users	The method is appropriate in routine movement of users such as in an indoor environment	Movement of users is not entirely routine but sometimes users have crisscrossing paths that make the technique complex

Ref	Method used	Major findings related to this work	Strengths of the method	Weaknesses of the method and gaps identified
(Jacobson & Kanber, 2015)	Genetic Algorithm	Resource allocation is based on an inheritance model from parent to child (Selection, Crossover, Mutation)	It is appropriate in computational processing where one process gives rise to another	It is not much practical in a mobile environment due to the instantaneous nature of the changing parameters such as SNR
(Walker, 2017)	Particle swarm Algorithm	Users move in a swarm in individual iterative movements towards a particular point	The swarm eventually finds the best position in a cell for all the users	This involves too much iteration to move the entire swarm. In addition, it is not practical for users to move towards one direction in a femtocell

Ref	Method used	Major findings related to this work	Strengths of the method	Weaknesses of the method and gaps identified
(Sudhir B. Lande, 2012)	Proportional rates constraints algorithm	Use of a predetermined system parameter to set users' data rates	Data rates can be regulated to any desired values per user	Reducing data rates reduces throughput per user
(Sudhir B. Lande, 2012)	Rate craving and amplitude craving greedy technique	Prioritizes users with the highest transmission rates and channel gain	The throughput is maximized by allocating resources to the best users	There is no pro-rata resource sharing with the other users and hence other users tend to get locked out
(Sudhir B. Lande, 2012)	Maximum fairness algorithm	Equalizes power allocation to all users with the use of a water filling algorithm	Achieves equality for all users using the channel	There is an imbalance in power allocation where low power users get most power reallocation. This affects the throughput of the entire channel

CHAPTER THREE
METHODOLOGY

This research focuses on combinational resources allocation technique that ensures resources availability for a user equipment to be allocated.

Combinations are a mathematical evaluation of possible arrangement of a given set of objects in a certain space, either individually or in stated groups (Brualdi & Richard, 2010). It takes into account the total objects to be arranged plus also the groups that need to be maintained.

In a given femtocell, this algorithm runs taking into account the resource blocks being requested per use, by computing the total and comparing it with the available ones. The SINR levels are calculated from the system bandwidth, transmission rate and throughput calculations elaborated in the Results chapter.

All the users are pre-recorded in a table with information of their individual user resource requests and SINRs. In addition, all possible arrangements of users' requests are listed in another matrix. From here, their entire group SINRs totals are then listed.

Furthermore, their SINRs totals are hereby calculated so that the highest SINR total group could be determined. This gives the best SINR total that maximizes the throughput and hence selects the best group of users' requests to be allocated the resources at the femtocell.

Finally, as a check on fairness of the allocation to the users with low SINR values who have been left out in the initial allocation, a check is done on the final allocation to see if all users have been allocated at least a resource for communication in the femtocell. If all users have not been allocated a resource, then, a resource would be reallocated from the user with the next lowest SINR on the current allocation, to the user/users with the lowest SINR values that have been left out from the current allocation done. In some instances, they can share this single resource in given timeslots to enable them to be able to at least communicate in the femtocell.

3.1 Signal to Interference plus Noise Ratio Determination

The channel throughput of a Femtocell network can be determined from the channel bandwidth and transmission bandwidth configuration as shown in Table 2.1 and described in Section 2.4 of chapter 2.

The channel bandwidth ‘C’ can be used to obtain the number of subcarriers from the resource blocks (since one resource block has 12 subcarriers) (Anritsu, 2013).

Given the system’s bandwidth is B and the channel capacity of the network is C, the formula as stated by Shannon–Hartley theorem, would be outlined as per equation 2.11 in the literature review chapter.

$$SINR = 2^{[C/B]} - 1 \tag{3.1}$$

The Signal to Interference plus Noise ratio is a measure of the quality of the resources to be allocated to users. SINR is an LTE parameter that is sent as a measurement report from a users’ equipment to the femtocell. It is translated into a CQI report that ranges from index 1 to index 15 as shown in table 2.2 (Mohammad T. Kawser, 2012). The CQI indices from 1 to 15 allocate a modulation scheme using the Adaptive Modulation Code. It allocates from QPSK to 64 QAM. As a result, a higher SINR value generates a higher CQI index that allocates more bits per symbol for transmission. This achieves a higher throughput of the channel (Farhana Afroz, 2015).

The SINR is the main LTE parameter being used in this research to determine resource allocation to users against the resources requested. This is in line with the objective of investigating the effect of SINR in determining the most effective resource allocation to users (Farhana Afroz, 2015).

3.2 Combinational Approach

In this research, requests are considered to be higher than the available resources. Therefore the combinations formula is then applied to obtain all the possible arrangements of the resources requests in the available spaces (Stephen Musyoki, 2016). This is elaborated in Formula 3.2.

$$^{n}C_{x} = \frac{n!}{x!(n-x)!} \tag{3.2}$$

Where:

n! Denotes the factorial of n

x! Denotes the factorial of x

(n-x)! Denotes the factorial of (n-x).

$^{n}C_{x}$ refers to the number of different ways of arranging ‘n’ items in a space of ‘x’ items without regard to order. This is also known as the possible ‘n’ combinations of ‘x’

3.3 Determination and analysis of the effectiveness of Combinations as an arrangement technique

This subtopic tends to determine the effectiveness of combinations as an arrangement technique plus analyze it in the different scenarios of resource requests in a femtocell. The scenarios that will be analyzed in this research are: Single resource requests and multiple resource requests. This will be done in section 3.3.1 and 3.3.2. This is in line with the first and the second specific objectives of this research.

3.3.1 Single resource request per user

The first scenario analyses a situation where the users are requesting for a resource to connect to the femtocell. This is in line with the first specific objective of determining combinations as an effective arrangement technique. This occurs when the cell phone is switched on. The first step is to search for a resource in the cell to connect to the network. The resource that carries out this step is the synchronization signal (Stefanis, Issam, & Mathew, 2011). At this stage, the cell phone does the symbol and frame timing acquisition. The two main resources used at this stage are the primary synchronization signal and the secondary synchronization signals as per the LTE Radio frames (Anritsu Corporation, 2009). These two signals are transmitted in intervals of 5 milliseconds (Stefanis, Issam, & Mathew, 2011). They usually occupy a single slot in a resource block. Therefore, they require a single resource for transmission (Stefanis, Issam, & Mathew, 2011). This is illustrated in figure 2.6 in the literature review. Hence, when a request is subjected to the combinational process, a user is given a single resource. This therefore means that the SINR consideration done per user is on a ratio of 1:1.

Users who are requesting for a resource using the synchronization signals are listed in a table such as Table 3.1 shown. Since it is for synchronization purposes, the resource required per user is a single resource (Stephen Musyoki, 2016).

Table 3.1: Table 'A' listing users and SINRs values

USERS	SINR value per user
1	SINR value for user 1
2	SINR value for user 2
⋮	⋮
k	SINR value for user k

Therefore, the combinational sequence is done per SINR value of a single request for the 'k' users requesting for resources, against the available 'e' resource blocks in the femtocell. A matrix is generated consisting of all the 'w' possible arrangement of the users requests in a space of 'e' available resource blocks. This arrangement is shown in Matrix 'B' in Figure 3.1.

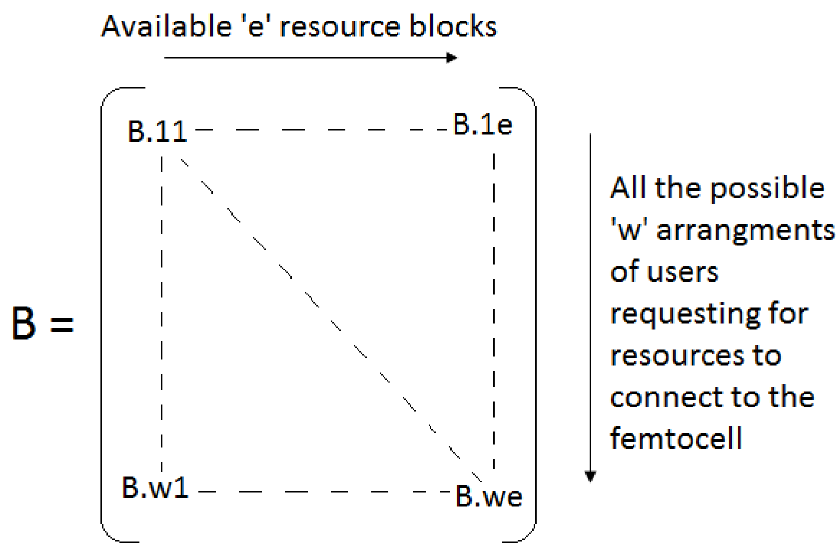


Figure 3.1: Matrix of all possible arrangement of users' single resources requests

The matrix outlines the arrangement of users in terms of SINR requirements. A further calculation is done per row to determine the groups' SINR totals, so as to determine which combination of users will produce the highest value so that they can be allocated resources. This is shown in another Matrix 'C' as shown in Figure 3.2.

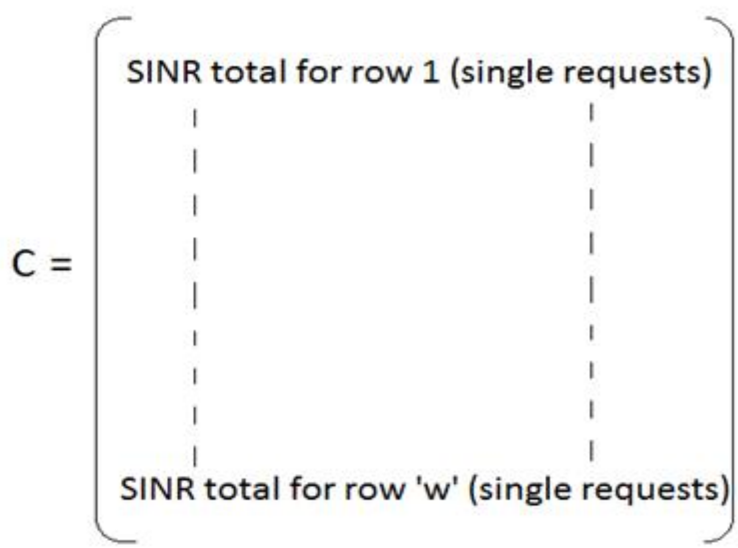


Figure 3.2: Matrix of SINRs row totals of all user single SINR values per row

From Figure 3.2 above, the group with the highest SINR total group can be selected then the users in that row are then allocated the resources required for synchronization (Stefanis, Issam, & Mathew, 2011).

3.3.2 Multiple resource requests per user

This instance seeks to tackle the second specific objective of determining combinations as an effective resource allocation scheme and analyzing it in a scenario where a user is requesting for more than one resource block. This is done with the aid of throughput calculation to determine the resource blocks needed as per user.

