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Energy Efficiency Optimization for Massive MIMO Communication System

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Abstract

In wireless systems of communication, the optimization of energy and spectral efficiencies are significant as they improved antenna array gain as well as spatial resolution. In order to achieve this optimization, large-scale antennae also called Massive MIMO antennae are deployed.

Recent works in the field of massive multiple-input multiple-output (MIMO) show that the user channels de-correlate when the number of antennas at the base stations (BSs) increases, thus strong signal gains are achievable with little inter-user interference.

Since these results rely on asymptotic, it is important to investigate whether the conventional system models are reasonable in this asymptotic regime.

In this research, we consider how capacity is implemented with a perfect Channel State Information (CSI) to formulate a challenge for maximizing Energy Efficiency (EE). With regard to this, we obtained the needed capacity with lower power consumption in a huge MIMO system. Our system also uses the Maximum Likelihood Detector to optimize capacity. We theoretically analyze the system performance in Massive MIMO based on Zero Forcing (ZF), Maximum Ratio Combined (MRC), and Mean Minimum Square Error Receiver (MMSER). We analyzed the Energy Efficiency (EE) optimization in both the downlink and uplink in a Massive MIMO System.

Keywords: Optimization, Channel Estimation, Energy Efficiency, Massive MIMO, Spectral Efficiency

I. INTRODUCTION

The enormous development of mobile phone clients is due to the fast improvement of remote communication advances. As of 2023, it has been told that the United States of America alone has over 252.6 million different phone users, with India at 1.11 billion and China at 1.32 billion users [1]. The current worldwide projection of portable phone users stands at 6.5 billion individuals. Due to the far-reaching utilization of keen contraptions, the requirement for advanced remote communication is quickly expanding. As a result, the issue of frequency resources is a limitation of this technology. Modern innovations like small cell and high-order modulation can enhance frequency efficiency to a greater extent [1].

The fifth-generation (5G) communication framework is considerably a developing innovation that enhances data speed, ultra-reliable low latency, and machine-to-machine communication [2]. Moreover, 5G wireless communication works with standardized versatile gadgets such as smartphones and portable workstations as well as device-to-device (D2D) networking [2].

It is now clear that 5G has given usa communication framework with incredible capacity, negligible complexity, better data rate, and minimum latency. Modern research has shown that technologies such as non-orthogonal Multiple Access (NOMA), millimeter wave, and Massive MIMO have been implemented in this new technology. This research mainly focuses on massive MIMO technology in 5G communication systems. [2].

After the MIMO technology, a comparable rising innovation called the Massive MIMO system which enhances network capacity, energy, and spectral efficiency as well as reduces latency has been used within 5G wireless communication. Massive MIMO uses 100s of antennas to serve many users utilizing the same time-frequency assets.

However, a large amount of RF chain resources such as amplifiers, mixers, ADC, filters, etc. are required whenever deploying a massive system. In so doing, due to a large amount of RF resources, the cost of implementing a Massive MIMO is extremely expensive. With the antenna selection algorithm, we can implement a massive MIMO system using some optimization methods with relatively reduced costs and effectiveness. This research is mainly concerned with antenna selection to optimize energy and spectral efficiency in Massive MIMO systems. Multiple data are sent from both the transmitter and receiver side at the same time in a MIMO system.

Conceptually, it has been demonstrated [2] that a system with a lot of antennas can perform significantly better in radiating energy efficiency. MIMO study first started with point-to-point MIMO and then later came the multi-user MIMO. Compared to point-to-point MIMO, multi-user MIMO has many advantages, but it also has some drawbacks, such as [3] the fact that roughly equal numbers of base station antennas and terminals are needed, as well as the fact that it is not a scalable technology. Also, refer to as large-scale antenna systems, Massive MIMO came about as a result of these issues following the development of multi-user MIMO and offers better advantages over both of these technologies. In comparison, the MU-MIMO system is equipped with fewer antennae compared to the massive MIMO system which has 100 BS antennas instead of the 10 antennas present in the MU-MIMO system.

We need a lot more RF chain resources as the Base Station antenna gets bigger. By doing this, the system's size and hardware design become more complex, its cost significantly rises, more power is consumed, and signal processing is required. This situation calls for the use of the recommended antenna selection optimization method. Instead of using every antenna, this method chooses a good number of antennas based on criteria like Maximum Combined Ratio and Zero Forcing are used. The system capacity is increased, the bit error rate (BIR) is decreased, the signal-to-interference plus noise (SINR) may be increased, or the energy efficiency (EE) may be optimized depending on the selection requirement [3].

An exact RF requirement, as well as the additional antennae, are necessary in order to improve the system's performance using spatial selection.

As a result, the cost, size, and complexity of the hardware are reduced while system performance is also maintained when using the antenna selection technique [4]. The necessary gain and radiation pattern cannot be met by a single-element antenna. In order to create an Antenna Array (AA), more single antenna elements must be combined. We take into account antenna arrays [5] to focus emitted energy on a particular path.

