MAXIMIZATION OF ENERGY-EFFICIENCY FOR OPTIMAL SPECTRAL-EFFICIENCY IN MASSIVE MIMO SYSTEM

A Project report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

G. Akhila (319126512083) **Ch. Sai Tejasri (319126512075)**

B. Sai Manasa (319126512071) **M. Nitish Kumar (319126512097)**

Under the guidance of

Dr. B. Somasekhar

M.E., Ph.D., MISTE, MIEEE

Associate Professor

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES

(UGC AUTONOMOUS)

(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC)*

Sangivalasa, Bheemili Mandal, Visakhapatnam Dist.

(A.P)

2022-2023

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES(A)
(UGC AUTONOMOUS)
(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC*)
SANGIVALASA, BHEEMILI MANDAL, VISAKHAPATNAM DIST. (A.P)

PRAGNANAM BRAHMA

ANITS

CERTIFICATE

This is to certify that the project report entitled **"MAXIMIZATION OF ENERGY-EFFICIENCY FOR OPTIMAL SPECTRAL-EFFICIENCY IN MASSIVE MIMO SYSTEM"** submitted by **G. Akhila (319126512083), Ch. Sai Tejasri (319126512075), B. Sai Manasa (319126512071) , M. Nitish Kumar (319126512097)** in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Anil Neerukonda Institute of technology and Sciences(A), Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

Project Guide	**Head of the Department**
Dr. B. Somasekhar	Dr. B. Jagadeesh
Associate Professor	Professor and HOD
Department of E.C.E	Department of E.C.E
ANITS (A)	ANITS (A)

Associate Professor
Department of E.C.E.
Anil Neerukonda
Institute of Technology & Sciences
Sangivalasa, Visakhapatnam-531 162

Head of the Department
Department of E C E
Anil Neerukonda Institute of Technology & Sciences
Sangivalasa 162

ACKNOWLEDGEMENT

We would like to express our deep gratitude to our project guide **Dr. B. Somasekhar**, Associate Professor, Department of Electronics and Communication Engineering, ANITS, for his guidance with unsurpassed knowledge and immense encouragement.

We are grateful to **Dr. B. Jagadeesh**, Professor & Head of the Department, Department of Electronics and Communication Engineering, for providing us with the required facilities for the completion of the project work.

We are very much thankful to the **Principal and Management, ANITS, Sangivalasa**, for their encouragement and cooperation to carry out this work.

We express our thanks to all **Teaching Faculty** of the Department of ECE, whose suggestions during reviews helped us in accomplishment of our project. We would like to thank all **non-teaching staff** of the Department of ECE, ANITS for providing great assistance in the accomplishment of our project.

We would like to thank our parents, friends, and classmates for their encouragement throughout our project period. At last but not the least, we thank everyone for supporting us directly or indirectly in completing this project successfully.

PROJECT STUDENTS

G. Akhila (319126512083)

Ch. Sai Tejasri (319126512075)

B. Sai Manasa (319126512071)

M. Nitish Kumar (319126512097)

ABSTRACT

High Demand for wireless throughput, communication reliability, and user density, in recent era of wireless connectivity, posting a significant challenge in the research community. To address this, Multiple Input and Multiple Output (MIMO) systems, emerged as an effective wireless technology, where more users can be accommodated with the diversified huge number of antennas. The vast energy consumption of wireless communication systems has been becoming a daunting task, with increase in users, to be dealt precisely.

Hence, in this project, an attempt put forth to present a decent study on impact of the energy efficiency (EE) on the Massive MIMO system. It is inferred that the maximal EE is attained when the base station is given several antennas and is configured to operate in "massive MIMO" mode, which lowers the energy cost per user due to multiplexing of many users and array gain from coherent detection reduces interference.

In this work, the energy efficiency maximization problem is solved analytically with respect to the number of antennas in Base Station, cell capacity(users) and pilot reuse factor. It is also evident from the study, that Spectral Efficiency (SE) gets effected with maximizing the energy efficiency. Furthermore, basic principles of the EE-SE tradeoff in relation to important system parameters, like the number of antennas in a base station and user equipment, are also explored.

CONTENTS

LIST OF FIGURES

LIST OF ABBREVATIONS

EE	Energy Efficiency
SE	Spectral Efficiency
MIMO	Multiple Input Multiple Output
BSs	Base Stations
UEs	User Equipment’s
DL	Downlink
UL	Uplink
OFDM	Orthogonal Frequency Division Multiplexing
MMSE	Minimum Mean Square Error
ASE	Area Spectral Efficiency
ATP	Area Transmit Power
PC	Power Consumption
CP	Circuit Power
ETP	Effective Transmit Power
BR	Bit Rate
SNR	Signal To Noise Ratio
SINR	Signal To Interference Plus Noise Ratio

CHAPTER 1

Introduction

CHAPTER 1
Introduction

1.1 WIRELESS COMMUNICATION

Transferring the data over a distance without any electrical conductors or "wires" is referred to as wireless communication. It is the transmission of information from one place to another using electromagnetic waves. Wireless communication can be either one-way or two-way, depending on the specific application. One-way communication, also known as broadcasting, involves the transmission of information from one device to multiple devices without the ability for those devices to respond. Two-way communication, on the other hand, allows for devices to both send and receive information.

We see many fields, including telephony, medicine, the military, and business, use wireless communication. Due to the growing usage of wireless communication, numerous standards and protocols that control how wireless devices communicate with one another have been developed. All wireless devices, regardless of their type or manufacturer, should be able to communicate with one another without any issues thanks to these standards and protocols.

The expansion in the usage of wireless communication has significantly entered into new dimensions. The days of connected telephones, computers, and Internet connections that could only be used in certain locations are long gone. Nowadays, these wireless communication services are accessible all over the Earth. As with electricity, wireless networking has become a need in modern civilization, and as a result, the technology itself encourages the development of new services and applications.

Wireless communication is applicable for many uses, including mobile communication (such as cell phones and smartphones), internet connectivity (such as Wi-Fi and Bluetooth), satellite communication, and broadcast communication (such as television and radio).

1.1.1 Types of Wireless Communication

1. **Wi-Fi:**

This is a wireless communication technique that sends data between devices using radio waves. Devices are frequently connected to the internet or a local network using Wi-Fi.

Wi-Fi is a wireless network which uses less power. They are accessible virtually everywhere on earth. In essence, a router is linked to a physical wired network. It develops a wireless network that is very localized.

2. **Bluetooth Communication:**

Bluetooth is a wireless technology standard used for exchanging data over short distances. It is commonly used in wireless earbuds, smartphones, and other personal devices.

Physical cords were intended to be replaced by Bluetooth technology at first. It does, however, have some drawbacks. It can extend 30 feet at most. Walls and other sturdy objects can help to limit this even more, but they cannot completely stop it.

3. **Infrared Communication:**

Infrared light is used in this sort of wireless communication to transfer data between devices. The majority of consumer electronics gadgets, including TV remote controls, employ infrared communication. Information is transmitted via IR using invisible light.

A transmitter and a photoreceiver are needed for infrared communication to receive the light beam. Infrared only works when there is line-of-sight visibility since any obstruction to the light will prevent the photoreceiver from receiving it.

4. **Broadcast Radio**

A form of wireless communication called broadcast radio communication involves the long-distance transmission of audio signals. Radio waves, a type of electromagnetic energy that can traverse the air, are used in this method of communication.

Radio broadcasting is used to transmit a wide variety of content, including news, music, talk shows, and other types of programming. Radio signals are typically broadcast over a specific frequency, which is set aside for the exclusive use of a particular station. To receive the broadcast, listeners use a radio receiver, which is designed to pick up the signal and convert it back into an audio signal that can be heard through speakers or headphones.

5. Microwave Communication

The worldwide use of microwave technology shows how useful it is for communication. There are two different categories for this technology.

Satellite Microwave Communication

Satellite microwave communication involves the use of a communication satellite to relay signals between two ground-based locations. The satellite receives signals from one location and retransmits them to another location on Earth. This allows for communication over long distances and in areas where it is difficult or impossible to lay fiber optic cables, such as in remote areas or across oceans. Satellite communication is commonly used in applications such as satellite television broadcasting, global positioning systems (GPS), and military and government communication.

Terrestrial Microwave Communication

Terrestrial microwave communication involves the use of microwave antennas mounted on towers or other structures to transmit signals between two ground-based locations without the need for a satellite. Terrestrial microwave communication is typically used in local or regional communication systems, such as cellular networks, wireless internet service providers, and private networks. It is also used in broadcasting, such as in the transmission of television signals from a broadcasting station to a local TV station.

6. Cellular Communication:

This is a type of wireless communication that uses cellular networks to transfer information between devices. Cellular communication is generally used for mobile phones, electronic gadgets etc.

7. **Mobile Communication Systems**

Similar technology to Wi-Fi is used in the growing mobile phone industry, but on a much larger and safer scale. Customers of mobile phone carriers are covered on a national or even worldwide level.

They accomplish this by utilizing a sophisticated fusion of satellite assistance, local networks, and transmitters.

8. Satellite Communication:

This form of wireless communication send data far distances using satellites. Satellite communication is commonly used for GPS navigation, satellite phones, and other applications that require communication over remote areas.

For many years, the volume of wireless voice and data transmissions has increased at an exponential rate. This pattern is known as Cooper's rule observed in the 1990s by Martin Cooper. In the near future, demand for wireless data access will likely continue to rise because our society is moving into networked zone where all technological devices link to the Internet.

A significant concern is how to advance present wireless communications technologies to fulfil the steadily rising demand and avert an impending data traffic congestion. How to meet the escalating demands of service quality is a matter of equal importance. Industrial and university researchers must work tirelessly to develop new cutting-edge wireless network technologies if they hope to keep up with the exponential growth rate of traffic and concurrently provide universal connections. The Massive Multiple-Input Multiple-Output (MIMO) technology is defined in detail along with the reasons why it is a promising way to handle more wireless data traffic than existing systems.

1.2 CELLULAR NETWORK

A cellular network is a telecommunications network that allows mobile devices, such as smartphones and tablets, to communicate with each other and with the internet through a series of interconnected cell sites or base stations. The network is divided into cells, each of which is served by a base station. The base station communicates with the mobile devices within its cell, and also communicates with other base stations in neighboring cells to create a seamless network.

These networks are typically operated by wireless carriers, such as AT&T, Verizon, and T-Mobile in the United States, who license the use of the wireless spectrum from the government and provide service to customers through various service plans.

The benefits of cellular networks include the ability to make and receive calls and messages, access the internet, and use mobile applications from almost anywhere, if there is coverage. Cellular networks have become increasingly important in modern society, providing essential communication and information services to individuals, businesses, and governments.

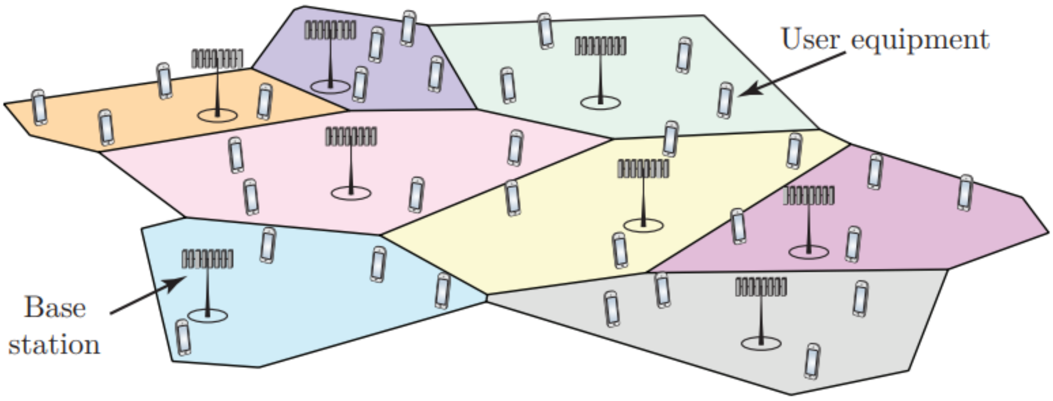

Figure 1.1: A Basic Cellular Network

A cellular network consists of a set of base stations and a set of user equipment's. Each user equipment (UE) is associated with a base station (BS), that offers service to it. The transmissions from the UEs to their respective BSs are referred to as the uplink (UL), signals delivered from the BSs to their respective UEs are referred to as the downlink (DL).

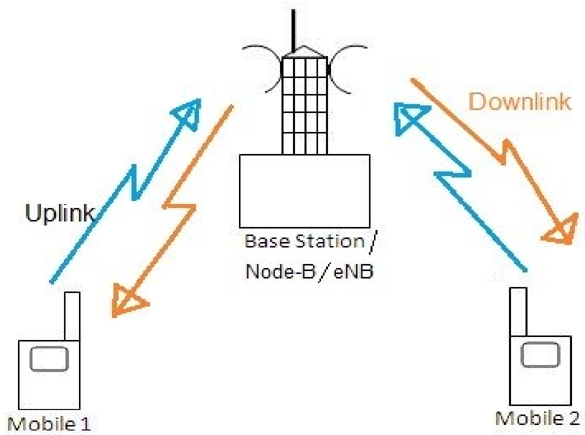

Figure 1.2: Uplink and Downlink

Although wireless data transmissions currently predominate, wireless voice communications were the primary purpose of cellular networks. The majority of cellular network traffic and the anticipated rise in traffic demand are both driven by video on-demand. Hence, the area throughput is a very important performance indicator for both current and future cellular networks. It is further observed, to achieve high network's area throughput:

1. Bandwidth allocation should be increased,
2. the network should be made denser by adding more BSs,
3. the SE per cell should be improved.

