SPACE TIME BLOCK CODED MULTI-CARRIER CDMA WITH MINIMUM TOTAL SQUARED CORRELATION SIGNATURES AND MULTIUSER DETECTION

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**SCHOOL OF ENGINEERING
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2010

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THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

SCHOOL OF ENGINEERING
AND INFORMATION TECHNOLOGY
UNIVERSITI MALAYSIA SABAH
2010

BORANG PENGESAHAN STATUS TESIS

JUDUL: SPACE TIME BLOCK CODED MULTI-CARRIER CDMA WITH MINIMUM TOTAL SQUARED CORRELATION SIGNATURES AND MULTIUSER DETECTION

IJAZAH: ELECTRICAL AND ELECTRONICS ENGINEERING (TELECOMMUNICATIONS)

SAYA: MOHAMMAD SIGIT ARIFIANTO SESI PENGAJIAN: 2010
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DEGREE : **DOCTOR OF PHILOSOPHY (TELECOMMUNICATIONS)**

VIVA DATE : **26 MAY 2010**

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ACKNOWLEDGEMENT

Praise be to Allah, The Cherisher and The Sustainer of the Worlds. Allah has bestowed upon me all that is necessary to finish this work: loving family, encouraging friends, competent mentors and colleagues, favorable environment and infrastructure for doing research and study, health, strength, passion, and patience.

This thesis can only be composed with the help and support from several great individuals. My deep appreciation goes to them. Dr. Ali Chekima provided very useful guidance and fulfilled the role of a caring and supportive academic supervisor/advisor for me. Not only that, his encouragement and the trust he has in me have elevated my self-confidence in finishing this work greatly. Mr. Liawas Barukang, the head of the Telemedicine Research Projects in the School of Engineering and IT, Universiti Malaysia Sabah, very generously allowed me to use the resources in his lab and to be involved in his research projects where ideas on wireless communications research spark intensely. Dr. Emir Mauludi Husni, who has left his post in UMS and joined the Institut Teknologi Bandung, Indonesia, attracted me to come and perform this research in the first place. I am also very thankful to the Vice Chancellor of Universiti Malaysia Sabah and the Dean of the School of Engineering and IT for providing policies, environment, and facilities, all conducive to Post-Graduate research work.

Special thanks to a number of outstanding people. The Examiners and the Post-Graduate Committee of the School of Engineering and IT were willing to spend their precious time to read this thesis and to provide me with valuable constructive comments. Dr. Swades K. De (was with the New Jersey Institute of Technology, USA) gave me useful comments and feedback on one of the techniques that I proposed in this thesis, namely the Pilot-Symbol Aided MC-CDMA with Minimum TSC Spreading Codes. Comments and feedback from anonymous reviewers who read the manuscripts that I submitted to various conferences and journals have also guided me in improving this thesis. Thanks to all fellow researchers in the Advanced Telecommunications and Network Research Group for the fruitful discussions we had. Also to all my friends, who have helped me to focus on my research by tremendously assisting me in coping and adapting with many aspects of life in Kota Kinabalu, Malaysia.

Thanks also to the exceptional personnel of Universiti Malaysia Sabah, particularly the people in the Telemedicine Research Projects, the School of Engineering and IT, the Centre for Postgraduate Studies, the Centre for Research and Innovation, and the UMS Library, who have helped me many times, since the day I started my research until the completion of this thesis.

I am very grateful for the supportive, understanding, and caring family I have. Especially, thank you to my wife Diana Fitriasari and my son Fahim. Not only they support me, they also let me devote much of my time to do the research and to write this thesis. Thanks also go to my late father, my mother, my sister, my brother, and my in-laws for their sincere help and support during my studies.

Lastly, this thesis would not exist without the fundamental thinking ability that was initially imprinted by my parents in the early years of my life and the skill that my late father taught me in my toddler years, reading. Thus, my vast gratitude is for them, and may Allah bless them.

