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PERFORMANC ANALYSIS OF ENERGY EFFICIENCY ENSURING TECHNIQUES IN MASSIVE MIMO FOR 5G COMMUNICATION NETWORKS

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Performance Analysis of Energy Efficiency Ensuring Techniques in Massive MIMO for 5G Communication Networks

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Abstract

Wireless communication technology is increasing to satisfy the needs of customers. With the emergence of new technologies, energy consumption is one of the most important performance metrics. According to the requirements of the 5^{th} generation wireless communication system, energy consumption should not increase from the level of the current networks (4G), even though the amount of data is expected to be significantly higher. Therefore, energy efficiency has been set as one of the major objectives for recent cellular networks. Massive multiple-input-multiple-output (M-MIMO) is the key technology to providing higher energy efficiency (EE) and data throughput in 5G wireless communication systems.

This thesis focuses on the performance analysis of energy efficiency higher than energy consumption for 5G networks using massive multiple-input multiple-output (M-MIMO). Minimizing the power consumption per user's equipment (UE) with increasing throughput. The main design parameters used are the power consumption per user's equipment (PC), the data rate of the system (R), and the massive number of antennas (M) and users' equipment (K). Energy efficiency is defined as the system throughput per unit of power consumption as a function of a massive number of antennas and users. The performance analysis and comparison used are pre-coding schemes such as multi-cell minimum means square error (M-MMSE), zero-forcing (ZF/RZF), and maximum ratio combination (MRC). MATLAB tools are used to analyze and demonstrate numerical results.

The analyzed results show that energy efficiency (EE) is higher than energy consumption in a massive MIMO for 5G wireless communication systems. The overall simulated result of multi-cell minimum mean square error (M-MMSE) is the best pre-coding technique to maximize energy efficiency (EE) rather than total energy consumption in massive MIMO for 5G wireless networks. However, MRC achieves the lowest performance and energy efficiency as the massive number of antennas increases in massive MIMO for 5G cellular communication networks.

Keywords: *fifth-generation (5^{th}G), massive multiple-input-multiple-output (MIMO), energy efficiency, power consumption, data rate and Precoding.*

Declaration

I declare that this thesis, which I submit to Addis Ababa Institute of Technology for examination in partial fulfillment of the award of a master degree in Electrical and Computer Engineering, is my original effort. It has not been presented for fulfillment of a degree in this or any other University and all sources and materials used for the thesis are duly acknowledged.

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Date of Submission: ______________________________

This thesis has been submitted for examination with my approval as university advisor

Dr-Eng. Yihenew Wondie ______________ ________

Advisor's name Signature Date

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List of Abbreviations

AAEE	Average Area Energy Efficiency
AATP	Average Area Transmit Power
ASD	Angular Standard Deviation
AWGN	Additive white Gaussian Noise
B_C	Coherence Bandwidth
BER	Bit Error Rate
BN_O	Noise power spectral density
BS	Base Station
C^{DL}	Downlink Capacity
CN	Noise channel
CP	Circuit Power
CSI	Channel State Information
C^{UL}	Uplink Capacity
DL	Downlink
EE	Energy Efficiency
EE^{DL}	Energy Efficiency Downlink
EE^{UL}	Energy Efficiency Uplink
EM	Electro Magnetic
ETP	Effective Transmit Power
FAIR	Fixed Asset Inventory Revenue
FDMRC	Frequency Division Maximum Ration Combination
GE	Gain Expectation
GIS	Geographical Information System
L_{BS}	Complex Operational value at the BS
L_{OS}	Line of Site
L_{UE}	Complex Operational value at the UE
MIMO	Multiple Input Multiple Output
MMSE	Minimum Mean Square Error
MRC	Maximum Ratio Combination
MU	Multi-User
OFDM	Orthogonal Frequency Division Multiplexing
PA	Power Amplifier
PB	Power Bandwidth
PC	Power Consumption
PH	Power Matrix
RF	Radio Frequency
RZF	Regularized Zero Forcing

SC	Single Career
SDMA	Space Division Multiple Access
SE	Spectral Efficiency
SINR	Signal Interference Noise Ratio
SNR	Signal Noise Ratio
SU	Single User
T_C	Coherence Time
TDD	Time Division Duplex
TRMRC	Time Reversal Maximum Ratio Combination
UE	User Equipment
ULA	Uniform Linear Array
ZF	Zero Forcing

List of symbols

Tρ	Pilot coherence
P	Power
H	Matrix H
‘ϕ^o	Phase angle
C	Set of complex numbers
$(.)^T$	Transpose of matrix
tr(.)	Trace of square matrix
$(.)^{-1}$	Inverse matrix
E[.]	Mean of the random variable/expectation
‖. ‖	Norm of vector
|. |	Absolute value
(0, σ2)	A gaussian random variable with zero mean and variance σ2
β	Path loss
B	Bandwidth
W	Precoding
τικ	Transmitted power of the payload data
ψ	Covariance matrix
x̂jk	Estimated signal
e^i	Identity matrix I_B
gjk	Arbitrarily user
Λj	Diagonal matrix
g^H_{jk} $\acute{h}_{jjk}$	True channel in the decoding

Chapter 1

1.1 Introduction

To bring faster data rates with a growing 'N' number of active users, the new wireless systems generation will rely on a much denser deployment of infrastructure to provide seamless connectivity. The spatial beam of a directive signal is being actively studied as a way to reduce both interference and increase the data rate throughput. The massive multiple-input-multiple-output (MIMO) wireless technology takes advantage of spatial degrees of freedom through the use of multiple antennas on both the transmitter and the receiver sides [1]. The spatial degrees of freedom (DoF) are used to reduce the outage probability and increase the peak achievable data rate in single-user (SU) systems. Adding more numbers of antennas gained in multi-user (Mu) systems is more significant to improve the data rate since large MIMO antenna arrays can be communicating simultaneously with many numbers of active users in a given cell area.

Multiple-input multiple-output (MIMO) has advanced rapidly over the last 20 years. One reason for this is that the fundamental technologies were developed well before they were fully exploited. In earlier years in the 1960s, antenna arrays would make spatial filtering and separate signals simultaneously arriving from different directions and references through an extensive review. The processing capabilities and manufacturing progressed array gain process received a surge of attention in the 1990s with the promise of energy-effective implementation in the area of wireless communications [1, 2]. The LANs have been successful in sending multiple data streams to a single-user device (''single-user MIMO,'' or SU-MIMO), due in part to the fact that laptops and tablets are big enough to accommodate multiple antennas. In wide-area wireless communication networks, where phone-sized devices predominate, SU-MIMO has limited benefits. However, since the dimensions of the base station aren't as tightly constrained, it's possible to extend the number of antennas there and utilize them for space-division multiplexing (forming geographic beams) or MU-MIMO) [3]. Even with more antennas at each base station, achieving high capacity within the wide-area wireless network remains a frightening task. Space division multiplexing is conceptually straightforward and relatively easy to implement with geographical information systems. Massive MIMO can greatly improve capacity without the devastating complexity of inter-cell coordination. The number of value antennas in the base station (Bs) becomes much larger than the number of user terminals (UE) M>K, it is possible to generalize beams such that, there is always a single active user (UE) in each beam, thus giving each user their interference-free and high-capacity link to the base station (Bs). The probability of a beam pointing toward a neighboring base station (Bs) becomes small as well and inter-cell interference approaches zero without coordination between the numbers of cell coverage. Small cell deployment is one of the foremost attractive aspects of massive MIMO [1, 2]. Massive MIMO is considered one of the keys enabling technologies for 5G networks. The classification capacity and benefits from deploying massive MIMO, coupled with the reservations of channel propagation characteristics and practical hardware design issues, have led to several demonstration projects ranging from large-scale simulations to actual hardware. The result has studied channel estimation and beam-forming. The mm-wave frequencies and system simulations have generally attempted to measure the performance of energy efficiency in massive MIMO in outdoor environments with the mobility of active users. In 2011, the green touch consortium demonstrated a 16-element array [1]. Effective antennas gain increase linearly with the number of antennas was the main result of the study. It allows the radiated transmit power per element to be reduced proportionally to the number of antennas in BS.

Massive-MIMO is a progressive version of the space-division multiple-access (S-DMA) which is pushing spatial multiplexing to an external level. The main assists of massive MIMO can be summarized as massive spectral efficiency, communication reliability, high energy efficiency, low complexity signal processing, favorable propagation, and channel hardening [2]. The massive MIMO receives all gains from conservative multi-user MIMO (MU-MIMO) i.e., with M (number of antennas) in the base station (Bs) and K (single-antenna) in active number of the user (UE), can achieve a diversity of order M (number of antennas) and a multiplexing gain of (M, K). Increasing both the number of antennas (M) in a base station (Bs) and K (single antenna) in an active user (UE), can obtain maximum energy efficiency (EE), spectral efficiency (SE), and very high communication reliability with simple linear processing schemes such as maximum ratio combination (MRC), zero forcing (ZF), and minimum-mean square error (MMSE) [2].

This thesis is dealing with the performance of energy efficiency ensuring techniques in massive MIMO, to improve energy efficiency (EE) by minimizing the power consumption per user equipment (UE), and the energy efficiency will be greater than the energy consumption, using techniques such as multi-cell-minimum means square error (M-MMSE), zero-forcing (ZF), regularized zero-forcing (RZF) and maximum ratio combination (MRC).

1.2 Statement of the problem

In wireless communication system there are a lot of challenges and problems. The major challenges include spectral efficiency, energy efficiency, and link reliability at anytime and anywhere. Those challenges are created due to the scarce availability of band width, propagation channel fading and wireless node mobility. To increases the data rate (R) reliability, a simple method is to increase the allocation bandwidth but, energy consumption is becoming one of the key performance indicators for network operators. Energy itself has no problem but its production is mainly non-renewable, as environmental and economic concerns problems due to, unbalanced energy consumption, and traffic load in wireless communication networks [5]. According to past literature, base stations alone were representing 5GW of power and 20 Mt of carbon dioxide per year [15], [16], [17]. Since then, the figures have been constantly increasing and becoming a problem for telecom industries. Therefore, in terms of operational expenses, and environmental impact, energy efficiency has been targeted at the international level as one of the key capabilities of 5G networks. As a result, this remained an engineering challenge ensuring efficient and optimized energy-wise usage.

Massive MIMO technology is one of the key optimizations of energy consumption and serving multiple users and antennas simultaneously with an increased data rate of the system. This work mainly aimed at the proper usage of energy and serving multiple users by using, Pre-coding techniques channel state information (CSI) such as (M-MMSE, ZF, and MRC) in massive MIMO systems. To minimize the energy consumption at the base station, users equipment and maximize the energy efficiency in massive MIMO for 5G wireless communication networks.

1.3 Objectives

1.3.1 General objective

The general objective of this thesis is to improve energy efficiency by minimizing energy consumption per user equipment, and base stations in massive MIMO for 5G wireless communication networks.

1.3.2 Specific Objective

The specific objective is the performance analysis of EE ensuring technique in massive MIMO for 5G wireless communication networks which satisfy the main requirements, these included

- Analysis of the bandwidth on energy efficiency in massive MIMO networks
- Analyse the effect of power consumption on energy efficiency in massive MIMO
- Maximize throughput/data rate in massive MIMO by analysing total power consumption
- Analyse of the effect of the number of users and reliable data rate throughput on energy efficiency
- Analyse and simulate the effect of a massive number of antennas on energy efficiency.
- Analyse and calculate energy efficiency (EE), and area throughput in a massive MIMO system.
- Identify the best Precoding techniques and simulation results for the performance of maximum energy efficiency in massive MIMO
- Design optimal networks which serve massive users have a massive number of antennas, and a reliable data rate.
- Analyse of maximum energy efficiency than power consumption, using the Precoding techniques in massive MIMO.

1.4 Literature review

Various studies have been made in massive MIMO technologies, to investigate the performance analysis of energy efficiency for 5G communication network systems. From those various researches, the following are reviewed based on proposed results and existing challenges.

The first breakthrough to massive MU-MIMO downlink TDD systems with linear Precoding and downlink pilots was made by **Thomas Marzetta, et al [8].** This reference considers an efficient channel estimation scheme to acquire channel state information (CSI) at each user, called beam forming training scheme. With the beam forming training schemes the base station precoders, the pilot sequences are forward to all users. Then, based on the received pilots, each user uses minimum mean square error channel estimation to estimate the effective channel gains. Then they drive a lower bound on the capacity for maximum ratio transmission and zero forcing precoding techniques to evaluate the spectral efficiency taking into account the spectral efficiency loss associated with the transmission of the downlink pilots. They also hinted for the potential benefit of massive MIMO for 5G wireless communication systems but not considering the maximum data rate (R).

Because of its advantage over convectional point-to-point communications as discussed, the massive MIMO concept has gained great attention in recent research. **E. Bjornson and E. G. Larsson [3]** investigate the optimal energy efficiency, achieved for a particular ratio of transmit power (Pt) and bandwidth (B), which typically corresponds to a low SNR. It depends strongly on which parameter value can be selected in practice and the energy consumption modeling. If it is modeled to capture the most essential hardware characteristics, then any data rate can be achieved by jointly increasing transmit power and bandwidth while keeping the optimal ratio. However, this work is concerned only with bandwidth and transmits power to maximize energy efficiency in massive MIMO systems.

In [4], Jose Carlos Marinello, Cristiano Ponzio, Taufik Abrao, Stefano Tomasin, compare the performance of energy efficiency of massive MIMO systems under time-reversal maximum ratio combination (TR-MRC) and frequency-domain maximum ratio combination (FD-MRC) receiver's up-link. have evaluated the total energy efficiency of massive MIMO systems under frequency-selective fading channels in the presence of pilot contamination. Compared the conventional FD-MRC receiver operating under OFDM versus the TR-MRC receiver operating under single carrier (SC) wave-form. The total energy efficiency metric on the basis of its comprehensiveness and the ability to incorporate several different aspects in a unified analysis. The results demonstrated the superiority of the FD-MRC receiver under OFDM waveform in terms of total energy efficiency. Despite the higher sum rates achieved by the TR-MRC/SC, and the lower power expenditures related to the transmitted signal and power amplifier (PA), the higher computational complexity required to run the TR-MRC processing makes the total energy efficiency of this scheme lower than that achieved by the FD-MRC under OFDM. However, this complexity is highly dependent on the length of the channel impulse response (CIR) such that if a shorter cell size is considered, the TR-MRC/SC becomes a better alternative in terms of total energy efficiency. Besides, the power required to run the detection algorithms decrease if the computational efficiency of the available pieces of equipment increases. The analysis has indicated that a 30% increase in the computational efficiency makes the TR-MRC/SC scheme more efficient than the FD-MRC/OFDM but not considering maximum throughput with energy consumptions.

In [5] the authors show the performance massive MIMO can potentially achieve a higher area throughput than current networks while providing substantial average transmit power (ATP) savings. The transmit power can be gradually reduced with the number of antennas while approaching a non-zero asymptotic spectral efficiency (SE).Therefore, massive MIMO networks reduce the transmit power required to achieve a given spectral efficiency (SE).While increasing the number of antennas has always a positive effect on the spectral efficiency, the energy efficiency (EE) first increases with M number of antennas, due to the improved spectral efficiency (SE), and then decreases with M number of antennas, due to the additional hardware that increases the circuit power (CP).The energy efficiency (EE) of a cellular network, defined as the number of bits that can be reliably transmitted per unit of energy (measured in bit/Joule), is a good performance metric to balance the throughput and consumed power. Substantial spectral efficiency (SE) gains are achieved by multiplexing K number of user equipment's (UEs) per cell, if a proportional number of antennas M are used to counteract the increased interference. A similar result cannot be achieved for the energy efficiency since adding more antennas increases the spectral efficiency but also the circuit power (CP) of the network. This means that the energy efficiency (EE) attains its maximum at a finite value of the antenna user equipment's (UE) ratio M/K. Multi cell minimum mean square error (M-MMSE) Precoding technique provides higher energy efficiency for any throughput value, only when more energy efficient hardware is used.

However, this work is concerned with improving the energy efficiency optimal value 44Mbit/Joule by reducing the total power consumption (PC) per base station (BS).

The work in [6] shows optimal design of energy-efficient multi-user MIMO systems. The results show that energy-efficient systems are, therefore, not operating in the low SNR regime, but in a regime where proper interference-suppressing processing (ZF or MMSE) is highly preferable over interference ignoring MRC/MRT processing. The radiated power per antenna is, however, decreasing with more value number of antennas (M), and the numerical results show that it in the range of 10-100mW. This specifies that massive MIMO can be built using low power consumption concerning transceiver equipment at the base station instead of conventional industry-grade high power equipment.

