

CONTENTS

EXECUTIVE SUMMARY	x
LIST OF ABBREVIATIONS	xiv
LIST OF FIGURES	xvi
LIST OF TABLES.....	xx
CHAPTER-1: INTRODUCTION	1
<i>1.1 Overview.....</i>	1
<i>1.2 Research motivation.....</i>	1
<i>1.3 Area of Study.....</i>	2
<i>1.4 Objectives of the Research.....</i>	2
<i>1.5 Overview of research approach.....</i>	3
<i>1.6 Contribution of research.....</i>	3
<i>1.7 Outline of thesis chapters.....</i>	3
CHAPTER-2: CONCEPTS OF 802.11n AND 802.11ac.....	5
<i>2.1 Enhancements in 802.11n WLANs over Legacy WLANs.....</i>	5
<i>2.1.1 Introduction.....</i>	5
<i>2.1.2 PHY layer enhancements.....</i>	5
<i>2.1.3 MAC layer enhancements.....</i>	11
<i>2.2 Enhancements in 802.11ac WLAN over previous WLANs.....</i>	12
<i>2.2.1 Modulation and Coding Schemes.....</i>	15
<i>2.2.2 Channel Bonding.....</i>	15
<i>2.2.3 Spatial Streams</i>	15
<i>2.2.4 Transmit Beamforming in 802.11ac.....</i>	15
<i>2.2.5 Multi-User MIMO</i>	20
CHAPTER-3: LITERATURE SURVEY	22
<i>3.1 QOS Mechanisms for IEEE 802.11 WLANs.....</i>	22
<i>3.2 Queueing</i>	23
<i>3.3 Call Admission Control.....</i>	23
<i>3.4 Aggregation.....</i>	24
<i>3.5 Rate Adaptation.....</i>	24

<i>3.5.1 Fast Decrease and Retry Scheduling</i>	25
<i>3.5.2 HAMM-CP</i>	26
<i>3.5.3 Dual Queue Rate-Controlled AP (DRAP)</i>	29
<i>3.5.4 Zig Zag MiRA</i>	30
<i>3.6 Scheduling</i>	32
<i>3.6.1 Traffic scheduling schemes</i>	32
<i>3.6.2 Request reservation approach</i>	34
<i>3.6.3 Polling</i>	35
<i>3.6.4 Using TXOP</i>	36
<i>3.6.5 Token Passing Mechanism</i>	38
<i>3.6.6 MAC Aggregation Approach</i>	39
<i>3.6.7 PHY Layer Scheduling</i>	41
<i>3.6.8 Out of Band Approach</i>	46
<i>3.6.9 Cross platform Approach</i>	48
<i>3.6.10 QoE based scheduling</i>	48
<i>3.6.11 Scheduler for 802.11ac</i>	50
<i>3.7 Additional Mechanisms to Handle QoS</i>	52
<i>3.7.1 Synchronized Time</i>	52
<i>3.7.2 Receiving-Opportunity Control</i>	53
<i>3.7.3 Cognitive Solution</i>	54
<i>3.7.4 FairWLAN</i>	55
<i>3.7.5 MAC-HCCA</i>	56
<i>3.7.6 Enhanced AEDCA</i>	58
<i>3.8 Review of Transmit Beamforming Mechanisms</i>	58
<i>3.8.1 Time Domain Quantization</i>	58
<i>3.8.2 Pre-coding and Temporal CSI</i>	59
<i>3.8.3 Explicit Feedback and Preamble Structure</i>	59
<i>3.8.4 DTTRA - Directional Transmit and Receive Algorithm</i>	59
<i>3.8.5 Beamforming with Multiple Spatial Streams</i>	59
<i>3.8.6 Single-User and Multi-User Beamforming</i>	60

