Research and Postgraduate Studies (RPGS) Unit

Thesis Title: "Scheduling and Resource Allocation for Heterogeneous Traffic in LTE-A Networks"

Submitted by

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Thesis Title: "Scheduling and Resource Allocation for Heterogeneous Traffic in LTE-A Networks"

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A dissertation submitted in partial fulfillment of the requirements for the degree of

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Supervisor: Dr. Richard MUSABE

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Declaration

I hereby declare that this thesis contains my own work except where specifically acknowledged.

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Certificate

This is to certify that the project work entitled "Scheduling and Resource Allocation for Heterogeneous Traffic in LTE-Advanced" is a record of original work done by ***Atupenda MUGISHA*** *with Reg no:* ***216350042*** *in partial fulfilment of the requirements for the award of Master of Science in Information and Communication Technology of College of Science and Technology, University of Rwanda during the academic year 2017-2018*

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Abstract

Mobile communication networks are experiencing a significant growth in data traffic, posing challenges to the overall systems that should become more adaptive towards evolving changes in traffic and network conditions. Long term evolution advanced (LTE-Advanced), also called International Mobile Telecommunications advanced (IMT-Advanced) is a recent mobile technology approved by the International Telecommunication Union (ITU) as the fourth generation of the mobile communication system. And since then, it has become the first choice of the operators when constructing the new network infrastructure, due to its high throughput and low latency.

However, as the number of mobile users are increasing exponentially, it is proving to be costly to share the scarce resources considering the rapid growth of wireless services plus increasing demand for bandwidth. Therefore, it is necessary to evaluate the performance of the system to ensure that it is utilised efficiently. The key radio resource management mechanisms are user scheduling and resource allocation methods that are suitable to each user for transmission of the downlink from the base station through the air interface for each mobile user.

The objectives of this research thesis are to study and analyze the existing scheduling and resource allocation in LTE-Advanced and find an optimized scheduling algorithm to fully utilise the features of LTE-Advanced. A new scheduling algorithm is proposed with an improvement to the existing algorithms to improve the performance. The effects of the changes are evaluated using the Vienna LTE Simulator. In this thesis, the round robin and proportional fair resource allocation schemes have been considered.

The key contribution of this thesis work is to propose a new scheduling algorithm that improves the throughput and the fairness by applying conducive parameters of LTE-Advanced. Proposed algorithm improves system capacity as compared to round robin and proportional fair. The recommended ITU Pedestrian B and MIMO systems have been used to evaluate the algorithms for increased throughput.

Keywords: LTE-A, Resource Allocation, Heterogeneous, Scheduling, Round Robin (RR), Proportional Fair (PF), Vienna LTE Simulator, Pico, Femto.

List of Symbols and Acronyms

ACM: adaptive coding and modulation

AMC: Adaptive Modulation and Coding

AS: Access Stratum

BLER: Block Error Ratio

CA: Carrier Aggregation

CST: College of Science and Technology

CLSM: Closed Loop Spatial Multiplexing

CoMP: Coordinated multipoint transmission and reception

CQI: channel quality indicator

DL: Downlink

DL-SCH: Downlink Shared Channel

EPC: Evolved Packet Core

E-UTRAN: Evolved-universal Terrestrial Radio Access Network

eNB: evolved Node B

FD: Frequency Domain

FDM: Frequency Domain Multiplexing

FIFO: first in first out

FTP: File Transfer Protocol

3G: 3rd Generation system

3GPP: 3rd Generation Partnership Project

GSM: Global System for Mobile communications

HOL: Head of Line

IP: Internet Protocol

ITU-R: International Telecommunication Union Radio Sector

LTE: Long Term Evolution

MATLAB: Matrix Laboratory

MAC: Media Access Control

MCS: Modulation order and Coding Scheme

MeNB: Macro evolved NodeB

MIMO: Multiple-Input-Multiple-Output

MME: Mobility Management Entity

OFDMA: Orthogonal Frequency Division Multiple Access

PAPR: Peak-to-Average Power Ratio

PDCP: Packet Data Convergence Protocol

PF: Proportional Fair

PLR: Packet Loss Ratio

PMI: Pre-coding matrix indicator

PND: Packet Data Network

PRB: Physical Resource Block

PS: Packet scheduling

QAM: Quadrature amplitude modulation

QoS: Quality of Service

RB: Resource Block

RNC: Radio Network Controller

RE: Resource Element

RR: Radio Resources

RRM: Radio Resources Management

RR: Round Robin

RSRP: Reference Signal Received Power

SC-FDMA: Single Carrier Frequency Division Multiple Access

S-GW: Serving Gateway

SINR: Signal to Interference and Noise Ratio

SNR: Signal to Noise Ratio

TD: Time domain

TTI: Transmission Time Interval

UE: User Equipment

UMTS: Universal Mobile Telecommunications System

VoIP: Voice over Internet Protocol

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Chapter 1. General Introduction

1.1. Introduction

The fast emergent of connected devices and the tremendous growth of subscribers are heightening the mobile broadband traffic, which has grown exponentially during the last years [1]. Also, mobile subscriber expectations are on the rise, users have come to expect a consistent, high-quality and seamless mobile broadband experience everywhere [2] [3]. To meet these expectations, the capacity and the coverage of the current cellular networks need to be improved to deliver high data throughput with low latency. The key option to achieve this target was the introduction of Long Term Evolution-Advanced (LTE-A) based Heterogeneous Networks by the 3GPP as an emerging technology to provide high network coverage and increase system capacity by bringing the network closer to the mobile users [4] [5].

The concept of heterogeneous networks has recently attracted considerable interest as a way to optimize the performance of the network, particularly for unequal user or traffic distribution situations. A heterogeneous network is composed of multiple radio access technologies, architectures, transmission solutions, and base stations of varying transmission power that can interoperate, thus creating a multilayer structure. The heterogeneous networks are the combination of multilayer networks such as a macrocell, small cell (Picocell and Femtocell) networks [4] [6].

In Long Term Evolution-Advanced (LTE-A) based heterogeneous networks, different aspects of radio resource scheduling such as fairness and Quality of Service (QoS) assurance must be provided for heterogeneous traffic, having different characteristics. However, the ever-growing number of mobile devices sharing the limited radio resources leads to higher cost and difficulty of information acquisition and computations in the resource scheduling process.

To meet the QoS requirements for LTE-A based heterogeneous networks, scheduling and resource allocation has been employed. Scheduling and resource allocation is one of the important tasks of the radio resource management layer in long-term evolution (LTE) and LTE-Advanced wireless systems [2]. Scheduling and resource allocation determines when and how the users share the available resources to meet the minimum QoS. Therefore, effective design scheduling and resource allocation algorithm justify its choice as the main target for this research thesis.

The aims of scheduling and resource allocation are maximizing system throughput, guaranteeing fairness among users and minimizing either or both Packet Loss Ratio (PLR) and packet delay. In this research thesis, the performance of the proposed scheduling and resource allocation for maximum throughput is studied by comparing with proportional fair and round robin algorithms. The comparison of those algorithms is performed using a MATLAB based simulator developed by the Vienna Institute of Telecommunication with the simulation of both real-time and non-real time traffics in the heterogeneous network.

1.2. Motivation

LTE-A is a recently standard with comprehensive performance targets, however, as the number of mobile users are increasing exponentially it is proving to be costly to share the scarce resources. Therefore, it is necessary to evaluate the performance of this system at the user stage to promote its smooth cost-effective and deployment. Scheduling is vital since it is used to determine the resource blocks to be assigned to the users.

In this research, issues related to the scheduling and resource allocation will be discussed and a new scheduling scheme is proposed to increase user throughput while considering the fairness of the system and other features of LTE-A such as high order antenna configuration and mobility. Our proposed scheme will be evaluated and analyzed based on the performance metrics such as average throughput, bit error rate, and the signal to noise ratio.

1.3. Background of to the Research project

Today, the demand for high data rates to support the Internet services and the widest range of multimedia has received a substantial attraction around the globe from mobile researchers and industries. An international collaboration project, known as Third Generation Partnership Project (3GPP) takes a host of members into account especially, from both mobile industries and research institutes in an effort to deliver a globally applicable Long Term Evolution Advanced (LTE-A) mobile phone system specification [2]. The deployment of the first release of LTE-A started in 2008. This involved the improvement of the existing LTE standard to cope with the ever-evolving future requirements such IP switched network, high data rates at high and low mobility environments, cost-effective, support of simultaneous users per cell and smooth handovers across the heterogeneous network [7].

1.4. Problem statement

With the rapid growth of mobile subscribers, LTE-Advanced has been developed to address the increased need for traffic data. However, the sharing of the same resources by users in a limited bandwidth remains a challenge. In this research thesis, a gap has been identified to improve the user traffic throughput by distributing the resource blocks among different traffic types efficiently. In this research thesis, a new scheduling and resource allocation scheme is proposed to improve the existing schemes by introducing conducive parameters to the algorithms which produces improved performances.

1.5. Objectives

1.5.1. General objective

The main purpose of this work is to study and analyze the performance of scheduling and resource allocation algorithms in LTE-A and maximizing the user throughput in the heterogeneous traffic by proposing a new scheduling and resource allocation scheme.

1.5.2. Specific objectives

The following work will perform under the following objectives:

1. Analyse different existing resource allocation schemes.
2. Determine the performance metrics used in heterogeneous traffic within LTE-A.
3. Propose the new scheduling scheme based on the existing to produce higher throughput.
4. Compare the proposed scheme with the existing schemes in literature.

1.6. Limitation of the Research project

This research thesis will first focus on LTE-A traffic like VIDEO and FTP within LTE-A heterogeneous network. A new scheme is proposed to improve the network throughput and its performances against the existing algorithms is evaluated using the Vienna LTE simulator implemented in MATLAB R2014a software.

1.7. Justification

The exponential increase of mobile subscribers in mobile communication has steered to the deployment of LTE-A with a great capability for user maximization. The design and deployment of LTE-A have not brought a specific scheduler, as a result many scheduling algorithms have been studied with the purpose to match the user demands. For the purpose of this research thesis,only proportional fair and round robin are considered as existing algorithms. Those existing algorithms present a drawback with the rapid increase of the number of users and mobility. To improve those drawbacks, a new algorithm is introduced to increase the user throughput and try to withstand the effects of mobility on the user throughput.

1.8. Hardware and software requirements

Hardware requirements: Desktop computer: HDD 500, RAM 8, Processor i7.
Software requirement: MATLAB R2014a, LTE-A DL System Level Simulator Rel-v1-9-Q2-2016, and Windows 7 Professional.

1.9. Organization of the study

This research thesis is organized into six chapters as follows; the first chapter gives a general introduction which contains the project objectives, scope, problem statement, project motivation, background and organization of the work. The literature review is provided in the second chapter. Chapter 3 provides the research methodology. Chapter 4 presents the system analysis and design including the theory used in this research thesis. Chapter 5 gives the results of this research thesis and Chapter 6 gives a conclusion and recommendation.

Chapter 2. Literature review

2.1. Introduction

This chapter describes the review of the related literature to this research thesis. It describes the review of evaluation of 4^{th} Generation of mobile communication from Long Term Evolution (LT-E) to LTE-Advanced. Literatures to LTE heterogeneous traffic are presented in this chapter and a critical review of this research thesis study.

