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A Minor Project Report

on

Reduction of Power Consumption using Massive MIMO and small cells

submitted in partial fulfillment of the requirement for the degree of

Bachelor of Engineering

in

Computer Science and Engineering

Submitted By

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2022 -23

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2022 - 2023

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CERTIFICATE

This is to certify that Minor Project titled **Reduction of Power Consumption using Massive MIMO and small cells** is a bona fide work carried out by the student team comprising of B Ajay Kushal (01FE20BCS289), Lavanya Shahapur (01FE20BCS185), Pragathi Pujari (01FE20BCS189), Kushagra Tomar (01FE20BCS063), Ashwini Jannu (01FE20BCS208) for partial fulfillment of completion of sixth semester B.E. in Computer Science and Engineering during the academic year 2022-23.

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Acknowledgement

We would like to thank our faculty and management for their professional guidance towards the completion of the project work. We take this opportunity to thank Dr. Ashok Shettar, Vice-Chancellor, Dr. B.S Anami, Registrar, and Dr. P.G Tewari, Dean Academics, KLE Technological University, Hubballi, for their vision and support.

We also take this opportunity to thank Dr.Meena S. M, Professor and Head, SoCSE for having provided us direction and facilitated for enhancement of skills and academic growth.

We thank our guide Mr.Parikshit P Hegde, Asst. Professor, SoCSE for the constant guidance during interaction and reviews.

We extend our acknowledgement to the reviewers for critical suggestions and inputs. We also thank Project Co-ordinator Mr. Uday N.Kulkarni and Mr.Guruprasad Konnuramath for their support during the course of completion.

We express gratitude to our beloved parents for constant encouragement and support.

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ABSTRACT

In recent years, the explosive growth in wireless data traffic has put significant pressure on the capacity of cellular networks. To cope with this demand, researchers have proposed the use of massive multiple-input multiple-output (MIMO) systems and small cells. Massive MIMO is a promising technology that can increase the spectral efficiency of wireless networks by using a large number of antennas at the base station, while small cells can improve coverage and capacity by providing localized coverage in densely populated areas.

In this project, we investigate the potential benefits of combining massive MIMO and small cells to reduce the power consumption of cellular networks while maintaining or even improving their performance. Specifically, we propose a joint optimization framework that takes into account the trade-offs between power consumption, network coverage, and user throughput. We show that by carefully configuring the number of antennas at the base station and the number of small cells deployed in a given area, we can achieve significant reductions in power consumption while maintaining high network performance.

To evaluate our proposed framework, we conduct extensive simulations using a realistic network model and compare the 3 algorithms. Our simulation results demonstrate that our proposed algorithm(RZF beamforming) can achieve least power consumption and achieve maximum eneregy efficiency. These findings have important implications for the design of future wireless networks, as they suggest that the combination of massive MIMO and small cells can be an effective way to meet the growing demand for wireless data while reducing the environmental impact of cellular networks.

Keywords : *MIMO, Small Cells, RZF(Regularized Zero forcing Algorithm)*

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

Due to the sharp increase in wireless data traffic, cellular networks' capacity and energy efficiency are severely strained. Massive MIMO and tiny cells are a viable approach to expand network capacity and lower power usage. In order to increase spectral efficiency, a technology known as massive MIMO makes use of several antennas at the base station, whereas small cells offer specialised coverage in densely populated locations.This project of Reduction of Power Consumption using Massive MIMO and Small cells aims to investigate the potential benefits of combining two promising wireless technologies, Massive MIMO and small cells, to reduce the power consumption of cellular networks while maintaining or improving their performance.

A technique called massive MIMO employs a lot of antennas at the base station to boost spectral efficiency and expand network capacity. Small cells, on the other hand, provide localized coverage in densely populated areas, which can improve network coverage and capacity.This makes a joint optimisation framework suggestion that takes into account the trade-offs between user throughput, network coverage, and power consumption. The framework seeks to achieve considerable reductions in power consumption while maintaining good network performance by carefully setting the number of antennas at the base station and the number of tiny cells distributed in a particular area.

The objective is to reduce overall power usage while meeting QoS requirements for users and power requirements for BS and SCAs.We demonstrate that the hidden convex nature of this optimisation issue makes it possible to identify the best solution in a polynomial amount of time. It has been demonstrated that the approach assigns each user to the best transmitter (BS or SCA) automatically or dynamically. The best option is contrasted with a low-complexity approach built on traditional regularised zero-forcing (RZF) beamforming.

1.1 Motivation

Massive MIMO technology uses a large number of antennas at the base station to simultaneously communicate with multiple users, resulting in increased data throughput and improved spectral efficiency. The technology is particularly useful in high-density environments, such as urban areas or stadiums, where many users are simultaneously accessing the network. Small cells, on the other hand, are low-power wireless access points that are typically used to supplement the coverage and capacity of traditional macrocellular networks. Small cells can be deployed in indoor or outdoor locations and can provide localized coverage in areas with high demand, such as shopping malls, airports, or residential neighborhoods. By using small cells, network operators can offload traffic from congested macrocellular networks and provide users with better network performance and reliability. The ICT sector already makes a sizable contribution to the global carbon footprint, energy consumption becomes a crucial issue for 5G networks.Long-Term Evolution (LTE)-based wireless networks currently in use are poorly designed, with a significant difference between peak and average rates and poor energy efficiency (EE).Although the macro-cell network design is ideal for delivering wide-area coverage, it is unable to keep up with the QoS demands and user growth.Maximising energy efficiency becomes essential to fulfil the stringent requirements of 5G networks and next-generation wireless platforms.

1.2 Literature Survey

Energy Efficiency in 5G Massive MIMO for Mobile Wireless Network For mobile wireless

networks using 5G massive MIMO, energy efficiency is essential. [1].Massive MIMO technology transmits and receives data using a large number of antennas, allowing for more effective use of the spectrum that is available and requiring less power for transmission. Multiple data streams can be sent and received at once using sophisticated signal processing techniques, which boosts network capacity and minimises the need for further base stations.The following are some methods for increasing energy efficiency in 5G Massive MIMO for mobile wireless networks:Massive MIMO employs the beamforming technique to focus the signal on the desired receiver.[2] Energy efficiency is increased because less energy is required to transmit the signal when the signal is directed towards the receiver.Spatial multiplexing: This method enables the simultaneous transmission of numerous data streams. This method can speed up data transfer, which cuts down on the time and energy needed to send data.The network can switch between uplink and downlink transmissions using the dynamic TDD (Time Division Duplexing) technology. As a result, the network can prioritise transmissions in a way that minimises energy usage, which can lower the energy needed for communication.Power control: Power control is a method for adjusting transmission power levels based on channel circumstances.[3] The network can reduce energy usage while ensuring dependable communication by altering the power level.Overall, the energy efficiency of mobile wireless networks can be significantly increased with the help of 5G Massive MIMO technology. High data transmission speeds and dependable communication can be maintained while requiring less energy through the use of sophisticated signal processing techniques and clever power management.