The authors in [7] the impact of nonlinear amplifiers is investigated on the energy efficiency of massive MIMO along with calculation of optimal parameters by using the proposed alternative algorithm under both the perfect and imperfect channel conditions at different circuit power consumptions. Contrary to the existing work, a realistic circuit power consumption model that shows the dependence of circuit power consumption on the number of transmitters and users. They have seen that when the channel conditions are not perfectly known, then the system needs to transmit more power in order to overcome the negative effects of imperfect channel situations, and, owing to more transmitted power amplifier (PA), the energy efficiency gets reduced as compared to the situation when the channel is perfectly known. Numerical results do not change much for a small change in the circuit power consumption but can otherwise change drastically. The alternative algorithm that they have used for joint calculation of optimal parameters works efficiently and converges quickly. The result shows that when the power amplifiers are working at higher efficiency, then the energy efficiency of massive MIMO also is increased, while it is better to have large cell coverage in the case of massive MIMO along with less circuit power consumptions. In future, circuit power consumptions will be reduced, resulting in further improved energy efficiency with less transmitted power, together with improved and simpler signal processing. The combination of energy efficient massive MIMO along with nonlinear amplifiers can be a fascinating option for low-cost future wireless communication systems.

1.5 Methodology

In the first stage of the research, a literature review of past and current works on the range of 5G MIMO, and massive MIMO networks will properly be conducted to extend awareness of such areas of study. Following the review, the execution starts by focusing on the energy efficiency performance and, on parameters compromising the performance of wireless networks.

System modelling and simulation: this includes system modelling of massive MIMO performance, specifying design parameters, analysis of mathematical circuit power consumption per user, defining total energy efficiency, and simulation of the main performance parameters to understand their effect on energy efficiency maximization of the system using MATLAB.

Result comparison: This includes performance analysis of energy efficiency used, precoding techniques, in the compromise analysis, linear Precoding and the effect of choosing a number of design parameters in total performance energy efficiency (EE).

Result and recommendation: the result obtained and analysed from the simulation analysis is studied and final conclusion and recommendation is drown.

1.6 Main thesis contributions

Due to technological development as well as the increasing network coverage area arising from wireless telecommunication service demand, energy consumption is one of the most challenging tasks in the telecommunication industry. Therefore, unique attention is given to reducing energy consumption and improving energy efficiency with data rate (throughput) in massive MIMO for 5G wireless communication networks. Maximizing the energy efficiency and throughput in massive MIMO using a knowledge of channel state information (CSI) linear Precoding techniques such as: (M-MMSE, ZF/RZF, and, MRC), In the final study simulation, energy efficiency was greater than the energy consumption, in massive MIMO for 5G wireless communication networks.

All the literature reviewed [3], [4] [5], [6], and [7], suggest that, to energy efficiency improvement through pre-coding techniques is achieved by reducing the total power consumption per base station (Bs), in massive MIMO systems. These not concerned with improving energy efficiency by reducing the power consumption per active user equipment. Design and analysis of energy efficiency with an increase in the number of antennas (M) in the base station and active user equipment (K) considered. It also, compares the best pre-coding techniques, less power consumption to maximum energy efficiency (EE) in massive MIMO 5G wireless communication systems.

1.7 Limitation of the thesis

The research would present the performance analysis of energy efficiency ensuring techniques to keep quality of service (QoS) by using different Precoding techniques in massive MIMO. There will be a costly expense in the design and deployment of the base station array antennas. Massive MIMO antenna designs are more complex and require more effort and time during the assembly line compared to traditional antenna designs. The energy efficiency can be increased, with increasing data rate but decreasing power consumption. Also, can be improved the energy efficiency through decreasing the data rate and reducing total power consumption (Pc).

In massive MIMO, the base station is equipped with a large number of antennas, which require a significant amount of power to operate. This can lead to higher energy consumption, which can be a concern for network operators looking to reduce their carbon footprint. Finally, the deployment of massive MIMO for 5G requires careful planning and optimization to maximize its benefits. For example, the optimal number of antennas and their configuration must be carefully selected to ensure that the network operates efficiently. Another method for future improved energy efficiency may be through adding more hardware in base stations (Bs) this will be a resource tradeoff that remains in conflict. If not deployed properly, the energy efficiency benefits of massive MIMO may not be fully realized.

1.8 Thesis structure

Chapter-1 Introduction: This Chapter starts with an introduction and is then followed by literature reviews, research objective, main contribution, and methodology of the thesis.

Chapters 2 and 3 present the theoretical fundamentals of massive MIMO, and energy efficiency to get the required general knowledge and presents the massive MIMO throughputs, configuration, supporting standards of energy efficiency (EE) coverage area analysis,

Chapter 4 presents the performance of energy efficiency and details simulation analysis results with discussion studies.

In Chapter-5 this work is finalized by drawing the main conclusions and recommendations for future works and references.

Chapter 2

The theoretical background of energy efficiency in massive MIMO for 5G cellular communication networks

2.1 Introduction

Wireless communication depends on the radio spectrum, implying that electromagnetic waves (EM) are intended to convey data from a transmitter to one or numerous receivers. Since the EM waves propagate in all potential ways from the transmitter, the signal energy spreads out and less energy arrives at an ideal recipient as the distance increases. To convey remote administrations with sufficiently high signal energy over wide inclusion regions, an analysis at Bell Labs proposed in 1947 that phone network geography is required [5]. As indicated by this thought, the inclusion zone is partitioned into cells that work independently utilizing a fixed-area base station (BS); that is, a bit of organization equipment that encourages remote correspondence between a device and the organization. A cell network comprises a bunch of base stations (BSs) and a bunch of user equipment (UEs). A piece of user equipment (UE) is associated with one of the base stations (BSs), which offers support to it. The downlink (DL) indicates signals sent from the BSs to their individual active user (AUs), while the up-link (UL) indicates transmissions from the user equipment (UEs) to their particular base station (BS).

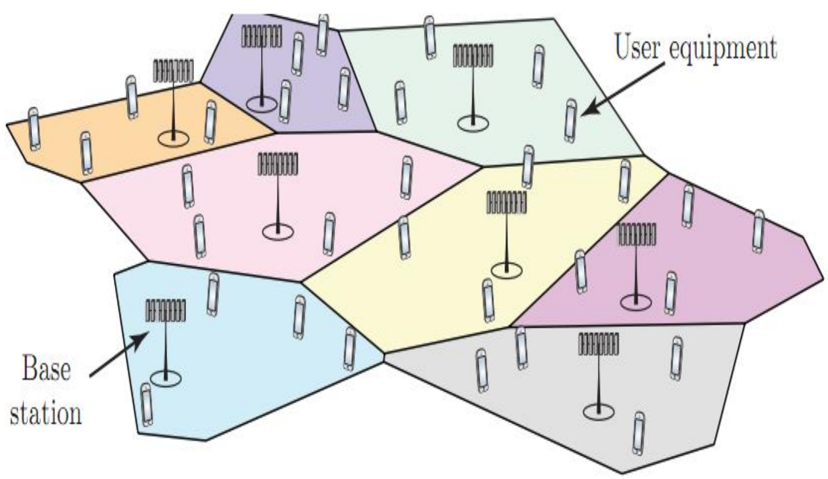


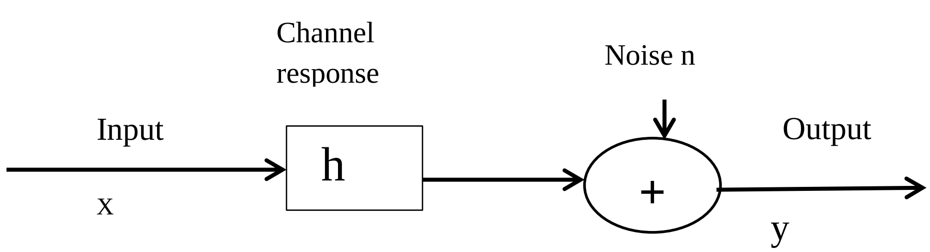
Figure2.1 cell organization, every base station (BS) covers a distinct geographical area [5].

It provides service to all active user equipment (UE) in it [5]. The region is known as a "cell" and it is outlined with a distinctive shade. The phone may comprise all geographic areas where this base station (BS) gives the most grounded downlink (DL) signal region.

Throughput [bit/s/km^2] = B [Hz]*D [cells/km^2] * SE [bit/s/Hz/cell] where B is the data transfer capacity or bandwidth, D is the normal cell density, and SE is the spectral efficiency per cell.

2.2 Definition of spectral efficiency (SE)

Presently a definition of spectral efficiency (SE) to a correspondence channel with a transmission capacity of megahertz (MHz) Nyquist-Shannon examining hypothesis implies that the band-restricted correspondence signal that is sent over this channel is controlled by 2B(bandwidth) real-valued esteemed equivalent divided samples every Second. While considering the complex-baseband description of the signal, B complex-esteemed examples every second is the more normal amount. These B tests are the levels of opportunity accessible for planning the correspondence signal. Spectral efficiency (SE) is the measure of data that can be transmitted dependably per complex-esteemed instance [5].



A discrete memory-less channel with input x and output y = hx + n,

Where h is the channel response and n are an independent Gaussian noise.

If h, is deterministic, then the channel capacity is given:

$$C = \log_2[1 + \frac{\rho|hx|^2}{\sigma^2}] \quad \ldots \text{(2-1)}$$

and it is achieved by the input distribution x ~ NC (0, p). If h is a realization of a random variable h that is independent of the desired signal and noise. The data streams function as independent single input single output (SISO) links as under favorable channel conditions are shown in figure 2.2, and can linearly increase the spectral efficiency with the number of terminals served [38]. However, the benefit of spatial multiplexing regarding spectral efficiency critically depends on the array size and accuracy of channel states at the base station (BS).

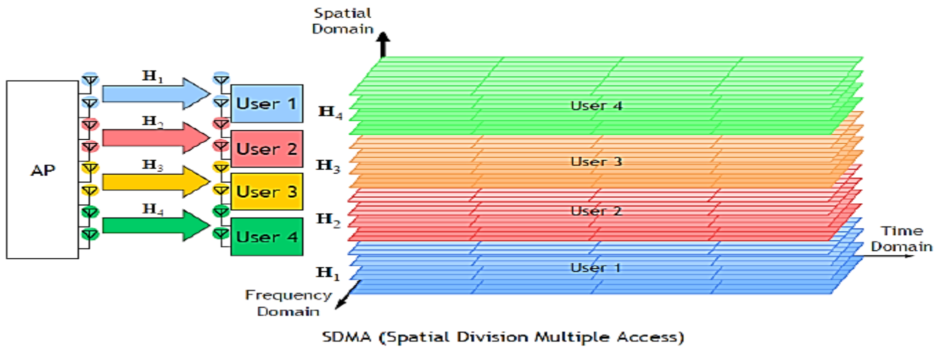
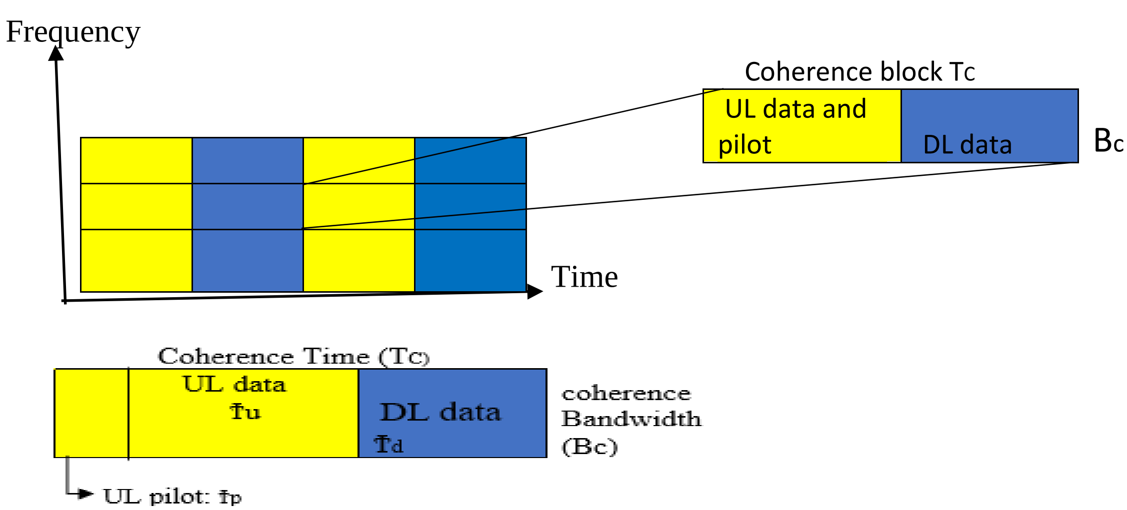


Figure2.2 Multi user MIMO [38]

2.3Massive-MIMO

A massive multiple-input-multiple-output (MIMO) network is a multi-carrier cell network with L cells that work standing to a simultaneous time division duplex (TDD) convention. An equipped base station (BSj) with several antennas (Mj) receiving to accomplish channel hardening. The base station (BSj) communicates with Kj (user) single-reception antennas user equipment's (UEs) all while on each time/frequency sample, with receiving antenna per user equipment (UE), proportion to several antennas to the number of a user (Mj/Kj) > 1. Every base station (BS) works exclusively and measures its signal utilizing direct get consolidating and straight communicates pre-coding. A given channel response includes, a coherence block channel with various active sub-carriers and time tests can be approximated as steady and flat-fading. If the coherence bandwidth is defined as: BC and the coherence time is Tc, at that point, every rationality block contains τc = BcTc complex-esteemed examples [5].



The time division duplex (TDD) multi-carrier modulation system of a canonical massive-MIMO network. Each channel time-invariant and frequency flat is divided into coherence blocks in time-frequency processing.

2.4Analysis Pre-coding design: up-link-down-link duality

The pre-coding vectors were because each user equipment (UE) is affected by the pre-coding vectors in the wireless networks and network-wide pre-coding optimization is highly impractical. Through this, the pre-coding procedure technique could balance self-directing and signals towards the active user (AU) and altruistically avoid causing interference to other user equipment (UEs) [5, 7]. The trouble is to find the right balance between these two goals, particularly when many active users are involved. It is accordingly, desirable to have a sensible controllable, design principle for pre-coding. Many heuristic pre-coding design principles can be found in the literature, but the well-designed ones are usually rather similar and strongly connected to a fundamental property called uplink-downlink (UL-DL) duality. Duality describes simplicity and how it can guide the pre-coding processing [5], there is a strong connection and an expression between the spectral efficiency (SE) for the uplink-downlink (UL-DL), except for the diverse system for the transmit powers, the signal terms are similar and the interference terms are comparable but the indices (j, k) and (i) are interchanged for every user equipment: the power(P) Precoding P E $\{|VH_{jk\,h_{jli}}|^2\}$ in the uplink (UL) is replaced by power (P) $E\{wH_{li}h_{ljk}\,|^2\}$ in the downlink (DL). This signifies the fact that the uplink (UL) interference from cell l is received over user (Kl) different user equipment channels (processed using a single combining vector), while all the downlink (DL) interference from the cell l is received over the channel from the base station (Bs) and depends on Kl (user1) pre-coding vectors. From the perspective of user equipment in the network, the base station cell (BSL) can separate the user equipment well spatially, while the base station (BSj) cannot (illustrated here as having a small angular difference between the user equipment's (UEs). The significance is that the users in cell j are affected by high interference from the other cell user equipment in the uplink (UL). While the user equipment in cell l receives high interference from the base station (BSj) in the downlink (DL). The active (UE) shows very different interference levels in the uplink and downlink. There is a symmetry that creates a fundamental, connection between the achievable spectral efficiency (SEs) in uplink (UL) and downlink (DL) despite the differences in how the interference is generated, which is called the uplink-downlink (UL-DL) duality [5],[18].

