Spectral Efficiency Analysis for Uplink Multi Cell Massive MIMO Cellular Communication System under Rician Fading Channels

Yibeltal Abebaw Molla

A Thesis Submitted to

The Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electronics and Communication Engineering (Communication Engineering).

Office of Graduate Studies

Adama Science and Technology University

June 2023

Adama, Ethiopia

Spectral Efficiency Analysis for Uplink Multi Cell Massive MIMO Cellular Communication System under Fading Channels

Yibeltal Abebaw Molla
Advisor: Dr. Rajeev K. Shakya
Co-Advisor: Mr. Eshetu Tessema

A Thesis Submitted to
The Department of Electronics and Communication Engineering
School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Degree of
Master's in Electronics and Communication Engineering
(Communication Engineering)

Office of Graduate Studies

Adama Science and Technology University

June 2023
Adama Ethiopia

APPROVAL PAGE OF MSC. THESIS

We, the advisors of the thesis entitled "Spectral Efficiency Analysis for Uplink Multi Cell Massive MIMO Cellular Communication System under Fading Channels" and developed by Yibeltal Abebaw; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

____________________	____________________	____________________
Major advisor	Signature	Date
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Yibeltal Abebaw have read and evaluated the thesis entitled "Spectral Efficiency Analysis for Uplink Multi Cell Massive MIMO Cellular Communication System under Fading Channels" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electronics and Communication Engineering (Communication Engineering).

____________________	____________________	____________________
Chair Person	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

____________________	____________________	____________________
Head of Dean	Signature	Date
School Dean	Signature	Date
Post Graduate Dean	Signature	Date

DECLARATION

I hereby declare that this Master Thesis entitled “Spectral Efficiency Analysis for Uplink Multi Cell Massive MIMO Cellular Communication System under Fading Channels” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certification in any other university. All sources of material used for this thesis have been duly acknowledged through citation.

Name of Student	Signature	Date

RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "Spectral Efficiency Analysis for Uplink Multi Cell Massive MIMO Cellular Communication System under Fading Channels" prepared under our guidance by Yibeltal Abebaw submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electronics and Communication Engineering (Communication Engineering). Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

________________	________________	________________
Major advisor	Signature	Date
________________	________________	________________
Co-advisor	Signature	Date

ACKNOWLEDGEMENT

Firstly, I would like to express my deepest gratitude to my supervisor, Dr. Rajeev and to my Co-Advisor Mr. Eshetu for their guidance, support, and encouragement throughout my research. Their expertise and insights have been invaluable in shaping my research and helping me to overcome the challenges I encountered.

I would like to thank my family and friends for their unwavering support and motivation. Their encouragement and belief in me have been my pillars of strength, and I could not have completed this thesis without them.

I would like to thank the staff and faculty at Adama Science and Technology University especially for ECE department for providing me with access to the resources and facilities necessary for my research. Their support has been crucial in enabling me to complete this thesis.

Finally, I would like to acknowledge the support of the broader academic community, whose work and research have inspired and informed my own.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

3GPP	Third Generation Partnership Project
FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
Gbps	Giga bit per second
HBF	Hybrid Beam Forming
IETF	Internet Engineering Task Force
IMTA	International Mobile Telecommunication Advanced
IOT	Internet of Things
ITU	International Telecommunication Union
Kbps	Kilo bit per second
LAN	Local Area Network
LOS	Line of Sight
LS	Least Square
LTE	Long Term Evolution
M2M	Machine to Machine
MAT AB	Matrix Laboratory
Mbps	Mega bit per second
MIMO	Multiple input multiple outputs
M-MMSE	Multi cell-Minimum Mean Square Error
NFV	Network Functions Virtualization
NLOS	Non Line of Sight
Pc	Pilot Contamination
Prf	Pilot reuse factor
PSTN	Public Switched Telephone Network
P-ZF	Pilot-Zero Forcing
QOS	Quality of Service
SDN	Software Defining Network
SINR	Signal Interference plus Noise Ratio
UE	User Equipment
ZF	Zero Forcing

ABSTRACT

Massive MIMO is a technology that expands on traditional MIMO by utilizing massive number of antennas attached to a BS to serve higher number of UEs simultaneously with the same time and frequency resources. However, this technology faces several challenges such as acquiring channel state information, PC, Latency, and complexity. With the high traffic demands of cellular BS and wireless LANs, higher area throughput is required. However, the available resources such as bandwidth and cell density are reaching their limits, making the system more expensive and decreasing the signal-to-noise ratio. To address this issue, we proposed a technique to improve the spectral efficiency of multi-cell massive MIMO networks under fading channels. This technique utilizes prf *to reduce the challenges of channel estimation while considering a ZF uplink combiner technique to mitigate inter-cell interference. The proposed model, which considers a multi-cell scenario, has been shown to improve the spectral efficiency of massive MIMO systems. By using efficient* prf*, multiple BS antennas, serving a large number of UEs per cell, and optimizing MMSE channel estimation using a ZF UL combiner, the average sum SE per cell can be increased significantly. Simulation results show that the proposed technique can significantly improve the spectral efficiency of multi-cell massive MIMO networks, especially in the presence of inter-cell interference. The simulation results demonstrates that* prf *of* $f = 3$ *has a better performance than other* prf $f \in \{1, 4\}$ *with a considerable number of UEs, SNR values, code block length and BS antenna numbers with proposed ZF-MMSE.*

Keywords: *massive MIMO, Rician fading channels, UL spectral efficiency,*Prf*, MMSE, EW-MMSE, LS, ZF, multi cell, fading channels, channel estimation.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Massive MIMO technology, which uses a large number of antennas at the base station to simultaneously serve multiple users, has been shown to significantly improve SE. The base station processes the signal using its antennas on both the uplink and downlink transmission sides greatly enhancing spectral efficiency (SE) (Abdelfatah et al., 2022).

On the other hand, massive MIMO is a more recent advancement that was implemented in 5G New Radio (NR) networks. The two main characteristics of MIMO technology that distinguish Massive MIMO from conventional MIMO are the quantity of antenna elements and the multi-user capabilities inside the antenna array.

To ensure future high traffic demand, we need to design and deploy a 5G network, which must enhance the performance of the network in terms of capacity, SE, EE, latency, network security, and overall robustness (Zerihun & Wondie, 2017). In order to fully realize the benefits of a Massive MIMO system, it is essential to have a precise alignment between the receiver and the real-world channel (Xin et al., 2020). The use of Time Division Duplexing (TDD) mode is a highly advantageous option for implementing a massive MIMO system. This is because it can effectively decrease the burden of acquiring Channel State Information (CSI) by exploiting channel reciprocity, which ensures that the channel response remains the same in both the uplink and downlink transmissions (Li et al., 2018; Xin et al., 2020). Multiple inputs multiple output (MIMO) technology refers to the use of several transmitting and receiving antennas on both the transmitter and receiver ends. This technology can exploit the available spatial resources to enhance channel capacity and communication quality, without the need for additional spectrum resources or increased transmission power from the antennas(Kang & Lu, 2019). The demand for advanced communication technology is driven by the increasing need for greater throughput in cellular wireless networks, as well as the emergence of new services such as IoT and M2M communications. Among the various techniques available to achieve high data rates in mobile networks, the MIMO technique stands out as a promising candidate, and is recognized as a crucial enabler of modern cellular technology (HOSANY, 2020).

If we can boost the SE per cell while keeping the bandwidth and cell density constant, we can enhance the area throughput of cellular networks (Krishna et al., 2016). The amount of data that can be transferred through the link between the UE and the BS is known as the SE, which is expressed in [bit/s/Hz]. In paper(Ali et al., 2018) developed a zero-forcing beam forming technique to improve the system's spectral efficiency. By reducing the interference that prevents massive MIMO systems from operating at their maximum spectral efficiency, the approach can raise that efficiency. When multiple antennas are used in huge MIMO systems, interference is the main issue. With a large number of connections, the 5G networks should be able to meet the needs of a variety of industries including transportation, healthcare, agriculture, finance, architecture, and electric power (Yifei & Longming, 2014).

To achieve the goals set for 5G network beam forming technologies and small cell base stations are the blueprint technologies.

1.2. Enabling Technologies to achieve the objective of 5G Mobile networks

Some of the technologies that facilitate the implementation of 5G cellular networks are illustrated in Figure 1.1 (Hossain & Hasan, 2015; Kaur & Garg, 2021; Yifei & Longming, 2014).

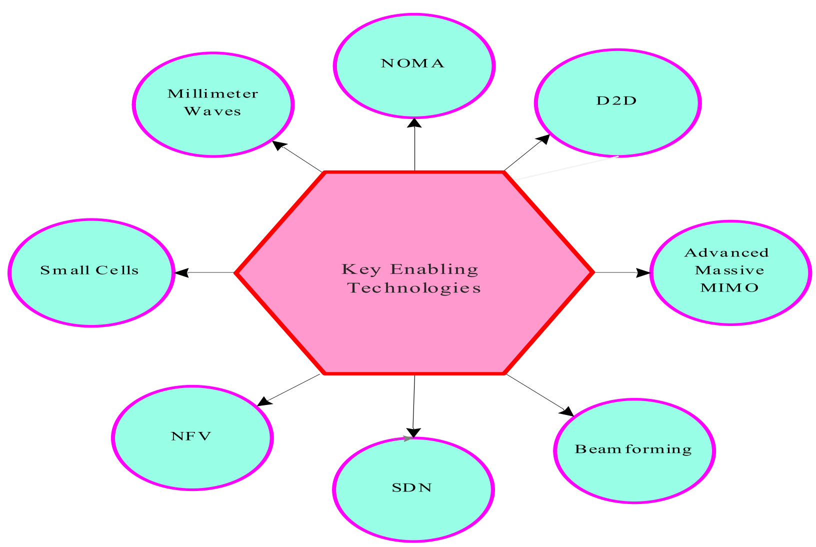

Figure 1. 1: Key-Enabling Technology for 5G Network

- **Advanced Massive MIMO:** advanced massive MIMO can improve the spectrum efficiency, by installing hundreds or thousands of antennas. The data rate also improved. Any wireless system's network capacity can be enhanced by adding more transmitting and receiving antennas to the system. To handle an incredible amount of data flow, we need to use several sending and receiving antennas simultaneously. The BS has 12 ports available to manage cellular traffic in 4G.

- **Beam forming:** In a conventional cellular system, the base station has the ability to deliver the signal in all directions. In huge MIMO systems, the user equipment (UE) are detected using a beam forming technique and signals are only sent in that particular direction. Its BS becomes effective in identifying the best path for delivering data to a certain user. It can reduce distortion and interference. Additionally, it could also make the signal being transmitted are more reliable. By effectively utilizing the spectrum, the beam forming approach contributes to the effective deployment of the 5G networks.
- **Millimeter Wave:** The major solutions for increasing the network's capacity to meet the demand of congested traffic are bandwidth utilization and spectral efficiency. The range of frequencies used by the current wireless communication technology was 300MHz to 3GHz. To satisfy the needs of the future network generation, this band needs to be improved.

  A millimeter wave is an electromagnetic wave with a frequency range of 3-300GHz. They have a 1 to 10 mm wavelength range. Compared to the current spectrum, the new spectrum can support thousands of times more data and increase capacity (Hossain & Hasan, 2015).
- **Small Cells:** Small cells are base stations that are 250 meters or more apart from one another and require less power to operate. The network operators in a small cell use both inside and outdoor operations to increase network capacity and coverage. The small cells serve as a relay for millimeter waves when they are unable to travel across long distances. It can facilitate quick changeover and minimize call drop issues. The device will transmit at a low power level if small cell base stations are nearby.
- **NOMA:** It stands for non-orthogonal multiple access. A technique serves numerous customers simultaneously while using various power resources but with the same time and frequency resources. NOMA helps in enhancing connection density and spectrum efficiency (Kaur & Garg, 2021). In addition to allowing for

flexibility between weak and strong users, it also minimizes interference from multiple access points.

- **Software Defining Network (SDN):** With the use of programming and software application support, Software Defined Network (SDN) can enable network operators to manage and control networks. SDN gives network systems flexible, dynamic, and programmable capabilities in addition to many other benefits including centralized control, reduced complexity, improved user experience, and a sharp drop in the price of network systems and equipment (Gelberger et al., 2013).
- **Network Functions Virtualization (NFV):** The structural component of a network system with multiple proprietary hardware components. These hardware components offer diverse capabilities and external interfaces. There is a cost associated with changing the entire interface each time a new network function needs to be introduced to the service.
- **D2D communications:** It is the exchange of information between two adjacent mobile users who are not connected to a base station or the cellular network's central gateway. Direct communication between devices reduces the base station's load. The maximum transmission distance of a D2D system is between 10 and 1000 meters.

1.3. Statement of the Problem

The spectral efficiency of multi-cell massive MIMO networks is limited by several factors, including inter-cell interference, channel estimation overhead, and fading channels. The high number of antennas at each base station makes it challenging to estimate the channel accurately for each user, and the presence of inter-cell interference further degrades the performance of the system. Therefore, it is crucial to develop techniques that can mitigate the impact of these factors and improve the spectral efficiency of multi-cell massive MIMO networks. The study aims to propose a technique to reduce the overhead of channel estimation and mitigate inter-cell interference to improve the spectral efficiency of multi-cell massive MIMO networks under Rician fading channels. The study also evaluates the effectiveness of the proposed technique through simulations in a multi-cell environment. The spectral efficiency and system stability can increase by eliminating pilot contamination. Pilot contamination is caused by the lack of orthogonal pilots and inter-cell interference. We employ prf, uplink combining, and channel estimator techniques to mitigate the pilot contamination. The global bandwidth shortage and cost of densifying the cells in cellular communication motivate us to study the UL SE of a multi cell massive MIMO system. Moreover, the results of this study can provide insights into the design of future wireless communication systems that can achieve high spectral efficiency in multi-cell massive MIMO networks.

1.4. Objective

1.4.1. Main Objective

The main aim of this thesis is to improve the UL SE of multi-cell massive MIMO networks under Rician fading channels. This objective is achieved by proposing a technique to reduce the overhead of channel estimation and mitigate inter-cell interference.

1.4.2. Specific objective

The general objective of this thesis can be accompanied by the following specific objectives:

- To analyze the UL SE of different pilot reuse factor (prf)using MMSE channel estimator combined with ZF uplink combiner.
- Evaluate and analyze the effect of increasing SNR values on the UL SE of different pilot reuse factor (prf) using proposed MMSE-ZF.
- Analyze the effect of increasing number of users, number of BS antenna and coherence block length on the uplink spectral efficiency of multi cell massive MIMO systems.
- To evaluate the performance of different pilot reuse factor (prf)in reducing the overhead of channel estimation and improving the spectral efficiency of multi-cell massive MIMO networks.

1.5. Significance

A significant challenge in a massive multi cell and multiuser MIMO system is to improve the spectral efficiency of both uplink and downlink in a specific cellular communication environment. Enhancing the uplink spectrum of massive MIMO communication used to answer the demand of mobile users in the world. Nowadays mobile users in the world become very high, which leads to the deficiency of spectrum in mobile communication. This thesis focuses on improving the spectral efficiency of a massive MIMO system in the uplink direction using various techniques. Pilot contamination is identified as a factor that reduces spectral efficiency, and reducing inter-cell interference is necessary to improve SE. Although increasing bandwidth and cell density can improve wireless area throughput, these resources are approaching their limits. Therefore, improving spectral efficiency is the optimal approach to increasing the throughput of cellular communication.

The analysis can provide insights into the design of future wireless communication systems that can achieve high spectral efficiency in multi-cell massive MIMO networks. This can help in the development of more efficient and robust wireless communication systems that can meet the growing demand for wireless connectivity. In addition, the analysis can help in achieving higher spectral efficiency by enabling efficient utilization of the available frequency spectrum. This, in turn, can lead to increased capacity in the network and better utilization of the limited resources.

1.6. Scope

The primary aim of this thesis is to enhance the uplink spectral efficiency in multi cell massive MIMO cellular networks. However, in a massive MIMO system, where there are many antennas on the base station and a large number of user equipment, two main challenges arise: pilot contamination and channel hardening. These problems affect spectral efficiency and area throughput of the cellular systems. However, future cellular communication system, need to be more effective and efficient to transmit high data rate along a given channel. To improve SE, upcoming cellular communication systems will require base stations that are equipped with multiple antennas. This will help to decrease error and enhance data rates when sending messages between cells. Investigating the impact of inter-cell interference on the SE of massive multi-cell MIMO networks is an important factor. The analysis performed through simulations in a multi-cell environment using realistic channel models and system parameters. The simulations will consider various scenarios, including different numbers of cells, users per cell, antennas per cell, and SNR levels. These are the scope of this study.

1.7. Main Contribution

This thesis primarily focuses on evaluating and improving the uplink spectral efficiency of a MIMO system that works across multiple cells. Specifically, we investigate how pilot contamination and CSI affect the UL SE. The main performance factors of massive MIMO cellular networks, including intercellular interference (pilot contamination), are also analyzed in this thesis. PC is the most significant problem faced by multi cell massive MIMO networks. This thesis aims to address this problem by reducing PC and improving the performance of multi cell massive MIMO cellular networks. We consider different prf to minimize pilot contamination (inter-cell interference) and enhance the SE. This thesis involves a comparison of the uplink spectral efficiency of various prf. Additionally, we examine how wireless communication channels behave in the absence of perfect Channel State Information (CSI). In this study, we investigate the effectiveness of three channel estimators, Namely MMSE, EW-MMSE, and LS, to generate the required CSI between user equipment and base station antennas. We analyze how the choice of channel estimator and prf affects SE across different numbers of base station antennas, SNR values, code block lengths, and user equipment. In this thesis, we use receiving combiner with low complexity, which is ZF combining. To decrease the complexity that happen in the CSI generation we consider a less complex receiver combiner.

1.8. Thesis Organization

This thesis can be organized in the following sections:

Chapter One: This section provides introduction, objective, significance and an overview of the problem addressed in the study.

Chapter Two: This section reviews the existing literature on the topic of SE of multi-cell massive MIMO networks.

Chapter Three: This section describes the proposed techniques to improve the SE of multi cell massive MIMO networks under Rician fading channels.

Chapter Four: This section presents and analyzes the simulation results obtained from applying the proposed technique to a multi cell massive MIMO networks under Rician fading channels.

Chapter Five: This section summarizes the study's findings and draws conclusions about the effectiveness of the proposed technique and provides recommendations for network operators and researchers on implementing and further optimizing the proposed technique to improve the SE.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Fundamentals of Massive MIMO Systems

Multi-cell massive MIMO networks have emerged as a promising technology for meeting the growing demand for high-speed wireless communication. However, the presence of inter-cell interference, fading channels, and channel estimation overhead can significantly affects the spectral efficiency of the system. The use of MIMO is an important technique for enhancing the reliability of transmission between transmitter and receiver. It uses a diversity strategy to increase the channels capacity and reliability between the transmitter and receiver. With the help of this technology, the capacity and speed of the upcoming 5G network could be increased (Chataut & Akl, 2020; Rusek et al., 2012).

Basic characteristics of Massive MIMO cellular networks (Sanguinetti et al., 2019):-

- Multiple cells are functioning with a synchronous TDD protocol, with a value of L^{th} cell greater than or equal to 2.
- Base stations are outfitted with M antennas, where M is greater than or equal to 64.
- Spatial multiplexing with a value of k greater than or equal to 8 is used in linear combining and precoding techniques.
- The ratio of base station antennas to active user equipment is greater than 1, represented as $M/K > 1$.

2.2. How Massive MIMO Works

Massive MIMO is an advanced antenna technology that enhances SE, EE, coverage, and potential data speeds in 5G NR networks. To handle several users simultaneously, it requires the use of large numbers of antenna elements in the transmitter and reception antennas.

To improve network capacity, it employs spatial multiplexing, diversity, and beam forming strategies. Diversity, Spatial multiplexing, and beam forming techniques are used to enhance data throughput and lowering interference. Massive MIMO is made up of three essential operations. Which are transmitting beam forming, receiving combining, and channel estimation. The initial stage involves channel estimation, which enables the base station (BS) to acquire CSI and use it to handle the signal in both UL and DL data transfer. Receive beam forming, which coherently combines the signals received from various UEs to identify the signal from the target UE.

2.2.1. Channel Estimation

A massive MIMO network needs CSI to detect its BS. The signals that the user transmits are identified by this CSI. Through uplink training with pilot sequences, this CSI was obtained. Each user in the cell transmits their uplink training sequences to the BS according to the TDD protocol. The BS is aware of pilot sequence transmissions by each users. The BS then uses these uplink-training sequences to estimate the uplink channels. In Section 3.1, the estimating schemes will be covered in further detail.

2.2.2. UL Data Transmission

In TDD mode, a section of the coherence interval is allocated for transmitting uplink data. During this period, all cellular users utilize the same time-frequency resources to send their data to the base station. Figure 2.1 demonstrates that the base station employs linear combining techniques with the channel estimator to detect signals sent by all users.

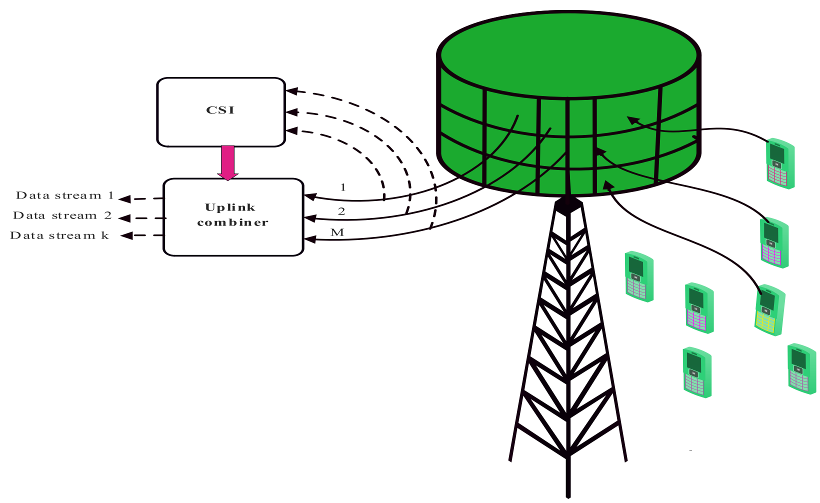

Figure2. 1: UL data transmission process for 5G massive MIMO with M-antennas and k-UEs

2.2.3. DL Data Transmission

During downlink data transmission, the BS transmits signals to all k users simultaneously over a shared time-frequency resource. As illustrated in Figure 2.2, the BS combines the symbols intended for each of the k users with estimated channel.

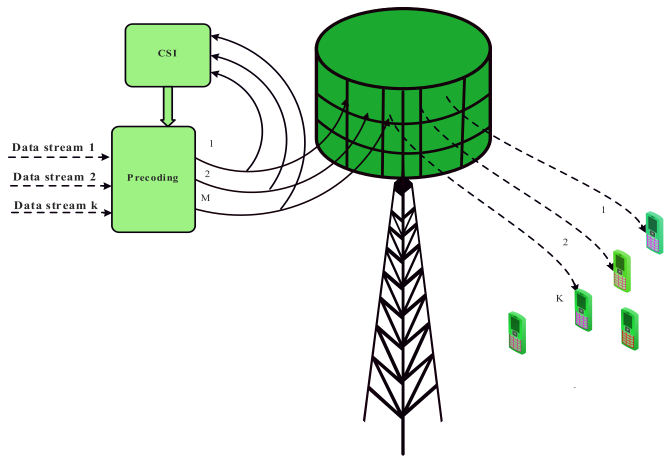

Figure2. 2: DL data transmission process for 5G Massive MIMO with M-antennas and k-UEs

2.3. Why Massive MIMO

Wireless data rate and communication reliability will constantly be in higher demand. Future wireless communication will require the development of novel technologies capable of providing high throughput services for high data users. To cope with the growing need for greater throughput in wireless cellular networks, it is necessary to create novel technologies. The best option for increasing data rates in mobile networks is massive MIMO technology. It also plays a crucial role in the modern cellular systems (HOSANY, 2020).

2.4. Massive MIMO Advantages

The fundamental advantages of a massive MIMO system can be summarized as: (Abdelfatah et al., 2022; Marzetta & Yang, 2016; Sun et al., 2017).

- **Good Communication Reliability and high Spectral Efficiency**: A large-scale MIMO network can direct its antenna beams towards a particular user. It enables it to attain spectral efficiency, which is 10 times greater than that of 4G (LTE) MIMO systems. By enhancing the systems signal power, wireless communication's spectral efficiency is raised. The system power consumption grows as signal power does as well. Consequently, energy efficiency is decreased (Zerihun & Wondie, 2017). To increase the system's spectrum and energy efficiency, we must deploy massive antenna arrays.
- **Improved Energy Efficiency:** In comparison to 4G (LTE) mobile networks, Massive MIMO systems may be able to run with lower radiated power due to the increase in energy efficiency. This contributes to energy conservation and energy consumption

reduction. More antennas on the BS allow for higher multiplexing gains, which can boost system throughput. Power increase in the circuit for the M BS antenna (Prasad et al., 2017).

- **Obey Large Dimensional Channel Hardening:** The impact of a randomly fluctuating or small-scale fading behaves like deterministic channels when the base stations antenna number is very high. Its channel gain is essentially constant and identical to its average channel gain. Simple linear detection and precoding algorithms can operate at maximum efficiency in many dimensions due to channel hardening.

2.5. Design Challenges of Massive MIMO systems towards 5G

The main objectives of 5G technology are to attain significantly faster data transfer rates, lower latency, improved dependability, enhanced SE, and greater EE. To overcome different challenges, technical requirements must be carried out for 5G networks to reach their goal (Benzaghta & Rabie, 2021). These challenges include channel state acquisition, the complicated nature of deployment scenarios, complexity of inverse operations in linear processing, and multi cell operation. To take advantage of massive MIMO systems, these technological issues must be resolved quickly and effectively. These challenges are outlined as follows:

- **Pilot contamination and multi cell operation:** Due to the constraint on channel coherence intervals, it is not possible to assign unique orthogonal pilot sequences to every user in multi-cell massive MIMO systems (Marzetta & Yang, 2016). Due to its high spectral efficiency and low power requirements, massive MIMO systems have emerged as a possible 5G network solution. (PC) is a performance constraint of massive MIMO systems (Zahoor et al., 2020).
- **Channel Modeling and CSI Acquisition:** For the BS to obtain a substantial spatial multiplexing gain, it is necessary to carry out signal processing on the received signals. Massive MIMO systems face difficulties in accurate channel estimation because of multiple antennas, beam forming, hardware constraints, and high mobility scenarios(Ngo, 2015).
- **Power control:** In massive MIMO systems, each user should receive resources based on their unique instantaneous channel state information (CSI), which differs between users(Ngo, 2015). The difficulties of channel estimation, resource allocation, and

spectrally and energy-efficient power studied in (Hu et al., 2020; Huang & Guo, 2018).