There are instances where users in a femtocell request for multiple resource blocks for communication. This indicates that classification based users' call admission control techniques allow multiple bit streams to be transmitted in cases of high bandwidth requirements such as video live streaming as described in section 2.5.1 in chapter 2 (AlQahtani, 2015) . This method gives a provision of multiple resource block requests for data transmission. In addition, throughput calculation is used to determine the number of resource blocks as illustrated by formula 2.5. This is dependent on the size of the resource block owing to the modulation scheme used on the resource block (Stefanis, Issam, & Mathew, 2011).

Users who are requesting for resources at the femtocell would be arranged in a Table 'A.2' of dimensions 'r' by '3'. It lists all prospective users, their individual resources requests plus their signal to interference plus noise ratios transmitted by the user equipment to the femtocell per user. This table is shown in Table 3.2 (Macharia A. R, 2017).

Table 3.2: 'Table A.2' List of users with their individual resource requests and SINRs values

Users	resource requests per user	Sinr value per user
1	Resources Requests for user 1	SINR value for user 1
2	Resources Requests for user 2	SINR value for user 2
⋮	⋮	⋮
r	Resources Requests for user r	SINR value for user r
	Total requests for all users = 'n'	

The femtocell hereby receives the resource block requests from the users and checks the on the number of resource blocks available. The resource requests are denoted by 'n' and the available resource blocks are denoted by 'x'.

A combinational computation is then carried out to determine all the possible arrangements of 'n' resource requests given that only 'x' resource blocks are available. Let 't' be the total number of possible arrangements of 'r' users' requests in 'x' available resource blocks. 't' is then determined as outlined by the combinations formula.

All the possible array of arrangements derived from the combinational sequence as shown in Table 3.2 are then listed in a Matrix 'B.2' of dimensions 't' by 'x'. There are: 't' number of possible arrangements in rows. This is done against only 'x' available number of resource blocks. The rows give a group of users' requests in serials, to be prioritized as shown in Figure 3.3. The serial numbers are generated by the MATLAB code in appendix B per matrix. This indexes each matrix row of users to specific requests values and their specific SINR values, in order to carry out the combinations.

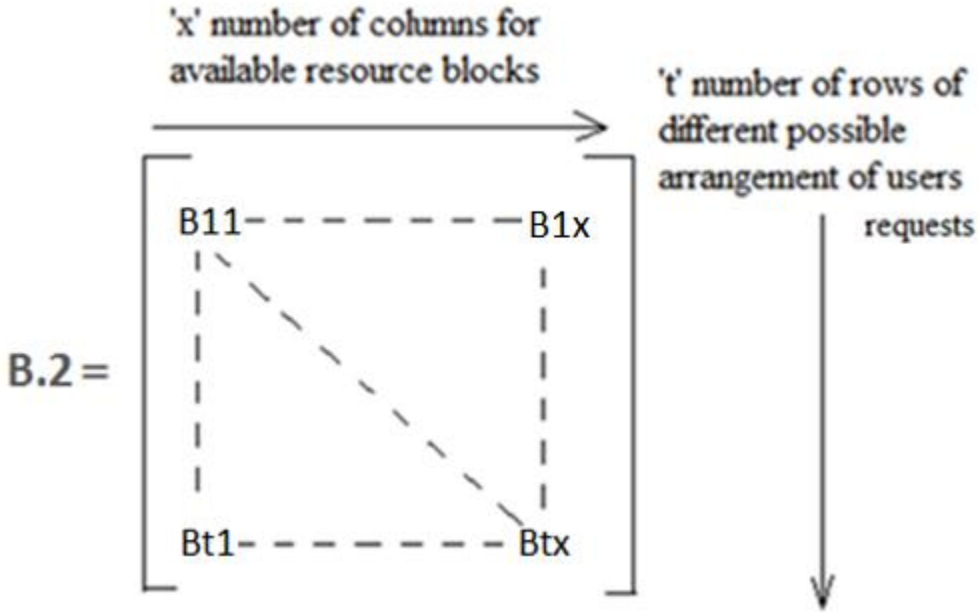


Figure 3.3: Matrix of all possible users' resources requests arrangement

For a given row of a given arrangement of 'r' users, the total SINR is done using their individual SINRs. The initial Table A.2 is queried to provide the SINRs per user corresponding to 't' rows in Matrix B.2. Totals are done per row for a given group of users (in a row) to be prioritized in the resource blocks to be allocated.

These totals are then rearranged to be ranked in an ascending Matrix 'C.2' of 't' number of SINR (totals) values as shown in Figure 3.4.

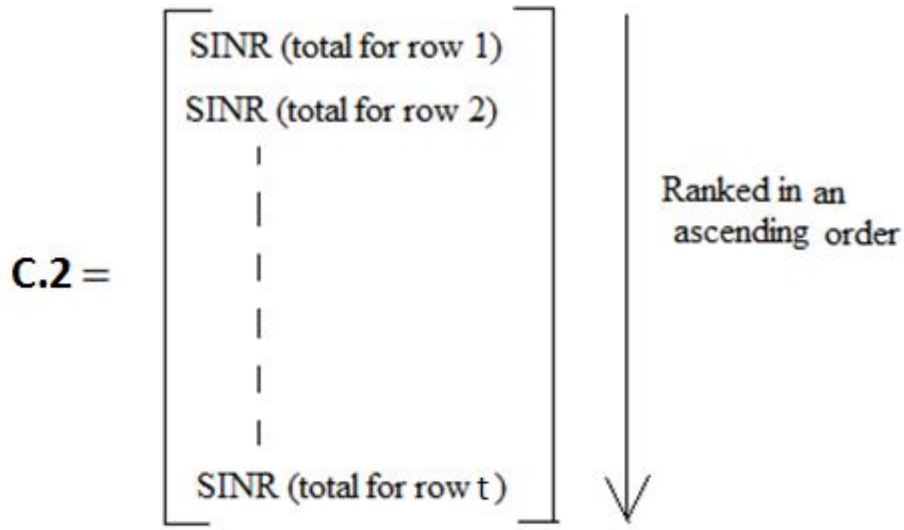


Figure 3.4: Matrix of SINRs row totals of all user groups per row

From the rank done in this matrix in Figure 3.4 above, the highest total of SINR is at the bottom of the matrix. This means that the users in the last combination of row of users give the best priority of arrangement for resources to allocate, since this would give the best throughput in the femtocell resources.

Hence, reference is made back to the users' resources requests combination Matrix B.2, of 't' by 'x'. From here, the users with the SINRs at the row are determined then priority is given to them while allocating available resource blocks in the femtocell.

The MATLAB code that implements section 3.3 is given in Appendix B: Combinational algorithm code in the appendices

3.4 Investigation of Fairness Scheme on the SINR during allocation of resources

This tends to investigate the effect of fairness on the SINR in determining the most effective allocation of resources in a femtocell. This covers the third specific objective on investigation of the effect of fairness on SINR in determining the most effective allocation of resources.

After the initial allocation is done with preference to high SINR valued users, a check is done to find out if all users who had initially requested for resources have been allocated at least a resource. This is done to assist the low SINR valued users to at least be able to get a resource to communicate. If some users have not been allocated, then one resource would be reallocated from the next low SINR valued user(s) in the current allocation. If he/she has more than one resource, then a single one can be re-allocated to the user(s) who do not have a resource. In other instances, if the next low SINR valued users also have a single resource, the new user can be incorporated and given rotation equal timeslots in the single resource with the existing ones to enable him communicate too. This is done to ensure fairness to all the users who are requesting for resources, though not as efficient as the other users who are allocated defined resources.

This will show that a small compromise on the SINR will achieve fairness and all users will be able to communicate. Therefore the third specific objective on the effect of fairness on the SINR on resource allocation will be addressed.

The MATLAB code runs together with the MySQL code to implement fairness. The full code is indicated in Appendix D. The MySQL code in appendix C is used to setup the main database that is used to run the MySQL code in appendix D code together with the MATLAB code

3.5 Validation with the Global Mobility technique

This subtopic seeks to validate the combinational technique as an improvement over the Global Mobility prediction technique. This is accordance with the fourth specific objective on validation as an improvement over the existing methods.

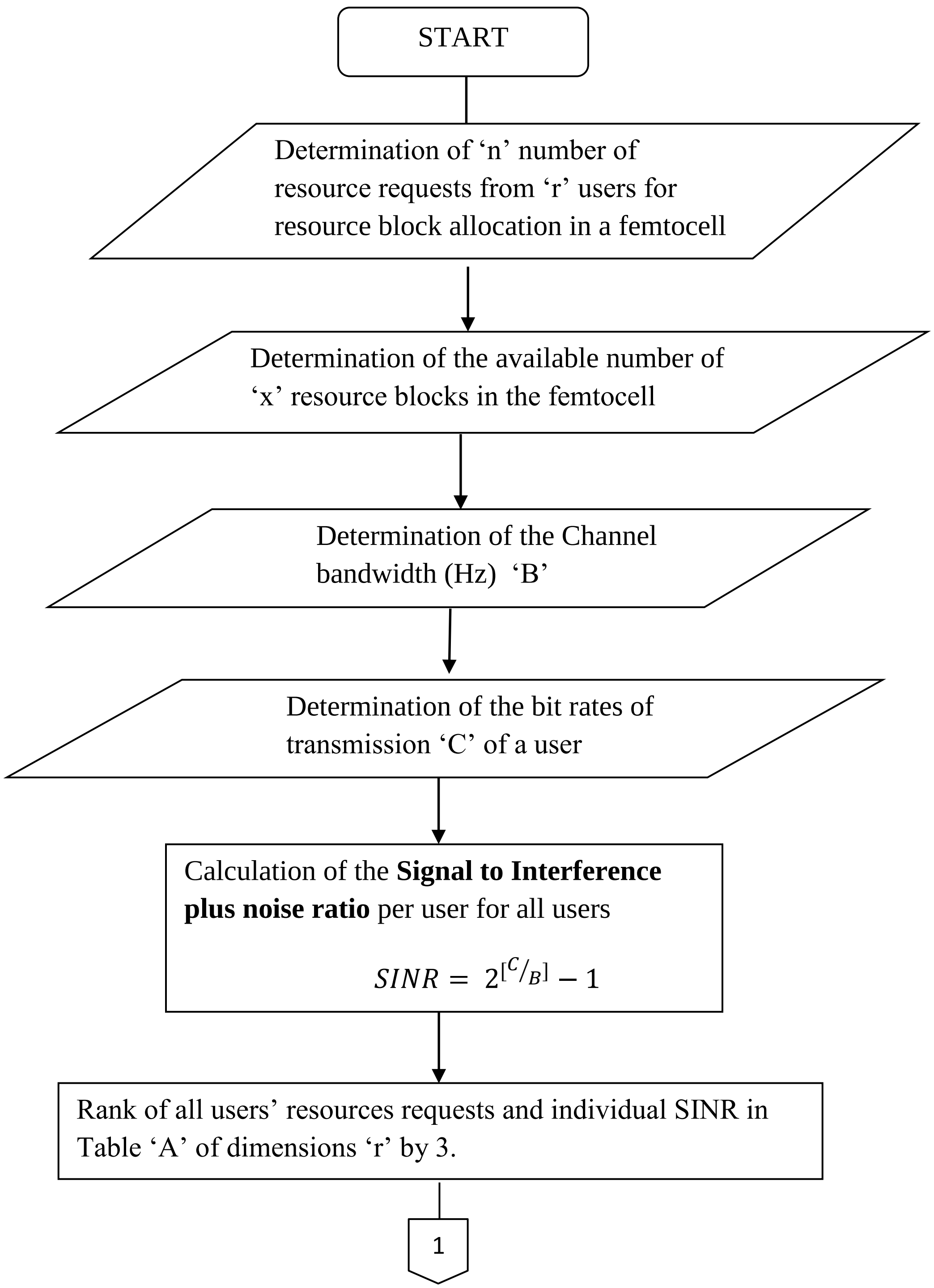
The main method of comparison done in this research is with the Global mobility prediction. The technique is described in section 2.9.5 and illustrated in Figure 2.7 whereby, a users' movement in a range of femtocells is captured and kept is a given sequence. For example in Figure 2.7 the sequence is 34, 33, 15, 4, 5, 4, 0, 1, 2, 1, 8, 9 and finally ends in femtocell 24. The femtocell then generates this sequence for a number of users. This is then computed in comparison with the proposed combinational technique. The SINR total values and the users’ allocation is tabulated and graphically compared. The outcome will effectively validate the SINR.

