CONTENTS

ABSTRACT I

ACKNOWLEDGEMENT II

CONTENTS III

LIST OF FIGURES VIII

LIST OF TABLES X

ABBREVIATIONS XII

CHAPTER 1 1

INTRODUCTION 1

1.1 ANYCAST SERVICE FOR THE INTERNET PROTOCOL VERSION 6 (IPV6) 1

1.2 ANYCAST ROUTING 2

1.3 MOTIVATION 2

1.4 THESIS OBJECTIVES 3

1.5 THESIS SCOPE 3

1.6 THESIS ORGANIZATION 5

CHAPTER 2 7

INTERNET PROTOCOL VERSION 6 (IPV6) 7

2.1 MOTIVATION 7

2.2 IPV6 FEATURES 10

2.3 DIFFERENCES BETWEEN IPV4 AND IPV6 14

2.4 IPV6 FORMATS AND FUNCTIONS 15

2.4.1 IPv6 Packet *15*

2.4.2 IPv6 Header *16*

2.4.3 Differences between the IPv4 and IPv6 headers *17*

2.4.4 Extension Headers *18*

2.5 IPV6 ADDRESSING ARCHITECTURE 21

2.5.1 Issues in current IPv4 Addressing Architecture *21*

2.5.2 IPv6 Addressing *22*

2.5.3 Addressing Model *23*

2.5.4 Address Type Specification *24*

2.5.5 IPv6 Prefixes *25*

2.5.6 Unicast Address *25*

2.5.7 Multicast Address *30*

2.5.8 Anycast Address *32*

CHAPTER 3 ..... **34**

MULTICAST TREES **34**

3.1 MULTICAST LISTENER DISCOVERY (MLD) 34

3.2 MULTICAST DISTRIBUTION TREES 36

3.2.1 Source-based Tree *36*

3.2.2 Shared Tree *38*

3.3 MULTICAST ROUTING PROTOCOLS 39

3.3.1 Distance Vector Multicast Routing Protocol (DVMRP) *39*

3.3.2 Multicast Open Shortest Path First (MOSPF) *41*

3.3.3 Core Based Tree (CBT) *42*

3.3.4 Protocol Independent Multicast Version 2 (PIM) *43*

CHAPTER 4 47

FUZZ SET THEORY AND FUZZY LOGIC CONTROL 47

4.1 FUZZY LOGIC 47

4.2 FUZZY SETS 48

4.3 FUZZY SET OPERATIONS 49

4.4 LINGUISTIC VARIABLES AND FUZZY IF-THEN RULES 50

4.5 FUZZY IF-THEN RULES 51

4.6 FUZZY LOGIC CONTROLLER 52

4.7 FUZZY RULE BASE 52

4.8 FUZZY INFERENCE ENGINE 52

4.9 FUZZIFIER 53

4.10 DEFUZZIFIERS 54

CHAPTER 5 57

ANYCASTING 57

5.1 BENEFITS OF ANYCASTING 57

5.2 ISSUES OF ANYCASTING 58

5.2.1 Limitations / Properties in the current Protocols 58

5.2.2 Upper Layer Protocol Issues 60

5.3 WORKS ON ANYCASTING 61

CHAPTER 6 64

PROPOSED NEAREST PIM-SM EXTENSION 64

6.1 RIPNG EXTENSION 64

6.2 PIM-SM EXTENSION 65

6.3 PROPOSED NEAREST PIM-SM EXTENSION 67

6.4 LOAD-BALANCING SCHEME 69

CHAPTER 7 77

SIMULATION ENVIRONMENT FOR ANYCAST ROUTING 77

7.1 PHASES OF IMPLEMENTATIONS 77

7.2 OVERVIEW OF SIMULATION ENVIRONMENTS 78

7.3 NETWORK SIMULATION COMPONENTS 79

7.4 OBJECTS AND CLASSES 81

7.5 TESTING AND IMPLEMENTATION 83

7.5.1 Neighbor Discovery and Stateless Autoconfiguration 84

7.5.2 RIPng 86

7.5.3 RIPng extension 88

7.5.4 PIM-SM extension 92

7.5.5 Load-balancing Scheme 94

7.5.6 Nearest PIM-SM extension 97

CHAPTER 8 100

PERFORMANCE EVALUATION OF THE PROPOSED NEAREST PIM-SM EXTENSION FOR ANYCAST ROUTING 100

8.1 SIMULATIONS RESULTS 100

8.1.1 End-To-End Delay 106

8.1.2 Packet Loss Percentage 122

8.1.3 Summary 129

CHAPTER 9 131

CONCLUSIONS AND FUTURE WORK 131

9.1 SUMMARY OF CONTRIBUTIONS 131

9.2 SUGGESTIONS FOR FUTURE RESEARCH 132

REFERENCES 134

LIST OF FIGURES

