PILOT RESOURCE ALLOCATION TO IMPROVE DATA RATE OF MULTICELL MASSIVE MIMO SYSTEM

Betelhem Zerihun Gudina

A Thesis Submitted to

The Department of Electronics and Communication Engineering

School of Electrical and Computing Engineering

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

Office of Graduate Studies

Adama Science And Technology University

June,2022.

Adama, Ethiopia.

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Co Advisor: Dr. Davinder Singh Rathee(Ph.D.)

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APPROVAL PAGE OF M.Sc THESIS

I/we, the advisors of the thesis entitled "**Pilot Resource Allocation To Improve Data Rate Of Multicell Massive MIIMO System**" and developed by Betelhem Zerihun, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Co-Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Betelhem Zerihun have read and evaluated the thesis entitled "**Pilot Resource Allocation To Improve Data Rate Of Multicell Massive MIMO System**" and examined the candidate during the 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.

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DECLARATION

I hereby declare that this Master Thesis entitled "**Pilot Resource Allocation To Improve Data Rate Of Multicell Massive MIMO System** " is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Betelhem Zerihun Gudina	________________________	________________
Name of student	Signature	Date

RECOMMENDATION

I/we, the advisor(s) of this thesis, hereby certify that we have read the revised version of the thesis entitled "**Pilot Resource Allocation To Improve Data Rate Of Multicell Massive MIMO System**" prepared under my guidance by Betelhem Zerihun submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Electronics and Communication Engineering. Therefore, we recommend the submission of the revised version of the thesis to the department following the applicable procedures.

Dr. Satyasis Mishra (Ph.D.)	____________________	______________
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Co-Advisor	Signature	Date

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LIST OF ABBREVIATION

3G	3rd Generation wireless telephone technology
4G	4th Generation wireless telephone technology
5G	5th Generation wireless telephone technology
AFPS	Asynchronous Fractional Pilot Schedules
BS	Base Station
CSI	Channel State Information
DL	Downlink
EWIG	Edge Weighted Interference Graph
FDD	Frequency Division Duplex
Hz	Hertz
ICI	Intercell Interference
IMT	International Mobile Telecommunications
LoS	Line of Site
LTE	Long Term Evolutions
Mbps	Megabits per second
MHz	Mega hertz
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MWC	Mobile World Congress
PC	Pilot Contamination
RF	Radio Frequency
SE	Spectral Efficiency
SIMO	Single Input Multiple Output
SINR	Signal to Interference Noise Ratio
SISO	Single Input Single Output
SPR	Soft Pilot Reuse
TDD	Time Division Duplex
UEs	User Equipment’s
UL	Uplink
Wi-Fi	Wireless Fidelity

LIST OF NOMENCLATURE

K	Number of the user in a cell
M	Number of antenna element in BS
L	Number of the cell
R	The cell radius
K_{CS}	Conventional Pilot Resource
$K_{e,i}$	The number of user in cell edge region for ith cell
$K_{e,ix}$	Number of set of pilot group that assigned cell edge zone users
$K_{i,c}$	The number of user in cell center region ith cell
$u_{(j,k)}$	The k-th user of the j-th cell.
$h^{i}_{(j,k)}$	The channel gain between the user u (j, k) and the i-th BS.
$g^{i}_{(j,k)} \in C^{Mx1}$	The small-scale fading between the user u (j, k) and the i-th BS. It can be modeled by a complex Gaussian distributed random variable with zero-mean vector and identity covariance matrix IM ,i.e., $g^{i}_{(j,k)} \sim CN(0, I_M)$
$z^{i}_{(j,k)}$	The log-normal shadowing between the user u(j, k) and the i-th BS
$10\log_{10} z^{i}_{(j,k)}$	Gaussian distributed with zero mean and the standard deviation of σ_s
$\beta^{i}_{(j,k)}$	The large-scale fading between the user u (j, k) and the i-th BS.
$r^{i}_{(j,k)}$	The distance between the user u (j, k) and the i-th BS.
A	The path loss exponent.
T_C	The coherent time interval.
φ_k	The orthogonal uplink pilot sequences, where τ out of Tc is used to transmit the P orthogonal uplink pilot sequences
ρ_u	The transmission power of the uplink data signals for the conventional schemes.
ρ_p	The transmission power of the pilot
ρ_i	The grouping threshold of the i-th cell for the conventional SPR scheme
$r^{u,c}_{(j,k)}$	The uplink data symbol transmitted by the user u(j, k) in the inner regions of the j-th cell

$r_{(j,k)}^{u,e}$	The uplink data symbol transmitted by the user u(j, k) in the outer regions of the j-th cell, respectively
$Y_{(i)}^{p}$	pilot sequences received at the BS of the i-th cell
$\eta_{i,k}$	The limit of the UL SINR of the k-th user in the i-th cell
$SINR_{i,k}^{UL}$	The UL signal to interference plus noise ratio (SINR) of the k-th user in the i-th cell
R_o	Cell radius
D_j^i	The largescale fading matrix relating all the K users in the j -th cell to the i-th cell's BS.
τ_p	Uplink pilot
$\hat{x}_i^i$	The detected symbol arriving from the k-th user in the i-th cell
$\in_{\boldsymbol{i,k}}^{\boldsymbol{u}}$	The interference
N_i^P	UL channel's AWGN matrix.
C_i^{UL}	The achievable UL rate
μ	The spectral efficiency reduction
φ_c	Set of pilot that are assigned to cell center zone users
$\varphi_{e,x}$	Set of pilot that assigned to cell edge zone user
φ_{mSPR}	Total set of pilot assigned to mSPR
$\widehat{H}_i^i$	The estimated channel matrix

ABSTRACT

Massive MIMO is being touted as one of the most promising technologies for 5G and beyond cellular networks, with tremendous data rates and capacity. Pilot contamination (PC), however, limits the systems performance that highly reduce data rate. It is formed when the user of home cell and neighboring cell are not orthogonal to each other. To overcome this problem and improve the data rate of multi-cells massive MIMO system, we proposed a new schemes namely modified Soft Pilot Reuse (mSPR). First, the users in a targeted cell are clustered to the center and edge zone based on the signal level they received. On clustered users, an mSPR is applied that allocates the same set of pilot resource to all center zone users that having low PC severity and assign a different set of orthogonal pilots to the user having the highest PC severity. Additionally, it reuses this set of pilots within a grouped cell in a system, also assures that none of the pilot group that is assigned to edge user of the center cell is reused in a single tire. Consequently, pilot overhead and inter cell interference are reduced. For center zone users, a random pilot assignment is applied which assigns pilots from the same group. To do this, first maximum user out of the cell is selected in order to allocate the pilot resource. Then, the users' pilot in the same cell is orthogonal and this center user is reused in another cell. The simulation results shows the data rate improvement of multi cell multi user massive MIMO system with the proposed modified Soft Pilot Reuse (mSPR) pilot resource allocations. Further, number of orthogonal pilots are reduced and improves the uplink achievable rate and spectral efficiency over pre-existing schemes.

KEYWORDS*: Pilot contamination, Massive MIMO, Modified soft pilot reuse(mSPR)*

CHAPTER 1
INTRODUCTION

1.1 Background

One of the biggest reasons for developing wireless communications is the constantly increasing user demand. The existing systems are not sufficient to meet these needs. To meet these demands, the next-generation 5G technology is expected to make improvements. (Esra Cansu Kose , Abdulkadir Yayilkan , Selman Kulac , H. Gokhan Ilk, 2022). The accuracy and capacity of channel estimation are becoming more important as wireless communication technology advances. Massive Multiple-input Multiple-output (MIMO) is a component of forthcoming 5G technology that improves channel estimate accuracy and quality. This technique comprises hundreds of thousands of antenna arrays at the base station serving a high number of users at the same time-frequency resources (F. Rusek,2013). When the number of base station antennas exceeds the number of user terminals, the throughput and channel estimation quality for each antenna improve. The base station (BS) requires complete and accurate channel state information (CSI) to realize the benefits of massive MIMO technology (Jose Flordelis,2018), (Erik G. Larsson,2014).

The channel estimation accuracy and capacity are determined by the channel state information (CSI) among users of BS and Serving (F. Rusek,2013). However, because the BS does not know the CSI in practice (Jose Flordelis,2018), an estimation can be done using channel reciprocity or feedback methods (Chataut & Akl, 2020). A cellular network can be either time-division duplex (TDD) or frequency-division duplex (FDD). TDD is superior to FDD because only one estimate is necessary (either uplink or downlink), as shown in Figure 1. 1 below, and channel reciprocity is applied in both directions (Jose Flordelis,2018). FDD, on the other hand, involves both directions of simultaneous feedback and estimation (Erik G. Larsson,2014). TDD has thus been recommended as a superior choice for big MIMO due to its efficient use of radio resources.

Because of its resource-saving and highly scalable qualities, the (TDD) model is used to communicate between BS and users. TDD-compliant BSs must collect channel state information (CSI) since it is a kind of uncertain knowledge (Chataut & Akl, 2020).

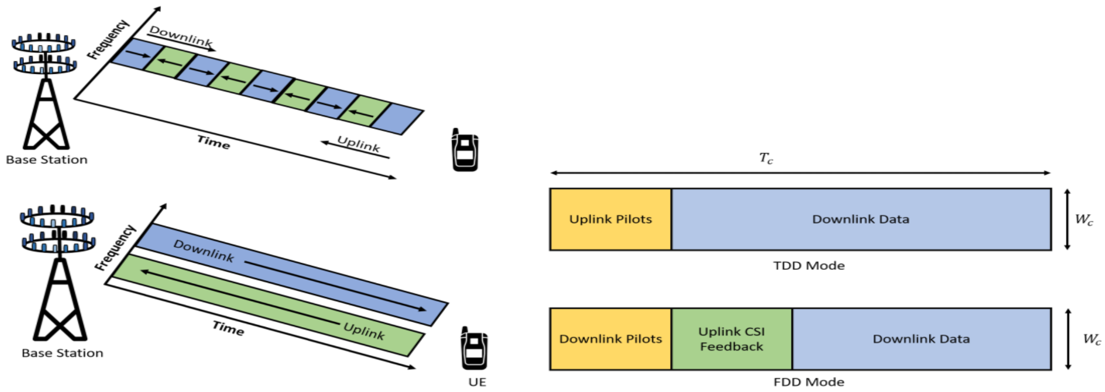

Figure 1.1 (a) Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) mode: (b) Typical pilot transmission and CSI feedback mechanism in FDD and TDD mode (Chataut & Akl, 2020).

In practice, the pilot sequences are used to estimate the CSIs. Due to limited available resources, the coherence time cannot be extended indefinitely (Adeeb Salh,2020), the pilot length is controlled within a narrow range, and the same set of pilots is used in an adjacent cell or they transmit the same pilot in the equivalent time-frequency resource (Zahoor MI,2020), resulting in the problem of pilot contaminations (PC), as shown in Figure 1. 2 below.

Furthermore, as a result of PC, the problem of reciprocal interference emerges, decreasing the accuracy of channel estimates. The mutual interference problem degrades channel estimation quality and renders it statistically interdependent. The mutual interference problem lowers channel estimate accuracy and makes it statistically interdependent, hence limiting the spectral efficiency of the system (F. Rusek,2013). Despite having a large number of BS antennas, the network's system capacity is limited due to the presence of a PC. To put it another way, the PC is the primary cause of system slowdown. As a result, the PC has been identified as a bottleneck for multi-cell massive MIMO systems' system capacity (H. Q. Ngo, E. G. Larsson and T. L. Marzetta, 2013).

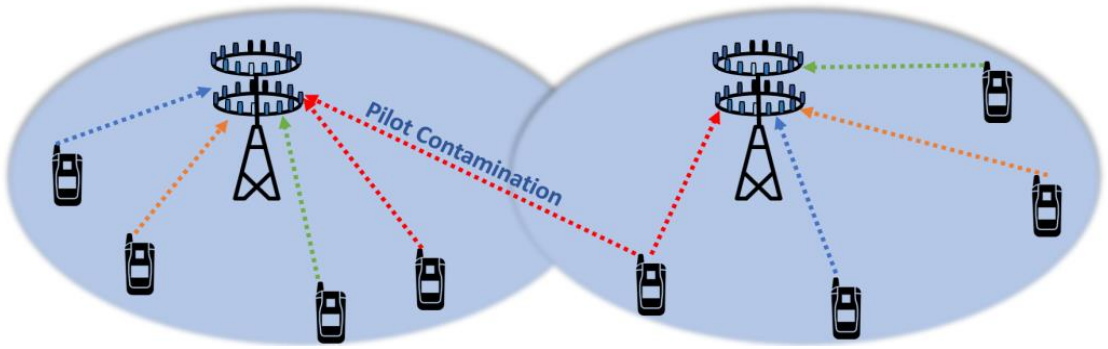

Figure 1. 2 Massive MIMO PC effect (Chataut & Akl, 2020)

As a result, the system's spectral efficiency is limited. Despite the availability of a PC, the network's system capacity is limited despite the huge number of BS antennas. To put it another way, the PC is the main source of system sluggishness. As a result, the PC has been identified as a bottleneck for the system capacity of multi-cell massive MIMO systems. There are several pilot resource allocation approaches to overcome the effect of the system's data rate drop owing to inefficient pilot resource allocation, which also leads to pilot contamination. One major issue, however, is the wasteful use of frequency resources.

1.2 Problem Statement

Due to an increased number of user equipment (UEs), there is an occurrence of the scarcity of available frequency resources including pilot resources. Pilot resources used in the same cell and adjacent cells should be orthogonal to each other, but within a given bandwidth (coherent block) the number of the orthogonal pilot is limited, due to this case we reuse the same pilot sequence in the same cell/adjacent cells which may lead to contaminations of pilots that degrade data rate of the system, time-frequency resources available are shared for both data transmissions and pilot sequence. If more resources are used for channel estimations (that is, for the pilot sequence), there are fewer resources available to send data, hence there is a reduction in data transmission capacity. To achieve data rate in massive MIMO, it is necessary to balance the amount of restricted resource shared among them.

1.3 Objectives

1.3.1 General Objective

- To develop a pilot resource allocation scheme that improves the data rate of a multi-cell massive MIMO system.

1.3.2 Specific Objectives

This thesis specifically aims to achieve the following specific objectives:

- To minimize the number of orthogonal pilot resources utilized in multi-cell massive MIMO System.
- To evaluate the achievable data rate and analysis of the performance of proposed schemes with some performance metrics like Sum rate bps/Hz versus a number of all antennas in BS and sum-rate versus transmission power.
- Compare the performance of the proposed pilot resource allocation system to some of the preexisting systems using parameters like CDF Vs SINR, CDF Vs average uplink achievable rate, CDF Vs Spectral efficiency.

1.4 Significance of the study

Some of the significances of the study are:

- To meet the growing demand, the throughput of cellular networks needs to be increased by orders of magnitude.
- To improve it; either extra cells, extra bandwidth, or higher spectral efficiency is needed.
  - Cell densification increase cost and interference, also extra bandwidth is not possible solution due to limited frequency resource.
  - Increasing the SE is a viable way of improving the throughput.
- Effective allocation of pilot sequence and mitigating pollution of pilot will assist for data rate enhancement for multi cell massive MIMO System is needed.

1.5 Thesis Contributions

Some of the contributions of this thesis as follows:

- Based on the signal intensity received, we present a user clustering technique in which users are sorted and clustered into cell edge and center zones. We have used the modified Soft Pilot Reuse scheme (mSPR) after clustering the users.
- In the mSPR pilot assignment scheme, not only the pilot assigned to the center user is reused, but also the pilot set assigned to the cell edge user is reused with a group

of cells in the system, assuring that within a single tire only one edge zone pilot group is used, resulting in a significant reduction in pilot overhead and, as a result, an improvement in the system's overall spectral efficiency.

- The simulation results reveal modified SPR enhanced the overall performance of the massive MIMO system by minimizing the inter-cell interference (ICI), reducing the pilot overhead, and drastically reducing the PC.

1.6 Scope and Limitation

There are some scopes and limitations of the thesis:

- The thesis work will only include the allocation schemes that efficiently utilize the available frequency resources for a given multicell massive MIMO system.
- This thesis proposed to make the channel estimation is accurate through pilot allocation, so we utilize any conventional channel estimation method.
- We adopt low complexity (matched filter) detector to detect the transmitted symbols.

1.7 Thesis Structure

This thesis organizes into the following five chapters:

Chapter 1: Background of the massive MIMO system, statement of the problems, objectives, significance, scope and limitation, and contribution of the research.

Chapter 2: presents the literature review of the subject matter and it is more important than the other. It provides a thorough overview of the problem's background. It refers to what has already been researched by others and has relevance to the present day.

Chapter 3: describes overview of massive MIMO system.

Chapter 4: deals with the system's mathematical model and system model.

Chapter 5: presents the proposed results and discussions.

Chapter 6: Conclusions and future research work directions are offered.

CHAPTER 2
LITERATURE REVIEW

A short and precise summary of some of the research is reviewed here. These techniques to reduce PC have been offered from three angles Intelligent channel prediction, interference-rejecting, and optimal pilot assignment are being used to reduce pilot contamination all of which have complimentary benefits.

For example, the authors of (Zheng, X.; Zhang, H.; Xu, W.; You, X, December 2014) proposed a semi-orthogonal pilot frequency transmission strategy in a Massive MIMO system that relied on the orthogonality of the asymptotic channel to ensure cancellation of interference continuously while reducing the common interference between pilot and dates. The proposed schemes dramatically increased the MIMO system's performance. (Mahyiddin, W.A.W.M.; Martin, P.A.; Smith, P.J., 14–17 September 2014) suggests a finite number of BS antennae and a time-shifted pilot technique. With limited users, the proposed approach increased transmission performance. This method, however, is inefficient if we increase the number of users in the system.

According to the review to overcome the PC issue they propose the scheme based on channel semi-blind linear estimation. In the TDD protocol, the uplink channels are determined using a linear estimating technique, and no need to estimate for downlink since we retrieve it from the concept of reciprocity contained in the TDD protocol system. To generate the intended targeted signal using linear LS and MMSE algorithm, the base station makes multiplication of incoming signal of the pilot and conjugates its transpose. The LS channel estimation, on the other hand, is highly influenced in noisy systems, whilst in systems using MMSE techniques due to the high computational cost, its performance is limited. For example, the authors of (Pereira de Figueiredo, Cardoso, Moerman, & Fraidenraich, 2018)suggested a channel estimator scheme based on maximum likelihood(ML), however, this scheme doesn't have information about cooperated cell interference and noise.

Apply (Massive MIMO, 2019) superimposed Pilot Schemes where the pilot sequence is superimposed over the data to reduce PC, which can significantly reduce the UL pilot overhead to achieve a good compromise between a UL & DL achievable rate. The system introduces interference between pilot and data transmission also it needs the right proportion of power for data and pilot.

