

# Supporting Quality of Service for Internet Applications

A thesis presented for the degree of  
**Master of Science Research**



Department of Computer Systems  
Faculty of Information Technology  
University of Technology, Sydney  
Australia

October, 2006

# Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree, except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of candidate

Production Note:  
Signature removed prior to publication.

**Ha Trung, Phan**

## Publications

H. T. Phan and D. B. Hoang, “A New QoS Architecture Supporting Resources Discovery, Admission and Congestion Controls”, *IEEE International Conference on Information Technology and Applications (ICITA05)*, 04-07 July 2005.

H. T. Phan, D. B. Hoang, and B. Yousef, “Performance Analysis of FICC-DiffServ Architecture”, *IEEE Conference on Local Computer Networks (LCN05)*, 15-17 November 2005.

H. T. Phan and D. B. Hoang, “Extension of BGP to support multi-domain FICC-Diffserv architecture”, *IEEE Conference on Advanced Information Networking and Applications (AINA06)*, 18-20 April 2006.

# Declaration

The work in this thesis is based on research carried out with the Advanced Research in Networking Group (ARN), the Department of Computer Systems, Faculty of Information Technology, University of Technology Sydney, Australia. No part in this thesis has been submitted elsewhere for any other degree or qualification and it is all my own work, unless referenced to the contrary in the text.

# Acknowledgments

I would like to acknowledge all the help and encouragement I have received in my Master of Science studies. I am especially grateful to my supervisor, Professor Doan B. Hoang, for teaching me how to be an independent researcher, for his continuous support and encouragement, and for his guidance throughout the years. Thanks for his valuable instructions and ideas regarding the research and his continuous and patient advising regarding my academic writing.

I would like to express my sincere thanks to the people in the Advanced Research Networking Lab (ARN). Many thanks to Bushar Yousef for his co-operation in the research of programmable router architecture and Hanh Le, Joe Chan for the discussion about the overlay network.

I would like to express the gratitude to my wife, who was always behind me and gave me support to make my study run smoothly.

I dedicate this thesis to my mom, who has been the main driving force behind my research work.

---

# Table of Content

Certificate of Authorship/Originality .....	i
Publications.....	ii
Declaration.....	iii
Acknowledgments .....	iv
Table of Content .....	v
List of Tables .....	viii
List of Figures.....	ix
List of Acronyms .....	xi
Abstract.....	xiii
Chapter 1. Introduction.....	1
1.1. Motivation .....	1
1.2. Problems .....	2
1.2.1. Intra-domain Problems.....	2
1.2.2. Inter-domain Problems.....	3
1.3. Contributions .....	5
1.3.1. Fair Intelligent Congestion Control DiffServ.....	5
1.3.2. QoS-BGP Extension for FICC-DiffServ Negotiation.....	6
1.4. Thesis Organisation.....	7
Chapter 2. Background and Related Work.....	8
2.1. Supporting QoS over the Internet.....	8
2.1.1. History of Internet QoS.....	8
2.1.2. Integrated Services (IntServ).....	10
2.1.3. Differentiated Services (DiffServ) .....	12
2.1.4. Multi-Protocol Label Switching (MPLS).....	15
2.2. QoS Enhancement in DiffServ .....	18
2.2.1. IntServ over DiffServ .....	18
2.2.2. Resource Discovery and Fair Intelligent Admission Control .....	19
2.2.3. Bandwidth Broker .....	20
2.3. BGP Extension for QoS Negotiation.....	21

Chapter 3. Fair Intelligent Congestion Control DiffServ Architecture .....	24
3.1. Overall System Structure.....	24
3.2. Fair Intelligent Congestion Control Algorithm.....	27
3.2.1. Target Operating Point ( $Q_0$ ) .....	28
3.2.2. Mean Allowed Class Rate (MACR) .....	29
3.2.3. Queue Control Function $f(Q)$ .....	29
3.2.4. Explicit Rate (ER) .....	31
3.3. Resource Discovery Protocol .....	31
3.4. Admission Control.....	33
3.4.1. Arrival Rate Computation .....	34
3.4.2. Class-level Admission Control.....	35
3.4.3. Flow-level Admission Control.....	35
3.5. Summary.....	37
Chapter 4. FICC-DiffServ Performance Analysis.....	39
4.1. Concepts .....	39
4.2. Simulation Environment.....	40
4.3. The Fairness.....	42
4.3.1. Packet Size Issue .....	42
4.3.2. Round-Trip Time (RTT) Issue .....	44
4.3.3. Type of Traffic .....	45
4.4. Network Topology Issue .....	46
4.4.1. Chain Configuration.....	46
4.4.2. Parking-lot Configuration .....	50
4.5. QoS Parameters Comparison.....	54
4.5.1. Average Packet Delay .....	54
4.5.2. Packet Jitter .....	55
4.5.3. Queue Length .....	56
4.5.4. Goodput.....	56
4.6. Effects of the Parameters.....	57
4.6.1. ER Calculation Frequency .....	57
4.6.2. Packet Size .....	59

