

Lin Bai · Jinho Choi

Low Complexity MIMO Detection

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To our families and friends

Foreword

What is the most important emerging technology leading to high data rate wireless services? With scarce wireless spectrum, the use of multiple antennas is becoming the key foundation to achieve the requirement. My colleagues, Prof. Bai and Prof. Choi have worked on this topic for many years. They have made good achievements and published a number of papers within this topic. In this book, they share their key findings.

With signal detection methods now representing a key application of signal processing methods to communication systems, this book provides a range of important techniques for signal detection when multiple transmitted and received signals are available. In this book, various optimal and suboptimal signal detection methods are explained in the context of multiple-input multiple-output (MIMO) systems, including list decoding and lattice reduction (LR)-aided detection, while various user selection schemes are also discussed within multiuser systems. Those techniques are then analyzed using performance analysis tools.

With a carefully balanced blend of theoretical elements and applications, this book is ideal for both graduate students and practicing engineers in wireless communications. All the techniques introduced in this book are quite new. Furthermore, this book makes an easy-to-follow presentation from the elementary to the profound level.

Beijing

Quan Yu
Academician
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Preface

In order to improve the spectral efficiency in wireless communications, multiple antennas are employed at both transmitter and receiver sides, where the resulting system is referred to as the multiple-input multiple-output (MIMO) system. In MIMO systems, it is usually required to detect signals jointly as multiple signals are transmitted through multiple signal paths between the transmitter and the receiver. This joint detection becomes the MIMO detection.

The MIMO detection can be performed by an exhaustive search method for the maximum likelihood (ML) detection. Unfortunately, although this method provides the optimal performance, it is impractical for a number of real systems since its complexity grows exponentially with the number of transmit antennas. For the case of MIMO channels in cellular systems where the transmitter is a base station and the receiver is a mobile terminal, since the receiver usually has a limited computing power for symbol detection, the use of ML detection based on an exhaustive search or those with high computational complexity becomes impossible. To avoid this prohibitively high computational complexity, computationally efficient suboptimal MIMO detection methods are investigated, including linear detectors that take the signals from the other antennas as the interference; but, poor performance is expected due to a high data error rate. Therefore, it is desired to develop MIMO detection methods that have near optimal performance as well as low computational complexity. In this book, we attempt to explain such low complexity MIMO detectors.

So far, there are many existing books related to MIMO systems. To be different from those books, our book focuses on low complexity MIMO symbol detection itself. Although our book is very specific, we have adopted an easy-to-follow presentation from the elementary to the profound level. Furthermore, we include a number of recent research outcomes that are also useful for those experts in this area.

Our group has worked on the design of low complexity MIMO detection for many years and has produced various new results on low complexity MIMO detection with the ideas of list decoding and lattice basis reduction. In addition, as an extension, multiuser MIMO and the corresponding strategies are also investigated. This book includes not only our research outcomes but also other recent research

outcomes that could be very useful to practitioners and postgraduate students who want to learn new outcomes of low complexity MIMO detectors in the field of wireless communications.

This book systematically introduces the signal detection in MIMO systems. It has been written for the reader who wants to become an expert from a beginner in the field of MIMO detection. In addition, it is suitable for postgraduate students who have some fundamental knowledge of wireless communications, and for R&D personnel who works in MIMO area.

Beijing
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Lin Bai
Jinho Choi

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Contents

1	Introduction	1
1.1	MIMO Systems	1
1.2	Point to Point MIMO	4
1.3	Multuser MIMO	8
1.4	Outline	10
Part I Point to Point MIMO		
2	Background of MIMO Detection	15
2.1	System Model	15
2.2	ML Detection	16
2.2.1	Exhaustive Search Approach	16
2.2.2	Performance Analysis	17
2.3	Linear Detection	20
2.3.1	ZF Detection	20
2.3.2	MMSE Detection	21
2.3.3	Performance Analysis	22
2.4	SIC Detection	23
2.4.1	QR Factorization	24
2.4.2	ZF-SIC	24
2.4.3	MMSE-SIC	28
2.4.4	Ordering	29
2.4.5	Performance Analysis	31
2.5	BER Versus SNR Simulation Results	36
2.6	Conclusion and Remarks	42
3	List and Lattice Reduction-Based Methods	43
3.1	List-Based Detection	43
3.1.1	Detection Algorithms	43
3.1.2	Ordering	46
3.1.3	Subdetectors	48