INTER-CELL AND INTRA-CELL COMMUNICATION:

In wireless communication, inter-cell communication and intra-cell communication refer to the communication between cells and within a cell, respectively.

Intra-cell communication: This refers to communication that occurs within a single cell or base station. In cellular networks, a cell is a geographical area covered by a base station, which provides wireless coverage to mobile devices within that area. Intra-cell communication is used to transmit data and signals between the base station and mobile devices within the same cell. It is also used for communication between different components of the base station itself, such as the antenna and control unit.

Inter-cell communication: This refers to communication that occurs between different cells or base stations. In a cellular network, adjacent cells are typically connected to each other and to a central network through a backhaul link. Inter-cell communication is used to enable handover of mobile devices from one cell to another as the user moves through the network, and to manage the allocation of resources and traffic between different cells.

In summary, intra-cell communication is the communication that takes place within a single cell or base station, while inter-cell communication is the communication that takes place between different cells or base stations. Both types of communication are important for enabling wireless networks to provide coverage and connectivity to mobile devices.

1.3 GENERATIONS OF WIRELESS COMMUNICATION

There are several different generations of wireless communication technologies that have been developed over the years, each with its own set of characteristics and capabilities.

First generation (1G):

First generation (1G) refers to the first commercially available analog cellular mobile phone systems that were introduced in the 1980s.1G networks used analog technology to transmit voice signals over the airwaves, with each call taking up a dedicated frequency channel. These networks were characterized by their limited coverage area, poor voice quality, and high cost. The first 1G phones were large and bulky, with limited battery life and only basic features such as voice calling and text messaging.

Second generation (2G):

Second generation (2G) refers to the second generation of cellular mobile phone systems, which were introduced in the 1990s. Unlike the analog 1G systems, 2G networks used digital technology for voice transmission and provided higher quality, greater security, and more efficient use of the radio spectrum. 2G networks were characterized by their use of digital signaling and circuit-switched technology, which allowed for improved voice quality and faster call setup times. In addition, 2G networks introduced new features such as text messaging, picture messaging, and basic data services.

Third generation (3G):

Third generation of cellular mobile phone systems, which were introduced in the early 2000s. 3G networks were a significant improvement over their 2G predecessors, offering faster data transfer rates, better voice quality, and more advanced features such as video calling and mobile internet access. One of the key benefits of 3G networks was their ability to support mobile internet access, enabling users to browse the web, send and receive email, and access a wide range of online services from their mobile devices. This opened up new opportunities for mobile operators and service providers, and helped to drive the growth of the mobile internet and the smartphone market.

Fourth generation (4G):

Fourth-generation wireless technology further increased data transfer rates and introduced new features such as video calling and mobile TV. This was introduced in the mid-2000s and includes technologies such as LTE and WiMAX, which provided higher data transfer rates and improved spectral efficiency. The data rate is the primary distinction between 3G and 4G. MIMO (Multiple Input Multiple Output) and OFDM are the two main technologies that have made 4G viable (Orthogonal Frequency Division Multiplexing). One of the key benefits of 4G networks was their ability to support bandwidth-intensive applications such as high-definition video streaming and online gaming, which were not possible on earlier generations of mobile networks.

Fifth generation (5G):

Fifth-generation wireless technology, which is currently being rolled out and promises even more capacity, lower latency, and quicker data transmission rates. Additionally, it has new components including huge machine-type communications and network slicing.

The way we engage and communicate with one another, as well as with our devices and the internet, has changed with each new generation of wireless technology that has been developed.

1.3.1 Comparison of 4G and 5G

Speed: 5G is designed to be much faster than 4G, with peak data transfer rates up to 20 Gbps, while 4G typically offers peak data rates up to 1 Gbps.

Latency: 5G is designed to have much lower latency than 4G, with typical latency of 1 ms, compared to 4G's typical latency of 30-50 ms.

Network capacity: 5G is designed to have much greater network capacity than 4G, meaning that it can support many more devices and users in the same area.

Energy efficiency: 5G is designed to be more energy-efficient than 4G, which is important for devices such as smartphones and other IoT devices that need to conserve battery life.

Spectrum: 5G uses higher frequency bands than 4G, which can offer greater capacity but require more infrastructure to cover the same area.

Applications: 5G is expected to enable new applications and services, such as augmented reality, virtual reality, and autonomous vehicles, which would be difficult or impossible to support with 4G.

Overall, 5G is designed to be a significant improvement over 4G in terms of speed, latency, capacity, and energy efficiency. It is expected to enable new and innovative applications and services that were previously not possible or practical with 4G technology.

CHAPTER 2

Literature Survey

CHAPTER 2

Literature Survey

2.1 LITERATURE SURVEY RELATED TO ENERGY EFFICIENCY

According to Jingon Joung, Chin Keong Ho, and Sumei Sun, two crucial metrics for wireless communication systems are Energy Efficiency (EE) and Spectral Efficiency (SE). However, in OFDM systems, non-linear effects and Power Amplifier (PA) inefficiencies have caused practical design challenges, impacting the SE/EE trade-off. The PA switching technique can enhance the SE-EE tradeoff, as demonstrated by a 323% increase in EE with only a 15% reduction in SE. The study highlights the importance of Power Amplifier, Power Amplifier switching, Spectral Efficiency, and Energy Efficiency as critical index terms in this area of research.

According to Jie Xu and Ling Qiu, studying the fundamental Energy Efficiency (EE) limits of MIMO broadcast channels (BC) is crucial for the advancement of eco-friendly wireless communication. They addressed the optimization of EE for MIMO-BC, incorporating a valuable power model that considers transmit-independent power linked to the number of active transmit antennas. They proposed a novel optimization approach based on active transmit antenna selection (ATAS), which optimizes the transmit covariance given a fixed set of active transmit antennas.

According to a research article, Chunlong He, Geoffrey Li, and You Xiaohu developed an energy-efficient resource-allocation scheme for down-link multiuser orthogonal frequency-division multiplexing (OFDM) systems with distributed antennas .Their main objective is to maximize energy efficiency (EE) while adhering to the constraints of each remote access unit's (RAU's) overall transmit power, proportional fairness data rates, and bit error rates. Due to the optimization problem's nonconvex nature, finding the optimal solution is computationally complex. To simplify the process, a low-complexity suboptimal method is used, which separates subcarrier allocation from power allocation. First, subcarriers are allocated assuming an equal power distribution. Then, the nonconvex optimization issue in fractional form is transformed into an equivalent optimization problem in subtractive form, which can be more easily solved using fractional programming.

According to a research article, Emil Bjornson, Luca Sanguinetti, and Marios Kountouris explored the design of a cellular network optimized for maximal energy efficiency. The study used stochastic geometry methods to model future cellular networks and obtain a new lower constraint on the average uplink spectral efficiency. By considering the number of base station (BS) antennas and users per cell, as well as the pilot reuse factor, the authors were able to formulate a manageable uplink energy efficiency (EE) maximization problem and solve it analytically. The closed-form expressions generated by this comprehensive framework for EE maximization provide valuable insights into the relationships between optimization variables, hardware properties, and propagation environment.

A group of researchers consisting of F.Meshkati, H.V.Poor, S.CSchwartz, and N.B.Mandayam investigated the cross-layer design problem of joint multiuser detection and power control, emphasizing energy efficiency through a game-theoretic approach. The study proposed a non-cooperative game, where users in the network can choose their uplink receivers and transmit powers to maximize their own utility. The study focused on the uplink of a direct-sequence code-division multiple-access data network and formulated a utility function that counts the number of reliable bits the user transmits per joule of energy consumed. With linear receivers as the main concern, the Nash equilibrium for the proposed game was obtained. The research demonstrated that the powers should be balanced in terms of the signal-to-interference-plus-noise ratio, and the receiver should be an MMSE detector to achieve equilibrium. Furthermore, the research compared the performance of the receivers in terms of the utility achieved at equilibrium, which is measured in bits per joule.

A research team comprising of Derrick Wing Kwan Ng, Ernest S.Lo, and Robert Schober investigated the design of a resource allocation algorithm for multiuser orthogonal frequency division multiplexing (OFDM) downlink systems with simultaneous wireless information and power transfer. The algorithm aims to maximize the energy efficiency of data transmission measured in bits per joule delivered to the customers. The issue formulation takes into consideration the circuit power consumption, the minimum required power transfers to the users, and the minimum system data rate. The study employs an iterative resource allocation approach that utilizes the time-sharing method and the properties of nonlinear fractional programming to solve the non-convex optimization issue. Using Lagrange dual decomposition, the optimal power allocation and user selection solution are obtained for each iteration.

Shuang Yang, Yueming Cai, Wendong Yang, Jianchao Zheng, and Tao Zhang proposed a resource allocation scheme for multi-cell orthogonal frequency division multiple networks with different user distributions in each cell. Their objective was to maximize the energy efficiency of the entire network, while considering circuit power consumption, minimum data rate requirements, and fairness weights for user distribution. To solve the non-convex optimization problem, the Dinkelbach method was used to convert it into a subtractive optimization problem, and an iterative solution was proposed with separate implementations of subcarrier and power allocations. The proposed algorithm was able to balance capacity between cells with varying user densities in a few iterations.

The study by Yang Lu, Ke Xiong, Yu Zhang, Pingyi Fan, and Zhangdui Zhong addresses energy-efficient resource allocation in OFDM relay networks, where K users receive information via L relays. The objective is to maximize system energy efficiency (EE) by optimizing relay selection, subcarrier assignment, and power allocation while adhering to proportional rate and available power constraints. Because the optimization problem is non-convex with integer variables, existing techniques are inadequate for solving it. To address this issue, the authors present a low-complexity solution that effectively tackles the problem. Simulation results demonstrate that their proposed resource allocation strategy can produce near-ideal outcomes. The study also highlights the importance of circuit power, which includes a constant and rate-dependent component, in restricting EE resource allocation and achieving high spectral efficiency.

Jingon Joung, Chin Keong Ho, and Sumei Sun proposed a novel power amplifier (PA) switching/selection (PAS) method for enhancing energy efficiency (EE) of multiple-input multiple-output (MIMO) systems. Their approach employs a combination of high-MaxOut PAs and low-MaxOut PAs that are identical to each other. The objective is to select the PAs with the highest EE that can support a target rate with the matching power level. The proposed method outperforms other methods such as employing similar PAs with or without power regulation, and MIMO systems with equal PAs and the same amount of PAS feedback, particularly in the low target rate domain where the low-MaxOut PAs are more energy efficient. Numerical findings demonstrate the effectiveness of the proposed PAS.

Ruoguang Li, Li Wang, Mei Song and Zhu Han proposed a resource allocation scheme for secure communication in an OFDM-based FD relaying network, aiming to maximize overall secure energy efficiency while satisfying a power constraint and minimal secrecy requirement. The problem involves subcarrier pairing and power allocation, which are solved using mathematical tools such as fractional programming, dual decomposition, alternative convex search, and DC programming. The proposed iterative algorithm converts the non-convex optimization problem into a convex one. Simulation results show that the suggested technique achieves good secure energy efficiency.

2.2 LITERATURE SURVEY RELATED TO SPECTRAL EFFICIENCY

Aymen Omri, Mazen O. Hasna, and Mohammed Nafie proposed a novel performance metric called effective area spectral efficiency (EASE) to evaluate the spectral efficiency and spatial characteristics of point-to-point transmission systems and decode and forward (DF) relaying networks with interference management. The authors derived a closed-form expression for the maximum transmission range for each transmission mode in a Rayleigh fading channel. They computed the average impacted area and the average ergodic capacity using the maximum transmission range and introduced the EASE equation to quantify the spatial spectrum utilization efficiency. The EASE metric for DF relaying is based on the source relay communication index (SRCndx). The authors demonstrated how the EASE metric can offer a fresh perspective on wireless transmission design, particularly in selecting the transmission power, through mathematical analysis and numerical simulations.

Xiu Zhang, Hao Qi, Xin Zhang, Liang Han stated that wireless signal transmission in harsh environments requires high quality of service for energy loss mitigation, channel estimation, and noise interference reduction. To meet these requirements, massive multiple-input multiple-output (MIMO) networks have been used in fifth-generation wireless communication. In particular, massive MIMO networks without cells are considered a promising solution for future wireless communication. Spectral efficiency (SE) is a crucial metric for evaluating such networks. This paper aims to enhance the SE and power control of massive MIMO networks without cells in both uplink and downlink transmission. The optimization model includes both SE and power control.

The authors, Jehangir Arshad, Abdul Rehman, Ateeq Ur Rehman, and Rehmat Ullah, investigated the use of massive MIMO systems to improve the area throughput by increasing the SE of each cell. They aimed to find optimal values of average cell-density (D), available bandwidth (B), and SE to maximize the area throughput. The study developed a SE augmentation model that incorporates increased transmit power and antenna array gain, while considering inter-user interference from neighboring cells and the incident angles of desired and interfering users.