Formula: Let P = $[Pt_1 \ldots Pt_l]^T$ with pj = $[Pj_1 \ldots PjKj]^T$, ------------------------------------- (2-2)

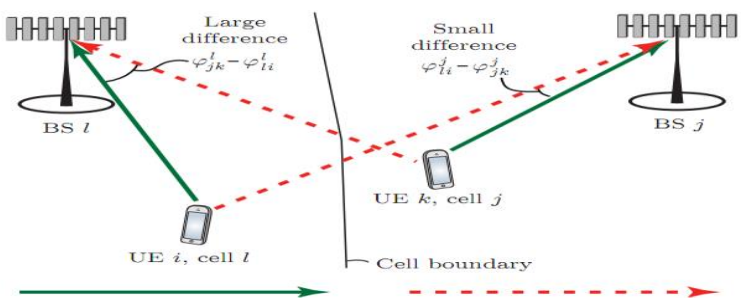
The Ktot × 1 vector with all the up-link given transmitting powers (Ptr) where

Ktot = denotes the total number of user equipment in the network. Consider the uplink (UL) signal interference noise ratio uplink from the user to the base station ($SINR_{jk}^{UL}$) and the downlink (DL) signal interference noise ratio from the base station to the user ($SINR_{kj}^{DL}$) for any given set of receive combining vectors {v, i} and given power (p) can achieve:

$SINR_{kj}^{DL} = SINR_{jk}^{UL}$ j = 1. . . L, k = 1. . . Kj -------------------------------------- (2-3)

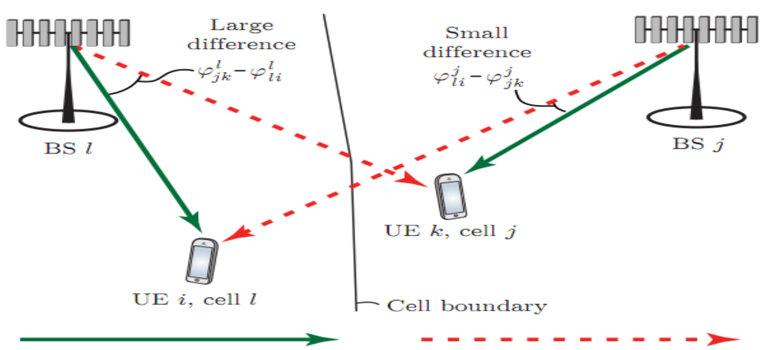
The Pre-coding vectors will be selected to be:

$W_jk = \frac{VjK}{\sqrt{E\{||VjK||^2\}}}$ where, V_{jk} combine vector ------------------------------------ (2-4)



Projected transmission Interfering transmission

Figure 2.3 (a) UL: UE k in cell j is affected by high interference from UE_i in cell l [5].



Projected transmission , Interfering transmission

Figure 2.4 (b) DL: UE_i in cell l, receives high interference from base station (BS_j) [5]

The above figure illustrates how the interference situation can change between the uplink (UL) and downlink (DL) [5]. The uplink interference comes from the user equipment, while the downlink interference is caused by the base station that serves the interfering user equipment (UE). In this setup, a base station (BSj) cannot separate the two-user equipment (UEs) due to the similar spatial channel correlation (as a small angular difference), thus its own user equipment is affected by high uplink. The interference and the other-cell user equipment will get high downlink interference. In contrast, a base station (BSL) can separate the user equipment well, which leads to little interference in both uplink and downlink [5], [7]. The simple two-cell Wyner network model shows that a power consumption (PC) model accounting for the transmit power as well as for the circuit power consumed by the transceiver hardware at the base station (BSj) and user equipment's (UEs) is essential to avoid misleading conclusions about energy efficiency (EE). This is not the only involvement that must be taken into account to properly evaluate the circuit power (CP) of the uplink and downlink of massive multiple input multiple outputs (MIMO). Also, it will be considering the power consumed by digital signal processing, back-haul signaling, encoding, and decoding of a circuit power (CP) model for a generic base station (BSj) in massive MIMO wireless networks.

$CP_j = P_{fixj} + P_{TC,j} + P_{CE,j} + P_{C/D,j} + P_{LP}$ -- (2-5)

And, $P_{TC} = MP_{BS} + P_{SYN} + KP_{UE}$ --- (2-6)

Where CP accounts for the power consumption of the transceiver chain P_{BS} is the power of the BS components attached to each antenna, P_{UE} is the power of all receiver components of each antenna user equipment (UE), and a signal oscillator with power P_{SYN} is used for all BS antennas.P_{fixj} is fix power in the base station, $P_{TC,j}$ is power transceiver chain, $P_{CE,j}$ is channel estimated power, $P_{C/D,j}$ is coding decoding power and P_{LP} is power for linear processing.

$P_{CE} = \frac{B}{T}\, 2\, \frac{MN^2}{LUE}$ -- (2-7)

Denotes power for the channel estimation process which is performed once per coherence block. Where P_{FIX} = Fixed power,

$P_{CD} = BN\,(P_{COD} + P_{DEC})$ -- (2-8)

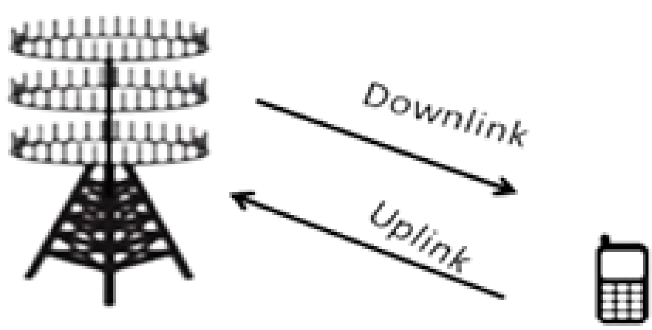
It is the power required for codding and decoding per symbol.

$$P_{LP} = B\left(\frac{T-\tau}{T}\right)\frac{MN}{L_{BS}} + \frac{B}{T}\left(\frac{N^2}{3L_{UE}} + \frac{3MN^2+MN}{L_{BS}}\right) \quad (2\text{-}9)$$

Represents the power for linear processing (P_{LP}). Where L_{BS} and L_{UE} are the computational complexity that measures the arithmetic complex-valued operation at the base station (BS) and user equipment's (UE) respectively [5], [8].

2.5 Time division duplex system protocol (TDD)

User-centric cluster and uniform user distribution where the coherence blocks and the channel is under uncorrelated Rayleigh flat fading network areas are considered to have a greater number of active users (AU). Perfect channel state information at the receiver side and the model parameters are M, K, R, A, and D. Where M is the number of antennas, K is the number of users, R is data rate, A is coverage area and D is cell density of the system. The main persistence of this paper is to analyze the physical area coverage energy efficiency and limits in a few different cases, particularly, to give simulation results in relevant techniques on the maximum possible energy efficiency. The ultimate limit of energy efficiency (EE) in the channels is deterministic and the consequence of this assumption is that perfect channel state information (CSI) is available everywhere (it is estimated to any accuracy with a negligible overhead). The capacity of a fading channel can be upper bounded by a deterministic channel having the channel realization from the fading distribution that maximizes the mutual information will be considered [9]



Base station Mobile station

Figure 2.5 Proposed system models for massive MIMO [10]

A large number of antennas in the panel base station would be connected to the active number of users of both downlink (DL) and up-link (UL) information exchanges. Consider the up-link Rayleigh fading channel:

$h_k = [h_{k1}, h_{k2} \ldots h_{km}]^T \sim CN(0,Im)$ ---(2-10)

Noise: n~ CN (0, Im), received signal $y = h_1 S_1 + h_2 S_2 + n$ ------------------------------ (2-11)

Maximum ratio filters linear detection:

$v_1 = \frac{1}{M} * h_1$ -- (2-12)

$v_1^H y = \frac{1}{M} * [h_1^H h_1 S1 + h_1^H h_2 S_2 + h_1^H n]$. --- (2-13)

As the number of antennas (M) tends to infinity (∞) then the received signal is

$S_1 \quad + \quad 0 \quad + \quad 0$ -- (2-14)

Where $h_1^H h_1 S1$ is S_1 the required received signal and $h_1^H h_2 S_2$ converges to zero at the number of antennas (M) tend to infinity (∞) in the identity matrix principle for interference-free communication with many numbers of antennas in massive MIMO systems.

2.6 Performance analysis of energy and spectral efficiency

2.6.1 Definition of energy efficiency with spectral efficiency

Energy efficiency refers to the ability of a device or system to perform its functions using the least amount of energy possible. Spectral efficiency, on the other hand, refers to the ability of a communication system to transmit the maximum amount of data using the least amount of bandwidth possible. Combing energy efficiency with spectral efficiency means designing communication systems that are optimized to transmit data using the least amount of energy and bandwidth possible, thus reducing the overall, energy consumption the system.

This section can analyze the energy efficiency (EE) of massive MIMO based on realistic power consumption (PC). Power consumption is a major concern for future cellular networks. Also, massive MIMO can potentially improve the area throughput while providing substantial power savings [5].

$$EE = \frac{(\text{"SE Sum Throughput" ["bit" /"channel use"/cell area]})}{\text{Total power consumption" ["Joule" /"channel use" /cell area]}}$$ ------------------------------------(2-15)

Where M is the number of antennas, K is the number of users, R is throughput and A is cell area

For conventional academic approaches analysis

Maximize throughput with fixed power and minimize transmit power for fixed throughput.

Data throughput = $\underbrace{K}_{\text{K-Multi-Users}} * \underbrace{(1 - \frac{\tau k}{U})}_{\text{Data fraction per frame}} \underbrace{B \log 2\ (1 + SINR)}_{\text{Data rate per user}}$ ------------------------------ (2-16)

Where, SINR is (signal interference noise ratio) given below equations:

$$\text{SINR} = \frac{M}{(K+\frac{BNo}{\rho}\ \left(1+\frac{2}{\tau(\alpha-2)}+\frac{BNo}{\rho}\right)+\frac{2K}{\alpha-2}\left(1+\frac{BNo}{\rho}\right)+\frac{k}{\tau}\left(\frac{4}{(\alpha-2)^2}+\frac{1}{\alpha-1}\right)+\frac{M}{\tau(\alpha-1)}}$$ -------------------------- (2-17)

Power consumption =

$$\underbrace{K\frac{\rho\omega\Gamma(\alpha/2-1)}{\mu(\pi\lambda)^{\frac{\alpha}{2}}}\left(1-\frac{\tau\kappa-1}{U}\right)}_{\text{Transmit power per amplifier}} + \overbrace{C0,\ 0}^{\text{Fixed circuit power}} + \underbrace{C0,\ 1M + C1,\ 0K}_{\text{power per transceiver chain}} + \overbrace{C1,\ 1MK}^{\text{Signal processing}} + \underbrace{A*\text{Data throughput}}_{\text{Coding/decoding/back-haul [7]}}$$ ------- (2-18)

Select Pre-coding technique analysis in massive MIMO system

The same rate R=R_k for all users

"Optimal" Pre-coding: extensive computations not efficient then:

Matrix form: $\mathbf{V} = [\mathbf{v}_1\ldots,]$, $\mathbf{H} = [\mathbf{h}_1\ldots,]$ --- (2-19)

Power allocation: $P_1\ldots$, from the heuristic closed-form pre-coding analysis

the maximum ratio combination (MRC): "vk=√ (P_k h $_{k)}$ --------------------------------------- (2-20)

For maximizing signal at the receiving side user equipment's (UE).

Zero-forcing (ZF) pre-coding: $\mathbf{V}=\mathbf{H}\ (\mathbf{H}^H\ \mathbf{H})^{-1}$ diag ($P1\ldots$, PK) for minimizing interference---- (2-21)

Regularized ZF (RZF) pre-coding: $\mathbf{V}=\mathbf{H}\ (\sigma^2\ \mathbf{I}+\mathbf{H}^H\ \mathbf{H})^{-1})$ diag ($P1\ldots\ PK$) -------------------- (2-22)

For balance signal and interference in massive MIMO systems [7].

2.6.2 Mathematical equations

$E\{e \, . \, y^H\} = 0$ --- (2-23)

Where; e = $\tilde{x}$-x = Gy-x

$E\{Gy - x) \, . \, y^H\} = 0$ --- (2-24)

$E\{Gyy^H - xy^H\} = 0$ --- (2-25)

$E\{Gyy^H\} - E\{xy^H\} = 0$ --- (2-26)

$GE\{yy^H\} - E\{xy^H\} = 0$ --- (2-27)

$G = E\{xy^H\}E\{yy^H\}^{-1}$ -- (2-28)

by expand the expectation E {} value to get power transmitted signal scalar.

$E\{yy^H\} = E\{(Hx + n)(Hx + n)^H\}$ --- (2-29)

$E\{(Hx + n)(x^H H^H + n^H)\}$ --(2-30)

$E\{Hxx^H H^H + Hxn^H + nx^H + nn^H\}$ --(2-31)

$E\{Hxx^H H^H + nn^H\}$ ---(2-32)

$H \, E\{xx^H\}H^H + E\{nn^H\}$ -- (2-33)

$H \, \{P. I\} \, H^H + \sigma^2 . I$

Power transmitted signal (a scalar) can determine the transmission power but would not be able to know the exact noise value added to each received signal data, but it can in long-term statistical properties of the noise.

$E\{xy^H\} = E(x\{Hx + n\}^H)$ -- (2-34)

$E\{x(x^H H^H + n)^H\} \quad = E\{xx^H H^H + xn^H\}, \; xn^H = 0$ ------------------------------- (2-35)

$E\{xx^H\}H^H \; = \; (P. I)H^H$ which is the Power of transmitted signal

Finally, the operator matrix [G] of gain of energy consumption follows:

$(P.I)H^H$ And $H\{P.I\}H^H + \sigma^2.I^{\cdot}$

$$G = E\{xy^H\}E\{yy^H\}^{-1} \text{ -- (2-36)}$$

$$= (P.I)H^H \ (H\{P.I\}H^H + \sigma^2.I^{\cdot} \text{ -- (2-37)}$$

$$= (P.H^H(PHH^H + \sigma^2.I)^{-1} \text{--- (2-38)}$$

Mathematically divide the energy power consumption (PC) to get the gain matrix [G].

$$G = H^H(HH^H + \frac{\sigma^2}{P}.I)^{-1} \text{ --- (2-39)}$$

Where H, indicates a matrix that includes the property of pre-coding and amplification mathematically the H is expressed as 'Amp*H*P', Amp amplification, H is the channel matrix over the air and P is power of the pre-coding matrix [11], [31].

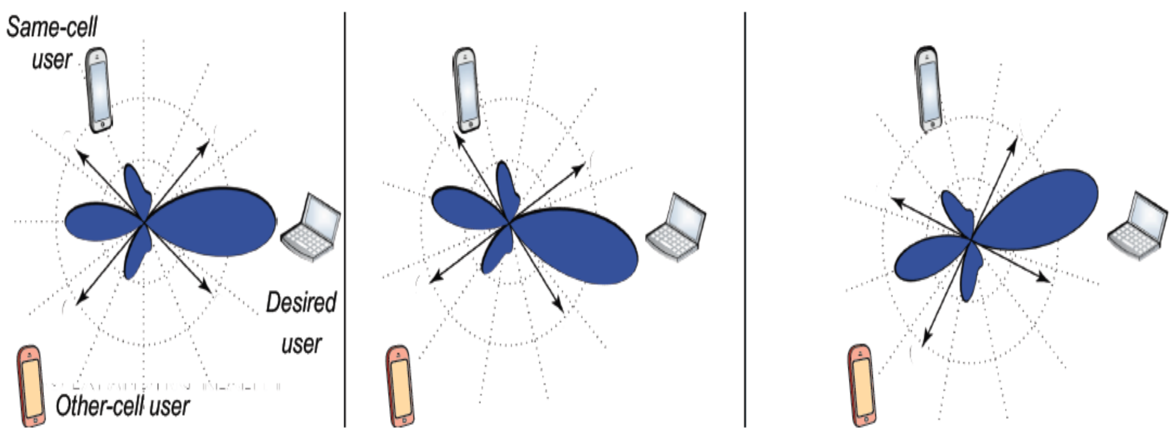


Figure2.6 comparison of Precoding techniques and reducing interference in massive MIMO [12]

Precoding technique for Uplink with L cells in massive MIMO system for 5G networks.

$H_L^j = \left[h_{l1....}^j \ h_{lk}^j\right] \in C^{M\times K}$ channels to base station ($BS_{j)}$ from the user equipment's (UE) in cell coverage area L.

Matched filter: $V_j = \frac{1}{M}H_j^j$ --- (2-40)

Regularized zero forcing: $V_j = (H_j^j(H_j^j)^2 + I)^{-1} H_j^j$ -- (2-41)

MMSE processing: $V_j = ([H_1^i \; ... \; H_L^j] ([H_1^i \; ... \; H_L^j]^H + I)^{-1} H_j^j$ --------------------- (2-42) [12].

2.6.3 Minimum mean square error (MMSE) in massive MIMO

A system model that minimizes the MSE (mean square error) of the received data with the channel model [27].

$$y = Hx+n \quad \text{--- (2-43)}$$

The pre-coding technique of multi-cell-minimum-mean square error (MMSE) as an equalizer is a kind of post-processing algorithm, the received data that is as close to the original data (transmitted data) with matrix G (operator matrix) as the inverse of channel matrix $(\widehat{\mathrm{H}} - 1)$ assume that no noise.

