

Contents

ABSTRACT	i
ACKNOWLEDGEMENT	ii
LIST OF FIGURES	ix
LIST OF TABLES	xii
ABBREVIATIONS	xiii
CHAPTER 1 INTRODUCTION	1
1.1 Introduction to IP Multicast	1
1.1.1 Internet Group Management Protocol (IGMP)	3
1.1.2 Multicast Routing Protocol	3
1.2 Introduction to Computer Simulation	4
1.3 Objectives of the Dissertation	5
1.4 Scope of the Dissertation	5
1.5 Organizations of Dissertation	6
CHAPTER 2 LITERATURE REVIEW	8
2.1 IP Multicast	9
2.1.1 Introduction	9
2.1.1.1 Advantages of IP Multicast	10
2.1.1.2 Multicast Applications	10
2.1.2 Model of IP Multicast	11
2.1.3 Multicast Group Address	12
2.1.4 Internet Group Management Protocol (IGMP)	13
2.1.4.1 IGMP Version 1	14
2.1.4.2 IGMP Version 2	17
2.1.4.3 IGMP Version 3	19

2.1.5 Multicast Forwarding Algorithms	19
2.1.5.1 Flooding.....	20
2.1.5.2 Spanning Tree.....	21
2.1.5.3 Reverse Path Broadcasting (RPB).....	23
2.1.5.4 Truncated Reverse Path Broadcasting (TRPB)	25
2.1.5.5 Reverse Path Multicasting (RPM)	25
2.1.5.6 Core Based Trees (CBT).....	27
2.1.6 Multicast Routing Protocols	28
2.1.6.1 Potocol Independent Multicast - Dense Mode (PIM-DM).....	29
2.1.6.2 Distance Vector Multicast Routing Protocol (DVMRP).....	31
2.1.6.3 Multicast Extension to Open Shortest Path First (MOSPF).....	32
2.1.6.4 Core Based Trees (CBT).....	32
2.1.6.5 Protocol Independent Multicast - Sparse Mode (PIM-SM)	33
2.2 Reviews on Computer Simulation.....	34
2.2.1 Computer Simulation	34
2.2.2 Programming Approach and Language.....	35
2.2.2.1 Approach.....	35
2.2.2.2 Java.....	37
2.2.3 ComputerNetwork Simulator	38
2.3 Analysis on UMJaNetSim	39
2.3.1 UMJaNetSim Architecture.....	39
2.3.1.1 Event Management Architecture.....	40
2.3.1.2 GUI Management Architecture.....	42
2.3.1.3 Simulation Components	43
2.3.2 UMJaNetSim API.....	43
2.3.2.1 Javasim	43
2.3.2.2 SimEvent	44
2.3.2.3 SimClock.....	45

2.3.2.4 SimComponentt	45
2.3.2.5 SimParameter	47
2.4 Summary.....	48
CHAPTER 3 ANALYSIS ON IGMP AND PIM-DM	49
3.1 Analysis on IGMP.....	49
3.1.1 IGMP Message	49
3.1.2 IGMP Group Table.....	51
3.1.3 IGMP Timers and Variables.....	52
3.1.4 Protocol Description	54
3.1.4.1 IGMP in Host.....	55
3.1.4.2 IGMP in Router.....	56
3.2 Analysis on PIM-DM	57
3.2.1 PIM-DM Control Message	57
3.2.1.1 PIM-Hello Message	59
3.2.1.2 Prune Message.....	59
3.2.1.3 Assert Message.....	59
3.2.1.4 Graft Message.....	59
3.2.1.5 Graft-Ack Message.....	60
3.2.2 Timers	60
3.2.3 PIM-DM Table.....	61
3.2.3.1 PIM-DM Multicast Forwarding Table.....	62
3.2.3.2 PIM-DM Neighbor Information Table.....	62
3.2.3.3 PIM-DM Membership Table	63
3.2.4 Protocol Analysis.....	63
3.2.4.1 Sending and Receiving Hello Message	64
3.2.4.2 Sending and Receiving Prune Message	65
3.2.4.3 Sending and Receiving Graft and Graft-Ack Message.....	65
3.2.4.4 IGMP Notification.....	66