2.2. Review LTE/LTE-A Network

In 2004, 3GPP started by investigating the Universal Mobile Telecommunication Service (UMTS) radio access core to define how to bridge to LTE by identifying the requirement of LTE radio access technology [8]. LTE was standardized by 3GPP as the nature of the evolution of GSM and UMTS as a result of an exponential increase in user demand and high traffic [9].

The overall objective for LTE was to provide an extremely high-performance radio access technology that offers full vehicular speed mobility and that could readily coexist with an earlier generation of mobile communication technologies [10]. As mentioned before, LTE was standardized by 3GPP where it reached its mature state since the end of 2009 [11]. Since 2009, LTE became a common global standard for paired and unpaired spectrum. LTE was recognized as the fastest growing mobile broadband technology and becoming the most widely adopted cellular standard. The popularity of LTE was mainly due to its high spectral efficiency and high peak data rates, low-latency IP-based network, and evolutionary roadmap. But LTE is not "true 4G" service and is technically still considered 3.9G [12].

On the heels of the tremendous success of LTE, the International Mobile Telecommunications –Advanced (IMT-Advanced) defined a new standard which meets the requirement set for the fourth mobile generation by the InternationalTelecommunication Union Radio Sector (ITU-R). This evolved version was called LTE-Advanced [13] [14].

The LTE-Advanced matched and exceeded the requirements set in the IMT-Advanced [15]. The LTE-Advanced introduced new functionalities such as Intra and inter-band carrier aggregation (CA), Enhanced multiple-input-multiple-output (MIMO) supports up to eight antennas with up to eight parallel data streams, Coordinated multipoint transmission and reception (CoMP) and heterogeneous network [15] [3].

2.2.1. LTE-A Network Architecture

The core network of the LTE-Advanced system is separated into many parts. Figure 1 shows how each component in the LTE-Advanced network is connected to one another. LTE-A architecture was designed to optimize network performance, improve cost efficiency and facilitate the uptake of mass market IP-based services.

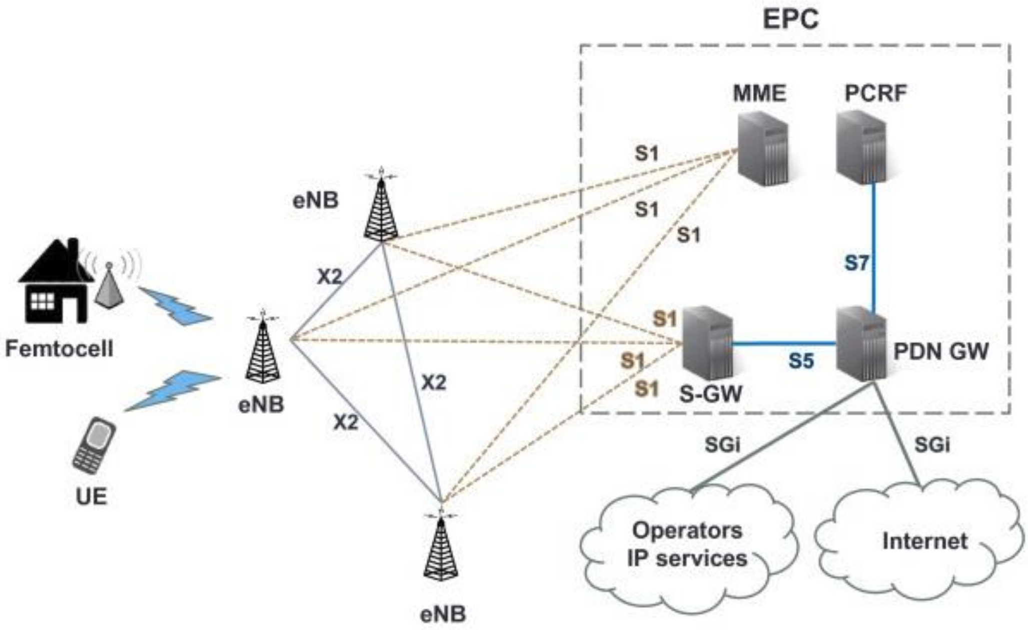

Figure 1: LTE-Advanced Network Architecture **[16]**.

NodeB in the 3G system was replaced by evolved NodeB (eNB), which is a combination of NodeB and radio network controller (RNC). The eNB communicates with User Equipment's (UE's) and can serve one or several cells at one time. E-UTRAN named as LTE-A radio access composed by eNB and UE, it handles tasks that are related to radio functionality of the radio access core such as coding, multi-antenna techniques, radio resource handling, retransmissions handling and scheduling. The evolved packet core (EPC) comprises the following four components. The serving gateway (S-GW) is responsible for routing and forwarding packets between UE's and packet data network (PDN) and charging. In addition, it serves as a mobility anchor point for handover. The mobility management entity (MME) manages UE access and mobility and establishes the bearer path for UE's [16] [17]. The eNodeBs are interconnected with each other through interface X2 and to the EPC by means of the S1 interface.

2.2.2. LTE-A Radio Access Network

LTE-A network architecture was designed in the simplified network which consists of a flat architecture that comprised a new core network that referred as the Evolved Packet Core (EPC) and as well as a new Radio Access Network named Evolved-universal Terrestrial Radio Access Network (E-UTRAN) [Figure 2] [18].

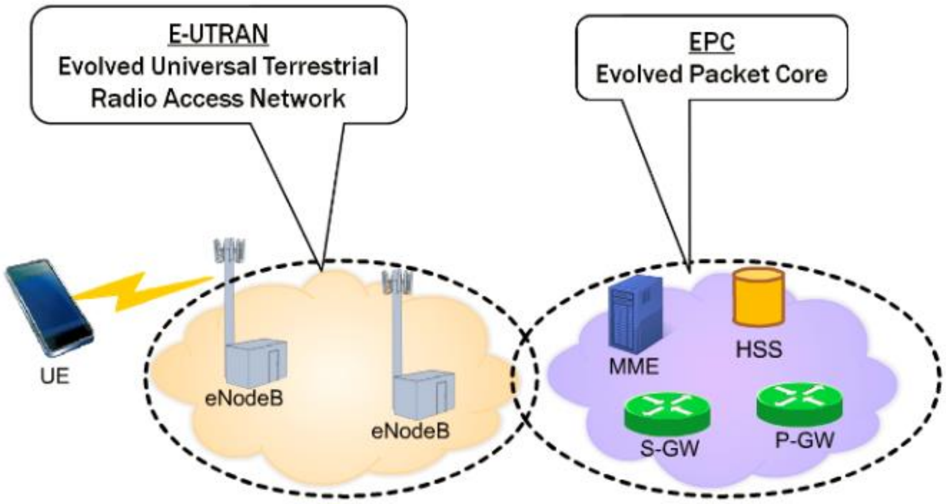

Figure 2: LTE- A Radio Access Network and Core Network Architecture

The E-UTRAN consists of Evolved Node B and User equipment's (UE'S). The function of Radio control is integrated into eNodeB, which allows tight interaction between the different protocol layers. The eNodeBs are connected to each other via an X2 interface and to the EPC through the S1 interface and more specifically to the MME through the S1-MME interface and to the S-GW through the S1-U interface. The protocols that run between the eNodeBs and the UE are known as the Access Stratum (AS) [19].

The eNodeBs are responsible for all radio related functions, which can be summarized as follows:

- ***Radio Resource Management:*** It includes radio bearer control, radio admission control, radio mobility control, scheduling and resource allocation in uplink and downlink.
- ***Header Compression:*** It is done in the Packet Data Convergence Protocol (PDCP) to compress the IP packet header, which helps to efficiently utilize radio resource, especially for small packets like VoIP.
- ***Security:*** Encrypt the data sent over the radio interface.

- ***Connectivity to the EPC:*** This consists of the signaling towards the MME and the bearer path towards the S-GW.

2.3. Review Heterogeneous Network

The wireless cellular system has evolved to the point where an isolated system achieves near-optimal performance, as determined by information theoretic capacity limits. Before the introduction of heterogeneous network, wireless networks were typically deployed as homogenous networks using a macro-centric planning process in which all the base stations have similar transmission power levels, antenna patterns, receiver noise floors and similar backhaul connectivity to the data network. Based on the evolution in wireless networks, the future gains of the wireless network will be obtained more from the advanced network topology, utilizing a diverse set of base stations, can be deployed to improve spectral efficiency per unit area. In response to the above-mentioned challenges, the heterogeneous network was introduced to give a flexible way to expand radio capacity by deploying many small cells in outdoor/indoor hotspot areas that require a large amount of capacity [20] [21].

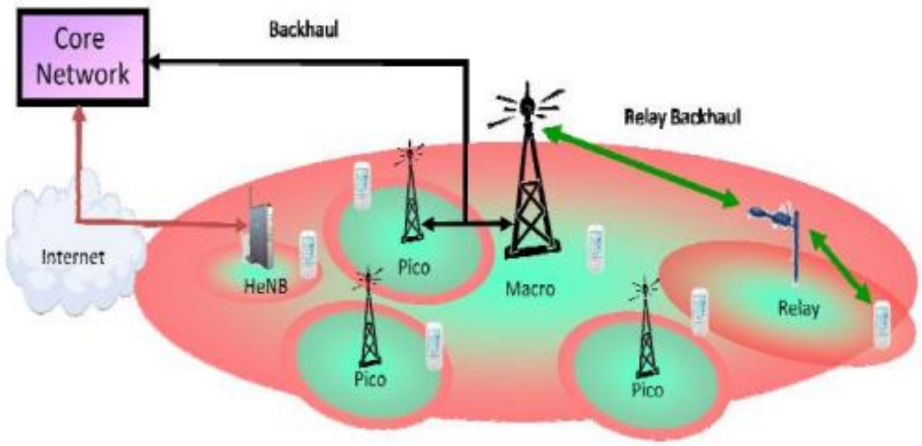

Figure 3: Heterogeneous Network **[6]**

Small cells are primarily added to increase capacity in hot spots with high user demand and to fill in areas not covered by the macro network both outdoor and indoors. They also improve network performance and service quality by offloading from the large macro-cells. The result is a heterogeneous network with large macro-cells in combination with small cells proving increased bitrates per unit area. In heterogeneous networks the cells of different sizes are referred to as macro-, micro-, pico- and femtocells; listed in order of decreasing base station power. The actual cell size depends not only on the eNodeB power but also on antenna position, as well as the location environment; e.g. rural or city, indoor or outdoor [22]. It is important to note that, while the macro base stations transmitting at high power levels of about 5W -40W are deployed in a carefully planned manner, the macro, pico, femto and relay base stations typically transmit at a very low power levels ranging from 100mW -2W and are deployed in a relatively unplanned manner based on rough information on coverage issue and traffic density with the network [23] [24] [25].

2.3.1. Heterogeneous Network deployment

To keep pace with the ever-increasing need for the mobile traffic, the cellular networks are undergoing major changes by deploying small, low-power nodes to increase cellular capacity [26]. The deployment of these low power nodes is discussed in [27] and [28]. These networks take the heterogeneous characteristics and are considered as heterogeneous networks [29] [30].

When deploying new pico and femtocells, the main goal is to find the deployment locations such that the overall downlink network outage is decreased for the percentage of users experiencing the low QoS [31]. Two different deployment strategies have been used for pico and femto respectively on the basis of the different transmission power and deployment constraints. The deployment of picocells in the outdoor is only done in accordance with the smart algorithm; the details are discussed in [32]. The author provides two steps of the algorithm: the first is a fast non iterative algorithm that selects the first set of locations based on network outage spatial information; given the initial set of positions, the second step consists of a meta-heuristic algorithm that iteratively shifts the positions of the new pico cells to new locations in the study area. In the meta-heuristic search, the network performance is re-simulated for each iteration, and the algorithm ends when the best network outage is achieved or the maximum number of iterations is exceeded.