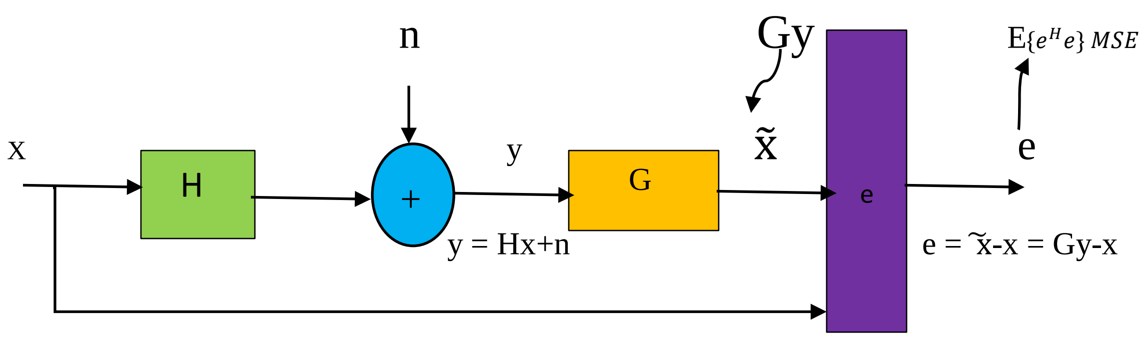
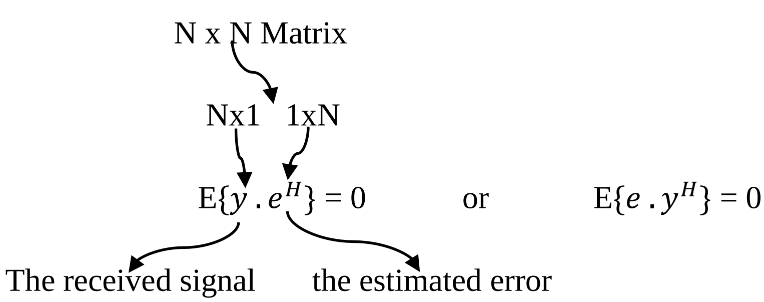


Figure**2**.7 Block diagram MMSE

Where x is the desired received signal, H is the channel matrix, n is noise, G is the operator matrix which is to minimize mean square error (MSE) and e is the error. The above block diagram indicates a specific condition where there is no correlation between the received data vector and the error vector.



Overall, MMSE in massive MIMO for 5G network is a powerful technique for improving the quality of received signals by reducing interference and noise, which enables more efficient use of the available spectrum and higher data rates.

2.7 Performance analysis of antenna schemes

I. Multiple antennas value: In the system cases both, through that the communication takes place over a given bandwidth of B in Hz, the total transmit power (Pt) is denoted by P in W, and the noise power spectral density BN_0 in $\frac{W}{Hz}$. Treat B and P as design variables [3].

II. Single-antenna systems without interference

Begin by considering a single-antenna system; the channel is represented by a scalar coefficient of h ε C. The receiving desired signal y ε C is given by y = hx + n where x ε C is the transmit signal with power P and n = NC (0, BNo) is AWGN. Perfect CSI is available, the capacity value of the channel is:

$$C = B \log_2 \left\{ 1 + \frac{P\beta}{BN0} \right\} \text{ [bit/s]} \quad \text{------ (2-44)}$$

Where $\beta = |h|^2$ denotes the channel gain. The capacity value is achieved by x~ NC (0, P). When the transmit power is the only factor contributing to the energy consumption, an upper bound on the area coverage energy efficiency (EE) is:

$$B \log_2 \left\{ \frac{1 + \frac{P\beta}{BNo}}{\text{Power}} \right\} \quad \text{------ (2-45)}$$

It increases a monotonically function concerning $\frac{B}{P}$ Hence, the energy efficiency (EE) is maximum as $\frac{P}{B} \rightarrow 0$, which can be achieved by taking the transmit power $P \rightarrow 0$, taking the bandwidth $B \rightarrow \infty$ or combination theorem. The limit is easy to compute by considering a Taylor expansion of the logarithm around $\frac{P\beta}{BNo} = 0$,

$$B\log_2 \left(1 + \frac{\frac{P\beta}{BNo}}{P}\right) = \frac{B\log2\,(e)}{P}\left(\frac{P\beta}{BNO}\right) - \sum_{k=2}^{\infty}(-1)n\left(p\beta/BNO/n\right)^n \quad \text{------ (2-46)}$$

$$\rightarrow \text{Log}_2{}^{(e)} \frac{\beta}{No} \quad \text{as } \frac{P}{B} \rightarrow 0 \quad \text{------ (2-47)}$$

Where e means Euler's, number recognizes this as the proportional of the traditional least energy-per-chomped $\frac{No}{\log2(e)}$ = Noln2 for an AWGN channel [3], [4], with the only difference that a deterministic channel gain bandwidth (B) has been included. To quantify the energy efficiency (EE) coverage area that can be achieved in this case, use the typical noise power spectral density BNo = -174 dBm/Hz at room temperature and consider a range of channel gains B from -110 dB to -60 dB. The subsequent energy efficiency inclusion zone has appeared.

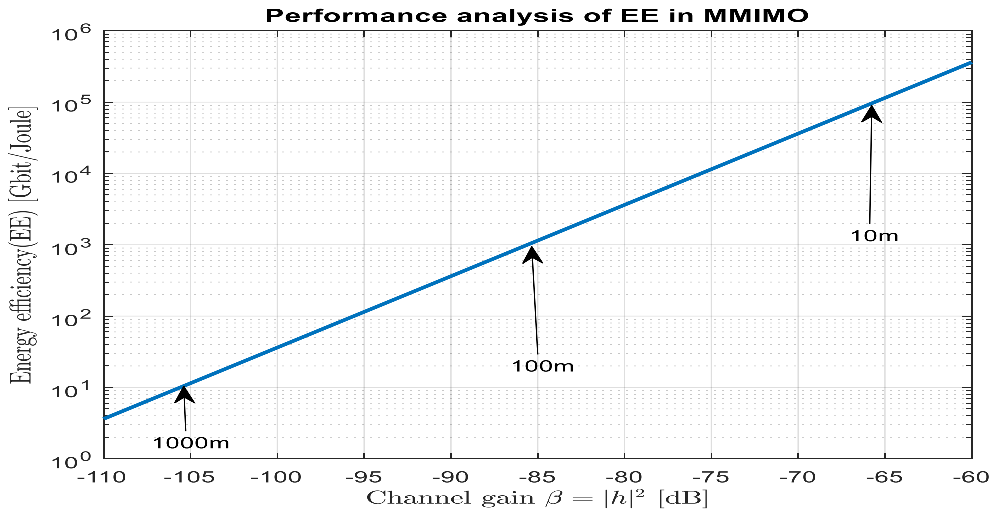


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Figure **2**.8 Max EE coverage area in a single-antenna system depends on the channel gainβ [3]. The propagation distances which computed for free-space propagation at 3 GHz, with lossless isotropic antennas, while the distances are often much shorter in the practice analysis in massive MIMO systems [3].

III. Constant circuit power performance analysis

For practical analysis of the energy consumption model P + μ where **μ ≥ 0** is the circuit power the power dissipated in the analog and digital circuitry of the transceivers. When the communications a given long-distance, it is common to have P + μ ≈ P, but in future smalls cells it is possible that μ > P In the case of a single-antenna value without interference, the energy efficiency (EE) with cell coverage area can be generalized, and upper bounded given as

$$EE = \frac{B\log2\,(1+p\beta/BNo)}{P+\mu} \leq^{(a)} \frac{\log2(e)p\beta/No}{P+\mu} \leq^{(b)} \frac{\log2(e)\beta}{N_0} \quad \text{-------------------------(2-48)}$$

The energy efficiency coverage area is an increasing function with bandwidth (B) and letting B → 1, it indicates that from letting transmit power (P) →1. With additional way to view that transmit power and bandwidth are going jointly to infinity, but the bandwidth has a significantly higher convergence speed such that $\frac{B}{P} \rightarrow 0$**.** Where the upper bound, is the same as in the presence of the circuit power value μ did not change the coverage cell area energy efficiency limit, but only made the conditions for achieving it stricter and more applied analysis. The value of μ was not purposely removed in the bounding but, it can be made negligible by taking the transmit power (P) →∞. The large MIMO: Some Known Facts (Notation: M antennas, K terminals, power per terminal (P) linear processing (MRC/MRT, ZF ...) nearly optimal as M ≫K ≫1, P and M "large enough" ⇒ pilot contamination limits performance [27].

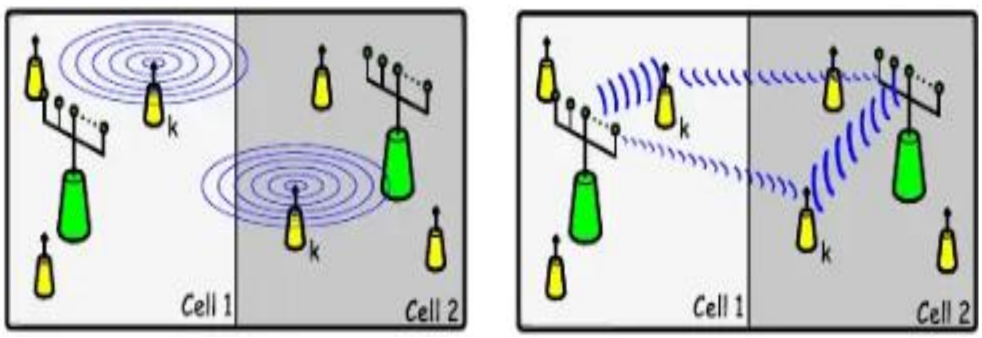

Figure 2.9 pilot contamination limit performance [27]

Scaling down P with M ⇒ noise will limit performance. Perfect CSI and optimal processing ⇒ P can be scaled as $\frac{1}{\sqrt{M}}$. Given linear processing and imperfect CSI, in a multi user (MU) system, P can be scaled as $\frac{1}{M}$.

2.8 multi-cell minimum mean square errors (M-MMSE)

Multi-cell minimum mean square error(M-MMSE) is a signal processing technique used in massive MIMO to improve the performance of energy efficiency in wireless communication networks. Multi-cell minimum mean square error in massive MIMO is that it can mitigate the inter – cell - interference (ICS) caused by the transmission of signals from multiple cells to the same users. Multi cell minimum mean square error works by estimating the channel between the transmitter and the receiver for each user and then using this information to cancel out the interference caused by signals from other cell.

Each received signal at the BS_j during the up-link payload data transmission phase is each received signal at the base station (BSj) [13].

During the up-link payload, data transmission phase is given

$$Y_j = \sum_{\iota\epsilon\mathcal{L}} \sum_{k=1}^{k} \sqrt{\tau\iota\kappa h}\, j\iota\kappa X\iota\kappa + nj \quad \text{-----} \quad (2\text{-}49)$$

Where the symbol, x_{lk} ~ CN (0, 1) is the value transmitted signal from a Gaussian code book and nj ~ CN (0, $\sigma^2 I_M$) is additive white Gaussian noise (AWGN). τικ is a transmitted power of the payload data from user (K) in cell L. The linear decoder used by base station (BSj) for arbitrarily user K in its cell as gjk then the estimate x̂jk of the signal xjk is given:

$$\hat{x}jk = g^H{}_{jk\,yj} = g^H{}_{jk} \sum_{\iota\epsilon\mathcal{L}} \sum_{k=1}^{k} \sqrt{\tau\iota\kappa h}\, j\iota\kappa X\iota\kappa + g^H{}_{jk} nj \quad \text{-----} \quad (2\text{-}50)$$

With the following up-link ergodic spectral efficiency (SE) can be achieved

$$R_{jk}^{Ul} = (1-\frac{B}{S})\ E\ \{\dot{h}_{(j)}\}\ \{\log_2 (1+\eta_{jk}^{Ul})\}, \quad \text{-----} (2\text{-}51)$$

Where the SINR $\eta_{jk}^{U\iota}$ is given below

$$\eta_{jk}^{u\iota} = \frac{\tau jk\, |g_{jk}^H\, \hat{h}_{jjk}|^2}{\{\tau_{jk}|g_{jk}^H \hat{h}_{jjk}|^2 + \sum_{(\iota,m)\neq(j,k)} \tau_{\iota m} |g_{jK}^H\, h_{jlm}\, |^2 + \sigma^2\ \ ||g_{jk}||^2\, |\hat{h}_{(j)}\}} \quad \text{-----} \quad (2\text{-}52)$$

$$= \frac{\left(\tau jk g_{jk}^H \hat{h}jjk \hat{h}_{jjk}^H\, g_{jk}\right)}{g_{jk}^H \left[\tau jk Cjjk + \sum_{(l,m)\neq(j,k)} \tau lm (\hat{h}jlm \hat{h}_{jlm}^H + cjlm) + \sigma^2 I_M\right] g_{jk}} \quad \text{-----} \quad (2\text{-}53)$$

and $E\{\dot{h}_{(j)}\}$ is the expectation with respect to the channel estimates known at base station (BSj).

$g^H{}_{jk}\, \acute{h}_{jjk}$ as the true channel in the decoding and treating interference and channel uncertainty as worst-case uncorrelated Gaussian noise [13].

R_{jk}^{Ul} = the lower bound on the up-link ergodic capacity. Consequently, a new multi-cell-MMSE detector that is signal interference noise ratio (SINR) in [13] for a given channel estimate can derived as:

$$g_{jk}^{M-MMSE} = (\sum_{\iota\epsilon\mathcal{L}} \sum_{k=1}^{k} \tau\iota\kappa (\hat{\acute{h}}_{j}\iota_k \hat{h}^H{}_{j}\iota_k + C_j\iota_k) + \sigma^2 I_M)^{-1}\, \hat{\acute{h}}_{jjk} \quad \text{-----} \quad (2\text{-}54)$$

This detector minimizes the mean square error in the estimating x_{jk}.

$$E\{|\hat{X}jk - Xjk|^2|\hat{h}_{(j)}\}. \quad \text{-- (2-55)}$$

The estimation error covariance matrix can be expressed as followed:

$$C_{j\iota\kappa} = d_j(Z_{\iota\kappa})\left(1 - P_{\iota\kappa}d_j\,(Z_{\iota\kappa})\alpha_{ji\iota\kappa}B\right)I_M \quad \text{-- (2-56)}$$

It allows the channel estimated is formulated as:

$$\hat{h}_{j\iota_k} = \sqrt{\rho}\iota\kappa d_j\,(Z\iota\kappa)\,\hat{H}\upsilon,\acute{j}^{eilk} \quad \text{-- (2-57)}$$

Where the symbol, e^i is denotes the i^{th} column of the identity matrix $I_{B.}$

By substituting the above equation, the M-MMSE detector can be expressed as:

$$g_{jk}^{M-MMSE} = (\hat{H}\nu, j\Lambda j\hat{H}_{\nu,j}^H + (\sigma^2 + \varphi j)I_M)^{-1}\,\acute{h}_{jjk} \quad \text{-------------------------------------- (2-58)}$$

Where $\Lambda j = \sum_{\iota\epsilon\mathcal{L}}\sum_{k=1}^{k}\tau\iota\kappa p\iota\kappa d_j^2(Z\iota\kappa)e_{i\iota\kappa}e_{ilk.}^H$ Λj is a diagonal matrix and i^{th} diagonal element λ_{ji} depends on the large-scale fading, the pilot power and payload power of the users that use the i^{th} pilot sequence in ν. The scalar is given:

$$\varphi j = \sum_{\iota\epsilon\mathcal{L}}\sum_{k=1}^{k}\tau\iota\kappa dj(Z\iota\kappa)\,(1 - p\iota\kappa dj\,(Z\iota\kappa)\alpha_{ji\iota\kappa}B, \quad \text{--------------------- ------ (2-59)}$$

Where $\alpha_{ji\iota\kappa}$ is defined as estimation error [13].

$$V_{i\iota\kappa}^H\,\psi_j^{-1} = \underbrace{\frac{1}{\sum_{\iota\epsilon\mathcal{L}}\sum_{m=1}^{k}\rho\iota m dj\,(Z\iota m)\,V_{i\iota\kappa}^H\,V_{i\iota m}+\sigma^2,}}_{\alpha_{ji\iota\kappa}}V_{i\iota\kappa}^H \quad \text{------------------------------------ (2-60)}$$

And ψ is the covariance matrix

Overall, multi cell minimum mean square error is an effective technique for improving the performance energy efficiency of massive MIMO for 5G systems by mitigating the effects of inters cell interference and improving the system capacity

2.9 Single-cell minimum mean square error (S-MMSE)

A single-cell minimum mean square error can be defined [13].

$$g_{jk}^{S-MMSE} = (\sum_{m=1}^{K} \tau jm\, \hat{h}_{jjm}\hat{h}_{jjm}^{H} + Zj + \sigma^2 I_M)^{-1}\ \hat{h}_{jj\kappa} \quad \text{-- (2-61)}$$

The inter-cell interference is either ignored by setting $Z_j = 0$ or only considered statistically with:

$$Zj = E\ \{ \sum_{m=1}^{K} \tau jm\, \hat{h}_{jjm}\hat{h}_{jjm}^{H} + \sum_{\iota \neq j}\sum_{m=1}^{K} \tau jm h_{j\iota m}\, h_{\iota\iota m}^{H} \} \quad \text{---------------------- (2-62)}$$

A single cell minimum mean square error (S-MMSE) pre-coding detector only utilizes the user (K) estimated channel directions from within the serving cell and treats directions from other cells as uncorrelated noise. The minimum means square error (M-MMSE) detector, however, utilizes all the bandwidth (B) available estimated directions in the channel estimation Precoding ($\hat{H}_{\nu,j}$) so that base station can be (BSj) actively suppress all parts of inter-cell interference where bandwidth (B) > user (K). Therefore, this can maximize the signal interference noise ratio (SINR) while a single cell minimum mean square error can be in single-cell cases [13].