<i>3.8.7 Smart Antennas</i>	60
<i>3.9 Review of MU-MIMO Mechanisms.....</i>	61
<i>3.9.1 General.....</i>	61
<i>3.9.2 MAC Layer.....</i>	62
<i>3.9.3 PHY Layer.....</i>	67
CHAPTER-4: PERFORMANCE EVALUATION.....	74
<i>4.1 Introduction to performance evaluation features.....</i>	74
<i>4.2 Performance Evaluation of IEEE 802.11ac and 802.11n.....</i>	75
<i>4.2.1 Introduction.....</i>	75
<i>4.2.2 Performance Test.....</i>	75
<i>4.2.3 Results and Discussion.....</i>	76
<i>4.2.4 Conclusion.....</i>	87
<i>4.3 Evaluation of Rate Adaptation Techniques.....</i>	87
<i>4.3.1 Introduction.....</i>	87
<i>4.3.2 Performance Test.....</i>	90
<i>4.3.3 Results and Discussion.....</i>	91
<i>4.3.4 Conclusion.....</i>	109
<i>4.4 Evaluation of Transmit Beam Forming.....</i>	110
<i>4.4.1 Introduction.....</i>	110
<i>4.4.2 Test set-up</i>	111
<i>4.4.3 Results and discussion.....</i>	113
<i>4.4.4 Example Scenarios where Beamforming can be applied.....</i>	126
<i>4.4.5 Conclusion.....</i>	127
<i>4.5 Evaluation of MU MIMO performance.....</i>	127
<i>4.5.1 Introduction.....</i>	127
<i>4.5.2 Simulation, results and discussion.....</i>	128
<i>4.5.3 Conclusion.....</i>	134
CHAPTER-5: CONCLUSION AND PROPOSAL OF A SCHEDULER FRAMEWORK.....	135
<i>5.1 Introduction.....</i>	135

<i>5.2 Conclusions of the Research</i>	136
<i>5.3 Need for a scheduler.....</i>	136
<i>5.3.1 Current State of Advanced Applications.....</i>	137
<i>5.3.2 Vendor Features</i>	137
<i>5.4 Conclusions Derived in the Thesis Leading to Recommendation of a Scheduler</i>	140
<i>5.4.1 QoS.....</i>	140
<i>5.4.2 Interference issues in WLANs</i>	142
<i>5.5 Proposed Framework.....</i>	144
<i>5.5.1 Block diagram.....</i>	144
<i>5.5.2 Components of the Scheduler</i>	144
<i>5.5.3 Description.....</i>	153
<i>5.6 Scenarios.....</i>	154
<i>5.6.1 Factors Impacting the Scheduler.....</i>	155
<i>5.6.2 Use-case scenarios.....</i>	156
CHAPTER-6: FUTURE WORK.....	158
<i>6.1 Scheduler for 802.11ac.....</i>	158
<i>6.2 Extending the Frame Work to Next Generation WLANs – 802.11ax.....</i>	158
APPENDIX-1: SIMULATION TOOLS	159
APPENDIX-2: BACKGROUND OF WLANs.....	160
APPENDIX-3: MECHANISMS FOR QoS ENHANCEMENT.....	166
<i>A3.1 Queueing.....</i>	166
<i>A3.2 Call Admission Control.....</i>	166
<i>A3.3 Aggregation</i>	166
<i>A3.4 Rate Adaptation.....</i>	168
<i>A3.5 Scheduler.....</i>	170
<i>A3.6 Additional Mechanisms for handling QoS.....</i>	170
APPENDIX-4: SCHEDULING IN CELLULAR NETWORKS.....	171
<i>A4.1Introduction.....</i>	171
<i>A4.2 Scheduling in WIMAX.....</i>	171
<i>A4.3 Scheduling in LTE.....</i>	177

APPENDIX-5: GENERAL CHARACTERISTICS OF VoIP TRAFFIC.....	179
APPENDIX-6: EVALUATION OF PERFORMANCE PARAMETERS.....	180
APPENDIX-7: MODIFICATIONS TO 802.11 STANDARD RESULTING FROM ADDITION OF MU-MIMO FEATURE.....	182
APPENDIX-8: PUBLICATIONS BASED ON THIS THESIS	194
REFERENCES	195