1.1.Massive MIMO (Massive Multiple Input Multiple)

Massive MIMO, also known as Very large MIMO, differs significantly from conventional MIMO in that it operates in time division duplex mode and makes use of a significant number of antennas above active terminals. More antennae are used in order for the energy to be directed efficiently (beamforming). With this, we greatly increase throughput and effectively radiate energy [6].

The widespread use of inexpensive, low-power components, decreased latency, generalization of the media access control (MAC) layer, and resistance to deliberate jamming are additional benefits of massive MIMO. The next generation of wireless networks has a high potential for Gigabit data rates, and massive MIMO systems are capable of handling this [30]. Massive MIMO at BS boosts data rate in comparison to any other technology.

The following are a few of the massive MIMO systems' early advantages.

- The extraordinary beam-forming determination merely reduces inter-user interference.
- Processes for low-complexity signal processing are asymptotically ideal.
- Due to coherent beam forming and combining, there is a significant array gain that reduces propagation damages.
- In the large-dimensional vector space, errors in channel estimation that result in interference leakage are eliminated asymptotically.

1.2.Linear Pre-Coding Process

When the total number of transmitted antennas exceeds infinity, massive MIMO systems can be condensed into Single-input-to-Single-output (SISO) systems [7]. To make the most of the spectrum resources available in large MIMO systems, pre-coding is used at the transmit end to minimize system complexity, minimize noise, and optimize stream data transmission [7]. Three popular linear pre-coding techniques are the MRC, ZF, and MMSE procedures.

1.2.1. Maximum-Ratio Combined (MRC)

In order to increase SNR, this technique aims to increase power at the receiver combiner. MRC is regarded as a suitable linear reception strategy for large MIMO systems because it can be implemented in a distributed manner.

The MRC mathematical model is as follows.

$$A = \frac{gk}{\|g_k\|}\| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.0$$

As the number of antennas increases infinity times, MRC also performs admirably in the low-power regime, sometimes even achieving the best outcomes. Although systems based on the MRC scheme experience significant inter-user interference as power levels rise [8], this problem is not unique to them.

1.2.2. Zero-Forcing

Inter-user interference is eliminated by the ZF scheme by projecting received signals into orthogonal elements. You could also write it as [8]

$$A = G(G^H G)^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

Systems based on the ZF pre-coding scheme perform badly in the low-power regime because the ZF approach does not take noise into account. Performance approaches are ideal in the high-power regime [8,9]

1.2.3. MMSE

Inter-user interference and background noise are both targets of the MMSE process. Compared to MRC and ZF, MMSE has a more complex system. [9].

$$A = G\left(G^H G \frac{1}{P_u} I_k\right)^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2$$

1.2.4. Spectral Efficiency

The data rate that can be achieved over a specific bandwidth is referred to as spectral efficiency in a particular wireless communication system. According to Shannon, the wireless communication system is as follows.

$$R_d = \log_2(I_{NR}\boldsymbol{P}A^H\boldsymbol{G})\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.3$$

$R_d$is the data rate, given that I_{NR} is an $N_R * N_R$ matrix, the power used at the sender side [10] is given as P, while the channel matrix is given as [10].

By representing the pre-coding process, the total system capacity is written as [11],

$$R^{\mathcal{U}} = \sum_{k=1}^{k} \mathcal{E}\{\log_2(1 + SINR^{\mathcal{U}})\}\ldots\ldots\ldots\ldots\ldots 1.4$$

$\mathcal{U}$ represents pre-coding schemes which is, MMSE, ZF, MRC. The Signal to Interference - Noise- Ratio (SINR) can be expressed as:

$$SINR_k^{\mathcal{U}} = \frac{|\vec{a}^H \vec{g}_k^{\mathcal{U}}|2}{\sum_{j\neq k}^{k} k\left|\vec{a}^H \vec{g}_k^{\mathcal{U}}\right|^2 + \sigma^2}\ldots\ldots\ldots\ldots\ldots\ldots 1.5$$

Whereσ^2 is the noise power variance, while a_k is the *Kth* Column of ***A*.**

1.3.Energy Efficiency in Massive MIMO

The energy efficiency (EE), which is the quantity of bits transmitted per Joule, is the ratio of capacity to transmitted power consumption [12]. In a large MIMO system, where M is the number of transmitted antennas, the spatial efficiency is increased by M and $\sqrt{M}$, respectively, for perfect and imperfect CSI systems when the transmitted power is distributed evenly among the antennas. In addition, noise and small-scale fading decrease as the number of antennas rises, and channel similarity declines as antenna distance rises. According to data [12], channels between antennae and users will begin to resemble orthogonality when the number of antennas is significantly greater than the number of users. Transmission power consumption is given priority over energy efficiency [13] in traditional MIMO systems [13].

