

**DESIGN AND ANALYSIS OF A DYNAMIC SPACE-CODE MULTIPLE
ACCESS WITH LARGE AREA SYNCHRONOUS SCHEME USING THE
SMART ANTENNA SYSTEM**

By

NG CHEE KYUN

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

January 2007

DEDICATIONS

*“To my family members especially my beloved parent
for their endurance support and love.”*

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

DESIGN AND ANALYSIS OF A DYNAMIC SPACE-CODE MULTIPLE ACCESS WITH LARGE AREA SYNCHRONOUS SCHEME USING THE SMART ANTENNA SYSTEM

By

NG CHEE KYUN

January 2007

Chairman: Associate Professor Sabira Khatun, PhD

Faculty: Engineering

The most important property in wireless systems, when it comes to increase the system capacity and spectrum efficiency, is eliminating interference. Code Division Multiple Access (CDMA) is considered interference-limited system. Spatial filtering using smart antenna has emerged as a promising technique to improve the performance of cellular communication systems; hence, Space Division Multiple Access (SDMA) has recently received increasing interest in improving the performance of wireless systems. These interference-limited systems are susceptible to time of arrival (TOA) and angle of arrival (AOA) of individual user signals, thus, a non-uniform traffic can severely degrade the performance of CDMA and SDMA systems. In this thesis, new approach of the joint multiple access system arising from the combination of CDMA and SDMA systems is designed, and its system performances are then investigated.

An innovative approach to eliminate the existing interferences in this joint multiple access system is proposed. The spreading sequences of Large Area Synchronous Even

Ternary (LAS-ET) which exhibited an interference free window (IFW) in their correlation are exploited here. The spatial signature from smart antenna narrower beam is exploited to drive all the multipath propagation signals to arrive within the IFW in reverse link transmission. The size of IFW is adaptable with the size of smart antenna beamwidth through dynamic space code (DSC) algorithm. Hence, this double signatures scheme forms a novel multiple access scheme called Dynamic Space Code Multiple Access (DSCMA) system. From the nature of spatial filtering of smart antenna systems, a dynamic sequence reuse assignment is possible in DSCMA to increase its spectrum efficiency. The non-zero pulse intervals and sequence length of LAS-ET are arranged in even numbers which has demonstrated some performance improvements in ternary phase shift keying (TPSK) signalling. On the other hand, the combined spreading sequence and spatial signature scheme also prompts a possibility of developing a novel Space Division Duplexing (SDD) scheme. The reverse and forward links are transmitted within a narrower beam of smart antenna, and both links are distinguished by different LAS-ET sequences.

The simulation results indicate that the reverse link system capacity in DSCMA using LAS-ET spreading sequences together with smart antenna system is increased dramatically compared to traditional binary spreading sequences. The results also showed that the spectrum efficiency of DSCMA is increased when the number of elements in smart antenna system is increased. Finally, it can be concluded that the system capacity and spectrum efficiency are increased significantly from DSCMA using smart antenna systems due to its perfect interference cancellation scheme.

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

**REKA BENTUK DAN ANALISIS SATU CAPAIAN BERBILANG RUANG KOD
DINAMIK DENGAN SKIM LUAS RUANG SEGERAK MENGGUNAKAN
SISTEM ANTENA PINTAR**

Oleh

NG CHEE KYUN

Januari 2007

Pengerusi: Profesor Madya Sabira Khatun, PhD

Fakulti: Kejuruteraan

Sifat yang sangat penting dalam sistem wayarles apabila menyentuh tentang penambahan muatan sistem dan kecekapan spectrum adalah penghapusan gangguan. Capaian Berbilang Pembahagian Kod (CBPK) boleh dianggap sebagai sistem gangguan terhad. Penurasan ruang dengan menggunakan antena pintar telah muncul sebagai satu teknik harapan untuk meningkatkan prestasi sistem komunikasi bersel; iaitu baru-baru ini Capaian Berbilang Pembahagian Ruang (CBPR) telah menerima sambutan yang tinggi dalam peningkatan prestasi sistem wayarles. Sistem-sistem gangguan terhad ini mudah terpengaruh kepada masa ketibaan dan sudut ketibaan isyarat seseorang pengguna; iaitu ketidakragaman sesebuah lalu-lintas boleh menyusutkan prestasi sistem-sistem CBPK dan CBPR dengan lebih teruk. Dalam tesis ini, pendekatan baru capaian berbilang bersepadu hasil daripada penggabungan sistem-sistem CBPK dan CBPR direkabentukkan, dan seterusnya prestasi sistem itu diselidiki.

