

TABLE OF CONTENTS

ABSTRACT	I
ACKNOWLEDGEMENT	II
TABLE OF CONTENTS	III
LIST OF FIGURES	VI
LIST OF TABLES	VIII
NOTATIONS	IX
CHAPTER 1	I
INTRODUCTION	1
1.1 BREAKING PUBLIC KEY CRYPTOSYSTEM	1
1.2 PROJECT MOTIVATION	2
1.3 PROJECT OBJECTIVES	2
1.4 PROJECT SCOPE	3
1.5 EXPECTED OUTCOME	4
1.6 PROJECT SCHEDULING	5
CHAPTER 2	6
LITERATURE REVIEW	6
2.1 RSA ENCRYPTION ALGORITHM	6
2.1.1 Choice of p and q	8
2.1.2 Choice of e and d	8
2.1.3 Advantages	8
2.1.4 Disadvantages	9
2.2 FUNDAMENTAL THEOREM OF ARITHMETIC	10
2.3 FACTORING ALGORITHM	11
2.3.1 Trial Division	12
2.3.2 Pollard - ρ algorithm	13
2.3.3 Quadratic Sieve Algorithm	14
2.3.3.1 Fermat's difference-of-square Technique	14
2.3.3.2 Enhancement of difference-of-square Technique	15
2.3.3.3 Smooth Number and Complexity	17
2.3.3.4 The Quadratic Sieve	18
2.3.3.5 Solving Congruence	19
2.3.3.6 Building Factor Base	20
2.3.3.7 Sieving	21
2.3.3.8 Choosing Appropriate Congruence	22
2.3.3.9 Variants of Quadratic Sieve	24
2.4 DISTRIBUTED AND PARALLEL COMPUTING	24
2.4.1 Benefits of Distributed Computing	25
2.4.2 Challenges	26
2.4.3 Tuple Space	27
2.4.4 JavaSpaces	30
2.4.4.1 JavaSpaces Operations	31
2.4.4.2 Associative Lookup	31
2.4.4.3 Atomic Transaction	32
2.4.5 Space-based Communication and Parallel Computing	32
2.4.6 JINI (Java Intelligent Network Infrastructure)	33
2.4.6.1 JINI Service Architecture	34

2.5	DIFFERENCES BETWEEN LINDA AND JAVASPACEs	36
2.6	CURRENT RESEARCH	37
2.7	CHAPTER SUMMARY	38
CHAPTER 3		40
REQUIREMENT ANALYSIS AND SYSTEM SPECIFICATION		40
3.1	SYSTEM PRE-REQUISITION	40
3.2	NON-FUNCTIONAL REQUIREMENTS	42
3.3	USE CASE DRIVEN ANALYSIS	42
3.3.3	Use Case Diagram	42
3.3.2	Use Case: Start Factoring Process	44
3.3.3	Use case: Resume Previous Incomplete Process	46
3.3.4	Use Case: Access Task Pool and Access Result Pool	47
3.3.5	Use Case: Remote Access Control	49
3.4	CHAPTER SUMMARY	49
CHAPTER 4		50
SYSTEM DESIGN		50
4.1	CRITERIA FOR PARALLEL IMPLEMENTATION	50
4.2	SPACE-BASED PARALLEL APPLICATION PATTERNS	51
4.3	CHOSEN FACTORIZATION ALGORITHM	53
4.4	QS-SPACE ARCHITECTURE	54
4.4.1	System Operational Analysis	57
4.4.2	Data Type	58
4.4.3	Classes Identification and Design	59
4.5	USER INTERFACE DESIGN	65
4.5.1	GUI for Master Module	65
4.5.2	GUI for Slave Module	74
4.6	DATABASE DESIGN	74
4.7	CHAPTER SUMMARY	76
CHAPTER 5		78
SYSTEM IMPLEMENTATION AND DEPLOYMENT		78
5.1	DEVELOPMENT ENVIRONMENT	78
5.2	PLATFORM INDEPENDENT PROGRAMMING LANGUAGE	79
5.3	COOPERATING JINI INTO QS-SPACE DESIGN	80
5.3.1	JINI enabled system	80
5.3.2	JavaSpaces	80
5.4	CLASS DIAGRAM REFINEMENT	82
5.5	QS-SPACE IMPLEMENTATION	87
5.5.1	Accessing JavaSpaces	87
5.5.2	Quadratic Sieve (QS) Algorithm Implementation	95
5.5.3	Integrating Sieving Stage into QSTask	96
5.5.3.1	Sieving Algorithm	98
5.5.3.2	Consideration	104
5.5.4	Master Module	105
5.5.4.1	Tasks Generating and Results Collecting	105
5.5.4.2	Ticket Dispenser and Sieve Queue	108