3.1.4	Performance Analysis	52
3.1.5	Simulation Results	54
3.2	Lattice Reduction-Based Detection	56
3.2.1	MIMO Systems with Lattice	56
3.2.2	Lattice Reduction-Based MIMO Detection	58
3.2.3	Lattice Reduction Schemes for Two Basis Systems	64
3.2.4	Gaussian Lattice Reduction for Two Basis Systems	69
3.2.5	LLL and CLLL Algorithms	74
3.2.6	Performance Evaluation	79
3.2.7	Simulation Results	86
3.3	Conclusion and Remarks	90
4	Partial MAP-Based Detection	91
4.1	MAP Detection	91
4.2	Partial MAP Detection	92
4.2.1	The Case of 2×2 MIMO	92
4.2.2	General Case	93
4.2.3	Theoretical Analysis	97
4.3	Partial MAP-Based List Detection	99
4.3.1	System Model	100
4.3.2	The Case of List Length $Q = 1$	101
4.3.3	General Case	103
4.3.4	Algorithm of the Partial MAP-Based List Detection	107
4.3.5	Simulation Results	110
4.4	Conclusion and Remarks	112
5	Lattice Reduction-Based List Detection	113
5.1	Lattice Reduction-Based List Detection	114
5.1.1	Algorithm Description	114
5.1.2	Lattice Reduction-Based Detection	116
5.1.3	List Generation in the LR Domain	117
5.1.4	Impact of List Length	118
5.1.5	Complexity Analysis	122
5.1.6	Components of the LR-Based List Detection	122
5.1.7	Simulation Results	130
5.2	Error Probability-Based Column Reordering Criteria	131
5.2.1	System Model with CRIS	133
5.2.2	Detection Algorithm with CRIS	134
5.2.3	OD-CRC	135
5.2.4	EP-CRC	136
5.2.5	Simulation Results	137
5.3	Conclusion and Remarks	139
6	Detection for Underdetermined MIMO Systems	141
6.1	Joint Detection for Underdetermined MIMO Systems	143
6.1.1	System Model	143

6.1.2	Existing Approaches	144
6.1.3	Prevoting Cancellation-Based MIMO Detection	146
6.2	Selection for Prevoting Vectors Depending on SubDetectors	147
6.2.1	Selection Criterion with Linear Detector	148
6.2.2	Selection Criteria with LR-Based Linear and SIC Detectors	148
6.3	Performance Analysis	150
6.3.1	Diversity Analysis	150
6.3.2	Complexity Analysis	157
6.4	Simulation Results and Discussions	158
6.4.1	Simulation Results	158
6.4.2	Discussion	161
6.5	Conclusion and Remarks	165
Part II Multiuser MIMO		
7	Selection Criteria of Single User	169
7.1	System Model	169
7.2	User Selection Criteria	170
7.2.1	Maximum Mutual Information Criterion	171
7.2.2	User Selection Criteria for ML Detector	172
7.2.3	User Selection Criterion for Linear Detectors	175
7.2.4	User Selection Criteria for LR-Based Detectors	177
7.3	Simulation Results	181
7.4	Conclusion and Remarks	183
8	Selection Criteria of Multiple Users	185
8.1	System Model	187
8.2	User Selection Criteria	189
8.2.1	ML and Linear Selection Criteria	190
8.2.2	LR-Based Linear and SIC Selection Criteria	191
8.3	LR-Based Greedy User Selection Using an Updating Method	193
8.3.1	LR-Based Greedy User Selection	193
8.3.2	A Complexity Efficient Method for LR Updating	197
8.4	Diversity Analysis and Numerical Results	203
8.4.1	Diversity Gain Analysis from Error Probability	204
8.4.2	Numerical Results	210
8.5	Conclusion and Remarks	215
9	Conclusion of the Book	217
References		219
About the Authors		225
Index		227