The author of (T. C. a. E. Björnson, , 2017.) employs proximity statistics to calculate the distance between customers in specific cells. Customers with a shorter distance and greater similarity are assigned, orthogonal pilots. The results demonstrated that combining pilot sequence optimization and pilot allocation significantly improved spectral efficiency.

Several pilot allocation schemes that highly overcome the PC problem are discussed here, For example, in (Jin, F.; Zhang, R.; Hanzo, L, , 1–4 April 2012;), (Zhou, Y.; Liu, L.; Du, H.; Tian, L.; Wang, X.; Shi, J. , 19–21 November 2014;) the authors canceled the inter-cell interference by assigning frequencies which are orthogonal to each other orthogonal to users on the edge of neighboring cells this scheme introduces high pilot overhead. The authors of (Lee, D.; Seo, H.; Clerckx, B.; Hardouin, E.; Mazzarese, D.; Nagata, S.; Sayana, K. , Mag. 2012,) proposed an FDD-based CoMP which is transmission based on a coordinated multi-point that successfully reduced the PC between neighbor cells. However, the system pilot overhead due to the FDD system makes the system inefficient as the number of BS antennas increases. To overcome feedback overhead, In (Choi, J.; Chance, Z.; Love, D.J.; Madhow, U. , 2013,)a non-coherent trellis-codded quantization is proposed. However, the increased complexity with an increasing number of BS antennas makes the system inefficient.

Authors in (Yue, S.; Liu, J.; Zhai, C.; Wang, Q. , 15–17 October 2015;) proposed a user pilot scheduling approach that was successful in reducing PC of the number of users in low channel quality with MSE (Mean Square Error). Nevertheless, while the proposed system was successful in lowering the PC still there is noise problem remained.

The authors of (Verenzuela, D.; Bjoernson, E.; Sanguinetti, L. J, , 4–8 December 2017;; Liu, M.; Chen, X.; Xu, W.; Zhang, H.; You, X.; Miao, W., 13–15 October 2016;) Angle of Arrival (AOA) based estimation of the channel is proposed, and it successfully reduced PC, however, the way how Method control power is incompetent as base station antenna number increases. (Atzeni, I.; Arnau, J.; Debbah, M., 8–12 June 2015;) proposed the scheme based on fractionally reusing pilots to reduce the PC. The identical pilot sequence was used by users in neighboring cells near BS. Furthermore, a variety of merging/combining methods is used that increase pilot overhead also adding the complexity of systems.

In (E. &. B. A. &. G. R. &. C. J.-Y. Ghayoula, ", 2014.), the proposed system assigns the optimum sequence of pilots to the user who has high pilot contamination severity based on a greedy algorithm. However, the scheme is only efficient for a small number of users mainly less than 5, also the algorithm they use introduces pilot overhead into the system.

In (Zhang, C.; Ma, L., . 2015,), the authors proposed an FPR method that increased system capacity and transmission quality. There are two types of FPR schemes: rigorous and soft FPR, The power control mechanism is utilized for soft FPR, which inhibits its ability to execute as the number of BS antennas grows. The scheme in (Wang, W.; Zhao, X.; Zhang, J.; Xu, L.; Zhang, H.; Li, X., 8–11 October 2018;) proposed a system based on the user grouping trial allocation approach. First separated users into the edge and core users and added separate pilots for them, here pilots are only assigned to the target cell depending on their SINR. This approach, however, does not provide information about pilot allocation in surrounding cells.

In (Seyyed MohammadMahdi Shahabi, Marjan Abbasi Mosleh, Mehrdad Ardebilipour,, 2020) proposed scheme in terms of complexity, it performs better than existing procedures. (fast convergence), yet there was a drop in the uplink sum rate. Also, to deal with the non-convex optimization, the difficulty becomes solved iteratively and sequential convex programming becomes exploited.

In (Zheng, X.; Zhang,2014) two pilot scheduling schemes are proposed to overcome the contaminations of the pilot namely AFPS and FPR, the PC in the uplink massive MIO with TDD system PC was drastically reduced and the amount of data transmitted is maximized, However, the overhead and inter-cell interference (ICI) were still too high to make it infeasible solution.

The soft pilot reuse strategy proposed in (Zhu, et al., May 2016), that each cell are partially benefited from the pilot set. This scheme first divided the available pilot group into center and edge, the center pilot group is reused in every cell in the system, However, the system divided the edge pilot group into all edge users of cell available in the system which increase pilot overhead makes the system inefficient. Also, to use these scheme efficiently more pilot resource is needed for the system, This can reduce the amount of bandwidth available for data transfer. To reduce PC, (F. Rusek,2013) proposes a pilot assignment-based color of a weighted graph, the proposed WGC-PD scheme however some limitations work the large number of users that increase system computational complexity.

(Erik G. Larsson,2014)suggest Outer weight Graph coloring-based pilot assignment the strategy outperforms both Conventional Scheduling and weighted graph-based pilot assignment strategies (F. Rusek,2013), but the average of the uplink achievable rate is going down as the number of antennae increases, which makes the system inefficient.

In (Luis A. Lago,2019), (W. Magnus,2014) weighted graph is used in conjunction with the Soft Pilot Reuse Scheme (SPRS) and cell classification. SPRS and cell classification will be presented to deal with the pilot overhead. The cell classification program will divide cells into two groups and prepare orthogonal pilots to align two groups of cells orthogonally. By using a large-scale-fading factor, users in a single cell will be divided into edge users and center users. An edge-weighted interference graph (EWIG) will measure center users' degrees of affection by pilot contamination and form the weighted graph (F. T. a. T. L. M. E. G. Larsson,, January 2014.), which will then be used as a reference to assign a pilot. However, in this system, the classified cells do not work cooperatively and also add pilot overhead, which makes the system inefficient.

In this thesis, we proposed a new schemes namely modified Soft Pilot Reuse (mSPR). First, the users in a targeted cell are clustered to the center and edge zone based on the signal level they received. After that, the user reuses this set of pilots within a grouped cell in a system, also assures that none of the pilot group that is assigned to edge user of the center cell is reused in a single tire. Consequently, pilot overhead and inter cell interference are reduced. The simulation results shows the data rate improvement of multi cell multi user massive MIMO system with the proposed mSPR pilot resource allocations. Further, number of orthogonal pilots are reduced and improves the uplink achievable rate and spectral efficiency over pre-existing schemes.

CHAPTER 3
OVERVIEW OF MASSIVE MIMO

3.1 Introduction

Massive MIMO (Multiple Input Multiple Output) is a wireless technology that uses multiple transmitters and receivers to transfer more data at once. Multipath, a radio-wave phenomenon in which transmitted data bounces off walls, ceilings, and other objects numerous times before arriving at the receiving antenna at slightly varying angles and times, is used in MIMO technology.

MIMO systems have several times the capacity of SISO systems. This can be demonstrated using a 20MHz communication channel as an example. Assume that the connection speed is 8 Mbps and that the SNR is some value. Using Shannon's equation, we can show that the new system's capacity will be 16 Mbps if we utilize a 2x2 MIMO system. Using the same logic, if a 4x4 MIMO system is used, the new system's capacity will be 32 Mbps. By doubling the antennae on both sides of the communication system, the system's capacity was doubled. Communication systems is a very promising technology. This is also why present communication systems are anticipating large MIMO systems.

Technology is continually improving. Point-to-point communication, also known as a single-input single-output communication system, was the earliest mode of communication (SISO). After that, single input multiple outputs (SIMO) and multiple-input single-output (MISO) communication systems were developed, followed by multiple-input multiple-output (MIMO) systems. SISO, SIMO, MISO, and MIMO systems are depicted in Figure3.1.

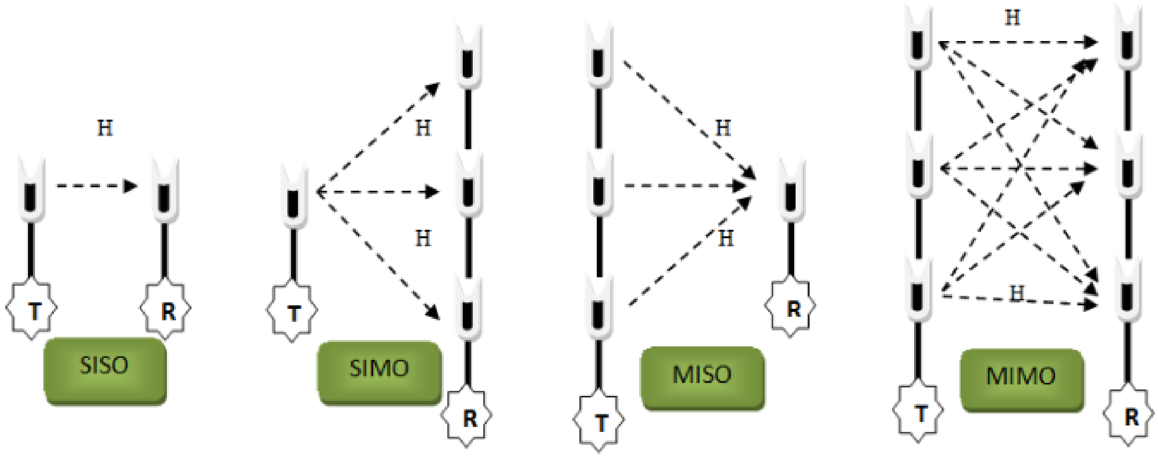

Figure 3.1 Basics of SISO, SIMO, MISO, and MIMO systems (Ghayoula, 2014)

It’s clear from the figure that MIMO systems have the high capacity as a result of the rise within the range of antennas. This is also why present communication systems are anticipating large MIMO systems. As can be seen from the graph, MIMO systems have an extremely high capacity due to the increase in antenna range.

Due to the utilization of many antennas, MIMO wireless technology can dramatically increase the capabilities of a given channel. By increasing the number of receive and broadcast antennas in the system, the channel turnout can be linearly enhanced with each try. As a result, MIMO wireless technology has risen to prominence in recent years. New tactics are needed to make better use of the available data as spectral bandwidth becomes a more valuable artifact for radio communications systems. One of these ways is MIMO wireless technology. MIMO to Massive MIMO advancements.

According to the study (Nokia,2019), today's MIMO antennas typically use two transmit and two receive antenna sections, double the capability of a standard antenna. In recent years, however, four to eight antenna pieces have been employed. Large MIMO, developed by Nokia's Bell Labs, goes even farther, employing several antenna sections to simultaneously send and receive streams of signals managed by a sophisticated package, resulting in far greater network capability (Nokia,2019). The capability improvements from MIMO systems were so great that many academics began to investigate the impact of dramatically increasing the number of antennas even outside of ordinary MIMO systems. This semiconductor diode is used in big MIMO systems. The high rate required by users is the most compelling justification for enhancing the capability of our communication systems. From time to time, this need grows stronger.

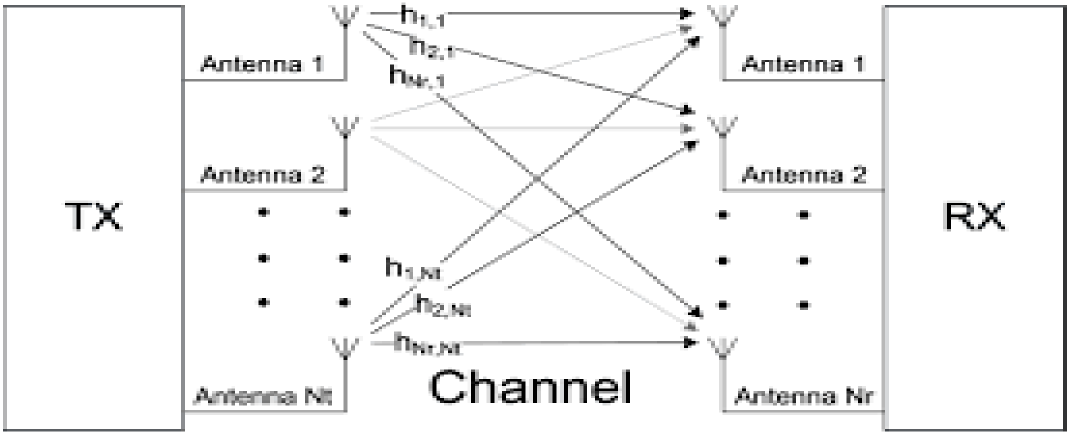

Figure 3.2 Line of site (LoS) antenna setup of a MIMO system (Abbas, Waseem & Abbas, Nasim & Majeed, Uzma & Khan, Sadaf., 2016).

When moving from MIMO to large MIMO, the key adjustments that were made were:

- In MIMO systems, the antennas used were two, four, eight, etc., however in large the antennas used are numerous, possibly thousands (E. Björnson,2017).
- Massive MIMO systems square measure characterized by:
  Number (BTS antennas) >> Number (users).
- Other notable properties of massive MIMO systems are derived from the higher properties of the massive MIMO system.

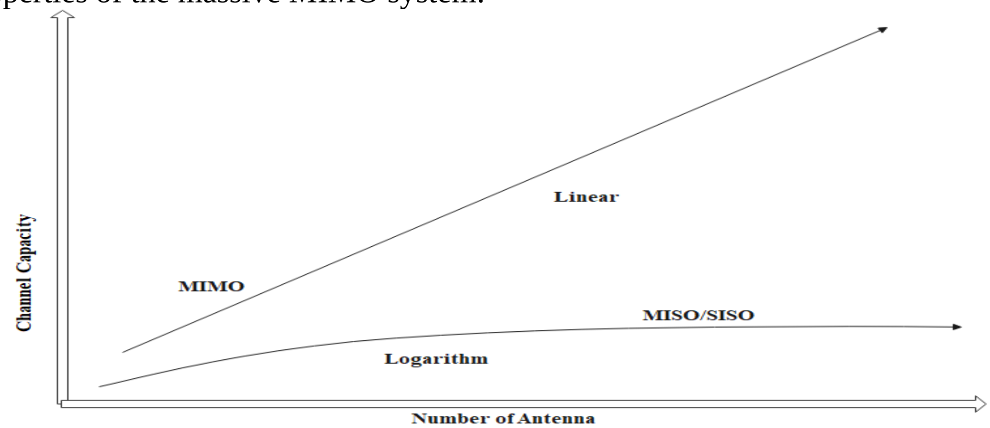

Figure 3.3 Channel capacity versus the number of the antenna of MIMO/SISO/MISO.

3.1.1 Massive MIMO Systems

Massive MIMO is the most intriguing wireless physical layer technology right now, and it's a key component of 5G networks. According to experts at Texas A&M University in the United States, massive MIMO could be a potential solution for future huge capability needs. Various simulations will be run simultaneously to assess the performance of various pilot contamination techniques. Large MIMO could be a massive system with multiple infrastructures and types of equipment. The antenna is one of the most important parts of a massive MIMO.

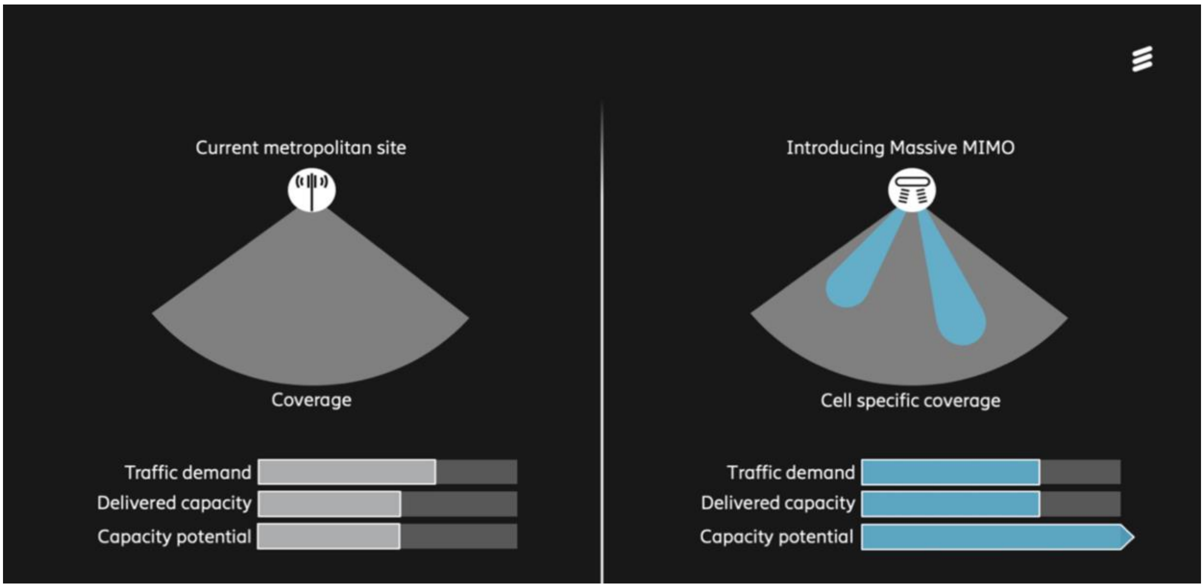

Figure 3.4 Cell Centric and User-Centric Cellular Networks_(Ericsson, June 2019).

Because there are so many antennas, they must be constructed in such a way that they produce the best results. Figure 3.6 depicts a huge MIMO antenna setup that is feasible.

Figure 3.5 depicts typical large MIMO systems that employ hundreds of antennas to serve tens of thousands of terminals within the same time-frequency resource. Future broadband (fixed and mobile) networks will be enabled by large MIMOs. which is energy-efficient, secure, and capable of making efficient use of the spectrum. As a result, it's a long-term enabler for digital society architecture that connects people, things, clouds, and other network infrastructure. Massive MIMO provides operators with a strong new tool for enhancing capability while preserving existing airwaves. (Nokia,2019). As a result, large MIMO is a stunning technology for the telecommunications industry.

Operators must maximize the use of their valuable spectrum resources to expand network capability as demand for mobile broadband services grows. The key to doing this is massive MIMO techniques and products.

Massive MIMO is based on spatial multiplexing, which requires good channel data from the bottom station on both the transmission and downlink. It is difficult to achieve over long distances, akin to the LTE (long-term evolution) standard for mobile communications.