1.4.Power Consumption Model

Since there are many antennas used, the circuit power consumption, which is primarily produced by the radio frequency (RF) chain, cannot be disregarded [14,15]. A communication system's antennas each have their own RF chain. The RF chain in the downlink is made up of many antennas are used, the circuit power consumption, mixer, filter, digital-to-analog converter (DAC), and synchronizers, as depicted in Fig. 1.1**.**

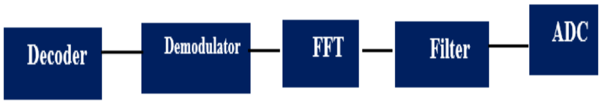


Figure 1.1: Radio Frequency Chain

The received signal x is first sent through a low-pass filter, band-selective filter, power amplifier, synchronization, and an AGC (Auto Gain Control Module) [16]. The analogue signal is then quantized, and an A/D converter is used to convert it to a digital signal.When there are more antennae, the circuit uses more power. This means that massive MIMO sacrifices energy efficiency for spatial efficiency. A serious risk is also posed by the system performance loss brought on by RF hardware [17].

Hardware losses include, for instance, quantization error, carrier frequency phase shift, and nonlinear power amplifier [18]. According to the data, having a large number of antennas in huge MIMO systems improves spatial efficiency and capacity but also consumes more power. As a result, finding a fair trade-off between various aspects of system performance is critical

1.4.1. Mathematical Model of Power Consumption

We may derive the mathematical model for total power usage based on the aforementioned analysis:

$$\boldsymbol{P_{ktotal}} = \frac{\frac{P_t}{n(1-\sigma feed)}+P_{cir}+P_{sta}}{(1-\sigma DC)(1-\sigma Ms)(1-\sigma cool)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.6$$

Where $Pk,\ l$ is kth use’s total power consumption. $Pcir$ is circuit power consumption which can be calculated by $Pcir\ =\ (Pdac\ +\ Pmix\ +\ Pfilt)\ +\ Ps$, $Pdac$ is DAC power consumption [18]. $Pmix$ is mixer power consumption. $\boldsymbol{P_{sta}}$ is ideal power consumption. N is activated transmitted antennas[19]. σDC, $\sigma feed$, $\sigma cool$, σMs are, respectively, the loss factors of the antenna DC-DC power supply, antenna feeder, active cooling system, and main power supply [19]. Loss factors are not taken into account in this project [19].

As a result, EE can be expressed mathematically as:

$$\boldsymbol{EE} = \frac{\sum Capital}{\sum_{i=1}^{k} P_{i,total}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.7$$

II. RESEARCH OBJECTIVES

In this study,

a) The history of the wireless communication system will be analyzed.

b) The importance of massive MIMO, system model, mathematic model, and problem formulation will be discussed.

c) The Dinkelbach Method will be applied to address the optimization problem with CVX.

d) The massive MIMO will remarkably improve energy and spectral efficiency by combining numerical results.

III. METHODOLOGY

This chapter explains how capacity is implemented in a perfect CSI system, how to create a challenge for maximizing energy efficiency in a massive MIMO system, and how to use the Dinkelback approach based on convex programming. The chapter before this one covered a basic large MIMO system model.
Huge MIMO systems enable us to achieve the required capacity with lower power consumption due to the extensive deployment of antenna arrays. This chapter will discuss the capabilities of massive MIMO systems.
The base station will, in theory, employ the maximum likelihood detector in order to achieve optimal capacity. But as the user base expands, so does the complexity on the receiving end.
The linear coding procedure that we previously discussed is one of our requirements. The theoretical analysis of the system achievement using Massive MIMO taking into account ZF, MRC, and MMSE is therefore carried out in this chapter

3.1.How Capacity is implemented under Perfect CSI.

The G wireless communication system, which is based on flawless CSI, will be the first thing we examine. Assume that a cell's N base station antennas and K users are represented by a detector matrix A with dimensions of N x K. A is based on G for MRC.

$$R_{\mathrm{P,K}}^{MRC} \rightarrow \log_2(1+\beta_k P_u) \quad \ldots\ldots For\ MRC\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1a$$

$$\widetilde{R_{\mathrm{P,K}}^{Zf}} = \log_2(1+P_u(M-K)\beta_k \ldots\ldots For\ \ Zero\ Forcing\ldots\ldots.3.2b$$

$$\tilde{R}_{P,k}^{mmse} = \log_2(1+(a_k-1)\theta_k \ldots\ldots For\ MMSE\ldots\ldots\ldots...3.3c$$

The received signal of user K for a specific user is as follows:

$$A = \begin{cases} & gt \quad MRC \\ G(G^H G) & ZF \\ G = \left(G^H \dfrac{G}{P_U}\right) & MMSE \end{cases}$$

$$r_k = \sqrt{p_{u a_k^H}} g_k x_k + \sqrt{P_u} \textstyle\sum_{i=1,i\neq k}^{k} a_k^H g_i x_i + a_k^h n \ldots\ldots\ldots\ldots 3.2$$

Where *ak* denotes A's kth column and *gk* denotes G's kth column. We treated system noise and interference as random variables in the received signal model, with zero mean and variance. With a zero-mean and variance, a random variable is created

$$p_u = \textstyle\sum_{i=1,i\neq k}^{k} |a_k^H g_i|^2 + \|a_k\|^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

The bottom bound of capacity can be approached by modeling this channel as an additive white Gaussian noise.

