Ain Shams University
Faculty of Engineering
Electronics and Communications Department

Impairments in Multicarrier Communication Systems Influence and Mitigation

A Thesis
Submitted in partial fulfillment for the requirements
of Master of Science degree in Electrical Engineering
(Electronics and Communications Engineering)

Submitted by:

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B.Sc. of Electrical Engineering
(Electrical and Communications Department)
El Shrouk Acadamy, 2006.

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Statements

This thesis is submitted to Ain Shams University in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering (Electronics and Communications Engineering).

The work included in this thesis was carried out by the author at the department of Electronics and Communications Engineering, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or qualifications at any other university or institution.

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Abstract

One of the main challenging issues in wireless system implementation is the imbalance between the In-phase (I) and Quadrature-phase (Q) branches, which can be present at both the transmitter (Tx) and receiver (Rx). These imbalance is associated with analog processing due to component imperfections, which are neither predictable nor controllable, and tend to increase as the fabrication technologies scale down. In particular, IQ imbalance can be categorized into frequency flat and frequency selective. The former is generally induced by an imperfectly balanced local oscillator (LO) which cannot produce equal amplitudes and an exact 90 phase shift between the I and Q branches. The latter is primarily caused by imperfections in other analog components, such as analog filters, amplifiers, and digital-to-analog (D/A) or analog-to-digital (A/D) converters.

Orthogonal frequency division multiplexing (OFDM) has received intense interest from the research community during the past few decades. Its robustness to frequency selective channels has made it one of the main candidates for high data rate transmission for current and next-generation wireless applications. In order to make OFDM more reliable, several transmitter and receiver diversity techniques utilizing space-time or space-frequency codes can be used. Alamouti-based space time coding is one of the most effective transmitter diversity techniques and when combined with OFDM, it enhances the system performance. However, OFDM, like any other digital communication systems, requires reliable IQ estimation and compensation schemes. Unfortunately, due to the narrow spacing and spectral overlap between the subcarriers, OFDM systems are much more sensitive to the IQ mismatch than single carrier systems. It leads to a loss of subcarrier orthogonality. This loss introduces intercarrier interference (ICI) which results in a degradation of the global system performance. Furthermore, higher order modulation is more vulnerable to IQ imbalance than lower order modulation. Additionally, the channel impulse response (CIR) must be known to coherently detect the transmitted data. Several IQ estimation and compensation algorithms considering either only a receiver IQ imbalance or a transmitter IQ imbalance individually have been developed.

In this thesis, we study two sources I/Q imbalance in the transmitter and the receiver. In addition, combine the effects of IQ coefficients for both the transmitter and receiver with the CIR into one parameter refereed as the overall CIR. Based on few pilots, the Maximum Likelihood (ML) principle is then used to estimate the overall CIR. By using the expectation maximization (EM) algorithm, the soft information resulting from the detector can be iteratively exploited to improve the estimation process. To reduce the complexity of the proposed algorithm, a sub-optimal estimation scheme is also introduced. Furthermore, the problem of IQ imbalance is investigated and treated for Alamouti Coded OFDM Systems, and introduces an expectation maximization (EM) algorithm for jointly estimating the channel impulse response and frequency selective IQ imbalance in transmitter and receiver. Computer simulations confirm that the proposed estimation schemes are able to mitigate the effects of IQ, the multipath channel, and achieve additional diversity gain. In order to make the EM algorithm suitable for more practical cases, we also obtain a sub-optimal algorithm to reduce the complexity and keeping almost the same performance.

Key words– IQ imbalance, OFDM, Alamouti-code, diversity gain, ML and EM algorithms.

Glossary

Acronyms

ADC	Analog to Digital Converter
AL-STBC	Alamouti Space Time Block Code
ALOFDM	Alamouti Coded OFDM
AWGN	AdditiveWhite Gaussian Noise
BER	Bit Error Rate
BICM-ID	Bit Interleaved Coded Modulation Iterative Decoding
CFO	Carrier Frequency Offset
CIR	Channel Impulse Response
CP	Cyclic Prefix
DA	Data Aided
DFT	Discrete Fourier Transform
DSP	Digital Signal Processing
EM	Expectation Maximization
FFT	Fast Fourier Transform
flops	Floating point operations
GHz	Giga Hertz
GPS	Global Positioning System

GSM	Global System for Mobile
IC	Integrated Circuit
ICI	Inter Carrier Interference
IDFT	Inverse Discrete Fourier Transform
IFFT	Inverse Fast Fourier Transform
IQ	In-phase and Quadrature-phase
ISI	Inter Symbol Interference
LO	Local Oscillator
LTE	Long Term Evolution
MA	Multi Antenna
MC	Multi-Carrier
MHz	Mega Hertz
MIMO	Multi Input Multi Output
MISO	Multi Input Singel Output
ML	Maximum Likelihood
MSE	Mean Square Error
OFDM	Orthogonal Frequency Division Multiplexing
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
Rx	Receiver
SISO	Single Input Single Output
STBCs	Space Time Block Codes
Tx	Transmitter
UMTS	Universal Mobile Telecommunications System

WIMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Networks

Symbols and Notations

$[.]^T$	the matrix transpose
χ	the number of iterations
$\delta(t)$	the Dirac delta function which equals infinity at t = 0 and zero otherwise
$\hat{\mathbf{P}}$	the estimated channel matrix
$\mathbf{h}_{eq}$	the overall CIR
$\mathbf{u}_i^{(f)}$	the data block u from the f th antenna at block instant i
$\mathbf{w}$	the noise vector contribution
$\mathrm{E}[x]$	the mean of random variable x
ν	the cyclic prefix length
$\otimes$	the circular convolution
ϕ_{rx}	the phase imbalance parameter at the receiver
ϕ_{tx}	the phase imbalance parameter at the transmitter
$\sigma_l(t)$	the attenuation of the lth channel path at instant t
σ_n^2	the additive white Gaussion noise (AWGN) variance
$\tau_l(t)$	the propagation delay of the lth channel path at instant t
τ_{max}	the channel maximum delay spread
ε_{rx}	the gain imalance parameters at the receiver
ε_{tx}	the gain imalance parameters at the transmitter
$\widetilde{x}$	the trial value of x
B_c	the channel coherence bandwidth

$d_i\,(k)$	the data symbol modulating the kth sub-carrier in the ith data block
$h(t,\tau)$	the complex impulse response of a time variant multi-path channel
$H_I(f)$	the filter transfer function in in-phaes path
$H_i(k)$	the discrete-time channel response at the kth tone for the ith OFDM block
$H_Q(f)$	the filter transfer function inquadrature path
L	the channel length
L_f	length of LPFs
M	the received frame length
m_d	the modulation order
M_p	pilot blocks length
M_s	data blocks length
N	number of slower rate parallel channels
$n_i(k)$	the kth FFT output of AWGN for the ith OFDM block
$n_i(l)$	the lth sample of AWGN for the ith OFDM block
$r(n)$	the complex-valued received signal
$s'(n)$	the distorted signal
s_c	the last time-domain sample in the transmitted frame
S_I	the signal in in-phase path
$s_i\,(n)$	the discrete-time channel response at the kth tone for the ith OFDM block
S_Q	the signal in quadrature path
T_c	the channel coherence time
$W_i(k)$	the noise contribution

W_s	the transmitted signal bandwidth
x^*	the complex conjugate of x
$x_{RF}(t)$	the signal at Radio frequency

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