UNIVERSITI PUTRA MALAYSIA

BLOCK BASED LOW COMPLEXITY ITERATIVE QR PRECODER STRUCTURE FOR MASSIVE MIMO

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By

MOK LI SUET

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

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DEDICATION

This thesis is dedicated to

All those I love

Especially
My dearest parents
My family
My brothers

For their endless encouragement, patience, and support and for being a great source of motivation and inspiration

And to all my friends

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman : Professor Ir. Ts. Nor Kamariah binti Noordin, PhD
Faculty : Engineering

Increasing data traffic has exposed the need for multi-user multi-antenna wireless communication systems. Exploiting the excess degree of freedom owing to additional antennas at the receiver with spatial multiplexing has led to ensure higher per-user data rates along with higher system capacities. Massive Multiple-Input Multiple-Output (MIMO) have receiving a lot of attention and it is an illustration of this demand for high rates, especially in the downlink.

In this thesis, we study the Massive MIMO communication setup in the downlink data transmission. In addition, we attempt to solve the problem of system sum rate maximization with a constraint on computational complexity at the base station (BS).

In contrast to uplink, in the downlink system, interference cancellation is required to eliminate signals intended for other co-users. As the user terminals have strict restraints on physical dimensions, processing capabilities and power availability are extremely limited (relative to the base station). Therefore, we study the solutions from the literature in which most of the interference cancellation is performed by the base station (pre-coding). Meanwhile, we maximize the sum rate and also consider the restrictions on the computational complexity at the base station.

In this thesis, we also study and evaluate different conventional linear pre-coding schemes as well as how they relate to optimal structure of the solution which maximize the system performances. We also study one of the suboptimal pre-coding solutions known as Block-diagonalization (BD) applicable in the case where a receiver has multiple antennas and compare their performance.

Finally, we notice that regular BD schemes are not deployed in Massive MIMO despite the promising results in terms of the system sum rate performance. The reason for this is that they are computationally heavy. In this thesis, we attempt to reduce the complexity of the BD schemes by partitioning channel matrix into corresponding square matrix. We make use of QR-based BD method to precode in a lower dimension channel matrix rather than computing all of them.

The simulation of quasi-static is used. We generate the model and evaluate the performance in MATLAB. The simulated environment consists of single cell Massive MIMO with up to 512 antennas at the BS and 2 antennas per user. We have investigated two performance characteristics, system sum rate and computational complexity using various linear pre-coding schemes, including the proposed one. For the complexity, the simulation results show that the proposed BD pre-coding solution reduced complexity up to 90% compared to the other schemes. The number of flops required in the proposed solution is much less than the regular BD algorithm. It is shown that the proposed solution modifies the multiplexing order which reduced the complexity for the use in Massive MIMO. For the system sum rate, the results of the increase in the number of users with a fixed number of 128 and 512 BS antennas show that the proposed method achieved up to 24% and 35% respectively compared to the regular BD algorithm. Besides, it has achieved up to 60% and 65% respectively for a fixed number of 128 and 512 BS antennas compared to ZF algorithm. The results of the increase in the number of BS antennas with a fixed number of users, the proposed method achieved up to 20% and 60% compared to regular BD and ZF algorithms respectively. Although there were parts of the analytical results have a slightly lower sum rate compared to regular BD pre-coding, the overall results of the proposed BD method outperformed regular linear precoding. This is because the proposed low complex BD pre-coding solution is not a reliable quantity to reflect the true capacity. However, we observe that the proposed solution is an optimal pre-coding schemes and can be considered as an alternative in a more general framework for Massive MIMO with multiple antennas at the receiver.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

STRUKTUR PENGEKODAN QR REKURSIF YANG BERUMIT RENDAH BERDASARKAN BLOK UNTUK GERGASI MIMO

Oleh

MOK LI SUET

Jun 2021

Pengerusi : Profesor Ir. Ts. Nor Kamariah binti Noordin, PhD
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Dengan meningkatkan langanan mudah alih, sistem tanpa komunikasi pelbagai antena dan pelbagai pengguna tanpa wayar diperlukan. Ini adalah untuk memastikan kadar data per pengguna dan sistem kapasiti yang lebih tinggi dengan mengeksploitasi kebebasan yang berlebihan di penerima, ini disebabkan oleh pertambahan antena dengan spatial pemultipleksan. Populariti Gergasi MIMO yang semakin meningkat adalah ilustrasi permintaan kadar data yang tinggi, terutamanya pada pautan hadapan.