- **Linear Processing Computational Complexity:** With more users and BS antennas, linear processing becomes more computationally complex.

  In light of this it is more practical to utilize linear processing methods that are both efficient and straightforward for massive MIMO systems(Chataut & Akl, 2020). For our proposed system, we consider ZF uplink combiner due to its low computational complexity.

- **Hardware Impairment:** Massive MIMO systems have more antennas, which raises the hardware costs and computational complexity of the system. Using cheap components will contribute to hardware imperfections (Studer et al., 2010). Even if the hardware limitation cannot be eliminated, we can mitigate its impact by using the right compensating methods.

2.6. Related Works

The first paper (W. Ali et al., 2020) assumes a Laplacian centralized scattering model. This paper considers M-MMSE, which is a technique for eliminating pilot contamination. In this paper, to increase area throughput of cellular networks, uses M-MMS combining technique. It can assess the effectiveness of three different channel models, namely the uncorrelated Rayleigh fading channel, the one-ring scattering spatially correlated Rayleigh fading model, and the Laplacian-centralized scattering spatially correlated Rayleigh fading model.

It can also consider prf for the ZF, MRC, and M-MMSE combining methods to compare system performance. The authors conclude that Multi cell Minimum Mean Square error has a better performance than other combining techniques.

The future cellular communication system becomes a millimeter wave system. Because of the short wavelength spectrum range, the 5G cellular communication system becomes more directive. In our thesis, we consider a multi cell massive MIMO system over a Rician fading channel. In the receiver, we examine the Zero Forcing (ZF) processing technique, which is employed to reduce interference and improve the SE of a massive multi-cell MIMO network operating in fading channels.

(M. S. Reddy et al., 2017) It assumes that a 5G cellular network will have a massive multi cell MIMO network. The focus of this study is on a multi-cell MIMO system operating under favorable propagation conditions. The objective of this research is to examine how the SE of a massive MIMO system is influenced by factors such as the number of base station antennas and pilot contamination. For the sake of evaluating the spectral efficiency of the proposed system, this research employs three linear combiners. These are MRC, ZF, and pilot-zero forcing (P-ZFC) combiners. They do not use a specified channel model to analyze spectral efficiency. The impact of the line-of-sight path on SE is not considered. This thesis focuses on analyzing the SE of a multi-cell MIMO system, with particular attention given to the impact of various channel estimators. The study also investigates how the spectral efficiency of an uplink multi-cell massive MIMO cellular network operating in a Rician fading channel is influenced by variables such as the number of users, the number of base station (BS) antennas, and pilot reuse factor (prf).

(He et al., 2021b) It focuses on a multi-way massive MIMO systems spectral efficiency under Rician fading channels. The SE of a single-cell massive MIMO system employing a zero-forcing receiver combining technique is evaluated by the author of this study. This paper does not take into account the effect of pilot contamination on spectral efficiency. Also, the spectral efficiency of a massive multi-cell MIMO network is not assessed in this paper. However, in this thesis, we investigate a massive multi-cell MIMO system, by utilizing estimated channel state information at the receiver, with three different channel estimators being evaluated. We also consider the effect of interference on the spectral efficiency. Additionally, we aim to utilize, ZF linear uplink combiner, prf and channel estimators to enhance the spectral efficiency.

(Liu et al., 2018) This paper is focused on examining the spectral efficiency of a multi-cell massive MIMO system operating in Rician fading channels. Specifically, it explores the SE of a multi-cell massive MIMO system, which employs a linear maximal-ratio combining detector in the presence of Rician fading. In this paper, the author investigates how the spectral efficiency of a multi-cell massive MIMO network is impacted by the Rician factor and the number of base station (BS) antennas. The MMSE estimator is implemented to mitigate the effects of pilot contamination, but the authors did not take into account how the computational complexity of the channel estimator affects the SE. In addition, the effect of UEs is not considered. In this thesis, we proposed a channel estimator and prf to eliminate the pilot contamination issue.

(HOSANY, 2020) The main focus of this study is to evaluate the spectral efficiency of multi-cell massive MIMO systems in the context of 5G cellular networks. In this article, author considers a realistic 3GPP geographical model including both LOS and NLOS propagation. Furthermore, perfect channel state information (CSI) is employed in the investigation of the uplink spectral efficiency of a multi-cell massive MIMO system. It utilizes zero-forcing combiner (ZFC) and MRC. In this paper, the effect of pilot contamination also analyzed. The system uses perfect channel state information. In our thesis, we assess three pilot based channel estimators to generate the CSI. In our system, we assume the impact of pilot contamination. To mitigate the effect of pilot contamination, we use Zero Forcing with prf. Table 2.1 shows the summary of different literature review on SE for uplink transmission model.

Table2.1: Summary of Literature Review

No	Author	Title	Contribution	Weakens
1	(W. A. Ali et al., 2020)	SE enhancement in Massive MIMO system under pilot contamination	• The proposed system is LCSSC Rayleigh fading channels. • MMSE combining is employed to alleviate the effects of inter-cell interference.	• The effect of LOS component does not consider on the spectral efficiency of massive MIMO networks.
2	(M. Reddy et al., 2017)	Performance Analysis of Maximal Spectral Efficiency for Multi cell Massive MIMO Systems	• It considers multi cell massive MIMO system. • This study examines the impact of pilot contamination, the number of UEs, and the number of BS antennas on SE. • It uses MRC, ZF and P-ZF combining.	• It did not specify any channel model. • It did not consider the effect of LOS communication on SE.

3	(He et al., 2021c)	Spectral Efficiency of the Multiway Massive System over Rician Fading Channels	• To drive the closed form expression of SE, it considers ZF processing. • This research analyzes the impact of the K-Rician factor and the number of BS antennas on SE.	• considers only the effect of UE and BS antennas
4	(Liu et al., 2018)	Spectral efficiency analysis of multi cell massive MIMO systems with Ricean fading channels	• It can analyze the spectral efficiency using MMSE channel estimator to generate channel state information. • Consider the effect of K-rician factor and number of BS antennas. • Uses MRC detector to separate desired signal and interference signal.	• It doesn't consider additional way to eliminate the pilot contamination effect.
5	(HOSANY, 2020)	Spectral Efficiency analysis of massive MIMO systems for 5G cellular networks under perfect CSI.	• Spectral efficiency analysis using MRC and ZF combiners with 3GPP model. • Work on the comparative analysis of power control MRC and ZF (3GPP) with Rayleigh and Rician MRC and ZF	• It considers universal prf to remove pilot contamination effect. • Considers the effect of UEs and BS antennas.

CHAPTER THREE

3. METHODOLOGY

This section presents the system model that governs the design of a massive multi-cell MIMO system based on TDD. Additionally, this thesis proposes a system model for a massive multi-cell MIMO system. We observe how the system is expressed mathematically. Figure 3.1 shows a realistic system model operating under Rician fading channels. Massive multi cell MIMO is assumed in this TDD mode of operation. During uplink data transmission and uplink pilot training, all user equipment (UE) concurrently employs the available frequency-time resources. This means that the same time-frequency resources are utilized for these purposes. Although the channels remain constant throughout a coherence block, the channel realizations are not correlated between any two blocks. The total bandwidth for the system is B_w. It is distributed equally among all coherence blocks so that $\frac{B_w}{B_c}$, it is an integer.

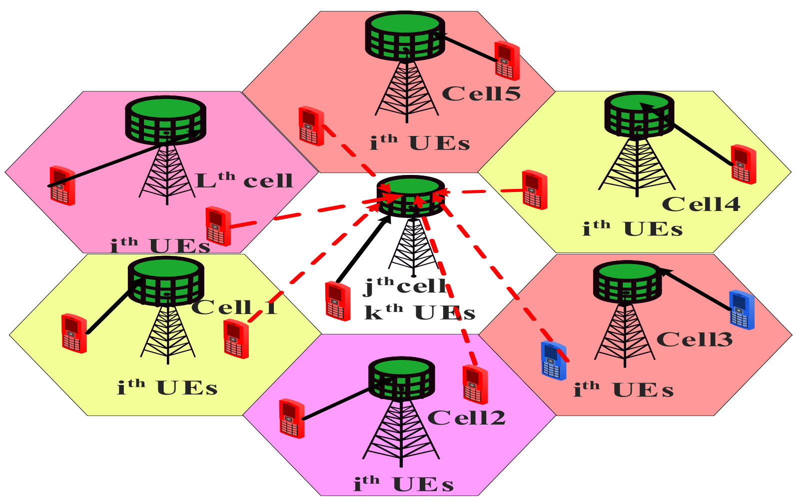

Figure 3. 1: System Model for multi cell massive MIMO

UL Training (desired signals + intera cell interference)

Pilot contamination (inter-cell interference).

The channel response h_{li}^{j} from users i in cell l to the BS in j^{th} cell is modeled as Rician fading channels as follow.

$$h_{li}^{j} = g_{li}^{j}\sqrt{\beta_{li}^{j}} \tag{3. 1}$$

Where β_{li}^{j} is the large-scale fading coefficient, g_{li}^{j} is the small-scale fading.

Since the large-scale fading coefficients change gradually within the coherence interval of $\tau_c = B_c T_c$ (Özdogan et al., 2019). In this thesis, we considered a multi-cell scenario where the pairs of BSs and UEs have correlated Riccian fading channels. The system under consideration is a massive MIMO system consisting of L cells. Each cell is equipped with a single BS that has M antennas and serves k user equipment (UE) units. The main protocol for the desired system is TDD mode. This system maintains a steady channel response over a coherence block of τ_c samples. We further suppose that there is no correlation between any two pairs of coherence blocks in the channel realizations.

The magnitude of the coherence block length is influenced by the carrier frequency, as well as external factors like the propagation environment and UE mobility (Khwandah et al., 2021).

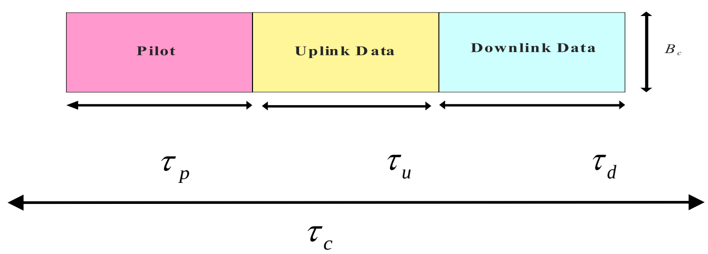

Figure 3. 2: TDD protocol

τ_c Provides three distinct assignments for cellular massive MIMO system in TDD protocol.

$$\tau_c = B_c T_c = \tau_p + \tau_u + \tau_d \quad (3.\ 2)$$

Where τ_c the coherence block sample size, τ_p Coherence block sample for UL pilot signal, τ_u Coherence block sample for UL data transmission and τ_d Coherence block sample for DL data transmission. In this thesis, the channels between user equipment (UE) k in cell L and the base station (BS) in cell j is denoted by $h_{lk}^{j} \in C^{M_j \times 1}$.

$$h_{lk}^{j} \approx NC\left(\bar{h}_{lk}^{j}, R_{lk}^{j}\right) \quad (3.\ 3)$$

Where $\bar{h}_{lk}^{j} \in C^{M_j \times 1}$ represents mean value, $R_{lk}^{j} \in C^{M_j \times M_j}$ is a positive semi definite covariance matrix. β_{lk}^{j} Is the large-scale fading coefficient and it is expressed as follows in dB.

$$\beta_{lk}^{j}(dB) = \Upsilon - 10\log_{10}\left(d_{lk}^{j} / 1km\right) + F_{lk}^{j} \quad (3.\ 4)$$

Where d_{lk}^{j} the separation between BS and UEs, α is the path loss exponent, Υ identifies channel gain, $F_{lk}^{j} \approx N(0,\sigma_{sf}^{2})$ A lognormal random variation, which is produced by shadow fading and occurs around the nominal value of $\Upsilon - 10\log_{10}\left(d_{lk}^{j} / 1km\right)$.

According to the 3GPP model, the presence of a LOS path depends on the separation between the transmitter and receiver. The probability of LOS for the channel between UE (l,i) and base station j will be.

$$pr(los) = \begin{cases} \frac{300 - d_{li}^{j}}{300}, 0 < d_{li}^{j} < 300m \\ 0, d_{li}^{j} > 300m \end{cases} \tag{3. 5}$$

If the LOS path component is present, the following calculation gives the proper large-scale fading coefficient (in dB):-

$$\beta_{li}^{j} = -30.1 - 26\log_{10}(d_{li}^{j}) + F_{li}^{j} \tag{3. 6}$$

According to 3GPP, model the value of F_{li}^{j} when the LOS component is exist the value of $\sigma_{sf} = 4$. The Rician factor is determined by

$$k_{li}^{j}(dB) = 13 - 0.03 d_{li}^{j} \tag{3. 7}$$

The Rician factor is employed to calculate the large-scale fading parameters.

$$\beta_{li}^{jLOS} = \sqrt{\frac{k_{li}^{j}}{k_{li}^{j}+1}}\beta_{li}^{j}, \beta_{li}^{jNLOS} = \sqrt{\frac{1}{k_{li}^{j}+1}}\beta_{li}^{j} \tag{3. 8}$$

In the absence of the LOS path, the large-scale fading parameter is modeled (in dB) as follows.

$$\beta_{li}^{j} = -34.53 - 38\log_{10}(d_{li}^{j}) + F_{li}^{j} \tag{3. 9}$$

Where $F_{li}^{j} \approx N(0,\sigma_{sf}^{2})$ is the shadow fading with $\sigma_{sf} = 10$, channel gain will be.

$$\beta_{li}^{jLOS} = 0, \ \beta_{li}^{jNLOS} = \beta_{li}^{j} \tag{3. 10}$$

$$h_{jk}^{j}(LOS) = \bar{h}_{jk}^{j} = \sqrt{\beta_{jk}^{j}} * (e^{-r(m-1)\frac{2\pi d}{\lambda}\sin(\theta_{jk})}) \tag{3. 11}$$

Where λ the wavelength of desired signal, d the antenna spacing, and $\theta_{jk} \in [0,2\pi]$ is the angle of arrival of user in cell j and r denotes imaginary unit.

MIMO systems using antenna diversity techniques are slower than spatially multiplexed MIMO systems in terms of data transmission rates (Cho et al., 2010). It increases the SE of

MIMO systems and allows for the transmission of numerous streams from various antennas. To support the spatial multiplexing of UEs in Massive MIMO, which requires accurate CSI, and all BS antennas must always handle the signals coherently (Verenzuela et al., 2019).

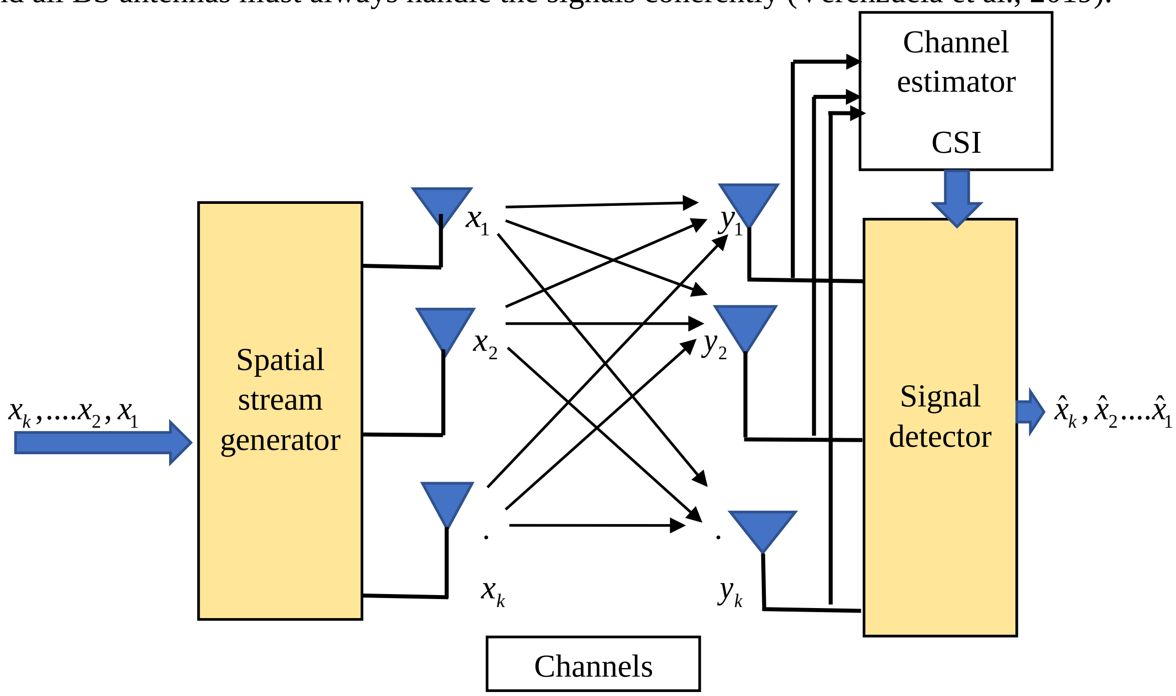

Figure 3. 3: Spatially multiplexing MIMO system

There is no interference from other cells while using single-cell massive MIMO. Intra-cell interference and noise are the only factors that reduce the system's performance. In a wireless cellular communication system, Figure 3.3 shows the spatial multiplexing of multiple inputs and multiple outputs.

Figure 3.4 shows the received signal in a single cell scenario. It can be modeled as follow.

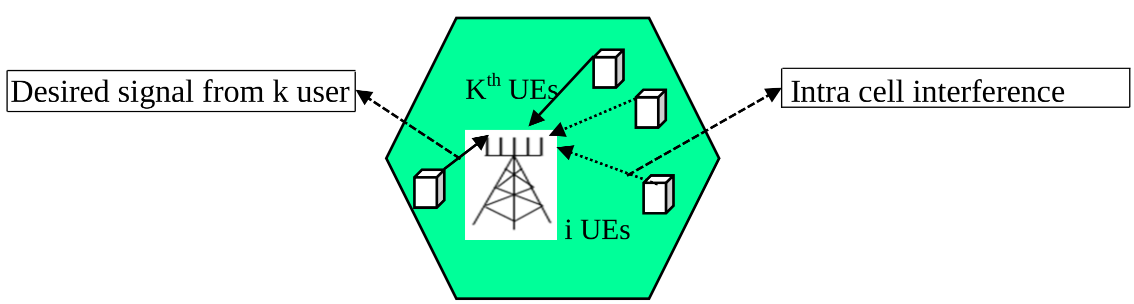

Figure 3. 4: Single cell Massive MIMO system model

$$y_M = \sum_{k=1}^{k_M} \sqrt{p_u} x_k h_{mk} + \sum_{\substack{i=1 \\ i \neq k}}^{k_m} \sqrt{p_u} x_i h_{mi} + n \quad (3.12)$$

Where y_M received uplink signal, $\sum_{k=1}^{k_M} \sqrt{p_u} x_k h_{mk}$ Desired signal transmitted from user equipment k , $\sum_{\substack{i=1 \\ i \neq k}}^{k_m} \sqrt{p_u} x_i h_{mi}$ Intra-cell interference from user equipment i ,and n Additive White Gaussian noise.

3.1. Uplink Pilot Signaling and Channel Estimation

Three types of pilot arrangements are taken into consideration depending on how the pilots are arranged.

These pilot signal arrangements are:

- Block type.
- Comb type.
- Lattice type.

According to figure 3.2, we consider block type pilot arrangement for our study. To obtain the estimated channel between UEs and BS antennas, we need to perform channel estimation techniques. Firstly, we use a pilot signaling process to estimate the channel between the user and BS antenna. Developing MIMO receivers always requires the implementation of signal detection and channel estimation methods that are both efficient and effective (Wang et al., 2020). User equipment transmits orthogonal pilot training sequences to the BS. Using the training pilot sequences, the base station can estimate the channels to the user equipment, albeit with some degree of estimation error. The pilot length of the pilot sequence is $\tau_p = kf \leq \tau_c$. Furthermore, in this thesis, it is assumed that every cell utilizes the same pilot sequences, which is prf. The k^{th} user in each cell will use the same training sequences.

To reduce interference in the transmission channel, a successful pilot assignment is critical. Optimizing limited resource is important for enhanced spectral efficiency, since it allows more pilots to be assigned to data transmission rather than channel estimation(Misso et al., 2020).

To estimate the channel between user equipment from different cells and the BS of the target cell, we had to use the channel model shown in Figure 3.1.

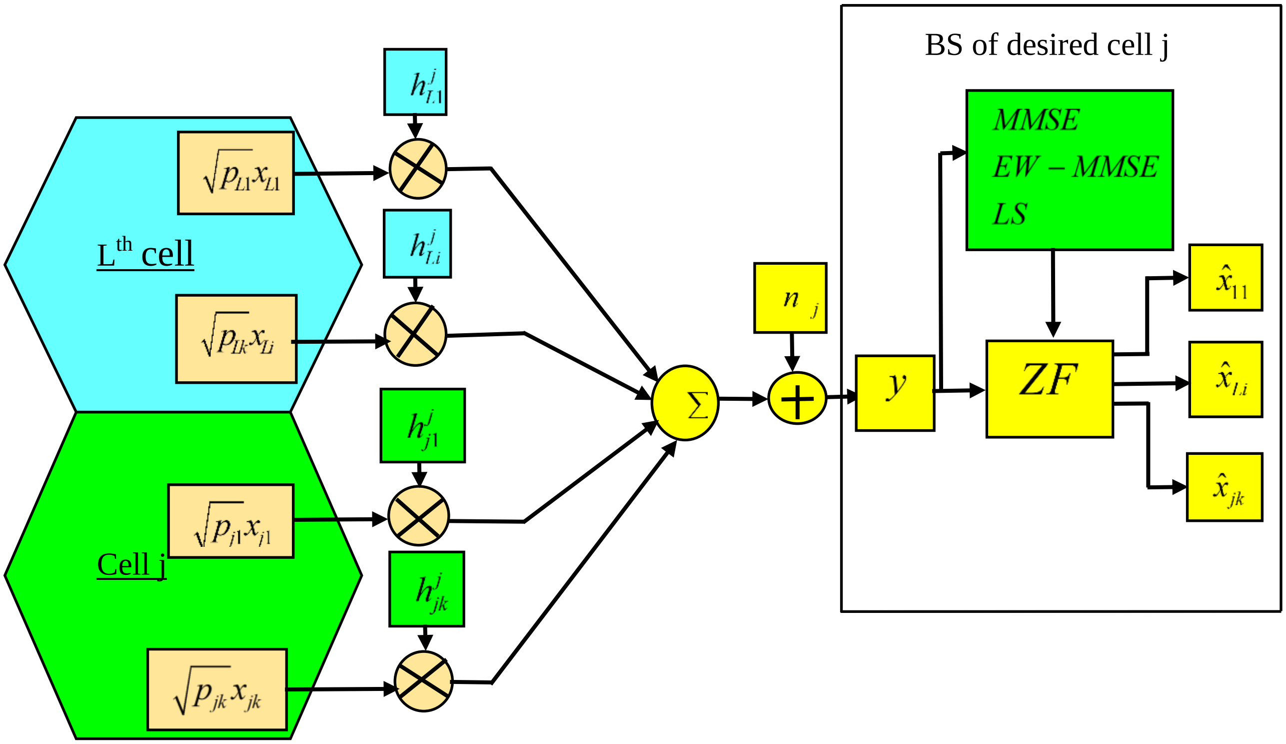

Figure 3. 5: Proposed system Model for uplink transmission model.

Figure 3.5 illustrates the transmission process of the uplink model as well as the system model for massive multi-cell MIMO cellular networks.