MU-MIMO uplink capacity can be calculated using [20] if the channel is periodic.

$$R_{PK} = E\left\{\log_2\left(1 + \frac{p_u |a_k^H\ g_k|^2}{p_u \sum_{i+1,i\neq k}^{k} |a_k^H\ g_i|^2 + \|a_k\|^2}\right)\right\} \ldots\ldots..3.4$$

Theoretically, baseband data encoding over realizations is possible to reach this capacity. In reality, though, we are able to encrypt source data using methods like Orthogonal Frequency-Division Multiplexing (OFDM) in the wideband domain.

In the event that the received side has flawless CSI, the receiver can perfectly reconstruct the signal. The channel's impact on interference and noise can be reduced as a result. The strength of the transmission and localized fading *βk.* impact a MIMO system's SINR.

3.2.Maximum-Ratio Combine

With the MRC detector, A=G in Equation 3.1. $a_k = g_k$ is something we can figure out. Equation 3.5 should therefore be rewritten as follows:

$$\boldsymbol{R_{\mathrm{P,K}}^{MRC} = E\left\{\log_2\left(1 + \frac{\mathrm{Pu}|g_k|4}{\mathrm{Pu}\sum_{i=1,i\neq k}^{K}|g_k^H g_i|2+||a_k||2}\right)\right\}} \ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

With M antennas in BS, total transmitted power on the transmitted side is $E_{u.}$ [21].

$$P_{u.} = \frac{E_{u.}}{\mathrm{M}}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

As the number of antennae grows indefinitely, the receiver's possible capacity with an MRC detector can be represented as [22].

$$\boldsymbol{R_{\mathrm{P,K}}^{MRC} \rightarrow \log_2(1+\beta_k E_u)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

The analysis above shows that the massive MIMO system can be broken down into a number of SISO systems as the number of antennae increases indefinitely. Under these circumstances, intra-cell interference and fast fading will be significantly reduced. To put it another way, the system capacity will multiply by M times if the transmitted power remains constant. In addition, spectral efficiency is increased by K times because the system may support K users concurrently.

3.3.Zero-Forcing Receiver

The detector matrix A for the ZF receiver, according to Equation 3.5, is G$(G^H)^{-1}G^H$.

Therefore,

$$a_k^H g_i = \delta_{ki} \ldots\ldots\ldots 3.8$$

Where δ_{ki} is the impulse function.
By applying Jensen's inequality, the lower bound of capacity for ZF detector can be given by

$$R_{\mathrm{P,K}}^{\mathrm{ZF}} \geq \log_2\left(1+\frac{P_u}{E\{[(G^H G)-1]kk\}}\right) \ldots\ldots\ldots 3.9$$

The noise and interference in a wireless communication system under the Rayleigh Channel can be represented as [23],

$$\begin{aligned} E\{[(G^H G)-1]kk\} &= \frac{1}{\beta_k} E\{[(H^H H)-1]kk\} \\ &= \frac{1}{K\beta_k} E\{[\mathrm{tr}(H^H H)-1]\} \\ &= \frac{1}{(M-K)\beta_k}, for\ M \geq \mathrm{k}+1 \end{aligned}$$

In so doing, we can represent the lower bound as:

$$\widetilde{R_{\mathrm{P,K}}^{Zf}} = \log_2(1+P_u(M-K)\beta_k \ldots\ldots\ldots 3.10$$

With the condition $P_{u=}\frac{\mathrm{E}_u}{\mathrm{M}}$ [23], the equation (3.13) can be written as:

$$\widetilde{R_{\mathrm{P,K}}^{Zf}} = \log_2\left(1+\tfrac{\mathrm{E}_u}{\mathrm{M}}(M-K)\beta_k\right) \rightarrow \log_2(1+\beta_k P_u)\mathrm{M}\ \text{goes}\ \textit{infinitely}$$

We can see from Equations (3.9) and (3.10), that when M continues endlessly, the lower bound becomes precise.

3.4.Minimum Mean-Squared Error Receiver

In Equation (3.1), we found the detector matrix A, which is given by

$$A = G\left(G^H G + \frac{1}{P_u} I_k\right)^{-1} \ldots\ldots\ldots 3.11$$

Thus,

$$A^H = G(G^H G + \frac{1}{P_u} I_k)^{-1} G^H = G^H(GG^H + \frac{1}{P_u} I_M)^{-1}$$

$$a_k = (GG^H + \frac{1}{P_u} I_M)^{-1} g_k = \frac{\Lambda_k^{-1} g_k}{g_k^H \Lambda_k^{-1} g_k + 1}$$

Where

$$\Lambda_k \triangleq \sum_{i=1,i\neq k}^{K} g_i g_i^H + \frac{1}{P_u} I_M \ldots\ldots\ldots 3.12$$