ABSTRACT

Space Time Block Coded Multi-carrier CDMA with Minimum Total Squared Correlation Signatures and Multiuser Detection

The merging of multimedia based applications with mobile communications in areas such as telemedicine, military, business, and entertainment implies that wireless communication systems have to provide high-speed broadband multiple-access solution to meet the demand. One approach to achieve the required solution is by combining Space Time Coding (STC) and Multi-Carrier Code Division Multiple Access (CDMA). The uncovering of the limits and capacity of Multiple Input Multiple Output (MIMO) system has placed STC, applied on MIMO system, as the answer for high-speed wireless communications. While Multi-Carrier CDMA, with its ability to combat frequency selective channel experienced by broadband signals, has been adopted as the enabling technology behind 3G communication systems and widely considered for the future 4G systems. This work focuses on the combination of a variant of STC, namely Space Time Block Codes (STBC) with the frequency domain spreading variant of Multi-Carrier CDMA, namely MC-CDMA. The thesis proposes the enhancement of STBC MC-CDMA through two new designs. Firstly, a Pilot Aided STBC MC-CDMA scheme based on overloaded Minimum Total Squared Correlation (TSC) signature set was introduced for the first time. Since overloaded signatures were utilized as the spreading codes, a number of sub-channels in STBC MC-CDMA were not used for data transmission. These sub-channels were exploited for comb-type pilot signaling. To maintain low system complexity, for the pilot sub-channels Least Square Estimation (LS) method was employed, and for interpolating the characteristics of the data sub-channels linear interpolator was applied. The validity of the scheme was confirmed by comparing its performance with that of the Walsh-Hadamard based STBC MC-CDMA with block-type pilot. The result showed that although the spreading codes of interest are not fully orthogonal codes, for a low number of users, e.g. less than 7 users in a system with a capacity of 32, the system under investigation performed better than its Walsh-Hadamard based counterpart with the same capacity. This will be valuable for Wireless Personal Area Network (PAN) where the number of users is typically low. Secondly, a multiuser detector (MUD) using Genetic Algorithm (GA) was devised specifically for the STBC MC-CDMA. Basically, optimum detection for CDMA based systems using conventional MUD has a high computational complexity. For K number of users for instance, the computational complexity grows exponentially with K. The problem presents even more impact for the more complicated CDMA derivation such as STBC MC-CDMA that requires more processing time. Although suboptimum detection methods with less complexity are available, they are less powerful than MUD. To achieve the optimality of MUD while avoiding the computational complexity, GA is included in the detector design. Furthermore, the STBC MC-CDMA system was simulated over a frequency selective rayleigh fading channel with the receiver employing the GA assisted MUD. The result showed that the system under investigation performed better than STBC MC-CDMA using Equal Gain Combining (EGC). For instance, at the BER value of 0.01, the required level of E_b/N_0 for 2×2 STBC MC-CDMA using GA assisted MUD was dropped by 3 dB compared to the 2×2 scheme using EGC.