Dalam tesis ini, kita mengkaji rangka kerja sistem Gergasi MIMO dan cuba menyelesaikan masalah pemaksimumam kapasiti dalam penghantaran data pautan hadapan dengan kekangan atas kerumitan komputasi di stesen pangkalan.

Sebaliknya dengan pautan terbalik, setiap pengguna dalam sistem diperlukan untuk melakukan pembatalan gangguan akibat isyarat yang disebabkan oleh pengguna lain. Oleh kerana terminal mudah alih mempunyai sekatan yang ketat pada dimensi fizikal, keupayaan pemprosesan dan ketersediaan kuasa yang kurang (berbanding dengan stesen pangkalan). Oleh itu, kita mengkaji penyelesaikan dari literatur di mana kebanyakan pembatalan ganguan dilakukan oleh stesen pangkalan (pengekodan). Semasa berbuat demikian, kita memaksimumkan kapasiti dan juga mempertimbangan sekatan atas kerumitan komputasi di stesen pangkalan.

Dalam tesis ini, kami juga mengkaji dan menilai skema konvensional pengekodan lurus yang berlainan dan bagaimana ia berkaitan dengan struktur penyelesaian optimum yang memaksimumkan prestasi sistem. Kami juga mengkaji salah satu penyelesaian pengekodan sub-optimum yang dikenali sebagai Blok-diagonal (BD) yang sesuai dalam kes penerima mempunyai pelbagai antena dan membandingkan prestasinya.

Akhirnya, kami mendapati bahawa keputusan yang menjanjikan dari segi kapasiti, ia tidak sesuai untuk Gergasi MIMO. Alasanya ialah skema BD yang klasik mempunyai komputasi yang komplek. Dalam tesis ini, kita cuba untuk mengurangkan kerumitan skema BD dengan mengasingkan saluran matriks ke persegi yang sepadan. Kami menggunakan kaedah BD berasaskan QR untuk mengekod saluran matriks yang dimensinya lebih rendah daripada mengira sepenuhnya.

Model kuasi static digunakan dalam simulasi. Kami menjana model dan menilai prestasi dalam MATLAB. Simulasi terdiri daripada satu sel Gergasi MIMO dengan menggunakan jumlah antena stesen pangkalan yang sehingga 512 dan 2 antena penerima di setiap pengguna. Kami menyiasat dua ciri prestasi, kadar jumlah sistem dan kerumitan komputasi menggunakan pelbagai skema pengekodan linear, termasuk yang dicadangkan. Mengenai kerumitan, keputusan simulasi menunjukkan bahawa kaedah pengekodan BD yang dicadangkan mengurangkan kerumitan hingga 90% dibandingkan dengan skema lain. Jumlah keupayaan komputer sesaat (flops) yang diperlukan dalam kaedah yang dicadangkan lebih kurang daripada algoritma BD umum. Ini ditunjukkan bahawa kaedah yang dicadangkan mengubah susunan multiplexs yang mengurangkan kerumitan untuk penggunaan dalam Gergasi MIMO. Mengenai kadar data, keputusan peningkatan jumlah pengguna dengan bilangan tetap antena transmisi 128 dan 512 menunjukkan bahawa kaedah yang dicadangkan masing-masing mencapai hingga 24% dan 35% berbanding algoritma BD biasa. Selain itu, ia mencapai sehingga 60% dan 65% masing-masing untuk bilangan tetap antena transmisi 128 dan 512 berbanding algoritma ZF. Keputusan peningkatan jumlah antena transmisi dengan jumlah pengguna yang tetap, kaedah yang dicadangkan mencapai sehingga 20% dan 60% berbanding algoritma BD dan ZF umum. Walaupun terdapat beberapa bahagian keputusan analitik yang mempunyai jumlah yang lebih rendah dibandingkan dengan pengekodan BD umum, keputusan keseluruhan dari kaedah BD yang dicadangkan melebihi prekod linear umum. Disebabkan BD yang dicadangkan bukan merupakan kuantiti yang boleh dipercayai untuk mencerminkan kapasiti yang sebenar.Walau bagaimanapun, kita dapat melihat bahawa BD yang dicadangkan merupakan skema pengekodan yang optimum dan dapat dianggap sebagai alternatif dalam rangka kerja yang lebih umum untuk Gergasi MIMO dengan mempunyai pelbagai antena pada penerima.

