

Contents

1. Introduction	11
1.1 Overview and Contributions	12
1.2 Notations	14
2. Signal Processing for Communications	17
2.1 Introduction	17
2.2 System Model	18
2.2.1 Baseband modeling of wireless communication systems	18
2.2.2 Block based transmission over multipath channel	20
2.2.3 OFDM based transmission over multipath channel	21
2.2.4 Generic system model and its interpretations	23
2.2.5 Transmitter receiver block diagram	25
2.3 Channel Precoding	26
2.3.1 Precoding under perfect CSI	27
2.3.2 Precoding in absence of CSI	27
2.3.3 Precoding under partial CSI	28
2.4 Channel Equalization	29
2.4.1 Detection without exploitation of the coding structure	29
2.4.2 Detection with exploitation of the coding structure	31
2.5 Channel Estimation	31
2.5.1 Pilot-assisted channel estimation	32
2.5.2 Blind channel estimation	33
2.5.3 Adaptive channel estimation and tracking	33
2.6 Robust Designs under Partial Knowledge	34
2.7 Conclusion	35
3. Robustness in Optimization under Uncertainty	37
3.1 Robustness – What it means?	37
3.2 Optimization under Uncertainty	39
3.3 Frameworks for Optimization under Uncertainty	41
3.3.1 Stochastic framework	42
3.3.2 Deterministic framework	43
3.3.3 Links between the stochastic and deterministic frameworks	45
3.4 Comparison of the Stochastic and Deterministic Frameworks	46
3.4.1 Design philosophy	46
3.4.2 Knowledge about uncertainty	47
3.4.3 Performance guarantee	47

3.4.4	Conservativeness of minimax solutions	48
3.4.5	Computational complexity	48
3.5	Deterministic Framework – Minimax Optimization	49
3.5.1	Preliminaries	50
3.5.2	Minimax inequality	51
3.5.3	Minimax theorem, Saddle point theorem	53
3.5.4	Implications of minimax equality on minimax robustness	54
3.6	Conclusion	56
4.	Minimax Robust Precoder Design under Imperfect CSI	57
4.1	Introduction	57
4.2	Precoder Design under Imperfect CSI	58
4.2.1	Related work and our contributions	59
4.2.2	System model and objective function	60
4.3	Maximin Robust Power Allocation (MRPA)	62
4.3.1	Problem formulation	63
4.3.2	Proposed MRPA – Optimization with unbiasedness constraint	64
4.3.3	Conventional MRPA – Optimization without unbiasedness constraint	67
4.4	Discussion and Insights	68
4.4.1	Worst-case unbiased uncertainty for a given power allocation	68
4.4.2	An intuitive analysis of the problem at hand	69
4.4.3	Uncertainty threshold and its relationship with probabilistic guarantees	70
4.4.4	Evolution of robust power allocation as a function of uncertainty level	71
4.5	Simulation Results	71
4.5.1	Worst-case SNR performance	72
4.5.2	Coded BER performance	73
4.6	Conclusion	77
5.	Minimax Robust Equalizer Design under Imperfect CSI	79
5.1	Introduction	79
5.2	Conventional Equalizer Design	80
5.2.1	System model	81
5.2.2	Linear a-priori information aware equalizer	82
5.2.3	Design requirements – Motivation for robust designs	83
5.3	Minimax Robust A-priori Information Aware Equalizer Design	83
5.3.1	Related work and our contributions	84
5.3.2	Problem formulation	84
5.3.3	Robust equalizer design for KL divergence based uncertainty class	87
5.3.4	Robust equalizer design for norm based uncertainty class	94
5.4	Discussion, Insights, and Extensions	97
5.4.1	Comparison between the uncertainty classes and associated designs	97
5.4.2	Worst-case uncertainty for an arbitrary equalizer	98
5.4.3	Uncertainty threshold and its relationship with probabilistic guarantees	99

5.4.4	Minimax robust turbo equalization	101
5.4.5	Evolution of robust equalizer as a function of uncertainty level	103
5.5	Simulation Results	104
5.5.1	Analysis as a standalone entity	105
5.5.2	Analysis in iterative detection setup	108
5.6	Conclusion	111
6.	Minimax Robust Channel Estimator Design under Partial Corr. Knowledge	113
6.1	Introduction	113
6.2	Pilot-Assisted MMSE Channel Estimator	114
6.2.1	System model	115
6.2.2	Problem formulation and solution	117
6.2.3	Design requirements – Knowledge of channel correlation function	119
6.3	Conventional Estimator Design under Partial Correlation Knowledge	121
6.4	Proposed Estimator Design under Partial Correlation Knowledge	123
6.4.1	Design approach	123
6.4.2	Characterizing the uncertainty class of correlation spectrum	124
6.4.3	Minimax problem formulation and solution	127
6.5	Discussion, Insights, and Extensions	130
6.5.1	Novel aspects	130
6.5.2	Computational complexity	131
6.5.3	Optimization criteria	131
6.5.4	Edge effects in finite dimensional pilot grids	131
6.5.5	Arbitrary pilot grid structures	133
6.5.6	Shape of the least favorable correlation spectrum	134
6.6	Simulation Results	136
6.6.1	MSE results	137
6.6.2	BER results	140
6.6.3	Staggered grid BER results	141
6.7	Conclusion	144
7.	Conclusion	147
A.	Complex Differentiation	153
A.1	Complex derivatives	153
A.2	Wirtinger calculus and its differentiation rules	154
A.3	Gateaux derivatives	156
B.	Optimization Fundamentals	157
B.1	Lagrangian duality	157
C.	List of Acronyms	159
	Bibliography	163