Due to the requirement of high data traffic, the large number of the macro base station is needed to be deployed which results in the huge cost and sometimes difficult in deployment in the certain geographic area. The small cells in the heterogeneous LTE/LTE-a networks are usually deployed with the purpose to fulfill the coverage holes within the macro cell and to increase capacity in densely populated areas and thereby reducing the deployment cost.

The macrocell is responsible for providing the overall cellular network coverage. The macro base station is expected as the largest base station with maximum transmits power of 46 dBm, called Macro evolved NodeB (MeNB) in LTE/LTE-A system. Picocells provide the coverage and capacity in some areas inside the macro cell. Picocells are lower-power station than macrocells with transmit power from 23 dBm to 30 dBm. They are deployed indoor or outdoor serving a few tens of users within a range of 300 meters or less. Picocells are preferred to provide the public area such as a transport station, shopping center. Femtocells are small user-installed nodes designed for enhancement of coverage inside apartment and office. Since the low quality of received signal caused by the penetration losses through walls will degrade the performance of indoor date access, the deployment of the small cell inside the house can enhance the link capacity by reducing the transmission distance [33]. Thus, the advantage of the deployment of small cells is to the decrease in the transmission range between the sender and the receiver, which in turn enables the mobile subscriber to use the network services with high data speed at anywhere.

Table 1*: Small cell nodes*

Node types	Transmit power	Coverage
Macrocell	43-46 dBm	few Km
Microcell	23-33 dBm	≤ 500 m
Picocell	23-30 dBm	≤ 300 m
Femtocell	≤ 23 dBm	≤ 50 m

2.4. Review of Resource allocation for LTE-A heterogeneous network

The technique used for radio transmission and reception in LTE is known as orthogonal frequency division multiple access (OFDMA). OFDMA carries out the same functions as any other multiple access technique, by allowing the base station to communicate with several different mobiles at the same time.

Multiple access techniques are used in order to allow a large number of users to share the allocated spectrum in the efficient way. As spectrum is a scarce resource, the sharing is essential to increase the capacity of the cell. In LTE/LTE-A systems, the multiple access schemes are based on FDM (Frequency Domain Multiplexing). OFDMA is widely chosen for the downlink and it has very robust characteristics against frequency selective channels. The main motive for using OFDMA in the downlink is the bandwidth flexibility it offers since changing the number of subcarriers used can be increased or decreased. In addition, it supports an enhanced QoS for multiple data services such as voice and other multimedia applications along with interference elimination. The SC-FDMA (Single Carrier Frequency Division Multiple Access) is a very desirable technique for the uplink transmission due to its low PAPR property most especially considering the low-cost devices with limited energy resources [34].

Data is allocated to the UEs in terms of resource blocks in both cases (downlink and uplink). Each UE may be served with one or more resource blocks depending on the required data rate, in each transmission time interval (TTI) of 1ms. Radio Resources (RR) are time/frequency allocated as described in details [35] [36].

The size of the TTI provides the granularity of transmissions. This size is defined as 1ms in LTE which means 1 sub-frame. The smallest element or basic unit in LTE is an OFDM symbol also called a resource element (RE). In the time domain, RRs are distributed every TTI. An OFDM frame is composed of 10 consecutive TTIs (10ms). Each TTI encloses 2-time slots of 0.5ms. A time slot corresponds to a one RB in the frequency domain. A RB corresponds to 7 OFDM symbols in normal cyclic prefix and to 6 OFDM symbols in the long cyclic prefix. In the frequency domain, the bandwidth is divided into many sub-channels of 180 MHz each one. Each sub-channel is composed of 12 consecutive OFDM subcarriers. The RB is the smallest element of resource allocation that can be assigned to users for a predetermined amount of time. It encloses two time slots in the Time domain (TD) and over a one sub-channel in the Frequency Domain (FD) [37].

The subcarrier spacing in the frequency domain is 15 kHz and 12 sub-carrier grouped together per slot normally named as a resource block (RB). Therefore, one RB is 180 kHz. 6 RBs fit in a carrier of 1.4 MHz and 100 RBs fit in a carrier of 20 MHz [38].

In each TTI, the scheduler considers the physical radio environment per UE, prioritize the requirements for quality of services among the UEs and provide information to UEs about the allocated radio resources [39]. The table 2 below provides the bandwidth and available RBs [40].

Table 2: *Bandwidth and available RBs.*

Bandwidth [MHz]	1.4	3	5	10	15	20
Number of RBs	6	15	25	50	75	100

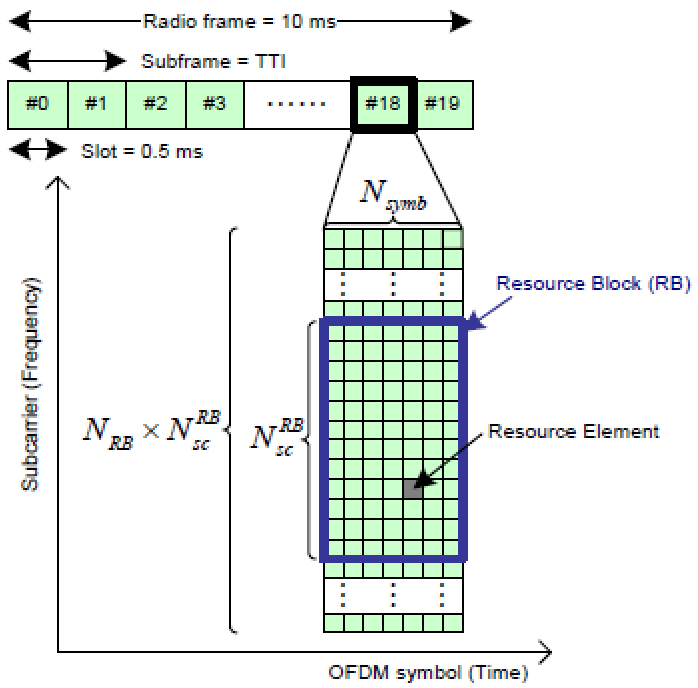

Figure 4: LTE-Advanced Frame structure **[16]**

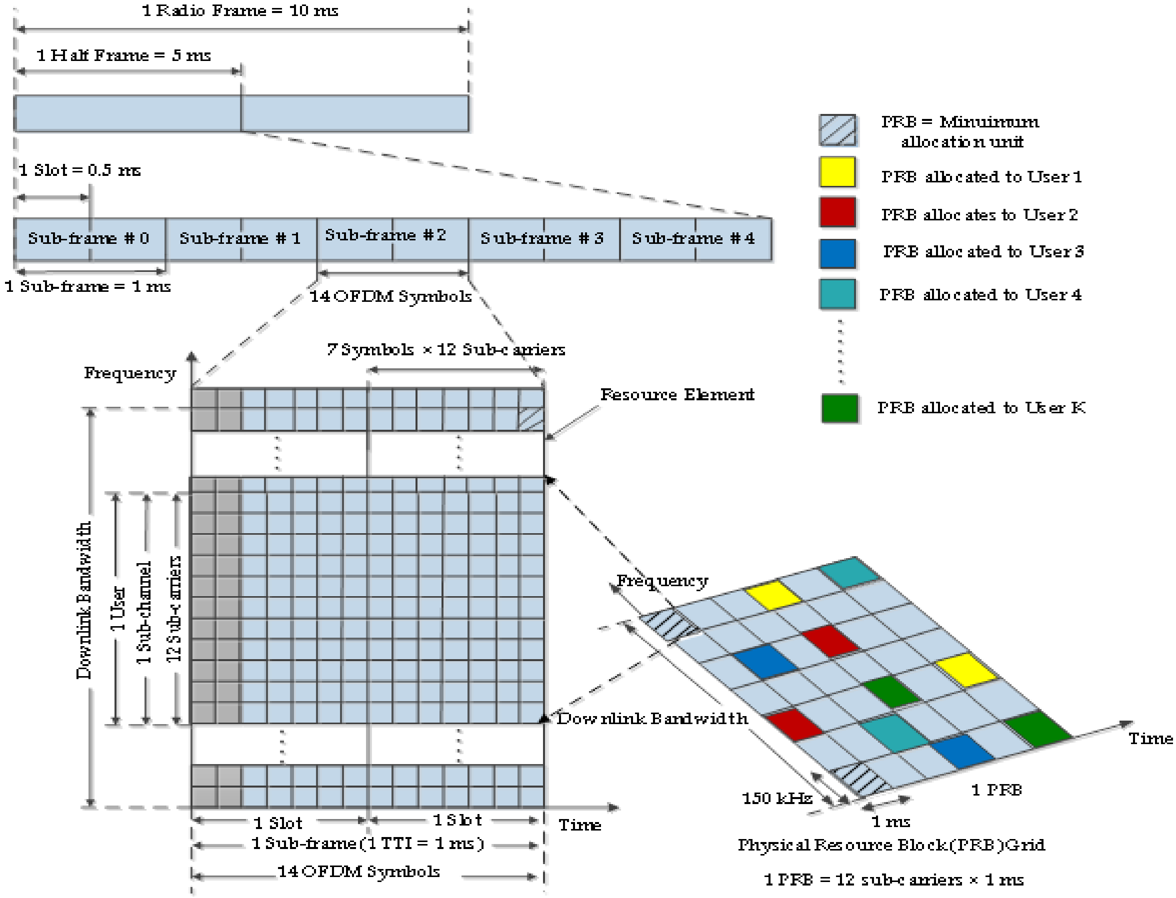

Figure 5: OFDMA Technology in LTE/LTE-A **[41]**

2.5. Scheduling in LTE-A heterogeneous network

Scheduling is a process of distributing available resources among the users who need service in such a way that Quality of Service [QOS] is maintained. In other words, scheduling is simply allocating resources to users in a communication system with a purpose of maximizing throughput and system efficiency. The basic idea is to schedule transmission for UEs that, at the current time and on a given frequency, are experiencing "good" channel conditions based on selected metric [42]. Scheduling in LTE downlink takes advantage of various factors including channel variations by allocating frequency and time resources to a user with transiently better channel conditions. The quality of service requirement in a multi-user communication system varies; therefore, the choice of a scheduling algorithm critically impacts the system performance.

Packet scheduling is one of the RRM functions and it is responsible for intelligent selections of users and transmissions of their packet. PS is located directly in the eNodeB and is performed on minimum allocation unit of 1ms TTI basis in order for the system to adapt to a fast channel variation and therefore benefit from multi-user diversity gain. The scheduler controls, for each time instant, to which users the shared resources should be assigned. It also determines the data rate to be used for each link, a function executes with Link Adaptation. The scheduler is also responsible for selecting the transport-block size, the modulation scheme, and the antenna mapping. The overall system performance in the downlink is based on how efficient the scheduler is.

In LTE downlink the flexibility of allocating available resource block on the physical layer is an inherent function of a user diversity system that depends on the various techniques adopted by the scheduling algorithm. These techniques are evaluated on the basis of the quality of service requirement of a user, and in terms of the maximum benefit, the system can derive from it using metrics of fairness, system throughput and most especially service level agreement. Basically, a good scheduling algorithm achieves a goal to satisfy the system and user requirements by throughput maximization and achieving fairness between users.