5.5.4.3	Slaves Coordination	110
5.5.4.4	SieveQueue Entries Collector.....	116
5.5.4.5	Execution/Running Time Analysis.....	117
5.5.4.6	Remote Access Service	120
5.5.4.7	Mathematic Utilities	123
5.5.5	Slave Module.....	126
5.5.5.1	<i>CommandListener</i> class.....	126
5.5.5.2	Task Retrieval and Execution.....	128
5.6	QS-SPACE DEPLOYMENT.....	129
5.6.1	JINI's Services Deployment.....	129
5.6.2	Master and Slave Module Deployment	131
5.6.3	HTTP Servers	132
5.6.4	Hardware and Software	133
5.7	CHAPTER SUMMARY	136
	CHAPTER 6.....	137
	COMPUTATIONAL RESULT.....	137
6.1	PERFORMANCE EVALUATION.....	137
6.1.1	Parallel Benchmark	139
6.1.2	Execution Time Proportion	142
6.1.3	Effect of Factor Base Size towards Running Time.....	150
6.2	PERFORMANCE ANALYSIS.....	152
6.3	OPTIMIZATION.....	155
6.4	CHAPTER SUMMARY.....	155
	CHAPTER 7.....	156
	CONCLUSION AND FUTURE WORK	156
7.1	CONCLUSION.....	156
7.2	SUGGESTION FOR FUTURE WORKS.....	157
	REFERENCES	159
	APPENDIX A	161
	APPENDIX B.....	168
	APPENDIX C.....	171

