An Improved Channel Estimation Approach for MIMO-OFDM Systems

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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List of Abbreviations

ADC (A/D)	Analog to digital converter
ADSL	Asymmetric digital subscriber line
AIC	Akaike Information Criterion
ANSI	American National Standards Institute
AWGN	Additive white Gaussian noise
BER	Bit-error rate
BLAST	Bell Laboratories space-time
bps	Bits per second
BPSK	Binary phase-shift keying
BWA	Broadband wireless access
CC	Convolutional coding
CME	Conditional Model order Estimation
CP	Cyclic prefix
CSI	Channel state information
CSIT	Transmitter channel state information
DAC (D/A)	Digital to analog converter
dB	Decibels
DFE	Decision feedback equalisation
DFT	Discrete Fourier Transform
DMT	Discrete multi-tone systems
DSL	Digital subscriber line
DSP	Digital Signal Processing
ETSI	European Telecommunication Standard Institute
FDE	Frequency domain equalisation
FEC	Forward error control
FER	Frame-error rate
FFT	Fast Fourier Transform
flops	floating-point operations
FPE	Final Prediction Error
FPGA	Field Programmable Gate Array
GSM	Global system for mobile communications, a second-generation mobile communication standard
HDSL	High-bit-rate Digital Subscriber Line
IEEE	Institute of Electrical and Electronic Engineering
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
ISI	Intersymbol interference
LMS	Least mean-squares
LOS	line-of-sight
LS	Least Squares
LST	Layered space-time code
MDL	Minimum Description Length
MIMO	Multiple-input multiple-output

MISO	Multiple-input single-output
ML	Maximum likelihood
MLSE	Maximum likelihood sequence estimation
MMSE	Minimum mean-square error
MRC	Maximum radio combine
MU	Multi-user
NLOS	non-line-of-sight
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiple access
OSTBC	Orthogonal space-time block codes
PDA	Probabilistic Data Association
PDF	Probability Density Function
PER	Packet error rate
PMPR	Peak to mean power ratio
PRBS	Pseudo Random Binary Sequence
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase-shift keying
QSTBC	Quasi-orthogonal STBC
RF	Radio frequency
RLS	Recursive least squares
RMS	Root mean square
RS	Reed-Solomon
SC	Single carrier
SER	Symbol to error rate
SIMO	Single-input multiple-output
SISO	Single-input single-output
SNR	Signal-to-noise ratio
SM	Spatial multiplexing
ST	Space-time
STBC	Space-time block code
STC	Space-time coding/space-time code
STTC	Space-time trellis code
SU	Single user
SUI	Stanford University Interim
3GPP	The third Group Partnership project
UMTS	Universal mobile telecommunications system
V-BLAST	Vertical BLAST
VDSL	Very-high-rate Digital Subscriber Line
WCDMA	Wideband code division multiple access
WiMAX	Worldwide Interoperability for Microwave Access, IEEE 802.16 standard
Wi-Fi	Wireless fidelity
WLAN	Wireless local area network
ZF	Zero Forcing

List of Mathematical Terms

f_c	carrier frequency
f_d	Doppler frequency
Δf	spacing between subcarriers
$\mathbf{F}$	FFT matrix
Fs	OFDM sampling frequency
G	guard interval
$\boldsymbol{h}$	channel impulse response
$\mathbf{H}$	channel frequency response
$\mathbf{I}$	identity matrix
Ip	pilot position
K	number of subcarriers
L	number of multi channel paths (number of arrival, tap length)
$\hat{l}$	the estimated number of channel paths
Nt	number of transmit antennas
Nr	number of receive antennas
P	number of pilot symbols
$\boldsymbol{s}$	transmitted space-time coded OFDM sequences
Tb	Useful Symbol Time
Tg	CP Time
$\boldsymbol{Ts}$	time duration of one OFDM symbol
v	vehicle speed
$\boldsymbol{y}$	received OFDM sequences
σ^2	noise variance
ε	transmitted power per symbol
τ	delay
$\mathbf{w}$	AWGN in time domain
Γ	gamma, $\Gamma(n+1)=n!$
$\mathbf{\Lambda}$	diagonal matrix
$\boldsymbol{D}(x)$	diagonal matrix with x in its diagonal
$[\,]^H$	Hermitian transpose
$[\,]^T$	transpose of a matrix

Abstract

In wireless environments, signals bounce off many obstacles such as mountains, buildings, trees, etc. as they propagate between transmitters and receivers. The resultant signal at the receive antenna is, therefore, often the sum of the attenuated transmitted signal and one or more delayed versions of the transmitted signal. The received signal also suffers from intersymbol interference which degrades the quality of signal to a certain extent.

However, MIMO-OFDM systems are designed to take advantage of the multi-path properties in wireless communications and are capable of improving transmission rate, range and reliability simultaneously. MIMO-OFDM attracts a good deal of research and commercial interest because of the perceived benefits, and has been adopted in many wireless standards such as IEEE 802.11n, IEEE 802.16e. Such systems are also potential candidates for fourth-generation (4G) systems. However, practical problems still exist in implementing MIMO-OFDM, for example, in the estimation of channel state information (CSI). This thesis studies the issues of MIMO, OFDM and the relevant techniques of MIMO-OFDM, and focuses on proposing a practical, low complexity and accurate channel estimation method for such systems.

In a MIMO-OFDM system, CSI is required at the receiver to perform space-time decoding or diversity combining. In many practical wireless applications, the propagation environment is both complex and time-variant, leading to CSI estimation errors and overall system performance degradation. A variety of channel estimation approaches have been proposed in the literature to address this problem. One of the most important parameters of CSI is the number of significant or dominant propagation paths, also referred to as the number of channel taps. However, in most existing estimation schemes for MIMO-OFDM, there is an assumption that the number of channel taps is known at the receiver. In reality, in order to perform space-time decoding, the receiver needs to estimate the number of channel taps from the received signal with this estimation process sometimes aided by the insertion of pilot tones into the transmitted signal.

In this thesis, a pilot-assisted, conditional model-order estimation (CME) based channel estimation algorithm is presented. The approach can be utilised to detect both the number of channel resolvable paths and channel gains for MIMO-OFDM systems. The performance of the proposed algorithm is compared with the commonly used minimum description length (MDL) algorithm by mean of simulation in the context of a 2×2 MIMO-OFDM system. Results indicate that the new algorithm is superior to the MDL algorithm in channel order estimation over an unknown, noisy, multipah fading channel with limited pilot assistance. Furthermore, the proposed scheme is tested in both fixed and mobile broadband MIMO-OFDM systems based on WiMAX techniques in Matlab simulation, and its capacity is verified again for those near practical broadband MIMO-OFDM systems in the absence of prior knowledge of model parameters.

Finally, with the purpose to "make the thing work in practice", a 2×2 MIMO baseband platform is built in order to demonstrate the proposed scheme. The platform consists of two DSP based, real-time development boards called SignalWAVe, produced by Lyrtech. Given the existing hardware components, the whole platform is built based on a fixed MIMO-OFDM system according to WiMAX standard, and the results demonstrate that the proposed algorithm is a valid approach in practice.