Ali M.A. and E.A. Jasmin investigated ways to optimize the spectral efficiency (SE) of a Time Division Duplex (TDD) massive MIMO system. They evaluated the system's performance under practical constraints, including limited coherence block length, number of base station (BS) antennas, and number of active users, using simulation. The study also compared the SE performance of two linear precoding techniques, namely, zero forcing (ZF) and maximum ratio combining (MRC). According to the simulation results, a massive MIMO system with hundreds of BS antennas can achieve significant improvements in spectral efficiency.

2.3 PROBLEM IDENTIFICATION

The problem identified in the study is the lack of energy efficiency in wireless communication technologies, resulting in short battery life, increased energy consumption, limited range, reduced network capacity, and higher costs. With the exponential growth of mobile devices in a particular area, each new mobile generation has brought with it a rise in energy consumption. To address this issue, the mobile industry is pursuing 5G technology, which has the potential to significantly expand traffic while reducing energy consumption across the network. The study aims to develop and deploy energy-efficient wireless communication technologies to minimize these issues and improve the overall performance and sustainability of wireless networks, which can have a significant impact on users, network operators, and the environment.

CHAPTER 3

Massive MIMO and Small Cells

CHAPTER 3
Massive MIMO and Small Cells

3.1 INTRODUCTION TO MASSIVE MIMO

The development of the cellular infrastructure began with the introduction of 1G analog systems, followed by 2G and 3G. These units were connected to the antennas at the top of a tall tower by thick low-loss coaxial cables that had amplifiers built in to make up for the power loss in the coaxial cables. Distributed networks, which were previously only employed in 1G and 2G systems, are now used in 3G and 4G systems. In traditional wireless networks, a small number of antennas are used at the base station to communicate with a large number of users. This approach can lead to congestion and interference, which can limit the capacity of the network and reduce the quality of the signal. With Massive MIMO, the number of antennas at the base station is greatly increased, which allows for more precise control of the radio signal and reduces interference.

Massive MIMO also uses advanced signal processing algorithms to optimize the transmission and reception of data, which further improves the efficiency and capacity of the network. By using a large number of antennas, Massive MIMO can provide significant improvements in data transfer rates and coverage, even in areas with high levels of interference.

3.2 TYPES OF MOBILE ANTENNA SYSTEMS

Modern mobile networks employ multi-antenna systems and sophisticated antenna systems. There are four different types of antenna systems: MIMO, SISO, SIMO, and MISO.

3.2.1 Single Input Single Output (SISO)

SISO is the simplest type of wireless communication system, with a single antenna at both the transmitter and receiver.

Since SISO antennas use just one antenna each for transmitting and receiving, they are unable to accomplish broadcast or receive diversity when used between a base station and a mobile phone, making them incapable of overcoming the effects of signal fading. The choices for enhancing signal quality and lowering disturbance in SISO are constrained, despite the fact that it is a straightforward implementation.

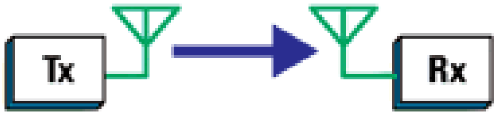

Fig 3.1 : Single Input Single Output (SISO)

3.2.2 Single Input Multiple Output (SIMO)

A single transmitting antenna (single input) and numerous receiving antennas are used in SIMO, or Single Input Multiple Output (multiple outputs). By enabling the receiver to receive the same signal over many antennas, SIMO helps networks lessen the detrimental effects of signal fading.

SIMO is founded on the receive diversity principle, which takes advantage of a wireless signal's multipath fading by adding numerous antennas for various paths. After combining the transmissions they have received using antenna diversity, the receiving antennas reproduce the signal. SIMO enhances the quality of the data connection while maintaining the same channel capacity.

SIMO increases the likelihood that a mobile phone's radio transmissions will be picked up by the base station's numerous reception antennas when it is used to connect a mobile phone and radio base station (cell tower).

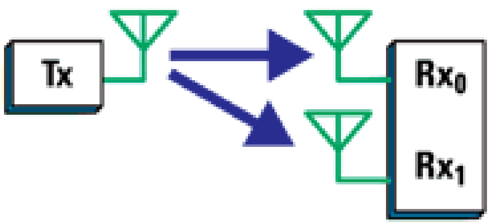

Fig 3.1: Single Input Multiple Output (SIMO)

3.2.3 Multiple Input Single Output (MISO)

Multiple Input Single Output (MISO) is a wireless communication technology that uses multiple antennas at the transmitter and a single antenna at the receiver. In MISO systems, the transmitter sends multiple data streams, each transmitted from a different antenna, to the receiver. The receiver then combines the received signals to reconstruct the original data.

MISO systems can offer several advantages over traditional single-antenna wireless communication systems. MISO systems can provide better data transfer rates, improved signal quality, and increased coverage. The use of multiple antennas at the transmitter allows for spatial diversity, which helps to mitigate the effects of fading and interference.

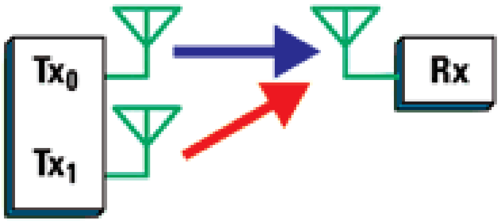

Fig 3.3 : Multiple Input Single Output (MISO)

3.2.4 Multiple Input Multiple Output (MIMO)

MIMO or Multiple Input Multiple Output is a wireless communication system that uses multiple antennas at both the transmitter and receiver to provide improved performance and increased capacity.

In a MIMO system, the transmitter sends multiple data streams to the receiver by simultaneously transmitting the same signal over multiple antennas. At the receiver, the multiple signals are separated and decoded to reconstruct the original data. This technique can increase the data rate, improve the reliability of the wireless link, and extend the range of the wireless network.

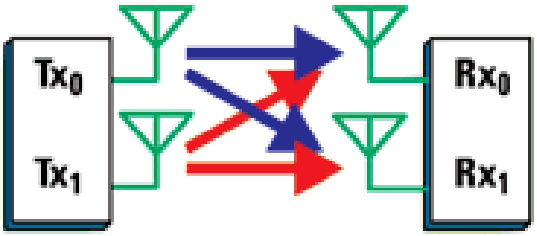

Fig 3.2: Multiple Input Multiple Output (MIMO)

3.3 TYPES OF MIMO SYSTEMS

There are several types of MIMO systems, including:

- **Spatial Multiplexing MIMO:** This type of MIMO system uses multiple antennas at the transmitter and receiver to transmit multiple data streams simultaneously over the same frequency band. This allows for higher data rates and improves spectral efficiency.
- **Diversity MIMO:** Diversity MIMO uses multiple antennas at the transmitter and receiver to improve the reliability of the wireless communication link by providing multiple signal paths. This helps to reduce the effects of fading and interference, resulting in a more stable and reliable wireless connection.
- **Beamforming MIMO:** Beamforming MIMO uses multiple antennas to create a directional signal that is focused on a specific receiver. This helps to increase the signal strength and improve the quality of the wireless connection, particularly in areas with high interference or a weak signal.
- **Cooperative MIMO:** Cooperative MIMO involves the cooperation of multiple users to transmit and receive signals. This can help to improve the reliability and efficiency of the wireless communication link by allowing users to share resources and cooperate to transmit and receive signals.
- **Multi-User MIMO:** Multi-User MIMO allows for the transmission of multiple data streams to multiple users simultaneously. This type of MIMO system can improve the overall capacity and efficiency of the wireless network by allowing for multiple users to transmit and receive data at the same time.
- **Massive MIMO**: Massive MIMO is an advanced type of MIMO system that uses a large number of antennas at the base station to provide improved

performance and increased capacity. In massive MIMO, there can be hundreds or even thousands of antennas at the base station, which can serve multiple user devices simultaneously.

3.4 FUNCTIONS OF MIMO

The main functions of MIMO (Multiple-Input Multiple-Output) technology in wireless communication systems are:

- **Increased data rate:** MIMO systems use multiple antennas at both the transmitter and receiver to transmit and receive multiple data streams simultaneously. This allows for higher data rates and improves spectral efficiency, as more data can be transmitted over the same frequency band.
- **Improved reliability and signal quality:** MIMO systems use multiple signal paths between the transmitter and receiver, which helps to reduce the effects of fading and interference, resulting in a more stable and reliable wireless connection.
- **Extended range:** By using multiple antennas, MIMO systems can transmit and receive signals over a longer distance, enabling wireless communication over a larger area.
- **Reduced power consumption:** MIMO systems can achieve higher data rates with lower power consumption, resulting in better battery life for mobile devices.
- **Improved network capacity:** MIMO systems can support multiple users and devices simultaneously, enabling a greater number of users to connect to the network and use high-bandwidth applications such as video streaming and online gaming.

3.5 MASSIVE MIMO (MULTIPLE-INPUT MULTIPLE-OUTPUT)

Massive MIMO (Multiple-Input Multiple-Output) is an extension of MIMO technology that increases the efficiency and capability of wireless communication systems by using numerous antennas at the transmitter and receiver. Typically, two or four receivers are used in MIMO networks. On the other hand, massive MIMO, which is a MIMO device with a particularly large number of antennas. The number of antennas in a massive MIMO (Multiple Input Multiple Output) system can vary, but typically it is on the order of hundreds or even thousands of antennas at the base station. In fact, one of the defining characteristics of massive MIMO is the large number of antennas, which provides a high degree of spatial diversity and enables the use of advanced spatial multiplexing techniques to improve the capacity and efficiency of wireless communication systems.

By using many antennas, the system can transmit multiple data streams to multiple users simultaneously with very high spectral efficiency. Massive MIMO systems rely on sophisticated signal processing techniques and beamforming algorithms to manage the complexity of processing the large number of signals transmitted and received. These systems can improve the data rate, network capacity, and overall reliability of wireless communication networks.

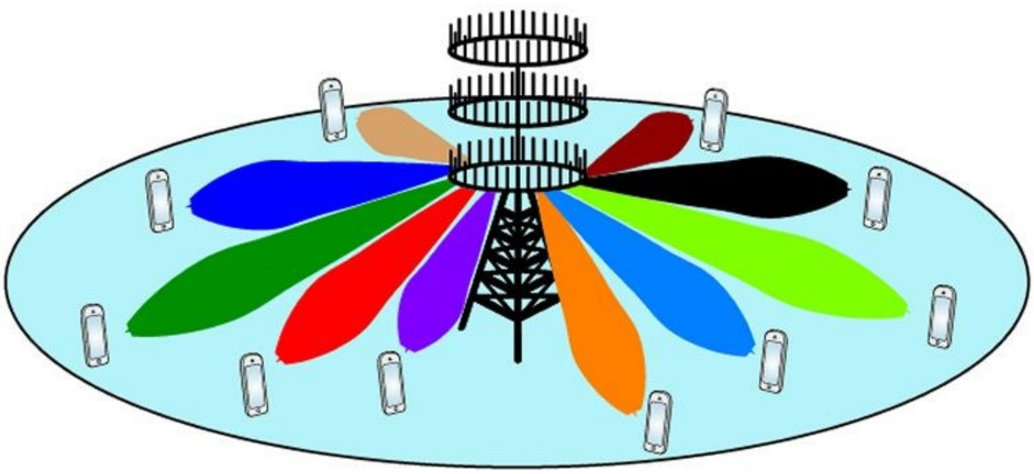

Fig 3.5: Massive MIMO

Massive MIMO is a promising technology for 5G and beyond, and it has the potential to revolutionize the wireless communication industry by enabling high-speed data transfer, low latency, and high-reliability communication.

3.5.1 Benefits of Massive MIMO

- **Increased network capacity:** Massive MIMO can support many users and devices simultaneously, enabling more users to connect to the network and use high-bandwidth applications.
- **Improved spectral efficiency:** With many antennas, Massive MIMO can transmit and receive multiple data streams simultaneously, resulting in higher spectral efficiency.
- **Enhanced coverage and reliability:** Massive MIMO can use beamforming to focus the signal on the direction of the receiver, resulting in improved coverage and reliability, even in areas with high interference and noise.
- **Lower power consumption:** Massive MIMO can achieve higher spectral efficiency with lower transmit power, resulting in lower power consumption and longer battery life for mobile devices.

Overall, Massive MIMO is a key technology in 5G networks, providing increased capacity, higher data rates, and improved reliability and coverage, which are essential for the next generation of wireless communications.

3.6 SMALL CELLS

Small cells are low-power, short-range wireless access points that are designed to provide localized wireless coverage in areas with high traffic density or where traditional macrocells are not effective. They are typically used to improve network capacity and coverage in indoor and outdoor areas such as shopping malls, airports, stadiums, and urban areas.

Small cells are low-power wireless access points that are used to improve wireless coverage and capacity in a specific area.

They are typically smaller and more compact than traditional macro cells (large cellular towers) and are deployed in areas where macro cells are unable to provide sufficient coverage or capacity.