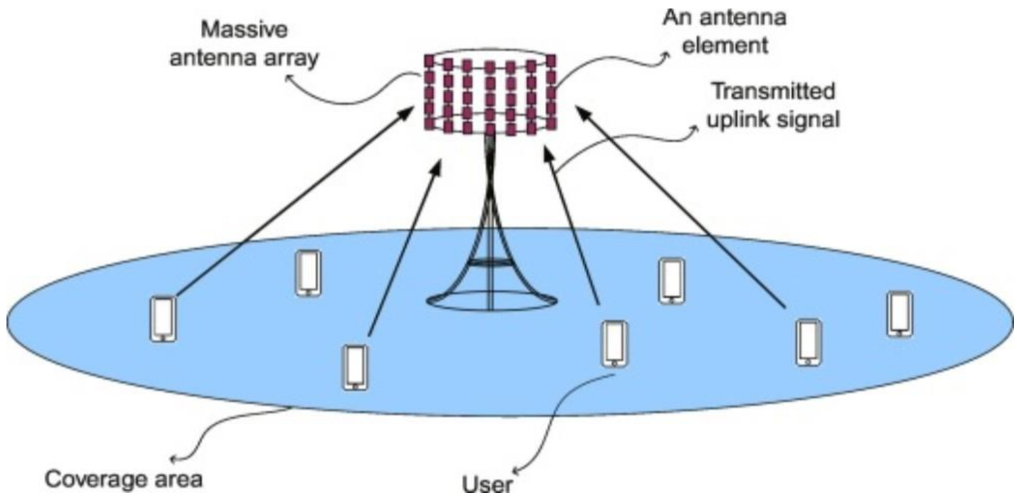

Figure 3.5 Particular massive MIMO system in the uplink transmission (Ngo H. Q., July).

The terminals employ pilot signals broadcast by the base station to estimate channel responses, quantify them, and send them back to the base station. For two reasons, massive MIMO systems will not be able to achieve this, at least not in a high-mobility environment.

Although FDD operation may be possible in some instances, operating in TDD mode and depending on reciprocity between the uplink and downlink channels is the ideal solution. The uplink resources needed to tell the base station of channel responses would be 100 times more than in traditional systems (F. T. a. T. L. M. E. G. Larsson,2014).

3.2 Massive MIMO and 5G

Regular MIMO concepts are presently used in several Wi-Fi and 4G protocols, but Massive MIMO will become more common once 5G is accessible. Massive MIMO is expected to be a critical enabler and component of 5G (J. M. a. K. Thomas,2019). Huge MIMO is the most crucial component of the 5G network.

One of the most critical functions of any 5G network will be to accommodate the impending huge rise in data consumption according to Cisco, by 2020.

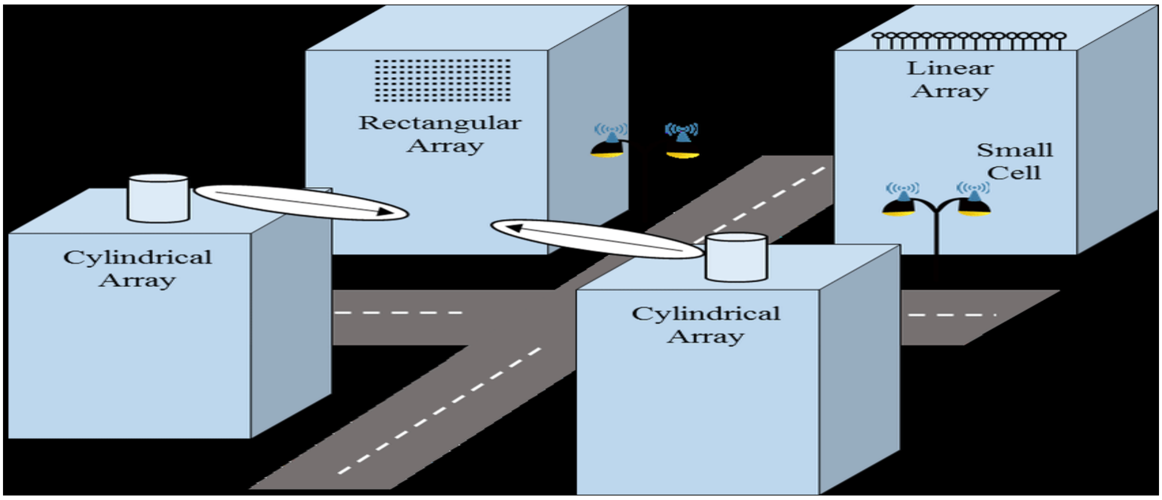

Figure 3.6 Some possible antenna configurations and deployment scenarios for a massive MIMO base station (E. G. Larsson, January 2014).

There will be 5.5 billion mobile users when 5G is ready to go global, each consuming an amazing twenty GB of data every month. Large MIMO's ability to simultaneously serve multiple customers - and multiple devices - in a small space makes it a viable solution for the forthcoming 5G era (J. M. a. K. Thomas,2019).

In general, 5G may use more radio spectrum than 2G, 3G, and 4G, as well as metric linear unit waves and metric linear unit waves like 3.5Gbps and twenty-eight Gbps and metric linear unit waves like 3.5Gbps and twenty-eight Gbps and metric linear unit waves like 3.5Gbps and twenty-eight Gbps. It has a radio propagation loss of about two gigabits per second, which is significantly higher than the previous sub-1GHz system.

Furthermore, factors like building shadowing, wall reflections, human bodies, and rain attenuation may all have an impact on 5G radio transmission. Massive MIMO coverage enhancement capabilities would stand out as a result of this vulnerability (M. Wang,2018). As previously stated, beam-forming and MU-MIMO will enhance single-user output and total network capability per base station. At higher frequencies, such as those slated for several 5G deployments (M. Wang,2018), large MIMO becomes considerably more practical .

According to a discussion session on "5G Deployments in High-Frequency Bands are Uneconomic" at The Mobile World Congress (MWC) will be held on February 26, 2019, Mr. rule Chauvin, president of Huawei's 5G line of merchandise, cautioned on the notion that Massive MIMO is the key to simplified 5G networks. Based on thorough theoretical research and in-depth testing data, he provided a detailed response to the much-discussed subject of the economics of 5G network construction. When compared to LTE in 1:1 mode, 5G with 3.5 GHz massive MIMO gives more coverage and capability, according to Mr. Principle. Additionally, operators could anticipate decreased cost per bit and overall cost of readying charges (Wang, W.; Zhao, X.; Zhang, J.;2018). Large MIMO appears to be quite promising for 5G in the long run. Massive MIMO may be the only way to achieve IMT-2020 in the long run, according to its high service providers (Zhang,2015).

3.3 Estimation of Channels

Channel estimation is a critical task in multiple-input multiple-output digital communications that has effects on end-to-end system performance.(Marius Arvinte, Jonathan I. Tamir,2022). Two units enable the concept of sharing the available spectrum in large MIMO systems. The important resources of duration and frequency that are shared by several mobile customers or terminals distinguish TDD and FDD area unit 2 topologies. Each of these flavors is used by LTE to allow mobile consumers or UEs to quickly use constrained resources.

3.3.1 Channel Estimation in TDD Systems

To get CSI at the BS, the big MIMO idea required TDD and relied on reciprocity. UEs send pilots during transmission (UL); each UE-to-BS channel may be determined, and each antenna has its radio frequency (RF). philosophy of nature The concept has advanced greatly since its start a decade ago: thorough information-theoretic studies are accessible, field trials have confirmed its performance in high-mobility situations, and logic gate prototypes have demonstrated the true usefulness of implementations (O. E. J. Flordelis,2017).

In a TDD system, transmission and downlink broadcasts use the same radio spectrum, but at completely different times. The downlink and transmission channels are unit reciprocal (H. Q. Ngo,2018).

Constant carrier frequency Fc is used for transmission and downlink transmission operations at completely separate time instants t1 and t2, as shown in Figure3.7. As a result, the following theme (see Figure3.8) can be used to create the CSI:

• For transmission: the BS wants the CSI to know about the K users' signals. This CSI can be determined at the BS. K users submit K orthogonal pilot sequences to the BS with great precision during transmission. The BS then calculates how successfully the channels processed the received pilot signals. This method necessitates the usage of at least K channels (H. Q. Ngo,2018).

• Each user wants the effective channel gain to see the required signals, whereas BSC wants CSI to pre-code the supplied signals for the downlink. The channel calculable at the BS during the transmission may be used to precode the broadcast symbols due to channel reciprocity.

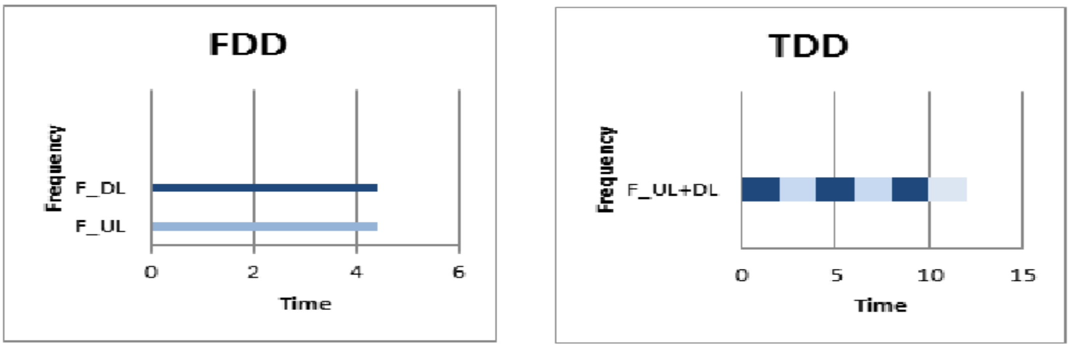

Figure 3.7 TDD and FDD topologies (Elshaer).

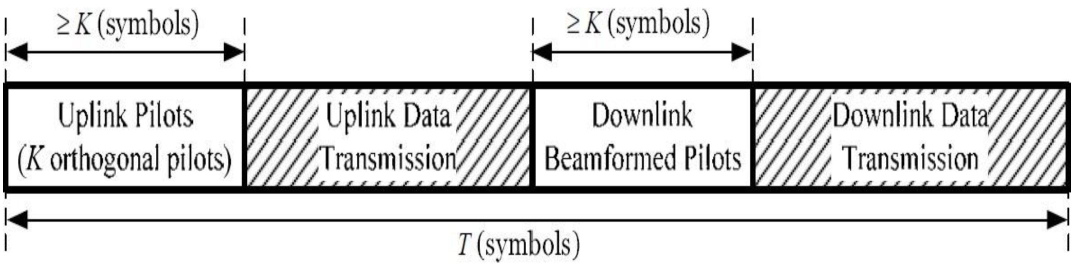

Figure 3.8 TDD system slot structure and channel estimation (Ngo H. Q., July).

Can beam from pilots, and each user can estimate effective channel gains based on the pilot signals received.

This necessitates the employment of at least K channels (Liu, M,2016). However, their information data is mapped in different time slots, therefore f1 = f2. Hence The same frequency has been assigned to both the uplink and downlink, as shown in figure 3.8, which demonstrates how the whole radio frame is broken into subframes that are used for both uplink and downlink.

3.3.2 Estimation of Channels in FDD Systems

In an FDD system, uplink and downlink broadcasts use independent frequency spectrums, therefore the uplink and downlink channels are not mutually exclusive(H. Q. Ngo,2018). The following training program can be used to get channel expertise at the BS and users:

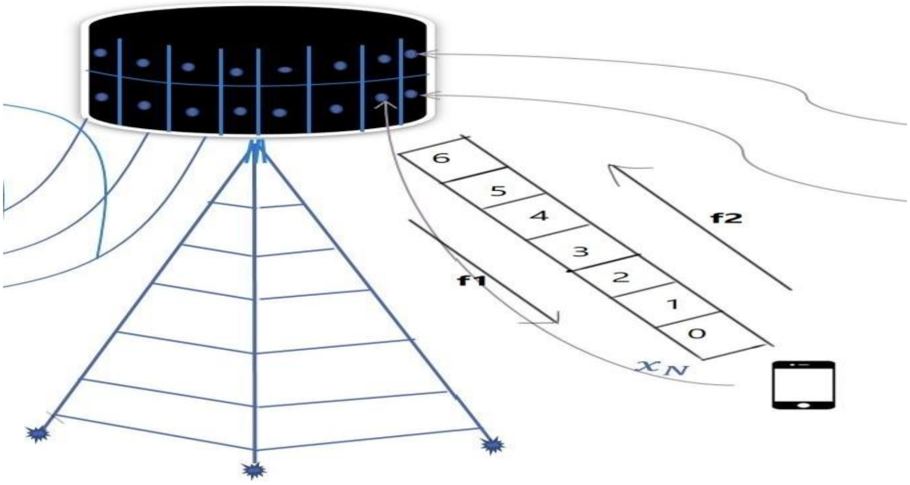

Figure 3.9 TDD scenario(Liu, M,2016).

As shown in Figure 3.9, two distinct carrier frequencies Fc1 and Fc2 are employed for transmission and downlink at the same time t1. With a guard band (i.e., duplex gap) between these components, the downlink is extended to the higher part of the spectrum and transmission to the lower portion of the spectrum.

F1 and f2 are one set of frequencies assigned on a separate basis for each transmission and downlink direction, as indicated in Figure3.10. As a result, f1 is assigned to the downlink band, whereas f2 is assigned to the transmission waveband. Over the downlink and transmission directions, the entire radio frame is used at the same time.

• Before delivering the symbols to the K users, the BS requires that CSI pre-code them for downlink transmission. The M BS antennas send M orthogonal pilot sequences to K users. Every user can assess how well the channel supported the received pilots. Then it sends its channel estimations back to the BS through transmission (M channel estimates). This method necessitates the use of at least M downlink channels and M transmission channels (Liu, M,2016).

• For transmission: the BS requests that CSI decipher the signals sent by the K users. One straightforward method is for the K users to send out K orthogonal pilots The BS is followed by sequences.

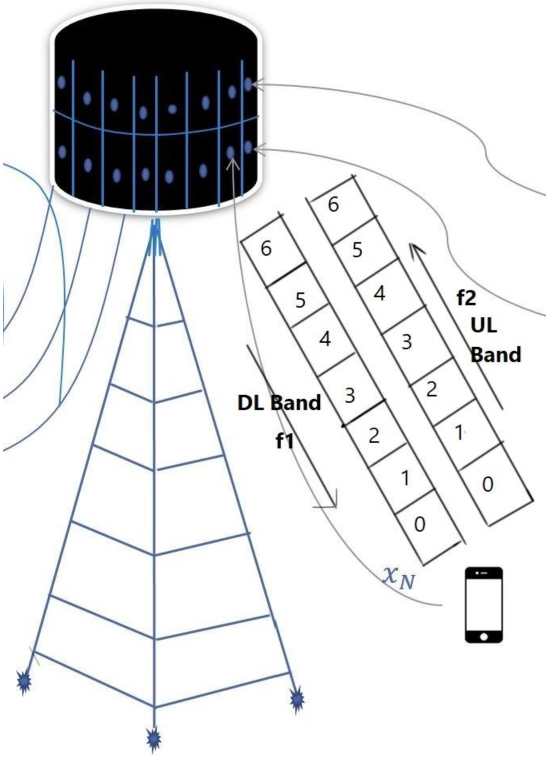

Figure 3.10 FDD scenario(Liu, M,2016).

The BS will then base on the pilot signals received, estimate the channels. For the uplink, this method necessitates the utilization of at least K channels (Liu, M,2016).

As a result, the complete channel estimation procedure necessitates at the least an M + K uplink channel makes use and an M downlink channel used. Assume the following coherence length constraints: M< T and M + K T. As a result, M + K <T is the restriction for the uplink and downlink FDD intervals to be the same and equal to T. Then there are the systems. Figure 3.11 (Liu, M,2016) depicts an example of channel estimation in FDD systems.

Because systems constraint is one factor for comparison, it could be used to pick the optimal system when comparing TDD and FDD. Based on the system constraint, the publication (Liu, M,2016) provides a great analogy of the two systems. The channel estimate overhead with FDD is a direct relationship to the number of BS antennas, M. TDD, on the other hand, has a channel estimation overhead that is independent of M. Because the M Interval in Massive MIMO is T = 200 symbols (equivalent to bandwidth for the coherence of 200kHz), TDD operation is preferred.

and hence, Assume, for example, that the number of users with coherence is limited. M + K <200, whereas TDD systems have a coherence time constraint of 1ms). Then, in FDD systems, the number of BS antennas and the total number of BS antennas on M and K is 2K < 200. Figure3.12shows the areas of feasibility (M, K) in both FDD and TDD systems. The FDD region is smaller than the TDD region. When using TDD, adding more antennas does not affect the resources required for channel estimation.

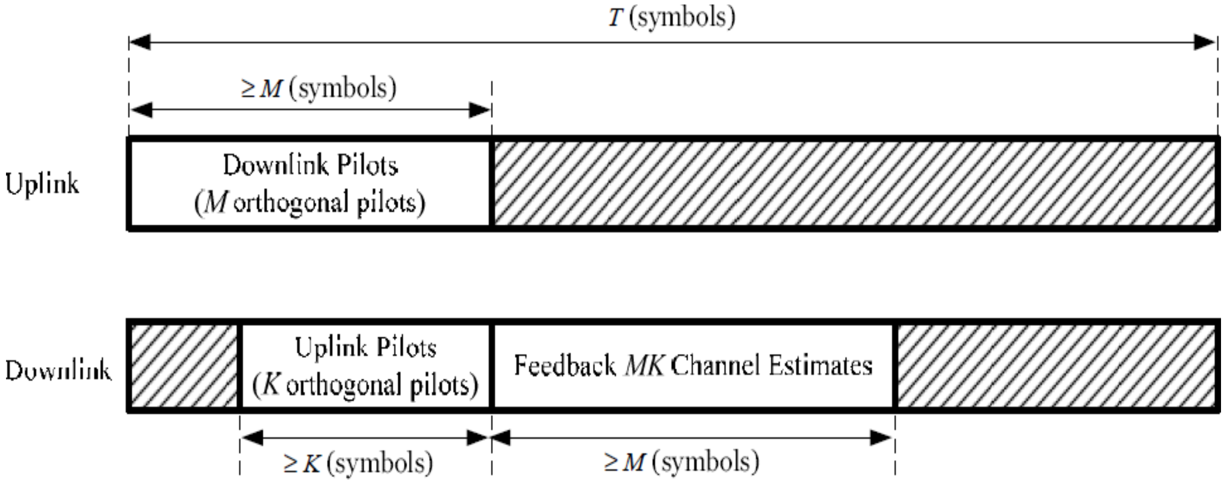

Figure 3. 11 In FDD systems, slot structure and channel estimation (Ngo H. Q., July).

Switching between TDD and FDD systems is not difficult because many chip-set Ericsson, Altair Semiconductor, and Qualcomm, for example, now support both TDD and FDD LTE on a single chip, and telecommunication operators can take advantage of this Adaptability in response to traffic and other requirements.

3.4 Beamforming and Massive MIMO

Beamforming and MU-MIMO (multi-user MIMO) are two key breakthroughs introduced by massive MIMO (M. Wang,2018). So, in this section, we'll provide you an overview of beamforming in massive MIMO. Huge MIMO systems make use of massive antenna arrays at wireless base stations to simultaneously serve a large number of autonomous terminals using spatial multiplexing. Multiplexing takes the form of beamforming, also known as multiuser precoding, which basically makes transmitted signals that add up constructively where the terminals are located and destructively almost everywhere else. Base stations are made up of a large number of antennas that connect with a number of spatially dispersed user terminals at the same time. One option for achieving this potency saving is to use frequency resources and multipath propagation.