3.2.4.5 Handling PIM-DM Timers	67
3.2.4.6 Receiving and Forwarding Multicast Packet	67
3.3 Summary	68
CHAPTER 4 SYSTEM DESIGN	69
4.1 Overall System Design	69
4.2 IGMP Design	70
4.2.1 System Architecture Design	70
4.2.1.1 IGMP Core Design	71
4.2.1.2 IGMP Group Table Design	72
4.2.1.3 IGMP Timers Design	72
4.2.2 Object-oriented Design	73
4.2.3 Class Design	73
4.2.3.1 IGMPv2 Class	73
4.2.3.2 Group Class	75
4.2.3.3 IGMPTimer Class	75
4.2.3.4 SimParamGroupTable Class	76
4.2.3.5 Modification in IPBTE Class	76
4.2.3.6 Modification in ATMLSR Class	76
4.3 PIM-DM Design	77
4.3.1 System Architecture Design	77
4.3.1.1 PIM-DM Core Design	77
4.3.1.2 PIM-DM SG Table Design	78
4.3.1.3 PIM-DM Neighbor Table Design	78
4.3.1.4 PIM-DM Membership Table Design	78
4.3.1.5 PIM-DM Timers Design	78
4.3.2 Object-oriented Design	78
4.3.3 Class Design	79
4.3.3.1 PIMDM Class	79

4.3.3.2 SG Class	81
4.3.3.3 SGOF Class	81
4.3.3.4 PIMNeighbor Class	82
4.3.3.5 PIMDMTimer Class	82
4.3.3.6 SimParamPIMDMTable Class	82
4.3.3.7 SimParamPIMDMNeighbor Class	83
4.3.3.8 Modification in ATMLSR Class	83
4.4 Multicast Applications Design	83
4.4.1 MulticastdataApp Class	83
4.4.2 IPMulticastApp Class	84
4.5 Summary	85
CHAPTER 5 IMPLEMENTATION	86
5.1 Implementation of IGMP	86
5.1.1 IGMPv2 Class	86
5.1.2 SimParamGroupTable Class	88
5.1.3 Modification in IPBTE Class	89
5.1.4 Modification in ATMLSR Class	90
5.2 Implementation of PIM-DM	91
5.2.1 PIMDM Class	91
5.2.2 SimParamPIMDMTable Class	95
5.2.3 SimParamPIMDMNeighbor Class	95
5.2.4 Modification in ATMLSR Class	96
5.3 Implementation of Simulation Application	98
5.3.1 MulticastdataApp Class	98
5.3.2 IPMulticast Class	99
5.4 System Flow for Implementation	100
5.5 Simulation Topology	102
5.6 Exclusions and Simplifications in Implementation	104

5.7 Summary.....	106
CHAPTER 6 TESTING AND PERFORMANCE EVALUATION.....	107
6.1 Introduction.....	107
6.2 Validation Test	108
6.2.1 Validation Test for MulticastdataApp.....	108
6.2.2 Validation Test for IPMulticastApp	110
6.2.3 Validation Test for IGMPv2	112
6.2.4 Validation Test for PIMDM.....	126
6.3 Performance Evaluation on IP Multicast through PIM-DM.....	136
6.3.1 Join Latency Test	144
6.3.2 Traffic Concentration Test.....	146
6.3.3 Protocol Overhead Test.....	147
6.4 Summary.....	148
CHAPTER 7 CONCLUSIONS	150
7.1 Summary of Dissertation	150
7.2 Achievement of Objectives.....	151
7.3 Contributions.....	152
7.4 Limitations.....	153
7.5 Future Enhancements	153
APPENDIX A IGMP STATE DIAGRAM.....	154
APPENDIX B CONSTANT USED IN IGMPV2 CLASS AND PIMDM CLASS	158
APPENDIX C SIMULATION RESULTS FOR PERFORMANCE EVALUATION.....	162
APPENDIX D MULTICAST ADDRESS CATEGORY	166
REFERENCES	167

List of Figures

FIGURE 2.1	THREE APPROACHES IN ONE-TO-MANY APPLICATIONS	9
FIGURE 2.2	BASIC IP MULTICAST MODEL	12
FIGURE 2.3	POSITION OF IGMP IN NETWORK LAYER	14
FIGURE 2.4	ENCAPSULATION OF IGMP PACKET	14
FIGURE 2.5	REPORTING MEMBERSHIP	15
FIGURE 2.6	MONITORING MEMBERSHIP	16
FIGURE 2.7	CONTINUING MEMBERSHIP	16
FIGURE 2.8	LEAVING MULTICAST GROUP	18
FIGURE 2.9	GROUP SPECIFIC QUERY	18
FIGURE 2.10	RESPOND TO GROUP SPECIFIC QUERY OR REPORT MEMBERSHIP	19
FIGURE 2.11	FLOODING ALGORITHM	21
FIGURE 2.12	EXAMPLE OF SPANNING TREE	22
FIGURE 2.13	SPANNING TREE ALGORITHM	22
FIGURE 2.14	REVERSE PATH BROADCASTING ALGORITHM	23
FIGURE 2.15	ENHANCED REVERSE PATH BROADCASTING ALGORITHM	24
FIGURE 2.16	TRUNCATED REVERSE PATH BROADCASTING ALGORITHM	25
FIGURE 2.17	REVERSE PATH MULTICASTING ALGORITHM	26
FIGURE 2.18	CORE BASED TREES ALGORITHM	28
FIGURE 2.19	ARCHITECTURE OF UMJANetSIM	40
FIGURE 2.20	EVENT MANAGEMENT ARCHITECTURE FOR UMJANetSIM	41
FIGURE 2.21	GUI MANAGEMENT ARCHITECTURE FOR UMJANetSIM	42
FIGURE 3.1	IGMP MESSAGE FORMAT	50
FIGURE 3.2	COMMON HEADER FOR PIM-DM CONTROL MESSAGE	58
FIGURE 4.1	NEW UMJANetSIM OBJECTS WITH IP MULTICAST	69
FIGURE 4.2	BASIC SYSTEM ARCHITECTURE FOR IGMP	70
FIGURE 4.3	IGMP OBJECT IN UMJANetSIM	73

