EFFECTIVE PILOT ASSIGNMENT SCHEMES IN MASSIVE MIMO SYSTEMS

By

AHMED SALEH NOMAN AL-HUBAISHI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATIONS

In memory of my father
To my mother for her endless love and infinite patience
To my wife, for her kindness and devotion, and for her endless support
To my daughter; ***Jana***
To my son; ***Mohammed***
To my beloved country, Yemen, to which this success is due
...

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January 2022

Chair : Professor Nor Kamariah Binti Noordin, PhD
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The explosive growth of mobile applications and services over cellular networks poses new challenges to network operators in upgrading existing cellular networks in order to handle huge wireless data transmission. Nonetheless, the fifth generation (5G) launch holds tremendous potential to address these challenges. 5G uses a powerful massive multiple-input-multiple output (MIMO) system between the base station (BS) and the users, which promises high speed, low latency, and massive connectivity. While extremely useful, intercell interference has been identified as one of the major challenges of massive MIMO-enabled cellular systems. When the same pilot sets are reused across adjacent cells to estimate the channel state information (CSI), this causes a so-called pilot contamination problem that saturates the signal to interference plus noise ratio (SINR). Furthermore, this problem cannot be mitigated by increasing the number of serving antennas.

In this thesis, an efficient pilot assignment scheme (EPA) is proposed to tackle the pilot contamination problem and consequently improve the uplink data rate of users in multi-cell massive MIMO systems, especially those who suffer from bad channel conditions. This was achieved by using the large-scale characteristics of the fading channel to minimize the amount of outgoing intercell interference at the target cell during the pilot assignment process.

Then, a partial pilot assignment scheme (PPA) is developed to reduce the time computational complexity accompanied by the EPA scheme. Specifically, the pilot assignment process is carried out for specific users who are tagged according to comparing their large-scale channel fading coefficients to

a specific threshold value. This scheme achieves a data rate that is close to that of the EPA scheme.

Furthermore, an effective pilot reuse-PPA scheme (EPR-PPA) is introduced to efficiently mitigate the impact of interference. Not only is the uplink data rate greatly improved, but also the time computational complexity is further reduced. In the EPR-PPA scheme, two pilot sets are used in the network and the PPA algorithm is implemented in cells that cause low interference at the serving cell, which share the same pilot set.

Simulation results showed that the proposed schemes outperformed both the existing smart pilot assignment (SPA) and conventional schemes. Herein, different linear receiving detectors are used in evaluating the performance of such proposed schemes. The obtained results ensure that the proposed schemes have significantly improved the system performance in terms of achievable uplink rate and cumulative distribution function (CDF) for both SINR and uplink rate. In particular, the improvements in the uplink data rate are roughly [12% – 78%], compared to the SPA schema. Moreover, the results of the evaluation explain the great improvements in the performance of poor SINR users, with the probability of achieving a higher SINR increasing almost by [20% – 37%], compared to the SPA assuming 64 antenna elements are equipped to the serving BS. The proposed schemes have also proved their high effectiveness and performance even in severe interference environments. In addition, the time computational complexity is reduced by approximately [52% – 72%] compared to the SPA.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

EFFECTIVE PILOT ASSIGNMENT SCHEMES IN MASSIVE MIMO SYSTEMS

Oleh

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Pertumbuhan pesat aplikasi mudah alih dan perkhidmatan rangkaian selular memberikan cabaran baru kepada operator rangkaian untuk menaik taraf rangkaian selular sedia ada bagi mengendalikan penghantaran data tanpa wayar yang luas. Walau bagaimanapun, pelancaran generasi kelima (5G) mempunyai potensi yang luar biasa bagi mengatasi cabaran-cabaran ini. 5G menggunakan sebuah sistem multiple-input-multiple output (MIMO) besar-besaran yang sangat kuat di antara base station (BS) dan pengguna, yang menjamin kelajuan yang tinggi, kelewatan yang rendah dan penyambungan yang luas. Walaupun sangat berguna, gangguan antara sel dikenalpasti sebagai satu cabaran besar di dalam sistem selular MIMO besar-besaran. Apabila set rintis yang sama digunakan semula merentasi sel-sel berhampiran untuk menganggar channel state information (CSI), hal ini menyebabkan masalah pencemaran rintis yang menyebabkan ketepuan signal to interference plus noise ratio (SINR). Tambahan lagi, masalah ini tidak dapat dikurangkan dengan menambahkan jumlah antena pelayan.