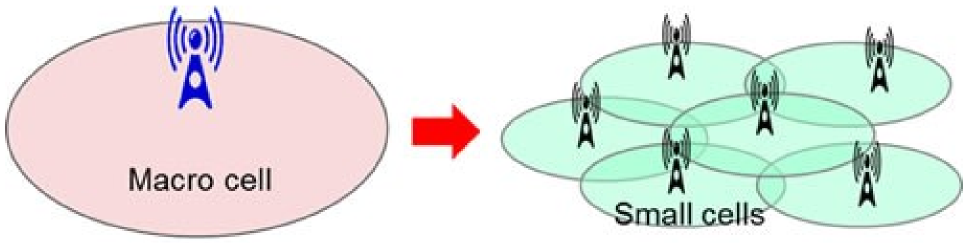

Fig 3.6: Small cells

3.6.1 Small Cell Categories

- **Femtocells:** These are small cells that are designed for use in residential or small business environments. They are typically used to improve indoor coverage and are connected to the network via a wired broadband connection.
- **Picocells:** These are small cells that are designed for use in small-to-medium sized indoor or outdoor environments. They are typically used to improve coverage in areas such as airports, shopping malls, and office buildings.
- **Microcells:** These are small cells that are designed for use in larger outdoor environments. They are typically used to improve coverage in areas such as sports stadiums, university campuses, and large public spaces.

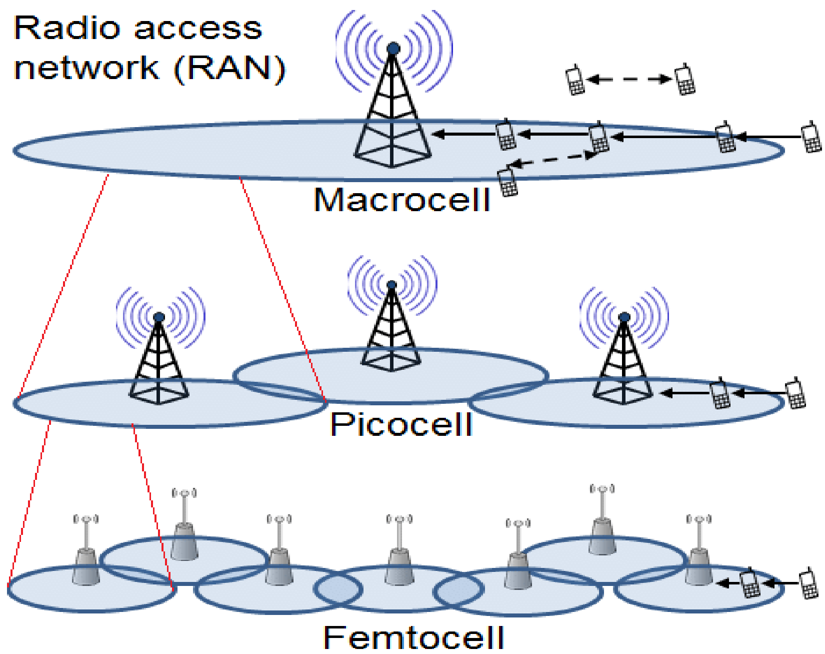

Fig 3.7: Small Cell Categories

Small cells can support a wide range of wireless technologies, including cellular (2G, 3G, 4G, and 5G), Wi-Fi, and Bluetooth, and can be deployed in different frequency bands. They can also be used to offload traffic from macro cells in areas with high demand, such as stadiums or shopping malls. This can help to reduce congestion on the network and improve overall performance.

Additionally, small cells can be used to provide wireless coverage in areas where it was previously unavailable, such as in rural areas or underground locations. They can also be used to provide additional capacity in areas with high demand, such as in urban areas with high population density.

Small cells can be deployed by wireless service providers, enterprises, or neutral host providers. They can be owned and operated by the service provider or leased to third parties such as neutral host providers, property owners or municipalities.

Small cells play an important role in wireless communication by improving coverage, capacity, and offloading traffic. They are widely used in different environments, supporting different wireless technologies and frequencies, and can be deployed by various entities.

3.6.2 Components of Small Cells

Small cells are typically made up of several components, including:

- **Radio Frequency (RF) Unit:** This is the component of the small cell that transmits and receives wireless signals. It includes the antenna, transceiver, and other RF components.
- **Baseband Unit (BBU):** This component of the small cell is responsible for processing the wireless signals. It includes the digital signal processor (DSP), memory, and other digital processing components.
- **Power Supply Unit (PSU):** This component of the small cell provides power to the other components. It can be powered by an AC or DC power source, or by a battery.
- **Control and Management Unit (CMU):** This component of the small cell is responsible for controlling and managing the other components of the small cell.

It can be used to monitor and configure the small cell, and to troubleshoot any issues that may arise.

- **Enclosure:** This component of the small cell houses the other components and provides protection from the elements. It can be made of various materials such as metal, plastic, or fiberglass.

3.6.3 Benefits of Small Cells

- **Increased network capacity:** small cells can help to offload traffic from overloaded macrocells, providing additional capacity and improving network performance.
- **Improved coverage and quality of service:** small cells provide localized coverage in areas where the macrocell signal may be weak or congested, resulting in improved voice and data quality.
- **Reduced cost and infrastructure requirements:** small cells require less infrastructure and are less expensive to deploy compared to traditional macrocells, making them a more cost-effective solution for expanding wireless coverage.
- **More flexible network design:** small cells can be easily deployed in a variety of locations and configurations, allowing for more flexible and customized network design.
- **Enable new services and applications:** small cells can support a wide range of new and emerging applications, such as internet of things (IoT) devices, augmented and virtual reality, and smart city applications.

CHAPTER 4

Energy Efficiency & Spectral Efficiency

CHAPTER 4

Energy Efficiency & Spectral Efficiency

4.1 INTRODUCTION TO ENERGY EFFICIENCY

Energy efficiency refers to the process of using less energy to accomplish the same task or achieve the same result. It involves minimizing the amount of energy required to power a device or perform an activity, without sacrificing performance or comfort.

Energy efficiency is important because it can help to reduce energy consumption, which can lead to a range of benefits, including cost savings, reduced greenhouse gas emissions, and improved energy security. By improving energy efficiency, it is possible to achieve the same level of service while using less energy, which can result in lower energy bills, reduced environmental impact, and improved sustainability.

Examples of energy efficiency measures include using energy-efficient light bulbs, upgrading to energy-efficient appliances, improving insulation in buildings to reduce heating and cooling needs, and using public transportation or carpooling to reduce fuel consumption. In general, energy efficiency is a key component of efforts to promote sustainable and responsible use of energy resources.

Energy efficiency is one of the easiest and most cost-effective ways to combat climate change, reduce energy costs for consumers.

4.2 ENERGY EFFICIENCY IN WIRELESS COMMUNICATION

Energy efficiency in wireless communication refers to the ability of a wireless communication system to transmit information while minimizing the amount of energy consumed in the process. This is an important consideration because wireless communication devices are typically powered by batteries, which have limited energy capacity.

Wireless networks use an increasing amount of energy to ensure quality of service as high-data-rate applications increase rapidly. As a result of limited energy resources and environmentally friendly transmission practises, energy-efficient communications have drawn more attention.

Energy efficiency is important in wireless communication for several reasons:

- Battery life: Most wireless devices are powered by batteries, which have limited energy capacity. Improving energy efficiency can help extend battery life and reduce the need for frequent recharging or battery replacement.
- Cost savings: Improved energy efficiency can also result in cost savings by reducing the energy consumption of wireless communication systems. This can lower the cost of operating and maintaining wireless networks, which can benefit both service providers and end-users.
- Environmental impact: Energy consumption in wireless communication can contribute to greenhouse gas emissions and other environmental impacts. By improving energy efficiency, it is possible to reduce the environmental footprint of wireless communication systems.
- Sustainability: Improving energy efficiency is an important step towards building more sustainable wireless communication systems. This is particularly important in the context of the Internet of Things (IoT), where a large number of small devices with limited battery life are expected to be deployed. By improving energy efficiency, it is possible to extend the battery life of these devices, reduce maintenance costs, and improve the overall sustainability of wireless communication networks.

Overall, improving energy efficiency in wireless communication is an important area of research and development, and can have significant benefits for both the environment and the economy.

4.3 ENERGY EFFICIENCY IN MASSIVE MIMO

Factors to maximize energy efficiency in massive MIMO:

- User scheduling: User scheduling is the process of selecting which users will be served by the BS in each time slot. Optimal user scheduling algorithms can reduce energy consumption by selecting users that are close to the BS, have strong channel conditions, or have low energy consumption requirements.
- Power control: Power control refers to the adjustment of the transmit power of the BS to achieve a desired signal-to-interference-plus-noise ratio (SINR) at each user. Energy efficiency can be improved by reducing the transmit power of the BS while maintaining a high SINR.
- Antenna configuration: The number of antennas and their arrangement at the BS can significantly impact energy efficiency. A properly designed antenna configuration can increase the spatial reuse of the available spectrum and reduce the total power consumption.
- Beamforming: Beamforming is the process of adjusting the phase and amplitude of the signals transmitted by each antenna to direct the energy towards the intended users and reduce interference to other users. Energy efficiency can be improved by using low-complexity beamforming algorithms that require less processing power.
- Energy-efficient hardware: The energy efficiency of the BS can also be improved by using energy-efficient hardware components, such as power amplifiers, low-power baseband processors, and efficient cooling systems.
- Improved signal processing: Advances in signal processing algorithms can help to reduce the energy required for transmitting and receiving signals, making the system more energy efficient.

By considering these factors and applying the appropriate techniques, energy efficiency can be significantly improved in massive MIMO systems, leading to a more sustainable and cost-effective communication infrastructure.

4.4 INTRODUCTION TO SPECTRAL EFFICIENCY

Spectral efficiency is a measure of how efficiently a communication system uses the available frequency spectrum to transmit information. It refers to the amount of information that can be transmitted over a given frequency bandwidth, typically expressed in bits per second per Hertz (bps/Hz).

A communication system with high spectral efficiency can transmit more information per unit of bandwidth, allowing more users to share the available spectrum without interfering with each other. Spectral efficiency is an important consideration in wireless communication systems because the available spectrum is limited and valuable and must be shared by multiple users.

Spectral efficiency can be improved by using advanced modulation and coding techniques, which allow more data to be transmitted over a given bandwidth. For example, using higher-order modulation schemes and more sophisticated error-correcting codes can increase spectral efficiency, but at the cost of increased complexity and sensitivity to noise and interference.

Spectral efficiency is often used as a key performance metric in wireless communication systems, and improving spectral efficiency is an important goal in the development of new wireless technologies. However, it is important to balance spectral efficiency with other performance metrics, such as reliability, latency, and energy efficiency, in order to achieve optimal overall system performance.

4.5 SPECTRAL EFFICIENCY IN WIRELESS COMMUNICATION

The importance of spectral efficiency in wireless communication can be explained by the following reasons:

Limited frequency spectrum: The frequency spectrum available for wireless communication is limited, and it is becoming increasingly congested with the growing number of wireless devices and services. Therefore, improving spectral efficiency is essential to make the most efficient use of the available spectrum.

Higher data rates: With the increasing demand for higher data rates in wireless communication, improving spectral efficiency is essential. Spectral efficiency directly impacts the amount of data that can be transmitted over a given bandwidth, and improving it allows for higher data rates and improved network capacity.

Cost efficiency: Increasing spectral efficiency can help reduce the cost of wireless communication services. By transmitting more data over the same frequency spectrum, more users can be accommodated, and fewer infrastructure investments may be required to meet the demand for wireless communication services.

Interference management: Spectral efficiency is closely related to interference management. As spectral efficiency increases, interference is reduced, leading to better network performance, increased capacity, and improved user experience.

CHAPTER 5

Maximization of Energy Efficiency in Massive MIMO

CHAPTER 5

Maximization of Energy Efficiency in Massive MIMO

5.1 ENERGY EFFICIENCY LIMITS IN DIFFERENT CASES

Every decade, a new generation of wireless technology is released, and the International Telecommunication Union (ITU), which establishes the minimum performance standards, guides the standardisation process.

A new metric has been added, along with stricter standards. That is energy efficiency (EE). A basic definition of the EE is

$$\text{EE [bit/Joule]} \; = \frac{\text{Date rate [bits/s]}}{\text{Energy Consumption [Joule/s]}} \tag{5.1}$$

The word energy consumption refers to the sum of hardware dissipation, baseband processing and transmit power. [5], [6]. There is a common regard that achieving faster data rates will require using more energy. A hundred times faster data rate corresponds to a hundred times greater consumption of energy if the EE remains unchanged.

Since wireless networks are typically not powered by renewable, eco-friendly sources, this is an issue for the environment. Although IMT-2020 states that improved spectral efficiency will be sufficient, it does not set any quantitative benchmarks for the considerably increased EE that is desired for 5G. The two basic methods for increasing spectral efficiency are enormous multiple-input multiple-output and smaller cells (MIMO).

As a result, for additive white Gaussian noise (AWGN) channels, which is a strict yet normalised version of EE analysis, the channel capacity per unit cost was explored. The main objective is to analyse the physical EE limits in a few distinct scenarios and, in particular, to provide estimates on the maximum attainable EE that are useful in real-world applications.