The lower bound capacity of the MMSE detector can thus be simplified as follows:

$$R_{P,k}^{mmse} = E\left\{\log_2\left(\frac{1}{[I_K P_u G^H G)-1]kk}\right)\right\}$$

$$\geq \widetilde{R_{\mathrm{P,K}}^{mmse}} = \log_2(1+\frac{1}{\mathrm{E}\left\{{}^{1}/_{\gamma_k}\right\}}) \ldots\ldots\ldots 3.13$$

Where $\gamma_k \triangleq \frac{1}{[I_K P_u G^H G)-1]kk}$,$\gamma_k$ follows Gamma distribution, with PDF

$$p_{\gamma k}(\gamma) = \frac{\gamma^{a_k-1} e^{\gamma/\theta_k}}{r(a_k)\theta_k^{a_k}}$$

Whereas:

$$a_k = \frac{(M-K+1+(k-1)\mu)2}{M-K+1+(K-1)k}$$

$$a_k = \frac{M-K+1+(K-1)k}{(M-K+1+(k-1)\mu} P_u \beta_k \ldots\ldots\ldots 3.14$$

Given that the channel is subject to Rayleigh Fading, the lower bound of system capacity can be calculated as follows:

$$\tilde{R}_{P,k}^{mmse} = \log_2(1+\frac{\Gamma(a_k)}{\Gamma(a_{k-1})}\theta_k) \ldots\ldots\ldots 3.15$$

Since Γ follows Gamma distribution, we have $\Gamma(x+1) = x\Gamma(x)$. Thus, the Equation ….3.15 can be expressed as

$$\tilde{R}_{P,k}^{mmse} = \log_2(1+(a_k-1)\theta_k) \text{………………………}3.16$$

MRC	$R_{P,K}^{MRC} \rightarrow \log_2(1+\beta_k P_u)$
ZF	$R_{\mathrm{P,K}}^{\widetilde{zf}} = \log_2(1+P_u(M-K)\beta_k$
MMSE	$\tilde{R}_{P,k}^{mmse} = \log_2(1+(a_k-1)\theta_k$

Table 3.1: Achievable Capacity with Perfect CSI

3.5.System Design

3.5.1. Problem Formulation for optimizing energy efficiency in massive MIMO system

The problem formulations for optimizing energy efficiency in huge MIMO systems will be demonstrated in this part.

3.6.Optimization for Energy Efficiency

Considering that we examined the achievable data rate of these three linear detectors in the previous sub-session, we will integrate this conclusion with the energy consumption model in massive MIMO presented in Chapter 2. We can get the EE model in massive MIMO systems with downlink communication as follows:

$$\boldsymbol{EE} = \frac{\sum capacity}{\sum_{i=1}^{k} P_{i,total,}} \text{……………………………………}3.17$$

Where $P_{k,total} = \dfrac{\dfrac{P_t}{\eta(1-\sigma_{feed})} + P_{cir} + P_{sta}}{(1-\sigma_{DC})(1-\sigma_{MS})(1-\sigma_{cool})}$

As a result, the problem formulation may be expressed as follows to optimize system performance in terms of EE:

$$\max_{A,N} \frac{R_{P,k}^{mmse,zf,mrc}(\mathrm{M})}{k_{P_u} + M * P_c} \text{………………………………………...}3.18$$

$$s.t\ C1: M \leq N_{max,}$$

$$C2: R_{P,k}^{mmse,zf,mrc}(M) \geq R_{min,}$$

$$C3: A \geq 0.$$

Constraints C1, C2, and C3 pertain to the total amount of power consumed, the necessary system capacity, and the precoding matrix, respectively. The amount of antennas that can be used in BS is constrained by C1. The maximum data rate that can be obtained using the fewest system resources is given by the equation C2, which is.

While there are K users per cell, there are M antennas in BS. *A* in C3 stands for the ideal precoding matrix, which is anticipated to be positive. The letter H stands for channel state data.

3.7.Analysis for Problem Formulation

Although the number of antennas can increase to their maximum amount of flexibility, eradicating intra-cell interference, route loss, and large-scale fading, such as shadowing, must be taken into account SNR may vary among users in the same cell as a result. In this circumstance, power control should be used.

According to theory, when developing a successful power control strategy, transmitted power and the number of users' K should be taken into account. The power control issue can only be used to control fading to a large extent. However, such a power control system might actually lead to new tradeoffs. Optimizing the number of active users also influences the trade-off between energy efficiency. We should consider whether the channel constants for diverse users should be adaptable if they differ significantly from one another.

Both techniques have the potential to act as power controls, despite having different operational meanings. In our investigation, we won't take into account the impact of large-scale fading, but it is mathematically represented by an Equation.

Given the rise in both transmitted and circuit power consumption, the trend in EE can be characterized as a concave curve in terms of energy consumption.With the number of transmitted antennas. As a result, M is increased to maximize EE, despite the fact that the absolute value of EE decreases as P_u increases.