2.5.1 Scheduling model

The generalized model for packet scheduling algorithm in the downlink LTE system with N Resource Block and K users is provided in Figure 6 [43]. The model implements a queuing system approach for the LTEsystem and a first in first out (FIFO) scheduling mechanism is used. The figure describes a process of user's packet arriving into an eNodeB and assigned a buffer, these packets are time stamped and queued for transmission based on FIFO.

In each TTI, the packet scheduler determines which users are to be scheduled based on a packet scheduling algorithm.

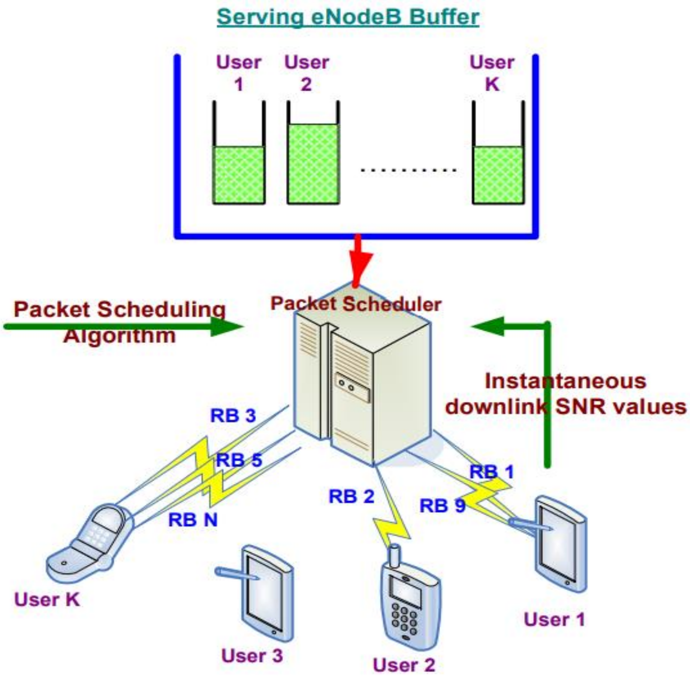

Figure 6: Generalized Model of Packet Scheduling in the Downlink 3GPP LTE

2.5.2 Scheduling Algorithms in LTE-A

Round Robin (RR): Round Robin scheduling scheme is a channel unaware technique in which resources are allocated in order of service requested by the user. This scheduling scheme guarantees the fairness among users and does not consider channel quality thus resulting in lower user throughput. It is one of the fundamental and widely used scheduling algorithms which do not consider the channel quality information from participating user equipment [44] [45]. The performance of this algorithm is best achieved only if the users have similar channel conditions and similar sized packet arriving at their buffers.

Proportional Fair (PF): The Proportional Fair scheduling scheme is a channel aware scheduling scheme that provides fairness in allocation as well as higher throughput and is most used scheduling scheme.

The authors in [46] [47]and [43] proposed a PF algorithm to provide a balanced performance between the fairness and system throughput. The PF algorithm takes both fairness among users and system spectral efficiency into consideration and allocates the radio resource to users based on the ratio of their achievable instantaneous throughput and their time averaged throughput [48]. It allocates a fair share of the radio resource to all users and maintains good system spectral efficiency at the same time, by considering the trade-off between user fairness and system spectral efficiency. The scheduler determines to which user the shared resources (time and frequency) for each TTI (1ms) should be allocated for reception of DL-SCH) transmission.

2.5.3 Resource allocation

With the knowledge of radio access spectrum used by LTE in downlink and uplink, the next important aspect to be thought of is resource allocation. The idea behind resource allocation is that whenever a user requests service, based on various network parameters like channel quality, RSRP (Reference Signal Received Power) and priority, resources are allocated to that particular user. Each system has different performance requirements and depending on this the resource allocation decisions are made. Few metrics that can be thought of are QoS requirement, size of the buffer, channel quality as reported by the user. If the per RB metric for a particular user is higher than any others requesting the service, then that user enjoys the benefit of being allocated. In order to understand resource allocation, it is very essential to understand how the available bandwidth is split into resource blocks. One of the important features of LTE is that it can operate over a wide range of flexible bandwidth ranging from 1.4MHz to 20MHz. In LTE, chosen bandwidth is divided into a number of frames with each radio frame 10ms wide.

2.5.4 Scheduling and Resource allocation with OFDMA

The feedback from the UE fulfils the scheduling and link adaptation task in the eNB. LTE implements AMC and closed-loop for adaptation of the transmission rate to the instantaneous channel conditions reported by the feedback. The frequency of UE feedback depends on the set periodicity. The feedback may include CQI, Pre-coding matrix indicator (PMI) and Rank Indicator (RI). The CQI carries the suitable transmission rate which is used for resource allocation and link adaptation by the eNB for the downlink. It is used for dynamic utilizing of the available system resources efficiently by selecting the appropriate Modulation order and Coding Scheme (MCS). The selected MCS matches current link quality that is usually estimated from Signal to Interference plus Noise Ratio (SINR) measured at UE. In the feedback, a number of antennas, types of receiver used etc. are taken into account. The feedback signaled is always the one that can achieve a target block error ratio (BLER) ≤ 0.1 which is the typical value for mobile communication [49].

2.5.4.1. Rank Indication

The mobile reports a rank indication when it is configured for spatial multiplexing in transmission mode 3 or 4. The rank indication lies between 1 and the number of base station antenna ports and indicates the maximum number of layers that the mobile can successfully receive. The mobile reports a single rank indication, which applies across the whole of the downlink band. The rank indication can be calculated jointly with the PMI, by choosing the combination that maximizes the expected downlink data rate.

2.5.4.2. Pre-coding Matrix Indicator

The mobile reports a pre-coding matrix indicator when it is configured for closed loop spatial multiplexing, multiple user MIMO or closed loop transmit diversity, in transmission modes 4, 5 or 6. The PMI indicates the pre-coding matrix that the base station should apply before transmitting the signal. The PMI can vary across the downlink band, in a similar way to the CQI. To reflect this, there are two options for PMI reporting. The mobile can report a single PMI spanning the whole downlink band or span all of the UE-selected sub-bands. When using multiple PMIs, it either reports both of these quantities, or reports one PMI for each higher layer configured sub-band. The base station uses the received PMI to calculate the pre-coding matrix that it should apply to its next downlink transmission. Once again, the base station actually transmits the data using one frequency-independent pre-coding matrix, despite the frequency dependence of the PMI.

2.5.4.3. Channel Quality Indicator feedback

The CQI signals on a per-code word basis the highest of the 15 MCSs indicated by channel quality indicator as shown in table 3 that ensures, given measured actual channel conditions, a Block Error Ratio (BLER) lower or equal to 10% [50] [51]. Table 3: Modulation scheme, Effective Code Rate of the channel encoder, and data (coded) bits per modulated symbol for each of the LTE-defined CQI [52].

Table 3: Modulation scheme, Effective Code Rate of the channel encoder, and data

CQI Index	Modulation	ECR	Data(bit/symbol)
0	Out of range		
1	4-QAM	0.08	0.15
2	4-QAM	0.12	0.23
3	4-QAM	0.19	0.38
4	4-QAM	0.30	0.60
5	4-QAM	0.44	0.88
6	4-QAM	0.59	1.18
7	16-QAM	0.37	1.48
8	16-QAM	0.48	1.91
9	16-QAM	0.60	2.41
10	64-QAM	0.46	2.73
11	64-QAM	0.55	3.32
12	64-QAM	0.65	3.90
13	64-QAM	0.75	4.52
14	64-QAM	0.85	5.12
15	64-QAM	0.93	5.55

The CQIs specify code rates ranging from 0.08 to 0.93 and uses 4, 16 and 64 QAM modulations. This is translated into an effective number of bits per modulated symbol from 0.15 to 5.55.

Chapter 3: Research methodology

3.1 Introduction

This chapter highlights the methods and approaches used and show how the analysis results were presented throughout the whole research thesis. The research methodology presented in this thesis is based on both the Qualitative and Quantitative approaches [53]. In the Qualitative approach, the identification of different scheduling schemes as the key factors affecting the performance of the network has been carefully considered based on the existing research and knowledge based on famous scholars, relevant articles, and journals. On the other hand, in the Quantitative approach, some steps have been considered such as; development of a network model based on qualitative approach and simulation approach.

In this research study, the simulation approach was also considered using the simulation tools like LTE-A simulator. The research approach used in this thesis lies under scientific research methods and indicates that scientific type of research covers almost the whole project and other methods were just used for clarification.

3.2 Development Research approaches

This part describes the overview of the research approaches and the steps involved in system development from the step of gathering the ideas to the final step of simulations and getting the result.

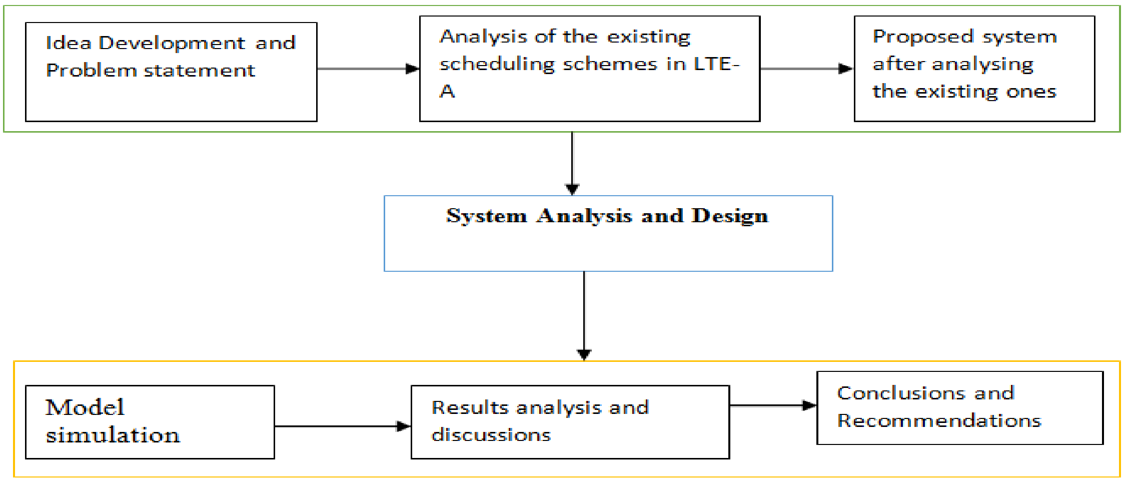

Figure 7: Research development approach

The primary objective is to analyse the scheduling and resource allocation for heterogeneous traffic in LTE-A and come up with the efficient, optimized scheduling algorithm to improve the QoS of the mobile users. Two development approaches are used in this research thesis. The first approach is a mathematical model and the second is the simulation model.

In this research thesis, the existing systems are analysed and a new approach is proposed where parameters are added to the existing scheduling schemes. In Figure 7, a detailed approach is shown on how this research was carried out.

3.2.1 Scientific research methods

Several scientific methods were used during the course of this research. The existing schemes were found in qualitative research methods and design, analysis, and simulation. For achieving the objectives of this research thesis, a quantitative approach was taken to evaluate how the existing schemes work, their weaknesses and what should be done in order to improve its performance. Resource efficient algorithm for heterogeneous traffic in LTE-A is developed and simulation is done with different parameter as it is discussed in the next chapter of this thesis. To come up with a consistent literature review; journals, reports, published papers, unpublished thesis were used in order to enrich the chapter.