2.9.1 Down-link multi-cell minimum mean square error (M-MMSE)

During the down-link payload data transmission, the received desired signal at the user (K) in the cell j is given:

$$Y_{j\kappa} = \sum_{\iota \epsilon \mathcal{L}} h_{\iota j\kappa}^{H} \sum_{m=1}^{K} \sqrt{\varrho\iota m}\ w_{\iota m} s_{\iota m} + n_{jk} \quad \text{---------------------------------- (2-63)}$$

Where $w_{\iota m}\ \epsilon \mathbb{C}^{M\times 1}$ is the pre-coder used by base station (Bs $\mathcal{L}$) for user m in its cell, $S_{\iota m} \sim \mathcal{CN}(0,1)$ is the payload data symbol for user m in cell $\mathcal{L}$, $\mathcal{Q}_{\iota m}$ is the corresponding down-link transmit power and $n_{jk} \sim \mathcal{CN}\ (0, \sigma^2)$ is AWGN. The multi cell minimum mean square error (M-MMSE) is the state-of-the-art up-link scheme the down-link [5], multi-cell minimum mean square error (M-MMSE) pre-coder is constructed equation given as:

$$w_{jk}^{M-MMSE} = \frac{g_{jk}^{M-MMSE}}{\sqrt{\Upsilon_{j\kappa}}} \quad \text{--- (2-64)}$$

Where $\gamma_{j\kappa} = \mathbb{E}\{\|g_{jk}^{M-MMSE}\|^2\}$ is normalizes the average transmit power for the user (k) in cell j to $E\{\|\sqrt{\varrho\iota m}\ w_{jk}^{M-MMSE} s_{\iota m}\|^2\} = \varrho\iota m$.Thus, the users do not know their instantaneous channel realization. However, they can learn their average equivalent channels are given, $\sqrt{\varrho j\kappa}\ \ \mathbb{E}\{h\}$

$\{h_{jjk}^{H} w_{jk}\}$, and the total interference variance. Then the desired received signal ($y_{j\kappa}$) is written as:

$$y_{j\kappa} = \sqrt{\varrho j\kappa}\ \mathbb{E}\{h\}\ \{h_{jjk}^{H} w_{jk}\} s_{jk} + \sum_{\iota\epsilon\mathcal{L}} h_{\iota j\kappa}^{H} \sum_{m=1}^{k} \sqrt{\varrho\iota m}\ w_{\iota m}\ s_{\iota m} - \sqrt{\varrho j\kappa}\ \mathbb{E}\{h\}\ \{h_{jjk}^{H} w_{jk}\} s_{jk} + n_{jk}.$$

------------- (2-65)

Then a down-link spectral efficiency (SE) is given that:

$$R_{jk}^{d\iota} = \zeta^{d\iota} = (1-\frac{B}{S})\log_2(1 + \eta_{j\kappa}^{d\iota})$$ -- (2-66).

2.9.2 Improving energy efficiency and decreasing loss in Massive-MIMO

The cell coverage area energy efficiency can be optimized in massive MIMO systems with common energy efficiency (EE) definition is the ratio of the spectral efficiency (bit/channel use) to the emitted power (Joule/channel use) [14]. It has been recently shown that the array gain value in massive MIMO systems can be utilized to reduce the emitted energy for systems with ideal design analysis for systems phase noise from free-running oscillators. Further specifically, this prior work shows that one, it can reduce the transmit power consumption (Pt) as $\frac{1}{N^t}$, for $0 < t < \frac{1}{2}$, and still achieve non-zero spectral efficiencies (SE) as N →∞1. By following this power scaling law, as N → 1 because the numerator has a non-zero limit and the denominator goes to zero as $1/N^t$.

Though the property specifies that massive MIMO systems can be very energy efficient, the un-boundless also shows that the conventional energy efficiency (EE) metric desires to be revised that applied to massive MIMO systems. Consider a refined metric of overall energy efficiency based on prior work and use it to analyze the overall energy efficiency analysis technique of massive MIMO systems [14]. Under the Time division duplex (TDD) protocol, the energy consumption in the amplifiers of the transmitters (per coherence period) is given by:

$$E_{amp} = \{\frac{(T_{pilot}^{DL} + T_{data}^{DL})p^{Bs}}{\omega^{Bs}}\} + \{\frac{(T_{pilot}^{UL} + T_{data}^{UL})p^{UE}}{\omega^{UE}}\} \text{ [Joule]},$$ --------------------------------------- (2-67)

Where the parameters $\acute{\omega}^{BS}$, $\acute{\omega}^{UE}$ ε [0, 1] are the efficiencies of the power amplifiers at the BS, and user equipment's (UE), respectively. The average power (Joule/channel use) can be separated as:

$$\frac{E_{amp}}{T_{coher}} = \beta_{DL} (\frac{T_{pilot}^{DL}}{T_{coher}} * \frac{p^{Bs}}{\omega^{Bs}}) + (\frac{T_{pilot}^{UL}}{T_{coher}} * \frac{p^{UE}}{\omega^{Bs}}) + (\frac{T_{data}^{DL}}{T_{coher}} * \frac{p^{Bs}}{\omega^{Bs}})$$ --------------------------------------(2-68)

For down-link power

$+ \beta_{UL} (T^{DL}{}_{pilot/Tcoh} {}_{*}P^{BS} /\omega^{BS} + T^{UL}{}_{pilot/Tcoh*P}{}^{UE}{}_{/\omega}{}^{Bs}) + T^{UL}{}_{data/Tcoh*}\ P^{UE}{}_{/\omega}{}^{UE}$ ---------------------(2-69)

For Up-link power

Where, the ratio of downlink (DL) and uplink (UL) transmission respectively follow as:

$$\beta DL = \frac{T^{DL}\ data}{T^{DL}\ data + T^{UL} data} \quad \text{-- -----------} \ (2\text{-}70)$$

$$\beta UL = \frac{T^{UL} data}{T^{DL} data + T^{UL} data} \quad \text{--} \ (2\text{-}71)$$

In addition to the power consumption by the amplifiers, generally a baseband circuit power consumption which modeled as Nρ + ʆ. Where the parameter value ρ ≥0 [Joule/channel use] describes the circuit power (cp) that scales with the number of antennas(M), design components that are needed at each antenna branch (converters, mixers, and filters) computational complexity that is relative to the N (channel estimation and computing maximum ratio transceiver/maximum ratio combination (MRT/MRC).In contrast, parameter ʆ > 0 [Joule/channel use] is a static circuit power term that is independent of N (but might scale with the number of active users (UEs)), the model's baseband processing at the base station (BS), and circuit power (Pc) at the active user equipment's (UE). Based on the power consumption (Pc) model defined above, and inspired by the seminal work in [14], define the overall energy efficiency (bit/Joule/cell area) as follows.

Down-link energy efficiency (EE) coverage area:

$$EE^{DL}{}_{Area} = \frac{C^{DL}}{\beta DL\ (T^{DL}{}_{pilot}/Tcoh*P^{BS}/\omega^{BS} + T^{UL}{}_{pilot/Tcoh*P}{}^{UE}{}_{/\omega}{}^{Bs} + Np + \int) + T^{DL}{}_{pilot/Tcoh}\ {}_{*}P^{BS}\ /\omega^{BS}} \qquad (2\text{-}72)$$

Up-link link energy efficiency (EE) coverage area:

$$EE^{UL}{}_{Area} = \frac{C^{UL}}{\beta UL\ (T^{DL}{}_{pilot}/Tcoh*P^{BS}/\omega^{BS} + T^{UL}{}_{pilot/Tcoh*P}{}^{UE}{}_{/\omega}{}^{Bs} + Np + \int) + T^{UL}{}_{pilot/Tcoh}\ {}_{*}P^{UE}\ /\omega^{UE}} \qquad (2\text{-}73)$$

The energy efficiency (EE), the coverage cell area of the transmission power system is found by replacing the capacities C^{DL} and C^{UL} with the achievable value spectral efficiency (SE). Which define by considering a single link, which can be any of the links in a massive-MIMO system the parameters ʆ and ρ should then be taken as the energy per channel use per user. Extend the power scaling laws to general system models with non-ideal design analysis. The down-link (DL) transmit power base station (P^{BS}) and up-link (UL) pilot power user equipment's(p^{UE}) are reduced with N equivalently to:

$$Lim_{N\to\infty} C^{DL} \geq \frac{T^{DL} data}{Tcoh} \log_2 \left\{ 1 + \frac{1}{Kr^{UE} + Kt^{UE} + Kr^{UE} Kt^{UE}} \right\} \text{---------------------------------------} \ (2\text{-}74)$$

Similarly, suppose the up-links transmit/pilot power (p^{UE}) is reduced with N proportionally to $1/N^{tUE}$. If $0 < t^{UE} < ½$.

$$\mathcal{L}im_{N \to \infty} C^{UL} \geq \frac{T^{UL}data}{Tcoh} \log_2 \left\{ 1 + \frac{1}{2Kt^{UE} + (Kt^{UE})^2} \right\} \text{--- (2-75)}$$

Then it decreases the down-link and up-link transmit powers as N grows large (roughly proportionally to ($\frac{1}{\sqrt{N}}$) and converges cell area to non-zero spectral efficiencies (SE). The asymptotic downlink (DL) capacity is lower bounded by the uplink (UL) capacity. These lower bounds only depend on the levels of impairments analysis at the user equipment's (UE). Therefore, the interfering transmissions might have to reduce their transmit powers as well if their impact should disappear asymptotically [14].

The lower bounds are achieved through the minimum mean square error (MMSE) estimator for channel estimation and simple linear processing at the base station (BS), approximate maximum ratio transmission (MRT) in the downlink (DL), and maximum ratio combination (MRC) in the (UL). The upper capacity defines how to maximize the energy efficiency (EE) coverage area. To maximize the energy efficiency of coverage metrics concerning the transmit power (Pt) and the number of antennas [14].

Let E $\{I_H^{UE}\} = 0$ and E $\{||Q_H||\}^2 = 0$. If $\rho = 0$, -- (2-76)

The maximal energy efficiency can be bounded as:

Where the lower limits are accomplished as $N \to 1$, utilizing the energy scaling law hypothesis. On the off chance that $\rho > 0$, the upper limits are as yet legitimate, yet the asymptotic energy efficiency:

$\mathcal{L}im$ max EE^{DL} = $\mathcal{L}im N \to \infty$ max $EE^{UL} = 0$ --- (2-77)

Where, $N \to \infty$ P^{BS}, $P^{UE} \geq 0$, $N \to \infty$ $P^{UE} \geq 0$

The lower limits for $\rho = 0$, are accomplished as depicted; the upper limits follow from dismissing the sent power term in the denominator and applying the upper limits. On account of $\rho > 0$, the energy efficiency is non-zero for N =1 for any non-zero sent power, while the energy efficiency goes to zero as $N \to 1$, Since the denominators of the energy efficiency measurements, develop and the numerators are limited. This result uncovered that the maximum generally energy efficiency (EE) is limited, in the massive MIMO system framework [14].

2.9.3 Multiuser MIMO

The MU-MIMO system where multi-antenna BS serves multiple UE is more practical than point-to-point MIMO. The main principle of multiuser MIMO is that each BS with multiple antennas can use the same frequency-time resources to serve a multiplicity of single antenna terminals that share the multiplexing gain [35]. One can intuitively understand the multiuser MIMO scenario as if the K-antennas terminal in the point-to-point MIMO was broken up into multiple autonomous terminals [35]. Cooperation between the antennas of the UE is possible in the case of the point-to-point MIMO, however, UEs in MU-MIMO cannot communicate with each other. Although the poor-quality channels can sometimes severely influence the throughput achieved by individual users, the break up actually improves the sum throughput of the system [38]. Hence, the impact of the propagation environment on the MU-MIMO system is less than the case of point-to-point MIMO due to the multi-user diversity. As a result, many communication standards such as 802.16 (WiMAX), 802.11 (WiFI), and LTE have included MU-MIMO. The BS usually is equipped with only a few numbers of antennas (i.e., 10 antennas or less) for most MIMO applications. Thus, only modest improvement is brought to the spectral efficacy using the MIMO technology so far.

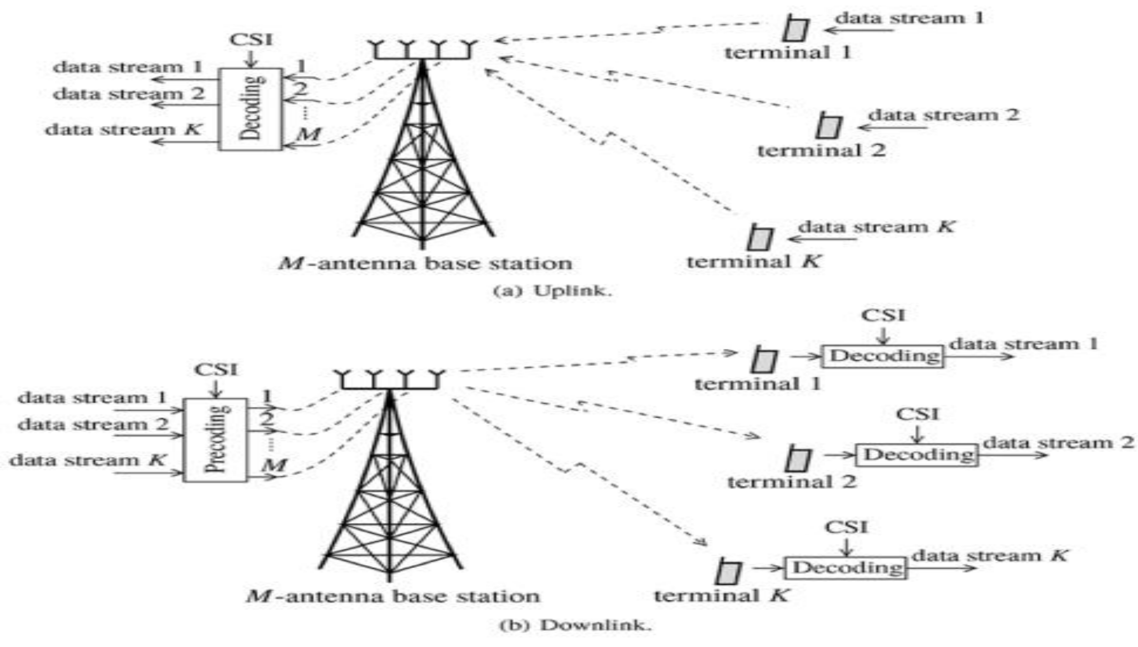

Figure **2**.10 Multiusers MIMO [35]

The performance of the MU-MIMO system if the terminals in **F**igure 2.5 with a single antenna each, K is served by the BS is better than the case of point-to-point MIMO. Knowing that G is the M*K matrix that represents the frequency response between the BS antennas and the K, the sum capacities of the UL and DL are given by:

$$C^{UL} = \log_2 |I_{M+\rho ulGG^H}| \quad \text{--} \quad (2\text{-}78)$$

$$C^{DL} = \underset{\substack{v_k \geq 0 \\ \sum_{k=1} vk \leq 1}}{m_a x} \log_2 |I_{M+\rho dlGDvG^H}| \quad \text{--} \quad (2\text{-}79)$$

Where v = [v_1,……… v_k]^T , ρdl is the DL SNR, and $\rho ul$is the UL SNR for every terminal. The total UL transmits the power of multiuser MIMO is greater than the transmit power of the point-to-point MIMO by a factor of K [35]. Computing the capacity of the DL depends on solving a convex optimization problem. CSI knowledge is important for both 2-78 and 2-79 in the above equations. On the UL only the BS is required to know the channel while every terminal must be separately informed about their permissible transmit rate. On the DL, however, CSI knowledge is required in the BS and the terminals [35].