LIST OF FIGURES

FIGURE 1.1 PROJECT SCHEDULE	5
FIGURE 1.1 PROJECT SCHEDULE	5
FIGURE 2.1 POLLARD- ρ	14
FIGURE 2.2 LINDA OPERATION ENVIRONMENTS	29
FIGURE 2.3 AN OVERVIEW OF <i>JAVA/SPACES</i> OPERATIONS: <i>WRITE</i> , <i>TAKE</i> AND <i>READ</i>	31
FIGURE 2.4 INTERACTION BETWEEN <i>JINI</i> 'S CLIENT AND SERVICE	36
FIGURE 2.5 <i>JINI</i> 'S <i>DISCOVERY</i> , <i>JOIN</i> AND <i>LOOKUP</i>	36
FIGURE 3.1 USE CASE DIAGRAM FOR QS-SPACE APPLICATION	43
FIGURE 3.2 SEQUENCE DIAGRAM START FACTORING PROCESS USE CASE	45
FIGURE 3.3 ACTIVITY DIAGRAM FOR START FACTORING PROCESS::SINGLE OPERATION AND START FACTORING PROCESS::CONSECUTIVE OPERATION	46
FIGURE 3.4 ACTIVITY DIAGRAM FOR RESUME PREVIOUS INCOMPLETE PROCESS USE CASE	47
FIGURE 3.5 ACCESS TASK POOL USE CASES	48
FIGURE 3.6 ACCESS RESULT POOL USE CASES	48
FIGURE 3.7 REMOTE ACCESS CONTROL USE CASES	49
FIGURE 4.1 REPLICATED-WORKER PATTERN	52
FIGURE 4.2 COMMAND PATTERN	53
FIGURE 4.3 2-TIER ARCHITECTURE OF QS-SPACE	54
FIGURE 4.4 PEER-TO-PEER DESIGN	55
FIGURE 4.5 MASTER/SLAVE APPROACH WITH DYNAMIC CODES DISTRIBUTION	56
FIGURE 4.6 QS-SPACE MAIN COMPONENTS REPRESENTED IN CLASS DIAGRAM	56
FIGURE 4.7 SEQUENCE DIAGRAM FOR OVERALL SYSTEM PROCESS	59
FIGURE 4.8 CLASS DIAGRAM OF QS-SPACE	61
FIGURE 4.9 MASTER MODULE GUI CLASS DIAGRAM	66
FIGURE 4.10 GUI FOR QSMaster CONTROL PANEL	68
FIGURE 4.11 DATABASE CONNECTIVITY SETUP (CLASS: DBCONNDialog)	69
FIGURE 4.12 INPUT BOX TO GENERATE A NEW COMPOSITE NUMBER	69
FIGURE 4.13 QS-SPACE SYSTEM CONFIGURATIONS (CLASS: SysCONFDialog)	69
FIGURE 4.14 CONFIRMATION BOX FOR CONSECUTIVE BATCH	70
FIGURE 4.15 INPUT FORM FOR CONSECUTIVE BATCH COMPOSITE NUMBERS (CLASS: CONBatchDialog)	70
FIGURE 4.16 MESSAGE BOX FOR ACCESSIBLE SLAVE NODES IN NETWORK	71
FIGURE 4.17 SYSTEM PERFORMANCE GRAFT (CLASS: GRAFTDisplay)	71
FIGURE 4.18 PARALLELISM CHART FOR SIEVING PROCESS (CLASS: PARALLELISMChart)	72
FIGURE 4.19 REMOTE ACCESS THROUGH JAVA APPLET	73
FIGURE 4.20 SLAVE ACTIVITIES CONSOLE	74
FIGURE 5.1 POSSIBLE ARRANGEMENT OF <i>JINI</i> -ENABLED COMPONENTS	80
FIGURE 5.2 ALL ENTRIES ARE SERIALIZED BY LOCAL PROXY OBJECT AND TRANSMITTED AND STORED IN THE REMOTE SPACE IN SERIALIZED FORM	81
FIGURE 5.3 REFINED VERSION OF QS-SPACE CLASS DIAGRAM	83
FIGURE 5.4 UML SEQUENCE DIAGRAM FOR DISCOVERY AND LOOKUP PROCESSES	93
FIGURE 5.5 ACTIVITY DIAGRAM OF QS ALGORITHM PROCESS	97
FIGURE 5.6 SIEVING PATTERN FOR EACH TASK ENTRY	99
FIGURE 5.7 ACTIVITY DIAGRAM FOR <i>NODESCOORDINATOR</i>	111
FIGURE 5.8 ACTIVITY DIAGRAM FOR <i>NODESCOORDINATOR::DISCOVERNODES()</i>	113
FIGURE 5.9 ACTIVITY DIAGRAM FOR <i>NODESCOORDINATOR::RECRUITENODES()</i>	114
FIGURE 5.10 ACTIVITY DIAGRAM FOR <i>NODESCOORDINATOR::PATROL()</i>	115
FIGURE 5.11 POSSIBLE ARRANGEMENT OF SIEVE TIME	118
FIGURE 5.12 REMOTE ACCESS VIA RMI	122
FIGURE 5.13 ACTIVITY DIAGRAM FOR COMMANDLISTNER	127
FIGURE 5.14 PACKAGES AND THEIR RELATIONSHIP	129
FIGURE 5.15 INTERACTION IN QS-SPACE	130
FIGURE 5.16 DEPLOYMENT DIAGRAM FOR QS-SPACE	135
FIGURE 6.1 TOTAL EXECUTION TIME	140
FIGURE 6.2 TOTAL SPEEDUP RELATIVE TO SERIAL IMPLEMENTATION	141
FIGURE 6.3 RUN TIME COMPOSITION FOR PARALLEL IMPLEMENTATION [SLAVE NODES=0]	143
FIGURE 6.4 RUN TIME COMPOSITION FOR PARALLEL IMPLEMENTATION [SLAVE NODES=1]	144
FIGURE 6.5 RUN TIME COMPOSITION FOR PARALLEL IMPLEMENTATION [SLAVE NODES=2]	145