3.2.2 Simulation approach

The simulation was done using LTE-A DL System Level Simulator Rel-v1-9-Q2-2016 implemented in MATLAB R2014a software. Under this method, a discussion of the simulation results considering different parameters was done. Tables for simulation, system models and graphs are used to show the comparison of the proposed scheme and existing schemes are presented.

3.3 Analysis and Design

The purpose of this stage was to analyse the existing schemes as detailed in the literature review. Another purpose was to identify the best option available to achieve the best system performance of heterogeneous traffic in LTE-A networks. This involved carrying out a thorough study of the system requirements and arriving at the exact requirements for the proposed system.

In this research thesis, a simulation approach is used where the suitable algorithms for each of the inspected schemes are recorded. Their performance is evaluated and compared with each other and finally, the performance is mainly evaluated relying on system level simulations.

Some simple theoretical analyses are also made when possible, in order to verify the simulation results.

In order to come up with an effective scheduling scheme for heterogeneous traffic in LTE-A network for a better performance, a clear analysis of different techniques with determined parameters is considered. To be systematic in the analysis each step will be critically and systematically analyzed. First of all, the existing scheduling algorithms will be analyzed to determine their performance and identify the gap in the existing scheme. From the gaps identified a solution is proposed to improve the performance. This analysis will be feasible through simulations and results will be interpreted. The design was specifically done after analyzing the existing schemes and then proposes a new scheme which was intended to achieve our objectives.

3.4 Conclusion

This chapter highlights the processes and approaches that were considered during the process of conducting this research work. Information on scientific research and simulation approach was provided. This chapter also indicates how the analysis and simulation will be carried out. The proposed system analysis and design are going to be explained in the next chapter.

Chapter 4: System analysis and design

The Vienna LTE-A Simulator is a Long Term Evolution advanced simulator designed by the Vienna University of Technology, Austria. It is composed of two parts such as the Link level simulator and System level simulator. The Vienna LTE-A simulator supports simulations to be carried out on two layers, one is the physical layer known as link level and the other is the MAC and network layer called system level [54].

The link level simulations assist in the investigation of channel estimation, modeling of channel encoding and decoding, Multiple-Input-Multiple-Output gains, adaptive modulation and coding (ACM) and feedback. The system level simulations assist in resource allocation and scheduling, mobility and interference management and network planning optimization [54]. In our simulation, we have used the System level simulator because we are evaluating the scheduling and resource allocation which have the performance at the Downlink System level. Downlink System level simulations are carried out to evaluate the user throughput and its constraints such as bit error ratio and signal to noise ratio. We have used the LTE-A DL System Level Simulator Rel-v1-9-Q2-2016 [55].

Downlink System-level simulation enables us to emulate all the features of transmission between the eNodeB, pico or femto and the User Equipment. This simulator is a MATLAB-based downlink system level simulator for LTE-A. It can carry out single-downlink, single-cell multi-user and multi-cell simulations.

Figure 8 depicts an overview of different possible simulation scenarios in the LTE simulator. But in this thesis, the focus is on downlink multi-cell, multi-user.

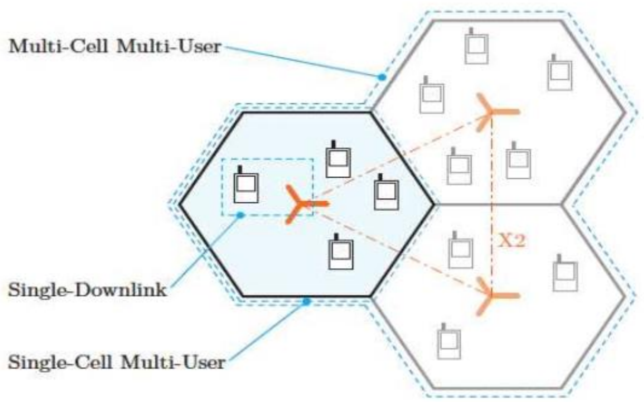

Figure 8: Simulation scenarios of LTE System simulator

4.1. System Model

The system is modeled as a graph with a link between two nodes indicating that the nodes are in a communication range of each other. When a link is scheduled, the transmitter can transmit at a fixed rate to the receiver. The transmission from a transmitter to a receiver is successful if there are no other transmitters within a pre-specified fixed radius around the receiver.

4.1.1. Proposed model simulation

As illustrated in this flowchart, the scheduler starts by investigating the conducive parameters, then assigns the resource blocks to the user. In order to perform scheduling, terminals send CQI to the base station and the BS transmits reference signal to terminals. Those reference signals sent by a eNodeB helps the UEs to measure the CQI where a higher CQI means a better channel condition. In order to allocate more resources this process is applied on eNodeB, pico and femto respectively. This algorithm provides an improvement in throughput as well as faireness among users. For the purpose of this thesis the new algorithm will be refered as proposed algorithm.

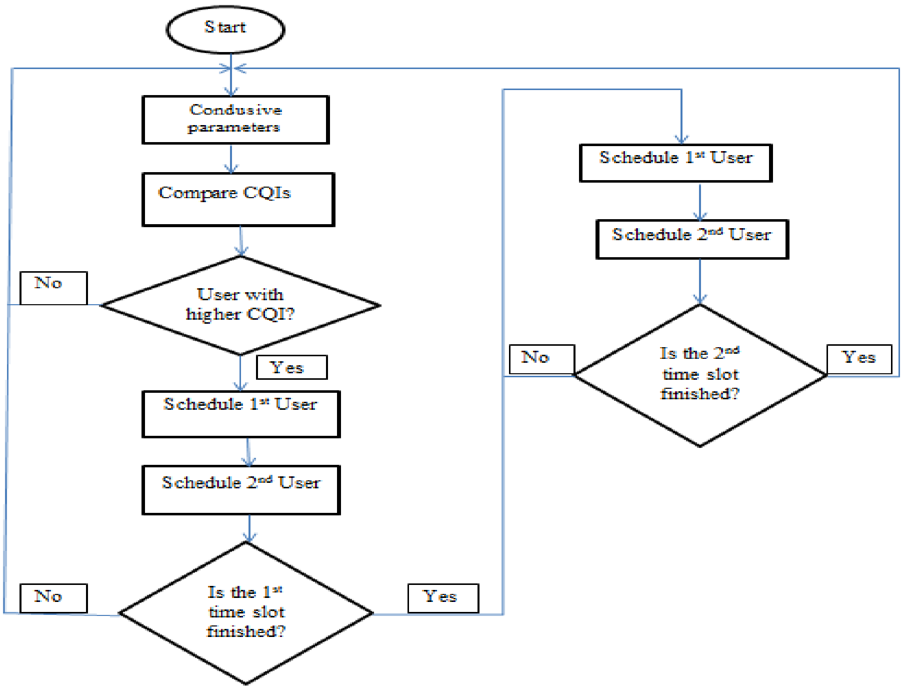

Figure 9: Flowchart of our proposed algorithm.

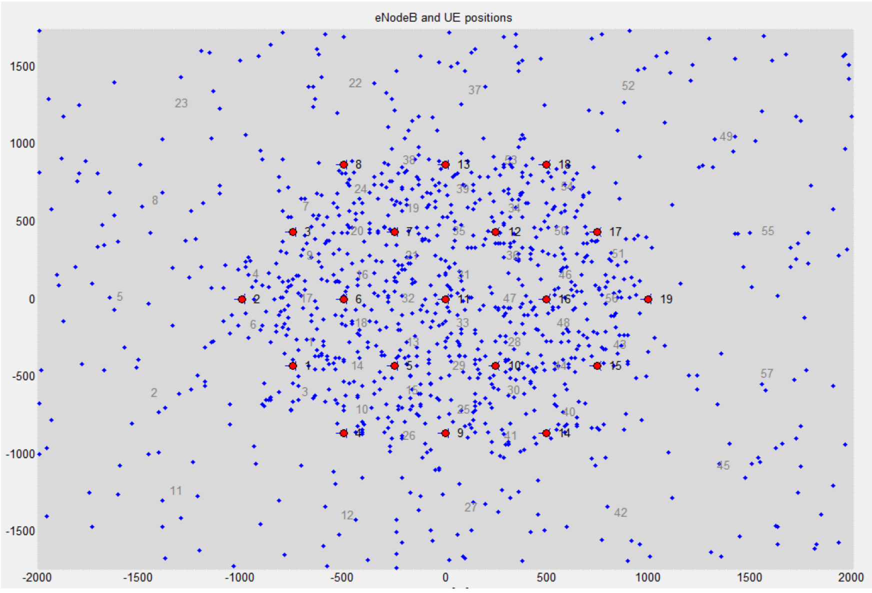

Figure 10: eNodeB and the attached users using simulation

In our project, the system has a number of transmitters (eNodeBs) and the number of users (UEs) where the transmitters send the packets to the users; we consider K, $e_t$as a maximum number of users and the rate vector respectively. K varies from K= {1,……/K} and the rate vector.

r_t= ($r_{1,t}$….$r_{K,t}$) and e_t the channel quality where $r_t \in R(e_t)$ which can maximize the system utility. To maximize the system utility function, we adopt the below formula [56];

$$maxU(Wt) = \max \sum_{i=1}^{K} Ui(Wi,t) \qquad (1)$$

Where U (wt) is total utility function, Ui(wi,t) the utility function of user I with average throughput wi,t and K the number of users.

The utility functions are used in the network optimization as they map network resources utilized by users into real numbers. The utility function can also show the level of satisfaction of the user which in turn helps in balancing the efficiency and fairness between the users. In LTE-A, as most wireless communication technologies, the transmission rate is the main factor that determines the level of serenity of the user.

If we take m_j as the transmission rate vector, then its utility function becomes U (m_t) should be a non-decreasing function of the transmission rate of $m_{j.}$ By using the above equation (1) we can calculate the utility function in function of transmission rate vector.

$$U(mj) = X_j \left\{\frac{1}{e^{-pj(mj-Rj)}} - Yj\right\} \quad (2)$$

Thus $Xj = \frac{1+e^{pjRj}}{e^{pjRj}}$ and $Yj = \frac{1}{1+e^{pjRj}}$ (3)

U(mj)is the utility function of user j with respect to their transmission rate.

P_j is the priority tag which is assigned to the real time traffic users,

$R_j$is the available resource block.

X_j, Y_j are the constants used to normalize the utility function.

During every transmission process, the user sends the instantaneous achievable signal to noise ratio (SNR) to their respective eNodeBs. The signal to noise ratio keeps changing with mobility and selective fading channels. Using (1) we can calculate the transmission rate of a given user j as the below equation.

$$mj(t) = \frac{Nbits}{symbols} * \frac{Nsymbols}{slots} * \frac{Nslots}{TTI} * \frac{Nsubcarriers}{RB} \quad (4)$$

Where Nbits, Nsymbols, Nslots,andNsubcarriers are the number of bits, number of symbols, number of slots and the number of subcarriers respectively according to the physical resource block characteristics. The path loss and channel fading also affect the characteristics of the physical resource block where there can be calculated based on the user location. The path loss is calculated using the extended COST-231 Hata model [57] for a typical urban environment.

$$PL_i(t) = 46.3 + 33.9 * log_{10}(f) - 13.82 * log_{10}(h_b) - a(h_m) + \big(44.9 - 6.55 * log_{10}(h_b)\big) * log_{10}(d_i(t)) \quad (5)$$

With

$$a(h_m) = (1.1 * log_{10}(f) - 0.7) * h_m - (1.56 * log_{10}(f) - 0.8) \quad (6)$$

Where $PL_i(t)$ is the path loss (in dB) and $d_i(t)$ is the distance (in km) of user *i*at time *t*. *f* is the carrier frequency (in MHz), h_b and h_m are the heights of eNodeB and user equipment (UEs in meters), respectively and $a(h_m)$ is the user antenna correction factor.