2.9.4 The wireless channel

A wireless channel is the air medium through which wireless transmission is performed via electromagnetic waves [38]. Since there is not restricted to taking a single path, it suffers reflection, deflection, and scattering, by buildings, hills, bodies, and other objects when traveling from the transmitter to receiver, hence multiple copies of the signal arrive at the receivers as shown in the figure below.

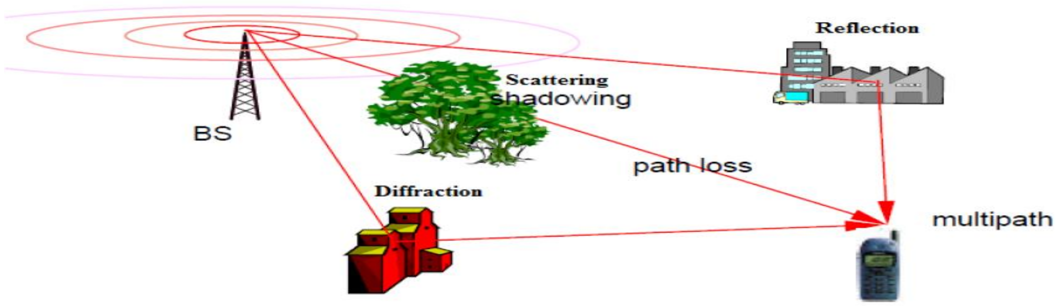

Figure 2.11Radio signal propagation [38]

Path loss refers to signal power dissipation in propagation to the distance between transmitter, and receiver. In the free space, path loss is given be:

$$L = \frac{\varepsilon GtGr}{(4\pi d)^2} \quad \text{--} \quad (2.80)$$

Whereε is the wavelength, Gt is the transmitter antenna gain, Gr is the receiver antenna gain, d is the distance between the transmitter and receiver.

Chapter 3

System model of energy efficiency in massive MIMO systems

3.1 Introduction

A massive multiple input multiple outputs (M-MIMO) refers to a system where the base station communicates with several users simultaneously. The base station and the user can be equipped with multiple numbers of antennas. The massive MIMO system enables many parallel communications in the same time and frequency resource known as space division multiple accesses (SDMA).

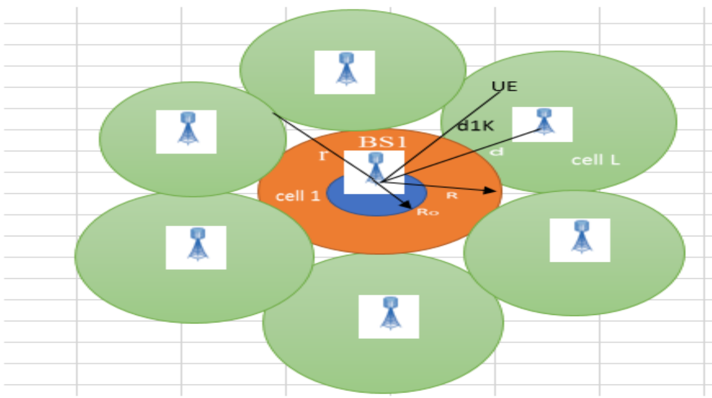

Figure **3**.1 System model L number of cells **[**9**]**

Area energy efficiency (AEE) is the optimization of power consumption of a system, and to be covered as shown in the system model the multi-cell multi-user in a massive MIMO system is composed of L hexagonal cells with radius r. Each BS has an 'M' number of antennas, and each cell has a 'K' number of users with a single antenna. The full frequency reuse factor of the L, cells are considered. The reference cell is denoted as a base station (BS1) and the other $L-1$ cell are the interfering cells. The distance between a base station (BS1) and the base station (BS) in an adjacent cell with the same area, each hexagonal cell is approximated as an equal area circle with radius R, where R is defined as:

$$R = \frac{\sqrt{3\sqrt{3}}}{(2\Pi)r} \quad \text{and } d = \sqrt{3r} \quad \text{-- (3-1)}$$

Where R_0 denotes the nearby distance from the mobile to BS, and $R_0 \ll R$. The random user location model is used, where the users are assumed to be independently and uniformly distributed in all of the cells [9].

The system considers a massive MIMO network consisting of cellular cells and each cell is equipped with base station antennas of M and active users K. the network cells and active users are assumed uniformly distributed. The work starts with the definition of energy efficiency in wireless communication, which is defined as the ratio of average data rate(R) to total energy consumption (PC). In mathematics, it is defined as [5], [7], [9], [11], [18], [20].

The network system is assumed to be circular and uniformly identical multi-user distribution uncorrelated Rayleigh flat fading. The overall workflow diagram is as follows below.

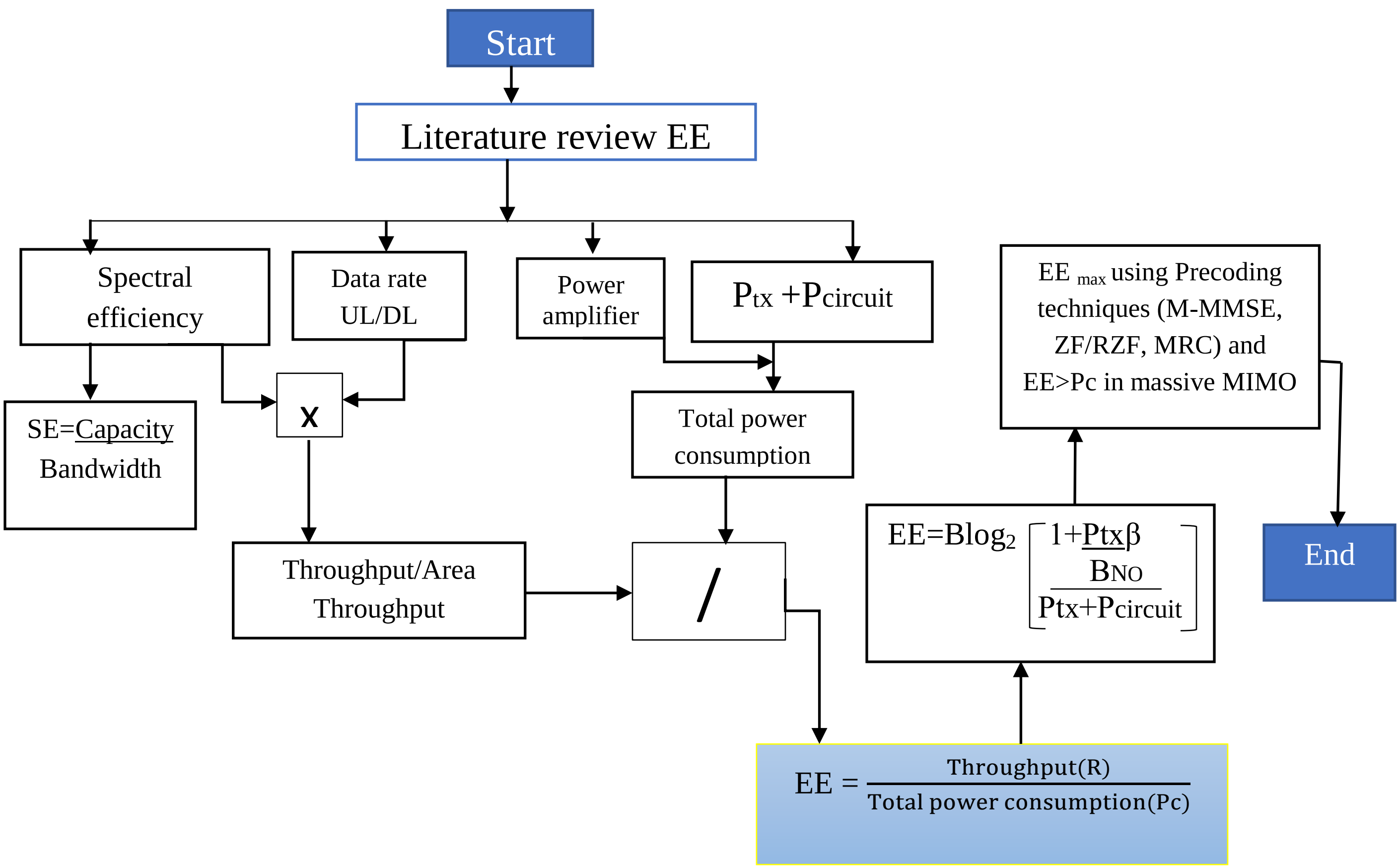

Figure 3.2 Work flow diagram of energy efficiency in massive MIMO systems

3.2. Comparison of circuit power (CP) with different Precoding techniques.

At each base station (BS) and K number of user equipment in each number of cells and there is M number of antennas. The Precoding techniques (multi-cell minimum mean square error, maximum ratio combination, and regularized zero forcing) as shown in the figure below. The Transceiver chain requires more power consumption (46.25 dBm). The signal processing needed for uplink (UL) reception and downlink (DL) data transmission consumes approximately 28.8dBm, while the smallest component is approximately7.27dBm of pre-coding vector computation [5, 38]. The value circuit power (CP) breakdown is desired by the schemes processing that is recorded for the channel estimate, computation of receive combining vectors, back-haul, and encoding/decoding. The power consumption (CP) consumed by intra-cell channel assessment is approximately 26 dBm) and the handling plan is autonomous. The value circuit power depends on the framework for the computation of receiving combining vectors and the highest circuit power (CP) is needed by multi-cell minimum mean square error (M-MMSE), for which it is approximately 40 dBm (10W). It accounts for the circuit power (CP) needed according to the power consumption by channel estimation [5**].**

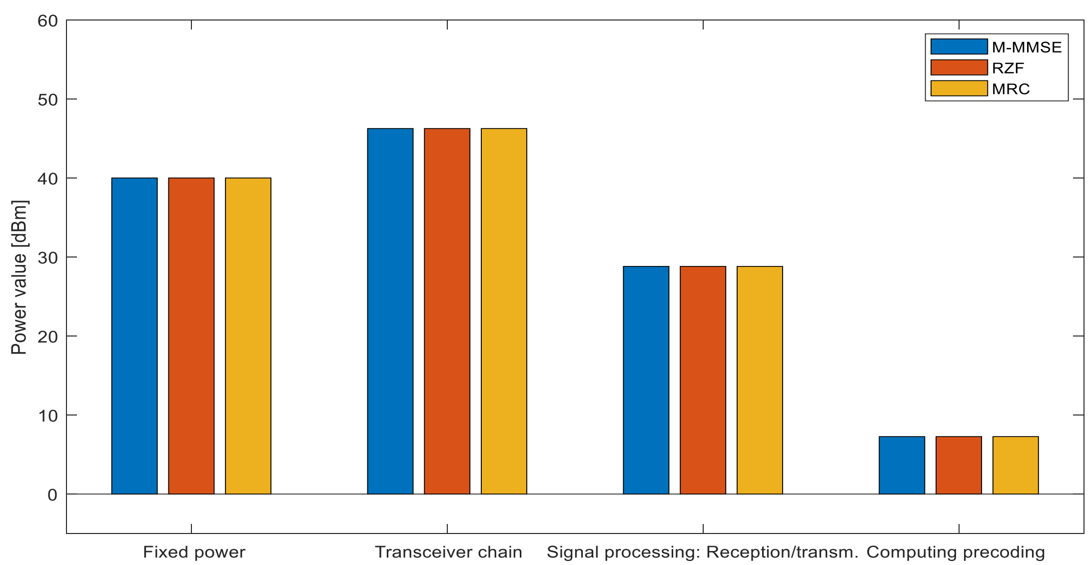

Figure**3**.3 Circuit power consumption breakdowns per cell Precoding techniques (M-MMSE, RZF, and MRC). With K = 20 user equipment, and M = 200 antennas in the base stations (Bs) [5].

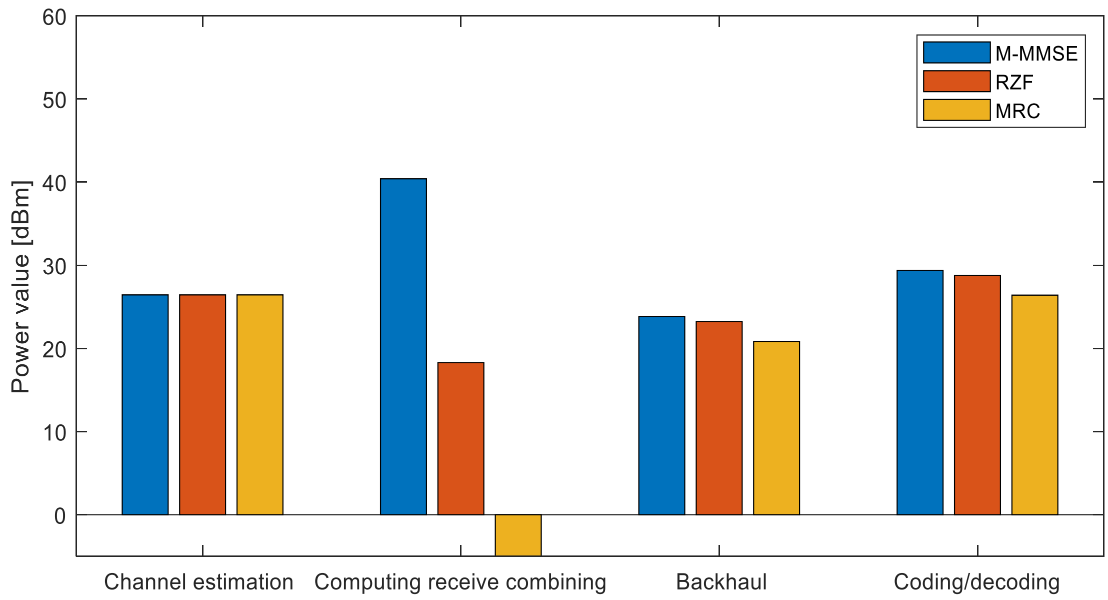

Figure**3**.4 circuit power consumption, breakdowns per cell Precoding, techniques such as: (M-MMSE, RZF, and MRC). With K = 20 user equipment, and M = 200 antennas in the base stations (Bs) [5].

3.3 Maximization of energy efficiency (EE)

The energy efficiency of a cellular network is the number of bits that can be reliability transmitted per unit of energy according to the definition of energy efficiency [5], [9], [35] defined as

$$\mathrm{EE} = \frac{\text{Throughput[bit/s/cell]}}{\text{Total power consuption[w/cell]}} = \sum_{k=1}^{k} \frac{E\{R_k^{ul}\}+E\{R_k^{dl}\}}{P_t^{ul}+P_t^{dl}+Pcp_{(M.K,R)}} \text{ -------------------------------- (3-3)}$$

Which is measured in bit/Joule, and can be seen as, the benefit-cost ratio, where the service quality (throughput) is, compared with associated costs (power consumption). Hence, it is an indicator of the network bit-delivery efficiency [5], [9], [35], [38]. The throughput can be, computed using any of the UL and DL spectral efficiency expressions provided. Which characterizes the performance of massive MIMO networks operating over large communication bandwidth unlike the ATP, the EE metric is affected by changes in the numerator and denominator since both are variable. This, means that some caution is required to avoid incomplete and potentially misleading conclusions from EE analysis. Particular attention should be paid to, accurately model the PC of the network. Assume for example, that the PC only comprises the transmit power. Lemma showed that the transmit power can be reduced, towards zero as when $M \rightarrow \infty$ while approaching a non-zero asymptotic DL SE limit. This implies the EE would grow without being bound as $M \rightarrow \infty$. Clearly, this is misleading and comes from the fact that the transmit power only captures a part of the overall PC. Moreover, we notice that the transmit power does not represent the effective transmit power (ETP) needed for transmission since it does not account for the efficiency of the PA. The efficiency of a PA is defined as the ratio of output power to input power [5], [9], [27], and [35]. Antenna array configuration: the number of antennas and their arrangement in the array can have a significant impact on the energy efficiency of massive MIMO system. Power allocation technique: can be used to optimize the power consumption of the system by allocating the power to the users in an efficient manner. User scheduling: can be used to select the users that should be served in each time slot, thus improving the performance of energy efficiency in massive MIMO for 5G network.

3.4 Tradeoff energy and spectral efficiency

The SE of a cell can be increased by, using more transmits power, deploying multiple BS antennas, or serving multiple UEs per cell. All these approaches inevitably increase the PC of the network, either directly (by increasing the transmit power) or indirectly (by using more hardware), and therefore may potentially reduce the EE. However, this is not necessarily the case. There exist operating conditions under which it is possible to use these techniques to jointly increase SE and EE. To explore this in more detail, the EE-SE trade-off is studied next and the impact of different network parameters and operating conditions are investigated [5], [10], and [39].