Single-antenna systems and multiple-antenna systems will be the two scenarios we focus on. In all scenarios, we assume that the communication occurs within a bandwidth of B Hz, that the total transmit power is P W, and that the noise power spectral density is N_0 W/Hz.

5.1.1 Single-Antenna Systems Without Interference

Initially a single-antenna system is considered. The scalar coefficient of the channel is given by h and y is represented as received signal, which is

$$y = hx + n \tag{5.2}$$

Where transmit signal is represented with x with power P and n~N_c (0, BN_0) is AWGN. We know that channel capacity,

$$C = B\, log_2(1 + SNR)\ [bits/s] \tag{5.3}$$

The channel capacity for perfect CSI is

$$C = B\, log_2\left(1 + \frac{P\beta}{BN_0}\right)\ [bits/s] \tag{5.4}$$

Here $\beta = |h|^2$ is channel gain (or) signal to noise ratio. The upper bound on energy efficiency in eq(5.1) is:

$$EE = \frac{B\, log_2\left(1+\frac{P\beta}{BN_0}\right)}{P} \tag{5.5}$$

The only factor affecting the amount of energy consumed is P, which stands for transmit power. Eq(5.5) varies (i.e. function increases) with respect to factor B/P. By making bandwidth B→ ∞ ,transmit power P →0 or a contribution gives P/B →0 which maximizes the energy efficiency. By using taylor expansion of the algorithm around $\frac{P\beta}{BN_0} = 0$, the equ.(5.5) is minimized as

$$EE = \frac{log_2\,(e)\beta}{N_0} \tag{5.6}$$

Eq(5.6) can be considered as below according to Additive White Gaussian Noise (AWGN) channel

$$\frac{N_0}{log_2 e} = N_0 \ln(2) \tag{5.7}$$

To check the energy efficiency, we take N_0=-174 dBm/Hz in room temperature and consider β from -130dB to -50dB.The energy efficiency in the graph from fig (7.1) ranged from 3Gbit/Joule to 3×10^6 G bit/Joule = 3 P bit/Joule.

5.1.2 Single antenna System with Interference

In this second case, interference is added to the system which may be caused by one or multiple systems whose goal is also to maximize energy efficiency. Here, the channel gains from all interfering transmitters are added together and it is considered as α, each transmitter makes use of the same P.

Hence total received power is P_{α} where Interference is treated as noise, then eq(5.5) becomes:

$$\text{EE}=\frac{B\,log_2\left(1+\frac{P\beta}{BN_0+P_{\alpha}}\right)}{P} \quad (5.8)$$

As we know from equ(5.5), that energy efficiency is an increasing function with respect to B/P. Hence maximized energy efficiency is achieved by letting P/B->0 .By further calculations, we get

$$\text{EE}=\frac{log_2\,(e)\,\beta}{N_0} \quad (5.9)$$

which is like equ.(5.6) where interference is not present in the system and this eq(5.9) is independent of α.

5.1.3 Multiple antenna System

In this case, let the transmitter be equipped with M antennas and the receiver with N antennas, which is known as MIMO system.

Here, in this case upper limit can be achieved by enclosing the transmitter with receive antennas forming a sphere like shape around it.

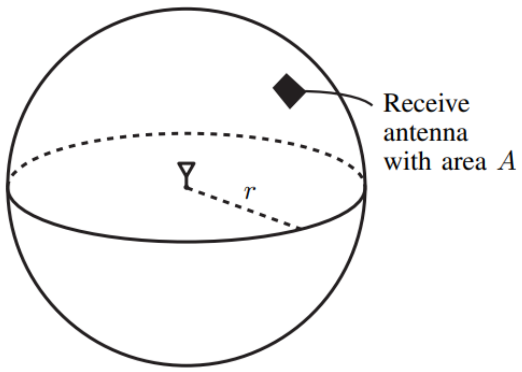

Fig 5.1: Sphere with Surface of Receive Antennas

The surface of the sphere is fully covered with receive antennas to capture all the transmitted energy, assuming that the antennas are ideal (lossless). Let 'r' be the radius of the sphere and area of the lossless antenna be A, as shown in figure. A total of $\frac{4\pi r^2}{A}$ antennas are required to cover the surface. From all the conditions, the energy efficiency of multiple antenna system is:

$$EE \leq \frac{log_2(e)}{N_0} \quad (5.10)$$

Which is also similar to eq (5.6) in single antenna system case, but the difference is channel gain β is replaced with its supper bound: 0 dB. As discussed in the above cases, the maximum energy efficiency is achieved by P/B → 0. For the energy efficiency, it doesn't matter whether it is p-> 0 or B->infinity, but for equation it matters more.

$$C = B\, log_2\left(1 + \frac{P\beta}{BN_0}\right) \rightarrow \begin{cases} 0 & , P \rightarrow 0 \\ \frac{log_2(e)P\beta}{N_0} & , B \rightarrow \infty \end{cases} \quad (5.11)$$

Generalization for the above equation is shown in fig (7.2) considering P = 20 dBm and N_0 = −174 dBm/Hz.

5.2 DEPLOYING DENSE NETWORKS FOR MAXIMAL ENERGY EFFICIENCY

The number of mobile devices in a particular area has grown at an exponential rate. The increase in energy consumption has accompanied every new mobile generation, and 5G is likely to continue this trend. The mobile industry has a chance to increase traffic while lowering energy consumption, but it requires more than just technological advancements. Currently, mobile networks use a significant amount of energy, with a global energy cost of USD 25 billion. As we move towards 5G, energy usage will likely increase. To mitigate this issue, the industry needs to take action to minimize the impact on the environment. Reducing energy consumption in mobile networks is a critical step towards achieving sustainability. As a result, it is necessary to focus on developing energy-efficient solutions for mobile networks.

Our latest report outlines a plan for service providers to adopt 5G networks nationwide while reducing energy usage, breaking the traditional energy curve. This presents a unique opportunity for service providers to achieve what was previously impossible. However, it will also require providers to increase network capacity, expand geographical coverage, and deploy advanced technology use cases nationwide. This will inevitably place greater demands on service providers. By following our blueprint, service providers can ensure a sustainable and efficient 5G network while meeting growing demands.

Service providers anticipate a doubling of energy consumption to meet traffic demands and deploy new 5G frequencies, requiring the densification of the network. This growth is unsustainable, both environmentally and financially. This demand for increased energy usage necessitates a sustainable solution. It is crucial to address this issue to ensure that the industry's growth does not harm the environment while continuing to meet customer needs.

Current network architectures are insufficient for supporting growth and efficiently adjusting to areas with different traffic demands. And To minimize the impact of increased traffic, 5G networks require greater energy efficiency and reduced CO2 emissions. Action must be taken to address this issue.

Ensuring consistent Quality of Service across the network necessitates a 1000-fold increase in network area throughput in the coming years, while simultaneously reducing power consumption. This is particularly challenging given that the need for lower power consumption and higher network area throughput are conflicting requirements in 5G networks. As a result, new approaches must be explored to strike a balance between these competing needs. Achieving this balance will be critical to the successful deployment of 5G technology.

Substantial network densification is crucial to achieving the dual goals of increased network area throughput and reduced power consumption in 5G networks. Two technologies that enable network densification are Small-cell networks and Massive MIMO systems. Small cells rely on ultra-dense and irregular deployment of low-cost, low-power base stations to increase network area throughput by bringing User equipment and Base stations closer. Similarly, Massive MIMO technology increases conventional base stations by using arrays consisting of hundreds or more small dipole antennas to achieve coherent multi-user MIMO transmission.

Massive MIMO systems offer a major reduction in emitted power due to the array gain from coherent processing, resulting in higher Energy Efficiency. Despite their name, Massive MIMO arrays are rather compact and help reduce transmit power while providing higher Energy Efficiency. However, both Small-cell networks and Massive MIMO systems require more hardware deployment, increasing circuit power consumption per BS. It is, therefore, essential to balance the need for increased network area throughput and reduced power consumption in 5G networks while exploring new approaches to strike this balance.

Both densification technologies, namely Small-cell networks and Massive MIMO systems, offer benefits such as improved area throughput and reduced radiated power. However, achieving these benefits requires deploying more hardware infrastructure. Thus, it is critical to strike a balance between these costs and benefits to improve the overall Energy Efficiency (EE) of the network.

This section examines the uplink (UL) of a multi-cell multi-user MIMO network, where base stations (BSs) are distributed based on a homogenous Poisson Point Process (PPP) of intensity λ. Each BS has M antennas and communicates with K single-antenna User Equipment (UEs) distributed uniformly within its coverage area. A maximization problem for EE assumes that a given average Spectral Efficiency (SE) target per UE must be met with equality to ensure good service quality while accounting for processing and backhaul infrastructure.

Here EE is defined as,

$$EE = \frac{\text{EE = Area spectral efficiency} \left[\frac{\frac{\text{bit}}{\text{symbol}}}{km^2}\right]}{Transmit\ power{+}circuit\ power\ per\ a.e. \left[\frac{\frac{j}{symbol}}{km^2}\right]} \tag{5.12}$$

5.2.1 Maximization of EE with respect to M (Number of base station antennas) and K (Number of User equipment):

EE varied for different values of (M, K). When Base station density (λ) tends to infinity (λ→ ∞) & SINR(γ) constraint is 3 or γ=3 , EE lower bound as a function of M and K with respective to pilot reusing factor (β) EE is studied for different values of

(M, K) ,We take 2 more iterations for studying EE.Those are for(M*, K*) = (91, 10), EE is 10.156 Mbit/J and (M**, K**) = (91.6, 10.1), EE is 10.1567Mbit/J ,The EE is increased by 0.009% than the integer-valued solution This shows that the EE performance is same around the global optimum.Here EE depends on 'β', from the equations

$$\beta * = \frac{B_1 * \gamma}{(1-\epsilon^2)^2 - B_2 \gamma} \tag{5.13}$$

$$B_1 = \left(\frac{4*K}{(\alpha-2)^2} + \frac{K+M*(1-\epsilon^2)}{(\alpha-1)} + \frac{2*(K+\frac{\alpha^2}{\beta})}{\alpha-2} \right) \tag{5.14}$$

$$B_2 = \left(K + \frac{\sigma^2}{\rho} + \frac{2*K}{\alpha-2}\right)\left(1 + \frac{\sigma^2}{\rho}\right) + (1-\epsilon^2)\epsilon^2 * M \tag{5.15}$$

$$\gamma = \frac{M(1-\epsilon^2)^2}{B_1/\beta + B_2} \tag{5.16}$$

$$EE_\infty = \frac{K*\left(1-\frac{K}{S}*\frac{\bar{B}_1*\gamma}{M*(1-\epsilon^2)^2-\bar{B}_2*\gamma}\right)*log_2(1+\gamma)}{C_0+C_1*K+D_0*M+D_1*M*K+A*K*\left(1-\frac{K}{S}*\frac{\bar{B}_1*\gamma}{M*(1-\epsilon^2)^2-\bar{B}_2*\gamma}\right)*log_2(1+\gamma)} \tag{5.17}$$

($\beta *$ = optimal pilot reuse factor,γ=SINR, α=Path loss, M=no. of base station antennas, K=no of user equipment's, ϵ=hardware impairments, $\frac{\sigma^2}{\rho}$ = 1/SINR, S = symbols used for pilot transmission, C_0 = Static energy consumption ,C_1 =Circuit energy per active UE,D_0 = Circuit energy per active BS antenna,D_1 = Signal processing coefficient)

Optimization Algorithm:

An approach for solving the integer-relaxed EE maximization issue using Theorems 1 and 2:

1) Choose a practical beginning point (M, K) to (5.19).

2) Utilizing 1st Theorem, fix the value of M and obtain the improved K.

3) Utilizing 2nd Theorem, fix the value of K and obtain the improved M.

4) Redo the above two steps until convergence is reached.

The algorithm is guaranteed to converge to the global optimum of the relaxed problem, as the Energy Efficiency (EE) has a finite upper bound and monotonically increases in each iteration. This algorithm obtained from Theorem 1 and Theorem 2.

Before going into these theorems, the EE maximization problem in equation (5.18) to reduces to equation (5.19)

Maximize EE (β^*)

$\rho_1 * \lambda \geq 0, M, K \in Z_+$

$$\text{Subject to} \quad \frac{B_1 * \gamma}{M*(1-e^2)^2 - B_2 * \gamma} \geq 1$$

$$\frac{B_1 * \gamma}{M*(1-e^2)^2 - B_2 * \gamma} \leq \frac{S}{K} \quad (5.18)$$

As λ approaches infinity, the Energy Efficiency (EE) represented by EE (β^*) is maximized, and it is a monotonically increasing function of λ.

Maximize EE_∞ $M, K \in Z_+$

$$\text{Subject to} \quad \frac{\bar{B}_1 * \gamma}{M*(1-e^2)^2 - \bar{B}_2 * \gamma} \geq 1$$

$$\frac{\bar{B}_1 * \gamma}{M*(1-e^2)^2 - \bar{B}_2 * \gamma} \leq \frac{S}{K} \quad (5.19)$$

THEOREM 1:

The first inequality of eq (5.19), number of antennas in BS and user equipments are practical values, is used to determine the optimal values of M and K. We replace M with $\bar{c}$=M/K, where the $\bar{c}$=M/K is the number of BS antennas per UE. The EE maximizing the value of k for a given value of $\bar{c}$ is determined as follows, The EE is improved by $\bar{c} = M/K$>0.