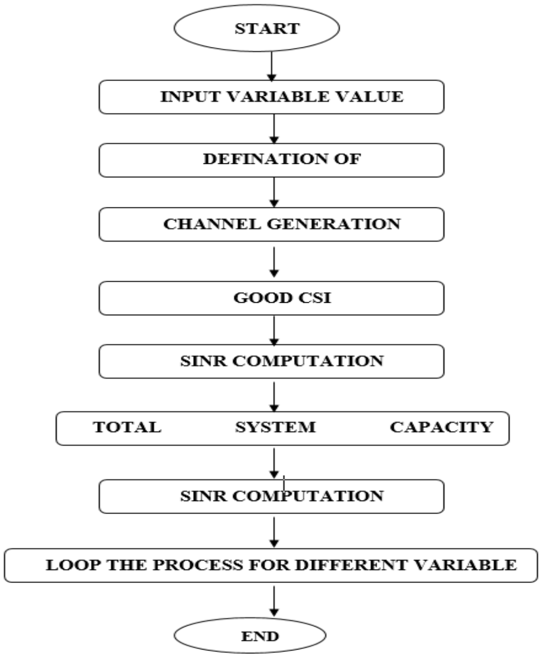


Figure 3.1. System Flow Chart

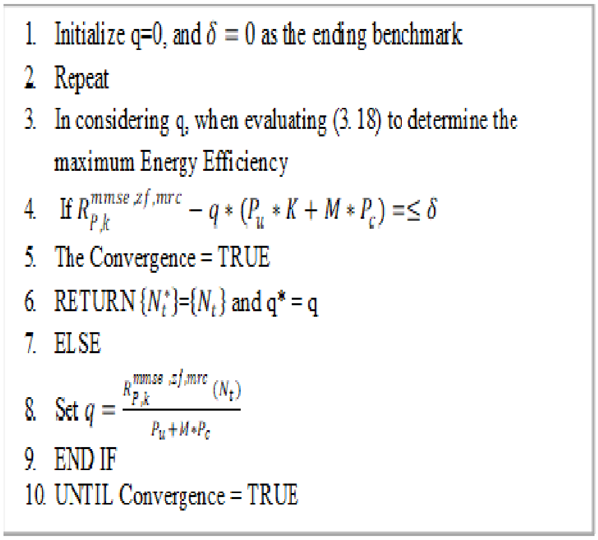
3.8.Convex Programming-Based Dinkelback Method

Equation 3.18 has a non-convex objective, so we are unable to solve it using the CVX method. The Dinkelback Method can be applied in this circumstance.

The maximum energy-saving capacity of the system is q. As a result, we can rewrite Equation 3.18 as

$$\max_{N_t} R_{P,k}^{mmse,zf,mrc} - q*(P_u*K+M*P_c) = 0\ldots\ldots 3.19$$

Table (3.2), we have the Pseudo code



```
Initialize q=0, and $\delta = 0$ as the ending benchmark
Repeat
    In considering q, when evaluating (3.18) to determine the maximum Energy Efficiency
    If $R_{P,k}^{mmse,zf,mrc} - q*(P_u*K+M*P_c) =\leq \delta$
        The Convergence = TRUE
        RETURN $\{N_t^*\}=\{N_t\}$ and q* = q
    ELSE
        Set $q = \frac{R_{P,k}^{mmse,zf,mrc}(N_t)}{P_u+M*P_c}$
    END IF
UNTIL Convergence = TRUE
```

Table 3.1: pseudo-code shows the Dinkelback approach for Imperfect CSI

The mathematic model for the entire system was thoroughly covered in this chapter. We created an optimization problem based on these models that depicts the trade-off between efficiency and energy efficiency. Because the optimization has non-linear variables, we used the Dinkelback method to solve it.

IV. RESULTS, ANALYSIS AND INTERPRETATION OF DATA

4.1. Overview

In the previous chapter, the calculation concept for spectral efficiency and EE has been analyzed. In this chapter, we will show you the simulation results to verify the theoretic analyses results. We will first demonstrate EE with the Dinkelbach results and then the simulation results will be given.

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4.1.1. EE and Antenna at Base Station

Based on pseudo codes, the simulation results are given in Fig 4.1

4.1.2. Analysis Illustration:

Proposition: Channel is under Rayleigh distribution and Receiver side has imperfect CSI.

For the purposes of this simulation, we presume that each set's circuit power consumption is 0W while transmitted power is set at 1W. Path loss factor is n = 20 and the shadowing factor is = 13 dB. Users and BS are all more than 100 meters away from one another. According to the simulation graph, the EE can be maximized for MRC detectors when the number of antennas in the BS is between 50 and 60, and the maximum value is roughly 0-point to 5b/Hz/W. Furthermore, the Energy Efficiency is roughly at 0.6 and the Zero Forcing is at a Base Station antenna of 60.

When the BS antenna is increased to 60 and the EE is set to 20 b/Hz/w, the energy efficiency in the ZF detector is optimized.

The EE of ZF is better to that of MRC when the number of antennas is under 30. However, when there are more than 30 antennas, ZF's performance will be improved than that of MRC. The performance of the system will be negatively impacted by critical intra-cell interference when the number of antennas is greater than 30, as the MRC algorithm ignores the effect of interference and only takes the noise effect into account. On the other hand, interference among users will dominate system performance for the ZF algorithm, which only takes into account noise effects, as the number of antennas approaches infinity. As a result, the ZF algorithm's capacity is superior to the MRC algorithm's when the number of antennas is greater than 30.