FIGURE 4.4 BASIC SYSTEM ARCHITECTURE FOR PIM-DM	77
FIGURE 4.5 PIM-DM OBJECT IN UMJANETSIM	79
FIGURE 5.1 SYSTEM FLOW FOR IMPLEMENTATION OF PIMDM CLASS	101
FIGURE 5.2 A MULTI-ACCESS NETWORK.....	102
FIGURE 5.3 NETWORK SIMULATION ENVIRONMENT.....	103
FIGURE 6.1 SIMULATION TOPOLOGY FOR VALIDATION TEST OF MULTICASTDATAAPP	109
FIGURE 6.2 SIMULATION TOPOLOGY FOR VALIDATION TEST OF IPMULTICATAPP.....	111
FIGURE 6.3 SIMULATION TOPOLOGY FOR INITIALIZATION OF IGMP TEST	113
FIGURE 6.4 SIMULATION TOPOLOGY FOR IGMP JOIN AND LEAVE TEST	116
FIGURE 6.5 EXAMPLE OF GROUP TABLE IN BTE1 AND R1 FOR TEST IN SCENARIO 1.....	116
FIGURE 6.6 EXAMPE OF GROUP TABLE IN BTE1 AND R1 FOE TEST IN SCENARIO 2.....	120
FIGURE 6.7 EXAMPLE OF GROUP TABLE IN R1 FOR TEST IN SCENARIO 3	123
FIGURE 6.8 EXAMPLE OF GROUP TABLE IN R1 IN TEST FOR SCENARIO 4.....	125
FIGURE 6.9 SIMULATION TOPOLOGY FOR PIM-DM INITIALIZATION TEST	126
FIGURE 6.10 EXAMPLES FOR PIM-DM NEIGHBOR TABLE FOR TEST 1.....	127
FIGURE 6.11 SIMULATION TOPOLOGY FOR TREE ESTABLISHMENT AND MULTICAST PACKETS FORWARDING TEST IN SCENARIO 1	128
FIGURE 6.12 EXAMPLE OF GUI PIM-DM (S, G) TABLE FOR ROUTER R5, R6 AND R7.....	129
FIGURE 6.13 CONDITION OF MULTICAST PACKETS FORWARDING AT 2ND SECOND OF SIMULATION ..	131
FIGURE 6.14 MULTICAST TREE AT 50TH SECOND OF SIMULATION	131
FIGURE 6.15 MULTICAST TREE AT 100TH SECOND OF SIMULATION	132
FIGURE 6.16 MULTICAST TREE AT 160TH SECOND OF SIMULATION	133
FIGURE 6.17 MULTICAST TREE AT 480TH SECOND OF SIMULATION	133
FIGURE 6.18 SIMULATION TOPOLOGY FOR TREE ESTABLISHMENT AND MULTICAST PACKETS FORWARDING TEST IN SCENARIO 2.....	134
FIGURE 6.19 MULTICAST TREE ESTABLISHED FOR THREE DIFFERENT MULTICAST GROUP.....	136
FIGURE 6.20 TOPOLOGY FOR 10 MEMBERS DENSE DISTRIBUTIONS	139
FIGURE 6.21 TOPOLOGY FOR 15 MEMBERS DENSE DISTRIBUTIONS	140