The incremented Energy Efficiency is given by ,

$$K^* = \frac{\sqrt{(G*C_0)^2+C_0*D_1*\bar{c}+C_0*G(C_1+D_0*\bar{c})}-G*C_0}{D_1*\bar{c}+G*(C_1+D_0*\bar{c})} \tag{5.20}$$

where,
$$G = \frac{1}{S}*\frac{\left(\frac{4*\gamma}{(\alpha-2)^2}+\frac{\gamma}{(\alpha-1)}+\frac{2*\gamma}{(\alpha-2)}\right)+\frac{\gamma*(1-\epsilon^2)}{(\alpha-1)}*\bar{c}}{(1-\epsilon^2)*(1-(1+\gamma)*\epsilon^2)\overline{*c}-\left(1+\frac{2}{(\alpha-2)}\right)*\gamma} \tag{5.21}$$

Equation (5.20) k^* is obtained from derivating equation (10) by equating it 0 and R= $log_2(1+\gamma)$

$$\frac{K*(1-KG)*R}{C_0+(C_1+D_0*\bar{c})*K+D_1*\bar{c}*K^2+A*K(1-K*G)*R} \tag{5.22}$$

The first constraint in equation (5.19) is independent of K so EE is maximized, If K is fixed, the EE maximizing value of $\overline{c*}$ is obtained as follows:

C_0 =Static energy consumption

C_1 =Circuit energy per active UE

D_0 = Circuit energy per active BS antenna

D_1 = Signal processing coefficient

THEOREM 2:

For K>0 , The EE is ,maximized by $\overline{c*}$ in equation (5.23)

$$\overline{c*}= \frac{a_1+a_3+\sqrt{a_1a_3+{a_1}^2+\frac{a_1a_2a_3}{a_5}+\frac{a_0a_3a_5}{a_5}-\frac{a_0a_1a_4}{a_5}-\frac{{a_0}^2a_3a_4}{a_2a_5}+\frac{a_0a_1a_3}{a_2}+\frac{a_0{a_3}^2}{a_2}}}{a_2-a_0} \tag{5.23}$$

Equation (5.19) is reduced to equation (5.24)

$$\frac{K\left(1-\frac{a_0\bar{c}+a_1}{a_0\bar{c}-a_3}\right)\log_2(1+\gamma)}{(a_4+a_5\bar{c})+AK\left(1-\frac{a_0\bar{c}+a_1}{a_0\bar{c}-a_3}\right)\log_2(1+\gamma)} \tag{5.24}$$

Maximized value of $\overline{c*}$ is obtained by taking first derivative of equation (5.24) and equating it to 0 that is equation (5.23).

EE is maximized by $\overline{c*}$ in equation (5.23)

If not, then EE monotonically increases for all $\bar{c}$ and largest valued obtained if the first constraint is satisfied, which is equation (5.25)

where,

$a_0 = \gamma * (K^*) * (1 - \epsilon^2) / (\tau * (\alpha - 1))$

$a_1 = (K^* / \tau) * (4 * \gamma / (\alpha - 2) ^2 + \gamma / (\alpha - 1)\ 2 * \gamma / (\alpha - 2))$

$a_2 = (1 - \epsilon^2) * (1 - (1 + \gamma) * \epsilon^2)$

$a_3 = (1 + 2 / (\alpha - 2)) * \gamma$;

$a_4 = C_0 + C_1 * K^*$

$a_5 = D_0 * K^* + D_1 * K^* {}^\wedge 2$.

Tau(τ) = Length of coherence block

$$\overline{c^*} = \frac{\gamma * \left(1 + \frac{4}{(\alpha-2)^2} + \frac{1}{(\alpha-1)} + \frac{4}{(\alpha-2)}\right)}{(1-\epsilon^2) * (1-(1+\gamma) * \epsilon^2) - \frac{\gamma * (1-\epsilon^2)}{(\alpha-1)}} \qquad (5.25)$$

Second constraint is automatically satisfied because the maximum cannot give a negative EE. The result is shown in fig 7.3 .

Chapter 6

Maximization of Energy Efficiency For Optimal Spectral Efficiency

Chapter 6
Maximization of Energy Efficiency For Optimal Spectral Efficiency

6.1 Maximization of Energy Efficiency For Optimal Spectral Efficiency

Cellular network traffic is expected to expand at a yearly rate of 41% to 59% for the foreseeable future, necessitating a 1000-fold increase in area throughput. According to the measurements, there is a 2–10-fold difference between the daily lowest and daily highest network loads. Non-peak hours are associated with considerable energy wastage at base stations.

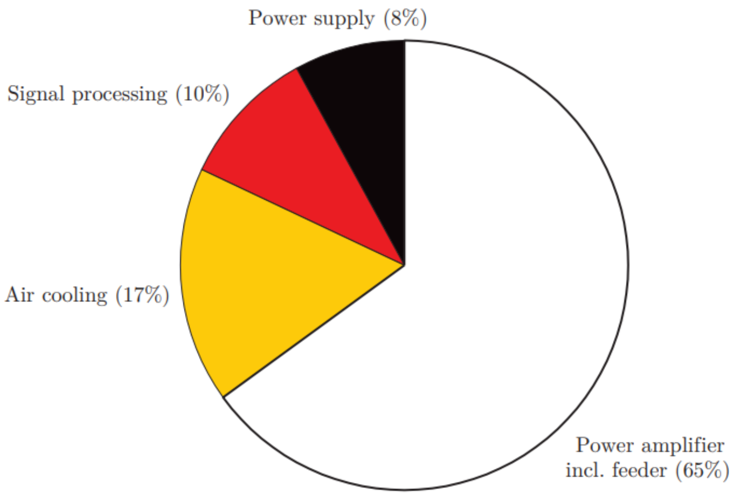

Fig 6.1: The power consumption of different components in a base station can be expressed as a percentage of the total power consumption.

A cellular network uses roughly 60% of its overall power on BSs, 20% on mobile switching hardware, and 15% on central infrastructure. Data centers, stores, and businesses use the remaining space. A BS uses both set (traffic-independent) and changeable (traffic-dependent) components to make up its overall power consumption. According to Figure 5.2, A diagram can be used to visualize the contribution of different components in the coverage layer of a base station to the total power consumption, the fixed component, which includes the power source and control signaling, consumes about a quarter of the total power. When there aren't any active UEs within a BS's service area during non-peak traffic hours, this quantity is either not effectively used or, worse yet, entirely squandered. The procedure of power enhancement consumes the majority of the energy. Remarkably, a significant amount of power, around 80% to 95%, is wasted as heat in the power amplifiers of base stations. This is surprising considering that the current efficiency of these amplifiers ranges between 5% and 20%. The reason for this is the modulation methods used in modern communication standards, such as LTE, which have signal envelopes that fluctuate significantly and have peak-to-average power ratios exceeding 10 dB. To avoid signal anomalies during transmission, the PAs must operate at levels well below their maximum capacity. Massive MIMO technology uses arrays with over 100 antennas, each of which transmits at a lower power level, in order to enhance the coverage of base stations. This results in coherent multiuser MIMO transmission, allowing multiple users to be multiplexed in the uplink and downlink of each cell. This leads to increased area output, but requires more hardware such as several RF chains per base station and digital signal processing (SDMA combining/precoding), which increases the power consumption per base station.

6.1.1 Transmit Power Consumption

The Area Transmit Power (ATP) is a measure used to assess the transmit power utilized by a wireless network, specifically the network-average power consumption for data transfer per unit area.The unit of measurement is W/km^2.

$$\text{ATP} = \text{transmit power [W/cell]} \cdot \text{D [cells/km2]}$$

Therefore, to optimize the overall Energy Efficiency (EE) of the network, which is defined as the amount of energy required to achieve a certain amount of work, it is necessary to balance the benefits and costs associated with it.

6.1.2 Definition of Energy Efficiency

EE is a measure of how efficiently energy is used to accomplish a certain task. In the context of cellular networks, it refers to the amount of successfully transmitted data bits per unit of energy consumed.

In accordance with the previous definition, we define the EE as

$$\text{EE} = \frac{\text{Throughput}\left[\frac{\frac{\text{bit}}{\text{s}}}{\text{cell}}\right]}{\text{Power consumption}\left[\frac{\text{W}}{\text{cell}}\right]} \tag{6.1}$$

The efficiency of a cellular network is typically measured in terms of Energy Efficiency (EE), which represents the number of bits that can be transmitted per unit of energy. This can be viewed as a benefit-cost ratio, where the level of service (throughput) is compared to the associated power consumption. However, simply measuring the transmit power does not accurately reflect the effective transmit power (ETP) required for communication, as it does not take into account the efficiency of the power amplifier (PA). When PA efficiency is low, a significant amount of power is wasted as heat. To properly assess EE, the power consumption (PC) must be calculated using the ETP, rather than the radiated transmit power, and should consider the CP required to operate the cellular network.

$$\text{PC} = \text{ETP} + \text{CP} \tag{6.2}$$

(CP=Circuit Power, ETP=Effective Transmit Power, PC =Power Consumption)

By employing higher transmit power, placing more BS antennas, or providing service to more UEs per cell, SE of a cell can be raised. The Multicell -Minimum Mean Square Error (M-MMSE) approach yields the highest SE. Each of the strategies listed above will definitely result in a rise in the network's PC and as a result, it have the potential to reduce EE.

For the EE-SE tradeoff, the effects of various network parameters and operational conditions are studied,

- with respect to multiple BS antennas
- with respect to multiple UEs

1. **Impact of Multiple BS Antennas**

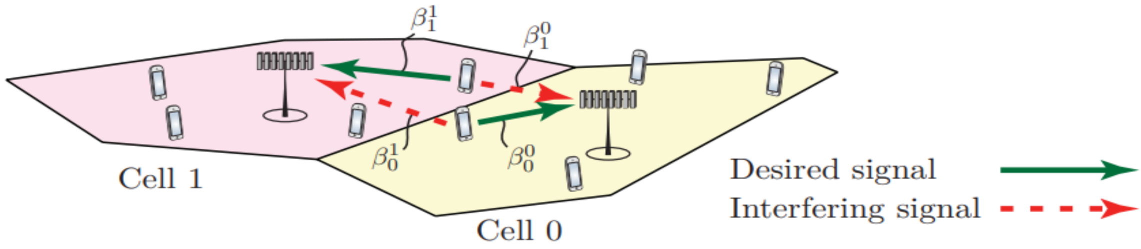

Fig 6.2: Description of Desired and Interfering Downlink Signals in a Two-Cell Wireless Network.

In the above scenario, each UE in cell 0 has similar value of an average channel gain β_0^0 and β_1^0 of and each UE in cell 1 has β_0^1 and β_1^1.

Suppose that cell 0 has just one user and no interfering signals are sent from adjacent cell. For that user in cell 0, a feasible SE is

$$SE_0 = log_2(1 + (M-1)SNR_0) = log_2(1 + (M-1)\frac{p}{\sigma^2}\beta_0^0 \qquad (6.3)$$

p - transmit power, σ^2 - noise power, β_0^0 - average channel gain of the active UE,

$CP_0 = P_{FIX}$

Suppose for the time being, In cell 0, only fixed power P_{FIX} is considered for the CP i.e., $CP_0 = P_{FIX}$. Hence for the cell 0 , the EE will be

$$EE_0 = \frac{Blog_2(1+(M-1)\frac{p}{\sigma^2}\beta_0^0}{\frac{1}{\mu}p+P_{FIX}} \qquad (6.4)$$

Where B – Bandwidth, $\frac{1}{\mu}p$ – ETP with $0 < \mu \leq 1$ being the PA efficiency. For a given SE, denoted as SE_0, we obtain the required transmit power as

$$p = \frac{(2^{SE_0}-1)\sigma^2}{(M-1)\beta_0^0} \qquad (6.5)$$

$$v_0 = \frac{\sigma^2}{\beta_0^0} \qquad (6.6)$$

$$EE_0 = \frac{B\, SE_0}{(2^{SE_0}-1)\frac{v_0}{M-1}+P_{FIX}} \qquad (6.7)$$

In a scenario where interference is not present, the transmit power p is an exponentially increasing function of SE_0, indicating that an increase in SE_0 is equivalent to increasing p. By multiplying (6.6) with $\frac{1}{\mu}$,we get (6.8)

$$v_0 = \frac{\sigma^2}{\mu h \beta_0^0} \qquad (6.8)$$

The relationship between Spectral Efficiency and Energy Efficiency for the UE in cell 0 is provided by the below equation.

$$EE_0 = \frac{B\,SE_0}{(2^{SE_0}-1)\frac{v_0}{M-1}} \tag{6.9}$$

When considering the power consumption (CP), increasing the spectral efficiency (SE) of a user equipment (UE) in cell 0 can result in a tradeoff between SE and energy efficiency (EE). Specifically, when CP is not considered, increasing SE always leads to decreased EE. However, in practical scenarios where P_{FIX}> 0, EE for UE in cell 0 follows a unimodal function. As such, EE initially increases with increasing SE as long as $(2^{SE_0}-1)\ \frac{v_0}{M-1} < P_{FIX}$ and then decreases to zero as $\frac{SE_0}{(2^{SE_0}-1)}$.

$$log_2\,(EE^*) + SE^* = log_2\left((M-1)\frac{B}{v_0 log_e(2)}\right) \tag{6.10}$$

where SE^* is such that

$$SE^*\left(2^{SE^*}\log_e(2)\right) = \left(2^{SE^*}-1\right) + \frac{M-1}{v_0}P_{FIX} \tag{6.11}$$

The identity (6.10) shows a linear dependence between log2 (EE^*)and SE^*

$$SE^* = \frac{\left((M-1)\frac{P_{FIX}}{v_0 e} - \frac{1}{e}\right)+1}{\log_e(2)} \tag{6.12}$$

By inserting the equation (6.12), which involves the Lambert function (denoted as W(·)), into equation (6.10)

$$EE^* = \frac{(M-1)Be^{-W\left((M-1)\frac{P_{FIX}}{v_0 e}-\frac{1}{e}\right)-1}}{v_0\log_e 2} \tag{6.13}$$

where we have used the fact that $2^{\frac{1}{\log_e 2}} = e^{-1}$. Equations (6.12) and (6.13) provide in EE^* and SE^*closed form and thus allow us to get insights into how both are affected by the system parameters. From (6.12), considering that W(x) is an increasing function for x ≥ e, it turns out that SE^*increases with M.