Figure 3.6 shows the method for computing and examining the UL SE of massive multi cell MIMO networks under rician fading channels. $\phi_{jk} \in \mathbb{C}^{\tau_p}$ is pilot sequence of UEs.

$$\left\|\phi_{jk}\right\|^2 = \phi_{jk}^H \phi_{jk} = \phi_{jk}^T \phi_{jk}^* = \tau_p \tag{3. 13}$$

$$y_j^{pilot} = \sum_{k=1}^{K_j} \sqrt{p_{jk}} h_{jk}^j \phi_{jk}^T + \sum_{\substack{l=1 \\ L \neq j}}^{L} \sum_{i=1}^{K_l} \sqrt{p_{li}} h_{li}^j \phi_{li}^j + n_j \tag{3. 14}$$

The value ϕ_{jk} is multiplied by the UL power of $\sqrt{p_{jk}}$ and the transmitted signal x_{jk} with UL sample gives the received UL signal of $y_j^{pilot} \in C^{M_j \times \tau_p}$ with BS j . It defines as follows:

$$y_j^{pilot} = \sqrt{p_{jk}} h_{jk}^j \phi_{jk}^T + \sum_{\substack{i=1 \\ i \neq k}}^{k_j} \sqrt{p_{ji}} h_{ji}^j \phi_{ji}^T + \sum_{\substack{L=1 \\ l \neq j}}^{L} \sum_{i=1}^{K_l} \sqrt{p_{il}} h_{li}^j \phi_{li}^T + n_j^{pilot} \tag{3. 15}$$

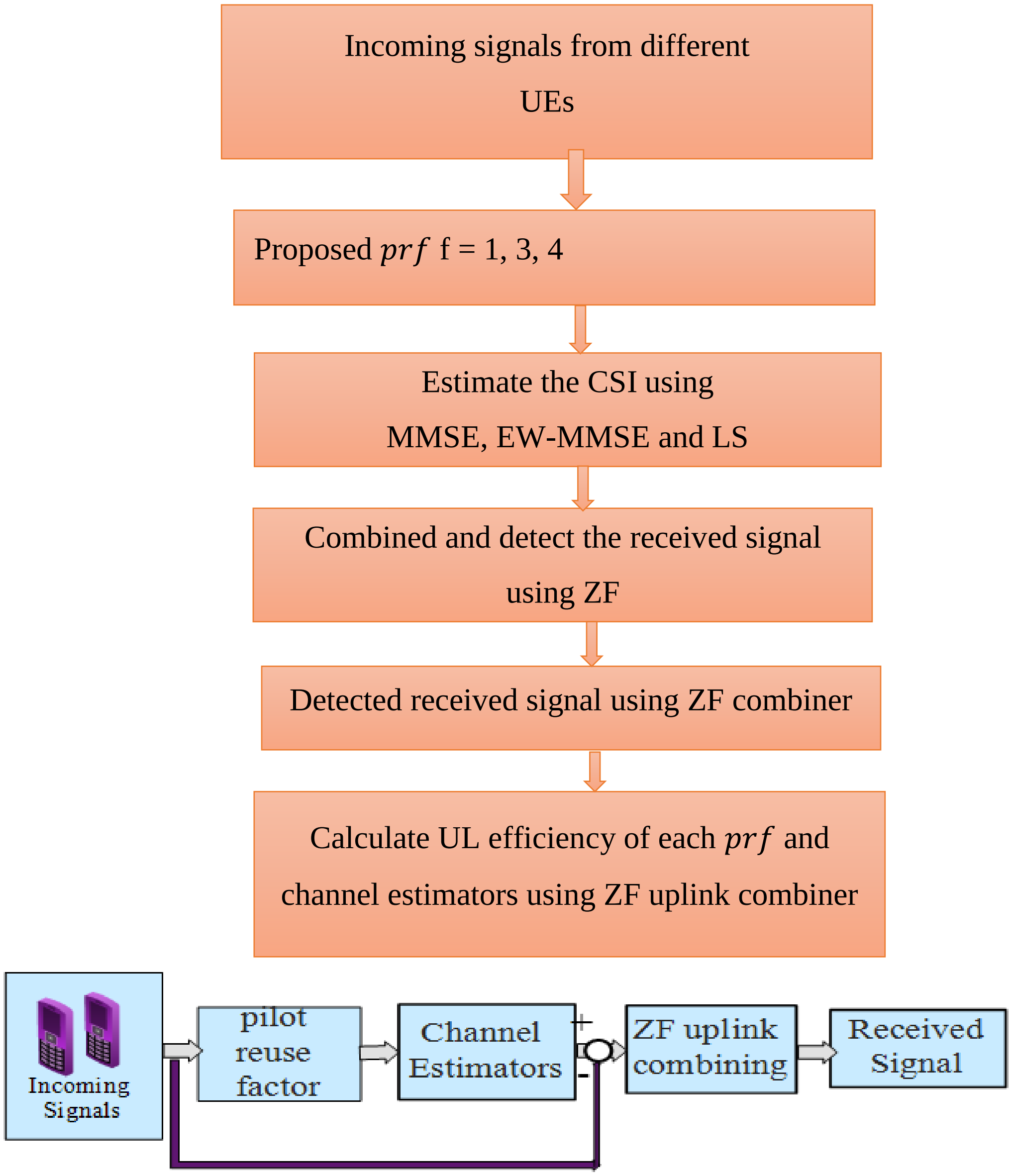

Figure 3. 6: proposed system model for UL SE of multi cell massive MIMO cellular networks.

Where

$\sqrt{p_{jk}}h_{jk}^{j}\phi_{jk}^{T}$ Desired pilot signal, $\sum_{\substack{i=1\\ i\neq k}}^{k_j}\sqrt{p_{ji}}h_{ji}^{j}\phi_{ji}^{T}$ Intra cell pilot signal, $\sum_{\substack{L=1\\ l\neq j}}^{L}\sum_{i=1}^{K_l}\sqrt{p_{il}}h_{li}^{j}\phi_{li}^{T}$ Inter cell pilot, and n_j^{pilot} Additive White Gaussian Noise. To generate the received pilot signal $y_{jli}^{pilot}\in C^{M_j}$, the base station multiplies $y_{jli}^{pilot}\in C^{M_j}$ with ϕ_{li}. Received pilot signal is expressed as follow.

$$y_j^{pilot}\phi_{li}^{*}=\sqrt{p_{jk}}h_{jk}^{j}\phi_{jk}^{T}\phi_{li}^{*}+\sum_{\substack{i=1\\ i\neq k}}^{k_j}\sqrt{p_{ji}}h_{ji}^{j}\phi_{ji}^{T}\phi_{li}^{*}+\sum_{\substack{L=1\\ l\neq j}}^{L}\sum_{i=1}^{K_l}\sqrt{p_{il}}h_{li}^{j}\phi_{li}^{T}\phi_{li}^{*}+n_j^{pilot}\phi_{li}^{*} \quad (3.\ 16)$$

$$y_{jli}^{pilot} = \sum_{\substack{L=1 \\ l \neq j}}^{L} \sum_{i=1}^{K_l} \sqrt{p_{il}} h_{li}^{j} \tau_p + n_j^{pilot} \phi_{li}^{*} \tag{3. 17}$$

$$\left. \begin{cases} \phi_{jk}^{*} \phi_{jk}^{T} = \tau_p \\ \phi_{li}^{*} \phi_{jk}^{T} = 0 \\ \phi_{li}^{*} \phi_{li}^{T} = \tau_p \\ \phi_{ji}^{*} \phi_{jk}^{T} = \tau_p, i = k \end{cases} \right\} \tag{3. 18}$$

We perform a projection of $y_j^{pilot}\ \phi_{jk}^{*}$ to obtain y_{jjk}^{pilot}, in order to allow k^{th} user within the home cell to determine the chosen channel from the signal received y_j^{pilot}.

$$y_j^{pilot} \phi_{jk}^{*} = \sqrt{p_{jk}} h_{jk}^{j} \phi_{jk}^{T} \phi_{jk}^{*} + \sum_{\substack{i=1 \\ i \neq k}}^{k_j} \sqrt{p_{ji}} h_{ji}^{j} \phi_{ji}^{T} \phi_{jk}^{*} + \sum_{\substack{L=1 \\ l \neq j}}^{L} \sum_{i=1}^{K_l} \sqrt{p_{il}} h_{li}^{j} \phi_{li}^{T} \phi_{jk}^{*} + n_j^{pilot} \phi_{jk}^{*} \tag{3. 19}$$

$$y_{jjk}^{pilot} = \sqrt{p_{jk}} h_{jk}^{j} \tau_p + n_j \phi_{jk}^{*} \tag{3. 20}$$

The strongest interference typically originates from within own cells. Pilot assignment for the desired cellular network is important to utilize the desired pilot sequence efficiently.

Due to the finite length of the coherence interval, which is defined as $\tau_p \leq \tau_c$, it is not feasible to allocate mutually orthogonal pilots to every UE. According to the rule of thumb the length of pilot sequence τ_p should always be smaller than $\frac{\tau_c}{2}$ (Özdogan et al., 2019).

We assume that our modeled system use the same pilot signals. In order to determine the necessary channels between the UE and BS antennas of the desired system, different cells will use the same pilot signals.

$$y_{jjk}^{pilot} = \sqrt{p_{jk}} \tau_p h_{jk}^{j} + \sum_{(l,i) \in \vartheta_{jk} \backslash (j,k)} \sqrt{p_{li}} \tau_p h_{li}^{j} + n_j \phi_{jk}^{*} \tag{3. 21}$$

The received signal y_{jjk}^{pilot} have better static for estimating the desired channel h_{jk}^{j}. Similarly, the received pilot y_{jli}^{pilot} have a better static for estimating h_{li}^{j}.

3.2. Channel Estimation Technique

In this thesis, a TDD-based multi cell massive MIMO cellular network is taken into consideration. In order to generate the channel state information (CSI), our study primarily focused on a pilot-based channel estimation method.

3.2.1. Pilot based Channel Estimation Techniques

Massive number of BS antennas in massive MIMO communication system is used to generate the accurate CSI between UEs and BS antennas. Because we use smart antenna systems. It can estimate the channels between UEs and BS antennas. The user equipment k and i pilot sequence in the specified cell is written as follows.

$$\phi_{jk} \in C^{\tau_p} \text{, and} \left\|\phi_{jk}\right\|^2 = \tau_p \tag{3. 22}$$

$$\phi_{li} \in C^{\tau_p} \text{, and } \left\|\phi_{li}\right\|^2 = \tau_p \tag{3. 23}$$

In order to optimize the SE of multi cell massive MIMO generating the channel state information of transmitter is a big deal. During uplink and downlink, process combining and precoding is desirable for amplify and suppressing interfered signals. Moreover, we define a pilot signal used to estimate the channel between UEs of home cell and BS of home cell that is y_{jjk}^{pilot}. The interfering signal must be amplified and suppressed; hence, knowledge of the UEs channel state information is necessary.

3.3. Types of Pilot Based Channel Estimation Techniques

In our study, we consider three different types of channel estimation techniques to generate CSI of the desired system. These are LS, MMSE and EW-MMSE channel estimators. To enhance the performance of a large multi-cell MIMO system, an accurate and reliable type of channel estimate is essential for the identification and precoding of the intended signal. TDD system is an efficient way to acquire channels with rapid channel changes, because the user equipment and base station use the same frequency band for transmission. We verified from different literature that the MMSE channel estimator has a higher computational complexity than other channel estimator techniques. In our study, we suggest an alternative channel estimator that reduces the computational complexity of MMSE estimators. Which is EW-MMSE estimator.

3.3.1. The Least Square (LS) Channel Estimator

For the purpose of analysis, we use x to represent both the transmitted data rate and the pilots sent from the user equipment to the BS.

$$y^{pilot} = h * x \tag{3. 24}$$

Where y^{pilot} the received pilot signal, h the unknown channel from UEs to BS antenna, x represents both the data rate and pilot length. From the received pilot signal, we estimate the unknown channels from UEs to BS antennas as follow.

$$h = y^{pilot} * x^{-} \tag{3. 25}$$

Here the noise is assumed zero. In practical communication system due to channel imperfectness, the noise is different from zero. For a fading environment, the pilot signal used to estimate the channel written as follow.

$$\hat{y}^{pilot} = \hat{h} * x \tag{3. 26}$$

Only first order statistics have been taken into account in the LS channel estimator. Channel statistics above the first order aren't taken into account by this algorithm. LS channel estimator can be used to determine the estimated channel. To estimate the unknown parameter h from an observed variable of $\hat{y}^{pilot}$ is the expected value. $\left\{\hat{y}^{pilot}/h\right\}$. Which defined as follow.

$$\hat{h} = E\left\{\hat{y}^{pilot}/h\right\} \tag{3. 27}$$

The LS channel estimator reduces the error as follows $(y^{pilot} - \hat{y}^{pilot})$.

$$\hat{y}^{pilot} = \hat{h} * x \tag{3. 28}$$

As we stated in the previous sentence, the purpose of using the LS algorithm is to reduce error $(y^{pilot} - \hat{y}^{pilot})$ and estimate the unknown channel between the UE and BS antennas. By substituting the value of $\hat{y}^{pilot}$ and y^{pilot} with a value of $\hat{y}^{pilot} = \hat{h} * x$, $y^{pilot} = h * x$ and we are trying to minimize it, we get the following expression.

Minimize $\left\| y^{pilot} - \hat{y}^{pilot} \right\|^2$ taking the first derivative of it.

$$\frac{d}{d\hat{h}} \left\| (y^{pilot} - \hat{y}^{pilot}) \right\|^2 = 0 \tag{3. 29}$$

$$\frac{d}{d\hat{h}} \left\| h * x - \hat{h} * x \right\|^2 = 0 \tag{3. 30}$$

$$\frac{d}{d\hat{h}} \left\| y^{pilot} - \hat{h} * x \right\|^2 = 0 \tag{3. 31}$$

$$\frac{d}{d\hat{h}} ((y^{pilot} - \hat{h} * x) * (y^{pilot} - \hat{h} * x)^H) = 0 \tag{3. 32}$$

By using distribution property, we can express the above equation as follow.

$$\frac{d}{d\hat{h}}[y^{pilot}(y^{pilot})^H-(\hat{h}*x)(y^{pilot})^H-y^{pilot}(\hat{h}*x)^H+(h*x)(\hat{h}*x)^H]=0 \tag{3. 33}$$

$$\frac{d}{d\hat{h}}(y^{pilot}(y^{pilot})^H)-2\frac{d}{d\hat{h}}(\hat{h}*x)(y^{pilot})^H+\frac{d}{d\hat{h}}(h*x)(\hat{h}*x)^H=0 \tag{3. 34}$$

$$0-2x(y^{pilot})^H+\frac{d}{d\hat{h}}(h*xx^H\hat{h})=0 \tag{3. 35}$$

$$-2x(y^{pilot})^H+2xx^H\hat{h}=0 \tag{3. 36}$$

$$-2x(y^{pilot})^H=-2xx^H\hat{h} \tag{3. 37}$$

$$h=x^{-}y^{pilot} \text{ Similarly } \hat{h}=\hat{y}^{pilot}\hat{x}^{-} \tag{3. 38}$$

Now substituting the value of $\hat{x}^{-}$ with the pilot vector and $\hat{y}^{pilot}$ by their values for multi cell massive MIMO scenario. To estimate the desired channel between UEs and BS antennas of home cell using LS algorithm defined as follow.

$$\hat{h}_{jk}^{j(LS)}=\frac{1}{\sqrt{p_{jk}}\tau_p}*y_{jjk}^{pilot} \tag{3. 39}$$

By substituting 3.19 to 3.38 we obtained the following expression.

$$\hat{h}_{jk}^{j(LS)}=\frac{1}{\sqrt{p_{jk}}\tau_p}*\left(\sqrt{p_{jk}}h_{jk}^{j}\tau_p+n_j\phi_{jk}^{*}\right) \tag{3. 40}$$

If the desired cellular system-performing pilot reuse to increase the system capacity and to reduce pilot contamination. Equation 3.39 becomes.

$$\hat{h}_{jk}^{j(LS)}=\frac{1}{\sqrt{p_{jk}}\tau_p}*\left(\sqrt{p_{jk}}\tau_p h_{jk}^{j}+\sum_{(l,i)\in\vartheta_{jk}\backslash(j,k)}\sqrt{p_{li}}\tau_p h_{li}^{j}+n_j\phi_{jk}^{*}\right) \tag{3. 41}$$

$$\hat{h}_{jk}^{j(LS)}=\bar{h}_{jk}^{j}+\sum_{(l,i)\in\vartheta_{jk}\backslash(j,k)}\sqrt{\frac{p_{li}}{p_{jk}}}h_{li}^{j}+\frac{1}{\sqrt{p_{jk}}\tau_p}*n_j\phi_{jk}^{*} \tag{3. 42}$$

To estimate the channels between UEs of L^{th} cells and j^{th} BS antennas LS algorithm will generate its CSI as follow. By substituting equation, 3.16 into 3.38 we will obtained the expression of $\hat{h}_{li}^{j(LS)}$ as follow.

$$\hat{h}_{li}^{j(LS)}=\frac{1}{\sqrt{p_{li}}\tau_p}*\left(\sum_{\substack{L=1\\ l\neq j}}^{L}\sum_{i=1}^{K_l}\sqrt{p_{li}}h_{li}^{j}\tau_p+n_j^{pilot}\phi_{li}^{*}\right) \tag{3. 43}$$

$$\hat{h}_{li}^{j(LS)} = \sum_{\substack{L=1 \\ l\neq j}}^{L} \sum_{i=1}^{K_l} h_{li}^{j} + \frac{1}{\sqrt{p_{li}\tau_p}} * (n_j^{pilot}\phi_{li}^{*}) \tag{3. 44}$$

In our study, we consider a Rician fading channels. Therefor the LOS components are considered. The estimated channel becomes the summation of the LOS and NLOS component.

$$\hat{h}_{jk}^{j(LS)} = \bar{h}_{jk}^{j} + (h_{jk}^{j} + \sum_{(l,i)\in\vartheta_{jk}\backslash(j,k)} \sqrt{\frac{p_{li}}{p_{jk}}} h_{li}^{j} + \frac{1}{\sqrt{p_{jk}\tau_p}} * n_j\phi_{jk}^{*}) \tag{3. 45}$$

$$\hat{h}_{li}^{j(LS)} = \bar{h}_{li}^{j} + \sum_{\substack{L=1 \\ l\neq j}}^{L} \sum_{i=1}^{K_l} h_{li}^{j} + \frac{1}{\sqrt{p_{li}\tau_p}} n_j^{pilot}\phi_{li}^{*} \tag{3. 46}$$

3.3.2. MMSE Channel Estimator

The MMSE channel estimation has high computational complex estimator technique. Any channel estimator aims to estimate an unknown channel parameter h using observed pilot signals of $\hat{y}^{pilot}$. In order to determine the estimated channel parameters, we must apply the idea of expected values. The estimated value will defined as $\hat{h} = E\left\{ h / \hat{y}^{pilot} \right\}$. The aim of designing MMSE channel estimator is to generate channel state information (CSI) at the receiver and to minimize the error due to interference.

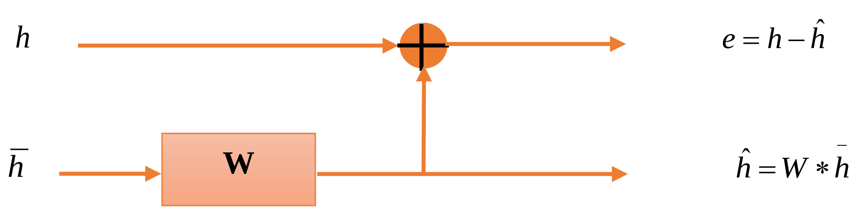

Figure 3. 7: MMSE channel estimation(Cho et al., 2010)

The MMSE estimator is complex since it needs both the calculation of the correlation function and the inversion of a matrix (Moqbel et al., 2017). MSE is expressed by its correlation matrix as follow. From figure 3.7, we can calculate the MSE of the channel estimate $\hat{h}$ is given as follow.

$$MSE = J(\hat{h}) = E\{\| e \|^2\} = E\{\| h - \hat{h} \|^2\} = E\{(h-\hat{h})(h-\hat{h})^H\} \tag{3. 47}$$

The weighted vector W is used to find a better channel estimation.

$$E\{e(\bar{h})^H\} = E\{(h-\hat{h})\bar{h}^H\} \tag{3. 48}$$

Insert the value of $\hat{h} = W * \bar{h}$ in to equation 3.48 to find the estimated channel.

$$E\{(h - W\bar{h}) * (\bar{h})\} \tag{3. 49}$$

$$E\{h*(\bar{h})^H - W\bar{h}*(\bar{h})^H\} \quad (3.50)$$

$$E\{h(\bar{h})^H\} - E\{W\bar{h}(\bar{h})^H\} = 0 \quad (3.51)$$

$$E\{h(\bar{h})^H\} - W[E\{\bar{h}(\bar{h})^H\}] = 0 \quad (3.52)$$

Where $E\{h(\bar{h})^H\} = R_{h\bar{h}}$ channel $W[E\{\bar{h}(\bar{h})^H\}] = W(R_{\bar{h}\bar{h}})$

$$R_{h\bar{h}} - W[R_{\bar{h}\bar{h}}] = 0 \quad (3.53)$$

$$R_{h\bar{h}} = W[R_{\bar{h}\bar{h}}] \quad (3.54)$$

$$W = R_{h\bar{h}} / R_{\bar{h}\bar{h}} = R_{h\bar{h}}(R_{\bar{h}\bar{h}})^{-1} \quad (3.55)$$

The estimated channel from the observation vector given as follow.

$$\hat{h} = \{R_{h\bar{h}}(R_{\bar{h}\bar{h}})^{-1}\}\bar{h} \quad (3.56)$$

Where $R_{h\bar{h}}$ The correlation matrix.

$R_{\bar{h}\bar{h}}$ The covariance matrix of observed parameter.

$\bar{h}$ The estimated channel

$$\bar{h} = x^{-1}y^{pilot} \quad (3.57)$$

$$\bar{h} = x^{-1}(hx + n^{pilot}) \quad (3.58)$$

$$\bar{h} = (h + x^{-1}n^{pilot}) \quad (3.59)$$

$$R_{\bar{h}\bar{h}} = E\{\overline{hh}^H\} \quad (3.60)$$

$$R_{\bar{h}\bar{h}} = E\{x^{-1}y^{pilot}(x^{-1}y^{pilot})^H\} \quad (3.61)$$

$$R_{\bar{h}\bar{h}} = E\{(h + x^{-}n^{pilot})(h + x^{-}n^{pilot})^H\} \quad (3.62)$$

$$R_{\bar{h}\bar{h}} = E\{(hh^H + h(x^{-1}n_{pilot})^H + hx^{-1}n_{pilot} + (x^{-1}n_{pilot}n^H_{pilot}(x^{-1})^H\} \quad (3.63)$$

$$R_{\bar{h}\bar{h}} = E[hh^H] + E[h(x^{-1}n_{pilot})^H] + E[hx^{-1}n_{pilot}] + E[(x^{-1}n_{pilot}n^H_{pilot}(x^{-1})^H] \quad (3.64)$$

The noise and the input signals are not correlated to each other.

$$R_{\bar{h}\bar{h}} = R_{hh} + E[n_{pilot}n^H_{pilot}] \Big/ E[x(x^{-1})^H] \quad (3.65)$$

$$R_{\bar{h}\bar{h}} = R_{hh} + (\sigma^2 / \sigma_x^2) * I \quad (3.66)$$

$$R_{hh} = E\{hh^H\} \quad (3.67)$$

Substituting the above expression into 3.56.

$$\hat{h} = \{R_{h\bar{h}}(R_{hh} + (\sigma^2 / \sigma_x^2) * I)^{-1}\}\bar{h} \quad (3.68)$$

$$\hat{h} = \{R_{h\bar{h}}(\frac{1}{\sigma_x^2}(\sigma_x^2 R_{hh} + \sigma^2 I_{MM}))^{-1}\}\tilde{h} \quad (3.69)$$

$$\hat{h} = \{R_{h\bar{h}}\left(1/\sigma_x^2\right)^{-1}\left(\sigma_x^2 R_{hh} + \sigma^2 I_{MM})\right)^{-1}\}\bar{h} \quad (3.70)$$

$$\hat{h} = \sigma_x^2 R_{h\bar{h}}\left(\sigma_x^2 R_{hh} + \sigma^2 I_{MM}\right)^{-1}\bar{h} \quad (3.71)$$

Substituting equation (3.57) into equation (3.70), we can obtain the following expression.

$$\hat{h} = \sigma_x^2 R_{h\bar{h}}\left(\sigma_x^2 R_{hh} + \sigma^2 I_{MM}\right)^{-1}(x^{-1} y^{pilot}) \quad (3.72)$$

Equation (3.72) is for Rayleigh fading channels. To modify this channel in to Rician model simply add the Line of Sight (LOS) component $\bar{h}$ on equation (3.72).

$$\hat{h} = \bar{h} + \sigma_x^2 R_{h\bar{h}}\left(\sigma_x^2 R_{hh} + \sigma^2 I_{MM}\right)^{-1}(x^{-1} y^{pilot}) \quad (3.73)$$

From LS, channel estimator we can get the value of $\bar{h}$. So equation (3.73) furtherly becomes

$$\hat{h} = \bar{h} + \sigma_x^2 R_{h\bar{h}}\left(\sigma_x^2 R_{hh} + \sigma^2 I_{MM}\right)^{-1}\left(\left(1/\sqrt{p_{jk}}\tau_p\right) * y_{jjk}^{pilot}\right) \quad (3.74)$$

Finally, we can get the following value for MMMSE channel estimation according to algorithm in (Özdogan et al., 2019).

$$H_{MMSE} = \hat{h}_{li}^j = \bar{h}_{li}^j + \sqrt{p_{li}} R_{li}^j \psi_{li}^j \left(y_{jli}^{pilot} - \bar{y}_{jli}^{pilot}\right) \quad (3.75)$$

Where $\bar{y}_{jli}^{pilot} = \sum_{(l',i') \in p_{li}} \sqrt{p_{l'i'}} \bar{h}_{l'i'}^j$, $\psi_{li}^j = \tau_p \operatorname{cov}\left(y_{jli}^{pilot}\right)^{-1}$ and $\bar{h}_{li}^j$ is the mean corresponding to the LOS component.