For simplicity, we focus on the UL of the two-cell Wyner model (i.e., $L = 2$) consider only uncorrelated Rayleigh fading channels over a bandwidth B, under the assumption that the BSs are equipped with M antennas, have perfect channel knowledge, and use MR combining.

3.5 Impact of Multiple BS Antennas

Assume that there is only one active UE (i.e., $K = 1$) in cell 0 and that no interfering signals come from cell1 [5], [21]. An achievable SE of the UE in cell 0 is

$$\mathrm{SE}_0 = \log_2(1 + (\mathrm{M}-1)\,\mathrm{SNR}_0) = \log_2(1 + (\mathrm{M}-1)\,\mathrm{SNR}_0)\,\frac{\mathrm{P}}{\sigma^2}\beta_0^0 \quad \text{------------------------} \quad (3\text{-}4)$$

where p is the transmit power, σ^2 is the noise power, and β_0^0 denotes the average channel gain of the active UE. We have omitted the superscript non line of sight (NLoS), since we do not consider the LoS case here. To evaluate the impact of M on the EE, we distinguish between two different cases in the computation of the PC: *i*) the CP increase due to multiple BS antennas is neglected; *ii*) the CP increase is accounted for. Assume, for the moment, that the CP of cell0 consists only of the fixed power P_{FIX}; that is, $CP_0 = P_{FIX}$. Hence, the corresponding EE of cell 0 is:

$$\mathrm{EE} = \frac{\mathrm{B}\log 2(1+(\mathrm{M}-1)\frac{\mathrm{P}}{\sigma^2}\beta_0^0}{\frac{1}{\mu}\mathrm{P} \;\; +\mathrm{P}_{\mathrm{fix}}} \quad \text{---} \; (3\text{-}5)$$

Where B is the bandwidth and $\frac{1}{\mu}P$ accounts for the ETP with $0 < \mu \leq 1$ being the PA efficiency [5], [21]. For a given SE, denoted as SE_0, from (3-4) we obtain the required transmit power as

$$\mathrm{P} = (\frac{2^{\mathrm{SE}0}-1}{(\mathrm{M}-1)})\frac{\sigma^2}{\beta_0^0} \quad \text{--} \; (3\text{-}6)$$

This inserted into (3-4) yields

$$\mathrm{EE}_0 = \frac{\mathrm{BSE0}}{(2^{\mathrm{SE}0}-1)+\mathrm{Pfix}} \quad \text{---} \; (3\text{-}7)$$

The throughput is obtained as the uplink and downlink spectral efficiency expressions as the energy efficiency of cell j is computed as

$$\mathrm{EE}_j = \frac{\mathrm{TRj}}{\mathrm{ETPj+CPj}} \quad \text{---} \; (3\text{-}8)$$

Where ETPj effective transmission power of pilot of sequence of cell j as well as of UL and DL signals: $\mathrm{ETP}_j = \frac{\tau p}{\tau c}\sum_{k=1}^{kj}\frac{1}{\mu UEJK}Pjk + \frac{\tau U}{\tau C}\sum_{k=1}^{Kj}\frac{1}{\mu UEjk}pjk + \frac{1}{\mu BSj}\frac{\tau d}{\tau c}\sum_{k=1}^{kj}\rho jk$ ----------------- (3-9)

Where $\frac{\tau p}{\tau c}\sum_{k=1}^{kj}\frac{1}{\mu UEJK}Pjk$ = ETP for pilot, $\frac{\tau U}{\tau C}\sum_{k=1}^{Kj}\frac{1}{\mu UEjk}pjk = ETP\ in\ the\ UL\ and$

Then μUEjK(0< μUEjK ≤ 1) is the power amplifier (PA) efficiency at UEk in cell j and μBSj(0 ≤ μBSj ≤ 1) is that of BSj. The energy efficiency and throughput tradeoff of different schemes were compared [5], [21], and [38].

Chapter 4

Simulation and numerical results

4.1 Introduction

MATLAB-based simulations are applied to confirm the numerical analysis given in the system provided in this chapter. This chapter simulation of the main design parameters on the impact of the performance of energy efficiency in massive MIMO for 5G wireless communication networks. The maximum and desired design parameters for performance energy efficiency are simulated using M-MMSE Precoding schemes at the end of the simulation result.

The simulation uses a sample of a massive MIMO scenario, number of antennas (M= up to 500), number of active users (K = up to 140), and transmission bandwidth of 20MHZ. and more simulation parameters are listed in the table below.

4.2 Simulation parameters

From the MATLAB demonstration, the following list of parameters is used. The parameters are taken from the telecommunication union standard reports (TUSR) and standard values mainly [3],[5],[9],[15],[20],[23],[25],[32],[35],[39].

Table 4.1 Simulation parameters used

Symbol	System Parameter	value
α	Path loss exponent	3.7
S	Length of coherence block	500
η	Power amplifier efficiency	0.35
Ŧ	Symbol time	1/ $2.10^{7[s/symbol]}$
A	Coding, decoding, and back-haul	$1.15.10^{-9}$[J/bit]
C0	Static power consumption	10w.T[J/Symbol]
C1	Circuit power per active UE	0.01w.T[J/Symbol]
D_0	Circuit power per active BS	0.2w.T[J/Symbol]
D1	Signal processing coefficient	$1.56.10^{-10}$[J/Symbol]
σ^2	Noise variance	10^{-20}[J/Symbol]
M	Maximum number of antennas	1 to 500

K	Maximum number of User	1 to 140
ω	Propagation loss ≤1 km	130dB
ε	Hardware losses	0.03
p_{fix}	Fixed power	10w
P_{LO}	Power for BS	0.2w
P_{BS}	Power per BS antennas	0.4w
P_{UE}	Power per UE	0.01w
A	Cell area	0.0625km^2
P_{COD}	Power for data encoding decoding	0.1W/(Gbit/s)
U	Coherence block (symbols)	500
LBS	Computational efficiency at BSs	12.8GW
LU	Computational efficiency at UEs	5W
$\frac{DL}{UL}$	Fraction of uplink and downlink transmission sample	1/3 and 2/3
B	Transmission bandwidth:	20MHz
f_c	Carrier frequency:	2GHz
T_C	Channel coherence time:	10ms

4.3 Simulation and result discussions

4.3.1 The impact of bandwidth on energy efficiency in massive MIMO for 5G networks

Here, the impact of bandwidth on the total energy efficiency of the system is analysed and evaluated. In this simulation, the energy efficiency of the system increases as the bandwidth with a gain of a number of antennas (M) increases. as shown in figure **4**.1 below.

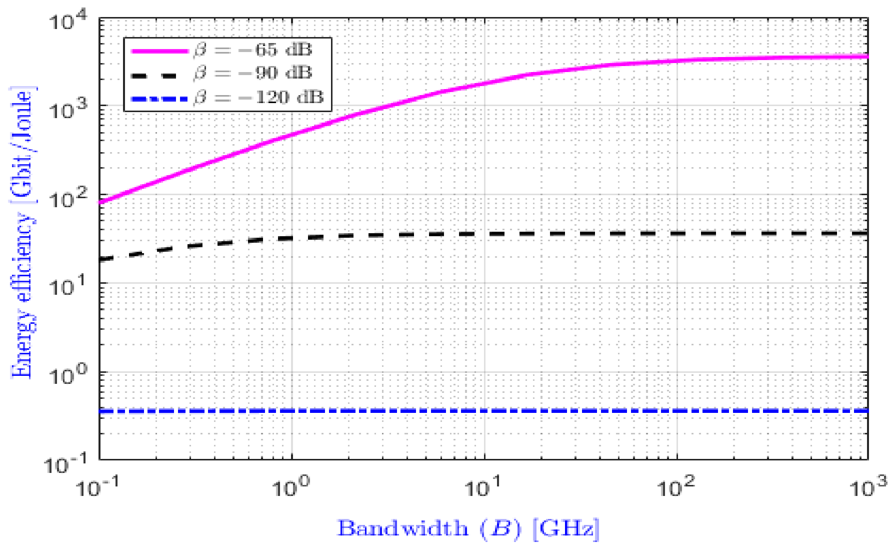

Figure 4.1 Simulation result energy efficiency with bandwidth in massive MIMO

Since the perfect channel state information (CSI) is available the capacity of the channel is [3]

$$C = B\log_2(1 + \frac{P\beta}{BNO})[bit/s] \quad \text{-------(4-1)}$$

Where $\beta = |h|^2$ denotes the channel gain(massive MIMO input). The capacity is achieved by x ~ N_C (0, P). When the transmit power is the only factor contributing to the energy consumption, an upper bound on the energy efficiency in [3] is

$$\frac{B\log_2(1+\frac{P\beta}{BNO})}{P} \quad \text{-------(4-2)}$$

The energy efficiency approaches its limit as B → ∞ when P = 20 dBm and N_0 = −174 dBm/Hz. Different values of β are considered and these are determining how quickly we approach the energy efficiency limit. For the cell-edge case of β = −110 dB, the limit is reached already at B = 1 GHz, while we need 100× more bandwidth every time β is increased by 20 dB the energy efficiency increases with the bandwidth. The limit and the convergence depend strongly on the channel gain β [3],[6].

The impact of bandwidth on energy efficiency in massive MIMO depends on several factors, including the number of antenna, the modulation scheme, and the signal-to-noise ratio (SNR) of the system. In general, increasing the bandwidth in massive MIMO can lead to an increase in energy consumption due to the need for more powerful signal processing hardware and increasing data transmission. The transmit power required to achieve a given level of performance, which can lead to an overall improvement in energy efficiency. Specifically, increasing the bandwidth in massive MIMO for 5G can lead to the following benefits:

1. Increased spectral efficiency: with more bandwidth available, more user can be served simultaneously, which increases the system's overall spectral efficiency (SE).

2. Higher data rates: with more bandwidth available, the system can be transmitting data at higher rates, which can lead to better user experience.

3. Reduced transmit power: with more bandwidth available, the required transmit power can be reduced, which can lead to an overall improvement in energy efficiency.

However, increasing the bandwidth in massive MIMO can also lead to the following challenges:

1. Increased complexity: with more bandwidth available, the signal processing hardware required to support the increased data rates can become more complex and expensive.

2. Increased interference: with more user being served simultaneously, the potential for interference between uses can increase, which can reduce the system's overall performance.

3. Reduced coverage: with more bandwidth being used, the coverage area of the system can be reduced, which limit the systems overall can reach.

In conclusion, the impact of bandwidth on energy efficiency in massive MIMO depends on several factors, and there is no one size fits all answer. However, increasing the bandwidth in massive MIMO can lead to both benefits and challenges, and careful consideration should be given to the specific requirements of the system before making any changes to the systems bandwidth.

4.3.2 Analysis of multi-users and circuit power in a massive MIMO system

The total circuit power (CP) per cell for the combined uplink (UL) and downlink (DL) scenario with different linear Precoding schemes, the circuit power required by M-MMSE is higher than with the RZF. This is mainly due to the increased consumption efficiency. ZF, MRC, and RZF consume less circuit power, since both invert matrices of dimensions K*K rather than M*M.

MRC only provides a substantial complex reduction compared to RZF and ZF when the number of the user equipment is very large in massive MIMO. Consider M = 500 and let the number of users (K) vary from 10 to 100. The circuit power increases with the number of users.

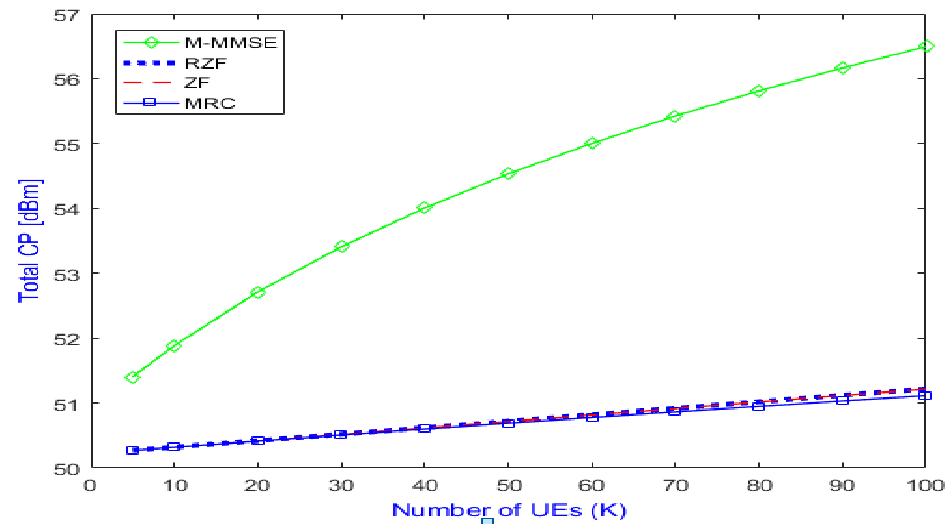

Figure 4.2 Total circuit power (CP) with user equipment (K) in massive MIMO

In this simulation result, the circuit power required by the different linear Precoding schemes is marginally different. For more comparison, this result is made for given configurations of (M, K) which do not necessarily present the optimal ones for maximum energy efficiency in massive MIMO for 5G wireless communication networks.

4.3.3 Analysis of throughput on energy efficiency in a massive MIMO system

The energy efficiency (EE) and throughput concentrate on the massive-MIMO network to emphasize without defining the bandwidth. Energy efficiency (EE) analysis cannot be performed for each base station (BS) and K number of users in each number of cells and number of antennas (M). The values of the number of antennas (M) and the number of users (K) can be defined. The cell coverage area energy efficiency (EE) is given in **f**igure **4**.3 below:

$$EE = \frac{\text{Throughput(R)}}{\text{ETPj+CPj}} \quad \text{---} \ (4\text{-}3)$$

Where ETP_j is effective to transmit power, and CP_j circuit power respectively. Average area transmission power (AATP), which is defined as the average network power consumption for data transmission per unit area is used, to calculate the transmission power consumed by a wireless network. The measurement unit of this metric is given $\frac{W}{KM^2}$

$$AATP = \text{Transmission power } \left[\frac{W}{\text{Cell}}\right] \text{ *Cell density number } \left[\frac{\text{Cells}}{KM^2}\right] \ \text{--------------------------------}(4\text{-}4)$$

Area throughput = $\frac{\text{Throughput}}{\text{km}^2}$ -- (4-5)

Area throughput = $\frac{2432\text{Mbit/s/cell}}{0.0625\text{km2}}$ = 38.912.8Gb/s/km2 for **M**-MMSE

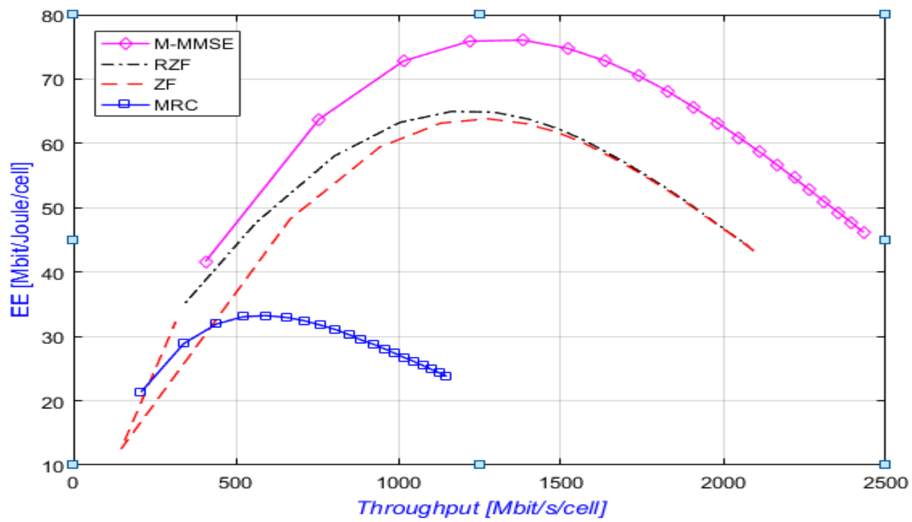

Figure 4.3 Simulation result energy efficiency with throughput in massive MIMO

The number of users (K) = 30 with the values number of antennas (M) = 500, in the above simulation result shows that the multi-cell minimum mean square error (M-MMSE) Precoding techniques allow the maximum energy efficiency (76.06Mbit/Joule) and maximum throughput but, maximum ratio combination (MRC) having the minimum energy efficiency (33.23Mbit/Joule) and throughput(1148Mbit/s/cell). As the number of the antenna (M), in the base station increases, and the cell coverage area is 0.25km x 0.25km with the power consumption per user equipment (PUE = 0.01w) in massive MIMO networks.