ABSTRAK

Penggabungan aplikasi multimedia dengan komunikasi bergerak (mobile) di dalam bidang seperti tele-kesihatan, ketenteraan, perniagaan, dan hiburan mempunyai implikasi bahawa sistem komunikasi tanpa wayar harus dapat memberi penyelesaian jalur lebar yang berkelajuan tinggi dengan kemampuan capaian berbilang. Salah satu pendekatan untuk mencapainya adalah dengan mengkombinasikan Space Time Coding (STC) dan Multi-Carrier Code Division Multiple Access (CDMA). Penemuan akan had dan kapasiti dari sistem Multiple Input Multiple Output (MIMO) telah menempatkan STC, dengan sistem MIMO, sebagai jawapan untuk memenuhi komunikasi tanpa wayar berkelajuan tinggi. Manakala Multi-Carrier CDMA, dengan ketahanannya terhadap saluran memilih frekuensi yang dialami oleh isyarat jalur lebar, telah dipakai sebagai teknologi asas untuk sistem komunikasi 3G dan juga secara meluas dipandang sesuai untuk sistem 4G. Kerja ini memfokus pada kombinasi antara suatu jenis STC yang dikenali sebagai Space Time Block Codes (STBC) dengan suatu jenis dari Multi-Carrier CDMA yang melakukan penyebaran dalam domain frekuensi, dikenali sebagai MC-CDMA. Tesis ini mengajukan penambahbaikan STBC MC-CDMA melalui dua rekabentuk baru. Pertama, sebuah skim berbantukan pilot, Pilot-Symbol Aided STBC MC-CDMA, berasaskan kepada set tandatangan overloaded Minimum Total Squared Correlation (TSC), telah diperkenalkan untuk pertama kalinya. Memandangkan set tandatangan tersebut dipakai sebagai kod penyebaran, sebilangan cabang saluran dalam STBC MC-CDMA tidak diguna untuk transmisi data. Sebilangan cabang saluran tersebut dimanfaatkan untuk comb-type pilot signaling. Untuk memastikan kerumitan system yang rendah, untuk sub saluran pilot, kaedah Least Square Estimation (LS) telah digunakan dan untuk interpolasi ciri-ciri cabang saluran data, linear interpolator telah diaplikasikan. Kebenaran skim ini dipastikan dengan membandingkan prestasi kerjanya dengan STBC MC-CDMA berkod Walsh-Hadamard yang memakai block-type pilot. Hasil penyelidikan menunjukkan bahawa meskipun kod penyebaran yang diselidiki bukanlah kod orthogonal, untuk bilangan pemakai yang kecil, sebagai contoh, kurang dari lapan pemakai untuk sistem dengan kapasiti 32, sistem baru yang memakai kod tersebut mempunyai prestasi kerja yang lebih baik dari sistem yang memakai kod Walsh-Hadamard yang orthogonal dengan kapasiti yang sama. Ini akan berguna untuk Wireless Personal Area Network (PAN), yang umumnya mempunyai bilangan pemakai yang kecil. Kedua, sebuah Multiuser Detector (MUD) dengan Genetic Algorithm (GA) telah diciptakan untuk STBC MC-CDMA. Pada dasarnya, pengesanan optimum pada sistem CDMA menggunakan MUD konvensional memiliki kerumitan pengiraan yang tinggi. Untuk bilangan pemakai K, kerumitan pengiraan bertambah secara eksponensial mengikut K. Masalah ini memberi kesan yang lebih pada terbitan CDMA yang lebih rumit seperti pada STBC MC-CDMA yang memerlukan pemprosesan yang lebih lama. Meskipun kaedah pengesanan cabang optimum dengan kerumitan yang lebih rendah dapat dipakai, tetapi kemampuannya lebih rendah dari MUD. Untuk mencapai keoptimalan MUD dengan mengelakkan kerumitan pengiraan yang tinggi, GA disertakan dalam rekabentuk pengesan. Tambahan pula, sistem STBC MC-CDMA disimulasi untuk saluran rayleigh fading memilih frekuensi dengan bahagian penerima yang menggunakan MUD berbantukan GA. Hasil simulasi menunjukkan bahawa sistem yang diselidiki

mempunyai prestasi kerja yang jelas lebih baik dari STBC MC-CDMA dengan Equal Gain Combining (EGC). Sebagai contoh, untuk BER sebesar 0.01, E_b/N_0 untuk 2×2 STBC MC-CDMA dengan MUD berbantukan GA adalah 3 dB lebih rendah dibandingkan dengan skim 2×2 dengan EGC.

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LIST OF ABBREVIATIONS

AWGN	Additive White Gaussian Noise
BAN	Body Area Network
BER	Bit Error Rate
bps	Bit per second
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CSI	Channel State Information
CP	Cyclic Prefix
CPI	Cyclic Prefix Insertion
CPR	Cyclic Prefix Removal
cps	Chip per second
DFT	Discrete Fourier Transform
DOA	Direction of Arrival
DS-CDMA	Direct Sequence CDMA
DSP	Digital Signal Processor
DSSS	Direct Sequence Spread Spectrum
ECG	Electrocardiogram
EGC	Equal Gain Combining
EIRP	Effective Isotropic Radiated Power
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform
FER	Frame Error Rate
FPGA	Field Programmable Gate Array
GA	Genetic Algorithm
GA-MUD	Genetic Algorithm Based Multiuser Detector
IDFT	Inverse DFT
IFFT	Inverse FFT
ISI	Inter Symbol Interference
JTC	Joint Technical Committee (for Personal Communication System)
LFSR	Linear Feedback Shift Register
LMS	Least Mean Square