## Table of Content

---

4.6.3. Target Operating Point Q0 .....	60
4.7. Summary.....	62
Chapter 5. BGP Extension to Support Multi-domain for FICC DiffServ ....	63
5.1. Border Gateway Protocol (BGP).....	63
5.1.1. Routing Information Exchange .....	64
5.1.2. Update Message Handling .....	65
5.2. QoS-BGP Implementation.....	67
5.2.1. New Explicit Rate (ER) Attribute .....	67
5.2.2. BGP Routing Table .....	68
5.2.3. QoS Route Selection .....	68
5.2.4. QoS Route Aggregation .....	69
5.2.5. QoS Information Update .....	69
5.2.6. BGP Overhead Reduction .....	71
5.3. Simulation Study .....	71
5.3.1. Network Performance .....	72
5.3.2. Effect of Exponential Smoothing Function.....	74
5.3.3. Effect of Thresholds on BGP Overhead.....	74
5.3.4. Traffic Engineering .....	75
5.4. Summary.....	77
Chapter 6. Conclusion and Future Work .....	78
6.1. Conclusion .....	78
6.2. Future Work.....	79
References.....	81



## List of Tables

Table 2-1. DSCP Allocation table .....	13
Table 4-1. Parameter values .....	41
Table 4-2. Chain topology – packet statistic in normal DiffServ .....	49
Table 4-3. Parkinglot – packet statistic in normal DiffServ .....	53
Table 4-4. Overhead calculation.....	58
Table 4-5. The range of packet size.....	59

# List of Figures

Figure 2-1. QoS signaling in IntServ domain.....	11
Figure 2-2. DiffServ architecture.....	12
Figure 2-3. MPLS architecture .....	16
Figure 2-4. IntServ over DiffServ model.....	18
Figure 2-5. Li's enhanced DiffServ model.....	19
Figure 3-1. FICC DiffServ Architecture.....	24
Figure 3-2. FICC queue length pattern .....	28
Figure 3-3. Mean Allowed Class Rate calculation .....	29
Figure 3-4. Queue control function $f(Q)$ .....	30
Figure 3-5. ER calculation pseudocode.....	31
Figure 3-6. RD protocol model.....	32
Figure 3-7. RD packet format.....	32
Figure 3-8. Admission Control components.....	34
Figure 3-9. Flow-level admission control.....	36
Figure 3-10. Mean Allowed Flow Rate Calculation.....	36
Figure 4-1. Peer-to-peer network configuration .....	41
Figure 4-2. Class-level fairness – different packet sizes .....	43
Figure 4-3. Flow-level fairness – different packet sizes.....	43
Figure 4-4. Class-level fairness – different RTT .....	44
Figure 4-5. Flow-level fairness – different RTT .....	44
Figure 4-6. Class-level fairness – different types of traffic .....	45
Figure 4-7. Flow-level fairness – different types of traffic .....	45
Figure 4-8. Chain configuration .....	47
Figure 4-9. Chain topology – TCP traffic throughput in normal DiffServ ...	47
Figure 4-10. Chain topology – TCP traffic throughput in FICC-DiffServ....	48
Figure 4-11. Chain topology – UDP traffic throughput in normal DiffServ .	48
Figure 4-12. Chain topology – UDP traffic throughput in FICC-DiffServ ...	48
Figure 4-13. Chain topology - bandwidth allocation.....	49
Figure 4-14. Parking-lot configuration.....	50

Figure 4-15. Parking lot – TCP traffic throughput in normal DiffServ.....	51
Figure 4-16. Parking lot – TCP traffic throughput in FICC-DiffServ.....	51
Figure 4-17. Parking lot – UDP traffic throughput in normal DiffServ.....	52
Figure 4-18. Parking lot – UDP traffic throughput in FICC DiffServ .....	53
Figure 4-19. Parking lot – bandwidth allocation comparison .....	53
Figure 4-20. Average packet delay.....	54
Figure 4-21. Packet jitter .....	55
Figure 4-22. Queue Length.....	56
Figure 4-23. Goodput comparison.....	57
Figure 4-24. Different ER calculation frequencies.....	58
Figure 4-25. Traffic goodput in different packet sizes .....	59
Figure 4-26. Queue length in different packet sizes .....	60
Figure 4-27. Balance between fairness and packet delay, jitter .....	61
Figure 4-28. $Q_0$ and Queue length with different packet sizes .....	61
Figure 5-1. Intra-domain and inter-domain routing protocols.....	63
Figure 5-2. UPDATE message handling .....	66
Figure 5-3. Explicit Rate attribute .....	67
Figure 5-4: BGP routing table extension.....	68
Figure 5-5. Multi-domain network configuration.....	72
Figure 5-6. Gold throughput in AS2.....	72
Figure 5-7. Gold throughput in AS1 with BGP.....	73
Figure 5-8. Gold throughput in AS1 without BGP.....	73
Figure 5-9. Explicit Rate comparison.....	74
Figure 5-10. Overhead reduction – ER threshold.....	74
Figure 5-11. Overhead reduction – RA threshold .....	75
Figure 5-12. Network topology for traffic engineering .....	76
Figure 5-13. Traffic throughput comparison .....	76