FIGURE 2.1 IPv6 PACKET WITH ALL EXTENSION HEADERS 15

FIGURE 2.2 IPv4 AND IPv6 HEADER 16

FIGURE 2.3 IPv6 EXTENSION HEADERS 19

FIGURE 2.4 IPv4 ADDRESS CLASSES 22

FIGURE 2.6 AGGREGATION-BASED IP ADDRESSES 27

FIGURE 2.7 SUBDIVIDING THE NLA ADDRESS SPACE 28

FIGURE 2.8 THE IPv6 MULTICAST ADDRESSES 30

FIGURE 2.9 THE MODIFIED IPv6 MULTICAST ADDRESS USING A 32-BIT GROUP ID 32

FIGURE 2.10 THE SUBNET-ROUTER ANYCAST ADDRESS 33

FIGURE 3.1 THE TREE ESTABLISHMENT PROCESSES FOR SOURCE-BASED TREE 37

FIGURE 3.2 TREE ESTABLISHMENT PROCESSES FOR SHARED TREE 38

FIGURE 3.3 TREE ESTABLISHMENT PROCESSES FOR DVMRP 40

FIGURE 3.4 THE TREE ESTABLISHMENT PROCESSES FOR MOSPF 41

FIGURE 3.5 TREE ESTABLISHMENT PROCESSES FOR CORE BASED TREE 43

FIGURE 3.6 TREE ESTABLISHMENT PROCESSES FOR PIM-SM 45

FIGURE 4.1 THE BASIC STRUCTURE OF A FUZZY LOGIC CONTROLLER (FLC) 52

FIGURE 6.1 A SCENARIO OF RIPNG EXTENSION FOR ANYCAST ROUTING 65

FIGURE 6.2 DEFINITIONS FOR FUNCTIONS F(.) AND G(.) 71

FIGURE 6.3 THE MEMBERSHIP FUNCTION OF THE TERM SET $T_j(Q)$ 71

FIGURE 6.4 THE MEMBERSHIP FUNCTION OF THE TERM SET $T(\Delta Q)$ 72

FIGURE 6.5 THE MEMBERSHIP FUNCTION OF THE TERM SET T(Y) 73

FIGURE 6.6 THE PRODUCT-SUM INFERENCE METHOD 75

FIGURE 7.1 JANETSIM NETWORK SIMULATOR OBJECTS 78

FIGURE 7.2 TOPOLOGY USED IN TESTING NEIGHBOR DISCOVERY AND STATELESS AUTONCONFIGURATION IN IPv6 84

FIGURE 7.3 TOPOLOGY USED FOR TESTING RIPNG 86

FIGURE 7.4 TOPOLOGY USED IN TESTING RIPNG EXTENSION FOR ANYCAST 89

FIGURE 7.5 TOPOLOGY USED IN TESTING PIM-SM EXTENSION 92

FIGURE 7.6 TOPOLOGY USED IN TESTING LOAD-BALANCING SCHEME UNDER NORMAL CONDITION 94

FIGURE 7.7 TOPOLOGY USED IN TESTING FUZZY SHORTEST PATH IN CONGESTION 95

FIGURE 7.8 TOPOLOGY USED IN TESTING NEAREST PIM-SM EXTENSION 97

FIGURE 8.1 MCI TOPOLOGY 100

FIGURE 8.2 TOPOLOGY A 104

FIGURE 8.3 TOPOLOGY B 104

FIGURE 8.4 TOPOLOGY C 105

FIGURE 8.5 TOPOLOGY D 105

FIGURE 8.6 TOPOLOGY E 106

FIGURE 8.7 AVERAGE END-TO-END DELAY VS. NUMBER OF SOURCES FOR TOPOLOGY A 108

FIGURE 8.8 AVERAGE END-TO-END DELAY VS. NUMBER OF SOURCES FOR TOPOLOGY B 111

FIGURE 8.9 AVERAGE END-TO-END DELAY VS. NUMBER OF SOURCES FOR TOPOLOGY C 114

FIGURE 8.10 AVERAGE END-TO-END DELAY VS. NUMBER OF SOURCES FOR TOPOLOGY D . 117

FIGURE 8.11 AVERAGE END-TO-END DELAY VS. NUMBER OF SOURCES FOR TOPOLOGY E .. 120

FIGURE 8.12 PACKET LOSS PERCENTAGE (%) VS. NUMBER OF SOURCES FOR TOPOLOGY A . 123

FIGURE 8.13 PACKET LOSS PERCENTAGE (%) VS. NUMBER OF SOURCES FOR TOPOLOGY B . 124

FIGURE 8.14 PACKET LOSS PERCENTAGE (%) VS. NUMBER OF SOURCES FOR TOPOLOGY E.. 127

TABLE 7.22 SIMULATION RESULTS FOR TESTING SHORTEST-PATH SCHEME UNDER NORMAL CONDITION 96

TABLE 7.23 SIMULATION RESULTS FOR TESTING SHORTEST-PATH SCHEME IN CONGESTION 96

TABLE 7.24 SIMULATION RESULTS USING PIM-SM EXTENSION 98

TABLE 7.25 SIMULATION RESULTS USING NEAREST PIM-SM EXTENSION 98

TABLE 8.1 VBR SOURCE CHARACTERISTICS 101