In the results chapter, the Global Mobility prediction will be demonstrated in a scenario of eight users who are crisscrossing a femtocell in eight different intervals at random in groups of four users per interval. This is to illustrate the comparison of the Global mobility technique compared to the Combinational users' selection scheme in a random environment of resource requests.

The Global mobility technique is implemented in the combinational code indicated in Appendix B. It runs alongside the main combinational code so as to compare the SINR output for both techniques.

3.6 Flowchart Diagram

Figure 3.5 shows the sequence of implementing the combinational allocation algorithm based on the requests made in a femtocell



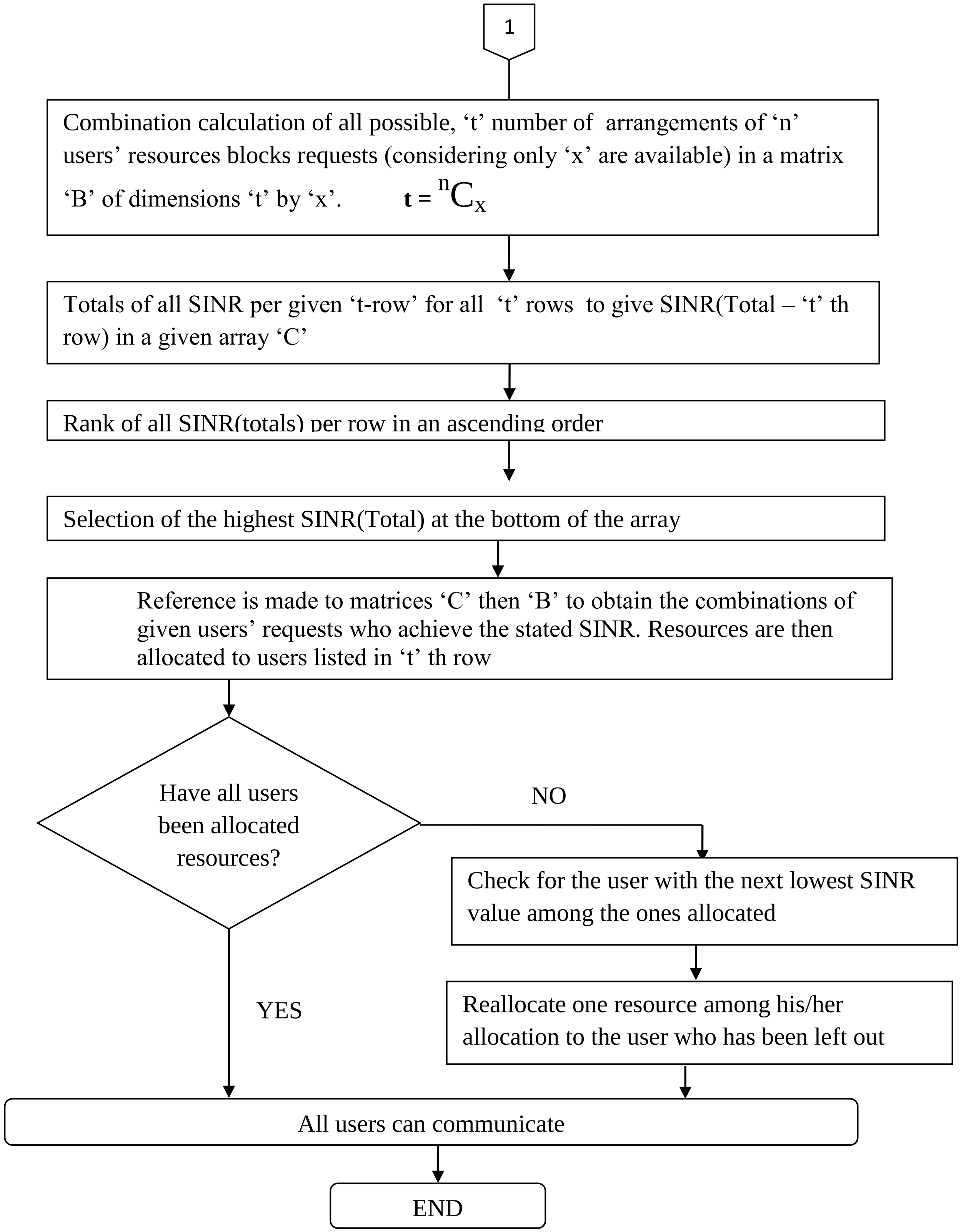


Figure 3.5: Flow chart for the proposed combinational resource allocation scheme

3.7 Software used in the Research

The softwares that were used in this research were MATLAB and MySQL. The full codes are indicated in the appendices as follows:

a) APPENDIX B: MATLAB Combinational Algorithm code: This is the main combinational algorithm code that generates the main 3D matrices for the combinational algorithm described in section 3.3. This also generates the simulation of the Global mobility prediction described in section 3.5 and compares the output.

b) APPENDIX C: MySQL Database Code*:* This is the code that is used to set up the database that is used for the fairness analysis with MATLAB and MySQL code in appendix D

c) APPENDIX D: MATLAB Fairness Resource reallocation code*:* This is the code that reassigns resources from the next low SINR users to the ones left out as described in section 3.4, therefore, enabling all users to communicate in the femtocell

CHAPTER FOUR
RESULTS AND DISCUSSION

Users vary in terms of resource requests. As described in chapter 2, there are scenarios where users request for a single resource and for more than one resource.

4.1 Scenario 1 (Single Resource Request)

This scenario tackles the first and the second specific objectives on determining the effectiveness of combinations plus analyses the first instance of a single resource request in a femtocell. This is also described in section 3.3.1 of the methodology chapter where combinations is done based on a single resource request with the ratio of users to requests being 1:1.

A Scenario 1 of six users in a femtocell is hereby considered. The femtocell is considered to be transmitting on 15 MHz as per the LTE Transmission bandwidth configuration described in Table 2.1. The selected modulation scheme is 64 QAM as outlined in Adaptive Modulation and Coding as explained in section 2.4 in chapter 2.

Their SINR values can be obtained using the Shannon–Hartley theorem outlined in Equations 3.1 and 3.2. The users' individual maximum bit rates (C) are obtained from the users' cellphones in order to assist with the determination of their individual SINR in the femtocell. A list of arbitrary users' bit rate values is tabulated in Table 4.1 as 'Maximum bit rate (C) in Mbps'

Table 4.1: Users' maximum bit rate values in a femtocell described in scenario 1

SCENARIO 1	
User	**Maximum bit rate (C) in Mbps**
1	51.89
2	99.87
3	75.42
4	30.86
5	61.12
6	90.03

The femtocell is transmitting on 15 MHz. The SINR is then calculated as per equation 3.3. For instance for user 3, the SINR value would be determined as 31.63 from equation 2.8 and the SINR value calculated as 15 dB per equation 2.11 :

The SINR values of the other users can be similarly calculated and tabulated as shown in Table 4.2.

Table 4.2: Users' SINR values in a femtocell described in scenario 1

	SCENARIO 1	
USER	**Maximum bit rate (C) in Mbps**	**SINR VALUE (dB)**
1	51.89	10
2	99.87	20
3	75.42	15
4	30.86	5
5	61.12	12
6	90.03	18

These are users in the femtocell who have just powered on their phones and are requesting for resources to connect in the femtocell. They make use of the Primary Synchronization Signal (PSS) and Secondary Synchronization Signals (SSS) as described in chapter 2. These signals only occupy one slot in the resource block and therefore, only one resource is used. The femtocell has only 4 available resource blocks and the users requesting for resources are 6. The combinational computation is done directly as per the requests above and all the possible arrangements are 15 as per the combinations equation 3.2 in section 3.2

The combinations evaluation shows that there are 15 different ways of arranging the users' single resource requests. Table E.1 in Appendix E gives the full table of the arrangement for the single resource requests. The SINR row totals are done per group and highest SINR group of users are found to be users': [2 3 5 6].

The SINR total is 65 dB. Therefore they are allocated resources for communication.

4.2 Scenario 2 (Multiple Resource Requests)

The second scenario considers a case where users are requesting for more than one resource.

This scenario is in accordance with the first and the second specific objectives of determining the effectiveness of combinations as an arrangement technique. In addition, it analyses the throughput of the resource allocation when a user requests for multiple resources. This is also described in the methodology chapter in section 3.3.2.

The users' arbitrary bandwidth requirements are first tabulated as shown in Table 4.3

Table 4.3: Users' bandwidth requirements in the femtocell

User	Bandwidth Requirements
1	3 Mbps
2	2 Mbps
3	5 Mbps
4	3 Mbps
5	5 Mbps
6	4 Mbps

This is followed by computing the resource block required per user. As per equation 2.4 in the literature review chapter on Adaptive Modulation and Coding, the data size transmitted per resource block for 64 QAM is determined to be 1.008 Mbps. This is then used to compute the number of resource blocks required per user in Table 4.4.

For example, for user 3 who is requesting to transmit 5 Mbps using 64QAM, the resource blocks required are 4.9603 which is rounded up to 5 full resource blocks. Therefore the number of full Resource Blocks (RBs) required are 5; for user 3 and user 5. The remaining users' requirements are computed in the same way and tabulated in Table 4.4.