Large MIMO is the popular term for this technique (multiple-input, multiple-output). Large MIMO such as beamforming with an enormous range of antennas will have been discovered. However, this raises the question, "What is beamforming?" in the United States of America.

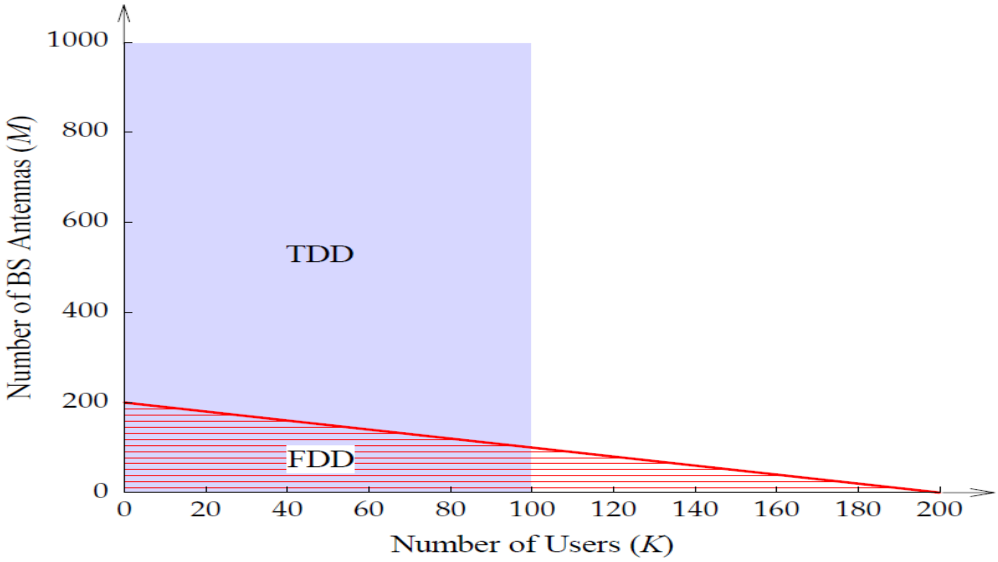

Figure 3.12 The regions of possible (M, K) in TDD and FDD systems, for a coherence interval of 200 symbols (Ngo H. Q., July).

The phrase "beamforming" means different things to different individuals. Beamforming is the capacity to tailor the emission pattern of an antenna array to a specific scenario. Many people imagine beamforming in cellular communications as directing a power lobe in a specified direction toward a user, as depicted in Figure3.13. Allowing the antenna array's output signals to add together coherently for a certain transmit/receive angle, but destructively canceling out for other signals. The relative amplitude and phase shifts are received by each antenna element. Rarely is the spatial environment in which the array and user are positioned taken into account. Although it is simply one type of implementation, this is beamforming (C. Masterson,2017). Antenna arrays can alter their radiation patterns with time and frequency for both transmission and reception, whereas individual antennas have a fixed radiation pattern. Although antenna arrays can undertake a variety of additional spatial filtering processes, this is commonly shown as the creation of spatial beams in one (or a few) distinct angular orientations. The array is regulated by signal processing, which can be used to focus a signal at any point in space in a rich multi-path propagation system, for example.

Because it matches to the surroundings, the radiated pattern has no dominant instructions and produces a superposition of the numerous angular beams. In the propagation environment, the array is also utilized to identify anomalies or moving objects. (E. Björnson, June, 2019).

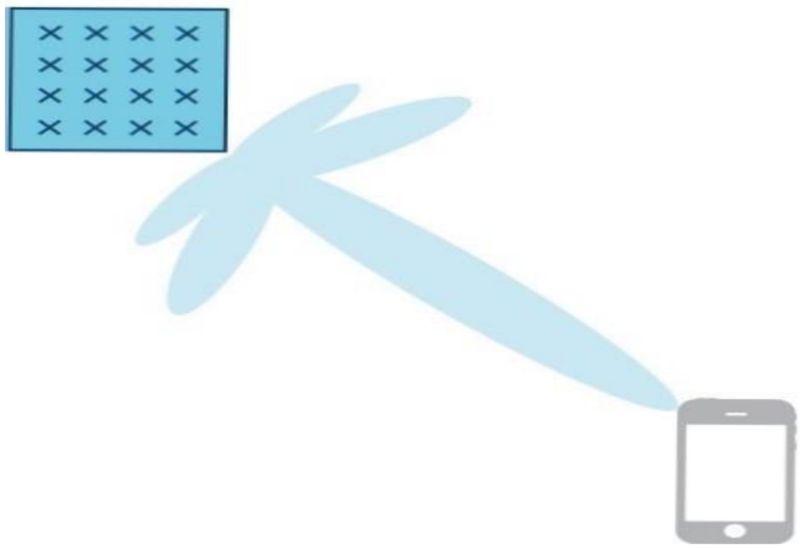

Figure 3.13 Traditional Beamforming (schwarz, August 2018).

Figure 3.14 shows how beam shaping on an antenna array can (a) focus the generated signal in one angular direction or (b) focus the signal at a specified location in space; in this case, dominant directionality is not required. The radiation patterns in this figure were computed using eight antenna uniform linear arrays. The terms beam creation and massive MIMO are sometimes used interchangeably. Massive MIMO may involve beam formation, or beamforming may be a subset of massive MIMO. In a multi-antenna array, beamforming uses numerous antennas to direct the path of a wavefront by balancing the magnitude and phase of individual antenna signals. In other words, a large number of antennas separated by a sufficient distance broadcast the identification signal (at least 1 wavelength). As a result, in any given place, the receiver will receive several copies of the same signal. The signals could be in opposite phases, destructively averaging each other out, constructively summing if the multiple copies are in the same phase, or anything in between, depending on the receiver's position (Abbas,2016). To accomplish a certain directivity or beamforming, an antenna array with amplitude and phase-weighted RF signals at each antenna element is required. There are three techniques to apply amplitude and phase shifts (R.

schwarz,2018). The following sections cover the various types of beamforming used in large MIMO systems.

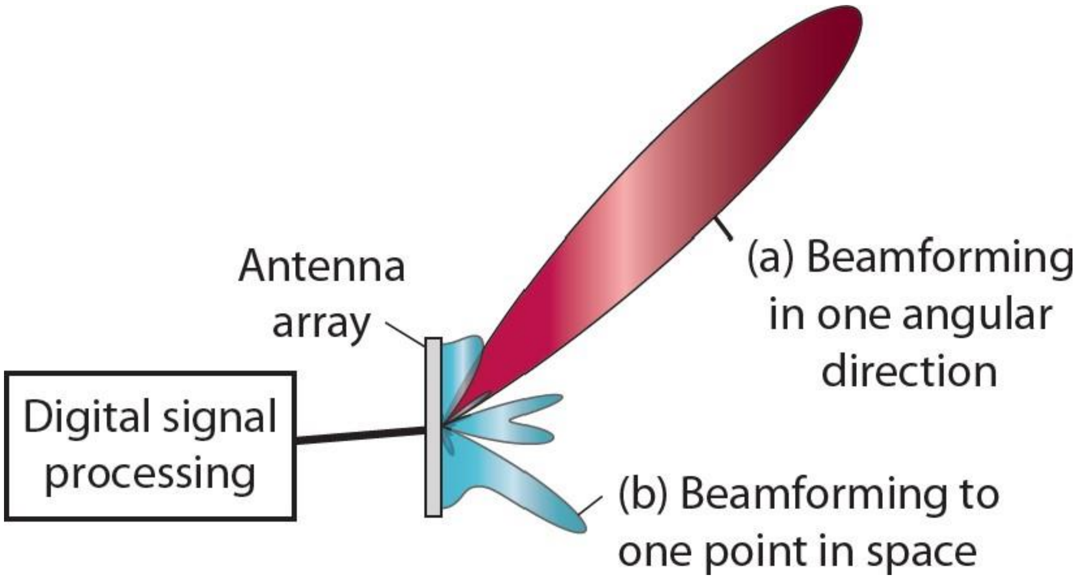

Figure 3.14 Beamforming from an antenna array (Zhou, Y.; Liu,2014)

• Digital Beamforming (also known as Baseband Beamforming or Precoding):

The signal is pre-coded (amplitude and phase changes) in baseband processing before RF transmission. Multiple beams (one for each user) can be generated simultaneously from the same set of antenna elements. In the context of LTE/5G, MU-MIMO is the same as digital beamforming. Multiple TRX chains are required in the base station, one for each simultaneous MU-MIMO user. Digital beamforming (MU-MIMO) is utilized in LTE Advanced Pro (transmission modes 7, 8, and 9) and 5G NR. Digital beamforming increases cell capacity because the same PRBs (frequency/time resources) can be used to transmit data for multiple users at the same time (M. Passoja,2010).

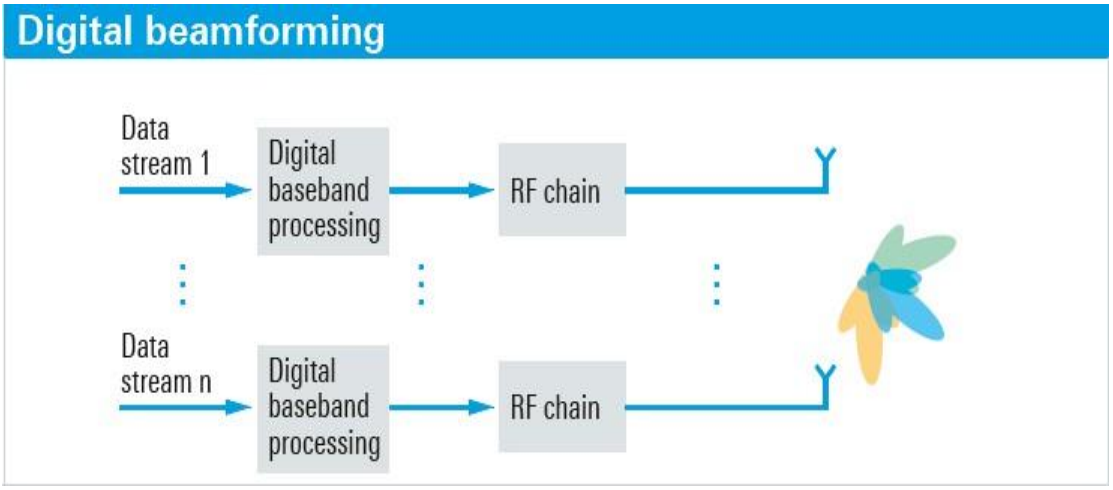

Figure 3.15 Digital Beamforming (schwarz, August 2018).

• **Analog Beamforming:**

In the RF domain, individual antenna signal phases are changed. The radiation pattern and gain of the antenna array are modified by analog beamforming, which improves coverage. Unlike digital beamforming, each set of antenna elements can only produce one beam. In mm-wave, analog beamforming's antenna gain boost helps to reduce the effects of high pathless. As a result, for the 5G mm-Wave frequency range, analog beamforming is required (Abbas,2016).

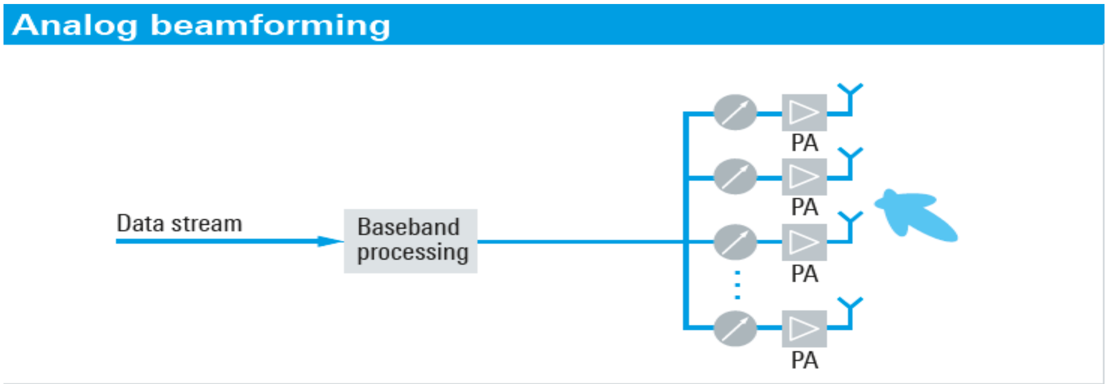

Figure 3.16 Analogue Beamforming (schwarz, August 2018).

• **Hybrid Beamforming:**

It combines analog and digital beamforming techniques. Hybrid beamforming is expected to be employed in mm-wave gNB (5G base station) deployments. One alternative is to use analog beamforming for coarse beamforming and a digital beamforming scheme, such as MU-MIMO or SU-MIMO, inside the analog beam (Abbas,2016).

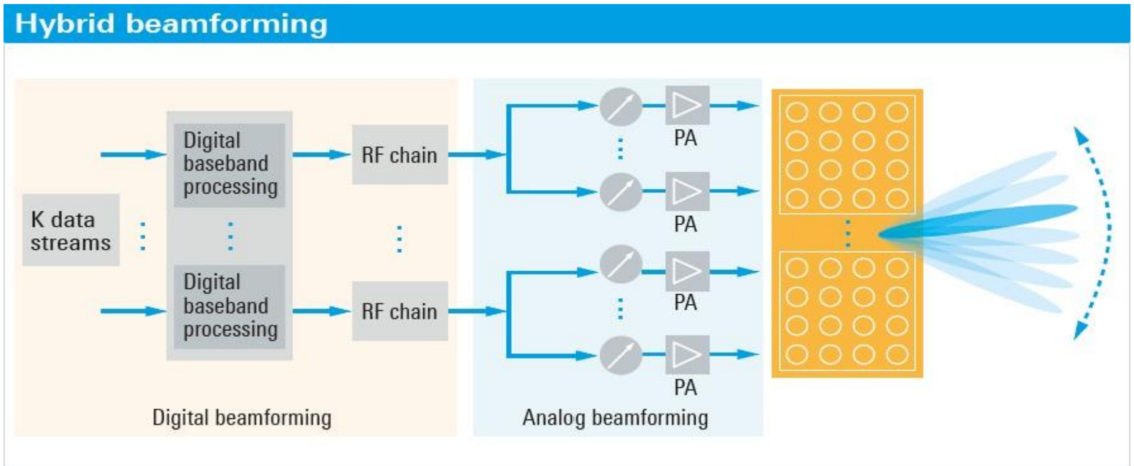

Figure 3.17 Hybrid Beamforming (schwarz, August 2018).

Properties and Advantageous of Massive MIMO

Massive MIMO is an MU-MIMO system with a large number of BS antennas and a large number of users. Massive MIMO uses hundreds of thousands of BS antennas to serve tens or hundreds of users on the same frequency resource. Some of the most important aspects of Massive MIMO are as follows:

TDD operation

As noted in Section 3.3.2, the channel estimate overhead with FDD is dependent on the number of BS antennas, M. TDD, on the other hand, has an independent channel estimate overhead. TDD operation is preferable in Massive MIMO because M is so large. The TDD Massive MIMO transmission scheme is shown in Figure 3.18.

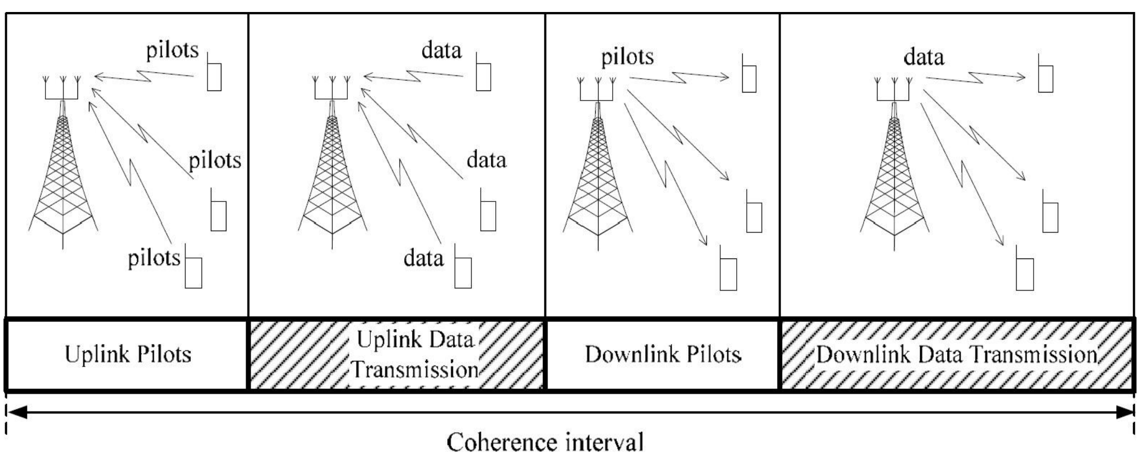

Figure 3.18 Transmission protocol of TDD Massive MIMO (Ngo H. Q., July).

Signal processing at the terminal ends must deal with huge dimensional matrices/vectors because to the large number of BS antennas and users. As a result, simple signal processing is recommended. In Massive MIMO, linear processing (uplink linear combing schemes and downlink linear precoding algorithms) is nearly optimal. (H. Q. Ngo,2018).

Favorable propagation occurs when the channel matrix between the BS antenna array and the consumers is well-conditioned. The beneficial propagation property holds in Massive MIMO under certain conditions due to the law of large numbers. (H. Q. Ngo,2018).

It is not necessary for a large BS antenna array to be physically massive. Consider a 128-antenna cylinder array with four circles of 16 dual-polarized antenna elements as an example. Because the distance between nearby antennas at 2.6GHz is roughly 6cm or half a wavelength, this array is only 28cm x 29cm (Liu, M,2016).

Because the BS learns the channels via uplink training while functioning in TDD mode, Massive MIMO is scalable. The number of BS antennas has no impact on the time it takes to estimate a channel. As a result, the number of BS antennas can be raised indefinitely while the channel estimate overhead remains constant. Furthermore, each user's signal processing is very simple and independent of the presence of other users, i.e., there is no multiplexing or de-multiplexing signal processing among the users. The activity of other users is unaffected by adding or removing some members from the service (Liu, M,2016).