FIGURE 6.6 RUN TIME COMPOSITION FOR PARALLEL IMPLEMENTATION [SLAVE NODES=3]	146
FIGURE 6.7 RUN TIME COMPOSITION FOR PARALLEL IMPLEMENTATION [SLAVE NODES=4]	147
FIGURE 6.8 RUN TIME COMPOSITION FOR PARALLEL IMPLEMENTATION [SLAVE NODES=5]	148
FIGURE 6.9 RUN TIME COMPOSITION FOR PARALLEL IMPLEMENTATION [SLAVE NODES=6]	149
FIGURE 6.10 RELATIONSHIP BETWEEN FACTOR BASE AND QS EXECUTION TIME.....	150
FIGURE 6.11 TOTAL EXECUTION TIME WITH DIFFERENT FACTOR BASE SIZE (DIGIT LENGTH=45)	151
FIGURE 6.12 TOTAL EXECUTION TIME WITH DIFFERENT FACTOR BASE SIZE (DIGIT LENGTH=50)	151
FIGURE 6.13 TOTAL EXECUTION TIME WITH DIFFERENT FACTOR BASE SIZE (DIGIT LENGTH=55)	152

List of Tables

TABLE 2.1 PRIME FACTORS FOR POSITIVE INTEGER	10
TABLE 2.2 C VALUE	22
TABLE 2.3 FACTORING RECORD SINCE 1970 [MON1995]	24
TABLE 4.1 BATCH TABLE.....	75
TABLE 4.2 SIEVE TIME TABLE.....	76
TABLE 4.3 B_SMOOTH_RETURNED TABLE	76
TABLE 4.4 SLAVEINFO TABLE.....	76
TABLE 6.1 NUMBER TO BE FACTORIZED IN EACH TEST RUNS	138
TABLE 6.2 PARAMETER VALUES ASSIGNED TO EACH TEST NUMBER	139
TABLE 6.3 TOTAL EXECUTION TIME FOR EACH FACTORING EXERCISE WITH INCREASING NUMBER OF SLAVE NODES	139
TABLE 6.4 SPEEDUP RELATIVE TO SERIAL IMPLEMENTATION	141
TABLE 6.5 EXECUTION TIME FOR SERIAL IMPLEMENTATION	143
TABLE 6.6 EXECUTION TIME FOR NUMBER OF SLAVE NODES =1	144
TABLE 6.7 EXECUTION TIME FOR NUMBER OF SLAVE NODES =2	145
TABLE 6.8 EXECUTION TIME FOR NUMBER OF SLAVE NODES =3	146
TABLE 6.9 EXECUTION TIME FOR NUMBER OF SLAVE NODES =4	147
TABLE 6.10 EXECUTION TIME FOR NUMBER OF SLAVE NODES =5	148
TABLE 6.11 EXECUTION TIME FOR NUMBER OF SLAVE NODES =6	149
TABLE 6.12 COMMUNICATION/COMPUTATION RATIO IN 6 SLAVE NODES	153
TABLE 6.13 ENTRY SIZE	154
TABLE 6.14 SPEEDUP OPTIMIZATION ON SIEVE TIME [NODES=6]	155

Notations

Symbol	Meaning
$a \equiv b \pmod{n}$	a is congruent to b modulus n
$a b$	a divides b
$a \nmid b$	a does not divide b
$\phi(n)$	Euler's totient function
G.C.D(a, b)	greatest common divisor of a and b
$[a, b]$	the interval $a \leq x \leq b$
\prod	product symbol where $\prod_{i=1}^n a_1 \cdot a_2 \cdot \dots \cdot a_n$
p	a prime number
$\left[\frac{a}{p} \right]$	Legendre symbol, defined if p is an odd prime
N	Modulus of RSA algorithm