Table 4.4: Users' resource blocks requirements calculated from their individual bandwidth

User	Bandwidth Requirements	Resource blocks required.
1	3 Mbps	2.976 ≈ 3 full RBs
2	2 Mbps	1.984 ≈ 2 full RBs
3	5 Mbps	4.961 ≈ 5 full RBs
4	3 Mbps	2.976 ≈ 3 full RBs
5	5 Mbps	4.961 ≈ 5 full RBs
6	4 Mbps	3.968 ≈ 4 full RBs

This now gives the resources requirements per user which can then be summarized alongside their individual SINR values as shown in Table 4.5. The available resources are determined from the femtocell to be 18.

Table 4.5: Summary of user's resource requests and their SINR values in scenario 2

	SCENARIO 2	
User	**Requests**	**SINR (dB)**
1	3	10
2	2	20
3	5	15
4	3	5
5	5	12
6	4	18
	Available resources = 18, requested = 22	

Combinations are carried out against the available resources. The best allocation sequence is determined to be:

[1 1 2 2 3 3 3 3 3 5 5 5 5 5 6 6 6 6]

The SINR total for this group is 267 dB.

The initial allocation sequence is found to have left out user 4 due to low SINR value. Fairness can be applied here by carrying out a check on the user with the next low SINR value. It is found out to be user 1. Therefore, a resource is re-allocated from user 1 to user 4 so that the user can be allowed to communicate in the femtocell. The new allocation sequence then becomes

[1 2 2 3 3 3 3 3 4 5 5 5 5 5 6 6 6 6]. The new SINR total is lowered to 262 dB. This lowers the SINR by 5 dB but all users can now communicate with the higher SINR valued users being prioritized with more resource allocation.

4.3 Scenario 3 (Validation with Global Mobility Prediction)

This scenario intends to validate the improvement of the combinational technique on the Global mobility prediction. This corresponds to the fourth specific objective on validation of the combinational technique with the Global mobility prediction as an existing technique. Section 2.9.5 and figure 2.7 describe how the Global mobility prediction works. This is further explained in the section 3.5 in the methodology chapter. With the aid of MATLAB, a simulation of both the Combinational technique and Global mobility prediction were done using a set of four chosen users. They were requesting resources for communication in a given femtocell and recorded in eight intervals at random. The rationale of choosing this approach was to compare the output of the SINR totals for both schemes: Global Mobility and Combinational approach, plus analyze the number of users connected to the femtocell. This has been described in section 3.5 on validation with the Global Mobility prediction in the methodology chapter. The codes used are outlined in appendix B and appendix D.

These users have different SINR values and resource requests which are shown in Table 4.6.

Table 4.6: Summary of users' resource requests and their corresponding SINR values

User	Resources Requests	SINR (dB)
1	3	8
2	2	10
3	4	6
4	5	2
5	3	9
6	2	7
7	4	3
8	3	4

The two methods: Global Mobility prediction and Combinational algorithm are used for resource allocation to the above users in a femtocell. This is done taking into consideration the available resources in the femtocell for communication.

The users in Table 4.6 move randomly across a femtocell and are recorded in eight intervals: A to H. These users request for resources for communication while on transit. The users present in the femtocell are recorded in different clusters of 4 members and are shown in Table 4.7.

Table 4.7: Summary of users present at the femtocell during trials A to H.

Intervals	Available Resources	Users Present In The Femtocell			
A	12	1	2	3	4
B	9	1	3	7	8
C	8	2	4	5	6
D	7	3	5	6	7
E	6	1	2	4	5
F	10	2	4	7	8
G	11	1	4	7	8
H	9	4	6	7	8

Their resource requests are analyzed during the eight interval snapshots for the two methods mentioned: Global mobility prediction and Combinational algorithm. A comparison is done to determine the best allocation technique in terms of SINR total values and the number of users allocated resources against the ones who have requested for resources.

4.3.1 Interval trials (A To H)

During Interval A, the users present at the femtocell requesting for resources are tabulated as shown in Table 4.8.

Table 4.8: Users' resource requests with corresponding SINR values during Interval A

Time Interval A		
User	**Requests**	**SINR (dB)**
1	3	8
2	2	10
3	4	6
4	5	2
Available resources = 12, requested = 14		

The two algorithms: Global mobility prediction and combinational computation are then carried out. The results are as shown in Table 4.9.

Table 4.9: Resources allocation sequence to users in the femtocell during Interval A

Combinational sequence	1	1	1	2	2	3	3	3	3	4	4	4	SINR TOTAL 74 dB
Global Prediction	1	1	1	2	2	3	3	3	3	4	4	4	SINR TOTAL 74 dB

Allocation during interval A provides resources to all users and coincidentally both sequences yield the same SINR total values: 74 dB. The full arrangement of all possible requests for interval A is tabulated in Table F.2 plus the possible SINR arrangement is also shown in Table F.3, both in Appendix F.

A second trial is done in the femtocell and recorded for users present during INTERVAL B as shown in Table 4.10.

Table 4.10: Users' resource requests with corresponding SINR values during Interval B

Time Interval B		
User	**Requests**	**SINR (dB)**
1	3	8
3	4	6
7	4	3
8	3	4
Available resources = 9 , requested = 14		

When the users are subjected to the Combinational and Global mobility prediction technique against the available resources in the femtocell, the allocation sequences are as shown in Table 4.11

Table 4.11: Allocation sequence to users during Interval B.

Combinational sequence Without (fairness)	1	1	1	3	3	3	3	8	8	*SINR TOTAL = 56 dB*
Combinational sequence With (fairness)	1	1	1	3	3	3	3	8	7	SINR TOTAL = 55 dB
Global Prediction	1	1	1	3	3	3	3	7	7	SINR TOTAL = 54 dB

As noticed in Table 4.11, the Global Mobility prediction leaves out user 8. Likewise, the combinational algorithm also leaves out user 7. Their SINR total values are 54 dB and 56 dB respectively. However, the proposed combinational sequence also has fairness scheme where it checks on the next lowest SINR valued user. It reallocates one resource from that user to the user left out, in this case from user 8 to user 7 so that all users can communicate. This lowers the SINR total value by 1 dB, but it ensures that all users can now communicate.

Hence the Combinational technique achieves a higher SINR total. In addition, All the users are able to communicate using the combinations scheme which achieves fairness.

Another interval trial is conducted in the femtocell and indicated as interval C. During this interval, the users requesting for resources are shown in Table 4.12

Table 4.12: Users' resource requests with corresponding SINR values during Interval C

Time Interval C		
User	**Requests**	**SINR (dB)**
2	2	10
4	5	2
5	3	9
6	2	7
Available resources = 8 , requested = 12		

From the results of the two sequences subjected to the users during interval C, the output is as shown in Table 4.13.

Table 4.13: Allocation sequence to users during Interval C

Combinational	2	2	4	5	5	5	6	6
sequence	SINR TOTAL = 63 dB							
Global	2	2	4	4	4	4	4	5
Prediction	SINR TOTAL = 39 dB							

From the output of the trials done at interval C, the combinational scheme allocates to all users requesting for resources in the femtocell. The Global prediction allocates resources to 3 users and leaves out user 6 in the process. This is because it only allocates according to the sequence of request of resources made in the femtocell. The SINR total for the combinational sequence is also higher compared to the Global prediction indicating that the previous method is a better method for allocating resources.

A fourth trial is conducted during interval D. As derived from Table 4.7, the users present in the femtocell are outlined in Table 4.14, with their corresponding resources requests and their SINR values. With the available resources being 7, the two algorithms are then subjected to determine the allocation of resources to users' requests.

Table 4.14: Users' resource requests with corresponding SINR values during Interval D

Time Interval D		
User	**Requests**	**SINR (dB)**
3	4	6
5	3	9
6	2	7
7	4	3
Available resources = 7 , requested = 13		

Table 4.15 shows the allocation sequence when the requests are subjected to the Combinational and the Global mobility prediction sequences respectively.

Table 4.15: Allocation sequence to users during Interval D

Combinational sequence	3	3	5	5	5	6	6
Without (fairness)	*SINR TOTAL = 53 dB*						
Combinational sequence	3	7	5	5	5	6	6
With (fairness)	SINR TOTAL = 50 dB						
Global Prediction	3	3	3	3	5	5	5
	SINR TOTAL = 51 dB						

For the combinational sequence, the initial allocation in interval D leaves out user 7. The SINR total value for the allocation without this user is 53 dB. When fairness scheme is applied, a resource is reallocated from user 3 to user 7. The new SINR total then becomes 50 dB.

As for the Global mobility prediction, only user 3 and user 5 are allocated resources. The other two users: 6 and 7 are left out. The SINR total value is 51 dB. This is slightly higher than the Combinational algorithm because the Combinational algorithm accommodated all the four users and this compromised the SINR total by 3 dB. This makes the margin of the SINR total value to be 1 dB lower compared to the Global prediction scheme but the users' allocation differs by 2.

Therefore, despite the combinational technique having a lower SINR total by 1 dB, all the users are able to communicate through fairness. This is a pointer to the limitation of fairness on the levels of compromise that it can have on the SINR total compared to accommodating all the users in the femtocell. As a result of this, the fairness will be evaluated separately in Scenario 4: Analysis of the fairness scheme, so as to visualize the overall effect of fairness and also its limitations in terms of the number of users that it can accommodate.

Furthermore, another trial is done in a fifth trial, named as Interval E. At this interval as per the initial sequence of users, the users present in the femtocell are as shown in Table 4.16

Table 4.16: Allocation sequence to users during Interval E

Time Interval E		
User	**Requests**	**SINR (dB)**
1	3	8
2	2	10
4	5	2
5	3	9
Available resources = 6 , requested = 13		

With the application of the simulations, the arrangement generated is shown in Table 4.17.

Table 4.17: Allocation sequence to users during Interval E

Combinational sequence	1 2 2 5 5 5
Without (fairness)	*SINR = 55 dB*
Combinational sequence	1 2 2 4 5 5
With (fairness)	SINR = 48 dB
Global Prediction	1 1 1 2 2 4
	SINR = 46 dB

From the two outputs, it is seen that for the Combinational algorithm, the allocation initially is done to 3 users and user 4 is left out. The SINR total value is 55 dB. When the fairness is applied, a resource is reallocated from user 5 to user 4 to ensure that all users are able to communicate. This is because, user 1 only has a single resource, so, despite being the next lowest SINR valued user, the scheme opts for the next user who has more than one resource for communication who is user 5.

For the Global mobility prediction, the allocation is done in the sequence of the resource requests therefore user 5 does not get any resource for communication. The reallocation makes the SINR total value to become 48 dB with fairness consideration for the combinational approach compared to 46 dB for the Global prediction. Therefore, for the combinational scheme, the SINR value remains higher.

A further example is done at interval F, where the users requesting for resources are as shown in the Table 4.18.

Table 4.18: Users' resource requests with corresponding SINR values during Interval F.

