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MOHAMMED ABDO SAEED HEZAM

FK 2008 63

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DOCTOR OF PHILOSOPHY
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By

MOHAMMED ABDO SAEED HEZAM

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

September 2008

To my loving parents, wife, and kids,

for their understanding, endless love, and support through the years

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

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MOHAMMED ABDO SAEED HEZAM

September 2008

Chairman: Professor Borhanuddin Mohd. Ali, PhD

Faculty: Engineering

In wireless communications, the demands for high data rates, enhanced mobility, improved coverage, and link reliability have enormously increased in recent years and are expected to further increase in the near future. To meet these requirements, new concepts and technologies are needed. Theoretical studies have shown that using multiple antennas at the transmitter and receiver, known as multiple-input multiple-output (MIMO) technology, can dramatically increase the capacity, coverage, and link reliability of a communication system. Orthogonal frequency-division multiplexing (OFDM) is an attractive technique for high data rates transmission over frequency-selective fading channels, due to its capability in combating the intersymbol interference (ISI). The combination of MIMO and OFDM results in a powerful technique that incorporates the advantages of both MIMO and OFDM, and is a strong candidate for fourth generation (4G) wireless communication systems.

In this thesis, two issues related to realizing practical mobile MIMO OFDM communication systems are addressed. The first issue is about MIMO channel

modeling and effect of realistic channels on the theoretical capacity. For this target, a geometrically-based three-dimensional (3-D) scattering MIMO channel model is developed. The correlation expressions are derived and analytically evaluated. The impact of spatial correlation on MIMO channel capacity is investigated under different antenna array configurations, angular energy distributions, and parameters. Analytical and numerical results have shown that the elevation angle has considerable effect on the spatial correlation and consequently on the MIMO channel capacity for the case when the antenna array of the mobile station (MS) is vertically oriented. This has led to a conclusion that 3-D scattering MIMO channel modeling is necessary for accurate prediction of MIMO system performance.

The second issue addressed in this thesis is the channel estimation in MIMO OFDM systems. New time-domain (TD) adaptive estimation methods based on recursive least squares (RLS) and normalized least-mean squares (NLMS) algorithms are proposed. These estimators are then extended to blindly track the time-variations of the channel in the decision-directed (DD) mode. Simulation results have shown that TD adaptive channel estimation and tracking in MIMO OFDM systems is very effective in slow to moderate time-varying fading channels. It was observed that the performance of the DD RLS-based estimator always outperform that of the DD NLMS estimator at low mobility and low SNR. In contrast, it was found that the DD NLMS estimator gives better tracking performance at moderate mobility and higher SNR. However, as the training rate is reduced, comparable performance with both estimators is obtained at high SNR. Finally, it has been shown that channel estimation in TD is more accurate with less complexity compared to its counterpart in frequency-domain (FD).

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

PERMODELAN SALURAN DAN TAKSIRAN DALAM TEKNOLOGI MASUKAN BERBILANG KELUARAN BERBILANG DAN PEMULTIPLEKSAN PEMBAHAGI FREKUENSI ORTHOGONAL DALAM SISTEM KOMUNIKASI TANPA WAYAR

Oleh

MOHAMMED ABDO SAEED HEZAM

September 2008

Pengerusi: Profesor Borhanuddin Mohd. Ali, PhD

Fakulti: Kejuruteraan

Dalam komunikasi tanpa wayar, tuntutan untuk data kelajuan tinggi, pergerakan yang meningkat, liputan yang ditambahbaik, dan kebolehpercayaan pautan sudah bertambah pada tahun kebelakangan ini dan dijangka akan kian bertambah dalam masa terdekat. Konsep baru dan teknologi terkini diperlukan untuk memenuhi keperluan ini. Kajian teoretikal menunjukkan bahawa penggunaan beberapa antena di pemancar dan penerima, yang dikenali sebagai teknologi masukan berbilang keluaran berbilang(MIMO), boleh secara dramatik menambah keupayaan muatan, liputan, dan kebolehpercayaan pautan suatu sistem komunikasi. Pemultipleksan pembahagi frekuensi orthogonal (OFDM) adalah suatu teknik menarik untuk pengiriman data kelajuan tinggi diatas saluran memudar yang frekuensi bersifat memilih, kerana kemampuannya dalam menangani masalah gangguan antara simbol(ISI). Gabungan MIMO dan OFDM, menghasilkan teknik terbaik yang mengambil kelebihan kedua-dua MIMO dan OFDM dan merupakan calon terulung untuk sistem komunikasi tanpa wayar generasi ke empat (4G).