Di dalam tesis ini, kami mencadangkan sebuah skim efficient pilot assignment scheme (EPA) untuk mengatasi masalah pencemaran rintis dan seterusnya menambah baik daya pemprosesan pautan pengguna di dalam perbagai sel sistem MIMO besar-besaran, terutama pengguna-pengguna yang menghadapi masalah saluran yang teruk. Hal ini telah dicapai menggunakan ciri-ciri skala besar saluran yang semakin menghilang untuk mengurangkan jumlah gangguan antara sel yang keluar pada sel sasaran semasa proses penugasan rintis.

Seterusnya, partial pilot assignment scheme (PPA) separa dibangunkan untuk mengurangkan kerumitan masa pengiraan yang disertakan bersama skim EPA. Secara khususnya, proses penugasan rintis dijalankan untuk pengguna-pengguna tertentu yang ditandai berdasarkan perbandingan pekali saluran berskala besar mereka yang semakin hilang dengan nilai had tertentu. Skim ini mencapai daya pemprosesan yang menghampiri skim EPA.

Tambahan lagi, effective pilot reuse-PPA scheme (EPR-PPA) telah diperkenalkan untuk mengurangkan kesan gangguan dengan cekap. Bukan sahaja daya pemprosesan pautan dapat ditingkatkan dengan sangat baik, tetapi kerumitan masa pengiraan juga dapat dikurangkan dengan lebih lagi. Di dalam skim EPR-PPA, dua set rintis telah digunakan antara rangkaian dan algoritma PPA telah digunakan di dalam sel-sel, menyebabkan gangguan yang rendah di dalam sel pelayan yang berkongsi set rintis yang sama.

Keputusan simulasi menunjukkan skim-skim yang dicadangkan dapat mengatasi prestasi smart pilot assignment (SPA) dan skim-skim kebiasaan yang lain. Keputusan-keputusan ini dapat memastikan skim-skim yang dicadangkan dapat menambah baik prestasi sistem dengan ketara dari segi kadar pautan yang boleh dicapai dan cumulative distribution function (CDF) untuk kedua-dua SINR dan kadar pautan. Secara khususnya, peningkatan di dalam daya pemprosesan pautan dianggarkan di antara [12% – 78%], berbanding dengan skim SPA yang baru dicadangkan. Selain itu, hasil penilaian menjelaskan peningkatan hebat dalam prestasi pengguna SINR yang lemah, dengan kebarangkalian untuk mencapai SINR yang lebih tinggi meningkat hampir sebanyak [20% – 37%], berbanding SPA dengan mengandaikan 64 elemen antena dilengkapi kepada BS yang berkhidmat. Skim-skim yang dicadangkan juga membuktikan keberkesanan dan prestasi yang tinggi walaupun di dalam persekitaran yang mengalami gangguan yang teruk. Di samping itu, kerumitan pengiraan masa dikurangkan kira-kira [52% – 72%] berbanding dengan SPA.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AoA	Angle of Arrival
AWGN	Additive White Gaussian Noise
BS	Base Station
CDF	Cumulative Distribution Function
CDMA2000	Code Division Multiple Access 2000
CoMP	Coordinated Multi-Point
CSI	Channel State Information
DL-PAS	Deep Learning Pilot Allocation Scheme
EPA	Efficient Pilot Assignment
EPR-PPA	Effective Pilot Reuse-PPA
ESA	Exhaustive Search Algorithm
EV-DO	Evolution-Data Optimized
FDD	Frequency Division Duplex
FPR	Fraction Pilot Reuse
GCA	Graph Coloring-Algorithm
GSM	Global System for Mobile Communications
3GPP	The 3rd Generation Partnership Project
5G	Fifth Generation
ICI	Inter-Cell Interference
IEEE	Institute of Electrical and Electronics Engineers
i.i.d	Independent and Identically Distributed
IGS	Iterative Grid Search
IS-95	Interim Standard 95
LOS	Line of Sight
LTE	Long-Term Evolution
LTE-A	LTE-Advanced