Time Interval F		
User	**Requests**	**SINR (dB)**
2	2	10
4	5	2
7	4	3
8	3	4
Available resources = 10, requested = 14		

When the combinational scheme and the Global mobility prediction schemes are applied, the allocation arrangement is as shown in Table 4.19.

Table 4.19: Allocation sequence to users during Interval F

Combinational sequence	2	2	4	7	7	7	7	8	8	8
	SINR TOTAL = 46 dB									
Global Prediction	2	2	4	4	4	4	4	7	7	7
	SINR TOTAL = 39 dB									

From the results in Table 4.19, it is seen that all the users requesting for resources are allocated using the combinational sequence hence no fairness is needed in this instance. For the Global prediction, it can be seen that user 8 is left out since the allocation uses the initial direct request sequence. Therefore, user 8 is left out without a resource for communication. The SINR total value of the combinational sequence is higher by 7 dB compared to the Global mobility prediction scheme.

During interval G, the users as initially presented in Table 4.7 in the femtocell are displayed in Table 4.20.

Table 4.20: Users' resource requests with corresponding SINR values during Interval G.

Time Interval G		
User	**Requests**	**SINR (dB)**
1	3	8
4	5	2
7	4	3
8	3	4
Available resources = 11 , requested = 15		

The two algorithms are then subjected to the requests in Table 4.20 to give the allocation sequences as shown in Table 4.21.

Table 4.21: Allocation sequence to users during Interval G

Combinational sequence	1 1 1 4 7 7 7 7 8 8 8
	SINR TOTAL = 50 dB
Global Prediction	1 1 1 4 4 4 4 4 7 7 7
	SINR TOTAL = 43 dB

The results yielded in the resource allocation sequences in Table 4.21 show that for the combinational sequence, all the 4 users are allocated resources to communicate. For the

Global prediction, user 8 is left out of the allocation sequence. The SINR total for the combinational sequence is 7 dB higher than that of the Global prediction. Hence the combinational scheme is more effective in allocating resources.

Finally, a last trial is done in an eighth trial: Interval H. In this instance, the users requesting for resources are shown in Table 4.22 shown.

Table 4.22: Users' resource requests with corresponding SINR values during Interval H

Time Interval H		
User	**Requests**	**SINR (dB)**
4	5	2
6	2	7
7	4	3
8	3	4
Available resources = 9, requested = 14		

Application of the two algorithms: Combinational computation and Global mobility prediction gives the data shown in Table 4.23.

Table 4.23: Allocation sequence to users during Interval H.

Combinational sequence	6 6 7 7 7 7 8 8 8
(Without fairness)	SINR TOTAL = 38 dB
Combinational sequence	6 6 4 7 7 7 8 8 8
(With fairness)	SINR TOTAL = 37 dB
Global Prediction	4 4 4 4 4 6 6 7 7
	SINR TOTAL = 30 dB

From Table 4.23 it is seen that initially, the combinational sequence leaves out user 4. The SINR total at this point is 38 dB. Then, when the fairness scheme is applied for consideration of low SINR valued users, in this case user 4, a resource is reallocated from user 7 to user 4. This ensures that all users are able to communicate in the femtocell. Then, the Global prediction leaves out user 8 who is the last in the request sequence. For the SINR values, the combinational scheme gives an SINR total of 37 dB and the Global prediction gives an SINR total of 30 dB. Therefore the combinational scheme gives better results.

The results tabulated from interval A to H are then summarized and displayed in Table 4.24 and Table 4.25. Table 4.24 gives a summary of users who have requested for resources to communicate in the femtocell and the allocation is compared using the two techniques: Global prediction and Combinational technique.

Table 4.24: Summary of users allocated resources using Global prediction and Combinational approach with and without fairness.

TRIALS	**Number of users who have requested for resources**	**Number of users allocated resources using the stated technique**		
		Global prediction technique	Combinational technique (without fairness)	Combinational technique (with fairness)
A(1)	4	4	4	4
B(2)	4	3	3	4
C(3)	4	3	4	4
D(4)	4	2	3	4
E(5)	4	3	3	4
F(6)	4	3	4	4
G(7)	4	3	4	4
H(8)	4	3	3	4

Furthermore, Table 4.25 gives a summary comparison of the SINR total values realized with allocation using both techniques: Global prediction and Combinational scheme.

Table 4.25: Summary of SINR total using Global prediction and Combinational approach with and without fairness.

TRIALS	SINR TOTAL VALUES IN dB		
	Global Mobility Prediction	Combinational Technique (Without Fairness)	Combinational Technique (With Fairness)
A(1)	74	74	N/A
B(2)	54	56	55
C(3)	39	63	N/A
D(4)	51	53	50
E(5)	46	55	48
F(6)	39	46	N/A
G(7)	43	50	N/A
H(8)	30	38	37

The graph in Figure 4.1 gives a plot of users requesting for resources in the femtocell together with the ones who are actually allocated the resources. This is derived from the findings recorded in Table 4.24 with fairness consideration.

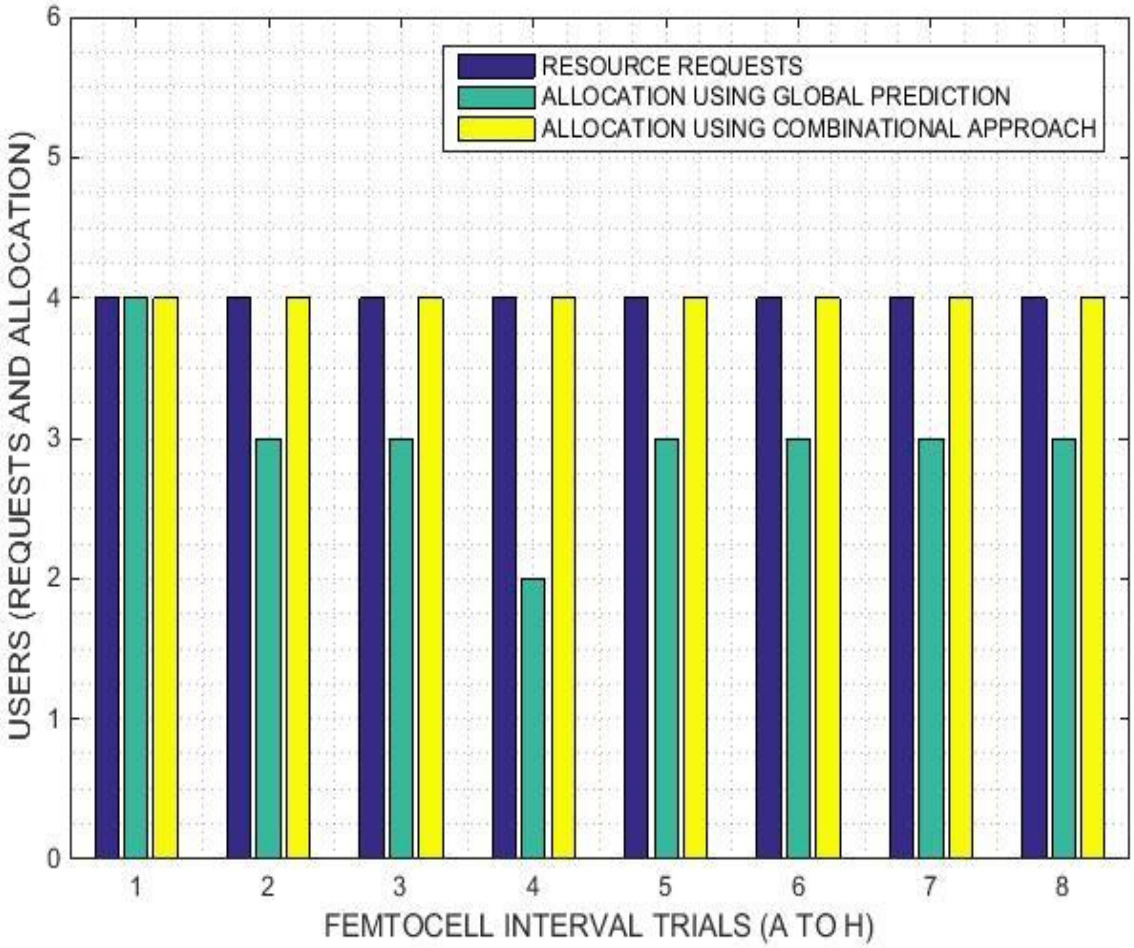


Figure 4.1: Plot of users' resources allocation for various trials in a femtocell.

The graph in Figure 4.2 shows comparison of the SINR total values that is as a result of allocation sequences done using the Combinational and Global prediction scheme. This data is obtained from Table 4.24. Figure 4.3 shows the graph for the fairness allocation of resource requests using both the Global Mobility prediction and the Combinational technique.

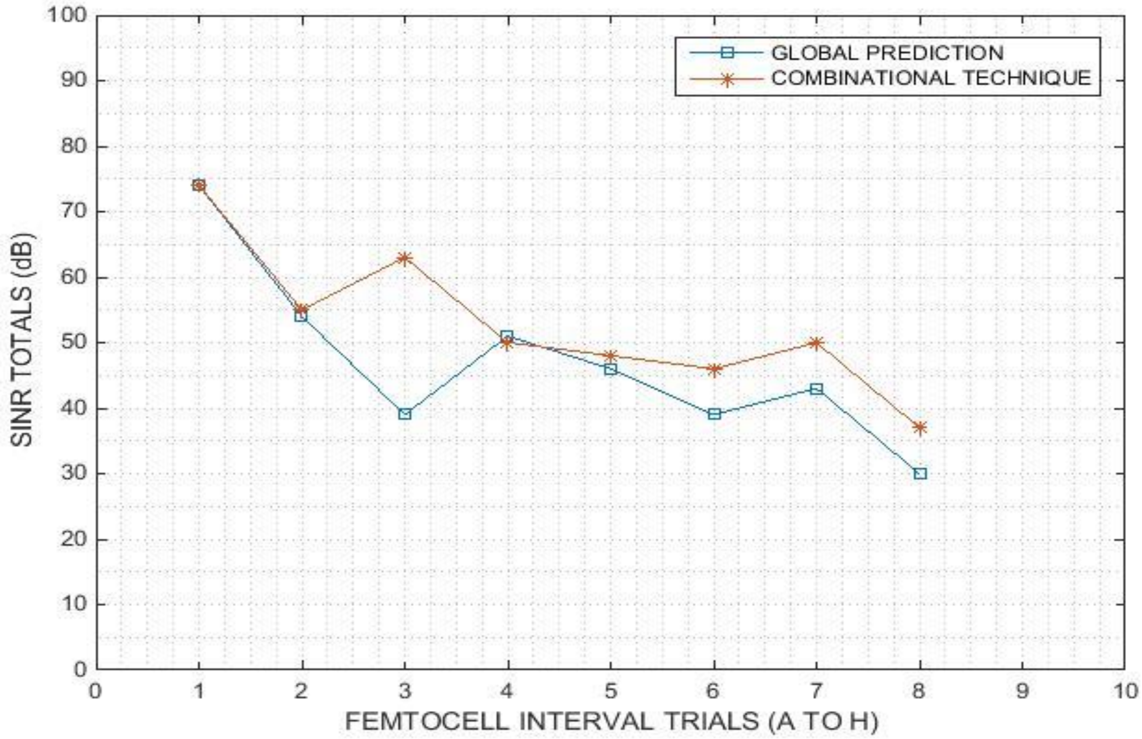


Figure 4.2: Plot of SINR total using the Combinational technique against Global Prediction technique