(Scaling law with M and/or P_{FIX},If M or P_{FIX} grow large, then

$$SE^* \approx \log_2(MP_{FIX}) \tag{6.14}$$

$$EE^* \approx \frac{eB}{(1+e)}\frac{\log_2(MP_{FIX})}{P_{FIX}} \quad (6.15)$$

$$CP_0 = P_{FIX} + MP_{BS} \quad (6.16)$$

where P_{BS} is the amount of power used by the circuit components such as OFDM modulation/demodulation, DACs, filters, I/Q mixers, Local oscillators and ADCs required for each BS antenna to function. Where eq(6.7) will be

$$EE_0 = B\,\frac{SE_0}{(2^{SE_0}-1)\frac{v_0}{M-1}+P_{FIX}+MP_{BS}} \quad (6.17)$$

If M, P_{FIX}, and/or P_{BS} grow large, then

$$SE^* \approx log_2\big(M(P_{FIX} + MP_{BS})\big) \quad (6.18)$$

$$EE^* \approx \frac{eB}{(1+e)}\frac{log_2(M(P_{FIX}+MP_{BS}))}{(P_{FIX}+MP_{BS})} \quad (6.19)$$

2. Impact of Multiple UEs:

The most effective technique to raise the per-cell SE is by SDMA transmission, which increases the no. of concurrently active UEs [7]. From fig.1 The inter-cell interference can be quantified by the relative strength $\bar{\beta}$, which is defined as the ratio of the received signal power from the serving base station to that from the interfering base station. It can be calculated as $\bar{\beta} = \frac{\beta_1^0}{\beta_0^0} = \frac{\beta_0^1}{\beta_1^1}$, we study the potential advantages that SDMA might have for the EE.

So, the SE for each user is

$$SE_0 = log_2\left(1 + \frac{M-1}{(K-1)+K\bar{\beta}+\frac{\sigma^2}{p\beta_0^0}}\right)^{-1} \quad (6.20)$$

A given SE_0 value is thus achieved by

$$p = \left(\frac{M-1}{2^{SE_0}-1} - K\bar{\beta} + 1 - K\right)^{-1}\frac{\sigma^2}{\beta_0^0} \quad (6.21)$$

The corresponding EE of cell 0 is

$$EE_0 = \frac{BKSE_0}{K\left(\frac{M-1}{2^{SE_0}-1}-K\bar{\beta}+1-K\right)^{-1}v_0+CP_0} \quad (6.22)$$

We have considered the fact that KSE_0 is the total SE in cell 0. We assume that the increased CP due to all mobile users.

$$CP_0 = P_{FIX} + MP_{BS} + KP_{UE} \tag{6.23}$$

where P_{UE} UE is the total amount of power used by each single-antenna UE's circuit components.

The expression is obtained by derivating the EE_0 from eq(6.22) with respect to SE_0 and making it equal to zero gives

$$K\left(\frac{M-1}{2^{SE_0}-1} - K\bar{\beta} + 1 - K\right)^{-1} v_0 + P_{FIX} + MP_{BS} + KP_{UE} = KSE^* \left(1 - \left(\frac{2^{SE_0}-1}{M-1}\right)\left(K\bar{\beta} - 1 + K\right)\right)^{-2} \frac{v_0 log_e(2)}{M-1} 2^{SE^*} \tag{6.23}$$

It yields the SE^* that optimises the EE. Adding this expression to eq(6.22) results in

$$EE^* = \frac{B}{\left(1-\left(\frac{2^{SE_0}-1}{M-1}\right)(K\bar{\beta}-1+K)\right)^{-2} \frac{v_0 log_e(2)}{M-1} 2^{SE^*}} \tag{6.24}$$

or, equivalently,

$$log_2\left(EE^*\right) + SE^* \text{-} 2 log_2\left(1 - \left(\frac{2^{SE^*}-1}{M-1}\right)\left(K\bar{\beta} - 1 + K\right)\right) = log_2\left((M-1)\frac{B}{v_0 log_e(2)}\right) \tag{6.25}$$

The expression in equation (6.25) remains the same as that in (6.10), except for the additional terms arising from intra-cell and inter-cell interference. Due to the presence of interference, an enclosed form solution for (6.23) cannot be obtained, unlike in the case of (6.11). Therefore, we numerically evaluate the relative strength of inter-cell interference ($\bar{\beta}$) and the number of User Equipments (UEs) (K) in the following section to determine their impact on the Energy Efficiency-Spectral Efficiency (EE-SE) tradeoff. We consider P_{UE} = 0.5W, $\sigma^2/\beta_0^0 = -6$ dBm, P_{FIX}= 10W , P_{UE} = 0.5W, B = 100 kHz,μ = 0.4, P_{BS} = 1W, M = 10 The impact of increasing β¯on the EE and SE is undesirable since the inter-cell interference term K$\bar{\beta}$ in (5.26) rises linearly with $\bar{\beta}$.

In contrast, the EE-SE tradeoff curve is a unimodal function of K and M (as shown in Figure 7.4). The optimal value of K is found to be 10, since for M is 10, the sum SE increases slowly with K, but each additional UE raises the power consumption (PC) by P_{UE} = 0.5 W. As K or $\bar{\beta}$ increases, the EE for a given total SE deteriorates. The impact of higher interference and new hardware prevents Space Division Multiple Access (SDMA) from enhancing EE. Moreover, when examining the effect of K on the cumulative SE, it is found that adding a corresponding number of antennas can reduce the increased interference, allowing for multiple UEs to be serviced simultaneously without a decrease in SE per UE. This leads to a preferred operating regime where the antenna-UE ratio of M/K ≥ c, where c is a constant value.

CHAPTER 7

Results

CHAPTER 7

Results

7.1 RESULTS

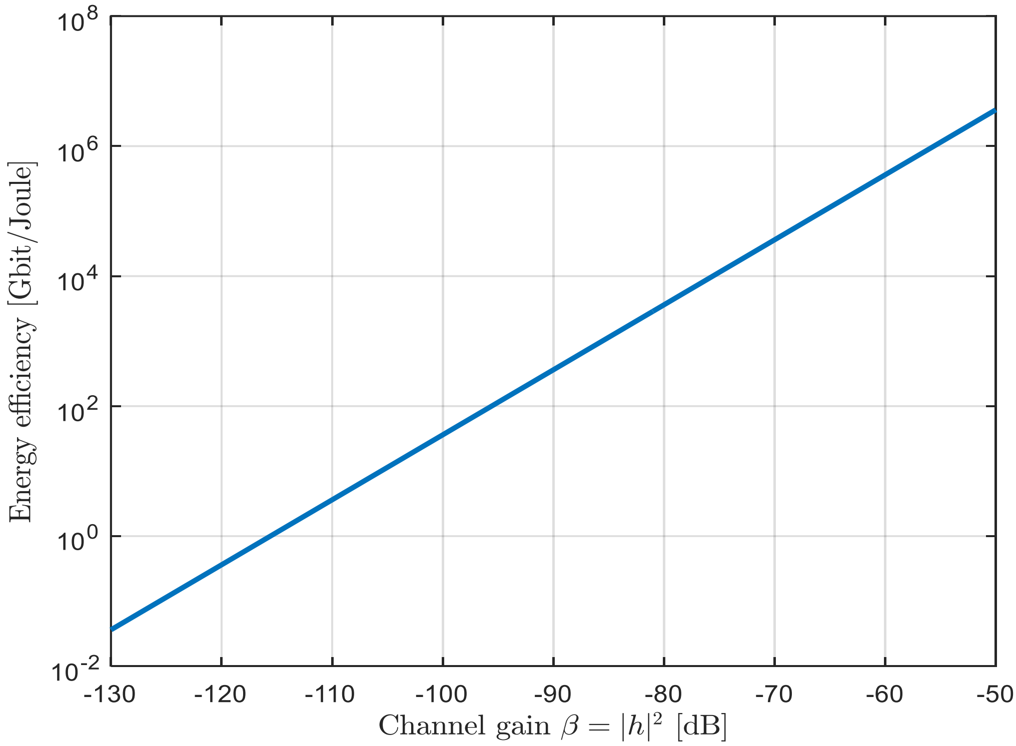

Fig 7.1: The maximum Energy Efficiency in a single-antenna system depends on the channel gain β.

We consider a feasible range of β from -130 dB to -50 dB. There is a drastic increase in the EE limits according to channel gain β, which is clearly greater than what our current systems provide. In the case of single-antenna system, the equations and above graph shows the maximum EE depends on the channel gain β.

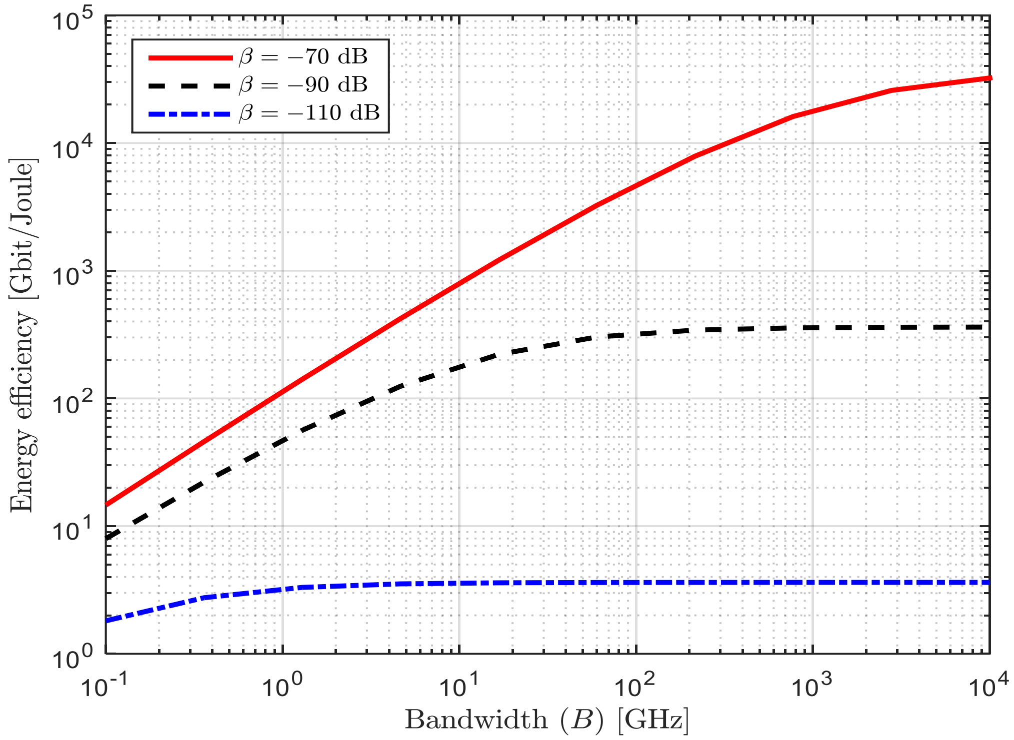

Fig 7.2: Maximization of Energy Efficiency with respect to B for different values of channel gain β.

The above graph shows increment in the EE as $B \rightarrow \infty$. The result for three different β values is observed with a increment of 20dB. Upon closer inspection, we find that the limit is already reached at a frequency of B = 1 GHz in the case where $\beta = -110$ dB, representing an extreme scenario. Where incrementing the value of β by 20dB every time, we require 100 times more bandwidth.