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

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LIST OF ABBREVIATIONS

BS	Base station
BD	Block-diagonalization
BLIQR	Blocks based on iterative QR
CSI	Channel state information
FDD	Frequency division duplex
IQRD	Iterative QR decomposition
MRT	Maximum ratio transmission
MIMO	Multiple-input multiple-output
MU-MIMO	Multi-user MIMO
SU-MIMO	Single-user MIMO
SVD	Singular value decomposition
TDD	Time division duplex
ZF	Zero-forcing

CHAPTER 1

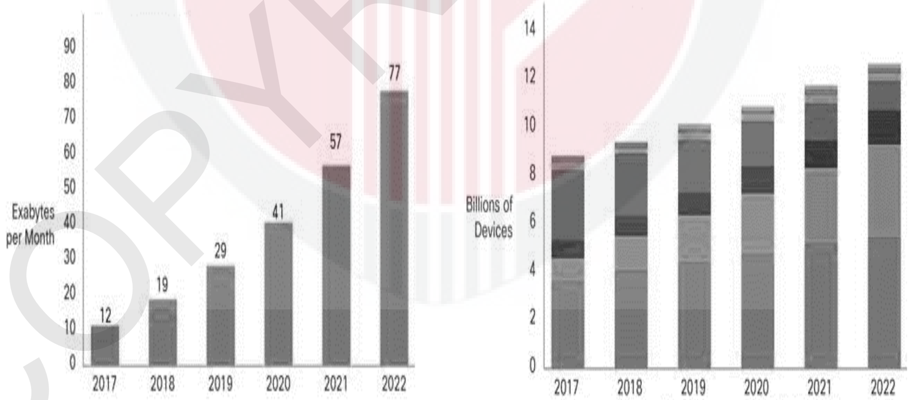
INTRODUCTION

1.1 Study Motivation

Over the past few years, data traffic has grown proportionally to users like smartphones, tablets, laptops, and other wireless devices [1]. Figure 1.1 shows the demand for data traffic and users. Overall global data traffic is expected to grow to 77 exabytes per month by 2022, a seven-fold increase over 2017 [1]. In addition, the number of users are expected to increase to 12.3 billion by 2022 [1]. According to the analysis, new technologies are required to meet the increased demand of wireless data traffic in the future. In relating to wireless data traffic, the key parameter of wireless throughput (bits/s) is defined as [2]:

$$\text{Throughput} = \text{Bandwidth (Hz)} \times \text{Spectral efficiency (bits/s/Hz)}$$

Clearly, throughput can be improved by increased bandwidth or spectral efficiency. In this thesis, we focus on downlink techniques that improve spectral efficiency. The most common way to increase spectral efficiency is using multiple antennas as transceivers.



(a) Global data traffic. **(b) Global user growth.**

Figure 1.1 : Demand for data traffic and number of users. [1]

In wireless communication, the fundamental challenge for reliable communication is that transmitted signals are attenuated by fading and shadowing due to multipath propagation and large obstacles between the transmitter and receiver. Transmissions with Multiple-

Input Multiple-Output (MIMO) have receiving a lot of attention due to the diversity of techniques that enhance communication reliability [3]. In addition, with multiple antennas, multiple data streams can be supported simultaneously and multiplexing gain can be obtained to significantly improve channel capacity.

The investigation of spatial multiplexing has shifted from Single-User MIMO (SU-MIMO) to Multi-User MIMO (MU-MIMO), where several users are simultaneously served by a multiple-antenna Base Station (BS). However, there is a tradeoff between system performance and computational complexity [4].

- Multi-user interference: Interference from other users reduces the system performance of a given user. To tackle this problem, the Block Diagonalization (BD) technique is used for the downlink [5]. This technique is complicated and has high computational complexity.
- Acquisition of Channel State Information (CSI): The BS needs to process the received signals coherently in order to obtain a high spatial multiplexing gain. This requires accurate and timely CSI acquisition. This can be challenging, especially in high mobility conditions.
- User scheduling: Since several users are served by the same time-frequency resource, scheduling schemes should be designed to exploit performance gain. This results in an increase in implementation complexity.