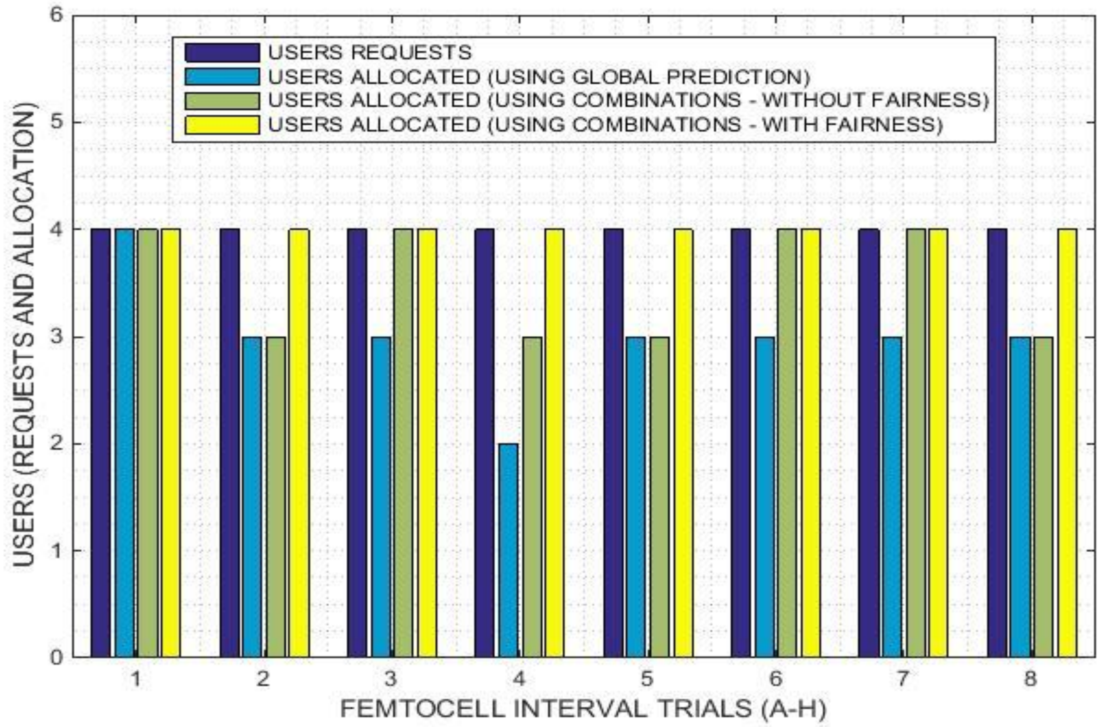


Figure 4.3: Plot of users' resources allocation with fairness comparison.

4.3.2 Overall discussion of results on impact of Combinational scheme to other technologies

The plot in Figure 4.2 shows that the combinational scheme with fairness yields higher output in the SINR total compared to Global mobility prediction technique. This is seen from most of the intervals, apart from one interval where Combinational scheme has a lower SINR total due to fairness that accommodates all users, compared to two in the Global mobility approach.

In overall, the Combinational technique is seen as an improvement over the Global technique while allocating resources to users in a femtocell. The combinational technique always prioritizes the higher SINR valued users in all the allocations. SINR is an LTE system parameter that is used by an RF measurement report to generate a CQI index for modulation. This is shown in table 2.2 in the Literature review chapter. The

CQI index determines the modulation scheme on the AMC in section 2.2 (Mohammad T. Kawser, 2012). The higher the SINR total the higher the CQI index (Farhana Afroz, 2015). A high CQI for instance, between index 10 and 15 will allocate 64 QAM which is 6 bits/symbol. This will achieve a higher throughput compared to a CQI index of between 1 and 6 that allocates 2 bits/symbol. This achieves a lower throughput in the channel.

4.4 Scenario 4 (Analysis of the Fairness Scheme)

This scenario is emphasizing on the third specific objective of investigating the effect of fairness on the SINR in determining the most effective allocation of resources to users in a femtocell. The fairness technique has been described in section 3.4 in the methodology chapter

The method presented uses combinational computation to determine the highest group of SINR users' then allocates this group. This method at times allocates the highest group and leaves out the low SINR valued users. As an improvement to the combinational scheme, a proposed fairness scheme is hereby presented.

This new scheme would scan for all users who have been allocated resources after the first sequence of combinational allocation. If a user has been left out, it checks for the next lowest SINR valued user(s) and reallocates a single resource from that user, to the one who has been left out due to low SINR value. Therefore, all users can now communicate.

This scenario tends to analyze the effect of fairness application on combinational allocation sequence alone.

4.4.1 Fairness Analysis in 8 Intervals (A.2 to E.2) for Scenario 4

A fourth scenario of users in a femtocell recorded in five different intervals is hereby presented for analysis of the fairness scheme. The five intervals in which the users have been recorded with their SINR values are as shown in Tables 4.26 – 4.30.

Table 4.26: Femtocell users' resource requests with SINR values recorded at interval A.2

Time Interval A.2		
User	**Requests**	**SINR (dB)**
1	3	8
3	4	6
7	4	3
8	3	4
Available resources = 9, requested = 14		

The allocation of available resources to the users in the femtocell is carried out using the combinational sequence. The allocation is analyzed per interval of requests to the users present.

For interval A.2, the allocation sequence using combinations is as outlined in Table 4.26:

[1 1 1 3 3 3 3 8 8]. The SINR total for this group is 56 dB. User 7 is left out, hence fairness re-allocates one resource from user 8 to user 7 to enable him communicate. The new arrangement now becomes [1 1 1 3 3 3 3 8 7]. The new SINR total with fairness application becomes 55 dB, lower by 1 dB but all users can now communicate.

Table 4.27: Femtocell users' resource requests with SINR values recorded at interval B.2

Time Interval B.2		
User	**Requests**	**SINR (dB)**
7	4	3
8	3	4
4	5	2
2	2	10
Available resources = 6, requested = 14		

In interval B.2 as shown in Table 4.27, the combinational sequence gives an allocation of resources to users who are requesting for resources in the following outline. [7 8 8 8 2 2]. The SINR total for this allocation is 35 dB. User 4 has been left out. When a scan is done, the next lowest SINR valued users are found to be user 7 and user 8. For fairness consideration, user 7 is found out to have 1 resource. Therefore, the next one is user 8 who has 3 resources. Hence, one resource can be reallocated from user 8 to user 4 to enable user 4 to be able to communicate in the femtocell. The new allocation outline is [7 8 8 4 2 2], and the new SINR total is 33 dB. From this example, it is seen that the SINR value is lowered by only 2 dB but all users are now able to communicate in the femtocell.

Table 4.28: Femtocell users' resource requests with SINR values recorded at interval C.2

Time Interval C.2		
User	**Requests**	**SINR (dB)**
8	3	4
4	5	2
7	4	3
1	3	8
Available resources = 10, requested = 15		

During interval C.2, as shown in Table 4.28, 15 requests from the users are subjected to combinations against 10 available ones. The allocation sequence is as follows: [8 8 8 7 7 7 7 1 1 1]. This allocation does not have user 4, thus, fairness is applied by reallocating a resource from user 7 to user 4 to enable him to communicate in the femtocell. Hence, the new allocation arrangement is as follows: [8 8 8 7 7 7 4 1 1 1]. The SINR total value changes from 48 dB to 47 dB respectively, thus lowering by only 1 dB, but now, all users can be able to communicate.

Table 4.29: Femtocell users' resource requests with SINR values recorded at interval D.2

Time Interval D.2		
User	**Requests**	**SINR (dB)**
4	5	2
8	3	4
2	2	10
5	3	9
Available resources = 7, requested = 13		

In interval D.2, as seen in Table 4.29, 13 resource requests are computed using the combinational algorithm against the available 7 resources. The initial best SINR allocation sequence is as follows: [8 8 2 2 5 5 5]. The SINR total is 55 dB. This arrangement leaves out user 4. With fairness application, a resource is re-allocated from user 8 to user 4. The new arrangement now becomes: [8 4 2 2 5 5 5]. This makes the new SINR total to become 53 dB.

Table 4.30: Femtocell users' resource requests with SINR values recorded at interval E.2

Time Interval E.2		
User	**Requests**	**SINR (dB)**
7	4	3
2	2	10
8	3	4
1	3	8
Available resources = 5, requested = 12		

Lastly, in interval E.2, as illustrated in Table 4.30 the resource requests are 12. Combinations are carried out against the available 5 resources. This yields the following arrangement of users:

[2 2 1 1 1]. The SINR total is 44 dB. But 2 users are discovered to have been left out: user 7 and user 8. Fairness is therefore required here. It re-allocates a resource each from user 1 and user 2 to user 7 and user 8. The new allocation sequence now becomes [2 7 1 1 8]. The new SINR total becomes 33 dB. The SINR total is significantly lowered by 11 dB so as to accommodate the 2 users left out to enable them to communicate.

Fairness achieves connection for all, but at a much wider compromise of the SINR total: 11 dB. This is a pointer that fairness, as a reassignment scheme, has a limitation on the number of users that it can comfortably reallocate resources. It is therefore recommended for small scale reassignment of resources for example in a femtocell.

All the five interval trials can now be summarized in a table showing the SINR total values for all the trials done comparing with and without fairness. This is shown in Table 4.31

Table 4.31: A summary of Femtocell trials during time intervals: A to E with SINR total values recorded

Time Interval	SINR total (dB)	
	Without fairness	**With Fairness**
A.2	56	55
B.2	35	33
C.2	48	47
D.2	55	53
E.2	44	33

A further analysis can also be done on the allocation of resources to users who are requesting for resources together with the ones allocated. This is outlined in Table 4.32.

Table 4.32: A summary of Femtocell trials during time intervals (A.2 to E.2) for the number of users who are requesting for resources versus the ones allocated

Time Interval	Users allowed to communicate in the femtocell	
	Without fairness	With Fairness
A.2	3	4
B.2	3	4
C.2	3	4
D.2	3	4
E.2	2	4

From these tabulated results, graphical plots can hereby be done to analyze the fairness scheme and its effects on the application to the combinational allocation scheme. The graph in Figure 4.4 shows the SINR total values for the 5 trials done in the femtocell with fairness comparison.