Satu pendekatan yang inovatif untuk menghapuskan sebarang gangguan yang wujud dalam sistem capaian berbilang bersepadu ini dicadangkan. Pelebaran jujukan oleh Luas Ruang Segerak Tigaan Genap (LRS-TG) yang mempamerkan satu tingkap bebas gangguan (TBG) dalam kolerasinya digunakan di sini. Pengenalan ruang daripada alur antena pintar yang sempit itu digunakan untuk memandukan semua perambatan isyarat berbilang laluan supaya tiba di dalam TBG dalam pemancaran rangkai bertentangan. Saiz TBG itu adalah diselaraskan dengan saiz lebar alur antena pintar melalui algoritma ruang kod dinamik (RKD). Justeru itu, skim pengenalan gandaan ini membentuk satu skim capaian berbilang yang baru dikenali sebagai sistem Capaian Berbilang Ruang Kod Dinamik (CBRKD). Dari kesemulajadian pengenalan ruang oleh sistem-sistem antena pintar itu, satu tugas penggunaan semula jujukan secara dinamik adalah munasabah dalam CBRKD untuk meningkatkan kecekapan spectrumnya. Selang antara denyutan-denyutan bukan sifar serta lebar jujukan LRS-TG itu disusun berbentuk nombor-nombor genap telah menunjukkan beberapa peningkatan prestasi dalam pengisyaratan penguncian anjakan fasa tigaan (PAFT). Di samping itu, skim gabungan pelebaran jujukan dan pengenalan ruang juga menyebabkan satu kemungkinan untuk membangunkan satu skim Dupleks Pembahagian Ruang (DPR) yang baru. Rangkai-rangkai bertentangan dan berhadapan dipancar melalui satu alur antena pintar yang sempit, dan kedua-dua rangkai itu dibezakan dengan jujukan LRS-TG yang beza.

Keputusan-keputusan simulasi menunjukkan bahawa muatan sistem dalam CBRKD dengan menggunakan jujukan pelebaran LRS-TG bersama-sama dengan sistem antena pintar dalam rangkai bertentangan ditingkatkan secara dramatik berbanding dengan jujukan dua an pelebaran tradisi. Keputusan-keputusan itu juga menunjukkan bahawa

kecekapan spectrum dalam CBRKD ditingkatkan apabila bilangan unsur dalam sistem antena pintar itu ditambah. Akhirnya, ini boleh disimpulkan bahawa muatan sistem dan kecekapan spectrum ditingkatkan dengan ketara daripada CBRKD dengan menggunakan sistem antena pintar disebabkan oleh skim pemansuhan gangguan yang sempurna.

ACKNOWLEDGEMENTS

I wish to express my deeply gratitude to the numerous people who have walked with me along the journey of this thesis. Firstly, I am grateful to my supervisor Associate Professor Dr. Sabira Khatun for her guidance and support throughout the study.

I also wish to extend my sincere appreciation and gratitude to Professor Dr. Borhanuddin Mohd. Ali for his professional and constructive inputs throughout my research, and insightful reviews in this thesis and other technical papers. This is my honour to be one of his researchers.

I am deeply indebted to Professor Dr. Sudhanshu Shekhar Jamuar for his invaluable ideas, suggestions, directions and inspirations throughout my research period. Also a big thank you is extended to Associate Professor Dr. Mahamod Ismail for his endurance guidance, continual supervision, throughput ideas and encouragement although he is from Universiti Kebangsaan Malaysia.

My special gratitude also go to my elder colleagues Nor Kamariah and Azmi Ahmad for their leading knowledge and wonderful guidance throughout our researches. Thank you for your patience of cares and guides to me. Not forgettable thanks are also extended to other colleagues from Wireless Broadband and Photonic groups for their supports and friendships. Thank you for accepting me as part of you.

