

# Contents

<b>Abstract</b>	<b>iii</b>
<b>Kurzfassung</b>	<b>v</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Motivation . . . . .	1
1.2 Objectives . . . . .	2
1.3 Contributions . . . . .	2
1.4 Outline . . . . .	3
<b>2 Relay Stations in Cellular Mobile Radio Networks</b>	<b>5</b>
2.1 The Cellular Concept . . . . .	5
2.2 Relay Stations . . . . .	11
2.2.1 Capacity Extension by RSs . . . . .	12
2.2.2 Coverage Extension by RSs . . . . .	13
2.3 Operation Parameters . . . . .	13
2.3.1 Duplex Schemes . . . . .	13
2.3.2 MAC Frame Structure . . . . .	17
2.3.3 Routing . . . . .	20
2.3.4 Scheduling of Radio Resources . . . . .	21
2.3.5 Relaying in ISO/OSI-Reference Model . . . . .	22
2.3.6 Backhaul Feeder Link . . . . .	26
2.3.7 Mobility . . . . .	26
2.3.8 Coexistence With Low-Power Base Stations . . . . .	27
2.4 Radio Standards Supporting RSs . . . . .	27
2.4.1 DECT . . . . .	27
2.4.2 WiMAX IEEE 802.16 . . . . .	29
2.4.3 LTE-A . . . . .	31
2.5 Related Work . . . . .	33
2.5.1 General Concepts . . . . .	33
2.5.2 RSs for Coverage Extension . . . . .	34

## Contents

2.5.3	RSs for Capacity Enhancement . . . . .	37
2.5.4	Optimal Placement of RSs . . . . .	39
2.5.5	Conclusions . . . . .	40
<b>3</b>	<b>ITU-R Scenarios for IMT-A</b>	<b>43</b>
3.1	Test Environments . . . . .	44
3.2	Deployment Scenario and Modeling Assumptions . . . . .	45
3.3	Pico BSs at Center of Site . . . . .	47
3.4	ITU-R Channel Model . . . . .	47
3.4.1	Path Loss . . . . .	48
3.4.2	Signal Shadowing . . . . .	50
3.4.3	Fast Signal Fading . . . . .	52
3.4.4	MIMO Transmission . . . . .	53
3.5	Further Modeling Assumptions . . . . .	54
3.5.1	Placement and Mobility . . . . .	54
3.6	Antenna Characteristics . . . . .	55
3.6.1	Base Station Antenna . . . . .	55
3.6.2	Mobile Station Antenna . . . . .	56
3.6.3	Relay Station Antenna . . . . .	56
3.7	Other Scenario Parameters . . . . .	56
<b>4</b>	<b>Model for Capacity Optimization</b>	<b>59</b>
4.1	System Model . . . . .	61
4.1.1	Wireless Channel Model . . . . .	61
4.1.2	Physical Layer Model . . . . .	61
4.1.3	MAC Layer Model . . . . .	65
4.2	Capacity Calculation . . . . .	70
4.2.1	Data Rate Calculation . . . . .	72
4.2.2	Association Strategy . . . . .	76
4.3	Simulated Annealing For Capacity Maximization . . . . .	78
4.3.1	Simulated Annealing . . . . .	78
4.3.2	Monte-Carlo Simulation . . . . .	88
4.4	Measurements For Evaluation . . . . .	88
4.4.1	MAC Frame Occupation . . . . .	88
4.4.2	Heat Map of Mean SINR . . . . .	89
4.4.3	Heat Map of Mean Spectral Efficiency . . . . .	90
4.4.4	Others . . . . .	90
<b>5</b>	<b>Evaluation And Validation</b>	<b>93</b>
5.1	Validation of Channel Model Implementation . . . . .	94
5.2	Capacity Enhancement by RSs . . . . .	96
5.2.1	Optimal Placement of RSs . . . . .	104

5.2.2 Capacity Increase Per RS . . . . .	108
5.3 Service Area Size of RSs . . . . .	109
5.4 Location-Dependent SINR and Spectral Efficiency . . . . .	110
5.5 Optimizing Relay Antenna Height . . . . .	114
5.6 Association Strategies for MSs . . . . .	115
5.6.1 SINR Offset . . . . .	116
5.6.2 Capacity Maximization . . . . .	117
5.7 Backhaul Link Conditions . . . . .	117
5.8 Resource Allocations . . . . .	119
5.9 RS Transmit Power . . . . .	124
5.10 Down Tilt of BS Antenna . . . . .	125
5.11 RS Antenna Pattern . . . . .	127
5.12 Comparison to Pico BS Networks . . . . .	129
5.13 Pico BS as Supplement to Relay-Enhanced Cell . . . . .	134
5.14 Interference Conditions For The Backhaul Link . . . . .	137
5.15 Improved BS Antenna Pattern . . . . .	139
<b>6 Conclusions</b>	<b>143</b>
6.1 Summary . . . . .	143
6.2 Outlook . . . . .	145
<b>A Heuristic to Calculate Mean RS Positions</b>	<b>147</b>
<b>B Simulation Environment openWNS</b>	<b>149</b>
B.1 OpenWNS Architecture . . . . .	149
B.2 Functional Unit Network Architecture . . . . .	150
B.3 Simulator Setup . . . . .	152
B.3.1 RISE Component / RISE Medium . . . . .	153
B.3.2 WiMAX MAC Layer Component . . . . .	153
B.3.3 IP Component . . . . .	160
B.3.4 Load Generator Component . . . . .	160
<b>C Comparison of IMT-A And 3GPP LTE Channel Model</b>	<b>161</b>
<b>D Optimized RS Placement Without Clipping SINR</b>	<b>167</b>
<b>Bibliography</b>	<b>175</b>
<b>Acronyms</b>	<b>183</b>
<b>Curriculum Vitae</b>	<b>187</b>
<b>Acknowledgment</b>	<b>189</b>