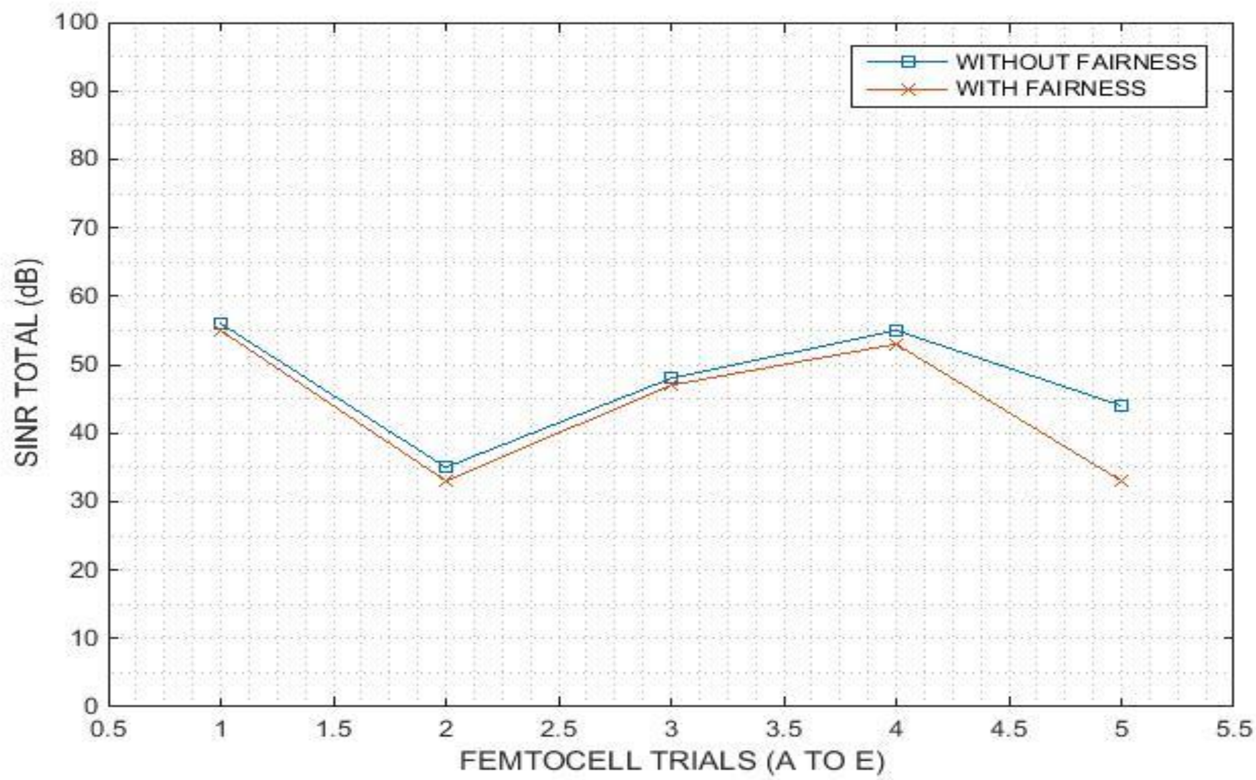


Figure 4.4: A graph of SINR total vs trials (with fairness comparison)

Furthermore, a graphical comparison analysis can be done using MATLAB for users who request for resources, against the ones that are allowed to communicate in the femtocells with and without fairness consideration, as tabulated earlier. This is plotted in Figure 4.5 shown.

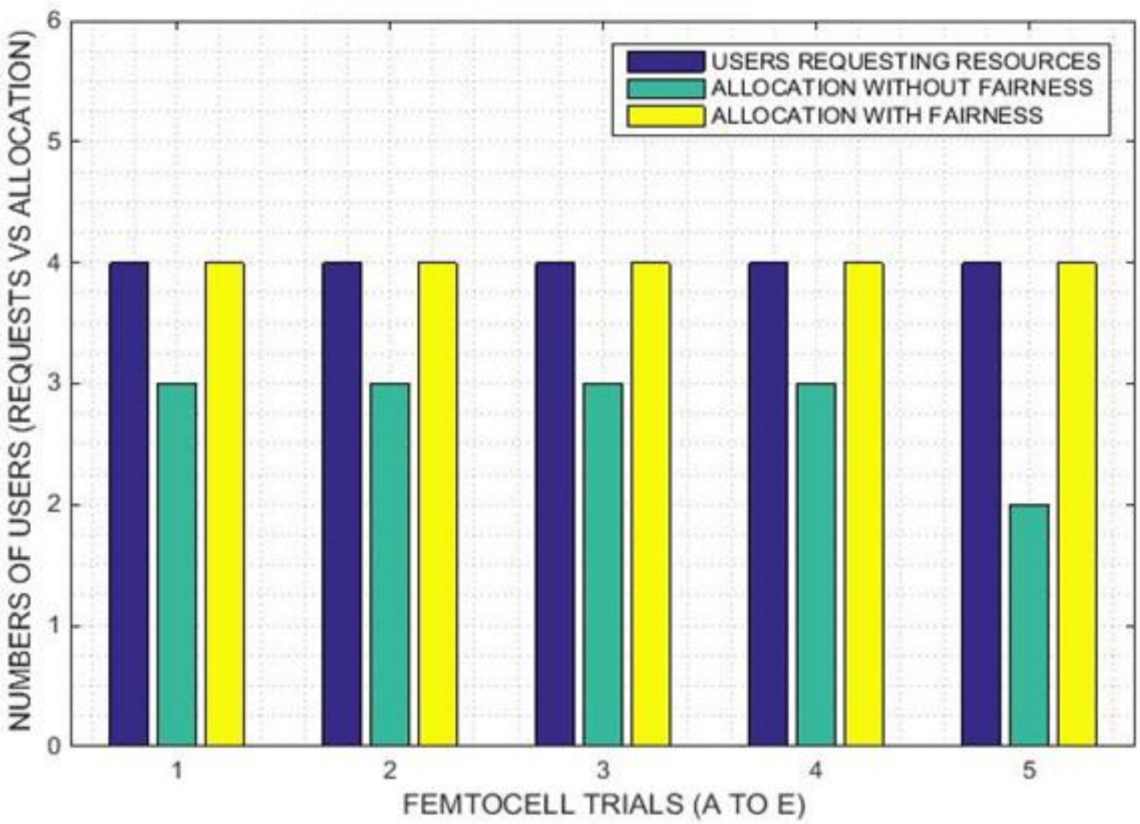


Figure 4.5: A graph of number of users requests vs allocation (with fairness comparison)

4.4.2 Discussion of the impact of the Fairness Scheme to other technologies

From the MATLAB plots done, it can be seen that SINR total values are lowered by 1 dB to 3 dB in intervals A.2 to D.2. This is done during the fairness reallocation of resources to the users left out. The last trial E.2 is lowered by a bigger margin of 11 dB because 2 users have been left out that need to be connected to the femtocell.

In summary, the fairness scheme is considered as a means of ensuring that all users are able to communicate with a small compromise on the SINR total, in small scale environments like a femtocell.

In a femtocell, the scheme would like to maintain a high SINR for high CQI and modulation due to throughput purposes as described in section 2.7 (Farhana Afroz, 2015). However, fairness is being pursued in accordance with the third specific objective on its effect on the SINR during allocation. Fairness is able to achieve connection to all users with just a small reduction in SINR. This reduction may not affect the modulation scheme significantly and can be recommended for adoption.

Fairness can be noted as an improvement on the combinational scheme since it enables all users to communicate in a femtocell utilizing the LTE technology. This is a small scale environment that has limited resources.

Finally, the entire research is done in a femtocell that normally accommodates within the range of 30 to 35 users as described in section 2.6 in the Literature review chapter. Therefore, the scenarios considered in this research range within the numbers that can be accommodated by a femtocell.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this thesis, resources allocation schemes that are used in a femtocell have been analyzed. The resource allocation schemes reviewed have various criteria for allocation. The different methods reviewed were: Proportional Constraints algorithm, Maximum sum rate algorithm and Maximum fairness algorithm (Sudhir B. Lande, 2012). Others were, historical movements of users used in the Global Mobility prediction and giving equal probabilities of movement of a user to all adjacent cells using the Local Prediction algorithm (Oyie Nicholas, 2014).

The proposed method used in this thesis is Combinational allocation algorithm with fairness consideration. The main comparison done is with the Global mobility prediction that used the historical movements of a user and were recorded then used to predict the next position that the user would move to. The combinational technique takes into account all possible arrangements of the users' resource requests and SINR. These are mapped on to the available resources and the best SINR valued users are allocated resources. Fairness then is considered for low SINR valued users. The combinational technique is regarded as an improvement due to the following factors:

i). In accordance with the first specific objective of determining the effectiveness of the combinational scheme as an arrangement technique, the movement of users does not actually determine the allocation sequence. This is so because, regardless of the users' position, the main factor in resource allocation is the available resource and the number of the resources that the user is requesting. This is illustrated in scenarios presented in Section 4.3 where comparison is done with the Global Mobility prediction that considers the historical movement of users. Hence, combinational approach is instantaneous in terms of resource allocation and more effective in a femtocell ii). The combinational technique can be applied to multiple scenarios of resources requests. This is witnessed in single resource requests such as synchronization for connection to a femtocell, plus also multiple resources requests per user in high bandwidth requirements. This is seen in Section 4.1 and 4.2 in the results chapter. This is also in line with the second specific objective of this research which seeks to analyze Combinations in terms of resource requests types and availability in a femtocell.

iii). The users' SINR values are also recorded for the execution of the technique and are used to prioritize the number of resources to allocate to a user. The high SINR valued users are prioritized in terms of the number of resources to be allocated. This is done by selecting the highest SINR total on the matrix of possible allocations. It puts emphasis on the first, the second and the third specific objectives where, SINR is used as the parameter to prioritize users in all scenarios analyzed in the methodology and results chapters. This is also done in accordance with the fourth specific objective, which is to validate the combinational scheme as an improvement on existing methods. In this research, the method used in the validation is the Global mobility prediction.

iv). Fairness is applied if low SINR valued users are left out by the allocation sequence. This point also analyses the third specific objective on investigating the effect of fairness on the SINR total in determining the most effective resource allocation to users in a femtocell. This is done after the combinations algorithm has allocated resources to the other high SINR valued users and some have been left out. It is executed by re-allocating a resource from the next low SINR valued user(s) to the user(s) who have been left out to enable them to communicate. This has been seen to lower the SINR total by a small value of about 1dB to 5dB. Extreme cases such as situations where 2 users have been left out have recorded a reduction of 11 dB in order to accommodate them. The Global Mobility prediction does not apply fairness to allocate any user who has been left out, thus, making this an improvement on the part of the Combinational scheme. The fourth specific objective is also emphasized here. The combinational approach achieves better results than the Global prediction, which is an existing method in terms of users' allocation and SINR values for throughput.