All of the complexities are contained in the BS (H. Q. Ngo,2018), Massive MIMO systems have a number of advantages over previous technology. One of these advantages is that it can increase capacity tenfold or more while also increasing radiated energy efficiency by a factor of 100 (F. T. a. T. L. M. E. G. Larsson,2014). Massive MIMO boosts capacity by using a huge number of antennas. The capacity of massive beamforming ensures energy efficiency. When a high number of antennas are utilized, energy is often focused exceedingly precisely into small areas of space, which allows for such a significant increase in energy efficiency. By appropriately structuring the signals sent out by the antennas, the bottom station may verify that all wavefronts collectively released by all antennas total up constructively at the locations of the intended terminals, but destructively (randomly) almost everywhere else. Interference between terminals can be decreased even more using various combination approaches and algorithms. The second advantage is that it will be made of low-cost, low-power components (Atzeni, I,2015).

In terms of relevant theory, systems, and implementation, Massive MIMO is the most suited technique. Massive MIMO replaces existing systems' pricey non-linear technology with low-cost linear equipment. Several large and costly items, such as massive coaxial cables, might be eliminated. The diameter of today's coaxial cables for tower-mounted base stations is over four centimeters! Massive MIMO frees each amplifier and RF chain from accuracy and linearity limitations. It's all about how they collaborate. Massive MIMO uses the law of big numbers to ensure that noise, fading, and hardware faults are averaged out when signals from several antennas are combined in the air. The fading resistance of massive MIMO is due to the same phenomena that make it extraordinarily resilient to the failure of one or more antenna units. The degrees of freedom in a huge MIMO system are plentiful. 180 degrees of freedom is pointless with 200 antennas serving 20 terminals, for example. These degrees of freedom are widely used for hardware-friendly signal shaping. Each antenna, in instance, can transmit signals with a low peak-to-average ratio or possibly a constant envelope at a low total radiated power cost (Atzeni, I,2015). The third advantage is that air interface latency can be significantly reduced.

Wireless communication systems suffer from fading, which has a substantial impact on their performance. Fading might make the received signal strength relatively poor at times. Low-latency wireless networks are challenging to construct because of this fading. If the terminal remains stuck during a fading dip, no data can be received until the propagation channel has sufficiently changed. Massive MIMO employs the law of massive numbers and beamforming to reduce fading dips and ensure that latency is not affected (Vu, T.X,2014).

The multiple-access layer is easier to understand with massive MIMO. The law of big numbers causes the channel to harden, making frequency-domain scheduling unprofitable. In an OFDM-based massive MIMO system, each subcarrier will have approximately identical channel gain. Because each terminal is typically allotted the entire bandwidth, much physical-layer control signaling is redundant. Another advantage of Massive MIMO is that it increases resistance to both unintentional and intentional jamming. The deliberate jamming of civilian wireless systems is a growing concern and a severe cybersecurity risk that the general public tends to be unaware of.

3.5 Pilot Contamination: Massive MIMO's Limiting Factors

Pilot contamination is a condition that occurs when the precoding matrix adopted at a base station is correlated with the channel of users in other cells because of non-orthogonal pilots allocated to users. In other word, the pilot contamination caused by sharing the non-orthogonal pilots among users is considered to be a bottleneck of massive MIMO system.

Every terminal orthogonal uplink pilot sequence will be assigned in a Massive MIMO system. However, dividing the duration of the coherence interval by the channel delay spread determines the maximum number of orthogonal pilot sequences that can occur. According to (Liu, M,2016), the maximum number of orthogonal pilot sequences within a one-millisecond coherence period in a typical operational situation is expected to be around 200. It's easy to exhaust the number of orthogonal pilot sequences available in a multicellular system. Pilot contamination is the result of reusing pilots from one cell to the next, as well as the negative consequences that come with it. A linear arrangement of channels at opposite terminals that have the same pilot sequence disrupts communications between two terminals.

When the service array correlates its received pilot signal with the pilot sequence for a specific terminal, it obtains a channel estimate that is contaminated by combinations of channels. Because downlink beamforming supports the polluted channel estimate, interference is focused on terminals with the same pilot sequence. Similar interference can be found in uplink data streams. This directed interference grows at the same rate as the desired signal as the number of service antennas increases (Liu, M,2016). Even when pilot sequences are only partially coupled, direct interference occurs. Pilot contamination isn't unique to massive MIMO, but it appears to have a significantly bigger influence on pilot MIMOs than on ordinary MIMOS (Verenzuela,2017) and could have implications for how radio signals are transported from Earth to space.

CHAPTER 4

SYSTEM MODEL

4.1 Introduction

To achieve the objectives of this thesis, we consider various methods, such as literature review, modeling the pilot contamination scenario, selecting and describing appropriate pilot decontaminations model, Computer simulations, and corresponding analysis. The simulation is Performed by MATLAB R2015a and the word is edited by using Microsoft office 2013.

First, massive MIMO systems with multiple cells and multiple users are considered, to deal with the problem of PC we consider the proposed Soft pilot reuse pilot decontamination schemes first, the user in a given cell is classified into edge and center zone users using efficient user grouping that is based on a large scale fading coefficient range then by applying some modifications on soft pilot reuse schemes assign the orthogonal pilot for cell edge user and similar set of a pilot is reused in a grouped cell of edge user, since there we are avoiding the pilot contamination for cell-edge users by assigning the orthogonal pilot to it but for cell center user the pilot contamination severity is not that much we assign the pilot for it randomly .In this chapter the mathematical model of general massive MIMO and the pilot decontamination schemes are developed also the simulation parameter is defined.

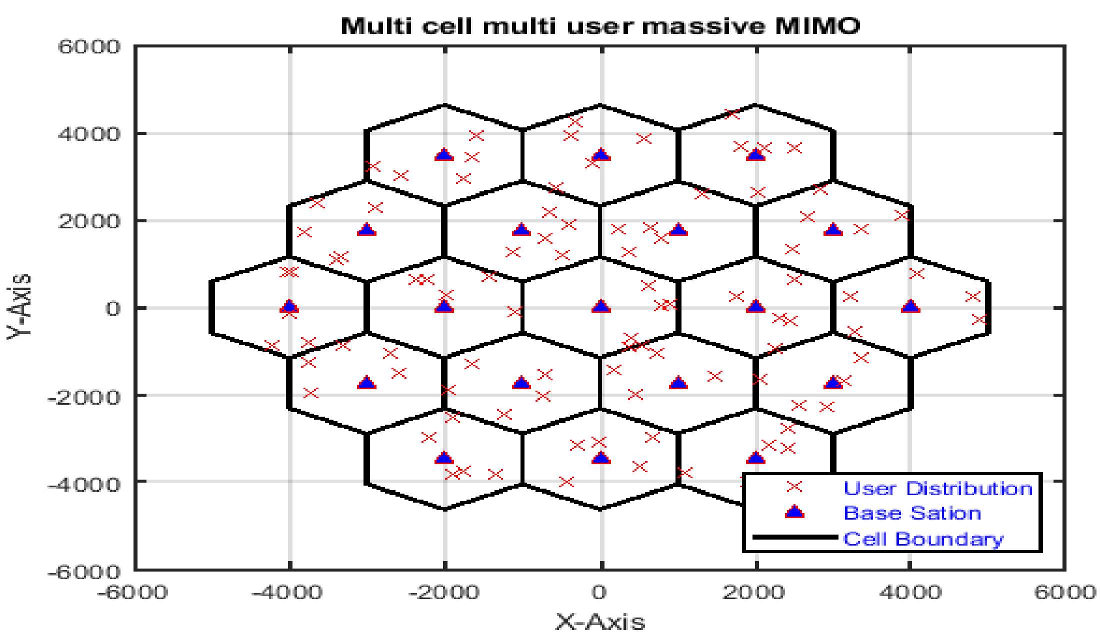

Figure 4.1 General multi-user multi cell massive MIMO System

4.2 System Model's and Pilot Contaminations

Figure 4.1 depicts a massive-MIMO system made up of L cells with a hexagonal shape, each with one BS at center and M antennas to provide services to K single-antenna users (Marzetta, 2010), (F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and FTufvesson, , January 2013), where the number of users in a single cell is much smaller than the number of antennas associated with the serving base stations, i.e. (K<<M). The channel vector is shown below in figure $h_{j,k}^{i} \epsilon \, \mathbb{C}^{M_J x \, 1}$ of the link between the base station in cell i[th] and k[th] users in j cell is expressed as

$$h_{j,k}^{i} = \mathrm{g}_{j,k}^{i}\sqrt{\beta_{j,k}^{i}} \qquad (1)$$

Where:-
$\mathrm{g}_{j,k}^{i}$= represents the vector of small scale fading coefficients
$\beta_{j,k}^{i}$= represents a vector of fading coefficients on a large scale

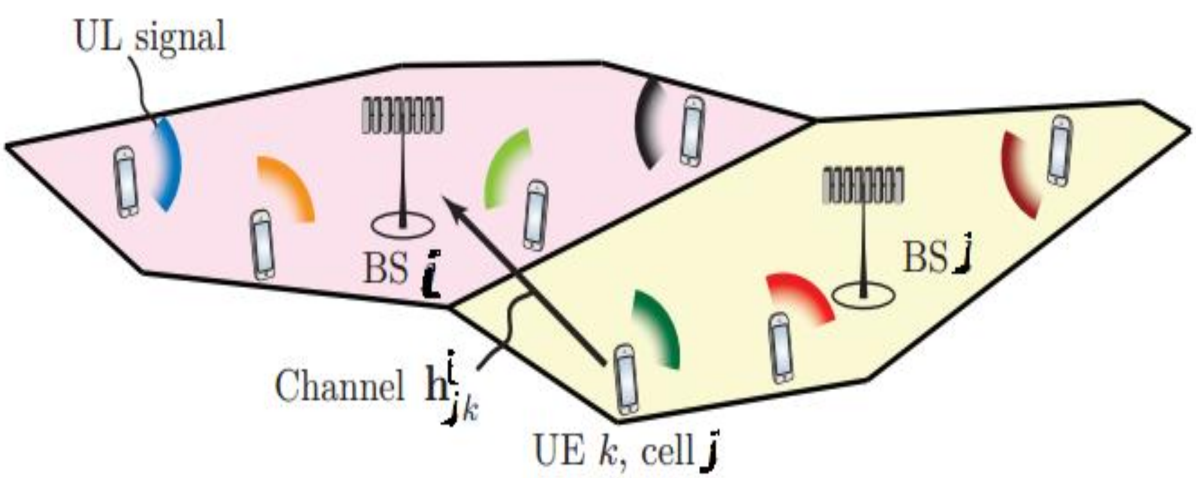

Figure 4.1 Multi-cell Massive MIMO System Description (Marzetta, T.L,2010).

The small-scale fading vectors $\mathrm{g}_{j,k}^{i} \epsilon \, \mathbb{C}^{M_J x \, 1}$ is not depend on K users, and They are distributed according to a complex-valued Gaussian distribution, with an I_M, covariance matrix, and a zero mean vector, resulting in $\mathrm{g}_{j,k}^{i} \sim \mathbb{C}N$ = (0,I_M). The large-scale fading coefficients $\beta_{j,k}^{i}$ have equal value for all antennas at the same base station, as shown in equation (1) above. They are, however, dependent on the user. Furthermore, they are linked to shadow fading and path loss, both of which will be discussed in-depth within the framework of our simulations. And here's how it's done:

$$\beta^{i}_{j,k}=\frac{z^{i}_{j,k}}{\left(\frac{r^{i}_{j,k}}{R_O}\right)^{a}} \qquad (2)$$

Where:-

$z^{i}_{j,k}$= Shadow fading coefficient with log norm distribution.=10$\log_{10} z^{i}_{j,k}$

r^{i}_{j}= The distance between Kth users in cell j to BS i

R_O=Cell radius

a=path loss exponent

In the j–th cell, the channel matrix of all the K users and the BS in the ith cell can be represented by

$$H^{i}_{j} = [h^{i}_{j,1}\ h^{i}_{j,2} \ldots .\ h^{i}_{j,k}] \qquad (3)$$
$$= [\ g^{i}_{j,1} \quad g^{i}_{j,2}\ \ldots\ \ g^{i}_{j,k}]\ D^{i}_{j}{}^{0.5}$$

Where D^{i}_{j}= diag ($\beta^{i}_{j,1}$, $\beta^{i}_{j,2}, \ldots \beta^{i}_{j,k}$) denotes the largescale fading matrix that connects all of the K users in the j -th cell to the BS in the i-th cell.

By utilizing the TDD protocol, the base station gets the DL channel estimate by utilizing the reciprocity of the UL and DL channels. More specifically, both the small-scale fading vectors and the large-scale fading coefficients may be considered equal for both the DL and UL directions, provided that the bandwidth is sufficiently low to avoid the DL and UL fading independently. We review the asymptotic favorable propagation or asymptotic orthogonality on random vector (Marzetta, 2010) before moving on to the PC phenomenon. Assume that $h_1 \epsilon\ \mathrm{C}^{M_J x\ 1}$ and h_2 $\epsilon\ \mathrm{C}^{M_J x\ 1}$ are two independent vectors with the same distribution $\mathbb{C}N$ = (0, cI_M) Then there's the law of big numbers.

$$\frac{h_1{}^{H} h_2}{M} \longrightarrow 0 \text{ as M tends to } \infty \qquad \frac{h_1{}^{H} h_1}{M} \longrightarrow \text{ C as M tends to } \infty. \qquad (3)$$

4.2.1 Pilot Contamination

We employ the commonly known block-fading channel model with the TDD protocol, in which the channel vectors $h_{j,k}^{i}$ stay constant and flat fading during the channel's coherence interval. As seen in Figure 4.2) below

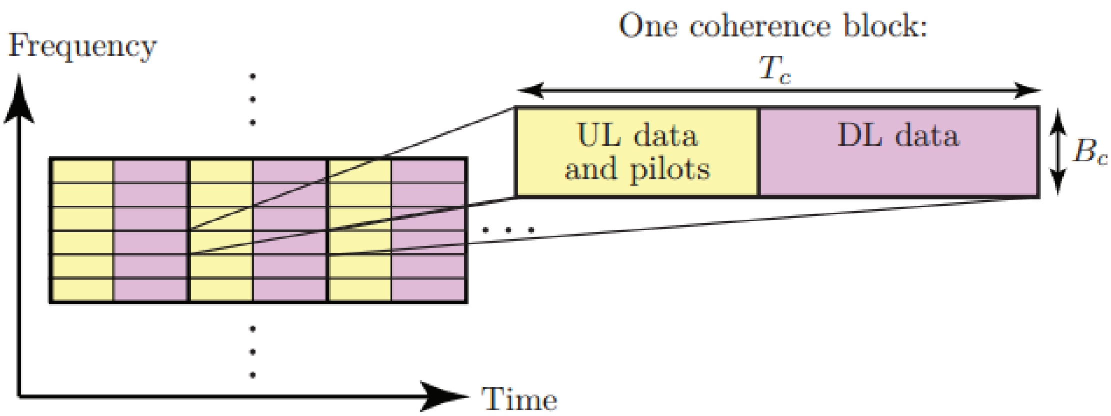

Figure 4.2 A classic Massive MIMO network's TDD multicarrier modulation technique. Each channel is time-invariant and frequency-flat in the time-frequency plane, which is split into coherence blocksReference11 (Marzetta, T.L,2010).

Each coherence interval is divided into three stages. for each user (Marzetta, T.L,2010) : 1) UL pilot transmission; 2) UL data transmission and 3) DL data transmission.

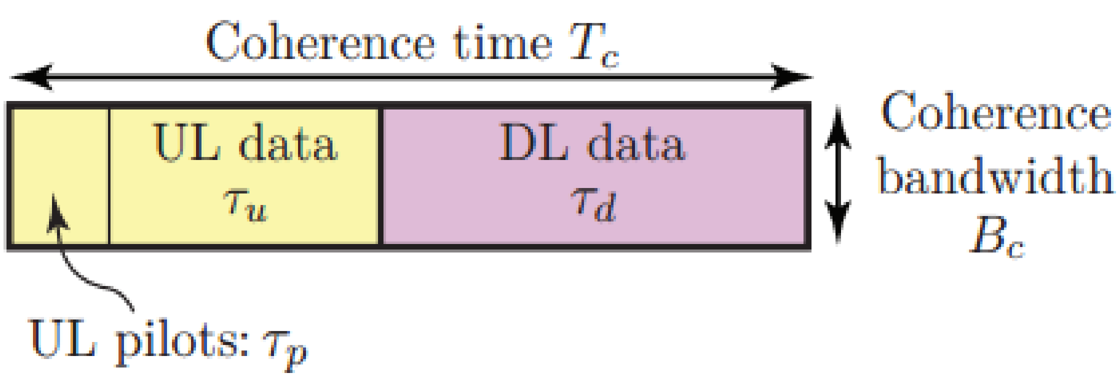

Figure 4.3 The samples will be used in UL pilots, UL data, and DL data. (Marzetta, T.L,2010).

The pilot sequences utilized inside a single cell in a typical Massive-MIMO system are orthogonal and have a length of l, thus no such pilots should be repeated in a single cell. As a result, the available S (S≥K) pilots' matrix $\Phi = [\emptyset_1 \ \emptyset_2 \ ... \emptyset_k \ ]^{T} \in= \mathbb{C}^{Kx\,T}$ whose column Vectors are orthonormal to each other, resulting in $\Phi\Phi^{H}=I_K$. Due to the restricted amount of orthogonal pilot sequences, the same pilot group is frequently repeated in neighboring cells. To demonstrate the pilot assignment, a variable a_{jK}= [1, 2…, S] is added to signify that the user$u_{jK}$is assigned the pilot sequence$\emptyset_{ajk}$, then A= [a_{jK}].

As a result, the uplink communication system, which is the matrix of pilot sequences received at the BS of the i-th cell and indicated by $Y_i^p \epsilon \mathbb{C}^{M_J x\, \tau_p}$, can be represented as

$$Y_i^p = \sum_{k=1}^{k_i} \sqrt{p_{ki}}\; h_{ik}^i \emptyset_{ik}^T + \sum_{\substack{l=1.\\ l\neq i}}^{L} \sum_{j=1}^{k_l} \sqrt{p_{kj}}\; h_{lj}^i \emptyset_{lj}^T + N_i^P \tag{4}$$

Desired pilot Intercell pilots Noise

In its simplest form: $Y_i^p = \sqrt{p_p}\; \sum_{j=1}^{L} H_J^i\, \Phi\; + N_i^P$, where the matrix, where the matrix Φ = [$\emptyset_1\ \emptyset_2\ ...\emptyset_k$] $^T \in \mathbb{C}^{Kx\, \tau_p}$ containing the transmitted pilot sequence fulfills $\Phi\Phi^H$=I_K, where p_p is the pilots' transmission power and N_i^P is the AWGN matrix for the UL channel and it is $\in \mathbb{C}^{M_J x\, \tau_p}$. The BS of the i-th cell gets an approximation of the channel matrix H_i^i during the third stages using any typical channel estimation that is mainly correlating the received pilot matrix with the local pilot matrix directly results the estimated channel as follow

$$\widehat{H}_i^i = \frac{1}{\sqrt{p_p}} Y_i^p \Phi^H = H_i^i + \sum_{i\neq j} H_j^i + \frac{1}{\sqrt{p_p}} N_i^p \Phi^H \tag{5}$$

From equation 6 we deduce that channel estimation of k th user that is in ith cell also depends on the user in j th cell that reused the same set of pilot. this correlation phenomenon of the channel is called Pilot contamination (F. Rusek, D. Persson,2013) (B. H. a. B. M. Hochwald,2014) and (Xudong Zhu; Linglong Dai; Zhaocheng Wang and Xiaodong Wang,2017).

