



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكرو فيلم

بسم الله الرحمن الرحيم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



MONA MAGHRABY



Ain Shams University
Faculty of Engineering
Electronics and Communications Engineering Department

Decontaminating Pilots in Massive MIMO -5G Systems

A Thesis

Submitted in partial fulfillment for the requirements for the degree of Doctor
of Philosophy in Communications Engineering
(Electronics and Communications Engineering)

By

Waleed Abd-Elshafi Ali Elshazly

Master of Science in Electrical Engineering
Electronics Engineering and Electrical Communications
College of Engineering and Technology, Arab Academy for science, Technology and
Maritime Transport, 2014

Supervised by

Prof. Wagdy Refaat Anis

Professor of Electronics and communications engineering, Electronics and
communications engineering Department, Faculty of Engineering, Ain
Shams University, Cairo, Egypt.

Dr. Hamed Abd-Elfatah Abd- Elaziz Elshenawy

Communications and computer Engineering Department, Higher Institute of
Engineering,
El-shorouk Academy, Cairo, Egypt.

Cairo, Egypt

2020



Ain Shams University
Faculty of Engineering
Electronics and Communications Engineering Department

Statement

This dissertation is submitted as a partial fulfillment of the degree of Doctor of Philosophy in Electrical Engineering (Electronics and Communications Engineering), Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Waleed Abd-Elshafi Ali Elshazly

Signature

.....

Date: / / 2020



Ain Shams University
Faculty of Engineering
Electronics and Communications Engineering Department

Researcher Data

Name: Waleed Abd-Elshafi Ali Elshazly

Date of birth: 24-6-1976

Place of birth: Cairo

Last academic degree: Master of Science in Electrical Engineering.

Field of specialization: communications engineering.

University issued the degree: College of Engineering and Technology,
Arab Academy for science, Technology and Maritime Transport.

Date of issued degree: 2014

Current job: Assistant Lecturer, Department of Communication and
Computer Engineering, Higher Institute of Engineering, AL- Shorouk,
Shorouk Academy.

Acknowledgement

First and foremost, I thank **Allah**, the most gracious most merciful for enabling me in finishing this work. I am indebted to my supervisors, **Prof. Wagdy Refaat Anis and Dr. Hamed Abd-Elfatah Abd-Elaziz Elshenawy** for providing me the opportunity to do research under their guidance and for their invaluable suggestions, patience and continuous encouragements throughout my research work, without which it would not have been possible to execute my research work.

I wish to express my appreciation to every **reviewer** and every **editor** who reviewed my work for possible publication. Thanks to their valuable comments and suggestions.

Last, but not least, I would like to thank my beloved family for their endless love and their support.

Thesis Summary

Time division duplexing (TDD) Massive multiple-input, multiple-output (MIMO) operation is limited by user terminals (UTs) mobility which leads to a short coherence block and a limited number of orthogonal pilots. In the multi-cell system, the pilots of the home cell are reused in the adjacent cells to some degree called pilot reuse factor r , so channel estimates in the home cell are contaminated with that of other cells using the same pilots. This is known as pilot contamination, which leads to degradation of channel estimation and occurrence of interference from the same pilot UTs which can't be removed by increasing base station (BS) antennas number.

Pilot contamination has two main effects on uplink (UL) and downlink (DL) data transmission in TDD Massive MIMO. First, it increases the mean square error (MSE) of channel estimation, which affects the quality of combining and precoding vectors that provide high array gains and mitigate the interference from different pilots UTs. Second, it increases the interference from the same pilots UTs that is enlarged by the array gain, similar to the desired signal.

The main objective of this thesis is to mitigate pilot contamination in Massive MIMO system and to enhance the system spectral efficiency (SE) by developing a mitigation technique to combat the pilot contamination problem and its effects. The proposed technique is Laplacian centralized scattering-spatially correlated Rayleigh fading channel model. This model gives a more accurate description, especially for cell-edge users. It results in an accurate spatial channel correlation matrix calculation that enhances the channel

estimation quality under pilot contamination and enhances the quality of combining and precoding vectors. Also, multi-cell minimum mean square error (M-MMSE) combining and precoding vectors are applied to mitigate pilot contamination and enhance cell throughput.

Spatial channel correlation increases the degree of favorable propagation when the UTs have different spatial characteristics. Spatial channel correlation is useful in practice to enhance the channel estimation quality under pilot contamination. In this thesis, the proposed centralized Laplacian scattering-spatially correlated Rayleigh fading model performance is compared with both one- ring scattering-correlated Rayleigh fading and uncorrelated Rayleigh fading channel models performances for different pilot reuse factors ($r=1, 2$, and 4) and for different combining and precoding schemes such as single-cell minimum mean square error (S-MMSE), Regularized Zero-Forcing (RZF), Zero-Forcing (ZF), and maximum ratio (MR) in mitigating pilot contamination and realizing larger SE.