3.3.3. EW-MMSE Channel Estimator

EW-MMSE channel estimator is a special type of MMSE channel estimators used to minimize the computational complexity. One of the main drawbacks of 5G massive MIMO system is its processing complexity. Due to high pilot overhead, massive MIMO systems generate an excessive amount of channel state information (CSI) feedback (Khan et al., 2019). The EW-MMSE estimator uses the main diagonal elements of the covariance matrix rather than the complete spatial correlation matrix (Björnson et al., 2017a). According to (Moqbel et al., 2017) MMSE channel estimator is complex. Therefore, less computational complexity is preferable for the system. The estimators ignore the correlation between the elements. According to (Björnson et al., 2017a)the EW-MMSE channel estimator is written as follow.

$$\hat{h}_{li}^{j,EW-MMSE} = \bar{h}_{li}^{j} + \sqrt{p_{li}} D_{li}^{j} \Lambda_{li}^{j} (y_{jli}^{pilot} - \bar{y}_{jli}^{pilot}) \tag{3. 76}$$

Where $D_{li}^{j} = diag(R_{li}^{j})$, $\Lambda_{li}^{j} = diag\left(\sum_{(l^{'},i^{'})\in p_{li}} p_{l^{'}i^{'}} \tau_p R_{l^{'}i^{'}} + \sigma^2 I_{mj}\right)^{-1}$

3.4. Uplink Data Transmission with Linear Detection (combining)

In this study, we assume M BS antenna terminals, l cells, and k user terminals. The received signal $y_j \in C^{M_j}$ at BS j defined as follow.

$$y_j = \sum_{k=1}^{k_j} h_{jk}^{j} x_{jk} + \sum_{\substack{l=1 \\ l\neq j}}^{L} \sum_{i=1}^{k_l} h_{li}^{j} x_{li} + n_j \tag{3. 77}$$

$$y_j = \sqrt{p_{jk}} h_{jk}^{j} x_{jk} + \sum_{\substack{i=1 \\ i\neq k}}^{k_j} \sqrt{p_{jk}} h_{jk}^{j} x_{jk} + \sum_{\substack{l=1 \\ l\neq j}}^{L} \sum_{i=1}^{k_l} \sqrt{p_{li}} h_{li}^{j} x_{li} + n_j \tag{3. 78}$$

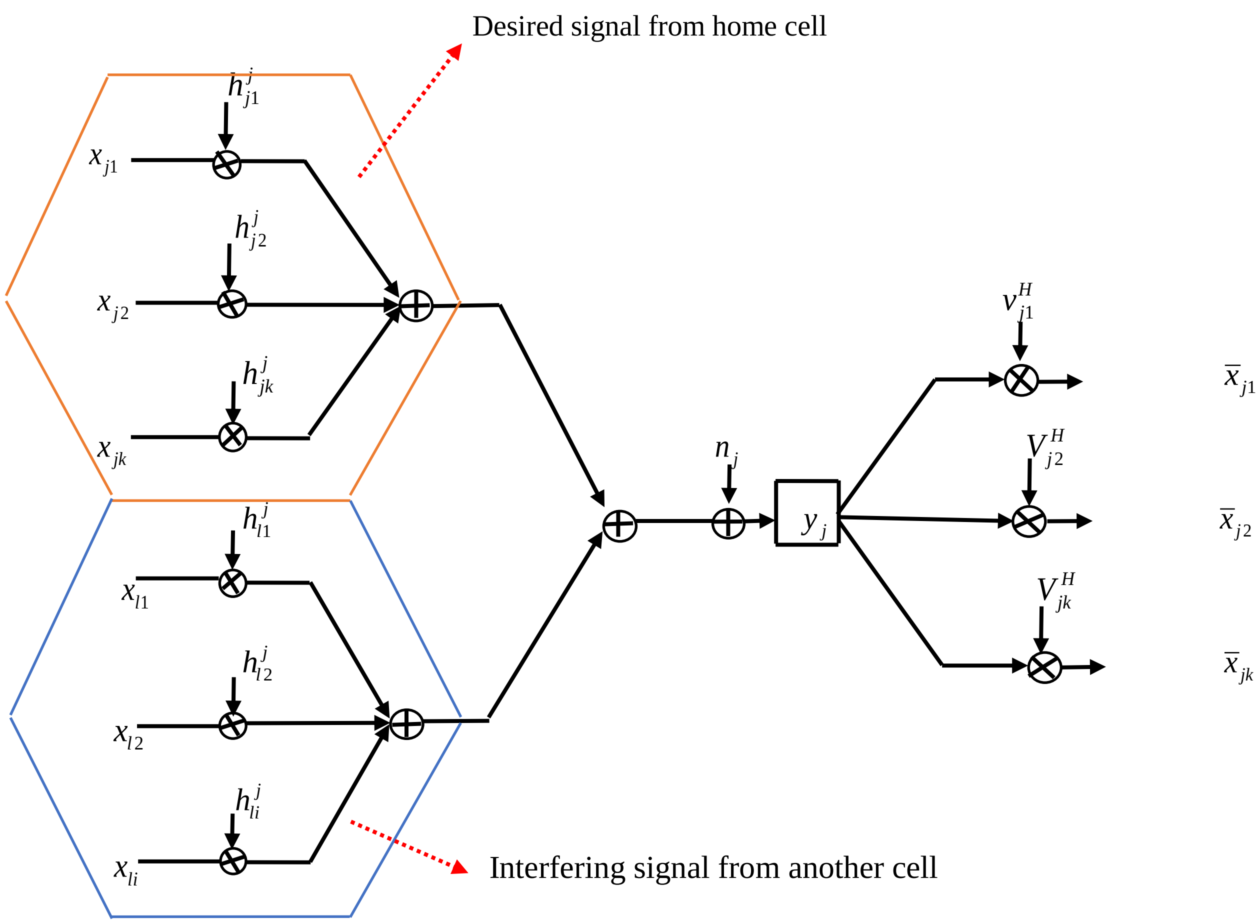

Figure 3. 8: Uplink Data Transmission with Linear Detection Algorithm

The channel between user terminals and BS antenna terminal defined as follow.

$$H = h_{jk}^{j} = \begin{pmatrix} h_{j1}^{1} & h_{j2}^{1} & h_{jk}^{1} \\ h_{j1}^{2} & h_{j2}^{2} & h_{jk}^{2} \\ h_{j1}^{Mj} & h_{j2}^{Mj} & h_{jk}^{Mj} \end{pmatrix}_{M\times K} \tag{3. 79}$$

Where h_{jk}^{j} is $M \times K$ channel matrix defined as follow.

$$H = h_{jk}^{j} = \begin{pmatrix} h_{l1}^{1} & h_{l2}^{1} & h_{lk}^{1} \\ h_{l1}^{2} & h_{l2}^{2} & h_{lk}^{2} \\ h_{l1}^{Mj} & h_{l2}^{Mj} & h_{lk}^{Mj} \end{pmatrix}_{M\times K} \tag{3. 80}$$

The received signal $y_j \in C^{M_j}$ at BS j defined as follow.

$$y_j^{uplink} = \sqrt{p_{jk}}\hat{h}_{jk}^{j} x_{jk} + \sum_{\substack{i=1\\ i\neq k}}^{k_j} \sqrt{p_{jk}}\hat{h}_{jk}^{j} x_{jk} + \sum_{\substack{l=1\\ l\neq j}}^{L} \sum_{i=1}^{k_l} \sqrt{p_{li}}\hat{h}_{li}^{j} x_{li} + n_j \tag{3. 81}$$

3.5.Linear Uplink Detection Vector

Based on the received signal model in (3.77) estimating the unknown transmitted signal vector X_{jk} and X_{li} from received signal y_j channel gain h_{jk}^{j}, h_{li}^{j} and knowledge of all the possible combination of the transmitted signal of X_{jk} and X_{li} is the purpose of massive MIMO detection (Bai & Choi, 2012). The base station processing methods, such as uplink combiners and downlink precoding techniques, are key solution for the emerging 5G technology. These precoding and uplink combiners combine the input signals in a pre-defined way and deliver them in the right proportion to the multiple antenna elements. MMSE uplink combiner provides a better performance than other linear uplink combiner techniques (Subitha & Vani, 2021). However, its computational complexity is very high. According to recent researchers, the emerging 5G technology needs to be low complex with better performance.

It is shown in (Li et al., 2017) that for multi cell massive MIMO systems where M is much larger than k for instance of M=500 to support 10 and 30 users. With minimal complexity in the signal processing, linear detection approaches can perform nearly optimally. All channel directions, which are estimated at each BS antenna element, can be used by the linear detection. From the estimated channel, we can bring very promising SE gains using MRC and ZF detection algorithm.

Linear detection techniques produce estimates of the transmitted symbols by applying linear transformations to the received signal, expressed as(Zhang et al., 2022).

$$\hat{X}_{jk} = V_{jk}^{H} y_{j}^{uplink} \tag{3. 82}$$

Where V_{jk}^{H} is the complex Hermitian of detection matrix. Assuming estimated channel state information (CSI) the detection matrix is given as follow.

$$V_{jk}^{H} = \begin{cases} \hat{h}_{jk}^{j} & MRC \\ \hat{h}_{jk}^{j}\left(\left(\hat{h}_{jk}^{j}\right)^{H}\hat{h}_{jk}^{j}\right)^{-1} & ZF \\ \hat{h}_{jk}^{j}\left(\left(\hat{h}_{jk}^{j}\right)^{H}\hat{h}_{jk}^{j} + \frac{\sigma^{2}}{p_{jk}} I_{jk}\right)^{-1} & MMSE \end{cases} \tag{3. 83}$$

We chose the ZF detection technique (uplink combiner) for our thesis.

3.6. Spectral Efficiency of the System

Massive MIMO efficiently uses radio network resources to expand network capacity, which leads to a greater throughput and multi-user support. The transmission power is directed in to a specific direction using beamforming techniques. This reduces interference while increasing network coverage. massive MIMO employs spatial multiplexing which efficiently utilize frequency and time resources to improve network capacity and bit rate (Chataut & Akl, 2020). In massive MIMO, different signal paths produced by multiple antennas are used as sub channels for sending and receiving data streams for multiple users. It is also a positive way to increase a cellular network's spectral efficiency. A user device can achieve higher overall bit rates by using multiple data streams through spatial multiplexing. Massive MIMO additionally generates a significant amount of higher capacity, because of multiple antenna elements. This can enable higher area throughput for multiple users transmit simultaneously. The amount of throughput gain that a network can accomplish is constrained if its SINR is not good. The base station must detect the user's data signal after receiving it, and then restore it to the user's original signal.

In order to proceed calculation we use a linear detector combination of ZF combining as we define in equation 3.83, i.e. $v_{jk} = \hat{h}_{j} = \hat{h}_{jk}^{j}\left(\left(\hat{h}_{jk}^{j}\right)^{H}\hat{h}_{jk}^{j}\right)^{-1}$ and $v_{li} = \hat{h}_{l} = \hat{h}_{li}^{j}\left(\left(\hat{h}_{li}^{j}\right)^{H}\hat{h}_{li}^{j}\right)^{-1}$

In our proposed system we use three different channel estimation techniques (algorithms) to generate channel state information (CSI) used for ZF to detect the user signal. Through estimated channels, we are able to obtain the vectors for signal detection. In our thesis, we obtain the expression of spectral efficiency of each estimation techniques.

As a result, the user signal received after ZF processing can be defined as follows.

$$\hat{x}_{jk} = v_{jk}^{H} y_{j}^{uplink} = \sqrt{p_{jk}}\hat{h}_{jk}^{j} v_{jk}^{H} x_{jk} + \sum_{\substack{i=1 \\ i\neq k}}^{k_j} \sqrt{p_{jk}}\hat{h}_{jk}^{j} v_{jk}^{H} x_{jk} + \sum_{\substack{l=1 \\ l\neq j}}^{L} \sum_{i=1}^{k_l} \sqrt{p_{li}}\hat{h}_{li}^{j} v_{jk}^{H} x_{li} + v_{jk}^{H} n_j \quad (3.84)$$

$$V_{jk} = \hat{h}_j = \left\{ \begin{array}{ll} \frac{1}{\sqrt{p_{li}}\tau_p} * \left(\sum_{\substack{L=1 \\ l\neq j}}^{L} \sum_{i=1}^{K_l} \sqrt{p_{li}} h_{li}^{j} \tau_p + n_j^{pilot} \phi_{li}^{*} \right) & LS \\ \bar{h}_{jk}^{j} + \sqrt{p_{jk}} R_{jk}^{j} \psi_{jk}^{j} \left(y_{jli}^{pilot} - \bar{y}_{jli}^{pilot} \right) & MMSE \\ \bar{h}_{jk}^{j} + \sqrt{p_{jk}} D_{jk}^{j} \Lambda_{jk}^{j} (y_{jli}^{pilot} - \bar{y}_{jli}^{pilot}) & EW-MMSE \end{array} \right\} \quad (3.85)$$

We assumed a discrete channel model as follow

$$y = hx + d + n \quad (3.86)$$

When the interference signal d satisfies the zero mean values has known as variance $pv \in R$ and it is independent of the input signal, we can get the following lower bound of channel capacity(Stepanets et al., 2018).

$$C \geq \log_2 \left(I + \frac{p \left| \hat{h}_{jk}^{j} v_{jk}^{H} \right|^2}{pd + \sigma^2} \right) \quad (3.87)$$

The variance of the random signal d (interference signal) is affected by the channel estimation of $\hat{h}_{li}^{j}$, the interference term d is;

$$d = v_{jk}^{H} \bar{h}_{jk}^{j} x_{jk} + \sum_{\substack{i=1 \\ l\neq j}}^{k} \sqrt{p_{ji}} v_{jk}^{j} h_{ji}^{j} x_{ji} + \sum_{\substack{i=1 \\ l\neq j}}^{L} \sum_{i=1}^{k} \sqrt{p_{li}} v_{jk}^{H} h_{li}^{j} x_{li} + v_{jk}^{H} n_j \quad (3.88)$$

From the above evidence, we can find that the conditional covariance of the interference signal (Liu et al., 2019) is: The value of pd from equation 3.87 is defined as follow

$$pd(r,z) = E\left\{ |v|^2 \left| \left\{ \hat{h}_{li}^{j} \right\} \right. \right\} = E\left\{ \left| x_{jk} \right|^2 \right\} E\left\{ \left| v_{jk}^{H} \bar{h}_{jk}^{j} \right|^2 \left| \left\{ \hat{h}_{li}^{j} \right\} \right. \right\} + \sum_{\substack{i=1 \\ l\neq j}}^{L} \sum_{i=1}^{k} E\left\{ \left| x_{li} \right|^2 \right\} E\left\{ \left| v_{jk}^{H} \hat{h}_{li}^{j} \right|^2 \left| \left\{ \hat{h}_{li}^{j} \right\} \right. \right\} + E\left\{ \left| v_{jk}^{H} n_j \right|^2 \left| \left\{ \hat{h}_{li}^{j} \right\} \right. \right\} \quad (3.89)$$

$$pd(r,z) = p_{jk} v_{jk}^{H} c_{jk}^{j} v_{jk} + \sum_{\substack{i=1 \\ l\neq j}}^{L} \sum_{i=1}^{k} p_{li} v_{jk}^{H} \left(\hat{h}_{li}^{j} \left(\hat{h}_{li}^{j} \right)^{H} + c_{li}^{j} \right) v_{jk} + \sigma_{ul}^{2} v_{jk}^{H} I_{mj} v_{jk} \quad (3.90)$$

We use three alternative channel estimator techniques to examine the uplink spectral efficiency of massive MIMO systems. These are MMSE, EW-MMSE, and LS. With the ZF receive combining scheme, the achievable spectral efficiency of these channel estimators is determined. As we discussed in equation 3.81 a signal $y_j^{uplink} \in C^{Mj}$ received at BS j and the uplink signal in cell L from user equipment UE k is x_{jk}^{uplink}. As in (Asif et al., 2022) the ergodic uplink capacity of UE k in cell j is lower bounded by.

$$SE_{jk}^{uplink} = \frac{\tau_u}{\tau_c} \log_2\left(1 + SINR_{jk}^{L}\right) \tag{3. 91}$$

The Prelog factor, which can be expressed as a ratio of $\frac{\tau_u}{\tau_c}$, that indicates the portion of the coherence interval dedicated to the uplink payload data. Therefore, by substituting equation 3.90 into equation 3.87, we can determine the value of SINR with uplink channel capacity of user k in cell j is:

$$SE_{jk}^{ul} = \frac{\tau_{ul}}{\tau_c} E\left(\log_2\left(1 + \frac{p\left|\left(\hat{h}_{jk}^{j} v_{jk}\right)\right|^2}{pd\left(r,z\right) + \sigma^2}\right)\right) = \frac{\tau_u}{\tau_c} E\left\{\log_2\left(1 + SINR_{jk}^{L}\right)\right\} \tag{3. 92}$$

$$SINR_{jk}^{ul} = \frac{p_{jk}\left|E\left\{v_{jk}^{H} h_{jk}^{j}\right\}\right|^2}{\sum_{l=1}^{L} \sum_{i=1}^{kl} p_{li} E\left\{\left|v_{jk}^{H} h_{jk}^{j}\right|^2\right\} - p_{jk}\left|E\left\{v_{jk}^{H} h_{jk}^{j}\right\}\right|^2 + \sigma_{ul}^2 E\left\{\left|v_{jk}\right|^2\right\}} \tag{3. 93}$$

$$SE_{jk}^{ul} = \left(1 - \frac{\tau_p}{\tau_c}\right)\left(1 + \frac{p_{jk}\left|E\left\{v_{jk}^{H} h_{jk}^{j}\right\}\right|^2}{\sum_{l=1}^{L} \sum_{i=1}^{kl} p_{li} E\left\{\left|v_{jk}^{H} h_{jk}^{j}\right|^2\right\} - p_{jk}\left|E\left\{v_{jk}^{H} h_{jk}^{j}\right\}\right|^2 + \sigma_{ul}^2 E\left\{\left|v_{jk}\right|^2\right\}}\right) \tag{3. 94}$$

$$SE_{jk}^{ul} = \left(1 - \frac{fk}{\tau_c}\right)\left(1 + \frac{p_{jk}\left|E\left\{v_{jk}^{H} h_{jk}^{j}\right\}\right|^2}{\sum_{l=1}^{L} \sum_{i=1}^{kl} p_{li} E\left\{\left|v_{jk}^{H} h_{li}^{j}\right|^2\right\} - p_{jk}\left|E\left\{v_{jk}^{H} h_{jk}^{j}\right\}\right|^2 + \sigma_{ul}^2 E\left\{\left|v_{jk}\right|^2\right\}}\right) \tag{3. 95}$$

Where all expectations values are in relation to all sources of randomness. Any combining scheme and channel estimators allow for the numerical computation of the effective SINR. For our thesis, we consider ZF receiver combining and MMSE, EW-MMSE and LS channel estimators to compute the effective SINR.

SINR which is defined in equation 3.91 has the following interpretation.

$$SINR = \frac{p\left|\hat{h}_{jk}^{j} v_{jk}^{H}\right|^2}{pd + \sigma^2} \tag{3. 96}$$

We can rewrite the SINR as follow.

$$SINR = \frac{1}{\frac{pd}{p\left|\hat{h}_{jk}^{j} v_{jk}^{H}\right|^2} + \frac{\sigma^2}{p\left|\hat{h}_{jk}^{j} v_{jk}^{H}\right|^2}} \tag{3. 97}$$

Where p is the transmitted power, $p\left|\hat{h}_{jk}^{j} v_{jk}^{H}\right|^2$ is the received signal power pd is the interference power, σ^2 is the variance of the noise, $\frac{pd}{p\left|\hat{h}_{jk}^{j} v_{jk}^{H}\right|^2}$ is the interference ratio, $\frac{\sigma^2}{p\left|\hat{h}_{jk}^{j} v_{jk}^{H}\right|^2} = \frac{1}{SNR}$ Is inverse of signal to Noise ratio.

$$SNR = \frac{p\left|\hat{h}_{jk}^{j} v_{jk}^{H}\right|^2}{\sigma^2} \tag{3. 98}$$

According to equation 3.97, the SE can be improved by raising SNR, which stands for signal-to-noise ratio. The interference ratio, which measures interference power in relation to signal power, improve system performance it should be decreased.

3.6.1. UL SE using LS estimator

We have the estimated channel with LS estimator in section 3.3.1, $\hat{h}_{jk}^{j(ls)} = h_{jk}^{j(ls)}$ given by

$$\hat{h}_{jk}^{j(LS)} = \frac{1}{\sqrt{p_{jk}}\tau_p} * y_{jjk}^{pilot} \tag{3. 99}$$

We now obtain the SE expression for the LS estimator by incorporating equation 3.96 into equation 3.95. (Björnson et al., 2017b)this paper developed the SNIR expression for the LS estimator. The following formula of SINR for the LS estimator is obtained after setting up the equation according to our proposed system.

$$SINR_{jk}^{ul} = \frac{p_{jk}\left|E\left\{\left(\frac{1}{\sqrt{p_{jk}}\tau_p} * y_{jjk}^{pilot}\right)^H h_{jk}^{j}\right\}\right|^2}{\sum_{l=1}^{L}\sum_{i=1}^{kl} p_{li} E\left\{\left|\left(\frac{1}{\sqrt{p_{jk}}\tau_p} * y_{jjk}^{pilot}\right)^H h_{li}^{j}\right|^2\right\} - p_{jk}\left|E\left\{\left(\frac{1}{\sqrt{p_{jk}}\tau_p} * y_{jjk}^{pilot}\right)^H h_{jk}^{j}\right\}\right|^2 + \sigma_{ul}^2 E\left\{\left|\left(\frac{1}{\sqrt{p_{jk}}\tau_p} * y_{jjk}^{pilot}\right)^H\right|^2\right\}}$$

(3. 100)

$$SINR_{jk}^{ul} = \frac{p_{jk}\left| tr\left(R_{jk}^{j}\right) + \sum_{(l,i)\in p_{jk}} \frac{\sqrt{p_{jk}}}{\sqrt{p_{li}}}\left(\bar{h}_{li}^{j}\right)^{H}\left(\bar{h}_{jk}^{j}\right)\right|^{2}}{\sum_{l=1}^{L}\sum_{i=1}^{kl} p_{li}\gamma_{li}^{ul,ls} - p_{jk}\left| tr\left(R_{jk}^{j}\right) + \sum_{(l,i)\in p_{jk}} \frac{\sqrt{p_{jk}}}{\sqrt{p_{li}}}\left(\bar{h}_{li}^{j}\right)^{H}\left(\bar{h}_{jk}^{j}\right)\right|^{2} + \sigma_{ul}^{2}\left(\frac{tr\left(\psi_{jk}^{j}\right)^{-1}}{p_{jk}\tau_{p}} + \frac{\left\|\bar{y}_{jjk}^{pilot}\right\|^{2}}{p_{jk}\tau_{p}^{2}}\right)} \tag{3. 101}$$

Where $p_{jk}\gamma_{li}^{ul,ls} = p_{jk}\tau_{p}^{2}E\left\{\left|v_{jk}^{H}h_{li}^{j}\right|^{2}\right\}$

$$p_{jk}\tau_{p}^{2}E\left\{\left|v_{jk}^{H}h_{li}^{j}\right|^{2}\right\} = \tau_{p}tr\left(R_{li}^{j}\left(\psi_{jk}^{j}\right)^{-1}\right) + 2\sqrt{p_{li}}\tau_{p}\operatorname{Re}\left\{\begin{array}{l}\left(\bar{y}_{jjk}^{pilot}\right)^{H}\bar{h}_{li}^{j}tr\left(R_{li}^{j}\right) \\ +\bar{y}_{jjk}^{pilot}R_{li}^{j}\bar{h}_{li}^{j} + \bar{x}_{jk}^{H}\left|\bar{h}_{li}^{j}\right|^{2}\end{array}\right\}(l,i)\in\rho_{jk}$$

(3. 102)

After determining the expression of SINR for our desired system, we can determine the expression of SE of the LS estimator using equation 3.95. When employing LS estimator with ZF receiving combining techniques, we just must replace the SINR expression in equation 3.93 with the expression for it derived in equation 3.99 to obtain the SE expression of our desired systems.

$$SE_{jk}^{ul,ls} = \left(1 - \frac{fk}{\tau_{c}}\right)\log_{2}\left(1 + \frac{p_{jk}\left| tr\left(R_{jk}^{j}\right) + \sum_{(l,i)\in p_{jk}} \frac{\sqrt{p_{jk}}}{\sqrt{p_{li}}}\left(\bar{h}_{li}^{j}\right)^{H}\left(\bar{h}_{jk}^{j}\right)\right|^{2}}{\sum_{l=1}^{L}\sum_{i=1}^{kl} p_{li}\gamma_{li}^{ul,ls} - p_{jk}\left| tr\left(R_{jk}^{j}\right) + \sum_{(l,i)\in p_{jk}} \frac{\sqrt{p_{jk}}}{\sqrt{p_{li}}}\left(\bar{h}_{li}^{j}\right)^{H}\left(\bar{h}_{jk}^{j}\right)\right|^{2} + \sigma_{ul}^{2}\left(\frac{tr\left(\psi_{jk}^{j}\right)^{-1}}{p_{jk}\tau_{p}} + \frac{\left\|\bar{y}_{jjk}^{pilot}\right\|^{2}}{p_{jk}\tau_{p}^{2}}\right)}\right)$$

(3. 103)

3.6.2. UL SE using MMSE Estimator

From section 3.3.2, we have the expression for $h_{jk}^{j} = \hat{h}_{jk}^{j,MMSE}$ is given by

$$h_{jk}^{j} = \hat{h}_{jk}^{j,MMSE} = \bar{h}_{jk}^{j} + \sqrt{p_{jk}}R_{jk}^{j}\psi_{jk}^{j}\left(y_{jjk}^{pilot} - \hat{y}_{jjk}^{pilot}\right) \tag{3. 104}$$

From equation 3.95, the value of $E\left\{\left|v_{jk}^{H}h_{li}^{j}\right|^{2}\right\}$ in the case of MMSE channel estimator given by the following expression. We assume $\hat{h}_{jk}^{j} = \hat{h}_{jk}^{j}\left(\left(\hat{h}_{jk}^{j}\right)^{H}\hat{h}_{jk}^{j}\right)^{-1}$

$$E\left\{\left|v_{jk}^{H}h_{li}^{j}\right|^{2}\right\}=E\left\{\left|\left(\hat{h}_{j}\right)^{H}h_{li}^{j}\right|^{2}\right\}=E\left\{\left|\left(\bar{h}_{jk}^{j}+\sqrt{p_{jk}}R_{jk}^{j}\psi_{jk}^{j}\left(y_{jjk}^{pilot}-\hat{y}_{jjk}^{pilot}\right)\right)^{H}h_{li}^{j}\right|^{2}\right\} \tag{3. 105}$$

$$E\left\{\left|v_{jk}^{H}h_{li}^{j}\right|^{2}\right\}=p_{jk}\tau_{p}tr\left(R_{li}^{j}R_{jk}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)+p_{jk}\tau_{p}\left(\bar{h}_{l}\right)^{H}R_{jk}^{j}\psi_{jk}^{j}R_{jk}^{j}\bar{h}_{li}^{j}+\left(\bar{h}_{l}\right)^{H}R_{li}^{j}\bar{h}_{jk}^{j}+\left|\left(\bar{h}_{j}\right)^{H}\bar{h}_{li}^{j}\right|^{2},(l,i)\in\rho_{jk} \tag{3. 106}$$

$$E\left\{\left|v_{jk}^{H}h_{li}^{j}\right|^{2}\right\}=p_{jk}p_{li}\left|tr\left(R_{li}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)\right|^{2}+2\sqrt{p_{jk}p_{li}}\tau_{p}\operatorname{Re}\left\{tr\left(R_{li}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)\left(\bar{h}_{j}\right)^{H}\bar{h}_{li}^{j}\right\},(l,i)\notin\rho_{jk} \tag{3. 107}$$