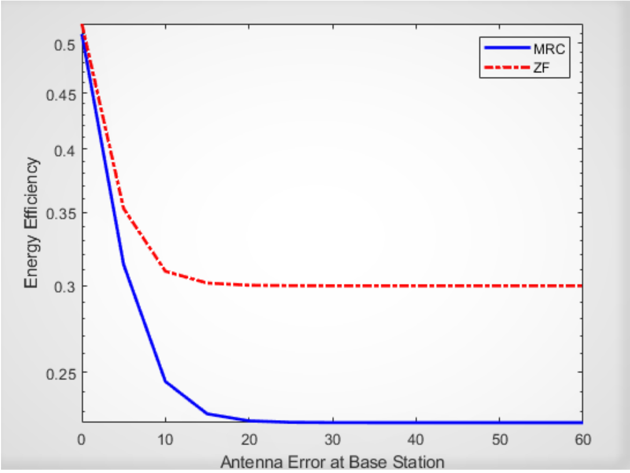

Figure 4.1.Energy Efficiency and the Antenna Error at Base Station.

4.2. Spectral Efficiency Simulation when Considering Signal to Noise Ration

To shows the relations between SNR and capacity, we simulated this in figure 4.2.

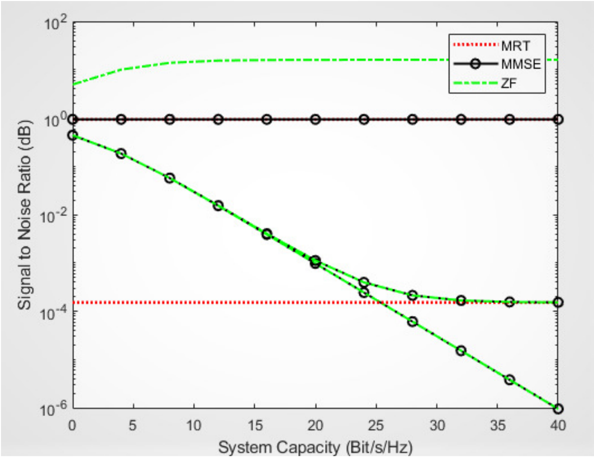

Figure 4.2: System Capacity (Bit/s/Hz) vs Signal to Noise Ratio (dB)

The system capacity is determined by the number of active antennas and the transmitted. In this simulation, we examine the transmitted power and system capacity. Perfect channel state information is available at both the transmitter and receiver ends.

The performance of the MMSE system in terms of capacity among the entire power echelon is clearly shown by this simulation figure to be the lowest. The achievable data rate is 31 bits/s/Hz when SNR is equal to 10^{-3}dB. Additionally, the capacity rises in step with the transmitted power. It goes through a similar process to that of ZF. Though it performs poorly in the low power regime because noise is not taken into account. The capacity of ZF dramatically decreases with SNR greater than $10^{-3}dB$. In the high-power echelon, it is almost as far apart as the MMSE. Due to less inter-user interference, the performance of the system based on the MRC precoding scheme is approaching MMSE in the low power echelon. The capacity, on the other hand, nearly stabilizes when SNR is greater than 10^{-2} dB, primarily due to high user interference.

4.3. Comparing the Total Spectral Efficiency with Number of Antennas

In view of simulation results as indicated in Fig4.3, we can identify that the capacity will be greater as the transmitted power increases. We have analyzed the relationship between spectral efficiency and the number of base station antennas.

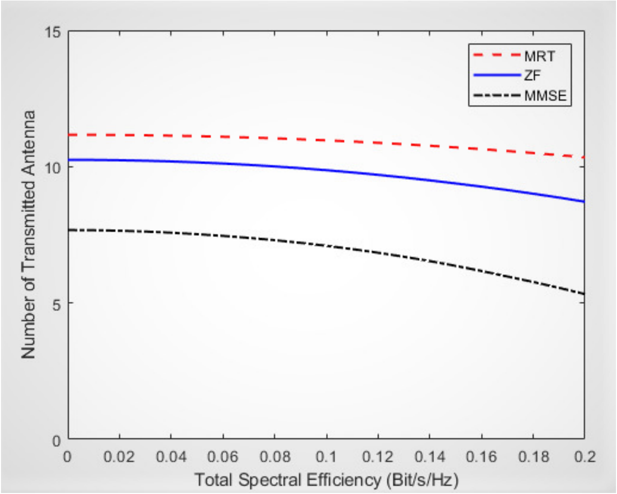

Figure 4.3: Number of Transmitted Antenna (Spectral Efficiency) VS Total Spectral Efficiency

From the simulation's outcomes, as displayed in Fig. 3 point 1. We are aware that as transmitted power rises, capacity will as well. The relationship between capacity and the number of antennas, which is depicted in Fig. 4.3, will be examined.Rayleigh fading is the channel in this simulation, with the transmitter side and receiver side assuming perfect knowledge of the channel state, and the given SNR is equal to 10dB. The energy efficiency of the MRC, ZR, and MMSE increases as we add more antennae.