The shadow fading also has an effect on the user signal attenuations caused by signal reflection, diffraction and shielding phenomenon from obstructions such as building, trees, and rocks. The shadow gain can be calculated using the below equation.

$$\delta_i(t+1) = \rho_i(t) * \delta_i(t) + \sigma * \left(\sqrt{1-\rho_i(t)^2}\right) * W(t) \quad (7)$$

Where δ_i *(t+1)* is shadow fading gain for user *i* at time (*t+1*), σ is the shadow fading standard deviation, and *W(t)* is a Gaussian random variable at time *t*. The above equation has a shadow fading autocorrelation function which can be computed using the below equation.

$$\rho_i(t) = \exp\left(\frac{-v_i(t)}{d_0}\right) \quad (8)$$

Where $v_i(t)$ is the speed of user *i* at time *t*, and d_0 is the shadow fading correlation distance.

By using the above equation (5) and (7) we can compute the channel gain of our system where it is the function of the path loss and the shadow fading.

$$Gain_{i,j}(t) = 10^{\frac{PL_i(t)}{10}} * 10^{\frac{\delta_i(t)}{10}} * 10^{\frac{mpath_{i,j}(t)}{10}} \quad (9)$$

Where $mpath_{i,j}(t)$ is the multi-path fading gain of user i on a PRB j at time t.

From the above equation of channel gain, the user can calculate the instantaneous SINR value (*SINRi,j(t)*) of user *i* on PRB *j* at time *t* is using the given approach.

$$SINR_{i,j}(t) = \frac{P_{total} * Gain_{i,j}(t)}{N_{PRB}(I+N_0)} \quad (10)$$

Where $P_{total}$is the total eNodeB downlink power, $N_{PRB}$is the number of PRBs, $N_o$is the thermal noise and *I* is the inter-cell interference.

4.1.2. Average user throughput

The simulator keeps the tracks of average UE throughput filtered with an exponential window. The average throughput as in [58] can be obtained by $T_k(t)$ for each user k updated using an exponentially weighted low-pass filter

$$T_k(t+1) = \begin{cases} \left(1-\frac{1}{t_c}\right) T_k(t) + \frac{1}{t_c} R_k(t), & k \in k^* \\ \left(1-\frac{1}{t_c}\right) T_k(t), & k \notin k^* \end{cases} \quad (11)$$

Where k^* is the scheduled UE set and $R_k(t)$is the rate of the k-th user. t_c is the length of the window.

4.1.3. Packet delay

Packet delay is one of the quality of service requirements. The Head of Line (HOL) delay is defined as the time duration from the packet's arrival time in the buffer to the current time. Average packet delay describes the average HOL waiting time of all users' packets throughout the simulation time. In the simulation, the delay is fixed at a given number so that the packet can be dropped when their have an extra time in the buffer for the delay sensitive traffic.

$$packet\ delay = \frac{1}{K}\sum_{i=1}^{K}\frac{1}{T}\sum_{t=1}^{T}W_i(t) \qquad (12)$$

Where $W_i(t)$ denotes the HOL delay of user *i* at time *t*.

4.1.4. Packet loss ratio

Real time and Non-real time traffic require different delay deadlines for the packet transmission. A packet will be discarded when the HOL delay of the packet goes beyond the user traffic delay deadline. Packet Loss Rate (PLR) is defined as the proportion of the total discarded packet size to total arrived packet size.

$$PLR = \frac{\sum_{i=1}^{K}\sum_{t=1}^{T}pdiscard_i(t)}{\sum_{i=1}^{K}\sum_{t=1}^{T}psize_i(t)} \qquad (13)$$

4.1.5. Fairness

Fairness evaluates the difference between the users who have the most and least transmitted packet size. The maximum value of fairness is one and occurs when all users transmit an equal amount of packets.

$$Fairness = 1 - \frac{ptotaltransmit_{max} - ptotaltransmit_{min}}{\sum_{i=1}^{K}\sum_{t=1}^{T}psize_i(t)} \qquad (14)$$

Where $ptotaltransmit_{max}$ and $ptotaltransmit_{min}$ are maximum and minimum values of all users' total transmitted packets size respectively.

4.2. LTE-A system simulation

Our system level simulator was designed to simulate a system with 19 sites, 57 eNBs (cells) with variable users. Each site has 3 cells to coves 120 degrees in both directions. The users are distributed randomly in the space and each evolved base station comprises of 20 users. In order to evaluate the performance of our new scheduling and resource algorithm, we compare it with the existing algorithm at different bandwidth 1.4MHz, 3MHz, 5MHz, 10MHz, 15 MHz, and 20MHz.

The objective of scheduling and resource allocation is to assign the available resources to the shared LTE-A network described by the Physical and Medium Access Control (MAC) layer.

4.3. Simulation Scenarios

In order to verify and compare the existed scheduling with the improved algorithm with the help of Vienna LTE simulator, different simulations scenarios have been selected. These scenarios are meant to understand the performance of the new algorithm with those which are already in the simulator. We investigate the performance of the existed and the new scheduling algorithms in terms of resource allocations and throughput for those different scenarios. In the simulation, we focused on different bandwidth, channel model, mobility and the number of user's per eNodeB.

Chapter 5: Results and Analysis

The main objective of this project was to demonstrate an effective scheduling and resource allocation scheme in LTE-A by using Vienna LTE-A System Level Simulator. Most existing scheduling and resource allocation algorithms have been studied in 3GPP and show a great performance. The introduction of LTE-A with the advanced technologies cause the drawbacks of most of those scheduling. Our aim was to introduce the conducive parameters to the built-in scheduling and resource allocation scheme and evaluate its performances with a goal to produce an effective scheduling and resource allocation that can work efficiently and maximize the system throughput. With Vienna LTE-A Simulator being the simulator of interest, we undertake the following tasks and show how efficiently our scheme works with the evolution of the network.

In this section, we compare our new scheduling and resource allocation scheme with those existing one to evaluate the performance of those different scheduling schemes using the Vienna LTE-A Simulator. We compare our new scheme with the well-known scheduling schemes like Round Robin and Proportional Fair.

In this section, we associate these scheduling schemes for their performance evaluation with an increase in a number of users, antenna configuration, and mobility. The results obtained help us to decide the best scheduling scheme for a network to overcome network bottleneck and highlight features of the Vienna LTE-A simulator.

5.1. Simulation Parameters.

Table 4: Simulation parameters

Parameters	Value
Simulation type	Tri sector tilted traffic
Power	46dBm
Pathloss Model	TS 36942 - Urban
Schedulers	Proportional fair, Round Robin,Our algorithm.
Channel model	TU
Speed	4X4 CLSM PedB
Network Geometry	Regular Hexagonal Grid
UE per eNodeB	5, 10, 20
Transmission time interval	100TTI
Traffic Model	Video, FTP
System frequency	2.4GHz
Bandwidth	20MHz

5.2. Simulation Results.

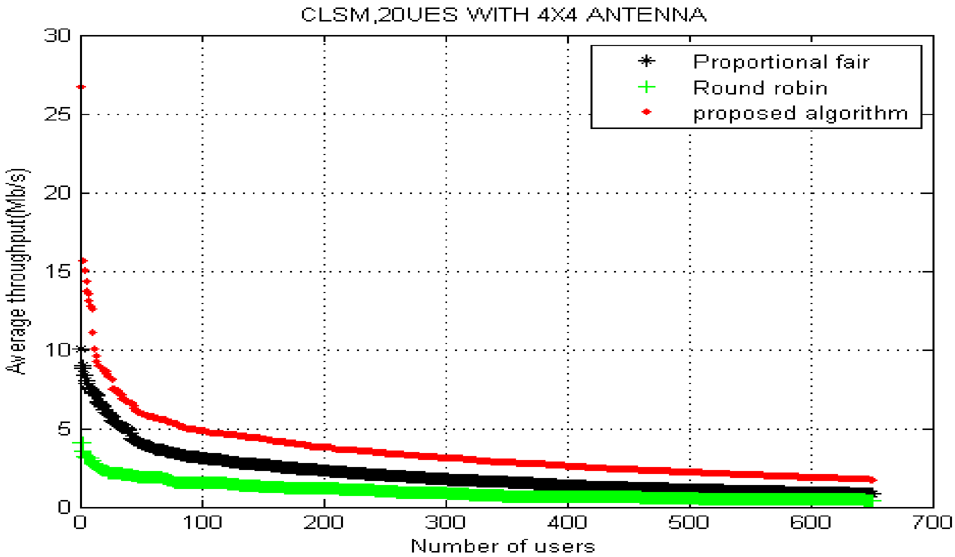

Figure 11: 4x4 CLSM FTP simulation with 20ues/cell

Figure 11 shows the number of users versus the throughput for 3 schedulers, Round Robin, Proportional fair and our new proposed algorithm. The proposed scheduling is obtained by adjusting the parameters to the existing ones. We compare our proposed scheme with the built-in algorithms (RR and PF). The new algorithm takes into account the features of LTE-A. The LTE-A has different higher order configurations which helps to achieve its targets. In the above graph we have considered the MIMO (4x4) antenna configuration for all three schedulers and plot the obtained results. The average throughput for all built-in algorithms PF and RR decreases with an increase on number of users. The proposed scheduling and resource algorithm adapts to the change in antenna configurations and as a results shows an improvement to the average system throughput. From the graph, it is shown that the proposed algorithm produces a high average throughput of about 27.5 Mb/s for ftp traffic compared to 5 and 10 Mb/s for RR and PF respectively.

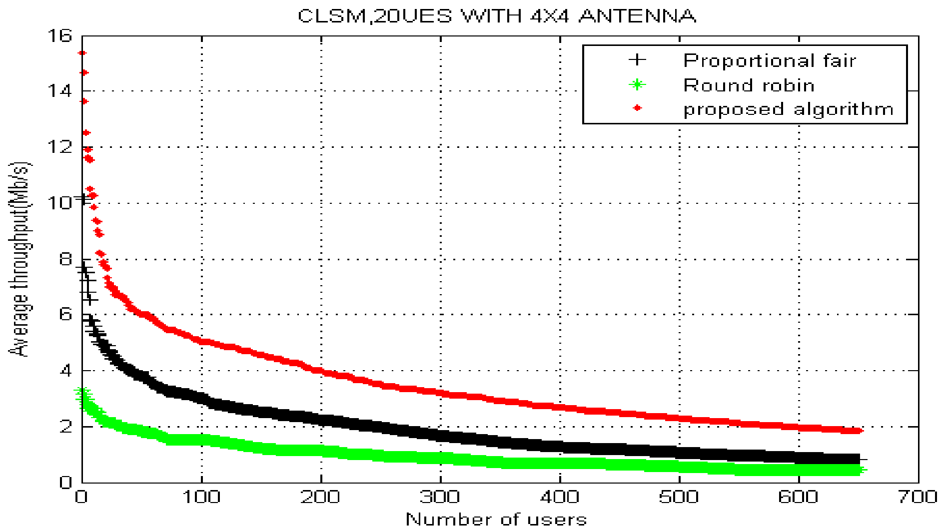

Figure 12:4x4 CLSM Video simulation with 20ues/Cell

Figure 12 depict the number of users versus the throughput for 3 schedulers, Round Robin, Proportional fair and our new proposed scheduler with video traffic. It is observed that the average throughput decreases with an increase in number of users. From the graph it is clear that different types of traffic do require different QoS requirements since using real time traffic in this case video, the maximum average throughput decreased compared to the results we got by using non real time (ftp) in figure 11.