The highest SE of the proposed Laplacian centralized scattering-spatially correlated Rayleigh fading model is achieved when using M-MMSE combining and precoding scheme and the pilot reuse factor equals 4 but at the expense of increased computational complexity. Increasing the pilot reuse factor improves system SE and reduces the effect of interfering signals but leads to an increase of pilot samples and reduction of the number of UL and DL data samples in the coherence block. The TDD Massive MIMO system achieves higher cell throughput than the long term evolution (LTE) system for the same channel bandwidth.

Multi-cell scenario is used, which is more practical and complex than single-cell massive MIMO scenario. The reason for better performance of M-MMSE combining and precoding scheme is the M-MMSE obtains useful

estimation of channels to UTs in other cells and use them to mitigate interference from the same pilot users and interference from different pilot users.

The optimum precoding and combining vectors are calculated and the corresponding maximum signal-to-interference plus noise ratios (SINRs) of UL and DL are calculated. The UL and DL SE per cell (bit/s/Hz/cell) of Massive MIMO system is calculated. The complexity of the proposed scheme is calculated and compared with other combining and precoding schemes. The theoretical results are validated by using Matlab Simulation.

Key words:

- Massive MIMO.
- Pilot contamination.
- Channel estimation.
- Spectral efficiency.
- Multicell MMSE.
- Large random matrix theory.
- Combining and precoding.
- Laplacian scattering-spatially correlated Rayleigh fading model.
- One- ring scattering-spatially correlated Rayleigh fading model.
- Uncorrelated Rayleigh fading.

Table of Contents

Acknowledgements	iii
Thesis summary	iv
List of Symbols	xii
List of Abbreviations	xix
List of Figures	xxiii
List of Tables	xxvi
Chapter 1 Introduction	1
1.1 Background	1
1.2 Problem Statement	3
1.3 Thesis Objective	4
1.4 Methodology	5
1.5 Tools Utilized	6
1.6 Thesis Organization	6
Chapter 2 MIMO Technology in 5G system	9
2.1 Introduction	9

2.2 Point-to-Point MIMO system.....	10
2.3 Multiuser MIMO system.....	12
2.4 Massive MIMO.....	14
2.5 Resources required for pilots and channel state information feedback	18
2.6 5G system	20
2.6.1 5G system overview	20
2.6.2 Comparison between 4G and 5G	22
2.6.3 Millimetre Wave.....	27
2.6.4 Beamforming.....	30
2.7 Summary.....	32

Chapter 3 Massive MIMO System 33

3.1 Introduction	25
3.2 Massive MIMO	33
3.3 Channel State Information	37
3.4 Spatially correlated Rayleigh fading channel	38
3.5 channel hardening and favorable propagation.....	40
3.6 Massive MIMO System Model.....	41

3.6.1	Independent channel model.....	41
3.6.2	Spatial correlated channel model.....	43
3.7	Pilot Contamination	44
3.7.1	Non-orthogonal pilot sequences reuse	44
3.7.2	Non-Reciprocal Transceiver.....	46
3.7.3	Hardware impairment.....	47
3.8	The pilot contamination impact.....	48
3.9	Summary	50

Chapter 4	Survey on Pilot Contamination Mitigation Techniques in Massive MIMO Systems	51
4.1	Introduction	51
4.2	Pilot Contamination Mitigation Techniques	51
4.2.1	Orthogonal pilot sequences allocation among adjacent cells.....	51
4.2.2	Data-aided channel estimation.....	53
4.2.3	Subspace projection based inter-cell interference mitigation.....	55
4.2.4	Multi-cell cooperative precoding and decoding.....	58
4.3	Comparison among different pilot contamination mitigation techniques.....	59
4.4	Summary	62

Chapter 5 A Proposed Pilot Contamination Mitigation Technique for	
Massive MIMO Systems	63
5.1 Introduction	63
5.2 TDD Transmission mode	66
5.3 Laplacian and one-ring centralized scattering –spatially correlated Rayleigh fading channel models.....	67
5.4 The system model	70
5.5 Spectral Efficiency calculation	75
5.6 The computational complexity of different combining and precoding schemes.....	80
5.7 Summary.....	83
 Chapter 6 Simulation Results and Analysis	84
6.1 Introduction	84
6.2 Simulation Setup	85
6.3 Uplink Interference-to-Desired Signal Power Ratio Simulation Results.....	86
6.4 Uplink Spectral Efficiency Per Cell.....	99
6.5 Downlink Spectral Efficiency Per Cell.....	105
6.6 Summary.....	112
 Chapter7 Conclusions and Suggestions for Future Work	113
7.1 Conclusions	113
7.2 Suggestions for Future Work	115

References 116