Di dalam tesis ini, dua isu yang berkaitan dalam merealisasikan sistem komunikasi praktikal MIMO OFDM bergerak dibincang. Persoalan pertama adalah mengenai permodelan saluran MIMO dan kesan saluran realistik terhadap kemampuan muatan teoritikal. Untuk sasaran ini, model saluran MIMO berselerak berdasar geometrik tiga dimensi (3-D) adalah dibina. Ungkapan hubungkait diterbitan dan dinilai secara analitik. Kesan hubungkait ke atas ruang muatan saluran MIMO bardasarkan konfigurasi tatasusunan antena yang pelbagai, taburan kuasa sudut dan parameter yang berbeza dikaji. Keputusan analitik dan numeric telah menunjukkan bahawa sudut peninggian mempunyai pengaruh ke atas hubungkait ruang dan seterusnya ke atas muatan saluran MIMO dalam kes tatasusunan antena stesen mobil (MS) diorientasikan secara vertikal. Ini mencetuskan kesimpulan bahawa permodelan saluran MIMO berselerak 3-D diperlukan untuk membuat ramalan yang tepat ke atas kecekapan sistem MIMO.

Isu kedua yang dibincang di dalam tesis ini adalah mengenai taksiran saluran dalam sistem MIMO OFDM. Kaedah taksiran penyesuaian baru domain masa (TD) berdasarkan re-kursif paling kecil kuasa dua (RLS) dan algoritma normal paling kecil purata kuasa dua (NLMS) dicadangkan. Taksiran ini dipanjangkan untuk mengesan variasi saluran dalam mod arahan-keputusan (DD). Hasil simulasi menunjukkan bahawa taksiran saluran adaptif domain masa dan pengesanan dalam sistem MIMO OFDM adalah berkesan dalam saluran pudar masa berubah perlahan ke pertengahan. Adalah diperhatikan bahawa hasil taksiran DD RLS sentiasa lebih baik daripada taksiran DD NLMS sewaktu pergerakan yang rendah dan pada nisbah isyarat ke bisingan (SNR) rendah. Sebaliknya kontra didapati bahawa taksiran DD NLMS memberikan pretasi pengesanan yang adalah lebih baik daripada DD RLS pada tahap pergerakan pertengahan dan SNR yang lebih tinggi. Walau bagaimanapun bila kadar latihan turun, keputusan yang sama antara kedua cara taksiran diperolehi pada tahap SNR yang tinggi. Akhir sekali, telah ditunjukkan bahawa penaksiran dalam domain masa adalah lebih tepat dengan kadar kompleks yang kurang berbanding dengan domain-frekuensi (FD).

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بسم الله الرحمن الرحيم

In the name of ALLAH, the Most Merciful and the Most Beneficent

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First of all, I would like to express my sincerely gratitude and deepest thanks to my advisor, Professor Dr. Borhanuddin Mohd. Ali, for his constant support, invaluable guidance, and encouragement through the years of my graduate studies at UPM. What I have learned from him will provide me with lifetime benefits.

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Finally, I would like to express my gratefulness and thanks to my wife for her love, support, enriching companionship, and taking care of our kids during my studies.

I certify that an Examination Committee has met on 2 September 2008 to conduct the final examination of Mohammed Abdo Saeed Hezam on his Doctor of Philosophy thesis entitled "Channel Modelling and Estimation in Multiple-input Multiple-output Orthogonal Frequency Division Multiplexing Wireless Communication Systems" 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 Doctor of Philosophy.

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

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Date: 19 December 2008

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.

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MOHAMMED ABDO SAEED HEZAM

Date: 14/01/2008

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LIST OF ABBREVIATIONS/ NOTATIONS

Abbreviations

1-D	One-dimensional
1G	First Generation
2-D	Two-dimensional
2G	Second Generation
3-D	Three-dimensional
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
AA	Azimuthal Angle
A/D	Analog-to-Digital Converter
ACF	Autocorrelation Function
ADSL	Asymmetric Digital Subscriber Line
AoA	Angle-of-Arrival
AoD	Angle-of-Departure
APS	Angular Power Spectrum
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BLAST	Bell Labs Layered Space-Time
BPSK	Binary Phase Shift Keying
BS	Base Station
BW	Bandwidth
CFR	Channel Frequency Response
CIR	Channel Impulse Response

CLA	Circular Linear Array
COST	European forum for CO-operative Scientific Research
CP	Cyclic Prefix
CSI	Channel State Information
D/A	Digital-to-Analog
DAB	Digital Audio Broadcast
dB	deciBel
DD	Decision-Directed
DDCE	Decision-Directed Channel Estimation
DFT	Discrete Fourier Transform
DMT	Discrete Multi-Tone
DoA	Direction-of-Arrival
DoD	Direction-of-Departure
DPSK	Differential PSK
DSL	Digital subscriber Line
DVB	Digital Video Broadcast
DVB-H	Digital Video Broadcasting – Hand-held
DVB-T	Digital Video Broadcast - Terrestrial
EA	Elevation Angle
ETSI	European Telecommunication Standardization Institute
EVD	Eigenvalue Decomposition
EW-RLS	Exponentially Weighted Recursive Least Squares
FD	Frequency Domain
FDM	Frequency Division Multiplexing
FFT	Fast Fourier Transform

