Contents

1 Introduction **1**

1.1 Background 2

1.2 Motivation and Contributions 4

1.3 Outline 6

2 Mobile Radio Channels **9**

2.1 Physical Properties of Mobile Radio Channels 9

2.1.1 Path loss 11

2.1.2 Shadowing 12

2.1.3 Multipath propagation 13

2.2 Channel Model for Multiple Antenna Systems 14

2.2.1 Spatial-temporal frequency-selective channel 15

2.3 Summary 17

3 Channel Capacity with Multiple Antennas **19**

3.1 Multiple Antenna Systems 19

3.2 Channel Capacity in Multiple Antenna Systems 22

3.2.1 Channel capacity for MIMO systems with ideal CSI 23

3.2.2 Channel capacity for MIMO systems with estimated CSI 31

3.3 Summary 35

4 OFDM Transmission Technique **37**

4.1 Fundamentals of OFDM 38

4.2 Transceiver Structure of OFDM Systems 42

4.3 Summary 43

5 MIMO-OFDM Systems **45**
5.1 Principles of MIMO-OFDM Systems 45
5.1.1 Transceiver structure of MIMO-OFDM systems 46
5.1.2 Signal model of MIMO-OFDM systems 46
5.1.3 Virtual subchannels in MIMO-OFDM systems 49
5.1.4 Channel capacity in MIMO-OFDM systems 50
5.2 Signal Processing in MIMO-OFDM Systems 50
5.2.1 Subcarrier-based MIMO signal processing 51
5.2.2 Water-filling and bit loading 51
5.2.3 Signaling of long-term channel state information 54
5.3 Summary 57

6 Subcarrier-Based Signal Processing in MIMO-OFDM Systems **59**
6.1 Classification of MIMO Techniques 60
6.2 MIMO Transmission Techniques 60
6.2.1 MIMO transmission with diversity 61
6.2.2 MIMO transmission with multiplexing 68
6.2.3 Trade-off between diversity and multiplexing 77
6.3 Summary 77

7 Performance of MIMO-OFDM Systems with Ideal CSI **79**
7.1 System Parameters and Channel Conditions 79
7.2 Simulation Results 80
7.3 Summary 86

8 Channel Estimation in MIMO-OFDM Systems **87**
8.1 Introduction 87
8.2 Pilot-Based Channel Estimation 89
8.2.1 Channel estimation procedure 89
8.2.2 Pilot distribution patterns 91
8.2.3 Training symbol length 95
8.2.4 Boosted pilot symbols 96

8.2.5 Interpolation methods to get CSI at data positions 97
8.3 System Performance with Estimated CSI 99
8.3.1 System performance with uniform pilots 100
8.3.2 System performance with boosted pilots 103
8.4 Summary 104

9 Link Adaptation in MIMO-OFDM Systems 107
9.1 Link Adaptation in MIMO-OFDM Systems 108
9.1.1 Transmission mode selection 110
9.1.2 Indicator candidates 111
9.1.3 Unified indicator-based TMS procedure 115
9.2 Simulation Results 117
9.2.1 Indicator results for link adaptation 118
9.2.2 System throughput results with link adaptation 122
9.3 Summary 127

10 Summary 129
10.1 Performance Analysis in MIMO-OFDM Systems 129
10.2 Design Considerations for MIMO-OFDM Systems 130

A Abbreviations and Symbols 133
A.1 Abbreviations 134
A.2 Symbols 138

Appendix 133

Bibliography 141