LOS	Line of Sight
LS	Least Square
MAI	Multiple Access Interference
MC-CDMA	Multicarrier CDMA (the Frequency Domain Spreading)
MC-DS-CDMA	Multicarrier DS-CDMA
MT-CDMA	Multitone CDMA
MCM	Multicarrier Modulation
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MMSE	Minimum Mean Square Error
MUD	Multiuser Detector / Multiuser Detection
MRC	Maximum Ratio Combining
OFDM	Orthogonal Frequency Division Multiplexing
OSSIE	Open Source SCA Implementation: Embedded
PAN	Personal Area Network
PL	Path Loss
PN	Pseudo-noise
p.d.f.	Probability Density Function
p.s.d.	Power Spectral Density
QPSK	Quadrature Phase Shift Keying
r.v.	Random Variable
SCA	Software Communications Architecture
SDR	Software Defined Radio
SIMO	Single Input Multiple Output
SISO	Single Input Single Output
STBC	Space Time Block Codes
STC	Space Time Coding
STTC	Space Time Trellis Codes
SVD	Singular Value Decomposition
TSC	Total Squared Correlation
USRP	Universal Software Radio Peripheral

LIST OF SYMBOLS AND NOTATIONS

$(\ )^*$	complex conjugate (placed as a superscript)
$*$	convolution
$a_n(t)$	the attenuation at the n-th path in a multipath channel
A_e	effective aperture of an antenna
A_{er}	effective aperture of the receiving antenna
A_{et}	effective aperture of the transmitting antenna
$b_k(n)$	n-th bit of the k-th user
$\hat{b}$	detected bit
B	bandwidth
B_c	coherence bandwidth
B_d	Doppler spread
B_S	bandwidth of a baseband signal with symbol period T_S
C	channel capacity
$\mathbf{c}$	spreading codes sequence
$c(\ell)$	the ℓ-th chip in the spreading sequence $\mathbf{c}$
c_m^u	the chip of the spreading codes of the u-th user in the m-th sub-channel
$\det(\ )$	determinant of a matrix
D	DC component in Rician distribution
D	the largest physical dimension of an antenna
d	distance from the transmitter
d_0	close-in distance, reference point for practical usage of PL
d_f	far-field distance
d_{pq}	distance between the p-th receiver and the q-th receiver
$E[\ ]$	expectation
E_b	energy per bit
f_d	Doppler shift
$f_{d\max}$	maximum Doppler shift
$f_A(\alpha)$	p.d.f. of the angle of arrival
G	coding gain or bandwidth expansion factor in DS-CDMA
G	gain of an antenna

G_r	gain of the receiving antenna
G_t	gain of the transmitting antenna
$(\ )^H$	hermitian operator (placed as a superscript)
$\mathbf{H}$	MIMO channel matrix
h_R	Rayleigh criterion
h_{ij}	channel coefficient for the path between the i-th receiver and the j-th transmitter in MIMO communications
$h_{ij,n}$	MIMO channel coefficient for the path between the i-th receiver and the j-th transmitter at the n-th symbol duration
$h_\ell(t,\tau)$	impulse response of time-varying multipath channel (low pass)
$h_\ell(\tau)$	impulse response of time invariant multipath channel (low pass)
i	the i-th receiver in MIMO communications
$\mathbf{I}$	identity matrix
$\mathrm{Im}(\ )$	imaginary part of a complex number
j	imaginary number, $\sqrt{-1}$
j	the j-th transmitter in MIMO communications
K	numbers of signatures in a signature set (capacity is implied)
K	K-factor of a Rician distribution
$\mathbf{K}_R$	lower triangular matrices from Cholesky decomposition of $\mathbf{\Theta}_R$
$\mathbf{K}_T$	lower triangular matrices from Cholesky decomposition of $\mathbf{\Theta}_T$
k	the k-th user in multiuser communications
K_o	number of operating users in multiuser communications
ℓ	the ℓ-th chip in a signature
L	non-propagation loss
L	length of a signature
L_{pn}	distance between the n-th transmitter and the p-th receiver
M	IFFT block size, number of sub-channels in MC-CDMA
$\min(\ )$	the minimum value among variables inside the parenthesis
n	path loss exponent
n	the n-th time slot in STBC transmissions
$\mathbf{n}$	vector containing AWGN noise in MIMO