## List of Acronyms

ABI	Available Bandwidth Index
AC	Admission Control
ACR	Allowed Class Rate
AF	Assured Forwarding
AFR	Arrival Flow Rate
AS	Autonomous System
BB	Bandwidth Broker
BGP	Border Gateway Protocol
CL	Controlled Load
COS	Class of Service
CPU	Central Processing Unit
CSFQ	Core-Stateless Fair Queuing
DiffServ	Differentiated Services
DSCP	DiffServ Code Point
EF	Expedited Forwarding
ER	Explicit Rate
FEC	Forwarding Equivalence Class
FER	Per-Flow Explicit Rate
FIAC	Fair Intelligent Admission Control
FICC	Fair Intelligent Congestion Control
FIFO	First-In First Out
GS	Guarantee Services
IANA	Internet Assigned Numbers Authority
IETF	Internet Engineering Task Force
IGP	Interior Gateway Protocol
IntServ	Integrated Services
IP	Internet Protocol
ISP	Internet Service Provider
LDP	Label Distribution Protocol

## List of Acronyms

---

LSP	Label Switch Path
LSR	Label Switch Router
MACR	Mean Allowed Class Rate
MAFR	Mean Arrival Flow Rate
MED	Multi Exit Disc (BGP Attribute)
MIB	Management Information Base
MPLS	MultiProtocol Label Switching
NE	Network Elements
NLRI	Network Layer Reachability Information
OSPF	Open Shortest Path First
PHB	Per-hop Forwarding Behaviour
P2P	Peer-to-Peer
QoS	Quality of Service
QPPB	QoS Policy Propagation via BGP
RD	Resource Discovery
RED	Random Early Drop
RFC	Request For Comment
RIB	Route Information Base
RIP	Routing Information Protocol
RSVP	Resource Reservation Protocol
RTT	Round-Trip Time
SLA	Service Level Agreement
TCP	Transmission Control Protocol
TOS	Type of Service
UDP	User Datagram Protocol
WRR	Weighted Round Robin

# Abstract

Regarding the dominance of IP applications and the requirement of providing quality of service for users, it is critical to provide an scalable network architecture capable of supporting sufficient Quality of Service (QoS). Of the two network models (Integrated Services and Differentiated Services) approved by the Internet Engineering Task Force (IETF) [1, 2], the differentiated service model has gained wider acceptance because of its scalability.

Differentiated Services (DiffServ) QoS architecture is scalable but inadequate to deal with network congestion and unable to provide fairness among its traffic aggregates. Recently, IETF has recommended additional functions including admission control and resource discovery to enhance the original DiffServ [2].

In this thesis, we propose a new framework based on DiffServ. The new architecture, called Fair Intelligent Congestion Control DiffServ (FICC-DiffServ), applies the FICC algorithm and control loop to provide fairness among traffic aggregates and control congestion inside DiffServ networks. The augmented architecture is realisable within the existing IP network infrastructures. Simulation results show that the FICC-DiffServ performs excellently in terms of guaranteed fairness, minimised packet delay and jitter, as well as being robust to traffic attributes, and being simple to implement.

Moreover, providing end-to-end QoS for Internet applications presents difficult problems, because the Internet is composed of many independently administrative domains called Autonomous Systems. Enabling end-to-end QoS, negotiations between domains is then crucial. As a means of negotiations, inter-autonomous system QoS routings play an important role in advertising the available network resources between domains. In this thesis, the Border Gateway Protocol (BGP) is extended to provide end-to-end QoS. The BGP is selected for two reasons: (1) BGP is an inter-domain routing protocol widely used on the Internet and (2) the use of attributes attached to routes makes BGP be a powerful and scalable inter-domain routing protocol.

For end-to-end QoS, a completed framework includes a FICC-DiffServ in each domain, an extended BGP between domains and an admission control at the edge router. Via simulation, we demonstrate the reliability of the BGP-extended architecture, including route selection policy and overhead reduction issues.