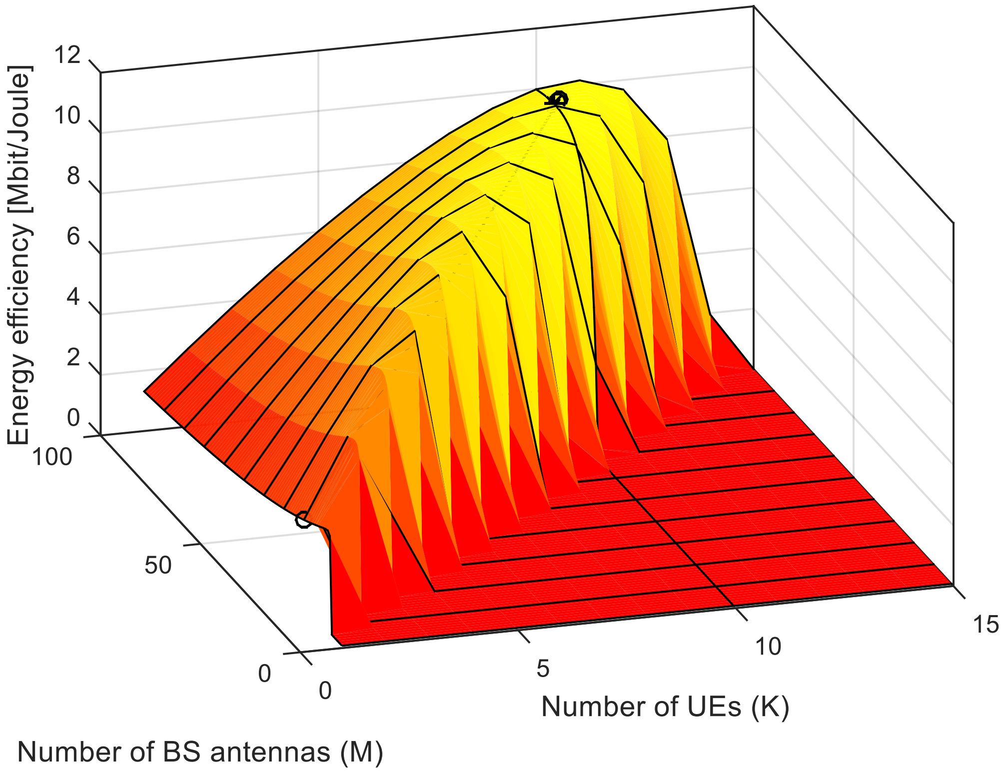

Fig 7.3: Energy Efficiency increase with respect to number of UE(k) and number of Base station antennas (in Mbit/J) with a fixed value $\gamma = 3$.

The above graph presented above depicts the behavior of EE with respect to M and K as the BS density λ approaches infinity. The star-marked region represents the optimal value, where the global maximum is attained at M = 91 and K = 10, with an EE of 10.16 Mbit/J."

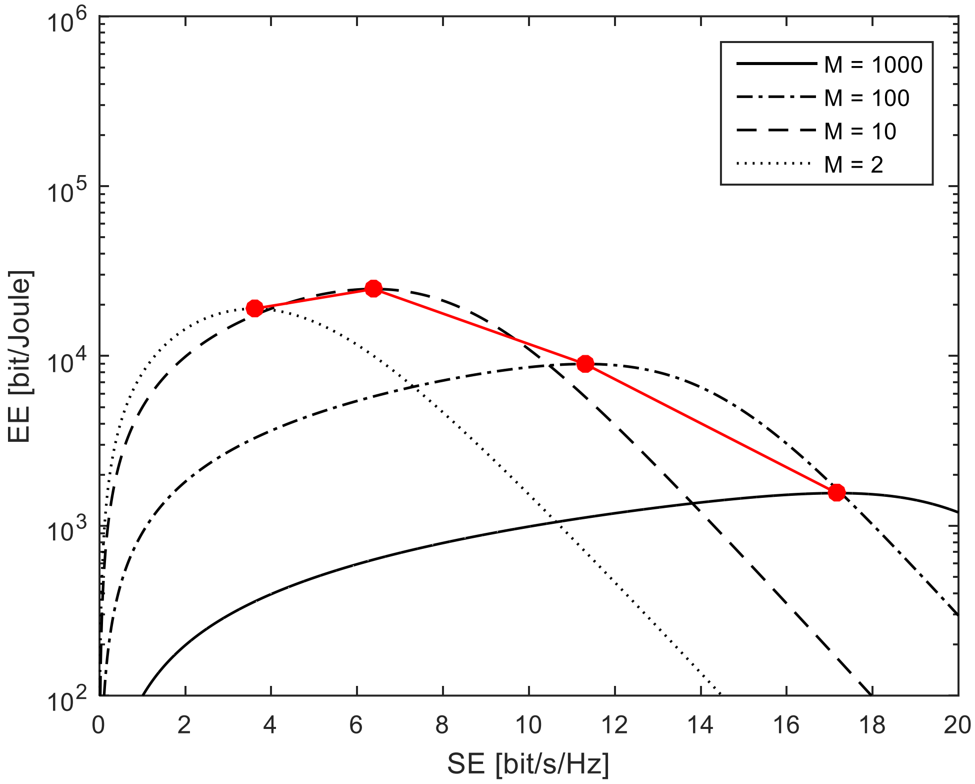

Fig 7.4: The relation between Spectral Efficiency and Energy Efficiency from eq(6.17)

The above Figure 5 shows the Under the given parameters of μ = 0.4, P_{BS}= 1W,P_{FIX}= 10 W, $\frac{\sigma^2}{\beta_0^0}$= −6 dBm, B = 100 kHz and μ = 0.4. we explore various values of M. It is worth noting that the EE*-SE* tradeoff does not increase indefinitely with the addition of antennas. This is due to the fact that each extra antenna contributes to an increase in CP by P_{BS}.

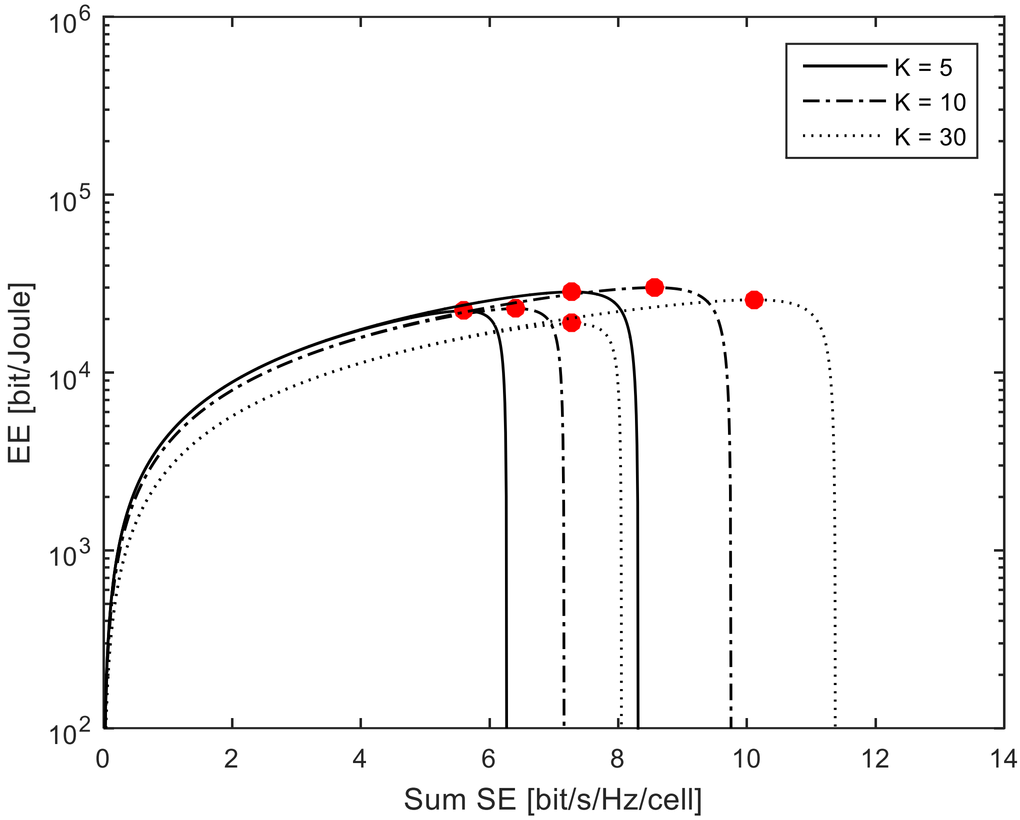

Fig 7.5: The relation between Spectral Efficiency and Energy Efficiency from Eq (6.25)

The above Figure shows various values of $\bar{\beta}$ (-3dB, -15dB) and the quantity of Users' equipment, denoted by K, is being evaluated under the assumption that M equals 10, P_{FIX}= 10W, P_{BS} =1Wand P_{UE}= 0.5W, B = 100 kHz, $\frac{\sigma^2}{\beta_0^0}$= −6 dBm, and μ = 0.4.

CONCLUSION

It is evident that a wireless communication system's energy efficiency greatly depends on the parameter values with the specific ratio of B and P, with which the optimized value for energy efficiency is attained, which gives an SNR value that is low. Here, the ration of B and P are expanded together with the proportion to accomplish the optimal information rate around 1 Pbit/Joule. Thus, to get the densified network setup with an optimal rate, it is figured out an EE maximization problem for the upward link (UL). In terms of the pilot reuse factor, cell capacity(users), and the number of antennas in a Base station; the EE expression was made tractable and analytically optimized. In relation to different massive MIMO parameters like multiple user equipment K, the antennas fixed at base stations M, the EE is observed and analyzed with the possible optimal SE. It is further observed the rise in EE with the enhancement in SE causes the EE to increase initially with the number of antennas but experiences a gradual decay with circuit complexity. Moreover, it is visible from the study, that a decent gains in both SE and EE are achieved with multiplexing different base stations with user equipment's. The result manifests that the maximum EE is reached for a certain value of M/K ratio.

PAPER PUBLISHED

Your paper has been submitted
1 message

EquinOCS <equinocs-admins@springernature.com> Tue, Mar 28, 2023 at 3:31 PM
To: AKHILA GORAKALA <akhila.2019.ece@anits.edu.in>

This message has been sent by the EquinOCS conference system
https://equinocs.springernature.com/

PLEASE DO NOT REPLY

========

Dear AKHILA GORAKALA,

We are pleased to inform you that the paper

157: "MAXIMIZATION OF ENERGY-EFFICIENCY FOR OPTIMAL SPECTRAL EFFICIENCY IN MASSIVE MIMO SYSTEM"

has been sucessfully submitted to

2nd International Conference on Data Science and AI (ICDSAI2023)

by SOMASEKHAR BORUGADDA (@somasekharb).

To access the paper:
- log into your EquinOCS account
- navigate to ICDSAI2023
- access the paper 157 via the 'Your Submissions' page

If you have no EquinOCS account yet, register with EquinOCS using the email address at which you have been receiving this notification. This way, the paper can be associated with your account. You will also find the licencing information there.

========

PLEASE DO NOT REPLY

This message has been sent by the EquinOCS conference system
https://equinocs.springernature.com/

See our Privacy Policy
https://www.springernature.com/gp/legal/privacy-statement/11033522

REFERENCES

[1]. Emil Bjornson, Luca Sanguinetti, and Marios Kountouris, "Deploying Dense Networks for Maximal Energy Efficiency: Small Cells Meet Massive MIMO",2015.

[2]. J. Hoydis, M. Kobayashi, and M. Debbah, "Green small-cell networks," IEEE Veh. Technol. Mag., vol. 6, no. 1, pp. 37–43, 2011.

[3]. L. Sanguinetti, A.L. Moustakas, and M. Debbah, "Interference management in 5G reverse TDD hetnets with wireless backhaul: A large system analysis," IEEE J. Sel. Areas Commun., vol. 33, no. 6, pp. 1187 – 1200, June 2015.

[4]. T. L. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas," IEEE Trans. Wireless Commun., vol. 9, no. 11, pp. 3590–3600, 2010.

[5]. E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," IEEE Commun. Mag., vol. 52, no. 2, pp. 186–195, 2014.

[6]. H. Yang and T. L. Marzetta, "Capacity performance of multicell largescale antenna systems," in Proc. IEEE Allerton Conf. Commun., Control and Comp., 2013.

[7]. Emil Björnson, Jakob Hoydis and Luca Sanguinetti, "Massive MIMO Networks: Spectral, Energy, and Hardware Efficiency", Foundations and Trends R in Signal Processing: Vol. 11, No. 3-4, pp 154–655, 2017.

[8]. H. Kwon and T. Birdsall, "Channel capacity in bits per joule," IEEE Journal of Oceanic Engineering, vol. 11, no. 1, pp. 97–99, 1986.

[9]. A. Mammela and A. Anttonen, "Why will computing power need particular attention in future wireless devices?" IEEE Circuits and Systems Magazine, vol. 17, no. 1, pp. 12–26, 2017.

[10]. Emil Björnson and Erik G. Larsson, "How Energy-Efficient Can a Wireless Communication System Become?", 2019.

[11]. C. E. Shannon, "Communication in the presence of noise," Proc. IRE, vol. 37, no. 1, pp. 10–21, 1949.

[12]. S. Verdú, "On channel capacity per unit cost," IEEE Trans. Inf. Theory, vol. 36, no. 5, pp. 1019–1030, 1990