MIMO	Multiple-Input–Multiple-Output
MME	Mobility Management Entity
MMSE	Minimum Mean Square Error
MRC	Maximum Ratio Combining
MU-MIMO	Multi User-MIMO
PCP	Pilot Contamination Precoding
PPA	Partial Pilot Assignment
QoS	Quality of Service
SDMA	Space Division Multiple Access
SE	Spectral Efficiency
SINR	Signal to Interference plus Noise Ratio
SIR	Signal-to-Interference Ratio
SNR	Signal to Noise Ratio
SPA	Smart Pilot Assignment
SPR	Soft Pilot Reuse
TDD	Time Division Duplex
UEBG	User- Exchange Based on Greedy
UMTS	Universal Mobile Telecommunications Service
WLANS	Wireless Local Area Networks
ZF	Zero Forcing

CHAPTER 1

INTRODUCTION

1.1 Background

Massive multiple-input–multiple-output (MIMO) systems are one of the promising technologies that have been conceived to meet the continuous increase in demand for high-speed data in future fifth generation (5G) wireless networks (Boccardi et al., 2014). The main work concept is to enable the transmission of large amounts of data with high reliability between the base stations (BSs) and multiple users instantaneously over the same channel resources. Specifically, many users can utilize the whole bandwidth at once to communicate with the corresponding BS. Hence, this technology provides hope to get through the scarcity of spectrum in wireless communication systems in the face of rapid growth in the volume of wireless data.

Typically, massive MIMO is about equipping the BS with large arrays of antenna elements (tens to hundreds (Gao et al., 2015)) at low cost and low power consumption. Many features are associated with this kind of technology and make it attractive in the sense that it increases the spectral efficiency (SE), improves the energy efficiency (EE), provides a reliable connection (Lim et al., 2015), (Larsson et al., 2014), (Rusek et al., 2013), (Björnson et al., 2014), (Osseiran et al., 2016) and makes the use of linear processing near optimal or even optimal.

While massive MIMO technology provides a solution to the rapid increase in wireless data, numerous hurdles can prevent this technology from working efficiently (Larsson et al., 2014). As a matter of fact, these hurdles represent the challenges of massive MIMO that badly degrade its capabilities so dense studies have emerged to avoid, or at least relieve, their effects. A prominent pilot contamination challenge is promoted in the massive MIMO-based time division duplex (TDD) protocol (Jose et al., 2011). This issue arises when the same group of training signals (pilot sequences) are configured in all cells for the sake of channel estimation in the uplink direction. Repeating the utilization of the same pilot group among the cells was suggested since the number of time-frequency resources is restricted in the TDD protocol. As a result, the channel response between the users and the serving BS will not be estimated correctly in the existence of pilot contamination. This leads to a drastic decrease in the system throughput, which in turn reduces the spectral efficiency. Due to that issue, high efforts have been made to address this issue in order to maintain efficient operation of massive MIMO technology. Assigning the pilot sequences to users is one of the effective methods that attracts the researchers' interest in treating the pilot contamination.

1.2 Research Motivation

Avoiding pilot contamination in massive MIMO systems is of great importance in the high data transmission trends of 5G technology. This work aims to mitigate inter-cell interference's effect by proposing effective pilot assignment schemes that greatly enhance the uplink throughput. The schemes handle the capabilities of long-term evolution-advanced (LTE-A) system components, ensuring that no additional components are required.

1.3 Problem Statement

Even though BS-enabled massive MIMO systems can support high data transmission, but an associated pilot contamination issue severely limits its performance. Various conceptions are presented to deal with such a challenge and each has different achievements in terms of interference mitigation and time computational complexity aspects. However, some of these conceptions still have a lack in their performance, and the issues that cause performance degradation need to be treated efficiently. The main problems that are concerned throughout this thesis are:

1. A smart pilot assignment (SPA)(Zhu et al., 2015b), which considers the pilot assignment method, does not have enough solutions for the poor signal-to-interference-plus-noise ratio (SINR) users that have weak connections to the serving BS. Specifically, in the SPA scheme, the set of users with the worst channel qualities are assigned pilot sequences with the lowest inter-cell interference. Although these pilot sequences have the lowest interference, they are still considered high interference pilot sequences when used by users with bad channel quality. Therefore, the associated interference needs to be minimized.