FIR	Finite Impulse Response
GBSB	Geometrically Based Single-Bounce
GBSBEM	Geometrically Based Single-Bounce Elliptical Model
GI	Guard Interval
GSCM	Geometry-based Stochastic Channel Model
HDSL	High-bit-rate DSL
HIPERLAN/2	High Performance Local Area Network type 2
HIPERMAN	High Performance Metropolitan Area Network
i.i.d.	independent identically distributed
IBO	Input Back-Off
ICI	Intercarrier Interference
IDFT	Inverse Fourier Transform
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IQ	In-phase and Quadrature-phase
ISI	Intersymbol Interference
LAN	Local Area Network
LMMSE	Linear Minimum Mean Square Error
LMS	Least Mean Squares
LoS	Line-of-Sight
LS	Least Squares
MCM	Multi-Carrier Modulation
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output
ML	Maximum Likelihood

MMAC	Multimedia Mobile Access Communications
MMSE	Minimum Mean Square Error
MS	Mobile Station
MSE	Mean-Square Error
MSI	Multistream Interference
NLMS	Normalized least Mean square
NLoS	Non-Line-of-Sight
OFDM	Orthogonal Frequency Division Multiplexing
OOB	Out-of-Band
P/S	Parallel-to-Serial
PAN	Personal Area Network
PAPR	Peak-to-average power Ratio
PAS	Power Azimuth Spectra
PDF	Probability Density Function
PDP	Power-Delay Profile
PN	Pseudo-Noise
PSD	Power Spectral Density
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature PSK
RF	Radio Frequency
RLS	Recursive Least Squares
RT	Ray-Tracing
Rx	Receiver
S/P	Serial-to-Parallel

SATURN	Smart card And Terminal User Requirements and Needs
SCM	Spatial Channel Model
SIMO	Single-Input Multiple-Output
SISO	Single-Input Single-Output
SNR	Signal-to-Noise Ratio
STBC	Space-Time Block Coding
STTC	Space-Time Trellis Coding
S-V	Saleh-Valenzuela
SVD	Singular Value Decomposition
TD	Time-Domain
ToA	Time-of-Arrival
Tx	Transmitter
ULA	Uniform Linear Array
URA	Uniform Rectangular Array
VHDSL	Very High Speed DSL
WiBro	Wireless Broadband
WiMAX	Worldwide Interoperability for Microwave Access
WINNER	Wireless World Initiative New Radio
WLAN	Wireless Local Area Network
WSS	Wide-Sense Stationary
ZF	Zero-Forcing
ZMCSCG	Zero-Mean Circularly-Symmetric Complex Gaussian

Notations and Symbols

Symbols with bold face represent either vectors or matrices as it is stated. The symbols with regular font are used for scalar quantities.

$(.)^T$	complex transpose
$\mathbf{a}^*$	complex conjugate of vector $\mathbf{a}$
$(.)^H$	complex transpose and conjugate (Hermitian)
$*$	convolution product
$\otimes$	Kronecker product
$\odot$	element-wise Schur-Hadamard multiplication operator
$(.)^+$	Moore-Penrose inverse
$\Vert . \Vert$	Euclidean norm
$\mathbf{A}^{-1}$	inverse of matrix $\mathbf{A}$
$\mathbf{A}^{-T}$	inverse transpose of matrix $\mathbf{A}$
$\mathbf{I}_N$	$N \times N$ identity matrix
det ($\mathbf{A}$)	determinant of matrix $\mathbf{A}$
$\mathrm{Re}\{\mathrm{a}\}$	real part of complex scalar a
$\mathrm{Im}\{\mathrm{a}\}$	imaginary part of complex scalar a
$Rank(\mathbf{A})$	rank of matrix $\mathbf{A}$
diag (.)	diagonal matrix of the argument vector
$vec\{\mathbf{H}\}$	stacks columns of the matrix $\mathbf{H}$ on top of each other
$unvec\{.\}$	inverse of $vec\{.\}$ operation
$tr(.)$	trace of the argument matrix
$E\{.\}$	expectation operator

$\delta(.)$	dirac delta function
min	minimum
max	maximum
arg max	maximizing argument
lim	limit
e	exponential function
$\hat{a}$	estimate of a
$I(\mathbf{x};\mathbf{y})$	mutual information between vector $\mathbf{x}$ and vector $\mathbf{y}$
$p(\mathbf{x})$	probability distribution function of the vector $\mathbf{x}$
$H(\mathbf{w})$	differential entropy of the vector $\mathbf{w}$
$\mathbf{R}_{\mathbf{xx}}$	covariance matrix of the vector $\mathbf{x}$
$\lvert\mathbf{a}\rvert$	magnitude of the complex vector $\mathbf{a}$
$J_0(.)$	*0*th order Bessel function of the first kind