I certify that an Examination Committee has met on 30 January 2007 to conduct the final examination of Ng Chee Kyun on his Doctor of Philosophy thesis entitled "Design and Analysis of a Dynamic Space-Code Multiple Access with Large Area Synchronous Scheme Using the Smart Antenna System" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

MOHAMAD KHAZANI ABDULLAH, PhD

Associate Professor / Head of Department
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

MOHD. ADZIR MAHDI, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

SAMSUL BAHARI MOHD. NOOR, PhD

Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

KAHARUDIN DIMYATI, PhD

Associate Professor
Faculty of Engineering
Universiti Malaya
(External Examiner)

HASANAH MOHD GHAZALI, PhD

Professor / Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 27 APRIL 2007

This thesis 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 are as follows:

Sabira Khatun, PhD

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Borhanuddin Mohd Ali, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Sudhanshu Shekhar Jamuar, PhD

Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mahamod Ismail, PhD

Associate Professor
Faculty of Engineering
Universiti Kebangsaan Malaysia
(Member)

AINI IDERIS, PhD

Professor / Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 10 MAY 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NG CHEE KYUN

Date: 3 March 2007

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	viii
APPROVAL	ix
DECLARATION	xi
LIST OF TABLES	xvi
LIST OF FIGURES	xix
LIST OF ABBREVIATIONS / NOTATIONS	xxiv
CHAPTER	
1 INTRODUCTION	1.1
1.1 Problem Statements and Motivations	1.3
1.1.1 A Variety of Existing Interferences in CDMA and SDMA Systems	1.3
1.1.2 Multipath Propagation Effects	1.5
1.1.3 Deficiency of Present Solutions	1.7
1.1.4 Quandary of Current Duplexing Schemes	1.10
1.2 The Proposed Joint Multiple Access of CDMA and SDMA Systems Approach	1.12
1.3 Aim and Objectives	1.13
1.4 Research Scopes and Contributions	1.14
1.5 Thesis Organizations	1.17
2 LITERATURE REVIEW	2.1
2.1 Multiple Access Techniques for Wireless Communications	2.3
2.1.1 Frequency Division Multiple Access (FDMA)	2.4
2.1.2 Time Division Multiple Access (TDMA)	2.5
2.1.3 Code Division Multiple Access (CDMA)	2.6
2.1.4 Space Division Multiple Access (SDMA)	2.8
2.2 Duplexing Techniques for Wireless Communications	2.10
2.3 Smart Antenna	2.12
2.4 The Properties of Orthogonal CDMA Sequences	2.14
2.5 Welch Bound in CDMA Systems	2.15
2.6 Large Area Synchronous (LAS) CDMA Sequences	2.16
2.6.1 Large Area (LA) Codes	2.16
2.6.2 Loosely Synchronous (LS) Codes	2.23
2.6.3 Construction of LAS Sequences	2.23
2.6.4 LAS-2000 Frame Structure	2.26
2.7 Power Control in CDMA Systems	2.27
2.8 Reverse Link Capacity of CDMA System	2.28
2.9 Phase Shift Keying (PSK) Modulation	2.30

2.10	Performance of PSK Modulation over AWGN Channel	2.32
2.11	Ternary Phase Shift Keying (TPSK)	2.33
2.12	Wireless Communication System Impairments	2.35
	2.12.1 Multipath Fading	2.36
	2.12.2 Delay Spread	2.37
	2.12.3 Co-channel Interference	2.37
2.13	Multipath Propagations and Fading Channels	2.38
2.14	Simplified Path Loss Model	2.40
2.15	Time-Varying Multipath Channel Impulse Response	2.43
2.16	Statistical Models for Multipath Fading Channels	2.46
	2.16.1 Rayleigh Fading Channel Model	2.47
	2.16.2 Rician Fading Channel Model	2.47
	2.16.3 Nakagami- m Fading Channel Model	2.48
2.17	Performance of BPSK Modulation over Frequency Nonselective Fading Channel	2.50
	2.17.1 Rayleigh Fading	2.51
	2.17.2 Nakagami- m Fading	2.52
2.18	Performance Improvement in Frequency Selective Fading Channel through Diversity	2.54
2.19	Performance of BPSK Modulation over Frequency Selective Fading Channel through Signal Diversity	2.56
2.20	Frequency Reuse Schemes for CDMA Systems	2.58
3	DESIGN AND MODELLING SMART ANTENNA FOR SDMA SYSTEM	3.1
3.1	Microstrip Antenna	3.2
3.2	Microstrip Patch Antenna	3.2
3.3	Fringing Fields of Microstrip Antenna	3.4
3.4	Substrates Materials	3.5
3.5	Feeding Techniques	3.5
	3.5.1 Microstrip Line	3.6
	3.5.2 Coaxial Probe	3.6
3.6	Microstrip Patch Antenna Design	3.7
3.7	Microstrip Patch Antenna Array	3.12
	3.7.1 Microstrip Patch Array Design	3.12
	3.7.2 Microstrip Patch Phased Array Antenna	3.13
3.8	Mathematical Model of Smart Antenna System Design	3.15
3.9	Antenna Array of Two Elements	3.15
3.10	Phased Array Antenna of N Elements	3.18
3.11	Smart Antenna Beamwidth	3.19
3.12	Smart Antenna Beamforming Analysis	3.20
3.13	Conclusion	3.23
4	LAS-ET SEQUENCES WITH TPSK SIGNALLING	4.1
4.1	Introduction to LAS Even Ternary (LAS-ET) Sequences	4.2
4.2	Modulation Techniques for DSCMA System	4.5