Energy-efficient wireless networks: A marriage between massive MIMO and small cells

Future wireless networks that use less energy could greatly benefit from the combination of massive MIMO and small cells. [4]. Low-power base stations known as small cells can be installed in heavily populated regions to expand network capacity and coverage. As was previously noted, massive MIMO technology transmits and receives data using a large number of antennas, allowing for a more effective use of the available spectrum and a reduction in the amount of power needed for transmission.Massive MIMO and small cells work together to provide wireless networks that are energy-efficient in the following ways:Better coverage and capacity: The network can offer users better coverage and capacity by placing tiny cells in densely populated regions.[5] As a result, users may not need to often switch between base stations, which can conserve energy by reducing the need for users to migrate to locations with stronger signals.Reduced interference: By focusing the signal towards the target receiver, massive MIMO technology can reduce interference. As a result, less energy is lost on broadcasts that fail to reach their target audience, which can lower the amount of energy required to carry the signal.[6] Dynamic TDD (Time Division Duplexing) is a technology that enables the network to switch between uplink and downlink transmissions as necessary. The network can lower the energy needed for communication by altering the transmission schedule.Power control: By altering the power level of transmissions based on the channel conditions, power control can also be employed to lower energy usage. This method allows the network to conserve energy while maintaining dependable communication.Overall, huge MIMO with small cells can result in future wireless networks that use less energy. High data transmission speeds and dependable communication can be maintained while requiring less energy through the use of sophisticated signal processing techniques and clever power management.[7]

Energy-efficient Design for MIMO Two-Way AF Multiple Relay Networks Two Way Relay Communication

Two nodes exchange information via a relay node in two-way relay communication, a form of wireless communication. [8].A type of wireless communication system known as MIMO (Multiple Input many Output) two-way AF (Amplify and Forward) multiple relay networks makes use of many relays to enhance network performance. Two nodes in this system communicate with one another via several relays. The signals are amplified and relayed to the other node.[9] The following are some design factors for MIMO two-way AF multiple relay networks that are energy-efficient: Relay placement: The positioning of the relays can significantly affect the network's energy efficiency. It is possible to shorten the distance between the nodes and the relays by strategically positioning them, which can lower the energy needed for communication.In MIMO two-way AF multiple relay networks, power allocation is a strategy that can be utilised to cut down on energy consumption.[10] It is feasible to lower the overall power needed for communication by distributing electricity to the relays based on how far away they are from the nodes. Relay selection: Relay selection is a different method for enhancing the network's energy effectiveness. Reducing the amount of energy needed for communication is attainable by choosing the relays with the strongest signal.Adaptive modulation and coding: This technology modifies the modulation and coding scheme according to the channel circumstances. By employing this method, high data transfer speeds can be maintained while requiring less energy for communication.[11] Overall, there are a number of design factors that may be taken into account to increase the MIMO two-way AF multiple relay networks' energy efficiency. Relays can be placed more effectively, power can be allocated, relays can be chosen, and adaptive modulation and coding can be used to conserve energy while preserving communication reliability.[12] Overall, there are a number of design factors that may be taken into account to increase the MIMO two-way AF multiple relay networks' energy efficiency. Relays can be placed more effectively, power can be allocated, relays can be chosen, and adaptive modulation and coding can be used to conserve energy while preserving communication reliability.

Energy Efficiency in Massive MIMO-Based 5G Networks: Opportunities and Challenges

Massive MIMO (Multiple Input Multiple Output) technology has emerged as an effective way to build 5G networks with great capacity and low energy consumption.[13].Massive MIMO (Multiple Input Multiple Output) technology is essential to 5G networks and has the ability to dramatically increase wireless communication systems energy efficiency. Massive MIMO transmits and receives data using a lot of antennas, allowing for more effective use of the spectrum that is available and requiring less power for transmission.[14] In large MIMO-based 5G networks, the following potential and difficulties for energy efficiency exist:Opportunities:Massive MIMO employs the beamforming technique to focus the signal on the desired receiver. Energy efficiency is increased because less energy is required to transmit the signal when the signal is directed towards the receiver.Spatial multiplexing: This method enables the simultaneous transmission of numerous data streams. This method can speed up data transfer, which cuts down on the time and energy needed to send data.[15] Challenges:Complexity: Complex signal processing methods are necessary for massive MIMO, and these algorithms can be computationally demanding and energy-intensive.Massive MIMO may potentially cause interference between antennas, which could lower the network's energy efficiency.Hardware restrictions: The deployment of the technology may be hindered by the pricey and power-intensive hardware needed for Massive MIMO.

Massive MIMO and Small Cells : Improving Energy Efficiency by Optimal Soft-Cell Coordination

A combination of massive MIMO and small cell technologies can increase the energy effectiveness of wireless networks. [16].Small cells and massive MIMO (Multiple-Input Multiple-Output) are two technologies that can boost network capacity and increase energy efficiency in wireless communication systems.Massive MIMO communicates with several users at once using a wide array of antennas at the base station. With the help of this technique, wireless communication systems' spectral efficiency can be considerably improved, allowing for the transmission of more data over the same bandwidth. Massive MIMO can also increase energy efficiency by enabling more accurate signal transmission and minimising interference.Hardware restrictions: The deployment of the technology may be hindered by the pricey and power-intensive hardware needed for Massive MIMO.To boost network capacity and coverage, small cells, on the other hand, are low-power base stations that are installed in crowded urban areas. These base stations can be installed on lamp posts or buildings and typically have a range of a few hundred metres.A method for enhancing the performance of both Massive MIMO and small cells is called soft-cell coordination. In order to maximise energy efficiency and reduce interference, soft-cell coordination entails the dynamic management of numerous small cells inside a certain area.Small cells in a soft-cell coordination system are dynamically reconfigured according to the network load and the users' locations. As a result, the system can adapt to shifting network conditions and make the best use possible of its resources.

A Survey on Recent Trends and Open Issues in Energy Efficiency of 5G Due to the growing

energy consumption of wireless networks and the desire to lower their carbon imprint, the energy efficiency of 5G networks has grown in importance as a study area. [17]. Significant advancements in wireless communication, including better data speeds, lower latency, and increased network capacity, have been made thanks to the development of 5G technology. These advancements have increased energy use, though, and this can have detrimental effects on the environment and the economy. As a result, there has been a lot of interest in enhancing 5G networks' energy efficiency.Hardware advancements, network optimisation, and energy-efficient protocols are the three recent advances in 5G energy efficiency.[18] The development of energy-efficient parts, like power amplifiers, filters, and antennas, is the main goal of hardware advancements. These elements can increase system efficiency and lower the radio access network's (RAN) energy usage. Utilising strategies like traffic unloading, dynamic spectrum allocation, and network densification, among others, is referred to as network optimisation. These methods can increase the efficiency with which network resources are used and decrease the need for energy-intensive tasks.The creation of novel protocols and algorithms that can lower energy usage without compromising performance is a component of energy-efficient protocols. By scheduling user transmissions optimally, for instance, energy-efficient scheduling algorithms can increase the system's energy efficiency.

Energy Efficient 5G Networks: Techniques and Challenges

High data rates, low latency, and dependable connectivity are anticipated from 5G networks to enable a variety of applications, such as virtual and augmented reality, driverless vehicles, and smart cities. [19].5G networks have drawn a lot of attention due to the rising need for fast internet. But because 5G networks need more equipment and processing power than earlier generations of mobile networks, they present a substantial energy consumption concern.[20] There are many strategies and difficulties to be taken into account in order to make 5G networks more energy-efficient.Network Architecture: The energy efficiency of 5G networks is greatly influenced by their design. The network should be built to use resources efficiently and conserve energy.[21] Energy consumption can be decreased by the use of tiny cells, dispersed antenna systems, and network slicing.Challenges:Scalability: To accommodate the rising demand for high-speed internet and the rising number of connected devices, energy-efficient approaches should be scalable.Security: The network's security must not be jeopardised by the use of energy-saving methods.To maintain sustainability and lessen the environmental impact of mobile networks, 5G networks must be energy-efficient. Utilising energy-saving methods can help to lower energy usage, maximise resource utilisation, and enhance network performance. To ensure the effective application of these strategies, a number of issues must be taken into account.