Given the estimated channel matrix $\widehat{H}_i^i$ and by adopting the low complexity MF detector, the detected symbol arriving from the k-th user in the i-th cell can be represented as

$$\hat{x}_i^i = \hat{h}_{i,k}^{i\ \ H}\ y_i^u \tag{6}$$

$$= \sqrt{p_u}\Big(h_{ik}^{i\ H} h_{ik}^i x_{ik}^u + \sum_{i\neq j} h_{jk}^{i\ H} h_{jk}^i x_{jk}^u \Big) + \in_{i,k}^u$$

$$\approx M\sqrt{p_u}\, \beta_{ik}^i x_{ik}^u + \sum_{i\neq j} \beta_{jk}^i x_{jk}^u \Big)$$

Where $v_{i,k}$, k-th column of $\frac{1}{\sqrt{p_p}} N_i^p \Phi^H$, $\in_{i,k}^u$ shows the interference, and $\overset{(a)}{\approx}$ denotes that the approximation using the law of big number holds as M → ∞.

For each user in the ith cell the uplink SINR(Signal to interference plus Noise Ration)

The UL signal to interference plus noise ratio (SINR) of the k-th user in the i-th cell can be formulated as follow:

$$SINR_{i,k}^{UL} = \frac{|h_{ik}^{i}{}^{H} h_{ik}^{i}|^2}{\sum_{i \neq j} |h_{jk}^{i}{}^{H} h_{jk}^{i}|^2 + \frac{|\in_{ik}^{u}|^2}{p_u}} \tag{7}$$

$$\overset{(a)}{\approx} \frac{\beta_{ik}^{i}{}^{2}}{\sum_{i \neq j} \beta_{j,k}^{i}{}^{2}}$$

And the achievable UL rate can be expressed as:

$$R_i^{UL} = (1 - \mu) E\{log_2(1 + SINR_{i,k}^{UL})\} \tag{8}$$

$$= (1 - \frac{S}{K}\, \mu_O)\, E\{log_2(1 + SINR_{i,k}^{UL})\}$$

Here the $0 < \mu < 1$ represents spectral efficiency loss resulted by allocation frequency resources from the coherent block for the transmission of the pilot (Hochwald, April), and μ_O represents the pilot overhead in a frame.

From above we deduce that PC highly affect UL attainable rate, we cannot get ride out of it by increasing the number of base station antenna(M) also the power of pilot & transmission ρ_u and/or ρ_p, so in all performance of multi-cell multi-user Massive-MIMO systems is reduced.

4.3 The Proposed Schemes

4.3.1 Clustering the user

Before we implement the proposed schemes, we first group/cluster the users in the targeted cell based on the clustering technique discussed below, taking into account that each user in a cell has a distinct level of pilot contamination severity (PCS), the majority of conventional paper (Jose, J.; Ashikhmin, 2011) assumes that each user in a cell has the same level of PCS. However, it is evident from equation (7) above that the PCS which is given as a denominator of achievable SINR is based on large-scale fading coefficients of non-targeted cell that is user-dependent so this tells as each user has a different contamination level of pilot. The below flow diagram shows the flow of how we implement the grouping strategy i.e. first parameter is initialized, then for each user in the targeted cell we calculate the large scale fading factor, based on the square of large scale fading value, user is sorted as in increasing order then apply decision algorithm that is mainly based of the real value of single space and how many pilot resource we have to decide how many users from sorted is categorized into cell edge and cell center zone users.

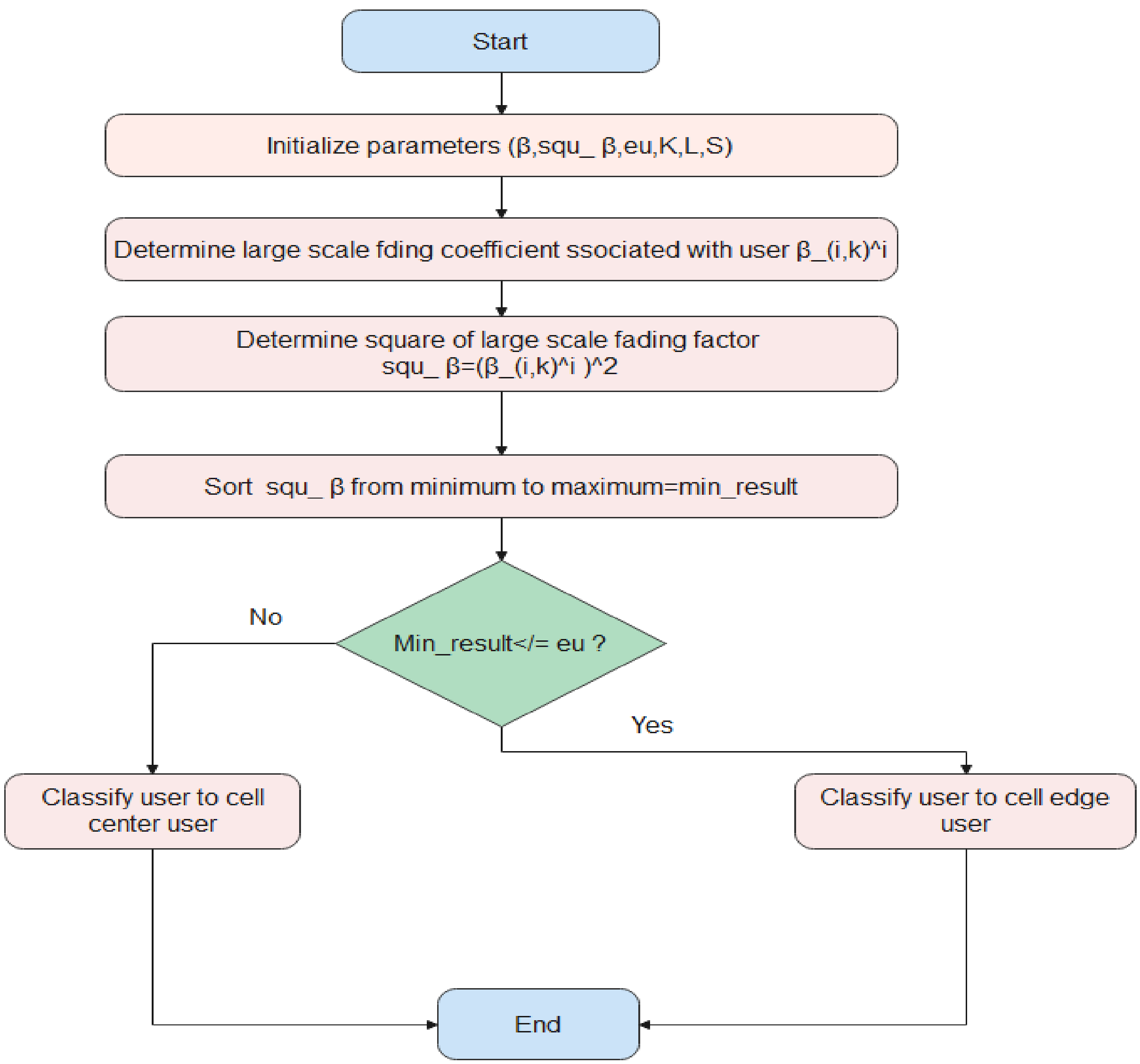

Figure 4.4 User Grouping Flow Chart

Note that the predefined threshold $\boldsymbol{e_u}$ is independent of the location of users, it is rather based on the signal space of $\{\boldsymbol{\beta}_{i,k}^{i}{}^{2}\}$ and how many resources we have and its value is constant.

Where $\boldsymbol{e_u}$ stands for edge user, the formula is given by:

$$\text{min result } (\boldsymbol{\beta}_{i,k}^{i}{}^{2}) \leq \boldsymbol{e_u} \quad \begin{cases} \text{yes} & \text{Cell edge zone user} \\ \text{No} & \text{Cell center zone users} \end{cases} \tag{10}$$

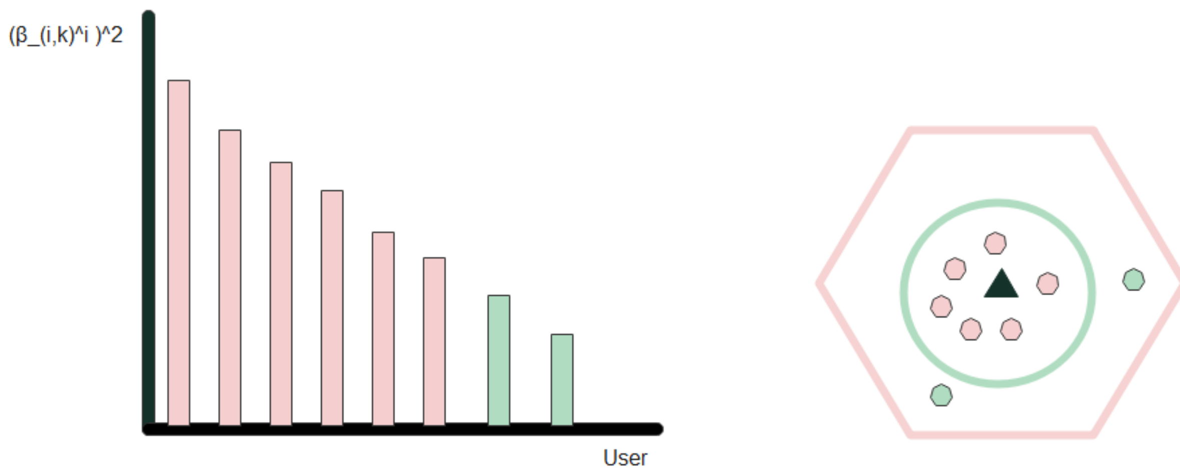

Figure 4.5 An illustrative example of the user division

From Figure 4.5 above the brown color indicates the cell center user and green shows the cell edge user. Additionally, central zone users are those who have modest PCS and have the highest level of the received signal, whereas cell edge zone users have the highest PCS and receive the lowest signal level. In the following section, we propose a more sophisticated scheme that assigns available pilot resources to grouped users per cell and to the whole system too.

4.3.2 Proposed Modified Soft Pilot Reuse Scheme (PmSPR)

From Soft Pilot Reuse pilot assignment schemes to mitigate the PC, the scheme first divides the available pilot resources into two groups, namely center, and edge then allocates orthogonal pilot subgroups to all (Zhu, et al., May 2016) users in the edge zone of neighboring cells to prevent significant ICI, while the same set of center pilot groups is utilized for all cell center users. We further extend this concept with the modification of also reusing the cell edge zone user pilot group with pre-grouped cells to further reduce pilot overhead, while also assuring that none of the edge user for center cells pilot sets is reused with a single tire, that further PC.

Consider a standard massive-MIMO system, that is made up of L hexagonal cells, with the i^{-th} cell supporting K_i users. The set of orthogonal pilot sequences required in the convention massive-MIMO (Lu, L.; Li, G.Y.; Swindlehurst, A.L.; Ashikhmin, A.; Zhang, R. , 2014,) , (Marzetta, 2010), (F. Rusek, D. Persson, B. K. Lau, E. G. Larsson, T. L. Marzetta, O. Edfors, and FTufvesson, , January 2013) system that randomly assigned the pilot is computed as

$$K_{RPA} = \max\{K_i, i = 1,2 \dots . L\} \quad (9)$$

Unlike the traditional LS-MIMO system, which treats as all users have equal strength of pilot contamination and assigned the set of the pilot randomly, the mSPR user in i^{-th} cell i.e., K_i is first split into two groups as discussed in section 4.3.1, which have cardinalities of.

$$K_i = K_{i,c} + K_{i,e} \quad (10)$$

$K_{i,c}$=card $\{ k : {\beta^{i}_{i,k}}^2 > e\,u \}$ specifies the center zone users, whereas $K_{i,e}$=card $\{k : {\beta^{i}_{i,k}}^2 < eu\}$ denotes edge zone users in i^{-th} cell.

As a result, the set of orthogonal pilot sequences required in the mSPR approach can be determined as follows:

$$K_{mSPR} = K_c + K_e$$
$$= K_c + \sum_{i=1}^{L_G} \sum_{=edu}^{g} K_{e,i} \quad (11)$$

Where:-

L_G =show grouped cell i.e L_G< L

<K_{mSPR} $^{=}$ Set of pilot group assigned to mSPR Schemes.

$K_C = \max\{K_{i,c}, i = 1,2 \dots . L_G\}$ Represents set of pilot sequences used in center zone user of the system and this pilot group is reused in all center zone users,by considering maximum users in grouped cell.

$K_e = \sum_{i=1}^{L_G} \sum_{=1}^{g} K_{i,ex}$ is the number of pilot sequences assigned to edge users, here unlike SPR in (Zhu, et al., May 2016), (You Zhou, ShuyuanShen, YitongWang, YaodongCui, 2020). (V. Doshi, D. Shah, M. Medard, and M. Effros, August 2010) the mSPR scheme also reuses the pilots for the system per L_G group of cells,that will highly reduce pilot overhead.

From equation (11) above

$$K_e = \sum_{i=1}^{L_G} \sum_{edu=1}^{g} K_{e,i} \tag{12}$$

Where L_G= is the maximum number of grouped cell

edu= is edge user

g =is the maximum number of edge users per cell

$K_{e,i}$= set of pilot that is reused in a grouped cell, where i=1,2,3,..

We consider L_G cooperative grouped cells, the complete set of pilot resources for a given system is $\Phi_{mSPR} \in \mathbb{C}^{K_{mSPR} x\, \tau_p}$ that are associated with $\Phi_{mSPR}\Phi_{mSPR}{}^{H}=I_{K_{mSPR}}$, can be divided into edge and center pilot groups, as shown below.

$$\Phi_{mSPR,all} = [\Phi_c{}^T \Phi_e{}^T]^T \tag{13}$$

Where $\Phi_c \in \mathbb{C}^{K_c x\, \tau_p}$ is used for the center users in all cells and $\Phi_e \in \mathbb{C}^{K_e x\, \tau_p}$ is used for the edge users of neighboring cells in the group. In addition, Φ_e can be split into a grouped cell of L_G divisions.

$$\Phi_e = [\Phi_{e,1}{}^T \quad \Phi_{e,2}{}^T \ldots \quad \Phi_{e,L_G}{}^T]^T \tag{14}$$

Where $\boldsymbol{\Phi}_{e,i} \in \mathbb{C}^{K_{e,i} x\, \tau_p}$ is applied to the grouped cell that is used in $K_{i,e}$ edge users in the system and reused in a group of cells L_G.

Also, to further reduce the PC and enhance edge user performance the system assures that the pilot set from $\Phi_{e,i} = [\Phi_{e,1}{}^T \quad \Phi_{e,2}{}^T \ldots \quad \Phi_{e,L_G}{}^T]^T$ that is assigned to the edge user of the center cell are not reused in a single tire system. Figure 4.6 below shows that when the grouped cell is integrated and how it looks the pilot assignment in a single tire system.

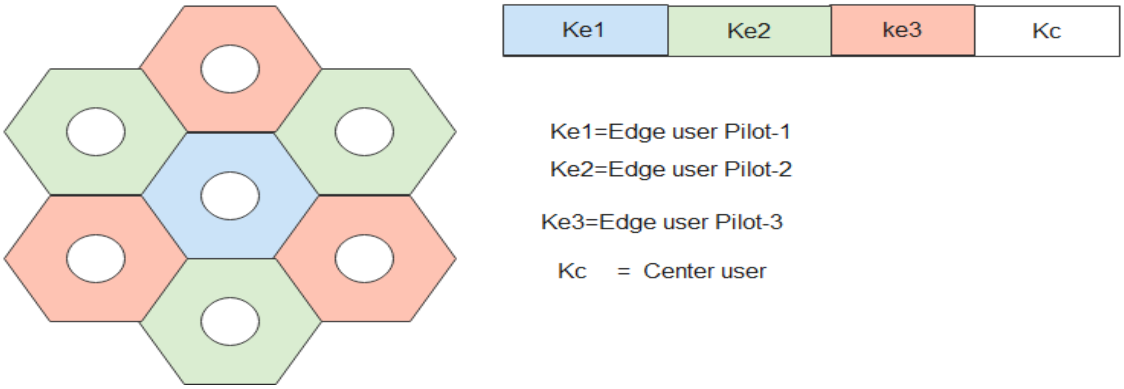

Figure 4.6 Pilot resource divisions and assignment scenario in Single tire massive MIMO system.

As discussed above and we saw from the above figure the pilot resource used in cell one is not reused within its tire, claimed that to reduce ICI, and further enhancing the performance of the cell-edge user, with that tire. First we classified available orthogonal pilot into 4 group; 1group for center grouped user and 3 for edge grouped cell. The edge users are grouped into three in order to maintain both orthogonality rule and reduce the coherence resource given for edge pilot sequence. If we group the edge user into four, we will need to increase the coherence resource given for the edge user which will decrease the data transmission rate. Since our aim is to increase data transmission rate, it is better to group the edge users into three.

We can structure the cells either separately or attached together in the system. In our case, the structure of the cell is attached together and we have grouped the edge users into three. In other case, we can group into 2 but the structure of the cells will be separated or isolated. Both ways are possible but when we structure separately there will be empty space between cells in other word the users in that place won't get any pilot resource. So the advantage of grouping into 3 over into 2 is that all users are included and there won't be an empty space. In general, we grouped into 3 in order to remove the empty space so that all the users will be included and in order to meet what we have planned on our general objectives.

Since our proposed system is highly beneficial if we consider a large number of cells, so integrating the above concept into a large number of multi-cell massive MIMO systems is discussed in detail, as shown below that derived from the concept of soft pilot reuse, which previously dividing the existing pilot resource into a center pilot and edge pilot set, and only the center pilot set is reused and assigned randomly while for cell edge zone user they assigned with an orthogonal pilot set to them that highly leads to decrease data rate of the system due to high pilot overhead as we understand from equation (8) above , to overcome to the problem of pilot overhead, so we propose the scheme that also reuses the edge orthogonal set of pilots at some distance extent and this orthogonal pilot set is reused in a group of three cell and the cell is arranged is as shown in Figure 4.7)below that assure none of the orthogonal pilots that are assigned to edge user of first tire center cell is reused in the system. This concept is further shown graphically as shown below.