The more antennas equipped by a BS, the higher the degree of freedom and the more users that can simultaneously communicate in the same time-frequency resource. Accordingly, a higher throughput can be obtained [6]. MU-MIMO systems with a hundred (or more) BS antennas simultaneously serve tens (or more) users in the same time-frequency resource are known as Massive MIMO systems. The main advantages of Massive MIMO systems are [7]:

- Huge spectral efficiency and high communication reliability: Massive MIMO have all the benefits of MU-MIMO, such that with M- BS antennas and K single antenna users, we can obtain a diversity of M orders and a multiplexing gain of $\min(M, K)$. Hence, huge spectral efficiency and high communication reliability can be obtained by increasing both M and K.
- High energy efficiency: The BS can focus energy into spatial directions where users are located. Hence, the radiated energy is reduced without an effect on system performance.
- Simple signal processing: With the use of an excessive number of BS antennas over the number of users, the channel vectors between users and BS are nearly orthogonal, such that inter-user interference and noise can be eliminated using linear pre-coding.

Massive MIMO has drawn a lot of interest as a promising technology for future wireless systems [8]. Although many researchers have studied this topic, there are several issues that still need to be investigated [9] [10] [11] [12] [13]. In this thesis, motivated by the advantages of Massive MIMO, the capacity bounds of low-complexity processing were derived and analyzed.

1.2 Problem Statement

Massive MIMO has attracted a great deal of interest due to their ability to boost channel capacity without using additional bandwidth as well as their ability to reduce radiated energy. Conventional simple signal pre-coding was Maximum Ratio Transmission (MRT) and Zero-Forcing (ZF) [14] [15] [16]. MRT techniques maximize signal gain, however MRT neglects the effect of inter-user interference [17]. The ZF technique takes inter-user interference into account and provides a higher sum-rate than MRT. However, the ZF technique is also known as the channel inversion operation and is confined to single-antenna use cases [18]. Block Diagonalization (BD) was introduced by [19] as an extension of ZF that can cope with users with multiple antennas. BD eliminates inter-user interference and transforms a multi-user MIMO channel into a plurality of parallel single user channels. The initial BD precoder design made use of a Singular Value Decomposition (SVD) operation that requires high complexity. In [20], the Iterative QR Decompositions (IQRDs) technique was proposed to reduce the computational complexity of SVD. However, IQRDs is preferable for full multiplexing orders and is not suitable for massive MIMO [21].

1.3 Study Aims and Objectives

(1) To enhance precoder algorithm that can cope with users with multiple antennas without using a large concatenated Massive MIMO matrix
(2) To design an optimum precoder for future wireless systems.

1.4 Thesis Scope

Massive MIMO is a MU-MIMO communication system where the number of BS antennas is large. With large antenna arrays, conventional signal processing techniques become complex due to high signal dimensions. BD pre-coding, which completely precancels multi-user interference, is very complicated to implement with large concatenated matrixes since it considers full multiplexing orders. Motivated by the high performance of BD and generalized for the cases when users have multiple antennas, a precoder for structure blocks based low complexity Iterative QR Decomposition (BLIQR) was proposed. The proposed precoder partitions the channel matrix into a square-wise pattern and applies IQRD to square-wise block channel matrixes with lower dimensions. The partitioned blocks modify the multiplexing order for use in a massive MIMO, which can greatly reduce computational complexity compared to IQRD. The optimal capacity bound of low-complexity processing (BLIQR) was derived and analyzed.

1.5 Thesis Organization

In this study, brief introductions to multi-user MIMO and Massive MIMO are given in Chapter 2. Key concepts are discussed, including spatial multiplexing and system modelling for MIMO systems, which are the foundations of both MIMO systems. In the same chapter, we also emphasize learning optimal structures for linear signal processing and how conventional linear processing solutions relate to it. Finally, we discuss how the modelling of both MIMO and signal transmission is performed using higher-order signal processing methods at the BS. This is a fundamental introduction to understanding the problem that we are attempting to solve.

In Chapter 3, BD techniques are elaborated. In the same chapter, we discuss the regular BD algorithm and alternative methods to implement it at a lower complexity. In the concluding sections, a novel alternative algorithm is proposed to implement a BD technique with much lower complexity than regular BD that is viable for Massive MIMO systems. Finally, we compare the complexity of different solutions and show the benefit of using the proposed solution.

Chapter 4 presents the analytical results used to evaluate different pre-coding methods. In the same chapter, we describe the simulation environment used in order to obtain these results. Furthermore, we also discuss the study results and associate them with the theoretical explanation given in earlier chapters.

Finally, in Chapter 5 we emphasize the important results and mention the key takeaways of this thesis work. At the end of the report, we provide some comments that can improve the proposed BD technique and provide ideas for future projects.

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