If ZF combining with $v_{jk}=\hat{h}_{j}=\hat{h}_{jk}^{j}\left(\left(\hat{h}_{jk}^{j}\right)^{H}\hat{h}_{jk}^{j}\right)^{-1}$ is based on the MMSE estimator then SE value of MMSE estimator can be obtained by substituting equation 3.101 in to equation 3.95. The value of SINR for MMSE estimator was derived by paper (Özdogan et al., 2019). The following expression of SINR for the MMSE estimator was produced after adjusting the equation match with our system.

$$SINR_{jk}^{ul,MMSE}=\frac{p_{jk}^{2}\tau_{p}tr\left(R_{jk}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)+p_{jk}\left|\bar{h}_{jk}^{j}\right|^{2}}{\sum_{l=1}^{L}\sum_{i=1}^{k_{l}}p_{li}\delta_{li}^{ul}+\sum_{(l,i)\in\rho_{jk}\backslash(j,k)}p_{li}\varsigma_{li}^{ul}-p_{jk}\zeta_{jk}^{ul}+\sigma_{ul}^{2}} \tag{3. 108}$$

Where $$\zeta_{jk}^{ul}=\frac{\left|\bar{h}_{jk}^{j}\right|^{4}}{p_{jk}\tau_{p}tr\left(R_{jk}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)+\left|\bar{h}_{jk}^{j}\right|^{2}} \tag{3. 109}$$

$$\delta_{li}^{ul}=\frac{p_{jk}\tau_{p}tr\left(R_{li}^{j}R_{jk}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)+p_{jk}\tau_{p}\left(\bar{h}_{li}^{j}\right)^{H}R_{jk}^{j}\psi_{jk}^{j}R_{jk}^{j}\bar{h}_{li}^{j}+\left(\bar{h}_{li}^{j}\right)^{H}R_{li}^{j}\bar{h}_{jk}^{j}+\left|\left(\bar{h}_{jk}^{j}\right)^{H}\bar{h}_{li}^{j}\right|^{2}}{p_{jk}\tau_{p}tr\left(R_{jk}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)+\left|\bar{h}_{jk}^{j}\right|^{2}} \tag{3. 110}$$

$$\varsigma_{li}^{ul}=\frac{p_{jk}p_{li}\left|tr\left(R_{li}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)\right|^{2}+2\sqrt{p_{jk}p_{li}}\tau_{p}\operatorname{Re}\left\{tr\left(R_{li}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)\left(\bar{h}_{jk}^{j}\right)^{H}\bar{h}_{li}^{j}\right\}}{p_{jk}\tau_{p}tr\left(R_{jk}^{j}\psi_{jk}^{j}R_{jk}^{j}\right)+\left|\bar{h}_{jk}^{j}\right|^{2}} \tag{3. 111}$$

We can now easily obtain the expression of SE using equation 3.109 after determining the expression of SINR for our proposed multi cell massive MIMO system. To do this, we simply need to substitute the value of SINR variable in equation 3.109 with the expression for it derived in equation 3.105. First, we rewrite equation 3.98 so that it now reads as the LS estimator. The SINR value of MMSE estimator is written as follows.

$$SE_{jk}^{ul,MMSE} = \left(1 - \frac{kf}{\tau_c}\right)\log_2\left(1 + SINR_{jk}^{ul,MMSE}\right) \quad (3.\ 112)$$

$$SE_{jk}^{ul,MMSE} = \left(1 - \frac{kf}{\tau_c}\right)\log_2\left(1 + \frac{p_{jk}^2 \tau_p tr\left(R_{jk}^j \psi_{jk}^j R_{jk}^j\right) + p_{jk}\left|\bar{h}_{jk}^j\right|^2}{\sum_{l=1}^{L}\sum_{i=1}^{k_l} p_{li}\delta_{li}^{ul} + \sum_{(l,i)\in\rho_{jk}\setminus(j,k)} p_{li}\varsigma_{li}^{ul} - p_{jk}\zeta_{jk}^{ul} + \sigma_{ul}^2}\right) \quad (3.\ 113)$$

3.6.3. UL SE with EW-MMSE Estimator

From section 3.3.3, we have the expression of estimated channel with EW-MMSE estimator $h_{jk}^j = \hat{h}_{jk}^{j,EW-MMSE}$ will be:-

$$v_{jk}^j = h_{li}^{j,EW-MMSE} = \bar{h}_{li}^j + \sqrt{p_{li}} D_{li}^j \Lambda_{li}^j (y_{jli}^{pilot} - \bar{y}_{jli}^{pilot}) \quad (3.\ 114)$$

From equation 3.95, the value of $E\left\{\left|v_{jk}^H h_{li}^j\right|^2\right\}$ in the case of EW-MMSE channel estimator given by the following expression.

$$E\left\{\left|v_{jk}^H h_{li}^j\right|^2\right\} = E\left\{\left|\left(\hat{h}_{jk}^j\right)^H h_{li}^j\right|^2\right\} = E\left\{\left|\left(\bar{h}_{li}^j + \sqrt{p_{li}} D_{li}^j \Lambda_{li}^j (y_{jli}^{pilot} - \bar{y}_{jli}^{pilot})\right)^H h_{li}^j\right|^2\right\} \quad (3.\ 115)$$

$$E\left\{\left|v_{jk}^H h_{li}^j\right|^2\right\} = p_{jk} p_{li} \tau_p \left(tr\left(D_{li}^j \Lambda_{jk}^j D_{jk}^j\right)\right)^2 + 2\sqrt{p_{jk} p_{li}}\,\tau_p \left(D_{li}^j \Lambda_{jk}^j D_{jk}^j\right) \mathrm{Re}\left(\left(\bar{h}_{jk}^j\right)^H \bar{h}_{li}^j\right), (l,i) \in \rho_{jk}$$

(3. 116)

$$E\left\{\left|v_{jk}^H h_{li}^j\right|^2\right\} = 0, (l,i) \notin \rho_{jk} \quad (3.\ 117)$$

$$E\left\{v_{jk}^H h_{jk}^j\right\} = E\left\{\left(\bar{h}_{li}^j + \sqrt{p_{li}} D_{li}^j \Lambda_{li}^j (y_{jli}^{pilot} - \bar{y}_{jli}^{pilot})\right)^H h_{jk}^j\right\} \quad (3.\ 118)$$

$$E\left\{v_{jk}^H h_{jk}^j\right\} = p_{jk} \tau_p tr\left(D_{jk}^j \Lambda_{jk}^j D_{jk}^j\right) + \left|\bar{h}_{jk}^j\right|^2 \quad (3.\ 119)$$

$$E\left\{\left|v_{jk}^H\right|^2\right\} = tr\left(p_{li} \tau_p D_{jk}^j \Lambda_{jk}^j D_{jk}^j \left(\psi_{jk}^j\right)^{-1} \Lambda_{jk}^j D_{jk}^j\right) + \left|\bar{h}_{jk}^j\right|^2 \quad (3.\ 120)$$

If ZF combining is used as a receiver combining, which gets the channel state information (CSI) with $v_{jk}^j = \hat{h}_j^{j,EW-MMSE} = \hat{h}_{jk}^j \left(\left(\hat{h}_{jk}^j\right)^H \hat{h}_{jk}^j\right)^{-1}$ then the SE value of EW-MMSE estimator is obtained by substituting equation 3.111 into equation 3.95. the value of SINR for EW-MMSE estimator was derived by paper(Özdogan et al., 2019). After we adjust the equation as our system, we obtained the following expression for SINR of EW-MMSE estimator.

$$SE_{jk}^{ul,Ew-MMSE} = \frac{p_{jk}\left(p_{jk}\tau_p tr\left(D_{jk}^j \Lambda_{jk}^j D_{jk}^j\right) + \left|\bar{h}_{jk}^j\right|^2\right)^2}{\sum_{l=1}^{L}\sum_{i=1}^{k_l} p_{li}\mu_{li}^j - p_{jk}\left(p_{jk}\tau_p tr\left(D_{jk}^j \Lambda_{jk}^j D_{jk}^j\right) + \left|\bar{h}_{jk}^j\right|^2\right)^2 + \sigma_{ul}^2\left(tr\left(p_{li}\tau_p D_{jk}^j \Lambda_{jk}^j D_{jk}^j \left(\psi_{jk}^j\right)^{-1} \Lambda_{jk}^j D_{jk}^j\right) + \left|\bar{h}_{jk}^j\right|^2\right)}$$

(3. 121)

Where

$$\mu_{li}^j = E\left\{\left|v_{jk}^H h_{li}^j\right|^2\right\} = p_{jk} p_{li}\tau_p \left(tr\left(D_{li}^j \Lambda_{jk}^j D_{jk}^j\right)\right)^2 + 2\sqrt{p_{jk} p_{li}}\,\tau_p \left(D_{li}^j \Lambda_{jk}^j D_{jk}^j\right) \mathrm{Re}\left(\left(\bar{h}_{jk}^j\right)^H \bar{h}_{li}^j\right), (l,i) \in \rho_{jk}$$

(3. 122)

Then after finding the expression of SINR for our proposed multi cell massive MIMO system, now we can easily find the expression of SE using equation 3.120 we just need to replace the SINR variable of equation 3.120 by the expression for it derived in equation 3.118. Firstly, we re-write equation 3.98 after modifying it for the LS estimator as. The expression of SINR for EW-MMSE estimator Written as follow.

$$SE_{jk}^{ul,EW-MMSE} = \left(1 - \frac{kf}{\tau_c}\right)\log_2\left(1 + SINR_{jk}^{ul,EW-MMSE}\right) \quad (3.\ 123)$$

$$SE_{jk}^{ul,EW-MMSE} = \left(1 - \frac{kf}{\tau_c}\right)\left(\frac{p_{jk}\left(p_{jk}\tau_p tr\left(D_{jk}^j \Lambda_{jk}^j D_{jk}^j\right) + \left|\bar{h}_{jk}^j\right|^2\right)^2}{\sum_{l=1}^{L}\sum_{i=1}^{k_l} p_{li}\mu_{li}^j - p_{jk}\left(p_{jk}\tau_p tr\left(D_{jk}^j \Lambda_{jk}^j D_{jk}^j\right) + \left|\bar{h}_{jk}^j\right|^2\right)^2 + \sigma_{ul}^2\left(tr(\xi) + \left|\bar{h}_{jk}^j\right|^2\right)}\right)$$

(3. 124)

Where $\xi = p_{li}\tau_p D_{jk}^j \Lambda_{jk}^j D_{jk}^j \left(\psi_{jk}^j\right)^{-1} \Lambda_{jk}^j D_{jk}^j$

To mitigate pilot contamination and enhance cell throughput utilize multi cell minimum mean square combining and precoding (W. A. Ali et al., 2020). In our proposed system, we consider LS, MMSE, EW-MMSE channel estimator and ZF combining techniques to mitigate pilot contamination.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

This part, simulation findings are presented in order to demonstrate how a multi cell uplink massive MIMO system can achieve SE in fading environments. We examine various methods for reducing interference and improving the spectral efficiency of multi cell massive MIMO systems. We look at the interference-filtering techniques ZF processing; LS, MMSE, and EW-MMSE channel estimator. In this section, the closed form of SE expressions derived in section three, which evaluated and validated by simulating a massive MIMO cellular networks. We have L^{th} cell setup where each cells covers $\frac{3\sqrt{3}}{2}0.25^2 km^2$.

We consider the effect of different number of user equipment's with in each cells. Each BS antennas separated by $\lambda/2$. It is the space between each BS antennas. The system assigns the user equipment (UE) to the base station (BS. The nominal angle of arrival (AoA) is accompanied by ASD of $=5^0$. We consider the total receiver noise power is $-94dB$ and a shadow fading of $\sigma_{sf}=10$. The spectral efficiency of uplink multi cell massive MIMO cellular networks is studied in this thesis, along with the effects of the number of UE, number of BS antennas, coherence block length, prf, and SNR. This means that UEs in different cells that belong to the same pilot group and occupy the same position in their respective cells will use the same pilot sequences. Increasing the number of orthogonal pilot sequence is a straight forward way to decrease pilot contamination but it reduces the data rate, another mechanism is required to negotiate the pilot contamination problem and required data. Prf is a mechanisem to improve the required throughput by reducing the pilot contamination. To determine the following simulation parameters in table 4.1 we consider different standards. Third Generation Partnership Project (3GPP) standards the values of parameters are:

Table4. 1: List of parameters used to simulate the output of our desired system

Simulation parameters	Value of each parameters
Cell type	Macro cell covers
Coverage Area for each cell	$\frac{3\sqrt{3}}{2}0.25^2\,km^2$
UE to BS separation distance	35m
Carrier frequency	2GHz
Linear detector	Zero Forcing Combining (ZF)
Channel estimator	MMSE, EW-MMSE, LS
Channel path loss model	Log-Normal model
Path loss exponent	3.7 for urban Environment
Number of cells	19
Number of BS antenna	We consider $M \geq 100$
Shadow fading standard deviation	$\sigma_{sf} = 4$ for LOS, $\sigma_{sf} = 10$ for NLOS
Number of UE per cell	We consider $k \geq 10$
Samples per coherence block	200, 300, 400, 500, 800
Pilot reuse factors prf	$f \in \{1,3,4\}$
Uplink transmit power	0.1 Watt
Receiver noise power	-94dBm(thermal noise + noise Figure
Channel gain at $1km$	-148.1dBm
Bandwidth	20MHz
Number of uplink pilot sequence	$\tau_p \geq k \approx \tau_p = k$ for universal pilot reuse $\tau_p = fk$ if prf $f > 1$

Table 4.1 shows values of simulation parameters to simulate the UL SE of proposed system.

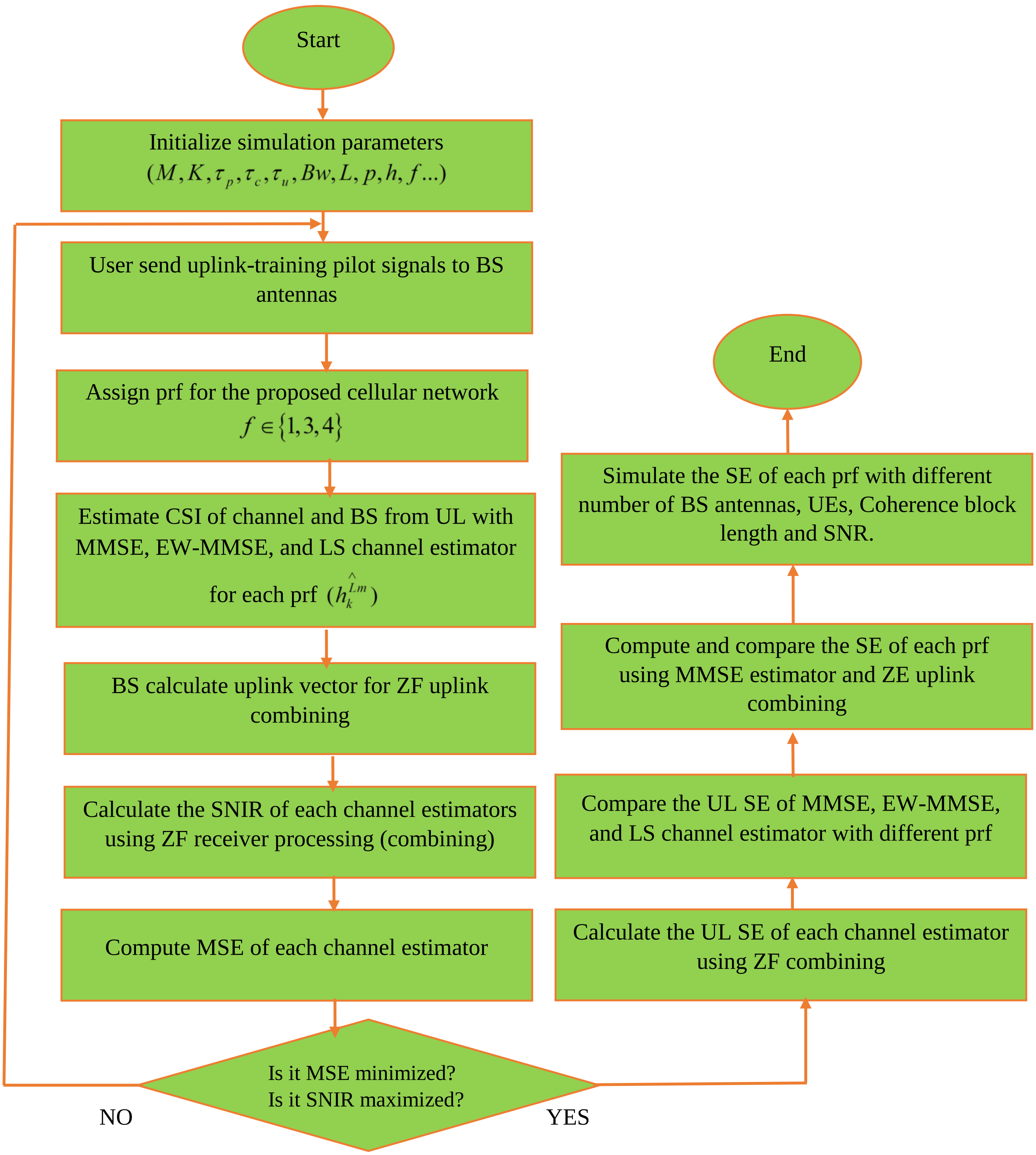

Figure 4. 1: flow chart for spectral efficiency analysis of uplink multi cell massive MIMO networks

4.1. Impact of Pilot Reuse factor (PRF) and number of BS on UL SE of Multi cell Massive MIMO networks

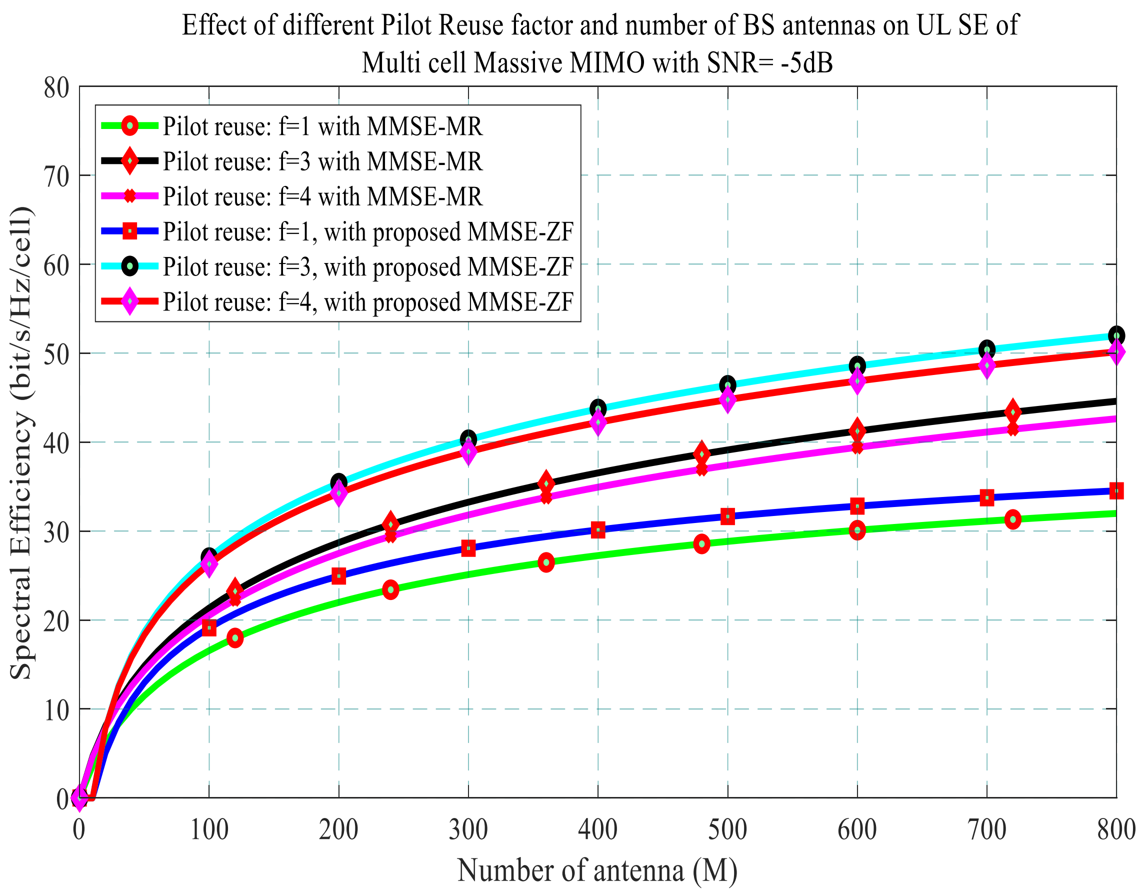

Figure 4.2: Uplink SE of multi cell massive MIMO system under fading channels with different number of BS antennas and prf at SNR=-5dB

In Figure 4.2, we consider a minimum value of SNR and the effect of BS antennas on the spectral efficiency of multi cell massive MIMO networks. When we consider a prf for effective utilization of time frequency resources, a pilot contamination problem will affect the performance of our system. A more efficient method of improving system performance is choosing a prf that gives higher performance. In our proposed multi cell massive MIMO networks for 5G applications with a BS antenna $M \in \{0-800\}$ with minimum SNR value and $k \geq 10$ for each cell we generate a maximum SE of the system which is 54bit/s/Hz/cell with MMSE channel estimators and Zero forcing uplink combining. The new SE in Figure 4.2 is four times the spectral efficiency of 4G networks as stated by telecommunication sectors. In Figure 4.2, prf of f=3 has a better spectral efficiency than other prf. This figure demonstrates the uplink spectral efficiency of multi cell massive MIMO networks under rician fading and the effect of pilot contamination and performance improvement.

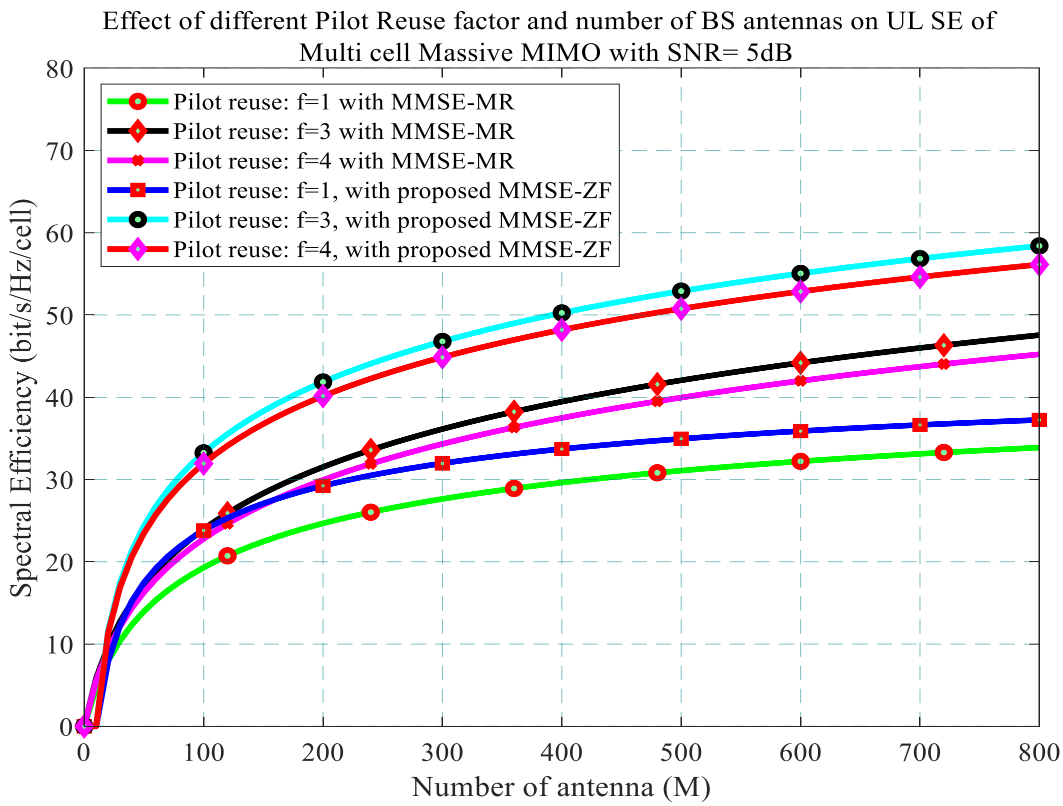

Figure 4.3: Uplink SE of multi cell massive MIMO system under fading channels with different number of BS antennas and prf at SNR=5dB

Figure 4.3 illustrates how the uplink spectral efficiency of massive multi-cell MIMO networks varies with different pilot reuse factor (prf) varying values of BS antennas. Figure 4.3 demonstrates the linear impact of the SNR and the number of BS antennas on UL SE. The uplink SE in Figure 4.3 shows enhanced as compared with Figure 4.2 with SNR value of 5dB. For any value of SNR and BS antenna numbers a prf $f = 3$ has higher UL SE than other prf $f \in \{1, 4\}$. Figure 4.3 illustrates the UL SE of massive multi-cell MIMO networks under Rician fading channels, with variations in the number of base station (BS) antennas, signal-to-noise ratio (SNR) values, and prf. The study uses the prf in conjunction with MMSE channel estimators and ZF uplink combining techniques to reduce pilot contamination and, as a result, indirectly enhance the uplink spectral efficiency. The proposed work MMSE-ZE with a pilot reuse factor (prf) f=3 has 58bit/s/Hz/cell uplink spectral efficiency. This shows a great improvement of UL SE of a cellular network under the effect of shadowing and coherence interference.