List of Figures

Fig. 1.1	A SISO system	2
Fig. 1.2	A 2×2 MIMO system.....	2
Fig. 1.3	Signal constellations and binary codes.....	4
Fig. 1.4	MIMO detection	6
Fig. 1.5	A multiuser MIMO system	9
Fig. 2.1	BER performance of ZF-SIC for each layer in a 4×4 MIMO system, where BPSK is used for signaling	35
Fig. 2.2	BER performance of conventional detectors in a 4-QAM 2×2 MIMO system	39
Fig. 2.3	BER performance of conventional detectors in a 16-QAM 2×2 MIMO system	39
Fig. 2.4	BER performance of conventional detectors in a 64-QAM 2×2 MIMO system	40
Fig. 2.5	BER performance of conventional detectors in a 4-QAM 4×4 MIMO system	40
Fig. 2.6	BER performance of conventional detectors in a 16-QAM 4×4 MIMO system	41
Fig. 2.7	BER performance of conventional detectors in a 64-QAM 4×4 MIMO system	41
Fig. 3.1	BER performance of different detectors in a 16-QAM 2×2 MIMO system	54
Fig. 3.2	BER performance of different detectors in a 16-QAM 4×4 MIMO system	55
Fig. 3.3	BER performance of list-based detectors using different types of subdetectors in a 16-QAM 4×4 MIMO system.....	55
Fig. 3.4	The decision boundaries of ZF detection with a lattice generated by the basis \mathbf{H} in (3.53)	60
Fig. 3.5	The decision boundaries of ZF detection with a lattice generated by the basis \mathbf{G} in (3.54)	61

Fig. 3.6	BER performance of various detectors in a 4-QAM 2×2 MIMO system	87
Fig. 3.7	BER performance of various detectors in a 16-QAM 2×2 MIMO system	87
Fig. 3.8	BER performance of various detectors in a 64-QAM 2×2 MIMO system	88
Fig. 3.9	BER performance of various detectors in a 4-QAM 4×4 MIMO system	88
Fig. 3.10	BER performance of various detectors in a 16-QAM 4×4 MIMO system	89
Fig. 3.11	BER performance of various detectors in a 64-QAM 4×4 MIMO system	89
Fig. 4.1	The lower bound of P_{cond}	98
Fig. 4.2	Bounds of P_{cond} for different list length with $N_1 = 2$	106
Fig. 4.3	Bounds of P_{cond} for different list length with $N_1 = 4$	107
Fig. 4.4	BER performance of various detection methods in Table 4.1 for a 16-QAM 2×2 system	110
Fig. 4.5	BER performance of various detection methods in Table 4.1 for a 16-QAM 4×4 system	111
Fig. 5.1	BER versus E_b/N_o of different MIMO detectors in a 4×4 MIMO system ($N_1 = N_2 = 2$) with 4-QAM signaling ...	131
Fig. 5.2	BER versus E_b/N_o of different MIMO detectors in a 4×4 MIMO system ($N_1 = N_2 = 2$) with 16-QAM signaling	132
Fig. 5.3	BER versus E_b/N_o of different MIMO detectors in a 4×4 MIMO system ($N_1 = N_2 = 2$) with 64-QAM signaling .	133
Fig. 5.4	BER versus E_b/N_o of different MIMO detectors in a 4×4 MIMO system ($N_1 = N_2 = 2$) with 4-QAM signaling	138
Fig. 5.5	BER versus E_b/N_o of different MIMO detectors in a 4×4 MIMO system ($N_1 = N_2 = 2$) with 16-QAM signaling	139
Fig. 5.6	BER versus E_b/N_o of different MIMO detectors in a 4×4 MIMO system ($N_1 = N_2 = 2$) with 64-QAM signaling .	140
Fig. 6.1	BER versus E_b/N_o of different detectors listed in Table 6.1 for 4-QAM, $M = 4$ and $N = 2$	160
Fig. 6.2	BER versus E_b/N_o of different detectors listed in Table 6.1 for 4-QAM, $M = 4$ and $N = 3$	161
Fig. 6.3	BER versus E_b/N_o of different detectors listed in Table 6.1 for 16-QAM, $M = 3$ and $N = 2$	162
Fig. 6.4	BER versus E_b/N_o of different detectors listed in Table 6.1 for 16-QAM, $M = 4$ and $N = 3$	163