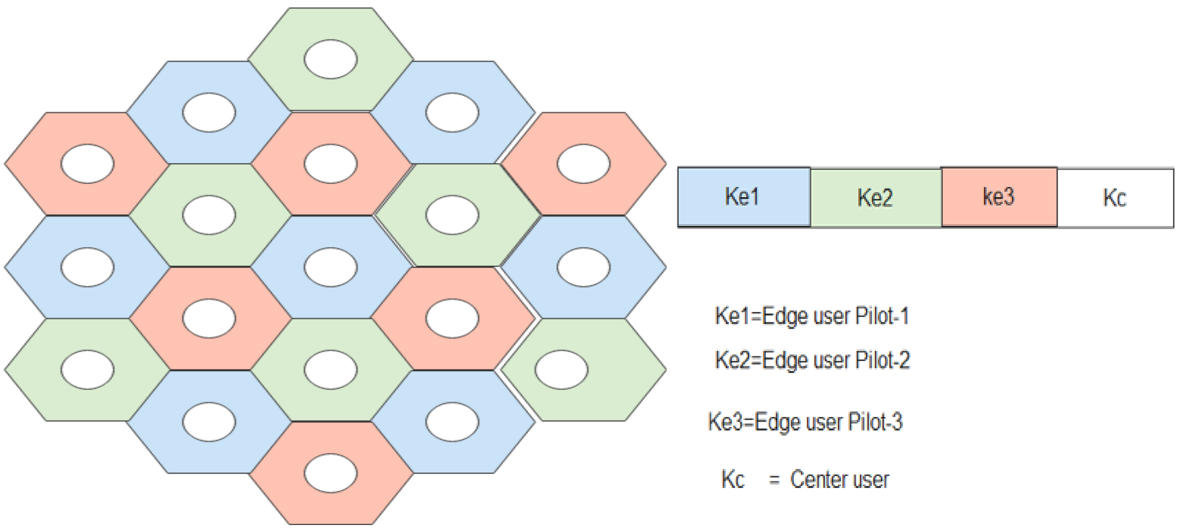

Figure 4.7 Pilot resource divisions and assignment scenario in the multi tire massive MIMO system

But in (Lu, L.; Li, G.Y,2014), (Jose, J.; Ashikhmin, 2011) and (Vu, T.X,2014) literature they assigned an orthogonal pilot set for all cell edge users available in the system without considering the reuse orthogonal pilot assigned to cell edge zone users. For this basic instance if we consider 7 cells in every 5 users, form concept of cell clustering 2 users for cell edge and 3 users, here if we consider SPR we need 17 pilots that mean 3 pilot group are reused in center cell and 14 pilot set (2X7) is used in a group of 2 sets to all edge of other cells in single tire system, but in the proposed (mSPR) system we only need 9 pilot set, 3 for a center user and 2 X 3 pilot set for cell edge, that are reused in grouped cell. we can see from this the mSPR scheme need 8 less pilot resource than SPR that is highly reduce pilot overhead and improve data rate of the system.

The proposed modified SPR method allows the BS to estimate the channels for its edge users in the absence of PC. The method can gain partial knowledge of the edge users' inter-cell channels in neighboring cells, which is the primary source of the ICI inflicted on adjacent cell edge users during the DL broadcasts.

We consider L_G hexagonal cells with Ki users in the i^{-th} cell. We split the channel matrix $\boldsymbol{H_j^i}$ as specified in (2) above into two pieces using the mSPR method.

$$H_j^i \rightarrow [H_j^{i\,c}\; H_j^{i\,e}] \tag{15}$$

Where $\boldsymbol{H_j^{i\,c}} \in \mathbb{C}^{MxK_{j,c}}$ represents the channel matrix of the link spanning from the j^{th} cell's center users to the i^{th} cell's BS, and $\boldsymbol{H_j^{i\,e}} \in \mathbb{C}^{MxK_{j,e}}$ denotes the channel matrix of the link spanning from the edge users in the j -th cell to the BS in the i^{th} cell.

The pilot sequence received at the i^{th} cell's BS can therefore be represented as

$$\overline{Y_\iota^p} = \sqrt{p_p}\; \left(\sum_{j=1}^{L} H_j^{i\,c}\, \Phi_c\big(r: K_{j,c}\big) + \sum_{j=1}^{L_G} H_j^{i\,e}\, \Phi_{e,j}\right) + \overline{N_\iota^P} \tag{16}$$

Where $\Phi_c\big(r: K_{j,c}\big)$ indicates the first $K_{j,c}$ rowΦ_c sub-matrix, and N_i^P signifies the equivalent AWGN matrix at the UL receiver. The BS can then estimate the channel of its center users as follows:

$$\begin{aligned}\widehat{H}_i^{i\,c} &= \frac{1}{\sqrt{p_p}}\overline{Y_\iota^p}\Phi_c{}^H\big(r: K_{i,c}\big)\\ &= H_i^{i\,c} + \sum_{j\neq i} H_j^{i\,c}\, \Phi_c\big(c: K_{i,c}\big) + \overline{N_\iota^c}\end{aligned} \tag{17}$$

Where $\overline{N_\iota^c} = \frac{1}{\sqrt{p_p}}\overline{N_\iota^p}\Phi_c{}^H\big(r: K_{i,c}\big)$ is minimized by increasing the value of antenna M, and $H_j^{i\,c}\, \Phi_c\big(c: K_{i,c}\big)$ denotes the matrix comprised of the first $K_{i,c}$ columns of $H_j^{i\,c}$.

Note that if we have $K_{i,c} > K_{j,c}$ then $K_{i,c} - K_{j,c}$ zero vectors are used to fill $H_j^{i\,c}\, \Phi_c\big(c: K_{i,c}\big)$. Because the PC placed on these center zone users is minimal, the suggested approach simply permits the center zone users to reuse the same pilot group of Φ_c, as opposed to the usual scheme of (5) above. As a result, the impact of the PC on the channel estimate of the center zone users indicated in (16) above is small. The BS of the i^{-th} cell, on the other hand, becomes capable of collecting without excessive PC usage, the channel estimate of its edge users by adopting the suggested modified SPR scheme, producing

$$\widehat{H}_i^{i\,e} = \frac{1}{\sqrt{p_p}}\overline{Y_\iota^p}\Phi_{e,i}^{H} == H_i^{i\,e} + \overline{N_\iota^e} \tag{18}$$

Where we have $\overline{N_i^e} = \frac{1}{\sqrt{p_p}} \overline{N_i^p} \Phi_{e,i}^H$.

By increasing the number of antennas at the BS, this may be made arbitrarily very small. It is apparent that for these edge users, the PC is eliminated, and as a result, the channel estimate accuracy of these edge users is considerably improved however there is still PC for center zone users that is shown by $\sum_{j\neq i} H_j^{i\,c}\, \Phi_c\big(c\!: K_{i,c}\big)$ which is the correlation of the estimated channel with targeted cell to the user who reuses the same pilot set. With the aid of the proposed mSPR scheme, the full channel estimate at the BS of the i-th cell is then given.

$$\widehat{H}_i^i = [\widehat{H}_i^{i\,c}\ \widehat{H}_i^{i\,e}]$$
$$= H_i^{i\,c} + \sum_{j\neq i} H_j^{i\,c}\, \Phi_c\big(c\!: K_{i,c}\big) + \overline{N_i^c} + H_i^{i\,e} + \overline{N_i^e} \quad (19)$$

As the number of antenna elements increases the effect of N_i^c and N_i^e negligible,

$$\approx H_i^{i\,c} + \sum_{j\neq i} H_j^{i\,c}\, \Phi_c\big(c\!: K_{i,c}\big) + H_i^{i\,e} \quad (20)$$

As we can see from above equation (20) above, Since the pilot sequences in a single cell are orthogonal to each other, there is no PC, and the cell edged users are free of extremely severe PC owing to mSPR, the only problem of PC is come from center zone user in system that re used the same set of pilot group that center user of once cell is assumed to be far from center user of other cell, that is why random pilot assignment method is considered.

4.3.3 The proposed system flow chart

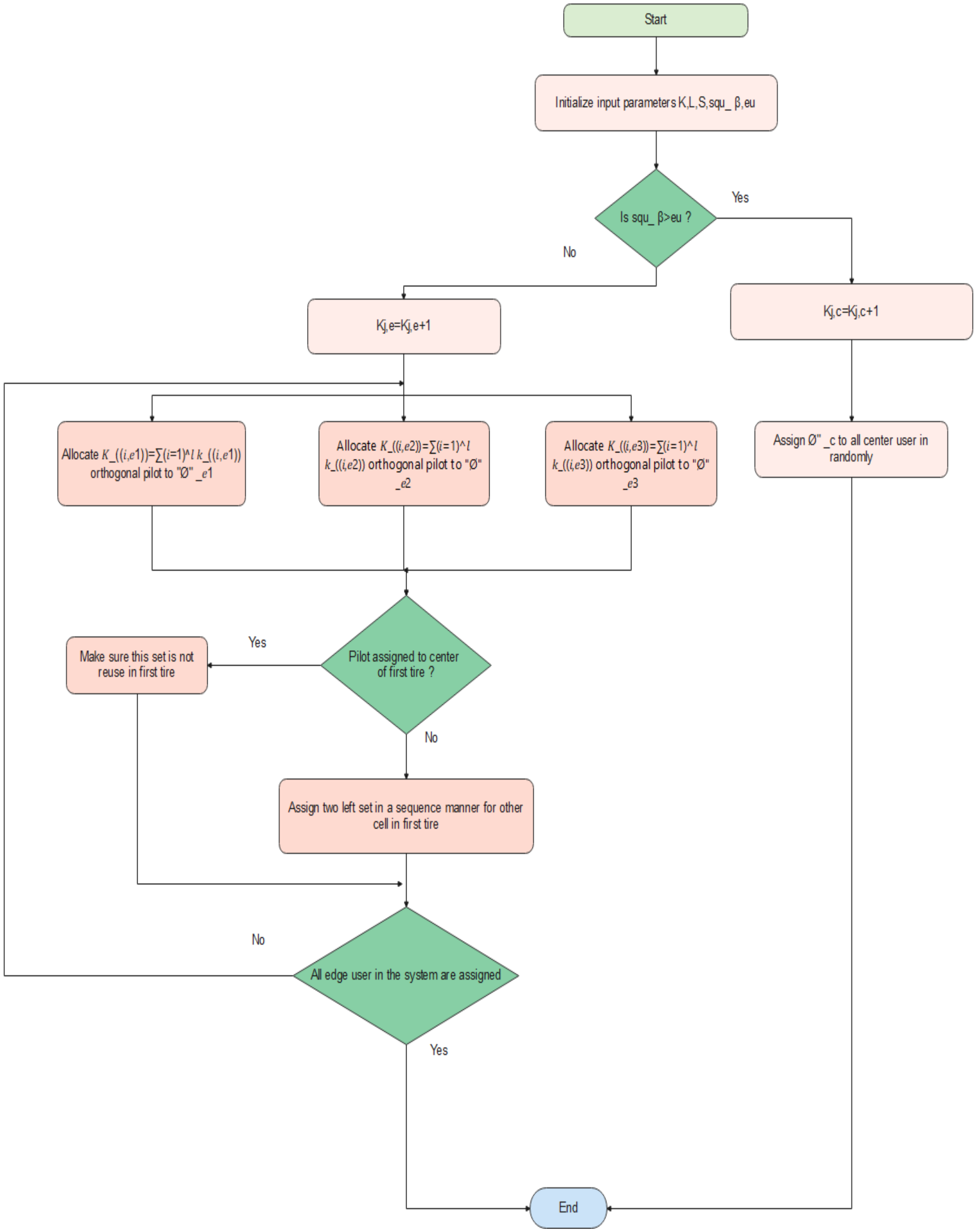

Figure 4.9 Flow chart of the proposed system.

Descriptions: First, initialize the parameters based on signal level received by the user in a targeted cell ,then user is classified into cell edge and cell center zone. For center zone user random pilot assignment scheme is applied which assigns the same set of pilots. for cell edge zone users, the mSPR is assigned, to do this first cell is grouped in three, then apply orthogonal pilot set to the edge of those cells, also make sure the orthogonal pilot set that is assigned to the center cell edge user of the single tire is not reused in the cell edge user of that tire. That means, if we consider the first tire has 1,2,3,..., 7 cells, the pilot set that is assigned to cell edge of cell one is not reused in the cell edge of cell from 2-7, and the other two left set of the pilot group is assigned for 2,4,6 cells from the first set and 3,5,7 cell are assigned with the second left set. Finally, the system checks all cells in the system are assigned.

While reading different thesis we have found the concept that edge orthogonal is summation of all edge user that mean if we assign large number of user to edge the number of orthogonal pilot used is increased which highly decreased our spectral efficiently, so it's better to classify small number of user with lowest received signal to edge user. Since it is the simulation parameter, We checked by making the edge number into two and meet our objectives.

Table 4.1 Simulation Parameters

Parameter	Symbol	Value
Number of the cell	L	19,7
Number of grouped cell	L_G	3
Number of Users	K	10
Cell Radius	r_c	1000m
Forbidden region	r_min	100
Pilot reuse ratio	S/K	3/2
Default spectral efficiency loss	mu2	0.1
Number of the antenna	M	32≤ M≤ 2048
Pass loss exponent	A	3.8
Uplink transmission power of signal	utp_s	10^(15/10)
Uplink transmission power of pilot	utp_p	10^(15/10)
Number of the pilot	S	15
The threshold parameter	Eu	2

CHAPTER 5
RESULT AND DISCUSSION

5.1 Introduction

In the last chapter, we have presented the set of approaches used in this thesis to improve the data rate of multi-cells massive MIMO system. Here simulation results following the analytical results discussed in chapter 4 will be discussed. As discussed in the last chapter, the proposed modified soft pilot reuse scheme improve the system's performance. To this end, the simulation results also show that the proposed schemes over-perform each scheme. The simulation result mainly demonstrates the performance of the proposed scheme using performance metrics such as average uplink achievable rate, SINR & Spectral efficiency. In all scenarios, the proposed schemes' performance is improved.

5.2 Performance Metrics

Average uplink achievable rate to pilot resource, CDF of SINR, Rate, Spectral Efficiency is considered as performance Metris to evaluate the validation of the proposed system.

5.2.1 CDF versus Signal to Interference and Noise Ration

The Cumulative Distribution Function of SINR, which demonstrates how well interference is mitigated, was described in this section. More interference mitigations take place with a better Cumulative Distribution Function, and system performance improves. Here it is shown that the proposed modified soft pilot reuse scheme is providing the best result in mitigating interference than conventional or random pilot assignment (RPA) and SPR with considerations of fixed pilot resource S/K value 15/10.

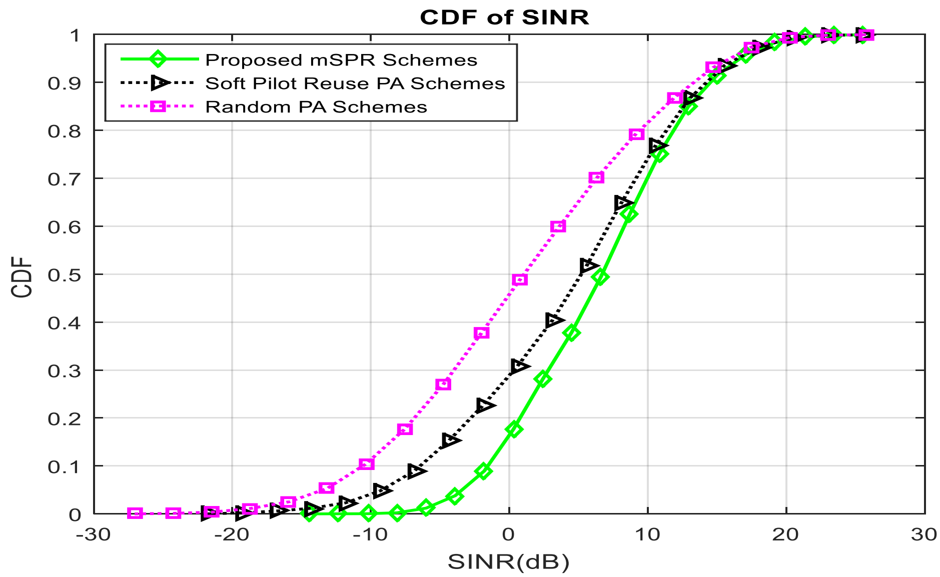

Figure 5.1 CDF versus SINR (dB)

The preceding theoretical component is supported by simulation results, as shown in Figure 5.1 above, where the highest data rate is reached by employing the suggested method at an (S/K) ratio of 10/15. For example, to obtain the highest data rate, 15 Pilot signals will be divided across 10 user terminals in each cell. As a consequence of the results, we can infer that the proposed modified soft pilot reuse scheme produces the best results than RPA (Random Pilot Assignment) and SPR (Soft Pilot Reuse) when the values of S and K are maintained constant, increasing the data rate.

5.2.2 Average Uplink Achievable Rate (R) versus Pilot Resource (S/K)

Here Average uplink achievable rate (R) of the user for the varied value of the pilot resource(S/K) is discussed. As demonstrated in Figure 5.2, increasing S/K causes spectral loss, which results in data rate loss. Also in other scenario increasing the value of S/K is that will help among user better pilot allocation, that will cause raise in SINR value and also increase the uplink data rate, this is why data rate is raise at first till it is the maximum value for specific S/K, but further increase S/K will lead to decrease average uplink achievable rate, that means there is a threshold for pilot resources to give maximum data rate, in our case when the value of S/K 3/2 the proposed system provides the maximum data rate than randomly assigned and soft pilot reuse scheme.

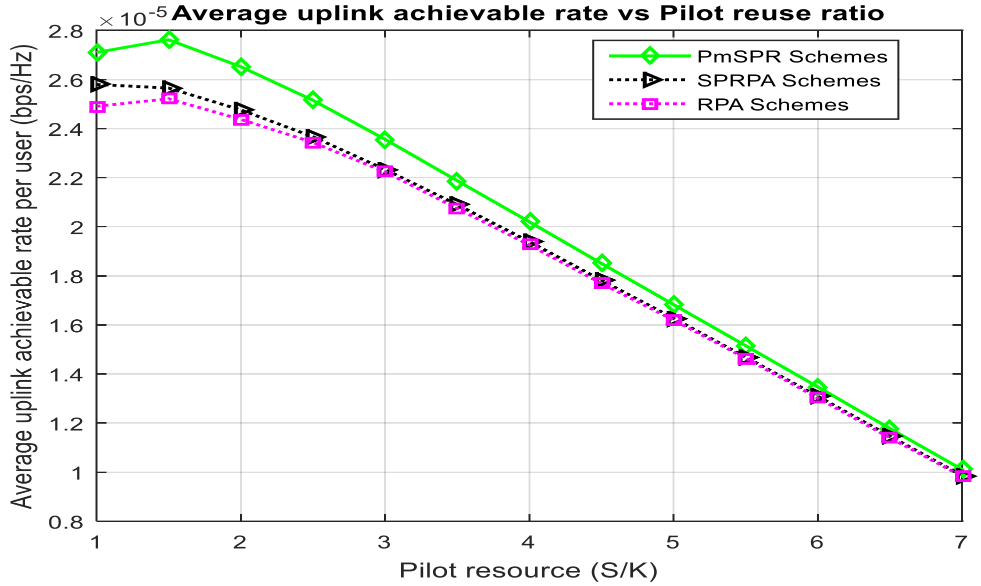

Figure 5.2 Average uplink R versus S/K.