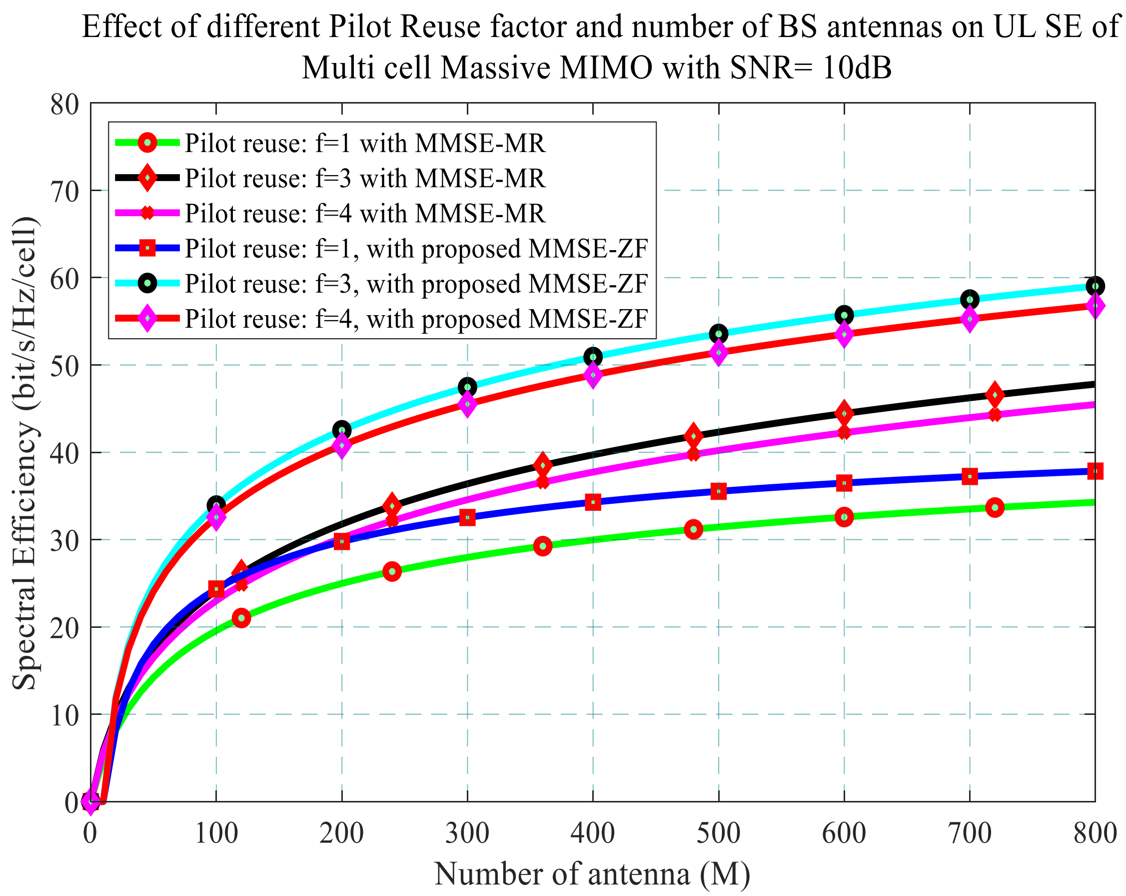

Figure 4. 4: Uplink SE of multi cell massive MIMO system under fading channels with different number of BS antennas and prf at SNR=10dB

Figures 4.2, 4.3, and 4.4 illustrate the total uplink spectral efficiency, averaged over multiple shadow fading realizations and various numbers of base station (BS) antennas. Our study considers a prf to determine the uplink spectral efficiencies of massive multi-cell MIMO systems in fading environments. The antenna gain is closely associated with the signal-to-noise ratio (SNR) of the received signals. The previous graphs demonstrate how the number of base station (BS) antennas, signal-to-noise ratio (SNR), and prf affect UL SE. These figures illustrate a simulation that validates the theoretical notion of uplink spectral efficiency in massive multi-cell MIMO communication systems. One way to reduce the interference of multi-cell massive MIMO cellular networks is to determine the prf that offers better SE. As we see the above figures, a prf $f = 3$ has better SE than the other two prf. In general, enhancing the uplink spectral efficiency (SE) is possible by increasing the number of base station (BS) antennas and improving the signal-to-noise ratio (SNR) of the system. Potentially $prf\ f=3$ generate a maximum SE. a pilot reuse factor $(prf)\ f=4$ also has a better performance than a universal prf, which is $f=1$.

Table 4. 2: Effect of SNR and number of BS antenna on UL SE

S.N	SNR values	Maximum SE at f=1 with proposed MMSE-ZF	Maximum SE at f=3 with proposed MMSE-ZF	Maximum SE at f=4 with proposed MMSE-ZF
1	-5dB	36	54	50
2	5dB	36	58	56
3	10dB	38b	60	58
S.N	SNR values	Maximum SE at f=1 with MMSE-MR	Maximum SE at f=3 with MMSE-MR	Maximum SE at f=4 With MMSE-MR
1 2	-5dB 5dB	32 33	44 46	42 44
3	10dB	35	48	46

Table 4.2 shows the numerical value of the uplink Spectral efficiency of multi cell massive MIMO cellular networks under fading environment. In this tthesis we consider the LOS and NLOS component of the cellular system. we consider a rician fading channel models to simulate all the desiored results.

4.2. Impact of different Pilot Reuse factor and number of UEs at different on UL SE

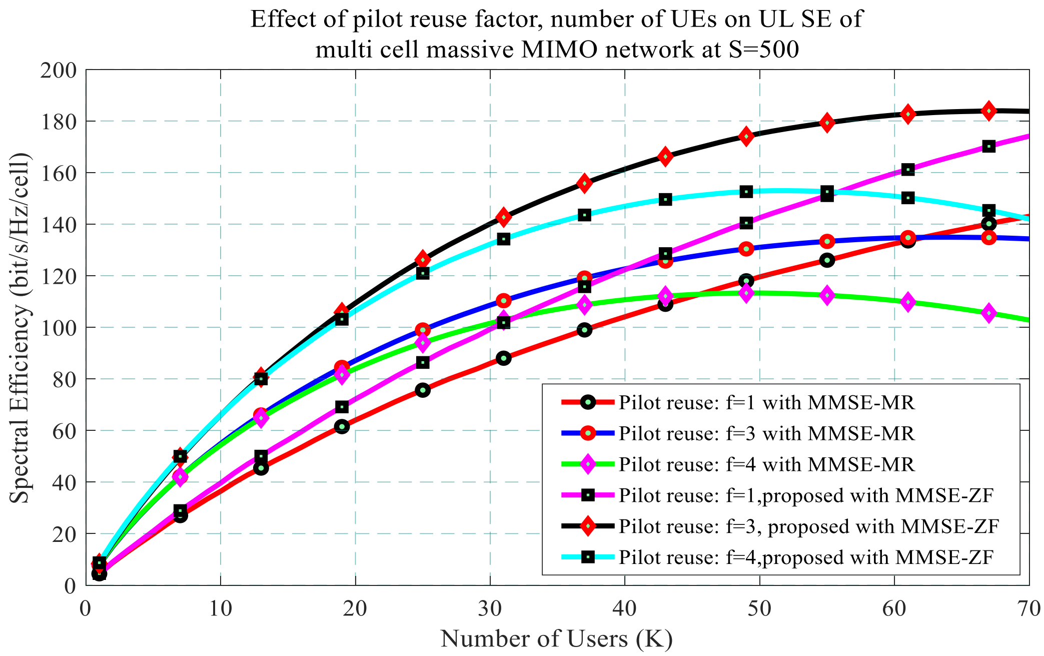

Figure 4. 5: Uplink SE of multi cell Massive MIMO system under fading channels with different number of users and different prf at coherence block length of S=500

Figure 4.5 shows the effect of $prf \quad f \in \{1,3,4\}$ and number of UEs with a coherence block of S=500 on the spectral efficiency of Uplink massive MIMO systems under fading channels. The above figure 4.5 demonstrate the UL spectral efficiency (SE) for $prf \; f \in \{3,4\}$ are saturated for a UEs ranges from 50 to 70, due to the presence of interference. For UEs, ranges from zero to 55 have improved SE as stated in IMT-advanced. The saturated SE for a UEs ranges from zero to 55 are 145, 181 and 155 for $prf \quad f \in \{1,3,4\}$ respectively. As we seen in figure 4.5, $prf \quad f = 3$ can improve the spectral efficiency of our desired systems with UEs up to 70. In figure 4.5, we conclude that for a large number of UEs using a universal $prf \quad f = 3$ is an important way to handle better SE for desired cellular networks. While for a UEs is up to 70 using a $prf \quad f = 3$ has a great potential to improve the spectral efficiency of multi cell massive MIMO networks. According to limited resource of TDD protocols, using a considerable prf and user equipment is an important way to improve its performance.

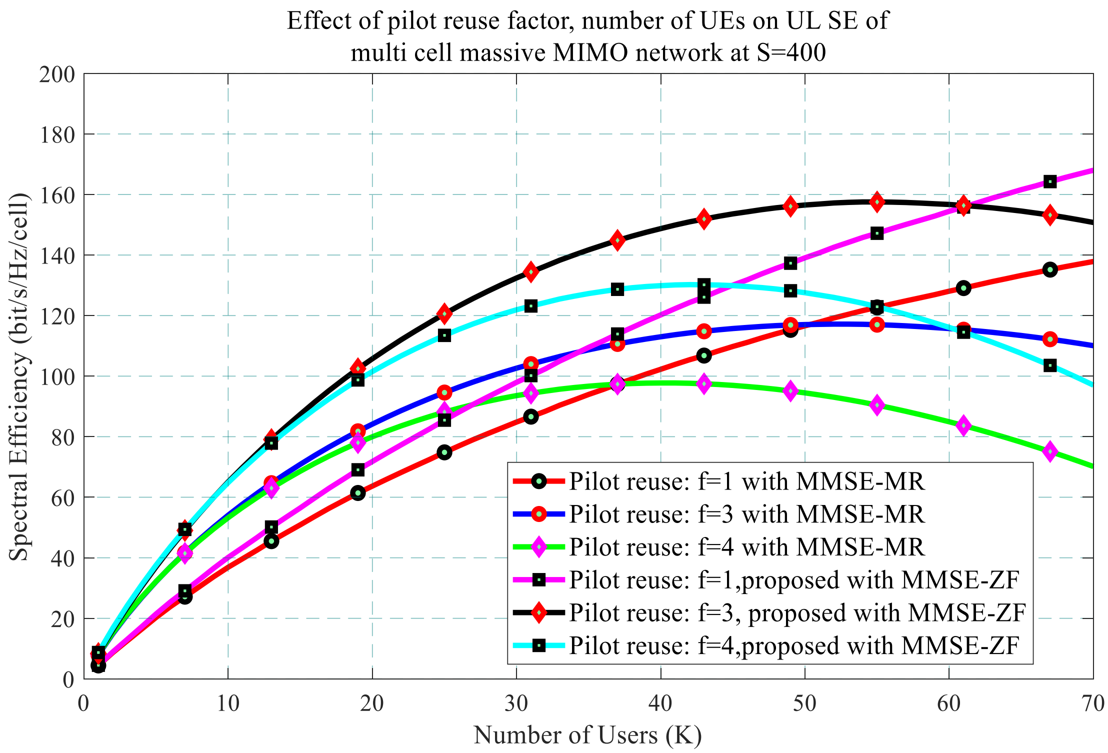

Figure 4.6: Uplink SE of multi cell Massive MIMO system under fading channels with different number of users and different prf at coherence block length of S=400

Figure 4.6 demonstrates the uplink SE of multi-cell massive MIMO systems for three different prf with a coherence block length of S = 400, as the number of UE within the cells varies. The sole difference between Figure 4.5 and Figure 4.6 is the allocation of coherence block length. Figures 4.5 and 4.6 demonstrate how the coherence block length values affect the uplink spectral efficiency. The results suggest that the spectral efficiency increases as the coherence block length values increase. As the value of coherence block length increases, the SE becomes more efficient and improved. If we have higher values of coherence block length, it is easy to allocate the pilot sequences for channel estimation and uplink data transmission. As we seen in figure 4.6 a UE ranges from 0 to 40, the maximum SE of each prf $f \in \{1,3,4\}$ is 125,135.5 and 150 respectively. However, for large number of users with in the desired system, still a universal prf $f = 1$ is dominant with higher Spectral efficiency. While prf $f \in \{3,4\}$ becomes minimum for higher number of UEs.

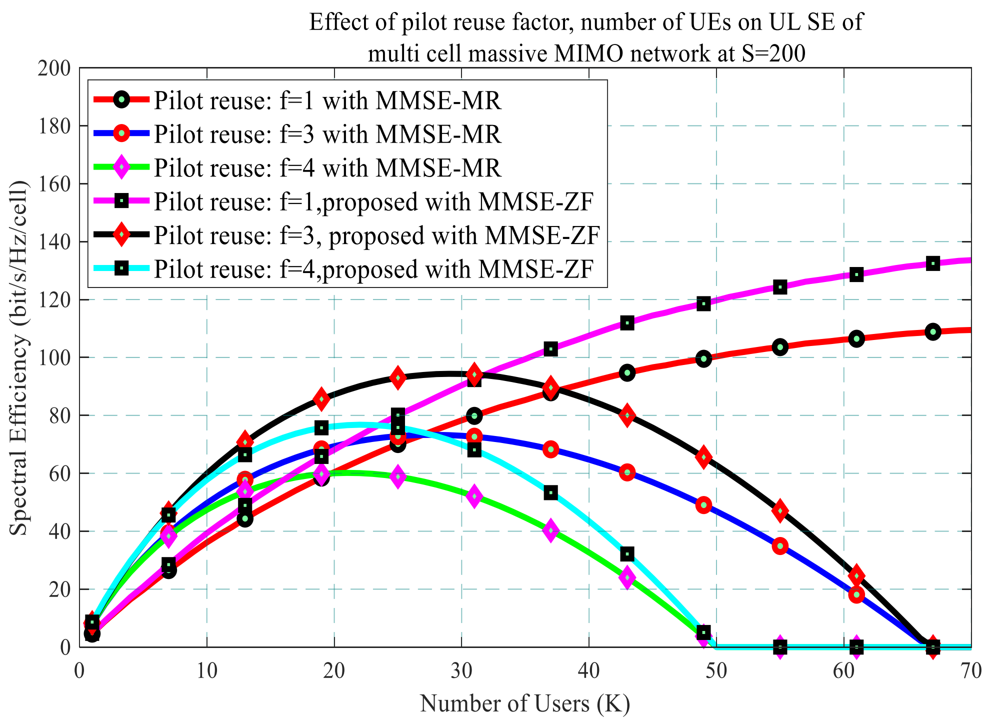

Figure 4.7: Uplink SE of multi cell Massive MIMO system under fading channels with different number of users and different prf at coherence block length of S=200

Figures 4.5, 4.6, and 4.7 illustrate the impact of prf, number of users, and coherence block length on the uplink spectral efficiency of massive multi-cell MIMO networks. As demonstrated, allocating more coherence blocks in the above figures has a significant potential to improve the spectral efficiency (SE) of the desired multi-cell cellular networks. Since time and frequency resources are limited, alternative methods must be explored to enhance the uplink spectral efficiency (SE) of multi-cell massive MIMO systems. Determining the number of users and the prf within a cellular network is one such strategy, it can improve the spectral efficiency of the cellular environment. In thus simulated graph, mainly we concern on which prf have a maximum spectral efficiency for a particular UEs. As the figure shows a cellular system with $k \le 30$ and a $prf\ f = 3$, have a maximum SE than the other prf with different number of coherence block length. In order to design a particular network having a multi cell and $k \le 30$, using a $prf\ f = 3$ have a great role to improve the uplink spectral efficiency and their area throughput. While a $prf\ f = 1$ have a linear effect on the uplink SE of multi cell massive MIMO networks with an increased number of UE, especially for a UE $k > 30$. This shows that as the number of user equipment's are increased the interference within a desired network will be increased. So using a universal $prf \quad f = 1$ have a positive effect on the SE of multi cell massive MIMO networks when we consider large number of users.

Table 4. 3: Effect of code block length and UEs on SE of multi cell massive MIMO system under fading channels

Maximum SE (bit/s/Hz/cell)when $K \le 30$ With proposed MMSE-ZF					Maximum SE(bit/s/Hz/cell) when $K > 30$ With proposed MMSE-ZF		
No	Coherence block length	f=1	f=3	f=4	f=1	f=3	f=4
1	S=200	68	98	78	135	≈ 0	≈ 0
2	S=400	125	150	135	155	150	100
3	S=500	145	181	155	170	181	155
Maximum SE (bit/s/Hz/cell)when $K \le 30$ With MMSE-MR					Maximum SE(bit/s/Hz/cell) when $K > 30$ With MMSE-MR		
No	Coherence block length	f=1	f=3	f=4	f=1	f=3	f=4
1	S=200	65	75	60	110	≈ 0	≈ 0
2	S=400	85	100	90	140	118	100
3	S=500	80	115	100	140	138	115

Table 4.2 summarizes the uplink spectral efficiency (SE) results from Figures 4.5, 4.6, and 4.7. It can show the effect of $prf \quad f \in \{1,3,4\}$, code block length and UEs on the uplink Spectral efficiencies of multi cell massive MIMO networks under fading channels. The table shows that a $prf \ f = 3$ for $k \le 30$ and code block length $S \in \{200,400,500\}$ and $M = 1000$ have an enhanced uplink SE than the other $prf \ f \in \{1,4\}$. In addition, $f = 4$ for very small number of UE have a better SE than a $prf \ f = 1$. The numerical value of the uplink SE of our desired system on the above table shows that the number of coherence block length have a linear effect on the enhancement of SE. due to limited resource of a system we consider another way of enhancing the spectral efficiency of our desired system, that is channel estimation and prf. For a UE $k \le 30$, different values of coherence code block length of

$S \in \{200, 400, 500\}$ and $M = 1000$ system with a prf of $f = 1$ has a great role to validate the enhancement for the SE of our desired system. Generally, the above three figure shows that a network with $k \le 30$ and code block length $S \in \{200, 400, 500\}$ and $M = 1000$ with a prf have greater uplink SE than other prf $f \in \{1, 4\}$.

4.3. Effect of different Pilot Reuse factor and number of BS antennas different UEs on UL SE

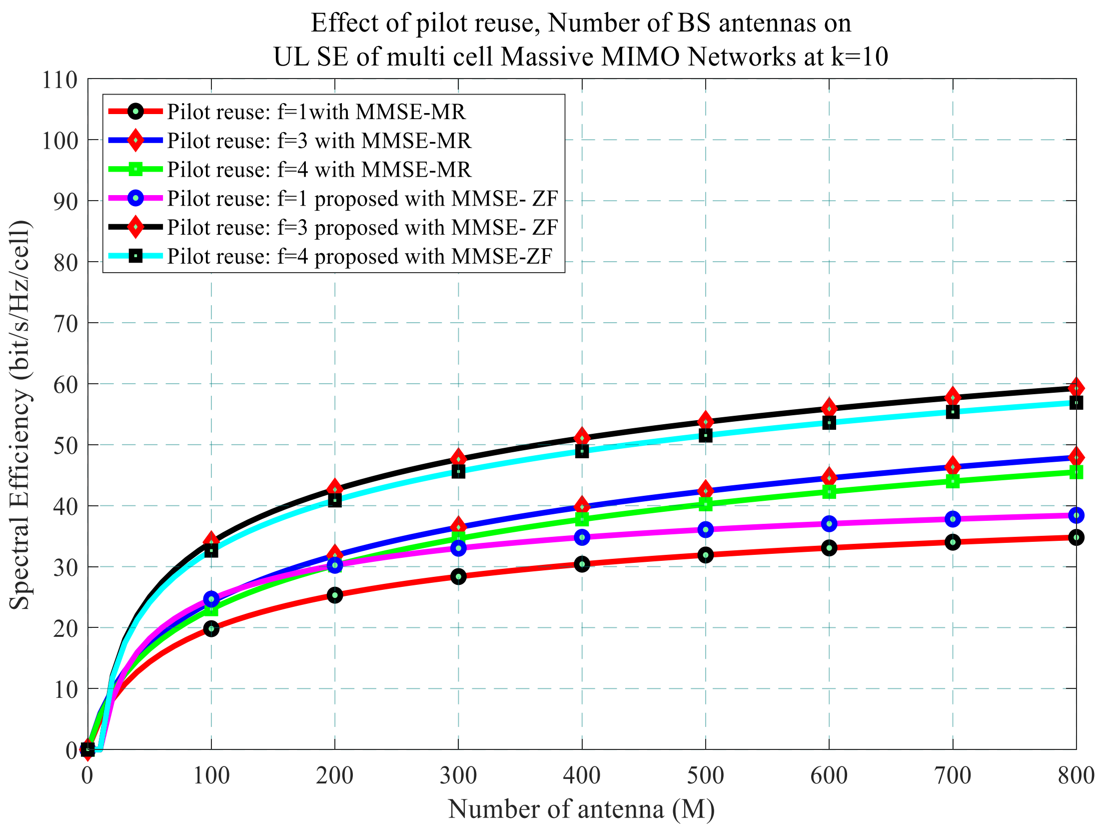

Figure 4. 8: Effect of different prf and number of BS antennas on the UL SE of multi cell massive MIMO network under fading channels at k=10

Figure 4.8 describes the uplink spectral efficiency (SE) of multi-cell massive MIMO networks under fading channels for different prf while varying the number of base station (BS) antennas, using a user equipment (UE) of k = 10. In figure 4.8, we consider a BS antenna ranges from 0 to 1000 and a UEs of k=10 for three different prf of $f \in \{1, 3, 4\}$. The graph presented in Figure 4.8 suggests that a prf of f=3 has a greater potential to improve the overall system's spectral efficiency.

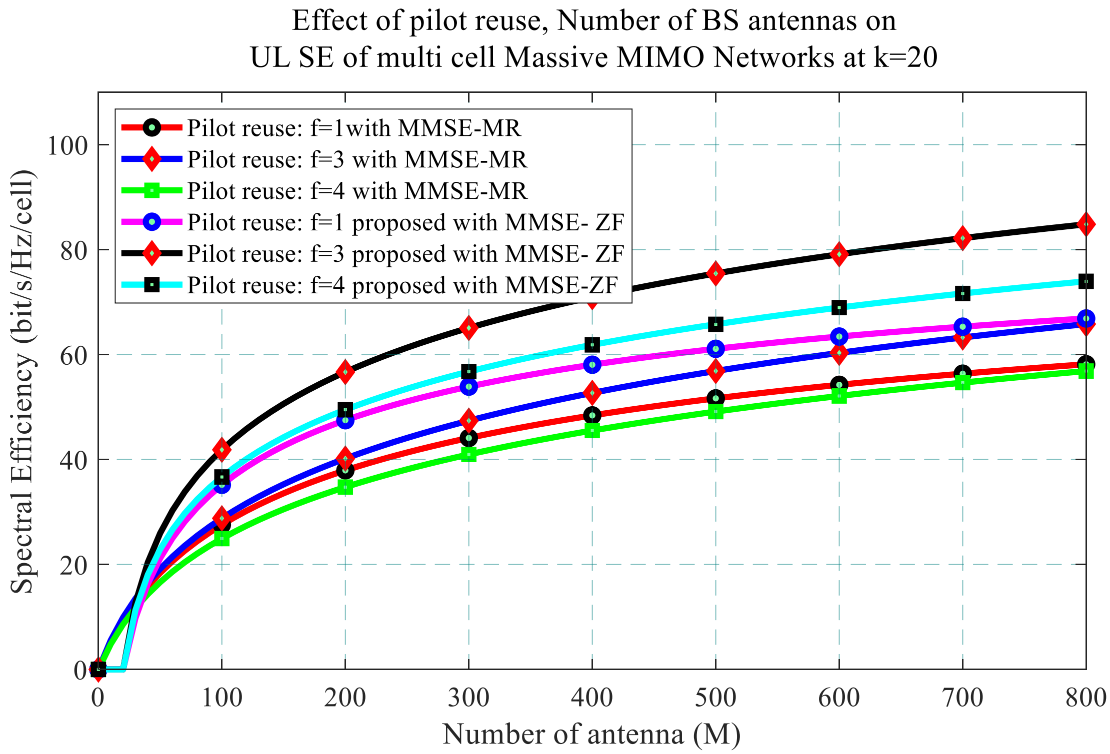

Figure 4.9: The Effect of different prf and number of BS antennas on the Uplink SE of multi cell massive MIMO network under fading channels at k=20

Figure 4.9 shows the corresponding spectral efficiency of our desired system for three different prfs of $f \in \{1,3,4\}$ for a UEs of $k = 20$. In this figure, we consider a coherence block length $\tau_c = 200$. As the number of users increase within the cell of a desired cellular network the spectral efficiency of a universal prf $f = 1$ becomes maximal. In figure 4.9, the SE of a prf $f \in \{1,4\}$ have a little difference for less number of antennas. However, they have same spectral efficiency for higher number of BS antenna numbers. A prf $f = 3$ still have a maximum spectral efficiency as compared with other prf. For a UEs $k = 20$ and a BS antenna ranges from 0 to 1000 the maximum spectral efficiency of different prf $f \in \{1,3,4\}$ becomes 60bit/s/Hz/cell, 70bit/s/Hz/cell and 60bit/s/Hz/cell respectively. As the above graph indicates that, the spectral efficiency between a prf of $f \in \{3,4\}$ have a little difference between them these two prf are more efficient and maximum Spectral efficiency (SE) with small number of users. A universal prf is more effective for large number of users within a desired cell of cellular networks.