It is observed that, the proposed algorithm where the parameters are adjusted to the existing algorithms (RR and PF) gives an improvement on average throughput. We can further state that all algorithms do not give better results on real time traffic.

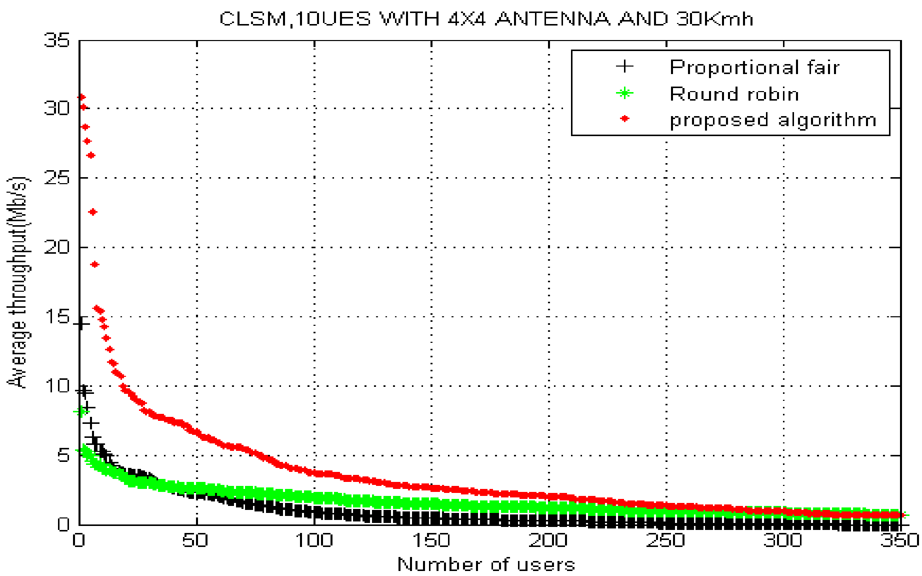

Figure 13: FTP simulation at 30Kmh.

Figure 13 shows the number of users versus the throughput for 3 schedulers. In the above graph, the schedulers are compared while applying the mobility using the PedB recommended by ITU and maintaining the 4x4 antenna configuration and plot the obtained results. The new scheduling and resource algorithm shows more advantage to the average user throughput. We determine also that the average throughput decreases considerably with the increase of the system users for ftp traffics where the increase of the system users increases also the congestion in the system even if LTE-A has more capability of congestion control.

It is also observed that as number of users increases while applying the mobility the RR outperform the PF. This is due to the fact that RR scheduling algorithm does not have an additional overhead of allocating resources dynamically depending on channel conditions which is present in PF scheduling algorithm.

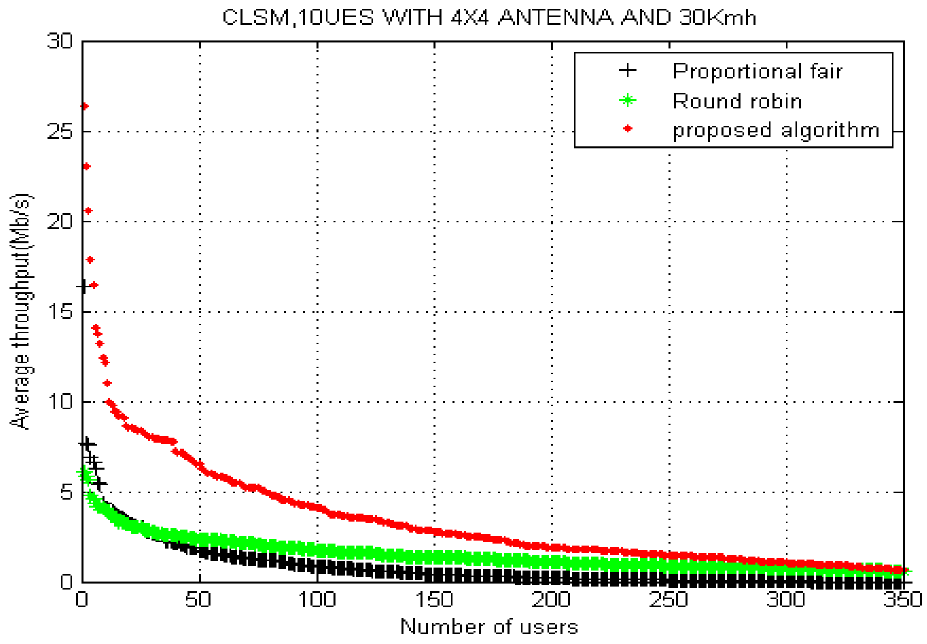

Figure 14: Video simulation at 30Kmh

Figure 14 depict the number of users versus the throughput for 3 schedulers for video traffic. In the above graphs, the schedulers are compared while applying the mobility using the PedB recommended by ITU and maintaining the antenna configuration and plot the obtained results. The new scheduling and resource algorithm withstand the effect of increased users and mobility hence improved average user throughput compared to PF and RR. It is observed that the mobility has an impact to the system performance for real time traffic compared to non-real traffic in figure 13. We determine also that the average throughput decreases considerably with the increase of the system users for video traffics where the increase of the system users increases also the congestion in the system even if LTE-A has more capability of congestion control.

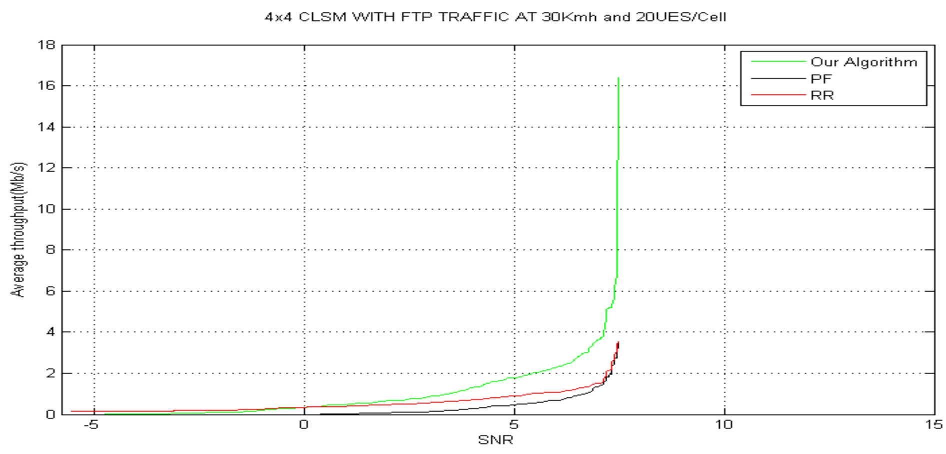

Figure 15: 4x4 CLSM with FTP traffic

The figure 15 shows the performance of three scheduling algorithms for ftp traffic while using the SNR as performance metric. The algorithms are compared while maintaining both mobility and number of users. It is observed that at the beginning with few number users at the eNodeB, the RR is considered to lead the others because round robin scheduler does not take into account the channel conditions. Both PF and our proposed algorithm take into account the channel conditions, where at low SNR present very low throughputs. But with the increase of the channel condition, proposed algorithm is more advantageous with respect to RR and PF for ftp traffic. This is due to the fact that; the proposed algorithm first considers a higher antenna which provides higher throughput than the built-in algorithms.

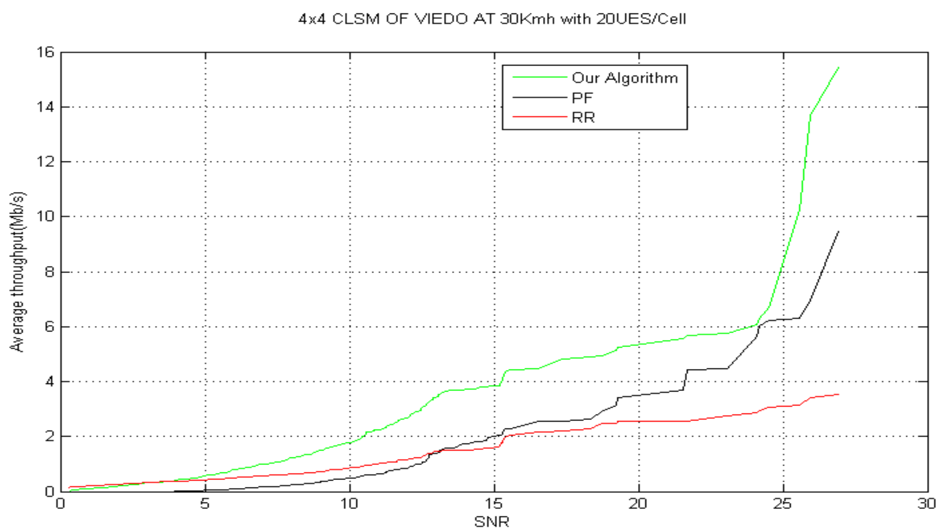

Figure 16: 4x4 CLSM with video traffic

Figure 16 depicts the performance of three algorithms with the use of SNR as metric. At the beginning with few number users at the eNodeB, the RR is considered to lead the others because RR scheduler does not take into account the channel conditions. Both PF and our proposed algorithm take into account the channel conditions, where at low SNR present very low throughputs. But with the increase of the channel condition, our new scheduler provides better throughput with respect to RR and PF for video traffic. As the proposed algorithm considers the higher transmission schemes, we can conclude that the higher the transmission schemes the higher the throughput.

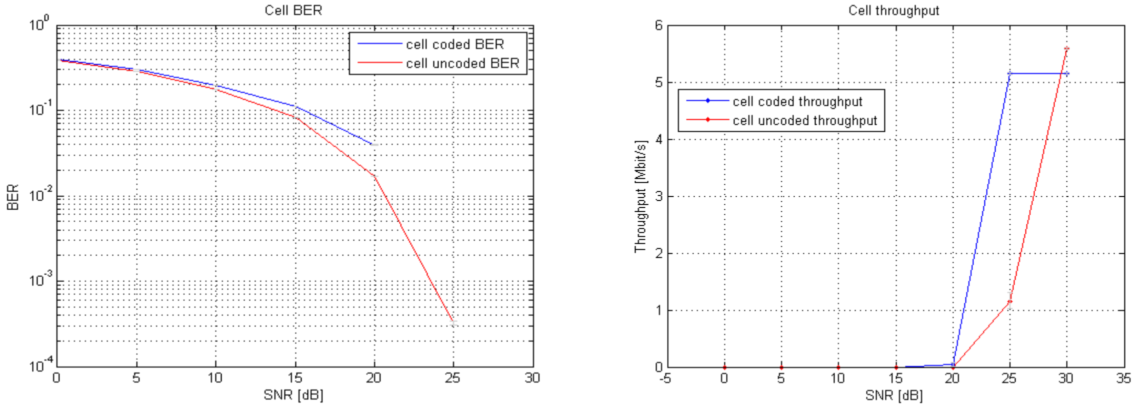

Figure 17: Simulation of cell bit error ratio at 1000 subframes using our proposed scheduler and Cell throughput at CQI=15 with 1000 subframes

The Block error rate decreases with the increase of the wideband signal to noise ratio as observed in the figure 17 on the left while the significant decrease of bit error rate provides a considerable increase in average cell throughput as shown in figure 17 on right.