4.3.4 Design and analysis of maximum energy efficiency in massive MIMO

To achieve maximum energy efficiency values with multi-cell minimum mean square error (M-MMSE), regularized zero force (RZF/ZF), and maximum ratio combination (MRC) for various value number of antennas (M) and some users (K) combinations, consider K ε {10, 20..., 140} and M ε {20, 30… 500}. With trade-off circuit power (CP) and transmit power value. M-MMSE is the best Precoding technique for a given maximum value (M, K) from a throughput perspective. Marginally M-MMSE has higher throughput than RZF and has disproportionately larger power consumption.

Hence, at a lower throughput value, the higher power consumptions per cell are the price to pay with RZF; energy efficiency offers the optimum with MRC, which is smaller than with M-

MMSE and RZF for an area throughput of 49.808Gb/s/km2, throughput 3113.032. (Mb/s/cell) and total power consumption (PC) of 64.72W per cell.

With M-MMSE, RZF/ZF, and MRC as a function of a massive number of antennas (M) and multi number of the active user (K). Maximum energy efficiency with fixed power 5w, power per base station (Bs) antenna = 0.2w, power per an active number of active users (PUE = 0.01W), power data encoding 0.01w/Gb/s and power data decoding 0.08w/Gb/s which, is maximum energy efficiency (EE) is 54.95 Mbit/Joule simulated in **f**igure 4.4 below.

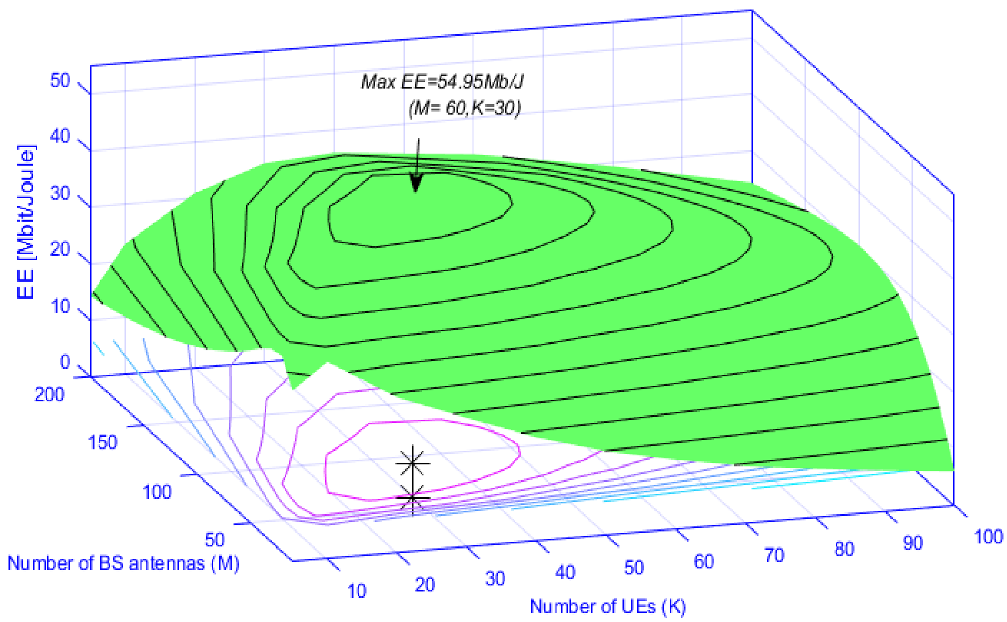

Figure 4.4 Simulation result EE with number of antennas (M) and active user equipment (UE) using M-MMSE precoding techniques in massive MIMO

$EE_{max} = \frac{\text{Data throughput(R)}}{\text{Total power consuption(Pc)}}$ then R = EE*Pc = 54.95Mbit/Joule*41.55w = 2283.1725bit/s

$= \frac{2283.1725\text{bit/s}}{41.55\text{w}}$ = **54.95**Mbit/Joule --- (4-6)

$EE_K = \frac{SE_K}{P}$ this formula used to calculate the energy efficiency for each user in massive MIMO system. Designing an optimal massive MIMO system that supports a massive number of users with high energy efficiency requires careful consideration of several factors, Including the antenna configuration, signal processing techniques, and resource allocation strategies.

1. **Antenna configuration**: the use of large number of antennas in a fundamental future of massive MIMO systems, and the antenna configuration plays a crucial role in the systems performance. The optimal antenna configuration depends on several factors, such as propagation environment, the number of users, and the available frequency bands. However, a common approach is to use a uniform linear array of antennas or a uniform planar array of antennas. **Resource allocation:** resource allocation strategies play a crucial role in determining the energy efficiency of the system. **In summary**, designing an optimal massive MIMO system that supports a massive number of users with higher energy efficiency requires careful consideration of several factors, including the antenna configuration, signal processing techniques, resource allocation, and hardware design. By optimizing these factors, it is possible to design a massive MIMO system that can support a large number of users while minimizing power consumption and maximizing energy efficiency.

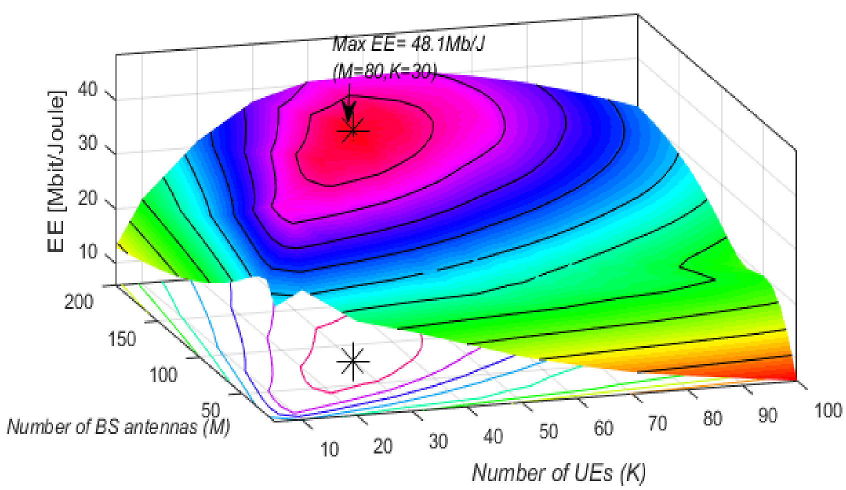

Figure 4.5 Simulation result EE with number of antennas (M) and active user equipment (UE) using RZF Precoding techniques in massive MIMO

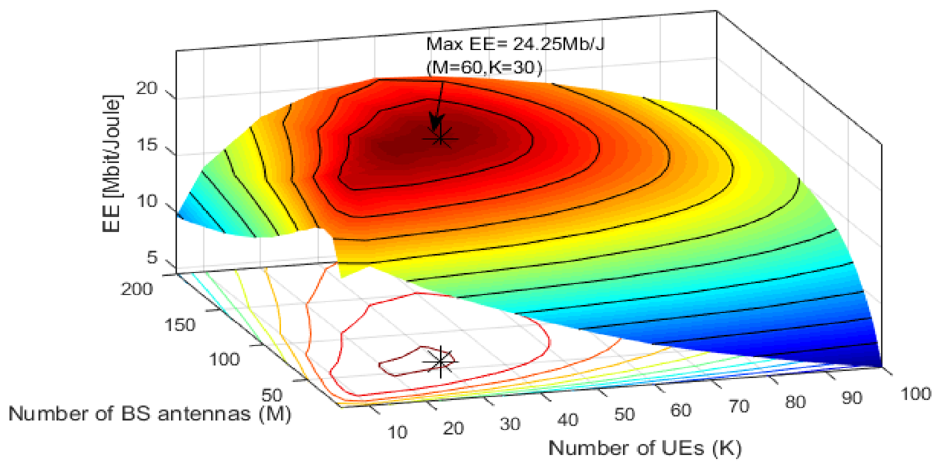

Figure 4.6 Simulation result EE with a number of antennas (M) and active user equipment (UE) using MRC Precoding techniques in massive MIMO.

Compared to the result in, Figures **4**.4, **4**.5, and **4**.6, M-MMSE becomes a potential solution for higher energy efficiency and low power consumption (PC) when more energy-efficient hardware is used in massive MIMO for 5G wireless communication networks.

4.3.5 Maximization of energy efficiency than energy consumption in massive MIMO

The simulation analysis result showed that the reduction of energy consumption is the way to maximize energy efficiency and the circuit power consumption (Pc) dominates, the transmit power because adding more antennas in the base station (BS) in each cell to spatially multiplex active users equipment (UEs). The corresponding energy efficiency gains come from overturning many antennas' intra-cell interference and sharing the costs of CP per cell among multiple active users (MUEs). In summary, the maximum energy efficiency than power consumption in massive MIMO that can be achieved using M-MMSE Precoding techniques depends on various factors such as the channel condition, the power constraints, and the modulation scheme used. Analyzing the achievable rate region and optimizing the energy per bit metric are two ways to assess the energy efficiency of Precoding techniques in wireless communication systems.

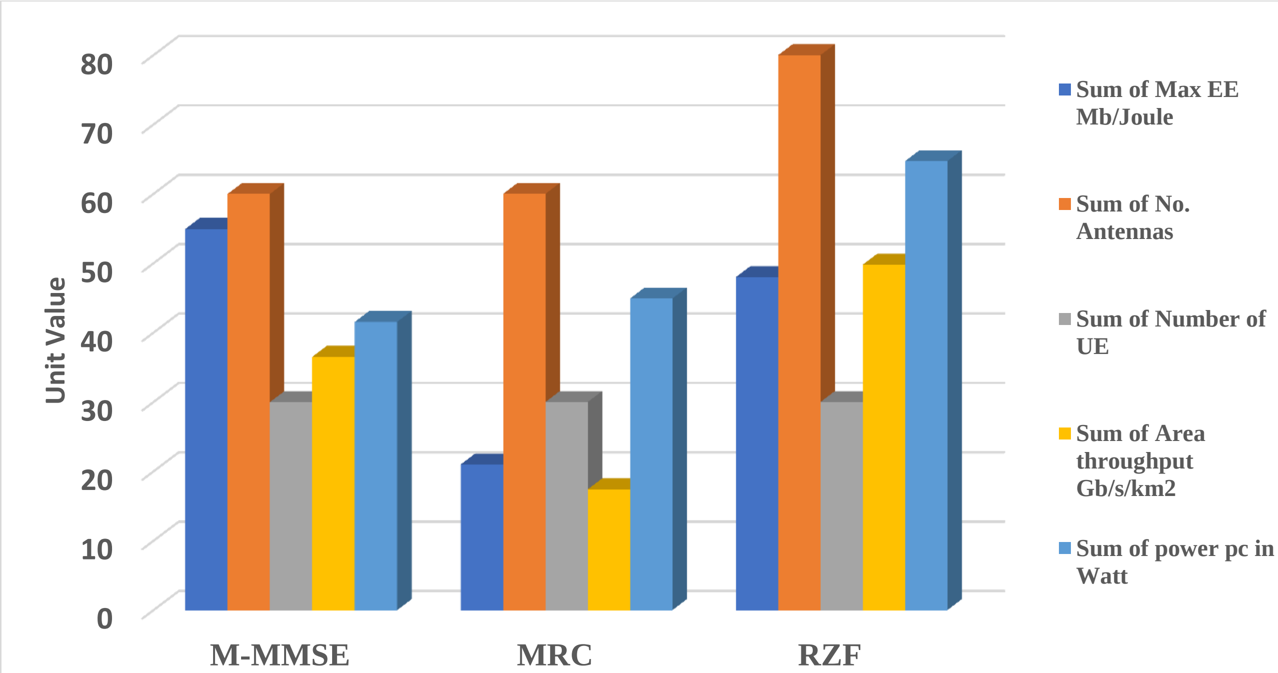

Figure 4.7 Simulation result EE *vs* power consumptions in massive MIMO for 5G wireless communication networks.

Table **4**.2 Simulation result energy efficiency vs energy consumptions from **f**igure 4.7 above:

Schema Technique	**M**aximum EE	**V**alues [K, M]	**A**rea throughput	**P**ower consumption [Pc]	**T**hroughput
M-MMSE	54.95Mb/J	[30,60]	36.53076 Gb/s/km^2	41.55w	2283.173[Mb/s/cell]
RZF	48.10 Mb/J	[30,80]	49.80851 Gb/s/km^2	64.72w	3113.032 [Mb/s/cell]
MRC	24.25 Mb/J	[30,60]	17.42896 Gb/s/km^2	44.92w	1089.31[Mb/s/cell]

The energy efficiency maximized at power consumption per active number of user equipment's (UE) = 0.01w of a wireless communication network defined as the number of bits that can be transmitted reliably per unit of EE (Mb/J), is a good performance metric that balances traffic load and power consumptions while increasing the number of antennas (M). In the simulation result, multi-cell minimum mean square error (M-MMSE) only offers the highest EE for any throughput value when the power consumption (Pc) lower values are used. The lower EE is reached by the MRC; RZF represents a good tradeoff between EE and throughput in massive MIMO for 5G communication networks.

The way to analyze the maximum energy efficiency that can be achieved using Precoding techniques is to consider the achievable rate region of the system. The achievable rate region is the set of all possible combinations of transmission rates that can be achieved by the system subjected to a given power constraint. In other words, it is the region in which the system can transmit data reliably while respecting a certain power budget. Using multi-cell minimum mean square error Precoding techniques can increase the achievable rate region by improving the systems channel capacity. This is because Precoding can exploit the spatial diversity of the wireless channel, which allows for higher data rates compared to traditional modulation schemes. By optimizing the Precoding schemes to minimize the energy per bit, it is possible to maximize the energy efficiency of the system in massive MIMO for 5G wireless communications. In summary, the maximum energy efficiency that can be achieved using multi-cell minimum mean square error Precoding techniques depends on various factors such as the channel condition, the power constraint, and the modulation schemes used.

Chapter 5

Conclusion and Recommendations

5.1 Conclusions

In this thesis, the performance energy efficiency of a cellular network can be defined as the number of bits that can be reliably transmitted per unit of energy measured in bits per joule, which is a good performance metric to balance the data rate (throughput) and energy consumption. In any case, pilot contamination gives rise to coherent impedance that develops with M, unless this impedance is restricted by utilizing M-MMSE pre-coding techniques. The consistency of interference is in addition to the predictable non-coherent interference that is unaffected by a number of antennas (M). The ratio performance of energy efficiency to the number of antennas with the number of users (M/K) in massive-MIMO is initially linearly increased but does not continue due to some neighbouring interference effect. Massive MIMO analysis allows for jointly increasing energy efficiency and throughput as compared to present wireless communication MIMO networks (3G/4G). Multi-cell minimum mean square error (M-MMSE) offers the highest energy efficiency (EE) for any output value only when more energy-efficient hardware is used. Maximum ratio combination (MRC) accomplishes the lowest energy efficiency result as the number of antennas increases in massive MIMO. In massive MIMO, as the number of antennas increases twice the number of active users (M = 2K), it results in maximum energy efficiency using Precoding techniques such as multi-cell minimum mean square error (M-MMSE) and maximum ratio combination (MRC) in massive MIMO wireless communication networks.

The transmitted power consumption in massive MIMO could be decreasing as the number of antennas increases (M). M-MMSE is a less power-consuming scheme in massive MIMO concerning MRC and RZF techniques. In this thesis, the maximum energy efficiency optimum value simulation result is 54.95Mb/Joule at a value of M = 60, K=30, and the power consumption per user (PUE = 0.01W). Multi-cell minimum mean square error is the best technique for maximizing energy efficiency, but MRC simulation results have the lowest energy efficiency in massive MIMO for 5G wireless communication networks. Finally, as compared with the Precoding techniques and the energy consumption, M-MMSE simulated higher energy efficiency (EE) than the energy consumption (PC) in massive MIMO wireless communication networks.

5.2 Recommendations for future work

In this thesis, results show that energy efficiency is maximized through pre-coding techniques such as M-MMSE by reducing the power consumption per UE, in massive MIMO wireless communication for 5G networks. Finally, the performance analysis of energy efficiency ensuring techniques in massive MIMO for 5G networks must take into account the dynamic nature of the system. The channel conditions and user traffic patterns can change rapidly, which can affect the performance of the system. Therefore, the analysis must be done in a way that captures the dynamic behavior of the system, such as using adaptive algorithms and real-time measurements. Then, optimize the system design parameters, such as the number of antennas and users, to achieve the desired energy efficiency while maintaining the required performance metrics.

In future work, it is recommended to do the following studies on energy efficiency and power consumption in massive MIMO cases:

- Design and implementation of effective energy efficiency-ensuring techniques in massive MIMO for the next generation.
- Deployment of massive MIMO via the best power-saving techniques at a low cost
- Design and implement massive MIMO networks for energy efficiency via more traffic load directional antennas and coverage areas using automatic switching techniques.

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