Energy Efficiency of the D2D Direct Connection System in 5G Networks

A promising technology in 5G networks, device-to-device (D2D) communication permits direct communication between nearby devices without the use of a base station or infrastructure. [22]. A characteristic of 5G networks called device-to-device (D2D) direct connection enables two devices to communicate with each other directly without going through a base station or core network. The distance between the devices, the modulation and coding schemes employed, the power consumption of the devices, and the channel conditions all affect how energy-efficient the D2D direct connection technology is in 5G networks. The D2D direct connection system's capacity to use less energy than conventional cellular networks is one of its key benefits, particularly in situations where the devices are close to one another.[23] D2D communication can lower device and network infrastructure power consumption by removing the need for traffic to pass via the base station.The quality of the wireless channel between the devices, however, also affects how energy-efficient the D2D direct connection technology is.[24] The devices may need to increase their transmit power to maintain the acceptable level of communication quality in situations where the channel conditions are bad, which can increase energy consumption.

Resource Allocation for Energy Efficiency in 5G Wireless Networks

In 5G wireless networks, resource allocation is a crucial component of energy efficiency.[25]. In 5G wireless networks, resource allocation is a key component of energy efficiency. Here are several tactics for allocating resources effectively in 5G networks to reduce energy use:Dynamic spectrum management: In 5G networks, spectrum-sharing methods including cognitive radio, dynamic spectrum access, and dynamic spectrum allocation can be used. By dynamically assigning the spectrum to different users, devices, and services according to their needs, these strategies can help the network use less energy.Power management: For 5G networks to be energy-efficient, power management is crucial.[26] A device's gearbox power directly correlates with how much power it uses. Therefore, adjusting the transmission power of devices and base stations can drastically cut down on the network's energy usage.Network virtualization: With the aid of network virtualization, virtual network functions that can be dynamically assigned to various physical resources can be created. Utilising resources more effectively and using less energy are possible with this method.These techniques enable 5G networks to retain performance and service quality while making significant energy savings.

A Survey of Energy-Efficient Techniques for 5G Networks and Challenges Ahead

As 5G networks are anticipated to offer a wide range of applications and services with high data rates and low latency, energy efficiency is a crucial component. [27]. The desire for faster data speeds, lower latency, and enormous interconnectedness is rising as 5G networks start to take off. However, these demands provide serious difficulties for energy usage, a critical component of sustainability. Energy-efficient methods are needed in 5G networks to address this issue.Energy-efficient 5G network technologies: Dynamically modifying the base station's transmit power, antenna radiation patterns, and the number of active cells according to traffic demand is the basis of the dynamic energy management technique, which aims to reduce the network's energy usage.Challenges:Heterogeneous networks: The deployment of heterogeneous networks, made up of several cell types, poses difficulties for network management, planning, and optimisation.[28] To manage the intricate network structure, new algorithms and methods must be developed.Network virtualization: Network virtualization, which abstracts network resources, presents problems with regard to energy efficiency. It necessitates the creation of brand-new virtualization technologies that are energy-efficient and capable of effectively allocating resources to meet the changing network demands.

1.3 Problem Statement

Reducing the Cellular Power Consumption by Combined Simulation of Massive MIMO and Small-Cells

1.4 Applications

- Cellular networks: The project's findings can be applied to cellular networks to reduce their power consumption and operating costs while maintaining high network performance.
- Smart cities: In highly populated metropolitan areas, the use of small cells with Massive MIMO can increase network coverage and capacity, assisting in the creation of smart cities.
- Internet of Things (IoT): The reduction in power consumption achieved through the project can help support the growth of IoT devices by extending their battery life and reducing the need for frequent recharging.
- Wireless communication systems in remote areas: Massive MIMO and small cells can be used together to increase network coverage in sparsely populated rural areas, providing more dependable wireless communication systems.

1.5 Objectives of the project

- To reduce overall power usage while meeting QoS requirements for users and power requirements for base stations and small cells.
- To offer encouraging modelling findings demonstrating how combining massive MIMO and tiny cells might reduce overall power usage.
- To compare and analyse the results of the proposed algorithm with other beamforming algorithms.

1.6 Scope of the project

- By combining Massive MIMO with Small-Cell technology, new methods and tactics to lower cellular networks' power consumption are being researched and developed.
- To determine the ideal Massive MIMO and Small-Cells technology combination that can reduce power consumption the most while preserving or enhancing network performance, including coverage, capacity, and data rate.
- To investigate the effects of many elements on the performance of the integrated system, including the number of antennas, the density of small cells, the kind of modulation, and the distribution of users.

Chapter 2

REQUIREMENT ANALYSIS

Requirement analysis is the comprehensive specification and description of the software requirements that must be met for the software systems to be developed successfully. Depending on the sort of requirement, they may be both functional and non-functional. In order to thoroughly grasp the needs of customers, interaction between various customers and contractors is done.

2.1 Functional Requirements

In order to satisfy the needs of its users and stakeholders, a system or product must have certain specified capabilities and features.These requirements describe what the system should do and how it should behave, and are typically specified in a functional requirements document or specification. In short, functional requirements define the essential functions that a system must perform to fulfill its intended purpose.

- The system must support massive MIMO and small-cell technology to optimize power consumption and increase network capacity.
- The system must have the ability to perform combined simulation of massive MIMO and small-cells to achieve energy-efficient communication.
- The system must be able to intelligently switch between massive MIMO and small-cells depending on the user's location and the network conditions to conserve energy.
- The system must have the capability to optimize beamforming and antenna selection to reduce power consumption while maintaining high-quality communication.
- The system must be able to monitor and control the power consumption of each antenna and small-cell to avoid wasteful energy consumption.

2.2 Non Functional Requirements

Non-functional requirements refer to the qualities, characteristics, and constraints that describe how a system should behave or perform, rather than what the system should do. These requirements are typically concerned with factors such as performance, scalability, reliability, security, usability, and maintainability. Non-functional requirements are important because they define how well the system satisfies the needs of its users and stakeholders, as well as its ability to meet industry standards and regulations. In short, non-functional requirements describe the qualities and constraints that define the overall behavior and performance of a system, rather than its specific features or functions.

- The system should have subcarriers more than 1000 for efficient and reliable communication.
- The system should have minimum of 10 users to compare with different algorithms/scenarios for best QoS along with reduced power consumption.
- The system should achieve a minimum energy consumption per user, such as less than 5 watts per user.
- The system should have MinUserDist(minimum user distance) of 35m from Base station and 3m from Small cell Access points.

2.3 Hardware Requirements

- Processor: Intel i7 / AMD Ryzen 7
- Core: 8 core
- GPU: Nvidia GTX 1650
- RAM: 16GB

2.4 Software Requirements

- Matlab version R2023a
- CVX software

Chapter 3

SYSTEM DESIGN

The system design of the project aims to investigate the potential benefits of combining Massive MIMO and small cells to reduce power consumption in cellular networks while maintaining high network performance. It will use a joint optimization framework, a realistic network simulation model, and performance metrics to evaluate the effectiveness of the proposed algorithm and compare it with other methods.

we are examining a downlink scenario in which a macro BS needs to transmit data to K users, each with a single antenna. Additionally, an overlay layer consisting of S >= 0 SCAs is present, with arbitrary deployment. The SCAs possess NSCA antennas each, usually ranging from 1 to 4, and operate under strict power limitations that restrict their coverage area. Conversely, the BS is subject to lenient power restrictions that enable it to achieve high-quality service targets over a broad coverage area. The number of antennas on the BS, NBS, can range from 8 to several hundred, with the latter implying NBS » K and is recognized as massive MIMO.