In order to evaluate the BER and SNR effects, the CQI is taken into account as the higher the CQI the highest throughput but at the cost of the fairness. Thus our scheduler can reach a minimum throughput but at a significant fairness because in a real system the fairness is more important than the highest throughput.

Chapter 6: Conclusions and Recommendations

6.1: Conclusions

In this thesis entitled Scheduling and Resource Allocation for Heterogeneous Traffic in LTE-A Networks, we have presented a new scheduling and resource allocation which has more advantages compared to the existing algorithm. I have worked on different scheduling algorithms Round robin, Proportional fair and from which a new algorithm was introduced by adjusting parameters to the built-in algorithms.

These scheduling algorithms have been implemented in a MATLAB-based System Level simulator of the Vienna University. A comparative analysis between the scheduling algorithms based on their throughputs for different scenarios different scheduling methods, different antennas transmission system, and different channel models and different number of users was carried out. We can see that our new scheduling presents more advantages than the built-in algorithms. The new scheduling algorithm has a better throughput performance than the Round Robin and Proportional fair scheduling. The ITU-channel types named Pedestrian B have been used to simulate different scenarios. We observe that our new algorithm works better than the two remained and it produces higher throughput than the Round Robin and Proportional fair.

6.2. Recommendations

The Vienna LTE-A Simulator is the recent simulator that can produce the higher outputs than the old simulators. For the simulator to reach the ITU recommendation in term of data rates, it is recommended that researchers further enhance the scheduling algorithms to adapt to the features of LTE-Advanced for real world data simulation.

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APPENDIX: I

```
%AVERAGE THROUGHPUT SIMULATION FOR ANTENNA AND MOBILITY
close all force;
clc;
cd ..

simulation_type = 'tri_sector_tilted_traffic';
simSet = [3 4 4];
%% Base configuration
LTE_config = LTE_load_params(simulation_type);
LTE_config.eNodeB_tx_power                    = 46; % 46 dBm
LTE_config.bandwidth                          = 20e6;
% LTE_config.simulation_time_tti              = 100;
% LTE_config.network_source                   = 'capesso';
LTE_config.pathlosses                         = [0 10 10];
LTE_config.scheduler                          = 'our scheduler'; % prop fair
Sun % round robin
LTE_config.channel_model.type                 = 'TU';
LTE_config.UE_speed                           = 25/3;
% LTE_config.UE_distribution                  = 'constant UEs per ROI';
LTE_config.network_geometry                   = 'regular_hexagonal_grid';
LTE_config.shadow_fading_type                 = 'claussen';
LTE_config.UE_per_eNodeB = 20;
LTE_config.simulation_time_tti = 100;
%
% % Misc options
% LTE_config.non_parallel_channel_trace       = true;
LTE_config.show_network                       = 0;
% LTE_config.channel_model.trace_length       = 1;
LTE_config.keep_UEs_still                     = true;
LTE_config.compact_results_file               = true;
% LTE_config.compact_results_file             = 3;
LTE_config.delete_ff_trace_at_end             = true;
% LTE_config.UE_cache                         = false;
% LTE_config.pregenerated_ff_file             = 'auto';
% LTE_config.cache_network = false;


LTE_config.nTX      = simSet(2);
LTE_config.nRX      = simSet(3);
LTE_config.tx_mode = simSet(1);
ticIdx = tic;
output_results_file = LTE_sim_main(LTE_config);
time = toc(ticIdx);

simulation_data                    = load(output_results_file);
GUI_handles.aggregate_results_GUI =
LTE_GUI_show_aggregate_results(simulation_data);
GUI_handles.positions_GUI          =
LTE_GUI_show_UEs_and_cells(simulation_data,GUI_handles.aggregate_results
_GUI);
```

```
%TRAFFIC MODELS SIMULATION
function model =
LTE_trafficmodel(trafficmodel_params,UE,HARQ_delay,max_TTI,varargin)
% This function chooses the actual traffic model for the user

aPrioriPdf = [0.1,0.2,0.2,0.3,0.2]; % a priori pdf according to which a
traffic model is picked (defined in RAN R1-070674); just use single
digit numbers for this, otherwise set will not work
% [ftp,http,video,voip,gaming]
% aPrioriPdf = [1,0,0,0,0,0];
if trafficmodel_params.usetraffic_model % if the traffic models shall be
used
    if isempty(varargin)
        set = [];
        for i = 1:length(aPrioriPdf)
            set = [set,i*ones(1,aPrioriPdf(i)*10)];
        end
        index = randi([1,length(set)]);
    else
        index = 1;
        set = varargin{1};
    end
    switch set(index)   % randomly pack one of the traffic models
according to the aPrioriPdf
        case 1
            model = traffic_models.ftp(UE,HARQ_delay);
        case 2
            model = traffic_models.http(UE,HARQ_delay);
        case 3
            model = traffic_models.video(650,3);
        case 4
            model = traffic_models.voip(UE,HARQ_delay);
        case 5
            model = traffic_models.gaming(UE,HARQ_delay);
        case 6
            model = traffic_models.fullbuffer(UE,HARQ_delay);
        case 7
            if varargin{2}
                model =
traffic_models.MLaner_traffic(UE,HARQ_delay,varargin{3});
            else
                model = traffic_models.fullbuffer(UE,HARQ_delay);
            end
        case 8
%              model = traffic_models.car(UE,HARQ_delay,max_TTI);
            if trafficmodel_params.seed_traffic
                model =
traffic_models.fixed_rate_tm(trafficmodel_params.packet_size,trafficmode
l_params.packet_periode,max_TTI,varargin{2},UE,trafficmodel_params.traff
ic_stream);
            else
                model =
traffic_models.fixed_rate_tm(trafficmodel_params.packet_size,trafficmode
l_params.packet_periode,max_TTI,varargin{2},UE);
            end
    end
else
    model = traffic_models.fullbuffer(UE,HARQ_delay);
end
end
```

```
%BER AND THROUGHPUT SIMULATION FOR CODED AND UNCODED
clear
%clear global
%close all
clc

%% DEBUG level
global DEBUG_LEVEL
DEBUG_LEVEL = 4;

%% SNR setting
SNR_30percent = [-7, -5, -3, -1, 1, 3, 3, 7, 9, 11, 13, 14.5, 16, 17.75,
19.5];
% SNR_stepsize = 1;
% SNR_window = 0.25;
% power = [];
% noise = [];
Simulation_type = 'MUMIMO';     %'SUSISO'
                                    %'MUSISO'
                                    %'SUMIMO'
                                    %'MUMIMO'
                                    %'SUSISO_quick_test'
                                    %'SUSISO_BLER_curves_batch'
                                    %'SUSISO_best_cqi'
                                    %'SUMIMO_quick_test'
                                    %'winner_model_example'
                                    %'wsa_2010_michal'

%  counti = 1;
%  channel_estimation_error_freq_depend = zeros(72,14,1,2,500);
% Hsave = zeros(72,1000,32);
%% Actual simulations
for cqi_i = 15
%     N_subframes = [200;ones(200,1);200];    %     SNR_vec =
SNR_30percent(cqi_i)-
SNR_window*2.5:SNR_stepsize:SNR_30percent(cqi_i)+SNR_window;SNR_vec =
50;
      N_subframes = 1000;
%     channel_estimation_error_freq_depend =
zeros(72,14,1,2,N_subframes);
%     SNR_vec =
[7.7;5.72;27.63;14.65;12.37;8.12;15.66;26.27;8.05;28.31;15.41;15.84;15.8
5;8.81;-0.42;26.45;12.09;10.88;32.96;11.22];
%SNR_vec = [10];
       SNR_vec(:,:,1) = [0:5:30];
      LTE_load_parameters;  % Single User Multiple Input Multiple Output
    LTE_sim_main
    % Code to generate the output filename
%     output_filename =
LTE_common_generate_output_filename(LTE_params,N_subframes);
    output_filename = ['Mobilkom_CLSM_4x4_xx_1/2'];
%     filename_suffix = [];
      save(fullfile([output_filename '.mat']));
%     setpref('Internet','SMTP_Server','smtp.nt.tuwien.ac.at');
%     setpref('Internet','E_mail','stefan.schwarz@nt.tuwien.ac.at');
%     sendmail('stefan-schwarz@gmx.at','simulation','here it
is',output_filename);
end
```

```
%MUMIMO CONFIGURATION PARAMETERS FOR OUR SIMULATION
classdef mumimoSimulationConfig < simulation_config.simulatorConfig
    % Simulation parameters for a MUMIMO simulation

    methods (Static)
        function LTE_params = apply_parameters(LTE_params)
            LTE_params.nUE = 650;     % number of user equipments to
simulate
            LTE_params.nBS = 19;     % number of base stations to
simulate (hard-coded to 1)
            LTE_params.Bandwidth = 20e6;              % in Hz, allowed
values: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20MHz => number of
resource blocks 6, 15, 25, 50, 75, 100
            LTE_params.introduce_timing_offset =  false;
            LTE_params.introduce_frequency_offset =  false;
            %% Define some User parameters (identical settings).
            LTE_params.UE_config.channel_estimation_method = 'PERFECT';
%'PERFECT','LS','MMSE'
            LTE_params.UE_config.mode = 3;                          %
DEFINED IN STANDARD 3GPP TS 36.213-820 Section 7.1, page 12
            % 1: Single Antenna, 2: Transmit Diversity, 3: Open Loop
Spatial Multiplexing
            % 4: Closed Loop SM, 5:
            % Multiuser MIMO
            LTE_params.UE_config.nRX = 4;                           % number
of receive antennas at UE
            LTE_params.UE_config.receiver = 'ZF'; % 'SSD','ZF'
            fd = 0; % Doppler frequency
            LTE_params.UE_config.user_speed =
fd/LTE_params.carrier_freq*LTE_params.speed_of_light;  % [km/h]
            LTE_params.UE_config.timing_offset = 23;    % timing offset
in number of time samples
            LTE_params.UE_config.timing_sync_method = 'perfect';%
'perfect','none', 'autocorrelation'
            LTE_params.UE_config.carrier_freq_offset = pi;    % carrier
frequency offset normalized to subcarrier spacing
            LTE_params.UE_config.freq_sync_method = 'perfect';
            LTE_params.UE_config.rfo_correct_method = 'subframe'; %
'none','subframe'
            %% Define BS parameters (identical settings).
            LTE_params.BS_config.nTx = 4;
            %% Define ChanMod parameters - now it is only possible to
have same channel parameters for BS and UE
            LTE_params.ChanMod_config.filtering = 'BlockFading';
%'BlockFading','FastFading'
            LTE_params.ChanMod_config.type = 'PedB'; % 'PedA', 'PedB',
'PedBcorr', 'AWGN', 'flat
Rayleigh','VehA','VehB','TU','RA','HT','winner_II'
            %% Scheduler settings
            LTE_params.scheduler.type = 'our scheduler';
            %        LTE_params.scheduler.type = 'constrained

            LTE_params.scheduler.assignment = 'static';
            %         LTE_params.scheduler.assignment = 'dynamic';
            % Parameters for the static scheduler
            LTE_params.scheduler.cqi  = 'set';
            LTE_params.scheduler.PMI  = 2;             % corresponds
CI for closed loop SM
        end
    end
```