5.2.3 CDF versus Average Uplink Achievable Rate (R)

The CDF (Cumulative Distribution Function) of the average attainable Data rate per user is shown in Figure 5.3 below. The findings show that the judgments made in the previous subsection were correct, i.e., the optimum average attainable data rate per user for the proposed scheme is reached when the Pilot Reuse ratio of 1.5 is used. For virtually all probabilities of the CDF curve, the suggested approach outperforms existing schemes with a pilot reuse ratio of 1.5.

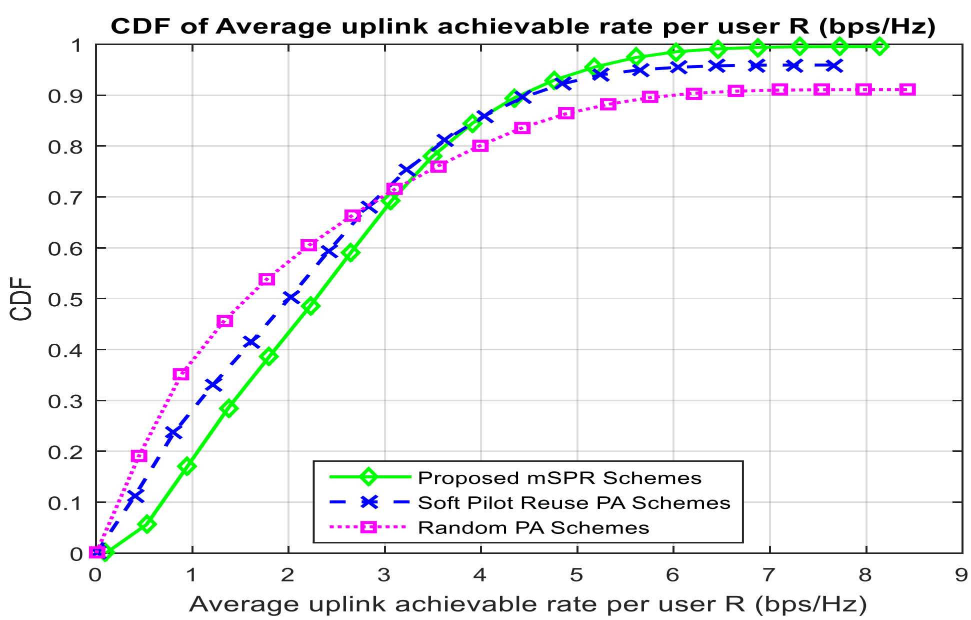

Figure 5.3 CDF versus R (bps/Hz)

5.2.4 CDF versus Spectral Efficiency

The cumulative distribution function of the Spectral Efficiency with different schemes is depicted in Figure 5.4. As can be seen, the proposed modified soft pilot reuse schemes obtained a higher SE over existing schemes by considering the optimal ratio of pilot resource S/K =1.5. This shows us as discussed in section 4.3 the proposed system highly reduce the number of pilot resource assigned to the system that means more resources are assigned for data transmission from the available coherent block, consequently there is a small amount of spectral loss that leads to the proposed modified soft pilot reuse schemes enhance per cell spectral efficiency than other schemes discussed.

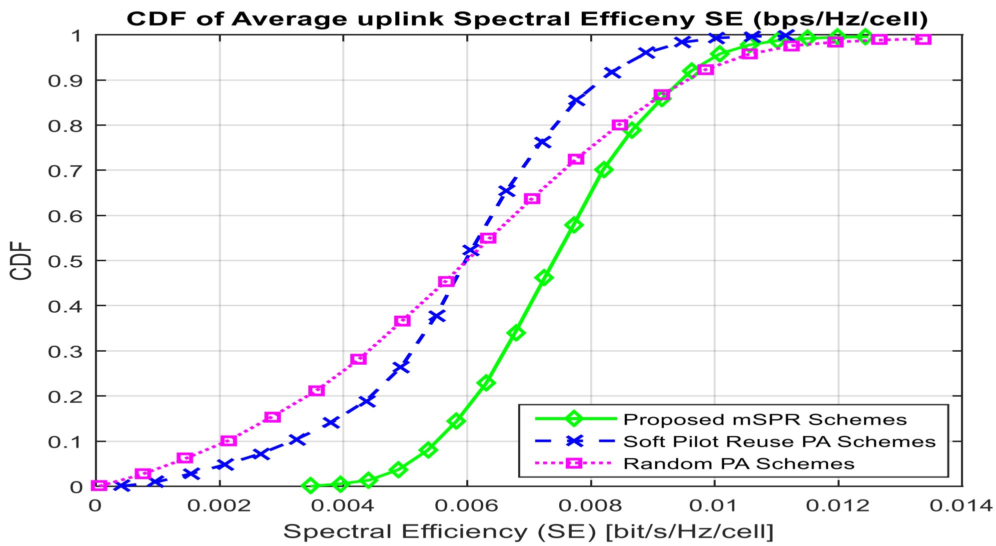

Figure 5.4 CDF versus SE (bps/Hz/Cell)

5.2.5 Average Uplink Achievable Rate (R) versus Number of Antenna Element M

With the addition of more BS antennas (M), the user uplink rate will undoubtedly grow. The statement is supported by the simulation findings Figure 5.5 below. The proposed modified soft pilot reuse schemes are demonstrated to provide the highest data rate in all values of M for an optimal Pilot Reuse ratio (S/K) of 1.5. When the number of BS antennas is increased, the proposed scheme delivers the best result of all other individual schemes.

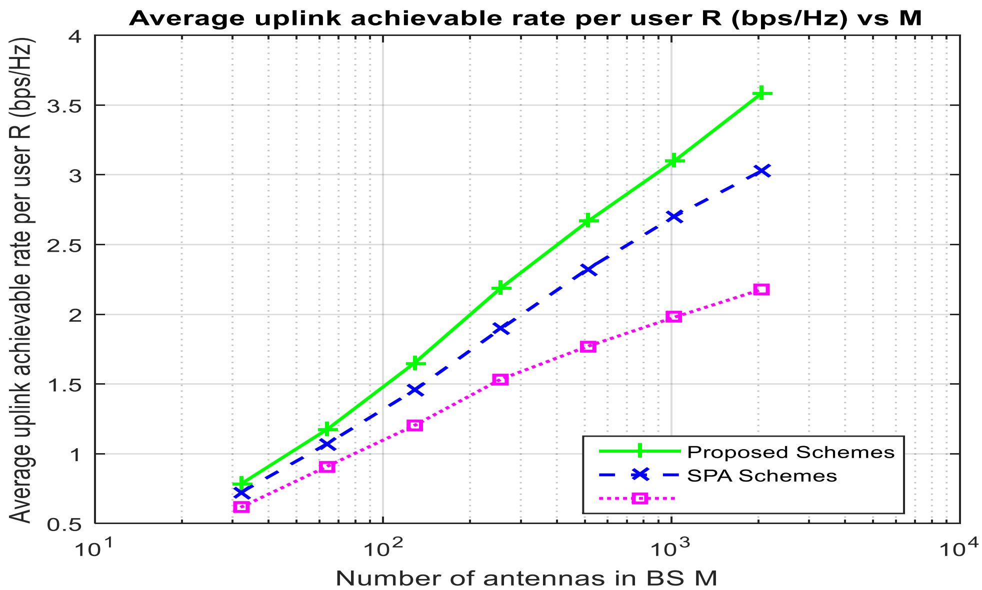

Figure 5.5 Average Uplink Achievable Rate vs Number of Antenna Element

5.2.6 Average Uplink Achievable Rate (R) versus Transmission power (ρ)

The average rate of uplink achievable when signal power is raised is shown in figure 5.6 below. Increasing signal power improves the SINR, which finally leads to increases in the uplink data rate deducible from equations (2) and (8) above, it can be observed that the proposed modified soft pilot reuse schemes provide the highest uplink achievable data rate for all values studied in consideration of constant pilot reuse ratio S/K = 1.5.

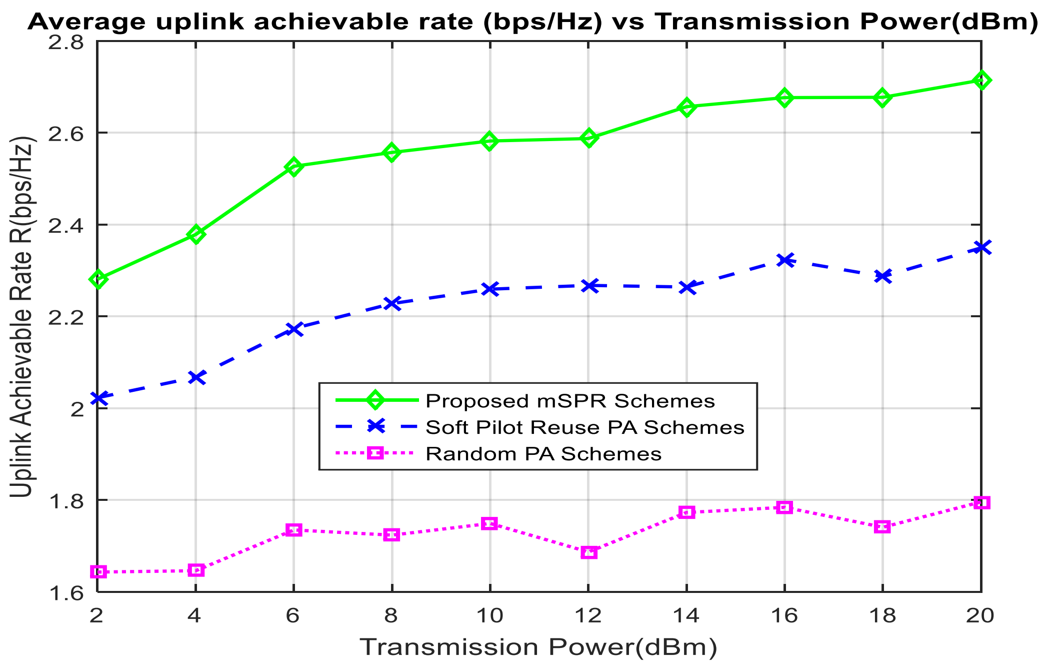

Figure 5.6 Uplink Average Achievable Rate versus Transmission power

5.2.7 Spectral Efficiency (SE) versus Number of antenna Element (M)

Increasing the number of BS antennas improves the SE, which even grows without bound when $M \to \infty$ as shown in Figure 5.7 below. This is because the BS can process its received signal over the array to selectively increase the signal gain without collecting more interference.

As shown on the result, when the number of antenna increase starting from 500 the new scheme provide better spectral efficiency than the preexisting schemes.

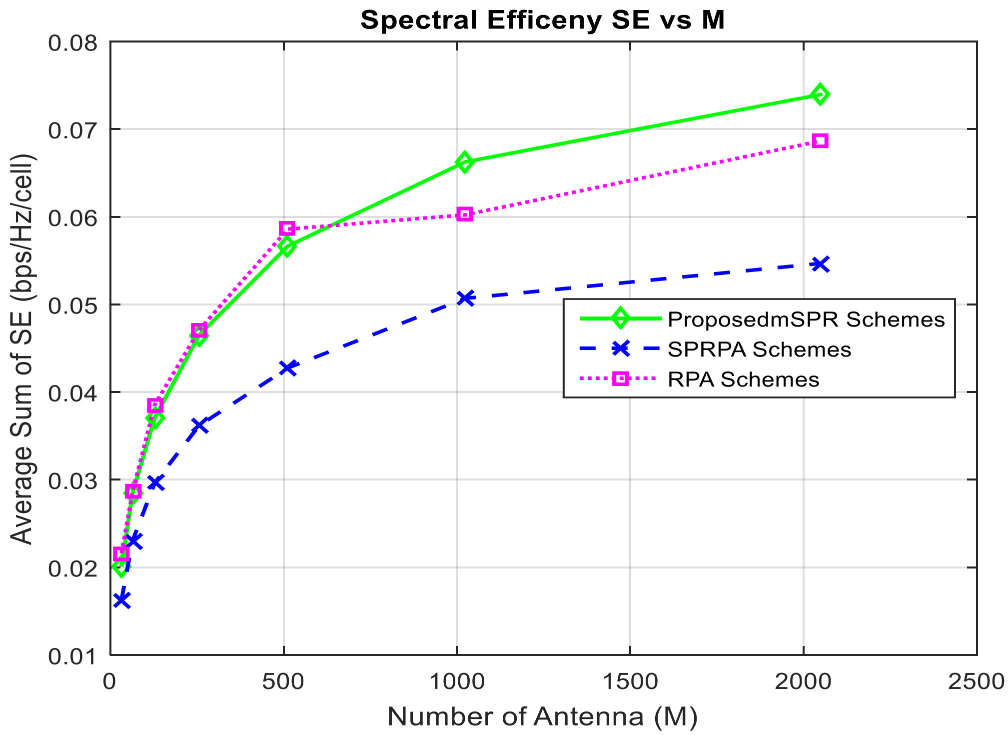

Figure 5.7 Spectral Efficiency (SE) versus Number of antenna Element (M)

The proposed modified Soft pilot reuses scheme over perform other pre-existing schemes , with fixing the value of pilot reuse ratio constant to 3/2 ,if we going from M=0 to M = 500 antennas, one can improve the SE from 0.02 bit/s/Hz/Cell to 0.06 bit/s/Hz/Cell, also for M>500 the proposed schemes highly increase in SE per cell than other schemes.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATION

6.1 Conclusion

Aims to improve the data rate of multi-cell massive MIMO systems, especially by minimizing inter-cell interference caused by pilot contamination with limited pilot resources. A proposed Pilot resource allocation scheme results in better performance than random and soft pilot reuse schemes. The proposed pilot resource allocation system reduces interference caused by pilot signal reuse while also increasing the data rate. According to simulations, the system can achieve a 3.5 bps/Hz uplink rate, which is 0.5 bps/Hz faster than SPRPA . In comparison to other schemes, the suggested approach provides a greater SINR and uplink sum rate on average. In comparison to other methods, it gives an average data rate of 3.5 bps/hz and 2.7bps/hz for varied numbers of base station antennas and transmission power.

The proposed pilot resource allocation is improving the data rate of multi-cell multi-user massive MIMO systems. Increasing the number of BS antennas (M) increases the data rate also spectral efficiency. However, the study is limited in its ability to choose the value of the Pilot Reuse Ratio (S/K).

6.2 Recommendations and Future works

However, the proposed schemes have still a room to improve, that the pilot allocation of cell edge zone users is independent of each and has certain limitations, that is to consider the mutual connection of each cell to reasonable allocate pilot throughout the system to further reduce the pilot resource assigned and enhance spectral efficiency of the system.

The impact of pilot contamination on forward link transmission is considered only on this thesis, it might also be interesting to investigate data signal reverse-link processing at the BS, which is predicted to have different SINR characteristics.

We looked into basic MF detectors with small complexity, which is extreme approaches in terms of maximizing signal power or minimizing intra-cell interference. Future research will look into different detectors, such as regularized zero-forcing.

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APPENDICES

%Proposed_modifiedSPR_Schemes.m

```
function [P_modifiedSPR_schemes_pilot eu] = Proposed_modifiedSPR_Schemes(L, K, S, Beta,lambda)
% This function for proposed mSPR assign pilot to the multi cell massive- mimo- system
eu=2;%Number of edge user
sigma=0; %Sigma=shadowing fading
P = zeros(L, K);%Initialize pilot sequence
squ_beta=zeros(K,L);%square of large scale fading factor
%% to calculate square of large scale fading factor
for l=1:L  % cell size
    for k=1:K
        squ_beta(k,l)= Beta(k,l,l)^2;
    end
end
%% apply modified soft pilot reuse scheme to system
  for l=1:L                              %assigning pilot for cell edge user
        [x result]=sort(squ_beta(:,l));  %sorting square of large scale fading factor in order, example B = sort( A , dim ) returns the sorted elements of A along dimension dim
        min_result=result(1:eu);
        %assigning orthogonal pilot
      if l==6||l==2||l==13||l==4||l==9||l==17
          for i=1:eu
           P(l,min_result(i))=100+i;%pilot group-1
          end
      end
       if l==3||l==7||l==19||l==5||l==11||l==15
           for i=1:eu
            P(l,min_result(i))=200+i;%
```

```
            end
        end
        if l==1||l==8||l==12||1==10||1==14||l==16||1==18
                for i=1:eu
            P(l,min_result(i))=300+i;%
                end
        end
    end

%for the center user the random scheme is used as below
 eta = zeros(L,K,L,K);%pilot contamination severity PCS,STRENGTH OF PILOT CONTAMINATION BETWEEN TWO USERS IN DIFFERENT CELL.
    for i1 = 1:L           % pilot contamination strength calculation
        for k1 = 1:K
            for i2 = 1:L
                for k2 = 1:K
                    if (i1~=i2)   %if both two cell using the same pilot sewienfs
                        eta(i1,k1,i2,k2) = Beta(k1,i2,i1)^2/Beta(k2,i2,i2)^2+Beta(k2,i1,i2)^2/Beta(k1,i1,i1)^2;%is the ratio between interference channel strength and effective channel strength
                    end
                end
            end
        end
    end
    eta_max = 0;
    %First, two users in different cells with
    %the largest weighted edge in the EWIG are selected , i.e., user
    %incellj1,k1 and user in j2,k2
    for j_bs = 1:L  %First 2 users pilot assignment
        for k_user = 1:K
```

```
        if P(j_bs,k_user)~=-1
         for j1_bs = 1:L
            for k1_user = 1:K
                if P(j1_bs,k1_user)~=-1 %xxxx is it cell center user
                  if j_bs~=j1_bs && eta(j_bs,k_user,j1_bs,k1_user)>eta_max
                    j_0 = j_bs;
                    k_0 = k_user;
                    j_1 = j1_bs;
                    k_1 = k1_user;
                    eta_max = eta(j_bs,k_user,j1_bs,k1_user);
                  end
                end
            end
         end
        end
    end
end
```