Fig. 6.5	BER versus E_b/N_0 of Detector III and Detector XI listed in Table 6.1 for $v_e = \{0, 0.02, 0.05\}$ with 4-QAM, $M = 4$ and $N = 2$	164
Fig. 7.1	Block diagram for multiuser MIMO uplink channels of K users equipped per user with M transmit antennas and the BS equipped with N receive antennas	170
Fig. 7.2	BER performance of various multiuser MIMO systems with 4-QAM, $M = N = 4$, and $K = 10$	181
Fig. 7.3	BER performance of various multiuser MIMO systems with 16-QAM, $M = N = 4$, and $K = 10$	182
Fig. 7.4	BER performance of various multiuser MIMO systems with 64-QAM, $M = N = 4$, and $K = 10$	183
Fig. 8.1	Block diagram for multiuser MIMO uplink channels of $K = 10$ users equipped per user with P transmit antennas and the BS equipped with N receive antennas, while 4 users are selected to transmit signals to the BS during a time slot interval.....	188
Fig. 8.2	Block diagram of virtual antennas in a single user MIMO system, while 4 AS are selected among 10 AS to transmit signals to the BS during a time slot interval.....	189
Fig. 8.3	BER versus E_b/N_0 of the multiuser MIMO systems listed in Table 8.9 for the case of $(M, P) = (4, 1)$ and $(M, P) = (2, 2)$ (16-QAM, $K = 5$, $N = 4$)	212
Fig. 8.4	BER versus E_b/N_0 of the multiuser MIMO systems listed in Table 8.9 for the case of $(M, P) = (4, 1)$ (16-QAM, $K = 5$, $N = 4$).....	213
Fig. 8.5	BER versus E_b/N_0 of the multiuser MIMO systems listed in Table 8.9 for the case of $(M, P) = (2, 2)$ (16-QAM, $K = 5$, $N = 4$).....	214
Fig. 8.6	BER versus K of the multiuser MIMO systems listed in Table 8.9 for the case of $(M, P) = (4, 1)$ (16-QAM, $E_b/N_0 = 12$ dB, $N = 4$)	215
Fig. 8.7	BER versus K of the multiuser MIMO systems listed in Table 8.9 for the case of $(M, P) = (2, 2)$ (16-QAM, $E_b/N_0 = 12$ dB, $N = 4$).....	216

List of Tables

Table 1.1	Received signal vectors of a 2×2 MIMO system	5
Table 1.2	Received signal vectors of a 2 users multiuser MIMO system under a certain user selection strategy	11
Table 2.1	Candidate vectors of 2 transmit antennas with 4-QAM	16
Table 2.2	d_{ml} corresponding to \mathbf{s} in Table 2.1	20
Table 2.3	Detection errors at symbol and bit levels	36
Table 2.4	ML detection	37
Table 2.5	MMSE detection	38
Table 2.6	MMSE-SIC detection	38
Table 3.1	List generation	44
Table 3.2	The average value of column swapping per iteration when the CLLL is employed for different MIMO channels ($N = 8$ and $M = 2, 3, \dots, 8$)	86
Table 4.1	Different MIMO detection methods	109
Table 4.2	The average complexity of various detection methods in Table 4.1 for a 16-QAM 2×2 system	109
Table 4.3	The average complexity of various detection methods in Table 4.1 for a 16-QAM 4×4 system	109
Table 4.4	The average list length of the partial MAP-based list detection with different SNR for 16-QAM 2×2 and 4×4 MIMO systems, where $N_1 = N_2$	110
Table 5.1	Signal and parameters for the LR-based detection in (5.5) and (5.7)	117
Table 5.2	Complexity analysis of different detectors	122
Table 5.3	Components of the LR-based list detection	123
Table 5.4	Gram-Schmidt algorithm	124
Table 5.5	Householder reflection algorithm	125

Table 5.6	Complexity comparison of Gram–Schmidt algorithm and Householder reflection algorithm	125
Table 5.7	Gaussian LR algorithm	126
Table 5.8	L–R decomposition	127
Table 6.1	Different detection methods for underdetermined MIMO systems	159
Table 6.2	Complexity comparison of C_{Sel} for Detectors IX, X, and XI, listed in Table 6.1	163
Table 6.3	Complexity comparison of different detectors listed in Table 6.1	164
Table 8.1	Matrices with the LR at each user selection	196
Table 8.2	Size reduction in CLLL	198
Table 8.3	Column swapping in CLLL	199
Table 8.4	Basis updating in UBLR (Part I)	200
Table 8.5	Basis updating in UBLR (Part II)	201
Table 8.6	The UBLR (based on the CLLL) algorithm at the m th user selection	202
Table 8.7	The average value of η in a multiuser MIMO system when the CLLL-based MMSE-SIC detector is used with the LRG and UBLRG user selection, where $K = 10$, $N = 8$, and $(M, P) = (8, 1)$	202
Table 8.8	The average value of η in a multiuser MIMO system when the CLLL-based MMSE-SIC detector is used with the LRG and UBLRG user selection, where $K = 10$, $N = 8$, and $(M, P) = (4, 2)$	203
Table 8.9	Nine multiuser MIMO systems employed in the simulations	211
Table 8.10	The average complexity of multiuser MIMO systems listed in Subject. 8.4.2	211