5.2 Recommendations

The following are the areas that can be considered for future research from the work covered in this thesis.

i). Fairness scheme can be improved by researching on ways of re-allocating resources to the users who have been left out without compromising the SINR levels in the femtocell. This can also be pursued in the newer technologies such as 5G and 6G where the resource block has been flexed. Therefore fairness can also be researched on how to accommodate it with power optimization done with NOMA and SIC techniques on a resource block.

ii). The combinational technique tends to get bulky during processing in cases of very large numbers. It can pose challenges when applied to many cell phone users as can occur in macro cells. The scope of this research is based on a femtocell that has limited bandwidth and limited number of users that it can accommodate. Therefore, better techniques to handle very many inputs in terms of resources requests and allocation can be recommended over the combinational technique for applications in macro cells so as to handle much higher traffic.

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APPENDICES

Appendix I: Published Work

1. Andrew Ruitie Macharia ,Philip Langat Kibet Stephen Musyoki, "An optimized dynamic fair resource allocation technique in a femtocell," *Journal of Sustainable Research in Engineering*, vol. 4, pp. 125-135, 2018.

2. Macharia A.R, Langat P.K., Musyoki S., "Optimal resource allocation in Femtocell using Combinational approach," in *4th DeKUT International Conference on Science, Technology, Innovation and Entrepreneurship*, Nyeri, 2018, pp. 166-177.

3. Andrew Ruitie Macharia, Philip Kibet Langat, and Stephen Musyoki, "Analysis of Combinational resources allocation for various user equipment application requests in a Femtocell," in *13th JKUAT Scientific, Technological and Industrialization Conference, Nairobi*, 2018, pp. 138-146.

Appendix II: MATLAB Combinational Algorithm Code

```
clear;
clc;
promptnousers = 'Enter the number of users in the femtocell \n';
innousers = input(promptnousers);
promptnoavailable = 'Enter the number of available resources in the femtocell \n';
innoresources = input(promptnoavailable);
usersmatrix = [];
for i=1:innousers
promptuser = 'Enter the user \n';
inusers = input(promptuser);
promptrequest = 'Enter the resources requests\n';
inrequests = input(promptrequest);
promptsinr = 'Enter the SINR\n';
insinr = input(promptsinr);
for m = 1:inrequests
userstotal = [inusers ,insinr];
usersmatrix = [usersmatrix; userstotal];
end
end
for u = 1:size(usersmatrix,1)
a(u)=u;
end
usersmatrix = [a' , usersmatrix];
usersmatrix
c(:,:,1) = nchoosek(usersmatrix(:,1),innoresources);
c(:,:,2) = nchoosek(usersmatrix(:,2),innoresources);
c(:,:,3) = nchoosek(usersmatrix(:,3),innoresources);
```

```
d = c(:,:,3);
[m,n] = max(sum(d,2));
fprintf('The users arrangement as per the combinational technique is \n');
c(n,:,2)
fprintf('The total SINR in dB for the combinational technique is \n');
display(m)
fprintf('The users arrangement as per the global prediction technique is \n');
global2 = usersmatrix(:,2)';
global2 (1:innoresources)
fprintf('The SINR sum of users arrangement as per the global prediction technique is
\n');
global3 = usersmatrix(:,3)';
sum(global3 (1:innoresources))
fprintf('The user(s) who requested for resource resources are/were \n');
checkuniqueuser1 = unique(usersmatrix(:,2))'
fprintf('The user(s) left out by the combinational technique are/were \n');
checkuniqueuser2 = unique(c(n,:,2));
leftuniqueuser2 = setdiff(checkuniqueuser1,checkuniqueuser2)
fprintf('The user(s) left out by the global technique were \n');
global4 = global2 (1:innoresources);
checkuniqueuser3 = unique(global4);
setdiff(checkuniqueuser1,checkuniqueuser3)
```

Appendix III: MYSQL Database Code

MYSQL PASSWORD: 12345

```
-------------CODE------------------
CREATE DATABASE JKUAT;
USE JKUAT;
DROP TABLE IF EXISTS `usersmatrix`;
/*!40101 SET @saved_cs_client     = @@character_set_client */;
/*!40101 SET character_set_client = utf8 */;
CREATE TABLE `usersmatrix` (
  `SN` int(10) DEFAULT NULL,
  `USER` int(10) DEFAULT NULL,
  `SINR` double(30,2) DEFAULT NULL
) ENGINE=InnoDB DEFAULT CHARSET=latin1;
```

Appendix IV: MATLAB Fairness Resource Reallocation code

```
dbname = 'jkuat';
username = 'root';
password = '12345';
driver = 'com.mysql.jdbc.Driver';
dburl = 'jdbc:mysql://localhost:3306/jkuat';
javaclasspath('D:\Softwares\mysql-connector-java-5.1.41-bin.jar');
conn = database(dbname, username, password, driver, dburl);
colnames = {'SN','USER','SINR'};
tablename = 'USERSMATRIX';
sqlquery1 = 'truncate table usersmatrix' ;
curs1 = exec(conn,sqlquery1);
insert(conn,tablename,colnames,usersmatrix)
sqlquery2 = 'select user,sinr from usersmatrix group by SINR order by SINR ASC LIMIT 1,1' ;
curs3 = exec(conn,sqlquery2);
curs4 = fetch(curs3);
r1 = curs4.data;
r1int = cell2mat(r1);
nextlowsinruser = r1int(1,1) ;
nextlowsinruservalue = r1int(1,2) ;
'Replace one resource from user'
nextlowsinruser(1,1)
'and reallocate to user'
leftuniqueuser2
sqlquery3 = 'select user,sinr from usersmatrix group by SINR order by SINR ASC LIMIT 0,1' ;
curs5 = exec(conn,sqlquery3);
```

```
curs6 = fetch(curs5);
r2 = curs6.data;
r2int = cell2mat(r2);
lowestsinrvalue = r2int(1,2) ;
'The new SINR total with fairness is'
SINRwithfairness = m-nextlowsinruservalue+lowestsinrvalue;
SINRwithfairness
'dB'
fprintf('The users arrangement as per the combinational technique WITHOUT fairness is
\n');
combwithoutfairness = c(n,:,2)
nextlowuserindex = find(combwithoutfairness==nextlowsinruser);
fprintf('The users arrangement as per the combinational technique WITH fairness is \n');
combwithoutfairness(nextlowuserindex(1,1))=leftuniqueuser2;
 combwithfairness = combwithoutfairness
```

Appendix V: Single Resource request trial

The tabulated result in Table E.1 is for the sequence of users' arrangement for scenario one displayed in Table 4.2 in chapter 4.

Table E.1: Possible combinational arrangement of Single user resource requests with the corresponding SINR values and SINR totals

S.no	Users arrangement	SINR corresponding arrangement	SINR total
1	1 2 3 4	10 20 15 5	50
2	1 2 3 5	10 20 15 12	57
3	1 2 3 6	10 20 15 18	63
4	1 2 4 5	10 20 5 12	47
5	1 2 4 6	10 20 5 18	53
6	1 2 5 6	10 20 12 18	60
7	1 3 4 5	10 15 5 12	42
8	1 3 4 6	10 15 5 18	48
9	1 3 5 6	10 15 12 18	55
10	1 4 5 6	10 5 12 18	45
11	2 3 4 5	20 15 5 12	52
12	2 3 4 6	20 15 5 18	58
13	2 3 5 6	20 15 12 18	65
14	2 4 5 6	20 5 12 18	55
15	3 4 5 6	15 5 12 18	50

SINR totals show that the users with SINR values [20 15 12 18] are the highest belonging to users [2 3 5 6].

Appendix VI: Example of a Multiple Resources Requests trial

Table F.2: Time Interval A (Multiple resource request example)

Time Interval A		
User	**Requests**	**SINR (dB)**
1	3	8
2	2	10
3	4	6
4	5	2
Available resources = 12, requested = 14		

Table F.2: Users' possible combinational arrangement for multiple resource requests for interval A

Users arrangement for Interval A											
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	3	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4

Users arrangement for Interval A (continued)

1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	4	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	4	4	4	4	4
1	1	1	2	2	3	3	4	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	3	4	4	4	4
1	1	1	2	2	3	3	4	4	4	4	4
1	1	1	2	2	3	3	4	4	4	4	4
1	1	1	2	2	3	3	4	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4

Users arrangement for Interval A (continued)											
1	1	1	2	3	3	3	4	4	4	4	4
1	1	1	2	3	3	3	4	4	4	4	4
1	1	1	2	3	3	3	4	4	4	4	4
1	1	1	2	3	3	3	4	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	3	4	4	4	4
1	1	1	2	3	3	3	4	4	4	4	4
1	1	1	2	3	3	3	4	4	4	4	4
1	1	1	2	3	3	3	4	4	4	4	4
1	1	1	2	3	3	3	4	4	4	4	4
1	1	1	3	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	3	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4

Users arrangement for Interval A (continued)											
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	3	3	3	3	4	4	4	4	4
1	1	2	3	3	3	3	4	4	4	4	4
1	2	2	3	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	3	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	2	3	3	3	4	4	4	4	4
1	1	2	3	3	3	3	4	4	4	4	4
1	1	2	3	3	3	3	4	4	4	4	4
1	2	2	3	3	3	3	4	4	4	4	4
1	2	2	3	3	3	3	4	4	4	4	4

Table F.3: Users' possible combinational arrangement of SINR totals for interval A

Combinations of SINR values for users											
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	6	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	2	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2

Combinations of SINR values for users (continued)											
8	8	8	10	10	6	6	2	2	2	2	2
8	8	8	10	10	6	6	2	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	6	2	2	2	2
8	8	8	10	10	6	6	2	2	2	2	2
8	8	8	10	10	6	6	2	2	2	2	2
8	8	8	10	10	6	6	2	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	2	2	2	2	2
8	8	8	10	6	6	6	2	2	2	2	2
8	8	8	10	6	6	6	2	2	2	2	2
8	8	8	10	6	6	6	2	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	6	2	2	2	2
8	8	8	10	6	6	6	2	2	2	2	2
8	8	8	10	6	6	6	2	2	2	2	2
8	8	8	10	6	6	6	2	2	2	2	2
8	8	8	10	6	6	6	2	2	2	2	2

Combinations of SINR values for users (continued)											
8	8	8	6	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	6	6	6	6	2	2	2	2	2
8	8	10	6	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	6	6	6	6	2	2	2	2	2
8	8	10	6	6	6	6	2	2	2	2	2
8	10	10	6	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	6	2	2	2	2

Combinations of SINR values for users (continued)											
8	8	10	10	6	6	6	6	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	10	6	6	6	2	2	2	2	2
8	8	10	6	6	6	6	2	2	2	2	2
8	8	10	6	6	6	6	2	2	2	2	2
8	10	10	6	6	6	6	2	2	2	2	2
8	10	10	6	6	6	6	2	2	2	2	2