ZF exhibits good performance in the simulation, but MRC outperforms it by a wide margin. In particular, when there are infinitely many transmitted antennas, ZF performs nearly as well as MRC. The capacity of the MMSE is lower than that of the ZF and MMSE. Once more, these three curves have a relatively high elevation when there are fewer than 15 antennas. On the other hand, as the number of antennae exceeds 15, the spectral efficiency slightly increases.

It may be determined that spectral efficiency cannot be increased gradually due to the restriction of power consumption. High power consumption and high hardware costs are caused by the base station's numerous antennas. The performance of the system will be governed by user interference as the number of antennas approaches infinity. This means that the strength of the inter-cell inference will increase with the number of users in the cells. The system's performance cannot grow linearly as the number of antennas rises. These simulation results show how the capacity is affected by transmitted power and antenna count. The capacity of the system cannot be increased indefinitely, we conclude. Given this, it is important to demonstrate the ideal number of activated antennas for maximizing system energy efficiency.

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4.4. Total Energy Efficiency Compare to Signal Noise Ratio.

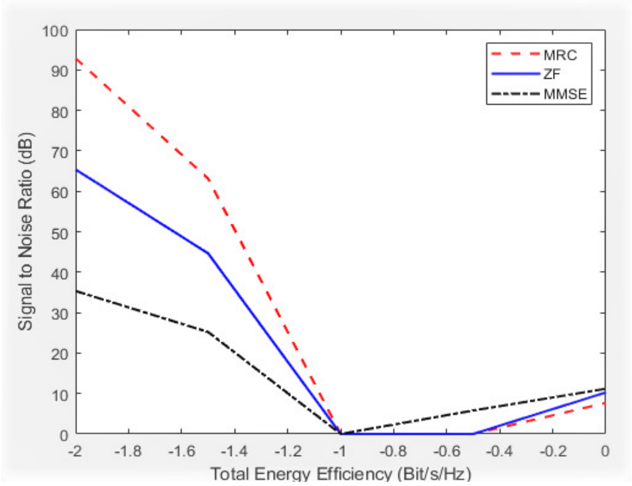

Figure 4.4: Signal to Noise Ration VS Total Energy Efficiency

The energy efficiency is based on theoretical analysis that takes into account the number of antennas and transmitted power consumption. Here, the effect of the total amount of transmit power on energy efficiency is our main focus. Rayleigh fading is present on the communication channel, and both the transmit and receive sides have complete knowledge of the channel state. MRC continues to perform at its peak level across the entire power spectrum, from -1 dB to 65 dB, as shown by the numerical results. It significantly increases from -1.4 bits/Joule with SNR equal to 0.1dB to 0.2 bits/Joule with SNR equal to 93dB. Furthermore, it falls off significantly when SNR falls below 10dB. ZF experiences a similar process even though it performs poorly in the low power echelon. Energy efficiency dramatically improves when SNR is greater than 10dB and reaches its peak when SNR is 65dB. As soon as the SNR drops to 8dB, it returns to 0.5. We state that MMSE has a similar process to the others, but has a very low energy efficiency compared to them. Between ZF and MRC, not much has changed. Its performance is better in the low power echelon than MRC and ZF. And as SNR increases, it can reach a maximum of -1 bits/Joule when SNR is equal to 10dB. Once SNR exceeds 30dB, it keeps getting better. The EE will then decline as the number of antennas rises. ZF's EE is higher than MMSE's, but it uses more power. On the other hand, MRC achieves the highest EE while consuming the least amount of transmitted power. As we previously discussed, the spectral efficiency of Massive MIMO systems does not scale linearly with the number of antennas. By doing this, the relationship between EE and transmitted power, which is influenced by SNR and the number of antennas, becomes convex.

V. CONCLUSIONS

Since the appearance of Massive MIMO, the system performance of wireless communication system has been improved significantly in terms of capacity, latency, reliability and etc. In this study, the history of wireless communication system was analyzed; the importance of massive MIMO, system model, mathematic model and problem formulation was highlighted; the Dinkelbach Method was clearly applied to address this optimization problem with CVX; and finally, the massive MIMO remarkably improved the energy efficiency and spectral efficiency through the combination of numerical results.

The most important focus of this research is on Energy Efficiency Optimization in Massive MIMO system. Even though we give significant consideration to power transmission in the uplink system, a considerable room for future research in this topic is necessary.

5.1. Consideration of Future Works

a. The energy efficiency prototype in this research only work with single cell massive MIMO system. More research work can be done in the near future to advance the system to multi-cells Massive MIMO system.

b. We consider that both transmit and receive end have greater CSI. It is predictable to advance to imperfect CSI.

c. Taking in to consideration the distances between users and Base Station is not be taken into account in this research. This should be deliberated on in upcoming work on this topic for more exact/ correct simulation outcomes.

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