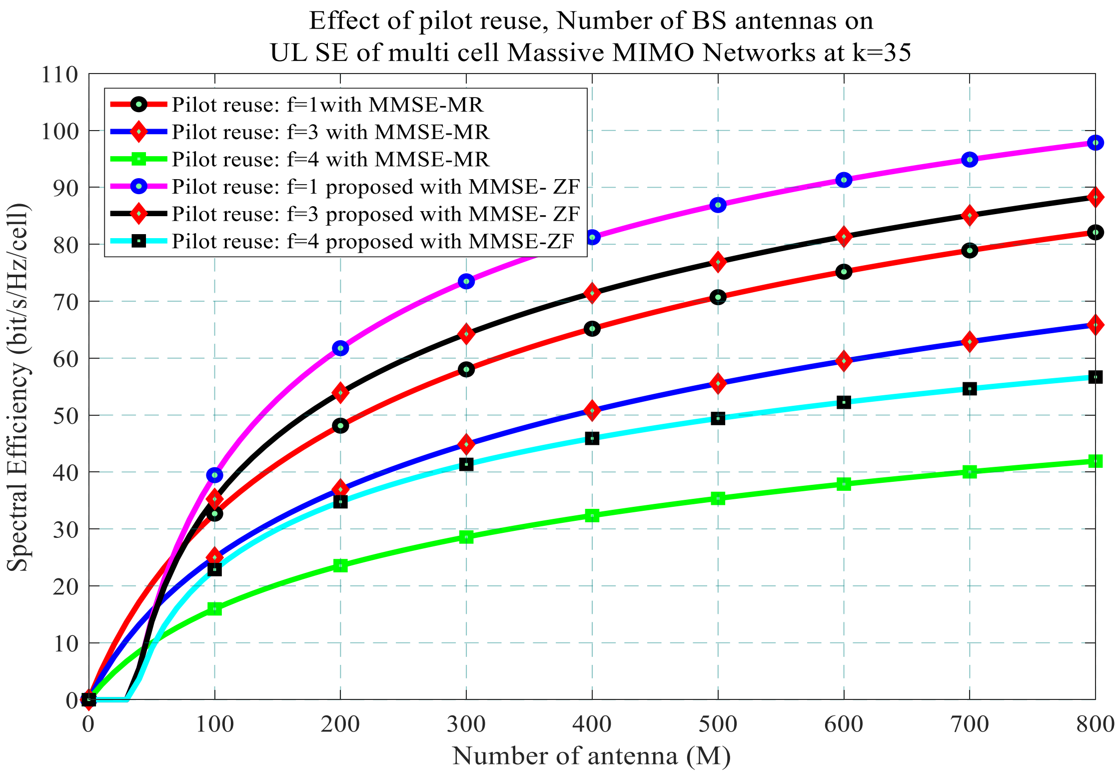

Figure 4.10: The Effect of different prf and number of BS antennas on the Uplink SE of multi cell massive MIMO network under fading channels at k=35

In this section, we consider the effect of different number of users and an optimal number of BS antennas on the spectral efficiency of three different prf for uplink multi cell massive MIMO networks. In order to simulate figure 4. 10 we consider UEs $k = 35$, 0 to 800 range of BS antenna numbers and a coherence block length of 200 for 3 different prf $f \in \{1,3,4\}$. The maximum scheduled users for different prf given by $k = \frac{\tau_c}{2f}$. For a coherence block length $\tau_c = 200$ the scheduled UEs for those prf are $k = 100, k = 34$ and $k = 25$ respectively. Those users indicate that each pilot reuse yields their maximum spectral efficiency with respect to the scheduled user numbers. In figure 4.10, the spectral efficiency of a prf $f = 1$ yields a maximum Spectral efficiency as compare with other prf $f \in \{3,4\}$. In figure 4.10 the optimal spectral efficiency of these prf $f \in \{1,3,4\}$ is 87, 70bit/s/Hz/cell and 47 respectively.

Table 4. 4: Numerical results of UL SE of three different prf

Maximum UL SE for different prfs with proposed MMSE-ZF				
No	Number of Users	f=1	f=3	f=4
1	K=10	38	64	60
2	K=20	70	90	78
3	K=35	100	90	60
Maximum uplink Spectral Efficiency for different $prfs$ with proposed MMSE-MR				
No	Number of Users	f=1	f=3	f=4
1	K=10	38	50	48
2	K=20	60	70	60
3	K=35	85	75	45

Table 4.3 demonstrates the maximum uplink spectral efficiency of our proposed system with different number of users for those three prf.

4.4. Effect of different number of BS antennas and UEs at different values of coherence block length on UL SE

Figure 4.11 shows the uplink SE of multi cell massive MIMO systems vs number of UEs under fading channels with a coherence block length of S=500. As we seen in figure 4.11 the number of BS antenna have a great potential to improve the SE of multi cell massive MIMO networks. Due to the technique of spatial multiplexing between the UEs and BS antennas, the SE will be improving.

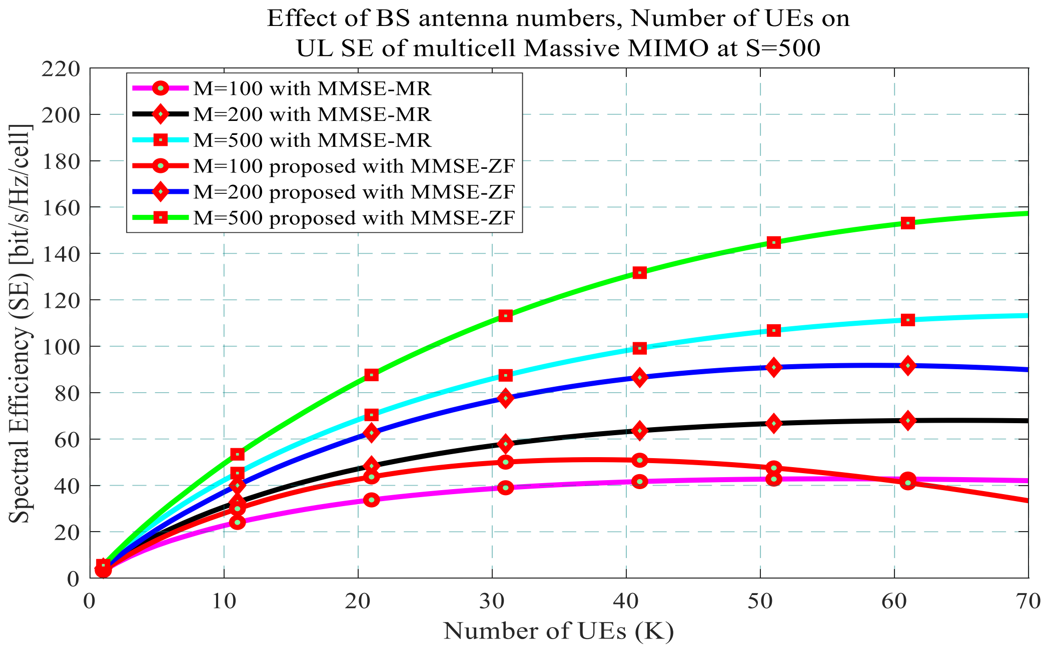

Figure 4.11: Uplink SE of multi cell Massive MIMO system under fading channels VS Number of UEs with different number of BS antennas at coherence block of S=500

In figure, 4.11 we can simulated the expected value of SE for 5G cellular networks. The maximum uplink spectral efficiency of multi cell massive MIMO network for different antenna numbers $M \in \{100, 200, 500\}$ is 55, 98 and 158 UL SE respectively. As the name suggested that massive MIMO network is a cellular network with higher number of BS antenna numbers. The theoretical concept of massive MIMO network is realize by figure 4.11. As we see in figure 4.11, massive number of BS antennas efficiently enhance the spectral efficiency as compared with lower number of BS antennas.

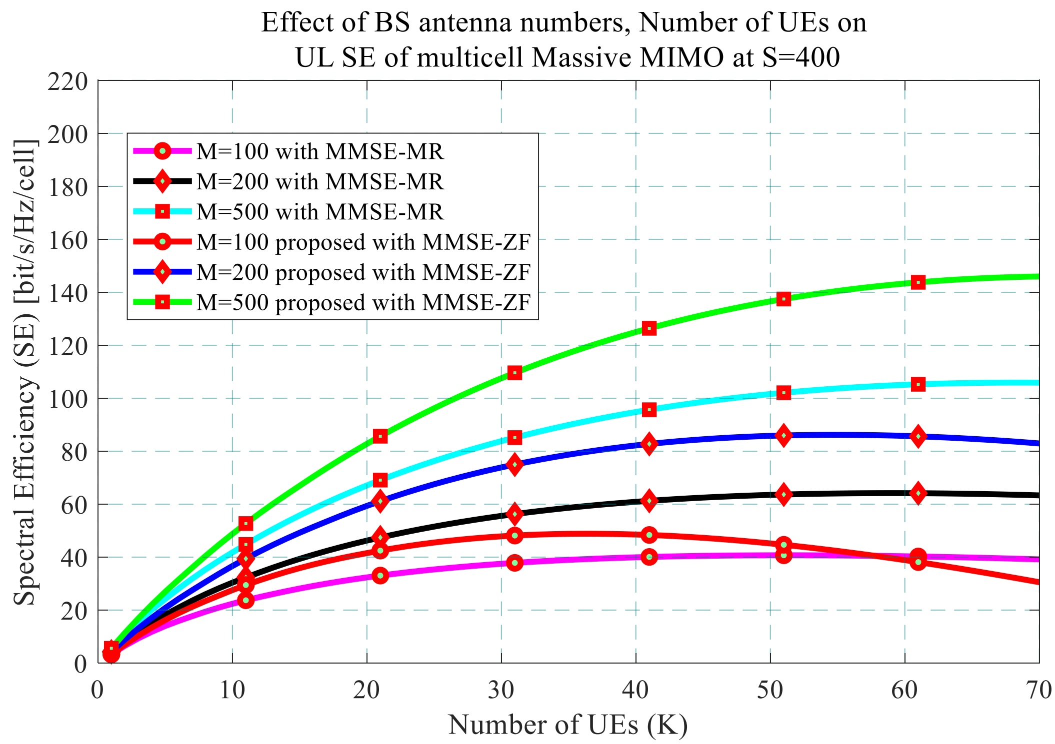

Figure 4. 12: Uplink SE of multi cell Massive MIMO system under fading channels VS Number of UEs with different number of BS antennas at coherence block of S=400

Figure 4.12 illustrates the uplink spectral efficiency (SE) of multi-cell massive MIMO systems for different numbers of user equipment (UE) and base station (BS) antennas, using a coherence length of S = 400. The only distinction between Figure 4.11 and Figure 4.12 is the allocation of the coherence block length of S = 400. To simulate these figures, the study employed a UE of k = 70 and various coherence block lengths. Additionally, Figure 4.12 highlights the impact of antenna numbers on the uplink SE of massive MIMO networks.

In order to design a particular cellular network, determining a considerable user distribution, antenna numbers and time frequency resource is the best way to analyze the performance of the systems. For a limited resource of time and frequency M=400 have a higher SE for a desired number of user. As shown in figure 4.12 the spectral efficiency becomes saturate as the number of users increase. For a coherence block length of S=400 the maximum Spectral Efficiency for different number of BS antenna numbers $M \in \{100, 200, 500\}$ is 42, 80, and 135 respectively. Generally as the value of coherence block increase the spectral efficiency also increase.

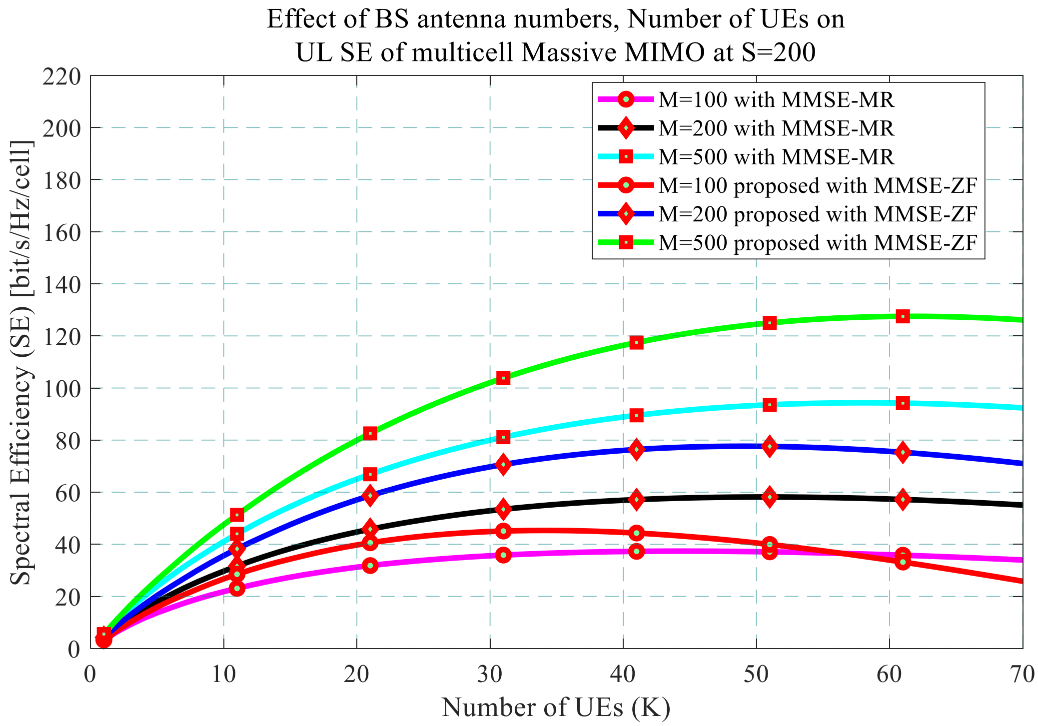

Figure 4.13: Uplink SE of multi cell Massive MIMO system under fading channels VS Number of UEs with different number of BS antennas at coherence block of S=200

Figure 4.11, 4.12 and figure 4.13 shows the effect of UE, different number of BS antennas with different numbers of coherence block length on the UL SE. For the above three graphs we consider 70 UEs, $M \in \{100, 200, 500\}$ and $S \in \{400, 500, 800\}$ with fading environment. As shown in figure 4.13 maximum Spectral efficiency is produced with a base station M=500 and coherence block length of 200. These findings suggest that a massive number of base station (BS) antennas and longer coherence block lengths have significant potential to enhance the spectral efficiency of multi-cell massive MIMO systems. Additionally, user equipment (UE) also has a positive impact on the spectral efficiency of these networks. However, increasing the number of UEs may negatively affect the performance of massive MIMO networks with a fixed number of BSS antennas. For a coherence block length of S = 200, the maximum uplink spectral efficiency can be achieved with M = 500.

4.5. Effect of different Pilot Reuse factor and three different channel Estimators with different values of coherence block length on UL SE

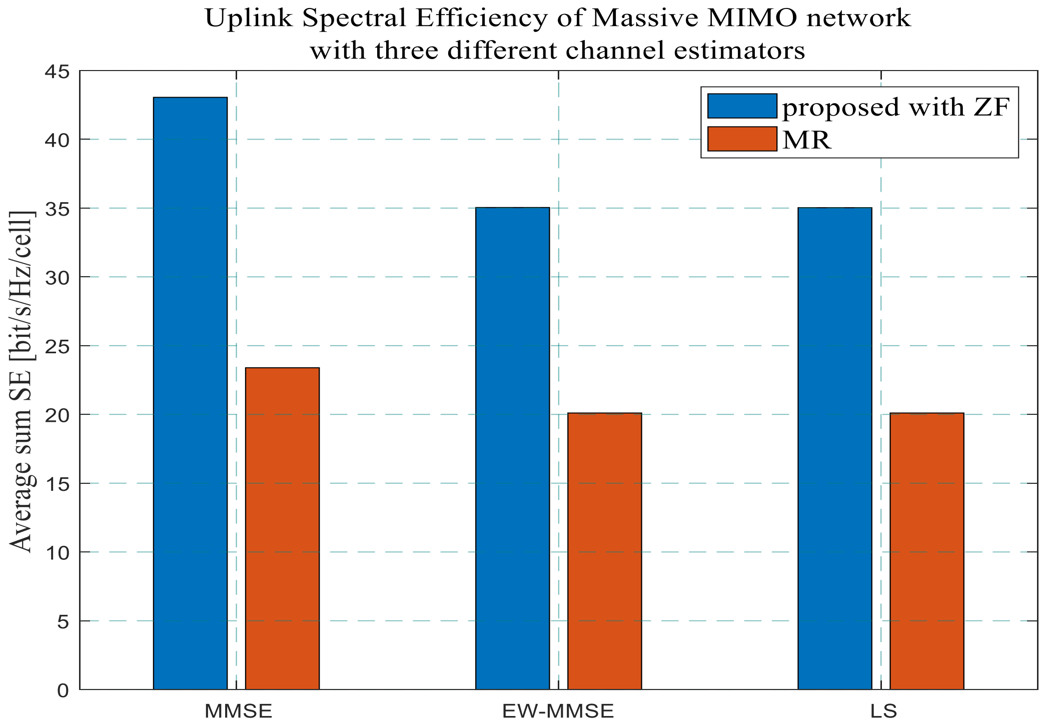

Figure 4.14: Average UL sum SE of multi cell massive MIMO network when using MMSE, EW-MMSE LS channel estimators and a prf of f=3

The thesis investigates the uplink spectral efficiency of a multi-cell massive MIMO network using MMSE, EW-MMSE, and LS channel estimators with zero-forcing (ZF) uplink combining and a prf of f = 3. Figure 4.14 presents the uplink spectral efficiency achieved with each channel estimator, where MMSE-ZF with a prf of f = 3 achieves the highest uplink spectral efficiency of 43.5, while EW-MMSE-ZF and LS-ZF with a prf of f = 3 achieve 35 SE each. ZF uplink combining is employed in the proposed system to suppress coherence interference. The results indicate that the uplink spectral efficiency of a massive multi-cell MIMO network can be enhanced by using a prf of f = 3, a MMSE channel estimator, and the ZF uplink combining technique under a Rician fading channel.

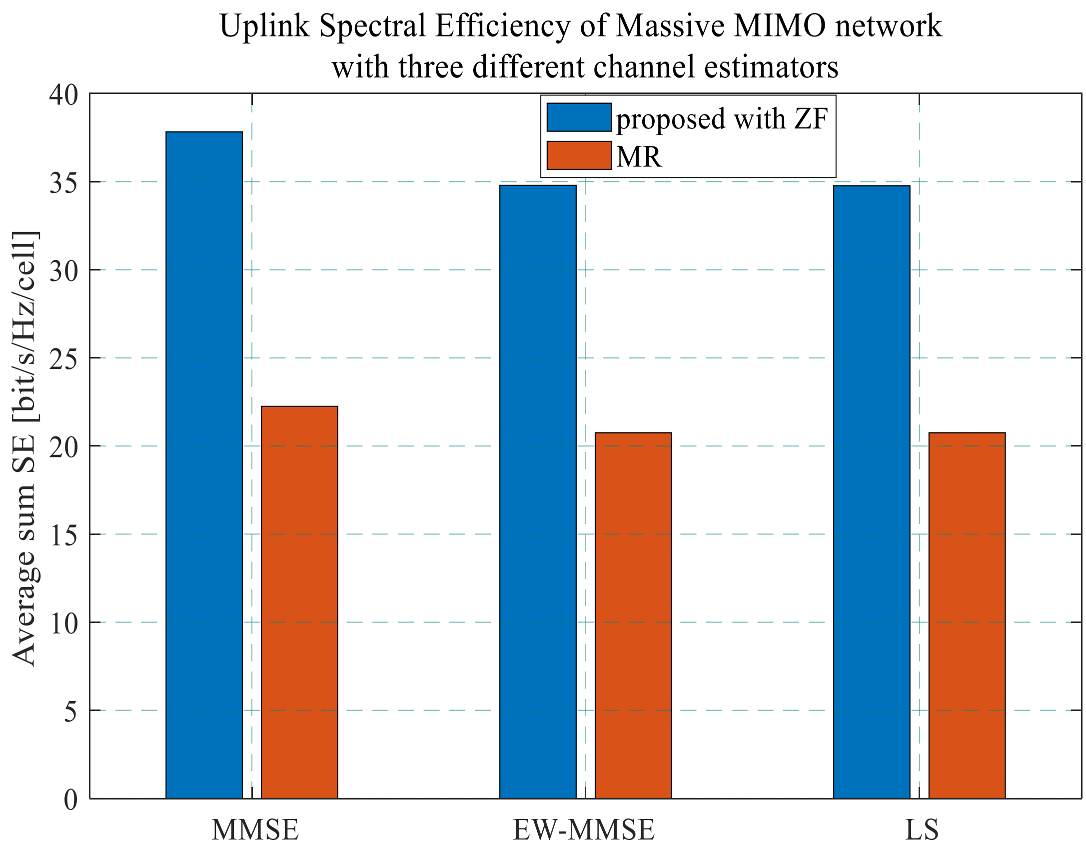

Figure 4. 15: Average UL sum SE of multi cell massive MIMO network when using MMSE, EW-MMSE LS channel estimators and a prf of f=4

Figure 4.15 illustrates the uplink spectral efficiency of a multi-cell massive MIMO network using MMSE, EW-MMSE, and LS channel estimators with zero-forcing (ZF) uplink combining and a prf of f = 4. In this figure, the uplink spectral efficiency achieved using MMSE-ZF with a prf of f = 4 is 37.5, while the uplink spectral efficiency of EW-MMSE-ZF and LS-ZF with a prf of f = 4 is 34.4 SE each. Even for a prf of f = 4, the MMSE channel estimation technique remains effective in suppressing coherence interference and enhancing the uplink spectral efficiency of a multi-cell massive MIMO system. The use of a ZF linear uplink combiner is also beneficial for suppressing coherence interference.

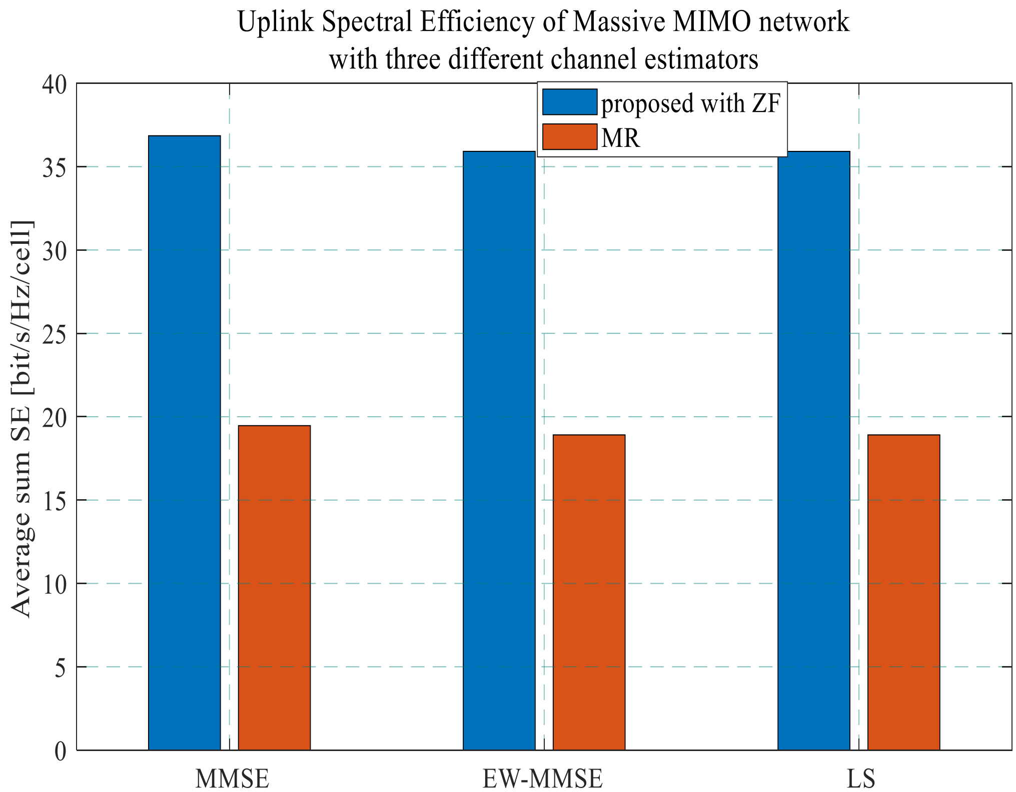

Figure 4.16Average UL sum SE of multi cell massive MIMO network when using MMSE, EW-MMSE LS channel estimators and a prf of f=1

Figure 4.16 demonstrates the uplink spectral efficiency of a multi-cell massive MIMO network using MMSE, EW-MMSE, and LS channel estimators with zero-forcing (ZF) uplink combining and a prf of f = 1. In this figure, the uplink spectral efficiency achieved using MMSE-ZF with prf of f = 1 is 38, while the uplink spectral efficiency of EW-MMSE-ZF and LS-ZF with prf of f = 1 is 36 each have. Generally, prf of f = 3 and a MMSE channel estimator with a ZF linear uplink combiner is more effective in enhancing the uplink spectral efficiency of a multi-cell massive MIMO network.