- Base Station Antennas: A Base Station is a wireless communication station that serves as the central hub for communicating with mobile devices, such as cell phones, laptops, and tablets. The base station is responsible for managing the wireless communication between mobile devices and the core network infrastructure. It typically consists of a radio transmitter and receiver, as well as antennas and other equipment that facilitate wireless communication. The base station is often located at a fixed location and provides wireless coverage to a specific geographic area, which is known as a cell. The project will consider the use of a large number of base station antennas in a Massive MIMO system. The antennas will be arranged in an array to create directional beams that can be used to communicate with multiple users simultaneously.

- Small Cells: Small cell access points (SCAs) are low-power wireless access points that are typically used to supplement the coverage and capacity of traditional macrocellular networks. They are designed to provide localized coverage in areas with high demand, such as shopping malls, airports, or residential neighborhoods. Small cells are deployed in indoor or outdoor locations and have a range of a few hundred meters to a few kilometers, depending on the specific use case. They can be connected to the core network via various backhaul technologies, such as wired Ethernet or wireless links, and can support a range of wireless technologies, such as 5G, or Wi-Fi. Small cell technology is used to increase the capacity and coverage of wireless networks, particularly in high-density environments where many users are simultaneously accessing the network. The project will investigate the use of small cells to enhance the coverage and capacity of the cellular network. Small cells are low-power, short-range base stations that can be used to extend the network's coverage and provide better service in areas where the macro base station signal is weak.

- Joint Optimization Framework: The project will develop a joint optimization framework to determine the optimal number of base station antennas and small cells to achieve significant reductions in power consumption while maintaining high network performance. The framework will consider the trade-offs between power consumption, network coverage, and user throughput. In addition to optimizing the number of base station antennas and small cells, the project is also focusing on optimizing the transmit power of the wireless network. This will be done using a beamforming algorithm known as Regularized Zero-Forcing (RZF) beamforming. RZF beamforming is a technique used to optimize the transmit power and reduce interference in a wireless communication network. By using RZF beamforming, the network can efficiently allocate power to the different antennas and small cells, reducing overall power consumption while still maintaining high network performance.

- Simulation Model: the simulation model that will be used to evaluate the effectiveness of the proposed framework for massive MIMO and small cell technology. The simulation model will be designed to mimic real-world wireless communication networks, taking into account various factors that can impact network performance. These factors may include network topology, user density, and traffic patterns, among others. By considering different scenarios, the simulation model will enable researchers to test the framework under various conditions and assess its effectiveness in improving network performance. The simulation model will be an essential tool for evaluating the proposed framework before it is implemented in a real-world wireless communication network.

3.1 Architecture Design

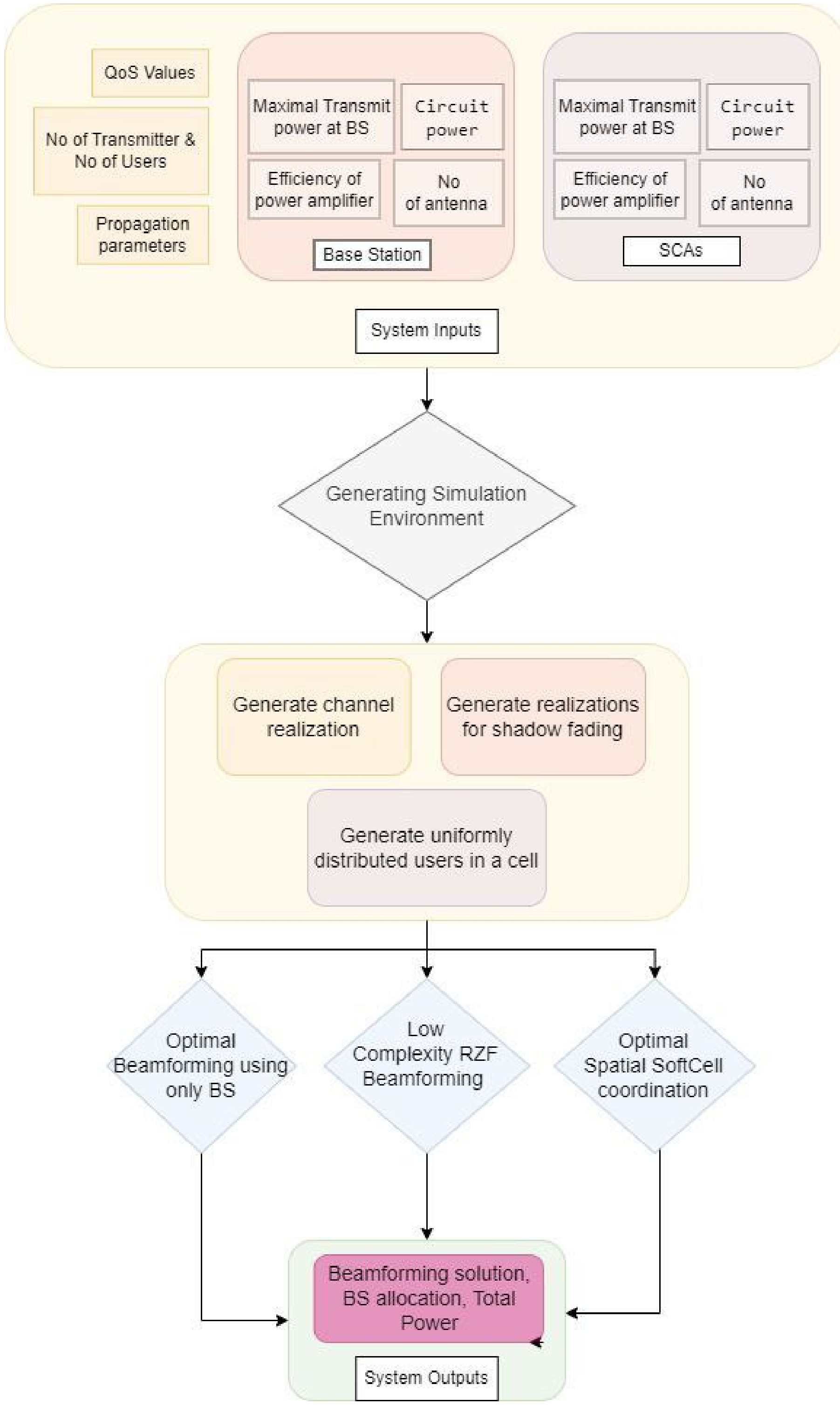

Figure 3.1: Architecture Design

From Figure 3.1, it implies that the system described here takes various inputs, including QoS values vector, the number of transmitters and users, and propagation parameters. Additionally, input parameters for both Base Station and SCAs are taken into account, such as maximal transmit power, circuit power, efficiency of power amplifier, and number of antennas. Once all of these inputs are received, the system generates a simulation environment, which involves generating channel realization, realizations for shadow fading, and uniform distributed users in a cell.