2. In order to ensure a better SINR and, consequently, a higher uplink data rate, the pilot assignment process needs to be implemented for each user. However, this is associated with high time computational complexity in SPA and (Li et al., 2013), especially in large networks. Hence, the time computational complexity needs to be reduced for the proposed scheme without causing a loss in the uplink data rate.

3. Reducing the effect of inter-cell interference from different angles during the pilot assignment process is considered for the purpose of achieving a higher uplink data rate and concurrently further minimizing the associated time computational complexity, which is not addressed in the SPA and the proposed schemes.

1.4 Research Objectives

In this research, the proposed schemes aim at reducing the effect of the pilot contamination issue very efficiently. To achieve that, the following points summarize the objectives of this thesis:

1. To demonstrate the pilot contamination issue and investigate the techniques that have been proposed to solve this issue by using the pilot assignment method.

2. To propose an effective pilot assignment scheme in order to enhance the SINR of poor users, which are badly affected by interference associated with pilot sequences.

3. To reduce the time computational complexity of the proposed scheme associated with implementing the pilot assignment process.

4. To develop a new pilot assignment scheme in order to achieve more significant improvements in the system throughput and the implementation time simultaneously.

1.5 Research Scope

This research is primarily interested in methods and techniques that effectively defeat the impact of pilot contamination to enable massive MIMO systems to operate efficiently in 5G technology. Identifying the leading cause of the associated issue, inter-cell interference, and studying the implications lead to practical solutions based on the pilot assignment method. Additionally, evaluating the performance of the proposed schemes in terms of achievable uplink data rate and time computational complexity to demonstrate performance improvements and compare their performance to some recent works. Moreover, examining the validity of the proposed schemes in environments that suffer from severe interference.

1.6 Research Contributions

The main contributions of this research include:

1. Minimizing the effect of inter-cell interference, which causes pilot contamination, to maximize the minimum uplink data rate. To accomplish this, an optimization problem is formulated, followed by the development of a heuristic algorithm to ensure efficient pilot assignment.

2. Reducing the time computational complexity of the proposed pilot assignment scheme. Specific users, determined according to a threshold value, are involved in the pilot assignment process. The defined threshold differentiate the interfering users according to their severity at the serving BS.

3. Increasing the system uplink data rate while reducing the time computational complexity at the same time by developing a pilot assignment scheme based on modified pilot reuse.

1.7 Research Challenges

Proposing a pilot assignment scheme to address the pilot contamination phenomenon in massive MIMO systems encounters several challenges that limit the efficiency of the scheme. These challenges are explained briefly as follows:

- Inter-cell interference: Inter-cell interference represents the main challenge that severely degrades the system throughput due to pilot contamination impact. Therefore, the effective pilot assignment schemes should be able to mitigate the effect of the inter-cell interference.

- Poor user Performance: the performance of users who are in weak connections with the serving BS are severely affected in the presence of pilot contamination. Enhancing their performance is a higher priority in designing the pilot assignment scheme.

- Implementation time: the execution time required to implement the pilot assignment process is an important metric in evaluating its efficiency. Minimizing this time has to be considered since it changes with increasing the network size (i.e., number of cells and users).

- Obligation to be applicable in the existing network: the concept of introducing new components or functions that help in implementing the proposed scheme is excluded. Proposing an affordable technique, according to the ability of the existing components, is preferred in order to get a reliable scheme.

1.8 Thesis Organization

The organization of this thesis is as follows:

- **Chapter 1** mostly presents the background, scope, objectives, contributions, and challenges of the research.

- **Chapter 2** gives a general overview about massive MIMO systems and their mechanisms in enabling high data transmission in radio interface plane. The main issues were demonstrated and the solutions that have been suggested so far.

- **Chapter 3** presents the proposed schemes in detail, including the formulated optimization problems and the mathematical expressions for the time computational complexity. It starts with introducing the system architecture that is supposed to be for this research.

- **Chapter 4** demonstrates the performance evaluation of the proposed schemes. It shows the simulation results for the proposed work as well as comparisons to other recent works.

- **Chapter 5** concludes this research and lists the recommended future works.

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