UNIVERSITI PUTRA MALAYSIA

EFFICIENT TREE SEARCH-BASED DETECTORS FOR MULTIPLE INPUT MULTIPLE OUTPUT WIRELESS SYSTEMS

AMJAD NAJIM JABIR

EFFICIENT TREE SEARCH-BASED DETECTORS FOR MULTIPLE INPUT MULTIPLE OUTPUT WIRELESS SYSTEMS

By

AMJAD NAJIM JABIR

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

August 2012

Abstract of thesis presented to the Senate of Universiti Putra Malaysia
in fulfillment of the requirement for the degree of Doctor of Philosophy

EFFICIENT TREE SEARCH-BASED DETECTORS FOR MULTIPLE INPUT MULTIPLE OUTPUT WIRELESS SYSTEMS

By

AMJAD NAJIM JABIR

August 2012

Chair : Professor Nor Kamariah Noordin, PhD

Faculty: Engineering

In Multiple Input Multiple Output (MIMO) systems, multiple antennas are deployed at both ends of the link to introduce both transmit and receive diversity. The MIMO principle has significant advantages to combat channel fading, increase reliability and data rates without increasing bandwidth or transmitted power compared to Single Input, Single Output (SISO) counterparts. However, MIMO detectors are more computationally demanding.

The tree search based Maximum Likelihood (ML) optimum MIMO sphere detectors (SD) minimize Bit Error Rate (BER) and can collect the diversity offered by the MIMO channels. This comes at a high complexity that grows with the size of MIMO system and the modulation constellation used that makes them difficult to implement. Linear detectors are of a much lower complexity but with a much inferior performance. Therefore, a great research effort has been devoted to reduce the

complexity of optimum detector and to devise sub optimum solutions to satisfy needs of real applications.

In this thesis we design methods to speed up the operation of the SD to reduce its complexity in terms of the average number of the visited nodes per the detection of one received vector. This reduction is achieved by searching smaller spaces utilizing the Complementary Distribution Function (CDF) of the noise encountered by the MIMO receiver.

While maintaining the diversity order of the known SD, our methods are very effective in reducing its complexity especially when it is high in large MIMO system dimensions and at low to medium Signal to Noise Ratio (SNR) values.

Our first method is efficient, yet simple and tolerable to fit with different implementations of the SD and adopt to make use of their particulars. It is based on speeding up the reduction of the tree search radius under certain condition using the noise CDF.

Testing shows that the proposed SD is capable to offer an average complexity reduction of 20% for a 8×8 MIMO system with 16 QAM, compared to an efficient implementation of the known SD.

Our second design is the First Point Found (FPF) based SD. We show that this FPF solution, despite the fact that it is sub optimum, can still preserve the diversity order of the SD with a typical SNR gap of 0.2 dB at the BER of 10^{-3} for the 4×4 MIMO system with 16 QAM. We elaborate further on the FPF idea and define a single probability parameter, the tuning of which can continuously adjust the BER performance-complexity tradeoff between the bounds of the FPF and the SD solutions. We show that this mainly affects the SNR range where the SD complexity

is high while maintaining the BER performance and the diversity order, simultaneously. Testing shows that the FPF based SD is especially suitable for large number of antennas where it can offer 60-80% complexity saving for the 8×8 system in the SNR range of 6-24 dB with 16 QAM compared to another efficient reference SD.

Our third design is the statistical FPF SD (SFPF). Based on the FPF idea, the SFPF SD offers another form of performance-complexity tradeoff while maintaining the diversity order of the SD but with some SNR gap. Testing shows that an additional 10% of nodes saving is possible by using the SFPF compared to the FPF SD.

In the coded case, the thesis considers Bit Interleaved Coded Modulation (BICM) MIMO systems where the tree search is used to find a group of transmitted vector candidates used to compute soft bit values to be fed to the soft input decoder. Based on noise characteristics, a method is proposed to define the group of such candidates without doing a full tree search which can reduce complexity by about 30% for the 4×4 system with 16 QAM compared to the known List SD (LSD).

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

**PENGESAN BERASASKAN CARIAN POKOK YANG CEKAP
UNTUK SISTEM WAYARLES
MASUKAN PELBAGAI KELUARAN PELBAGAI**

Oleh

AMJAD NAJIM JABIR

Ogos 2012

Pengerusi: Profesor Nor Kamariah bt. Noordin, PhD

Fakulti : Kejuruteraan

Di dalam sistem Masukan Pelbagai Keluaran Pelbagai (MIMO), antena berbilang digunakan pada kedua-dua hujung sambungan untuk membolehkan kedua-dua kepelbagaian hantaran dan terimaan bagi mengatasi pudaran saluran, meningkatkan kebolehpercayaan dan kadar data tanpa meningkatkan lebar jalur atau kuasa penghantaran berbanding dengan sistem Masukan Tunggal Keluaran Tunggal (SISO). Walaubagaimanapun, pengesan MIMO memerlukan kebolehan komputasi yang lebih tinggi.

Carian pokok berasaskan Kemungkinan Maksimum (ML) optimum Pengesan sfera (SD) MIMO meminimumkan Kadar Ralat Bit (BER) dan boleh mengumpul kepelbagaian yang ditawarkan oleh saluran-saluran MIMO tetapi pada kompleksiti tinggi yang meningkat berdasarkan saiz sistem MIMO dan konstelasi modulasi yang digunakan yang membuatkan sistem ini sukar dilaksanakan. Pengesan-pengesan

linear mempunyai kompleksiti yang lebih rendah tetapi menawarkan prestasi yang sangat rendah. Dengan itu, fokus adalah untuk menurunkan kompleksiti terhadap penyelesaian optimum dan untuk merangka yang tidak optimum bagi memenuhi keperluan aplikasi sebenar.