Once all the inputs are received, the system generates a simulation environment, which includes generating channel realization, realizations for shadow fading, and uniform distributed users in a cell. The next step is to send channel realization, the number of antennas, SINR constraints, weight matrix, and maximal transmit power as input to three modules. These modules include optimal beamforming using only BS, low complexity RZF beamforming, and optimal spatial soft cell coordination. These modules then generate beamforming solutions, BS allocation, and total power.

Finally, the system plots a graph of total power per QoS values for three different algorithms. This graph provides a visual representation of the performance of each algorithm, allowing the user to compare and contrast the effectiveness of each one.The overall objective of the system is to optimize the use of total power in a 5G network communication system while ensuring that QoS is maintained, thereby minimizing the total power required to achieve it. By optimizing the power consumption in the wireless network, the system aims to contribute to the development of more energy-efficient and sustainable communication technology.

3.2 Data Design

NA

3.3 User Interface Design

NA

Chapter 4

IMPLEMENTATION

This chapter gives a brief description about implementation details of the system by describing each component with its code skeleton in terms of algorithm.
The implementation is done completely on a virtual mode using a simulator tool provided by matlab 2023b and using the CVX is a software package for specifying and solving convex optimization problems. It provides a high-level modeling language that enables users to formulate convex optimization problems in a natural and intuitive way, while handling the complexity of the underlying optimization algorithms. The package supports a wide range of convex optimization problems, including linear and quadratic programming, semidefinite programming, and geometric programming. The tool finalised was matlab 2023 , as it was proven more practical and efficient when compared to the existing other platforms.

4.1 BS and SCAs allocation

we are examining a downlink scenario in which a macro BS needs to transmit data to K users, each with a single antenna. Additionally, an overlay layer consisting of S $>=$ 0 SCAs is present, with arbitrary deployment. The SCAs possess NSCA antennas each, usually ranging from 1 to 4, and operate under strict power limitations that restrict their coverage area. Conversely, the BS is subject to lenient power restrictions that enable it to achieve high-quality service targets over a broad coverage area. The number of antennas on the BS, NBS, can range from 8 to several hundred, with the latter implying NBS » K and is recognized as massive MIMO.

The base station and SCAs are fixed, with 10 users are uniformly distributed as in below figure.

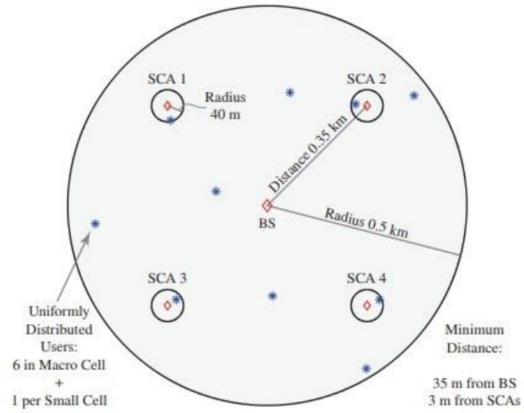

Figure 4.1 : Diagrammatic representation of the scenario with MIMO and small cells

There are 5 transmitters, one BS and 4 SCAs, BS is placed at the center. SCAs are located uniformly on a circle with this radius 0.5 km. Each cluster size is 40m. The BS has 50 antennas and each SCAs have 2 antennas as shown in the above Figure 4.1.

4.2 Optimal Beamforming using only BS

Algorithm implements an optimization problem using CVX to obtain a beamforming solution that satisfies SINR and power constraints. This algorithm considers the special case of only a macro base station. The power minimization under QoS requirements and power constraints is

minimize total transmit power

subject to SINRk >= SINRconstraints(k) for all users k, power constraints.

This optimization problem is convex. The computational complexity is therefore polynomial in the number of users, antennas, and power constraints. The implementation can, at least, handle 10 users, 100 antennas, and 100 power constraints.

```
function [Wsolution,transmitpower] = function_QoSproblem_singleBS(H,SINRconstraints,Qsqrt,q)
Kr = size(H,1); %Number of users
N = size(H,2); %Number of transmit antennas
L = length(q); %Number of power constraints


%Solve the power minimization under QoS requirements problem using CVX
cvx_begin
cvx_quiet(true); % This suppresses screen output from the solver

variable W(N,Kr) complex; %Variable for N x Kr beamforming matrix

minimize norm(W,'fro') %Minimize the square root of the total power

subject to

%SINR constraints (Kr constraints)
for k = 1:Kr
```

Figure 4.2: Code snippet of Optimal Beamforming using only BS

From Figure 4.2, The variable W(N,Kr) complex creates a variable W of size N x Kr that is complex-valued. This is the beamforming matrix that we are trying to optimize. The minimize norm(W,'fro') is the objective function which minimize the norm of W, which is equivalent to minimizing the square root of the total power transmitted by the antenna array. The variable transmit power The variable W(N,Kr) complex creates a variable W of size N x Kr that is complex-valued. This is the beamforming matrix that we are trying to optimize. The minimize norm(W,'fro') is the objective function which minimize the norm of W, which is equivalent to minimizing the square root of the total power transmitted by the antenna array.

4.3 Optimal Spatial SoftCell coordination

The CVX optimization toolbox to implement a convex optimization problem for MU-MIMO beamforming with SINR constraints and power constraints. This algorithm considers the general case with a macro base station and multiple small cells. The power minimization under QoS requirements and power constraints is

minimize total transmit power

subject to SINRk >= SINRconstraints(k) for all users k, power constraints.

This optimization problem is convex. The computational complexity is therefore polynomial in the number of users, antennas, and power constraints. The implementation can, at least, handle 10 users, 100 antennas, and 100 power constraints. This strategy takes use of the fact that the majority of data traffic is localised and requested by low-mobility users by deploying an additional layer of small-cell access points (SCAs) to offload traffic from BSs. This method shortens the typical distance between users and transmitters, which results in reduced propagation losses and increased energy efficiency.

```
function [Wsolution,transmitpower,BSallocation] = function_QoSproblem_relaxation(H,Nantennas,SINRconstraints,Q,q)

Kt = length(Nantennas); %Number of transmitters
Kr = size(H,1);  %Number of users
N = size(H,2); %Number of transmit antennas (in total)
L = length(q); %Number of power constraints


%Vector with indicies where the antenna indices of each transmitter starts and ends.
antennaInds=[0; cumsum(Nantennas)];

%Pre-compute the products of channel matrices for each transmitter
HH = zeros(N,N,Kr);
for j = 1:length(Nantennas)
    for k = 1:Kr
        HH(1+antennaInds(j):antennaInds(j+1),1+antennaInds(j):antennaInds(j+1),k) = H(k,1+antennaInds(j):antennaI
    end
end
```

Figure 4.3: Code snippet of Optimal Spatial SoftCell coordination

The optimization variable W as a complex-valued matrix of size N x N x Kr, where N is the number of transmit antennas and Kr is the number of receive antenna segments. The objective function minimizes the sum of the power allocated to all transmit antennas and receive antenna segments as shown in the above Figure 4.3. W stores the solution of the optimization problem as the beamforming matrix Wsolution.The transmit power calculates the total transmit power by summing the power allocated to all transmit antennas and receive antenna segments in the solution.

4.4 Low Complexity RZF Beamforming

Algorithm implements an optimization problem using CVX to obtain a beamforming solution that satisfies SINR and power constraints. This algorithm considers the general case with a macro base station and multiple small cells. Each transmitter applies regularized zero-forcing locally and perform joint power allocation to solve the following problem:

minimize total transmit power

subject to SINRk >= SINRconstraints(k) for all users k, power constraints.