Acronyms

APP	A posteriori probability
APRP	A priori probability
AWGN	Additive white Gaussian noise
AS	Antenna subset
BER	Bit error rate
BPSK	Binary phase shift keying
BS	Base station
cdf	Cumulative density function
CLLL	Complex-valued LLL
CMs	Complex multiplications
CRC	Column reordering criteria
CRIS	Column reordering index set
CSCG	Circular symmetric complex Gaussian
CSI	Channel state information
DFE	Decision feedback equalizer
DMT	Diversity multiplexing trade-off
DRC	Dimension reduction condition
EP-CRC	Error probability based CRC
flops	Floating point operation
GS	Gram–Schmidt
GSD	Generalized sphere decoding
ISI	Intersymbol interference
LAPPR	Logarithms of a posteriori probability ratios
LBR	Lattice basis reduced
LLL	Lenstra–Lenstra–Lovász
LLR	Log-likelihood ratio
LR	Lattice reduction
LRG	LR-based greedy
MAP	Maximum a posteriori probability
MD	Max–min diagonal term
MDist	Max–min distance

ME	Max–min eigenvalue
MIMO	Multiple-input multiple-output
ML	Maximum likelihood
MMI	Maximum mutual information
MMMSE	Min–max mean square error
MMSE	Minimum mean square error
MSE	Mean square error
OD-CRC	Orthogonality deficiency-based CRC
ODR	Optimal decision region
OFDM	Orthogonal frequency division multiplexing
PAM	Pulse amplitude modulation
pdf	Probability density function
PDR	Probability of dimension reduction
PEP	Pairwise error probability
PVC	Prevoting cancellation
PVS	Postvoting vector selection
QAM	Quadrature amplitude modulation
SDMA	Space division multiple access
SER	Symbol error rate
SIC	Successive interference cancellation
SINR	Signal to interference plus noise ratio
SISO	Single-input single-output
SNR	Signal-to-noise ratio
SSE	Sum of squared error
SVP	Shortest vector problem
TSD-CR	Tree search decoder-column reordering
UBLR	Updated basis LR
UBLRG	UBLR-based greedy
UILS	Underdetermined integer least squares
V-BLAST	Vertical Bell laboratories layered space–time
VLSI	Very large scale integration
ZF	Zero forcing

Notations

\mathbf{A}/\mathbf{a}	(Boldface upper/lower letters) complex-valued matrix/vector
$\mathbf{A}_r/\mathbf{a}_r$	(Boldface upper/lower letters) real-valued matrix/vector
$\mathbf{A}^T, \mathbf{A}^H, \mathbf{A}^\dagger$	Transpose, Hermitian transpose, Pseudo inverse, respectively
$[\mathbf{A}]_{p,q}$	The (p, q) th element of \mathbf{A}
$\mathbf{A}(a : b, c : d)$	The submatrix of \mathbf{A} with the elements obtained from rows a, \dots, b and columns c, \dots, d
$\mathbf{A}(:, n)$	The n th column vector of \mathbf{A}
$\mathbf{A}(n, :)$	The n th row vector of \mathbf{A}
$\text{Tr}(\mathbf{A})$	The trace operation of a square matrix \mathbf{A}
$\det(\mathbf{A})$	Determinant of matrix \mathbf{A}
$\text{adj}(\mathbf{A})$	Adjoint of matrix \mathbf{A}
$\mathcal{D}(\mathbf{A})$	Length of the shortest nonzero vector of the lattice generated by \mathbf{A}
$\lambda_{\min}(\mathbf{A})$	Minimum eigenvalue of \mathbf{A}
$\mathcal{L}(\mathbf{A})$	Lattice generated by \mathbf{A}
$E[\cdot]$	Statistical expectation
$\Re(\cdot), \Im(\cdot)$	Real and imaginary parts
$\langle \mathbf{a}, \mathbf{b} \rangle$	Inner product of two vectors \mathbf{a} and \mathbf{b}
$\mathcal{CN}(\mathbf{m}, \mathbf{C})$	Complex Gaussian vector distribution with mean \mathbf{m} and covariance \mathbf{C}
$\log(\cdot)$	Natural logarithm
$\mathbf{0}$	Matrix with all entries of 0
$\ \cdot\ $	2-norm
$\ \cdot\ _F$	The Frobenius norm
$\lceil \beta \rceil$	The nearest integer to β
$\lfloor \beta \rfloor$	The closest integer which is smaller than β
$ \beta $	Absolute value of scalar β
\setminus	Set minus