Di dalam tesis ini kami merekabentuk kaedah-kaedah untuk meningkatkan operasi SD bagi mengurangkan kompleksitinya dari segi purata bilangan nod-nod yang dilawat per pengesanan satu vektor yang diterima. Penurunan ini terhasil daripada pencarian ruang yang lebih kecil dengan menggunapakai Fungsi Agihan Pelengkap (CDF) bagi hingar yang dihadapi oleh penerima MIMO.

Di samping mengekalkan susunan kepelbagaian SD yang diketahui, kaedah-kaedah kami adalah sangat cekap di dalam mengurangkan kompleksiti sistem tersebut terutama apabila ianya tinggi dengan dimensi sistem MIMO yang besar dan pada nilai Nisbah Isyarat kepada Hingar (SNR) rendah hingga sederhana.

Kaedah kami yang pertama adalah mudah tetapi efektif dan boleh diterima dimana kaedah ini boleh disesuaikan dengan pelaksanaan SD yang berbeza dan disesuaikan untuk mengguna pakai ciri-ciri mereka. Ianya adalah berdasarkan kelajuan pengurangan radius carian pokok berasaskan CDF hingar.

Ujian menunjukkan bahawa SD yang dicadangkan mampu menawarkan penurunan kompleksiti tipikal tidak kurang daripada 20% bagi saiz sistem MIMO yang lebih besar berbanding beberapa kaedah lain yang dilaporkan di dalam kajian latarbelakang.

Kaedah kami yang kedua ialah SD berasaskan Titik Temuan Pertama (FPF). Kami menunjukkan bahawa penyelesaian FPF ini walaupun pada asasnya ianya adalah tidak optimum, ianya masih mampu memelihara kepelbagaian susunan SD dengan

jurang SNR tipikal 0.2 dB pada BER bernilai 10^{-3} untuk sistem MIMO 4×4 dengan 16 QAM. Kami menghuraikan secara lebih mendalam ide FPF dan mendefinisikan suatu parameter kebarangkalian di dalam julat [0,1], penalaan dimana boleh menyesuaikan timbal balik kompleksiti prestasi BER secara berterusan di antara batas-batas FPF dan penyelesaian SD yang memberi kesan terutamanya terhadap julat SNR dimana kompleksiti SD adalah tinggi di samping memelihara prestasi BER dan susunan kepelbagaian secara serentak. Ujian menunjukkan bahawa SD berasaskan FPF adalah sangat sesuai untuk bilangan antena yang besar dimana ia mampu menawarkan 60-80% pengurangan dari segi kompleksiti untuk sistem 8×8 di dalam julat SNR 6-24 dB dengan 16 QAM.

Rekabentuk kami yang ketiga adalah FPF SD statistik (SFPF). Berdasarkan ide FPF, SFPF SD menawarkan satu lagi bentuk timbal balik prestasi-kompleksiti sambil mengekalkan kebelbagaian susunan SD tetapi dengan beberapa jurang SNR. Ujian menunjukkan bahawa suatu penambahan sebanyak 10% terhadap penjimatan nod boleh dicapai dengan menggunakan SFPF berbanding FPF SD.

Di dalam kes terkod, tesis ini mengambilkira Modulasi Terkod Sisipan Bit (BICM) sistem MIMO dimana carian pokok digunakan untuk mencari satu kumpulan calon-calon vektor yang dihantar untuk mengira nilai-nilai bit lembut untuk disuap kepada penyahkod masukan lembut. Berdasarkan kepada ciri-ciri hingar, suatu kaedah dicadangkan untuk mengenalpasti kumpulan calon-calon tersebut tanpa membuat carian pokok penuh yang boleh mengurangkan kompleksiti sebanyak 30% untuk sistem 4×4 dengan 16 QAM berbanding dengan SD Senarai (LSD) yang diketahui.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my thanks and deep appreciation for all the help and support I have got from my supervisor Prof. Dr. Nor Kamariah Noordin, co supervisors: Prof. Dr. Sabira Khatun and Prof. Dr. Borhanuddin Mohd Ali. They were always there to help, encourage and suggest improvements. I have benefitted a lot from their wide experience that guided me through to improve this work.

My thanks go also to the Computer and Communication Systems Engineering Department at the Faculty of Engineering, UPM.

I certify that a Thesis Examination Committee has met on 28 August 2012 to conduct the final examination of Amjad Najim Jabir on his thesis entitled "Efficient Tree Search-Based Detectors for Multiple Input Multiple Output Wireless Systems" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Ahmad Fauzi bin Abas @ Ismail, PhD, -Ing.
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Makhfudzah binti Mokhtar, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Mohd Adzir bin Mahdi, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ekram Hossain, PhD
Professor
University of Manitoba
Canada
(External Examiner)

SEOW HENG FONG, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 22 October 2012

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

Nor Kamariah Noordin, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Sabira Khatun, PhD
Professor
School of Computer and Communication Engineering
Universiti Malaysia Perlis
(Member)

Borhanuddin Mohd Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

_____

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

_____

AMJAD NAJIM JABIR

Date: 28 August 2012

TABLE OF CONTENTS