Regularized zero-forcing (RZF) beamforming algorithm shows the implementation details of multi-user multiple-input multiple-output (MU-MIMO) systems. The best option is contrasted with a low-complexity approach built on traditional regularised zero-forcing (RZF) beamforming. Simulations are used to examine the possible benefits of various densified topologies.

```
function [Wsolution,totalpower,BSallocation] = function_QoSproblem_multiflowRZF(H,Nantennas,SINRconstraints,Q,q)

Kt = length(Nantennas); %Number of antennas at each transmitters
Kr = size(H,1);  %Number of users i.e. 10
N = size(H,2); %Number of transmit antennas (in total) i.e. 58
L = length(q); %Number of power constraints

g = zeros(Kt,Kr,Kr); %Placeholder for effective channel gain using RZF
QQ = zeros(Kt,Kr,L); %Placeholder for effective power constraints using RZF: QQ = u^H Q u

Wsolution = zeros(N,Kr); %Placeholder for beamforming solution

%Vector with indicies where the antenna indices of each transmitter starts and ends.
antennaInds = [0; cumsum(Nantennas)];

%Step 1: Go through all transmitters and all users. Transform the original
%problem into a simplified version using RZF
for j=1:Kt
```

Figure 4.4: Code snippet of Low Complexity RZF Beamforming Algorithm

From Figure 4.4, it loops over each user (j) and compute the beamforming direction using RZF for each receive antenna segment (i). Compute the corresponding channel gain between each transmit antenna (k) and each receive antenna segment (i) for each user (j).

Chapter 5

RESULTS AND DISCUSSIONS

Results were visualised through graphs and simulations were recorded in the matlab tool and CVX software for modelling the algorithms and the approaches used in the implementation.From Figure 5.1 and Figure 5.2, it shows the simulation files being executed for 10 users in the matlab software.

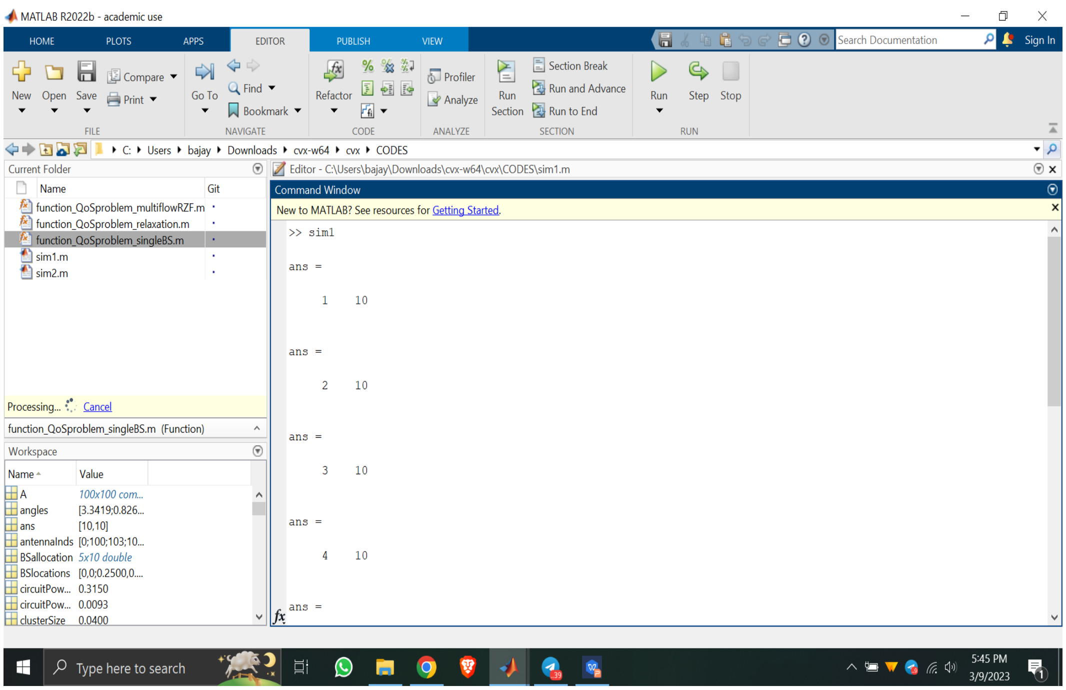

Figure 5.1: Simulation files being executed for 10 users in the matlab software

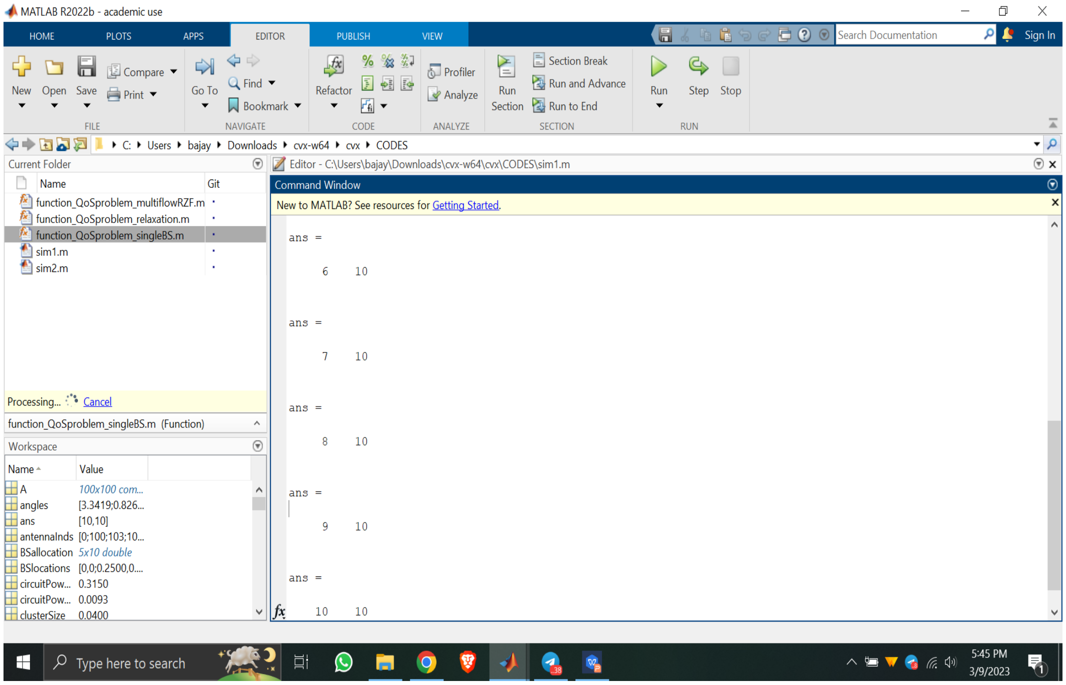

Figure 5.2: Simulation files being executed for 10 users in the matlab software

Three line graphs were plotted for each corresponding to Optimal Beamforming using only BS, Optimal Spatial SoftCell coordination and Low Complexity RZF Beamforming algorithm, for varied values of the usage of total power and the Quality of service concerned with that.

The analysis involved varying different parameters such as the number of antennas at the Base Station (BS) and Small Cell Access Point (SCA), the circuitry power consumed by both the BS and SCA, and the efficiency of the amplifiers present at both the BS and SCA. By varying these parameters, the system produced several graphs that show the relationship between these parameters and the overall performance of the system. These graphs were then compared with a base graph that was produced using base input parameters. This comparison allowed the us to identify the impact of each parameter on the system's performance and determine the optimal values for each parameter to achieve the desired performance.