N_0	constant density of a white noise for the one-sided p.s.d.
PL	path loss
$\overline{PL}$	mean value of path loss
$P(t,\tau)$	power delay profile of time-varying multipath channel
$P(\tau)$	power delay profile of time invariant multipath channel
P_r	received power
P_t	transmitted power
$q\ (t)$	spreading waveform
R	mutation rate in GA
$R_{i,n,m}$	FFT output at the STBC MC-CDMA receiver, representing i-th receiver, n-th time slot, and m-th sub-channel
Re( )	real part of a complex number
$\mathbf{r}$	MIMO channel output vector (received signal vector)
r	rank of matrix $\mathbf{H}$
$S_D(f)$	Jakes' s Doppler power spectrum
$(\ )^T$	transpose (placed as a superscript)
T	the time duration of the fading waveform produced by the Rician/Rayleigh fading simulator
T_c	coherence time
T_C	chip duration
T_S	symbol period
TSC( )	Total Squared Correlation of a signature set
v	velocity of a mobile user
var( )	variance
$\mathbf{W}$	the weighting matrix in STBC MC-CDMA processing at the receiver
w_m	weight for the m-th sub-channel
$\mathbf{x}$	MIMO channel input vector (transmitted signal vector)
$X \sim N(\mu,\sigma^2)$	a Gaussian r. v. with mean μ and variance σ^2
z	index of the crossover point in GA
α	angle of arrival, direction of arrival
Δf	frequency spacing

ΔR	equal spacing between adjacent antennas
$\delta(t)$	Dirac delta function
η	noise, AWGN
Λ	likelihood function
λ	wavelength
λ	Eigenvalue
μ	mean
σ^2	variance
σ_τ	RMS delay spread, time dispersion parameter of a channel
$\bar{\tau}$	mean excess delay
$\tau_n(t)$	the excess delay given by the n-th path in multipath channel
τ_x	maximum excess delay
$\boldsymbol{\Theta}_R$	the correlation of the receiver array
$\boldsymbol{\Theta}_T$	the correlation of the transmitter array
θ_{pq}	entries in correlation matrix $\boldsymbol{\Theta}$
$\phi(\tau)$	autocorrelation function
$\Phi_{nn}(f)$	p.s.d. function
$\mathbb{C}$	set of complex numbers
$\mathscr{P}(d)$	power density over unit area at distance d
$\mathbb{S}$	set of signatures

CHAPTER 1

INTRODUCTION

1.1 Background

The idea of undertaking the research work presented in this thesis was induced by issues arising in the development of mobile tele-emergency system in the School of Engineering and Information Technology, Universiti Malaysia Sabah.

The mobile tele-emergency system project aims at providing medical emergency services in remote areas and disaster struck areas by means of mobile medical units (Husni et al., 2004). Furthermore, since very remote areas and disaster struck areas normally lack telecommunications infrastructure, the medical units should be able to communicate with each other independently without any supporting conventional telecommunication infrastructures (Husni et al., 2006). The tele-emergency system must be able to provide real-time multimedia services, although for non-emergency situation non-interactive store and forward technique is acceptable, and to accommodate the needs of high-speed transmission of large medical information content and high quality video communications (Husni et al., 2004).

In order to support such operational abilities, the only possible technological solution for the communications is the broadband mobile wireless technology. Physical layer design, i.e. wireless communications design, is a key to the quality of the communication system building block of the medical units, which in turn will also define the quality of the medical services. Thus, it demands advanced wireless technologies supporting the system at the physical layer.

The obvious source of problems in mobile wireless communications is the wireless channel itself as the transmission medium. The mobility of the units affects the characteristics of the channel with fading phenomenon. The fading generally follows Rayleigh probability distribution function, except for short distance where it