4.3	Further Improvement of TPSK Scheme in DSCMA System	4.8
4.4	Conclusion	4.11
5	DYNAMIC SPACE CODE MULTIPLE ACCESS (DSCMA) SYSTEM	5.1
5.1	Correlation Properties of CDMA Sequences	5.2
5.1.1	Maximal-Length Sequences	5.3
5.1.2	Gold Sequences	5.4
5.1.3	Walsh-Hadamard Sequences	5.6
5.1.4	LAS-ET Sequences	5.8
5.2	Maximum Angular Spread of Received Signal	5.12
5.3	Maximum Propagation Delay Spread	5.14
5.4	Performance of Synthesized Narrow Beam using Smart Antenna	5.17
5.5	Reverse Link Capacity of SDMA System	5.20
5.6	Illustration of Dynamic Space Code Multiple Access (DSCMA) System	5.24
5.7	DSCMA Cellular System Model	5.27
5.7.1	Propagation Model	5.28
5.7.2	Smart Antenna Radiation Pattern Model	5.29
5.7.3	Spatial Channel Model	5.31
5.8	Performance Improvement in DSCMA System using DSC Algorithm	5.33
5.9	Reverse Link Interferences in DSCMA System	5.39
5.9.1	Intra-cell Interference	5.40
5.9.2	Inter-cell Interference	5.42
5.10	Illustration of DSCMA System Signalling	5.45
5.11	Probability of Error Evaluation in DSCMA System over AWGN Channel	5.46
5.12	Probability of Error Evaluation in DSCMA System over Multipath Fading Channel	5.49
5.13	Directional Diversity in DSCMA System	5.52
5.14	BER Performance Analysis in DSCMA System	5.55
5.14.1	BER Performance Analysis in DSCMA over AWGN Channel	5.59
5.14.2	BER Performance Analysis of DSCMA in Multipath Fading Channel	5.64
5.14.3	BER Performance Analysis of DSCMA in Multipath Fading Channel with Diversity Gain	5.68
5.14.4	Summary of BER Performance Analysis of DSCMA System	5.74
5.15	Conclusion	5.78

6	SPECTRUM EFFICIENCY IN DSCMA SYSTEM	6.1
6.1	Spectrum Efficiency Increment in LAS-ET Sequences	6.2
6.2	Spectrum Efficiency Further Improvement through Dynamic Sequence Reuse Assignment	6.5
6.3	Conclusion	6.11
7	SPACE DIVISION DUPLEXING (SDD) SCHEME IN DSCMA SYSTEM	7.1
7.1	Advantages of SDD Scheme in DSCMA System	7.4
7.2	Conclusion	7.4
8	CONCLUSIONS AND FUTURE WORKS	8.1
8.1	Key-Contributions	8.2
	8.1.1 A Perfect Interference Cancellation System	8.2
	8.1.2 Spectrum Efficiency Increase	8.3
	8.1.3 Directional Diversity	8.5
	8.1.4 SDD Scheme	8.5
8.2	Future Works	8.6
	8.2.1 High Spectrum Efficiency Spreading Sequences	8.7
	8.2.2 Multiuser Detection	8.7
	8.2.3 Radio Network Planning	8.8
	8.2.4 All IP Network	8.8
8.3	Concluding Remarks	8.9

REFERENCES

APPENDICES

BIODATA OF THE AUTHOR