In the experiment, four small cells access points are placed around a circular macro cell. There are 10 active users in the macro cell, 6 of them are evenly dispersed over the whole cell, and 1 user is evenly distributed within 40 metres of each SCA. We assess the typical performance across channel realisations and user locations.

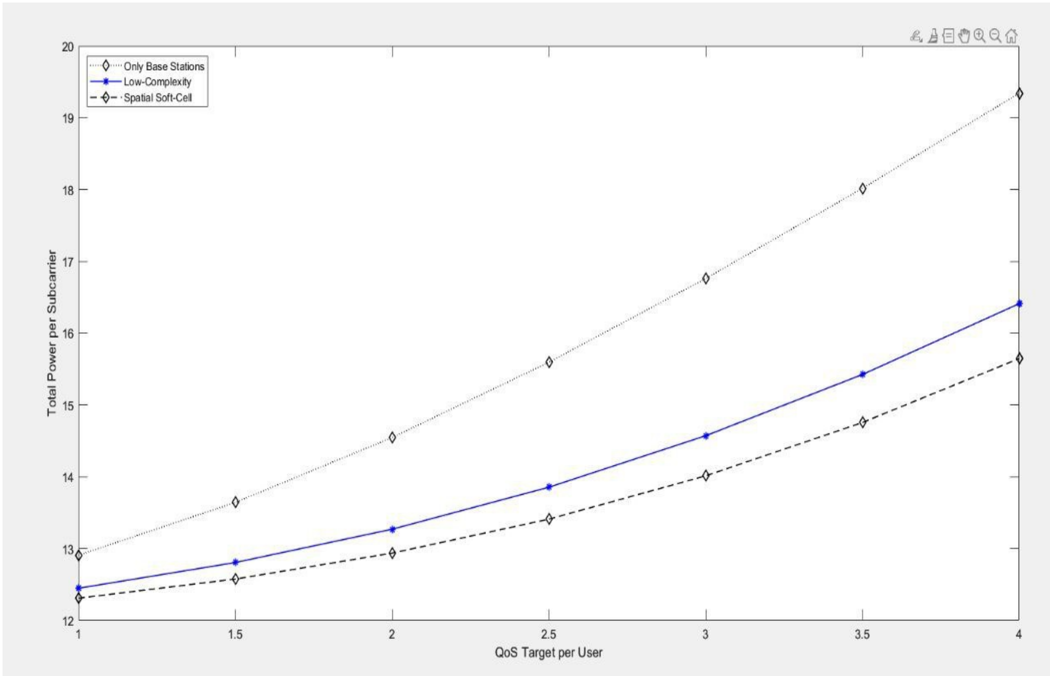

Figure 5.3: Base graph plotted for the different approaches for varied QoS

Schemes	QoS	Total Power
Only BS	1	12.9
Only BS	2	14.5
Only BS	4	19.2
Low Complexity RZF	1	12.5
Low Complexity RZF	2	13.1
Low Complexity RZF	4	16.4
Spatial SoftCell	1	12.4
Spatial SoftCell	2	12.9
Spatial SoftCell	2	15.6

Table 5.1: Base graph values obtained for different simulations for the three different schemes

The base graph is plotted with the following settings, number of antennas at BS and SCAs are 50 and 2 respectively, and maximal transmit power at BS and SCAs per subcarrier are 66 mW, and 0.08 mW respectively. Figure 5.3 displays that the total power consumed to achieve the same QoS values is more for Optimal Beamforming using only BS when coompared to both Optimal Spatial SoftCell coordination and Low Complexity RZF Beamforming algorithm. Table 5.1, displays the behavior of the base graph, which is mostly concerned with the quality of services(QoS) and the corresponding total power consumed for that QoS.

The base parameters such as the number of antennas present at the Base Station and the Small Cell Access Points, maximal transmit power at BS and SCAs per subcarrier and the distance between the concerned users and the power stations are not altered. Hence, the variation in the total power consumption corresponding to each QoS is noted according to the different parameters and the graph is plotted.

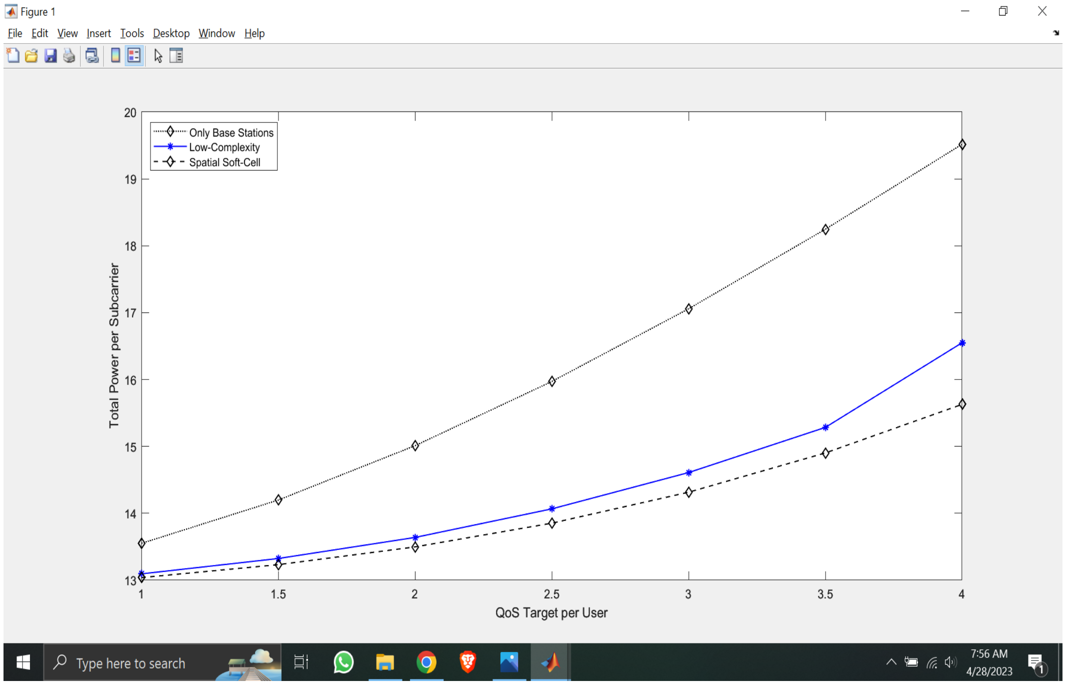

Figure 5.4: Graph A obtained for increased values of antennas and Qos constraints

Schemes	QoS	Total Power
Only BS	1	13.5
Only BS	2	15.0
Only BS	4	19.5
Low Complexity RZF	1	13.1
Low Complexity RZF	2	13.5
Low Complexity RZF	4	16.5
Spatial SoftCell	1	13.0
Spatial SoftCell	2	13.4
Spatial SoftCell	2	15.7

Table 5.2: Values of different parameters for three different schemes for second approach

Here, the number of antennas placed at the base station and the SCAs is increased by a gradual amount, while the maximal transmit power per subcarrier at the BS and SCAs are also increased gradually and the graph is plotted for the QoS values with the corresponding total power values are noted to see the variations and the parameters affecting. Figure 5.4 displays that the total power consumed to achieve the same QoS values is more for Optimal Beamforming using only BS when coompared to both Optimal Spatial SoftCell coordination and Low Complexity RZF Beamforming algorithm. Table 5.2, displays the behavior of the produced graph, which is mostly concerned with the quality of services(QoS) and the corresponding total power consumed for that QoS.