TABLE 8.2 ANYCAST SERVICE PROVIDER'S SOURCE CHARACTERISTICS 101

TABLE 8.3 ANYCAST ROUTING SCHEMES AND ITS MODE 102

TABLE 8.4 AVERAGE END-TO-END DELAY FOR EACH SIMULATION SESSIONS IN TOPOLOGY A .. 107

TABLE 8.5 AVERAGE END-TO-END DELAY FOR EACH SIMULATION SESSIONS IN TOPOLOGY B .. 110

TABLE 8.6 AVERAGE END-TO-END DELAY FOR EACH SIMULATION SESSIONS IN TOPOLOGY C .. 113

TABLE 8.7 AVERAGE END-TO-END DELAY FOR EACH SIMULATION SESSIONS IN TOPOLOGY D .. 116

TABLE 8.8 AVERAGE END-TO-END DELAY FOR EACH SIMULATION SESSIONS IN TOPOLOGY E .. 119

TABLE 8.9 PACKET LOSS PERCENTAGE (%) FOR EACH SIMULATION SESSIONS IN TOPOLOGY A .. 122

TABLE 8.10 PACKET LOSS PERCENTAGE (%) FOR EACH SIMULATION SESSIONS IN TOPOLOGY B .. 124

TABLE 8.11 PACKET LOSS PERCENTAGE (%) FOR EACH SIMULATION SESSIONS IN TOPOLOGY E .. 126

ABBREVIATIONS

ARP	Address Resolution Protocol
ATM	Asynchronous Transfer Mode
ATM LSR	Asynchronous Transfer Mode Label Switching Router
BGP	Border Gateway Protocol
BSR	BootStrap Router
B-TE	Broadband Terminal Equipment
CBT	Core Based Tree
CIDR	Classless Inter-Domain Routing
C-RP	Candidate-Rendezvous Point
DES-CBC	Data Encryption Standard-Cipher Block Chaining
DNS	Domain Name System
DNSSEC	Domain Name System Security
DHCP	Dynamic Host Configuration Protocol
DR	Designated Router
DVMRP	Distance Vector Multicast Routing Protocol
EIGRP	Enhanced Interior Gateway Routing Protocol
ESP	Encapulating Security Payload
EUI-64	64-bit Extended Unique Identifier
FLC	Fuzzy Logic Controller
FP	Format Prefix
GIA	Global Internet Protocol-Anycast
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force

IGMPv2	Internet Group Management Protocol Version 2
IGMPv3	Internet Group Management Protocol Version 3
IKE	Internet Key Exchange
IP	Internet Protocol
IPsec	Internet Protocol Security
IPv6	Internet Protocol Version 6
IPv4	Internet Protocol Version 4
IPX	Internetwork Packet Exchange
ISP	Internet Service Provider
ICMPv4	Internet Control Message Protocol Version 4
ICMPv6	Internet Control Message Protocol Version 6
LAN	Local Area Network
MAC	Media Access Control
MLD	Multicast Listener Discovery
MLDv2	Multicast Listener Discovery Version 2
MOSPF	Multicast Open Shortest Path First
MTU	Maximum Transmission Unit
NAT	Network Address Translator
NLA	Next-level Aggregators
ND	Neighbor Discovery
NSAP	Network Service Access Point
NTP	Network Time Protocol
OSPF	Open Shortest Path First
PDU	Protocol Data Unit

PIM	Protocol Independent Multicast
PIM-SM	Protocol Independent Multicast – Sparse Mode
PIM-DM	Protocol Independent Multicast – Dense Mode
RP	Rendezvous Point
RPF	Reverse-path Forwarding
SPT	Shortest Path Tree
QoS	Quality of Service
RIPng	Routing Information Protocol next generation
RSVP	Resource ReSerVation Protocol
SLA	Site-level Aggregators
TCP	Transmission Control Protocol
TLA	Top-level Aggregators
TLV	Type-length-value
TOS	Type of Service
UDP	User Datagram Protocol
VBR	Variable Bit Rate
WAN	Wide Area Network