FIGURE 6.22 TOPOLOGY FOR 20 MEMBERS DENSE DISTRIBUTIONS 140

FIGURE 6.23 TOPOLOGY FOR 25 MEMBERS DENSE DISTRIBUTIONS 141

FIGURE 6.24 TOPOLOGY FOR 10 MEMBERS SPARSE DISTRIBUTIONS 141

FIGURE 6.25 TOPOLOGY FOR 15 MEMBERS SPARSE DISTRIBUTIONS 142

FIGURE 6.26 TOPOLOGY FOR 20 MEMBERS SPARSE DISTRIBUTIONS 142

FIGURE 6.27 TOPOLOGY FOR 25 MEMBERS SPARSE DISTRIBUTIONS 143

FIGURE 6.28 JOIN LATENCY VERSUS NUMBER OF MEMBERS IN DENSE DISTRIBUTION AND SPARSE
DISTRIBUTION 145

FIGURE 6.29 TRAFFIC CONCENTRATIONS VERSUS NUMBER OF MEMBERS IN DENSE DISTRIBUTION AND
SPARSE DISTRIBUTION 146

FIGURE 6.30 PROTOCOL OVERHEAD VERSUS NUMBER OF MEMBERS IN DENSE DISTRIBUTION AND
SPARSE DISTRIBUTION 148

List of Tables

TABLE 2.1 ASSIGNMENT OF MULTICAST ADDRESS FROM IANA 13

TABLE 2.2 METHOD IN JAVASIM 44

TABLE 2.3 METHODS IN SIMEVENT 45

TABLE 2.4 PROPERTIES IN SIMCOMPONENT 46

TABLE 2.5 METHODS IN SIMCOMPONENT 46

TABLE 2.6 IMPORTANT OVERRIDES IN SIMPARAMETER 47

TABLE 3.1 IGMP VARIABLE AND COUNT 52

TABLE 3.2 LIST OF IGMP TIMER INTERVALS 53

TABLE 3.3 LIST OF IGMP TIMERS FOR HOST 53

TABLE 3.4 LIST OF IGMP TIMERS FOR ROUTER 54

TABLE 3.5 CONTROL MESSAGE TYPES FOR BOTH PIM-SM AND PIM-DM 58

TABLE 3.6 TIMERS IN PIM-DM 60

TABLE 3.7 IMPORTANT PARAMETERS IN PIM-DM 61

TABLE 3.8 TIMER EXPIRATION AND RESPONSE 67

TABLE 4.1 DESCRIPTIONS OF FUNCTIONS FOR EACH MODULE 72

TABLE 5.1 SIMULATION COMPONENTS 103

TABLE 6.1 RESULTS AND ANALYSIS OF VALIDATION TEST FOR MULTICASTDATAAPP 110

TABLE 6.2 RESULTS OF VALIDATION TEST FOR IPMULTICASTAPP 112

TABLE 6.3 INPUT PARAMETERS FOR SCENARIO 2 119

TABLE 6.4 INPUT PARAMETERS FOR SCENARIO 4 125

TABLE 6.5 RESULTS FOR TREE ESTABLISHMENT AND MULTICAST PACKETS FORWARDING TEST 129

TABLE 6.6 INPUT PARAMETERS FOR SCENARIO 2 134

TABLE 6.7 RESULTS RECORDED AT 180 SECONDS IN SCENARIO 2 135

TABLE 6.8 PERFORMANCE PARAMETERS FOR EVALUATING MULTICAST ROUTING PROTOCOL 137

Abbreviations

API	Application Programming Interface
ARP	Address Resolution Protocol
ATM	Asynchronous Transfer Mode
B-TE	Broadband Terminal Equipment
CBT	Core Based Trees
DVMRP	Distance Vector Multicast Routing Protocol
GenID	Generation Identifier
GUI	Graphical User Interface
HFC	Hybrid Fiber Coax
IANA	Internet Assigned Numbers Authority
ICMP	Internet Control Message Protocol
IGMP	Internet Group Management Protocol
INSANE	Internet Simulated ATM Networking Environment
IP	Internet Protocol
JVM	Java Virtual Machine
LAN	Local Area Network
MBONE	Multicast Backbone
MOSPF	Multicast Extension for Open Shortest Path First
NIST	National Institute of Standards and Technology of United State
OMNET++	Objective Modular Network Test Bed in C++
OPNET	Optimised Network Engineering Tool
OSPF	Open Shortest Path First
PARSEC	Parallel Simulation Environment for Complex System
PIM-DM	Protocol Independent Multicast – Dense Mode
PIM-SM	Protocol Independent Multicast – Sparse Mode
RARP	Reverse Address Resolution Protocol
RPB	Reverse Path Broadcasting
RPF	Reverse Forwarding Path

RPM	Reverse Path Multicasting
TRPB	Truncated Reverse Path Broadcasting
TV	Television
WAN	Wide Area Network