This shows that by gradually increasing the number of antennas at the BS and SCAs and the transmit power per subcarrier at the BS and SCAs we were able to achieve the same QoS values for a slight increase in the total power when compared with the base graph. The total power consumed to achieve the same QoS value by the Low Complexity RZF Beamforming is slightly more than that of the Optimal Spatial SoftCell coordination algorithm due to very the reason that Low Complexity RZF consumes more energy to perform complex mathematical operations needed to prevent interferences.

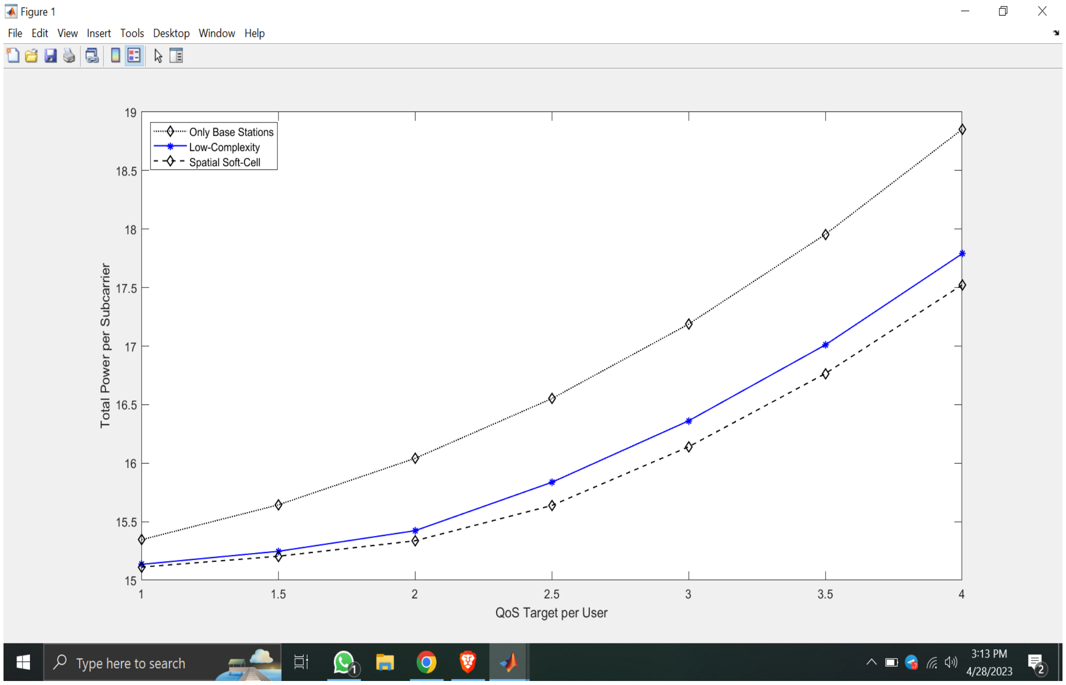

Figure 5.5: Graph B obtained for doubled values of number of antennas and variation in Quality of Service

Schemes	QoS	Total Power
Only BS	1	15.3
Only BS	2	16.1
Only BS	4	18.8
Low Complexity RZF	1	15.1
Low Complexity RZF	2	15.3
Low Complexity RZF	4	17.7
Spatial SoftCell	1	15.1
Spatial SoftCell	2	15.2
Spatial SoftCell	2	17.5

Table 5.3: Values of different parameters for three different schemes for third approach

Here, the number of antennas placed at the base station and the SCAs is doubled, while the maximal transmit power per subcarrier at the BS and SCAs are decreased gradually and the graph is plotted for the QoS values with the corresponding total power values are noted to see the variations and the parameters affecting. Figure 5.5 displays that the total power consumed to achieve the same QoS values is more for Optimal Beamforming using only BS when coompared to both Optimal Spatial SoftCell coordination and Low Complexity RZF Beamforming algorithm. Table 5.3, displays the behavior of the produced graph, which is mostly concerned with the quality of services(QoS) and the corresponding total power consumed for that QoS.

This shows that by doubling the number of antennas at the BS and SCAs and decreasing the transmit power per subcarrier at the BS and SCAs by gradually we were able to achieve the same QoS values but with an increase in the total power when compared with the base graph. The total power consumed to achieve the same QoS value by the Low Complexity RZF Beamforming is slightly more than that of the Optimal Spatial SoftCell coordination algorithm due to very the reason that Low Complexity RZF consumes more energy to perform complex mathematical operations needed to prevent interferences.

Chapter 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

- The total power of Only BS to achieve the required QoS is higher than the Low Complexity RZF and Spatial Soft Cell approach, due to high amount of power required to overcome the interference.

- We can achieve same Quality of Service (QoS) requirements with reduced total power with both Low Complexity RZF algorithm and Spatial Soft Cell usage.

- The total power of Low Complexity RZF is slightly more than the Spatial Softcell because of its high complexity and computational requirements. Still this approach is better due to its ability to mitigate user interference making it practical for real world applications.

- The reduction in the total power consumption , thus increases the energy efficiency of the hybrid system of the massive MIMO base station and the small cell access points.

- Thus, the proposed RZF approach used to reduce the power consumption in the system works much more optimally and is more valid practical solution , in comparison with other two approaches compared.

6.2 Future Scope

- Real-world Deployment: The proposed framework can be deployed in real-world cellular networks to evaluate its effectiveness under actual operating conditions. This can provide insights into the practical challenges and benefits of the framework.

- Optimization of Network Slicing: Network slicing is a technique used in 5G networks to partition a single physical network into multiple virtual networks. The proposed framework can be optimized for network slicing to support diverse applications with different energy requirements.

- Integration with AI/ML Techniques: The use of AI/ML techniques in wireless networks is becoming more prevalent. The proposed framework can be combined with AI/ML techniques to improve network performance and energy efficiency.

- Improvised Experience for users : The use of massive MIMO in the future advancements, will surely be one of the strong reasons to provide most user friendly applications and services, as there wont be much loss in the data transmission when compared to 4G and hence will be much more improvised than the current scenario.

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Appendix A

In this project, we aimed to reduce the cellular power consumption by simulating the combined use of Massive MIMO and Small-Cells technologies. This appendix provides additional information on the methodology, tools, and results of our study.

Methodology

To conduct this study, we used a combination of analytical and simulation-based approaches. We first analyzed the power consumption of existing cellular networks and identified the areas where significant power savings could be achieved. We then developed a simulation model that incorporated both Massive MIMO and Small-Cells technologies. .

Tools

We used several tools and technologies to conduct this study. The following is a list of the main tools we used:

- MATLAB and Simulink: We used MATLAB and Simulink to create our simulation model and to analyze the simulation results.
- CVX software tool: CVX is a software package for specifying and solving convex optimization problems.

Discussion

The results of this simulation show that the combination of massive MIMO and small cells can significantly reduce cellular power consumption. This is a promising approach for future wireless networks, as it can help to reduce the environmental impact of wireless communication. There are a number of factors that could affect the performance of the proposed system, such as the number of antennas at the BS and SCAs, the path loss model, and the noise power. Further research is needed to investigate the impact of these factors on the performance of the system.