4.6. Effect of BS antenna numbers and three different channel Estimators with different numbers of UEs on UL SE

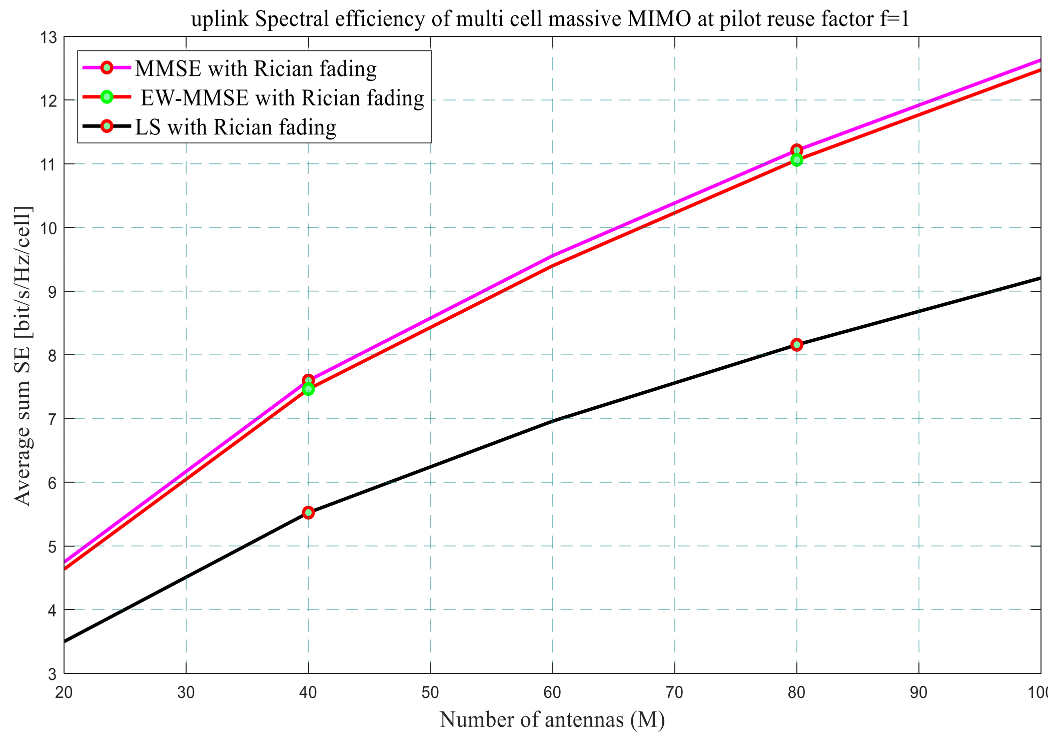

Figure 4.17: uplink spectral Efficiency for three different channel estimators over Rician fading channels with prf f=1

Figure 4.17 shows the average uplink spectral efficiency using ZF uplink combining with MMSE, EW-MMSE, and LS channel estimators, with a prf of f=1 with different user equipment (UE) locations and shadow fading conditions. The performance of the two estimators is comparable in this figure, because the EW-MMSE estimator takes advantage of the diagonal elements of the spatial covariance matrix of the MMSE estimator. The uplink spectral efficiency of the MMSE and EW-MMSE estimators is higher than that of the LS estimator. When Rician fading channel is present, mean vectors are used to improve channel estimate efficiency. Figure 4.17, looks at the UL SE of three channel estimators with zero-forcing (ZF) uplink combining with a universal prf, 10 user equipment (UE) per cell, and one hundred base station antennas (BS). The figure demonstrates that when applying MMSE, EW-MMSE, and LS channel estimators, the highest UL is 12.8, 12.7, and 9.2 respectively.

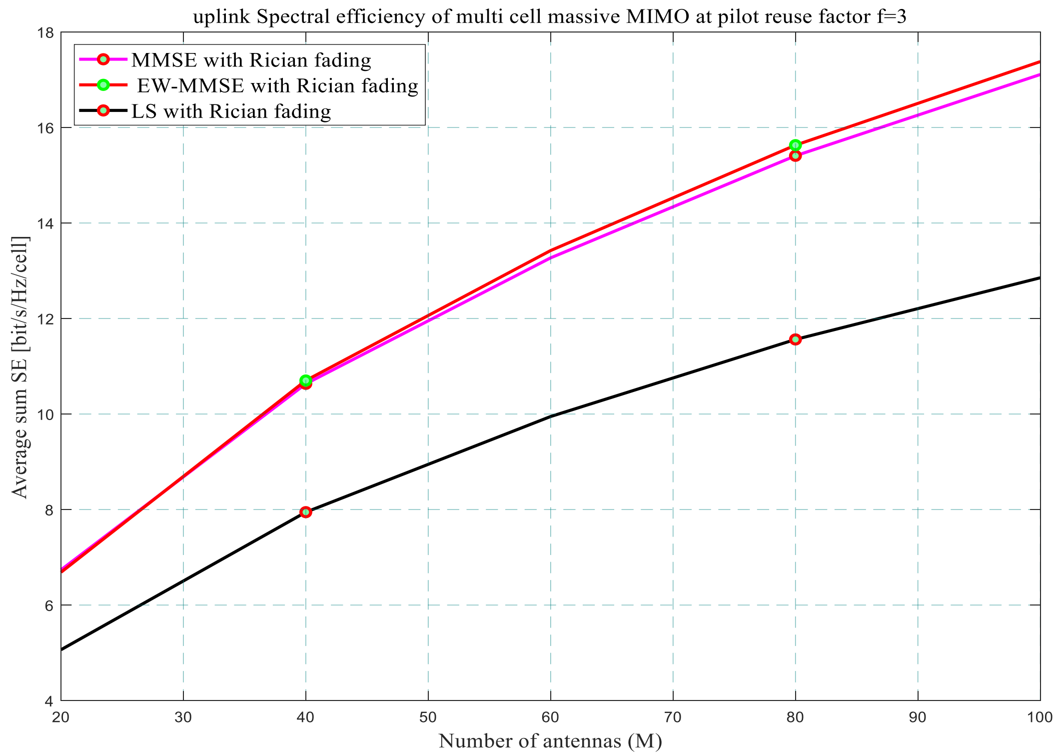

Figure 4.18: uplink spectral Efficiency for three different channel estimators over Rician fading channels with prf f=3

Figure 4.18 shows the uplink spectral efficiency of multi cell massive MIMO networks under Rician fading channels for three different channel estimators with a $prf\ f = 3$. In this figure we consider a UE of k=10 for each cell and BS antenna of M=100. In figure 4.18, the performance of the EW-MMSE and MMSE channel estimators is very close, and the EW-MMSE channel estimator performs better than the LS. In a Rician fading channel, LOS and NLOS components exist. As expected, the highest uplink spectral efficiency is obtained when MMSE and EW-MMSE estimators are employed, since the LOS and NLOS components are known and utilized. As shown in figure 4.18, the maximum uplink spectral efficiency of MMSE, EW-MMSE, and LS estimators is 17.6, 17.8, and 13, respectively.

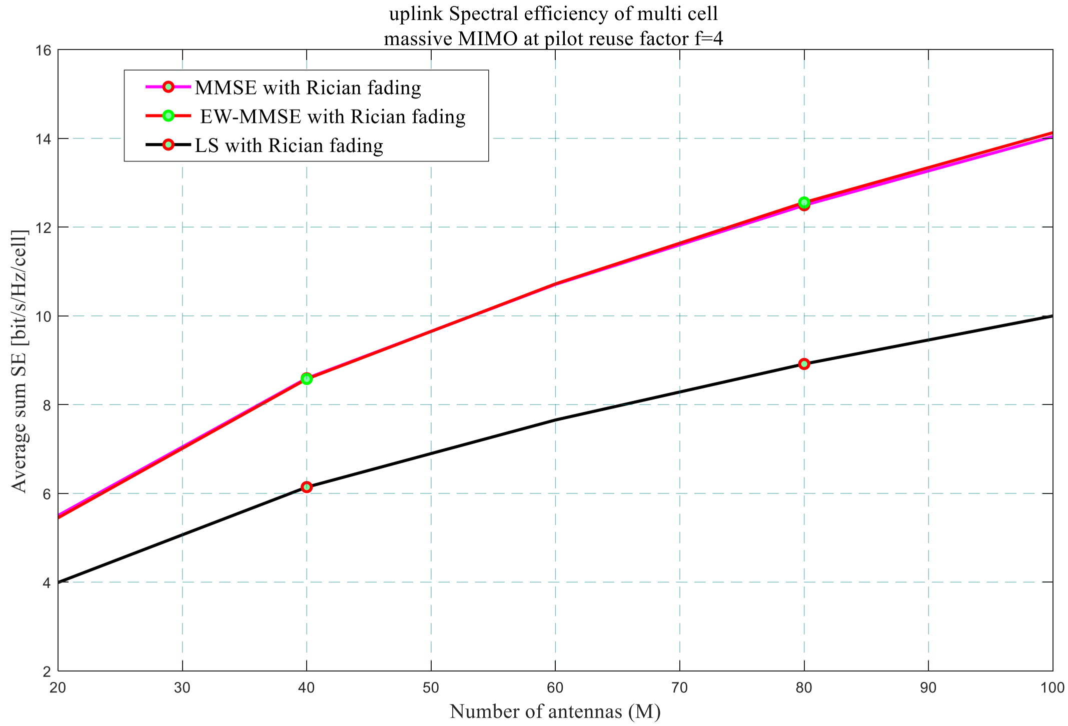

Figure 4.19: uplink spectral Efficiency for three different channel estimators over Rician fading channels with prf f=4

Figure 4.19 shows the uplink spectral efficiency of MMSE, EW-MMSE and LS channel estimators with $prf\ f=4$. In this thesis, we consider a multi cell massive MIMO networks in a fading environment. To simulate the above graph we consider a UE of k=10 and a BS antenna number of M=100. As shown in figure 4.19 the performance of EW-MMSE and MMSE channel estimator shows a little difference. The performance of each channel estimator depends on the quality, which can perfectly estimate the channel between each user and BS antennas. When we consider a $prf, f=4$ the performance of each channel estimator is reduced. In wireless communication systems, it is well known that increasing the prf can lead to increased levels of pilot contamination, which can have a major influence on system performance. Figure 4.19 demonstrates that, when using MMSE, EW-MMSE, and LS channel estimators, the maximum uplink spectral efficiency achieved is 14, 14, and 11.8 respectively.

Table 4. 5: Comparison: results in part, 4.2, 4.3, 4.4, 4.5, 4.6 and existing works

(W. A. Ali et al., 2020)					Result of Proposed Work				
Model	Prf	Cell type	Parameter	Results for UL SE of existing work (bit/s/HZ/cell)	Model	Pilot reuse factor	Cell type	Parameter	Results for UL SE Of proposed work
Rayleigh Fading	Not consider desired prf	Multi cell massive MIMO -DL	No UEs	71-MMSE 80-RZF 45-MRC	Rician Fading	1 3 4	Multi cell massive MIMO -UL	No UEs	140-ZF 180-ZF 155-ZF
Rayleigh Fading	1 2 4	Multi cell massive MIMO -DL	No BS antennas 0-200	80- MMSE 85- MMSE 88- MMSE	Rician Fading	1 3 4	Multi cell massive MIMO -UL	No BS antennas	70-ZF 90-ZF 78-ZF
(He et al., 2021a)					Result of Proposed Work				
Model	Channel type	Cell type	parameters	Results for UL SE of existing work (bit/s/HZ/cell)	Model	Channel type	Cell type	parameters	Results for UL SE Of proposed work
Rician fading	Perfect CSI	Single cell	No BS antennas 0-500	K=5,SE= 23 K=10 SE=11	Rician Fading	Estimated CSI	Multi cell	Prf, LS f=1,3,4	36 35 34.4
Rician fading	Estimated CSI	Single cell	No BS antennas 0-500	K=5,SE= 21 K=10 SE=8	Rician Fading	Estimated CSI	Multi cell	Prf, MMSE f=1,3,4	37 43 38
Rician fading	Perfect CSI	Single cell	SNR (-5-20 dB)	K=5,SE= 28 K=10 SE=14	Rician Fading	Estimated CSI	Multi cell	Prf, EWMMSE f=1,3,4	36 35 34.4
Rician fading	Estimated CSI	Single cell	SNR (-5-20 dB)	K=5,SE=27 K=10 SE=13		Estimated CSI	Multi cell	No BS antennas LS MMSE EW-MMSE	17 17 13.5

Table 4.5 shows the comparison between the existing work and proposed work with different perspectives. Which includes the effect of pilot contamination and its mitigation techniques channel model, parameters, pilot reuse factors, types of cell and results of uplink SE.

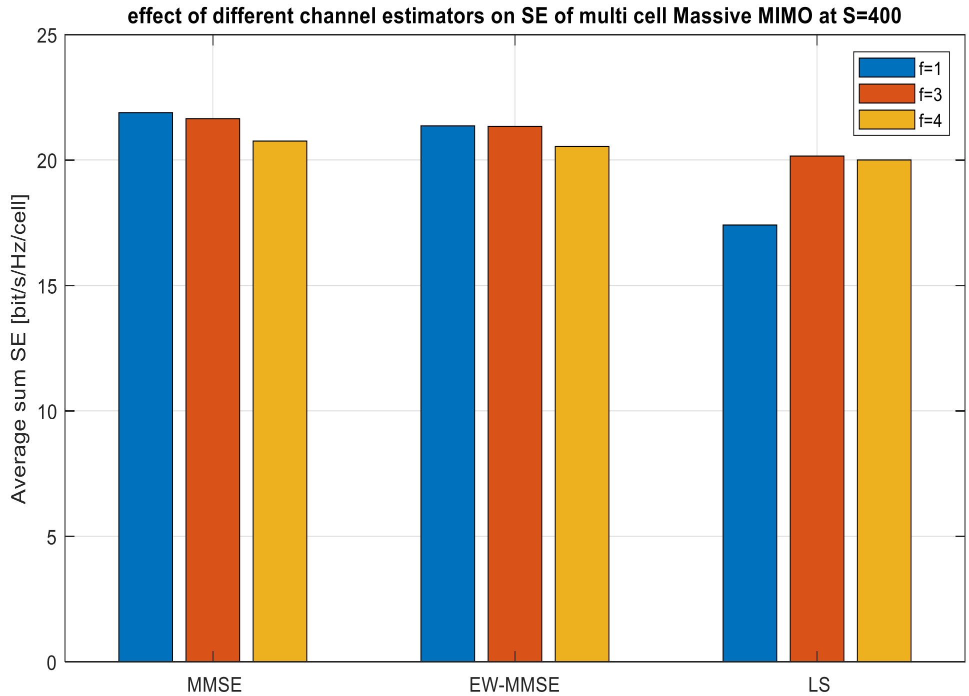

Figure 4.20: Uplink Spectral Efficiency of multi cell Massive MIMO networks for different prf and different channel estimators

Figure 4.20 shows the uplink spectral efficiency of multi cell massive MIMO networks for different channel estimators and three different prf. In this section, we are trying to see the effect of coherence block length; channel estimation and prf on the uplink spectral efficiency of multi cell massive MIMO networks. In figure 4.20, we can see the allocation of higher number of coherence block length is an important way of enhancing the uplink spectral efficiency of multi cell massive MIMO networks. As we see the graphical and numerical value of MMSE estimator, still it is a promising channel estimator for enhanced spectral efficiency. In this section we consider three different prf and three different channel estimators and a coherence block length of S=400. The uplink spectral efficiency of MMSE channel estimator for each prf $f \in \{1,3,4\}$ is 22.5, 22.3 and 21 respectively. The uplink spectral efficiency of EW-MMSE channel estimator for each prf $f \in \{1,3,4\}$ is 22, 22 and 20.8 respectively. And also the uplink spectral efficiency of LS channel estimators for three different $prf\ f \in \{1,3,4\}$ is 17.9, 20.2 and 20 respectively. A $prf\ f \in \{1,3\}$ have similar uplink spectral efficiency for EW-MMSE channel estimators. Therefore, $prf\ \ f = 3$ still dominant for higher spectral efficiency. EW-MMSE channel estimator also efficient to mitigate the inter cell interference coming from other cells.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This thesis focuses on enhancing the uplink (UL) spectral efficiency of multi-cell massive MIMO systems under Rician fading channels. The technique employs a pilot reuse factor(prf), uplink combining, and channel estimator techniques to reduce the overhead of channel estimation and to mitigate inter-cell interference. The study evaluates the effectiveness of the proposed technique through simulations in a multi-cell environment and demonstrates that it can significantly improve the spectral efficiency of multi-cell massive MIMO networks under Rician fading channels. The study's results show that eliminating pilot contamination is crucial for improving spectral efficiency and system stability. The proposed technique achieves this by mitigating pilot contamination caused by the lack of orthogonal pilots and inter-cell interference. Coherent transceiver processing is carried out, and channel state information (CSI) is produced at the receiver to achieve high spectral efficiency.

Generally, in our desired system we can enhance the UL SE using an efficient $prf\ f = 3$ with proposed ZF-MMSE and a $prf\ f = 3$ have a better performance than other $prf\ f \in \{1, 4\}$ with a considerable number of UEs, SNR values, code block length and BS antenna numbers.

5.2. Recommendation

The following recommendations are made for future work:

Explore the use of machine learning algorithms to optimize the proposed technique's performance based on real-time network conditions. This can help network operators adapt the technique to changing network conditions and achieve the best possible results. Investigate the use of other techniques, such as beam forming and power allocation, in combination with the proposed technique to further improving the spectral efficiency in multi-cell massive MIMO networks under Rician fading channels. Investigate the impact of the proposed technique on network energy consumption and explore the use of energy-efficient techniques to achieve high spectral efficiency while minimizing energy consumption. Overall, these future research directions can help advance the field of multi-cell massive MIMO technology and further improve the spectral efficiency of wireless communication systems.

REFERENCE

Abdelfatah, M., ElSayed, S., & Zekry, A. (2022). A Study on the Basics Processes of Massive MIMO. J. Commun., 17(3), 167-179.

Ali, A., Qureshi, I. A., Memon, A. L., Memon, S. A., & Saba, E. (2018). Spectral efficiency of massive MIMO communication systems with zero forcing and maximum ratio beamforming. International Journal of Advanced Computer Science and Applications, 9(12).

Ali, W., Anis, W., & Elshenawy, H. (2020). Spectral efficiency enhancement in Massive MIMO system under pilot contamination. International Journal of Communication Systems, 33, e4342. https://doi.org/10.1002/dac.4342

Ali, W. A., Anis, W. R., & Elshenawy, H. A. (2020). Spectral efficiency enhancement in Massive MIMO system under pilot contamination. International Journal of Communication Systems, 33(8), e4342.

Asif, R. M., Shakir, M., Rehman, A. U., Shafiq, M., Khan, R. A., & Khan, W. U. (2022). Performance Evaluation of Spectral Efficiency for Uplink and Downlink Multi-Cell Massive MIMO Systems. Journal of Sensors, 2022.

Bai, L., & Choi, J. (2012). Low complexity MIMO detection. Springer Science & Business Media.

Benzaghta, M., & Rabie, K. M. (2021). Massive MIMO systems for 5G: A systematic mapping study on antenna design challenges and channel estimation open issues. IET Communications, 15(13), 1677-1690.

Björnson, E., Hoydis, J., & Sanguinetti, L. (2017a). Massive MIMO networks: Spectral, energy, and hardware efficiency. Foundations and Trends in Signal Processing, 11(3-4), 154-655.

Björnson, E., Hoydis, J., & Sanguinetti, L. (2017b). Massive MIMO networks: Spectral, energy, and hardware efficiency. Foundations and Trends® in Signal Processing, 11(3-4), 154-655.

Chataut, R., & Akl, R. (2020). Massive MIMO systems for 5G and beyond networks—overview, recent trends, challenges, and future research direction. Sensors, 20(10), 2753.

Cho, Y. S., Kim, J., Yang, W. Y., & Kang, C. G. (2010). MIMO-OFDM wireless communications with MATLAB. John Wiley & Sons.

Gelberger, A., Yemini, N., & Giladi, R. (2013). Performance analysis of software-defined networking (SDN). 2013 IEEE 21st International Symposium on Modelling, Analysis and Simulation of Computer and Telecommunication Systems,

He, J., Zhang, J., Song, C., & Wu, M. (2021a). Spectral Efficiency of the Multiway Massive System over Rician Fading Channels. Security and Communication Networks, 2021, 1-8.

He, J., Zhang, J., Song, C., & Wu, M. (2021b). Spectral Efficiency of the Multiway Massive System over Rician Fading Channels. Security and Communication Networks, 2021.

He, J., Zhang, J., Song, C., & Wu, M. (2021c). Spectral Efficiency of the Multiway Massive System over Rician Fading Channels. Security & Communication Networks.

HOSANY, M. A. (2020). Efficiency analysis of Massive MIMO systems for 5G cellular networks under perfect CSI. 2020 3rd International Conference on Emerging Trends in Electrical, Electronic and Communications Engineering (ELECOM),

Hossain, E., & Hasan, M. (2015). 5G cellular: key enabling technologies and research challenges. IEEE Instrumentation & Measurement Magazine, 18(3), 11-21.

Hu, F., Wang, K., Li, S., & Jin, L. (2020). Energy Efficiency-Oriented Resource Allocation for Massive MIMO Systems with Separated Channel Estimation and Feedback. Electronics, 9(4), 582.

Huang, B., & Guo, A. (2018). Spectral and energy efficient resource allocation for massive MIMO HetNets with wireless backhaul. IEEE Wireless Communications Letters, 8(2), 552-555.

Kang, Y., & Lu, T. (2019). Channel estimation and data transmission in massive MIMO TDD systems. International Journal of Communications, Network and System Sciences, 12(10), 170-187.

Kaur, P., & Garg, R. (2021). A survey on key enabling technologies towards 5G. IOP Conference Series: Materials Science and Engineering,

Khan, I., Rodrigues, J. J. P. C., Al-Muhtadi, J., Khattak, M. I., Khan, Y., Altaf, F., Mirjavadi, S. S., & Choi, B. J. (2019). A Robust Channel Estimation Scheme for 5G Massive

MIMO Systems. Wireless Communications and Mobile Computing, 2019, 3469413. https://doi.org/10.1155/2019/3469413

Khwandah, S. A., Cosmas, J. P., Lazaridis, P. I., Zaharis, Z. D., & Chochliouros, I. P. (2021). Massive MIMO Systems for 5G Communications. Wireless Personal Communications, 120(3), 2101-2115. https://doi.org/10.1007/s11277-021-08550-9

Krishna, P., Kumar, T. A., & Rao, K. K. (2016). A Review on Importance of Improving Spectral Efficiency in Massive MIMO Communications. National Conference on Computer Security, Image Processing, Graphics, Mobility and Analytics (NCCSIGMA),

Li, J., Wang, D., Zhu, P., & You, X. (2018). Energy efficiency optimization of distributed massive MIMO systems under ergodic QoS and per-RAU power constraints. IEEE Access, 7, 5001-5013.

Li, X., Björnson, E., Larsson, E. G., Zhou, S., & Wang, J. (2017). Massive MIMO with multi-cell MMSE processing: Exploiting all pilots for interference suppression. EURASIP Journal on Wireless Communications and Networking, 2017(1), 1-15.

Liu, G., Deng, H., Qian, X., Wang, W., & Peng, G. (2019). Joint pilot allocation and power control to enhance max-min spectral efficiency in TDD massive MIMO systems. IEEE Access, 7, 149191-149201.

Liu, P., Luo, K., Chen, D., Jiang, T., & Matthaiou, M. (2018). Spectral efficiency analysis of multi-cell massive MIMO systems with Ricean fading. 2018 10th International Conference on Wireless Communications and Signal Processing (WCSP),

Marzetta, T. L., & Yang, H. (2016). Fundamentals of massive MIMO. Cambridge University Press.

Misso, A., Kissaka, M., & Maiseli, B. (2020). Exploring pilot assignment methods for pilot contamination mitigation in massive MIMO systems. Cogent Engineering, 7(1), 1831126.

Moqbel, M. A. M., Wangdong, W., & Ali, A.-m. Z. (2017). MIMO channel estimation using the LS and MMSE algorithm. IOSR J. Electron. Commun. Eng, 12(1), 13-22.

Ngo, H. Q. (2015). Massive MIMO: Fundamentals and system designs (Vol. 1642). Linköping University Electronic Press.

Özdogan, Ö., Björnson, E., & Larsson, E. G. (2019). Massive MIMO with spatially correlated Rician fading channels. IEEE Transactions on Communications, 67(5), 3234-3250.

Prasad, K. S. V., Hossain, E., & Bhargava, V. K. (2017). Energy efficiency in massive MIMO-based 5G networks: Opportunities and challenges. IEEE Wireless Communications, 24(3), 86-94.

Reddy, M., Kumar, T., & Rao, K. (2017). Performance Analysis of Maximal Spectral Efficiency for Multi-Cell Massive MIMO Systems. I J C T A, 10(8), 329-341.

Reddy, M. S., Kumar, T. A., & Rao, K. S. (2017). Performance Analysis of Maximal Spectral Efficiency for Multi-Cell Massive MIMO Systems.

Rusek, F., Persson, D., Lau, B. K., Larsson, E. G., Marzetta, T. L., Edfors, O., & Tufvesson, F. (2012). Scaling up MIMO: Opportunities and challenges with very large arrays. IEEE signal processing magazine, 30(1), 40-60.

Sanguinetti, L., Björnson, E., & Hoydis, J. (2019). Toward massive MIMO 2.0: Understanding spatial correlation, interference suppression, and pilot contamination. IEEE Transactions on Communications, 68(1), 232-257.

Stepanets, I., Fokin, G., & Mueller, A. (2018). Capacity estimation ways of massive MIMO systems. T-Comm Telecommunication and transport, 10.

Studer, C., Wenk, M., & Burg, A. (2010). MIMO transmission with residual transmit-RF impairments. 2010 international ITG workshop on smart antennas (WSA),

Subitha, D., & Vani, R. (2021). Analysis of linear precoding techniques for massive MIMO-OFDM systems under various scenarios. IOP Conference Series: Materials Science and Engineering,

Sun, Y., Wang, J., He, L., & Song, J. (2017). Uplink spectral efficiency analysis and optimization for massive SC-SM MIMO with frequency domain detection. IEEE Transactions on Vehicular Technology, 67(5), 3937-3949.

Verenzuela, D., Björnson, E., Wang, X., Arnold, M., & ten Brink, S. (2019). Massive-MIMO iterative channel estimation and decoding (MICED) in the uplink. IEEE Transactions on Communications, 68(2), 854-870.

Wang, X., Hua, H., & Xu, Y. (2020). Pilot-Assisted Channel Estimation and Signal Detection in Uplink Multi-User MIMO Systems With Deep Learning. IEEE Access, PP, 1-1. https://doi.org/10.1109/ACCESS.2020.2978253

Xin, Y., Shi, P., Xia, X., & Fan, X. (2020). Spectral efficiency analysis of multi-cell multi-user massive MIMO over channel aging. IET Communications, 14(5), 811-817.

Yifei, Y., & Longming, Z. (2014). Application scenarios and enabling technologies of 5G. China Communications, 11(11), 69-79.

Zahoor, M. I., Dou, Z., Shah, S. B. H., Khan, I. U., Ayub, S., & Reddy Gadekallu, T. (2020). Pilot decontamination using asynchronous fractional pilot scheduling in massive MIMO systems. Sensors, 20(21), 6213.

Zerihun, B. M., & Wondie, Y. (2017). Massive MIMO for 5G cellular networks: potential benefits and challenges. International Conference on Information and Communication Technology for Develoment for Africa,

Zhang, J., Deng, H., Li, Y., Zhu, Z., Liu, G., & Liu, H. (2022). Energy Efficiency Optimization of Massive MIMO System with Uplink Multi-Cell Based on Imperfect CSI with Power Control. Symmetry, 14(4), 780.