Resolving Competition for Resources between Multimedia and Traditional Internet Applications

Suntorn Witosurapot

School of Biophysical Sciences and Electrical Engineering

Swinburne University of Technology Melbourne, Australia

Thesis Submitted for the Degree of Doctor of Philosophy JULY, 2004

ABSTRACT

Although the Internet is the dominant broadband network, it still has a fundamental shortcoming in traffic management that does not properly support efficient use of resources together with differentiated quality of service for mixed traffic types. Even though a number of mechanisms have been proposed under key approaches of resource adaptation, resource reservation, and resource pricing, this problem remains unsolved to date because of its complexity and the way it relates to so many considerations of engineering and economics, and the diverse range of services desired by users. Hence it is considered difficult to devise a perfect mechanism that can universally solve this problem. In this respect, this dissertation contributes to insights into potential combinations and trade-offs of key approaches above in some efficient manner for managing traffic and scarce resources in the Internet.

The first part of this work considers the combination of relaxed resource reservation and resource pricing schemes for handling the unfair bandwidth distribution problem in soft-bandwidth guarantee services of the Differentiated Services (DiffServ) Internet. We show that this unfairness problem can be handled using a network-user cooperative approach that addresses both individual user satisfaction and global optimization. We propose to add a mechanism based on price-based feedback signaling to DiffServ-capable routers providing Assured Forwarding (AF) Service so that they can offer perflow signaling. This still allows them to work at an aggregate traffic level, hence the scalability feature of the DiffServ network can be retained. Our proposed mechanism allows the network to offer reliable service assurances via a distributed optimization algorithm, without introducing special protocols or requiring routers to have access of individual user requirements. Moreover, it can provide incentives for users to cooperate so that optimum performance can be accomplished. This approach has broad applicability and is relevant to all types of assured service classes.

The second part of this work considers the combination of a specific resource pricing scheme based on a distributed optimization algorithm and multimedia adaptation schemes. Such a capability has not been available because most utility functions of multimedia applications do not meet the concavity constraints required by optimization algorithm. We proposed to overcome this limitation by redefining user utility functions

into equivalent discrete forms and using combinatorial (discrete) optimization so that interfacing the resource-pricing scheme can be done in a normal way. However, to obtain feasible solutions in a scalable manner, an agent is included into the scheme for solving the combinatorial (discrete) optimization on behalf of a small group of users. In return, all users belonging to this group can benefit from social welfare maximization of their utilities over a network resource constraint.

The last part of this work considers the combination of relaxed resource reservation and resource pricing schemes to enable a proper charging scheme for adaptive applications in the DiffServ Internet. We provide an optimization formulation of the problems of revenue and social welfare maximization, applied at a service provider (SP) who gives access to the DiffServ Internet. In this scheme, resources are provisioned per QoS-oriented class in a long time scale (service level agreement (SLA) duration), then priced based on user demand in the short time scale. We also show that the proposed charging scheme can provide feedback and incentives for users to use the network resource optimally via the standard packet marking, hence eliminating the need for specific pricing protocol.

All of the proposals in this work can be used together, solving these key problems as a coordinated whole, and all use readily available network mechanisms.

ACKNOWLEDGEMENT

I am extremely grateful to Associate Professor Jim Lambert, my thesis supervisor and Dr. Iradj Ouveysi, my coordinating supervisor, for providing me the excellent guidance and support during my graduate studies. Their engaging arguments and strong feedback have contributed greatly to this dissertation. I hope and look forward to continued collaboration with them in the future.

I also would like to express my thanks to the Thai government and in particular the Minister Counsellor (Education) and officers at Office of Educational Affairs in Canberra and Bangkok, for providing the scholarship support without which this work would not have been possible.

DECLARATIONS

The term "we" is used in this thesis in preference to the personal pronoun "I" or writing in the third person. This is a matter of style only and does not indicate any assistance in performing this study except where due reference is made in the text of the thesis.

I declare that the thesis described herein contains no material which has been accepted for the award to myself of any other degree or diploma, and that, to the best of my knowledge, the thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

Signed:

Suntorn Witosurapot July 2004

PUBLICATIONS RELATED TO THE WORK PRESENTED IN THIS DISSERTATION

- 1. S. Witosurapot, J. Lambert and I. Ouveysi, "Combinatorial Approach to Optimization Flow Control", The Sixth Annual Melbourne-Adelaide Teletraffic Workshop, Grampians, December 2001.
- S. Witosurapot, J. Lambert and I. Ouveysi, "Optimization Flow Control for Aggregate Traffic Handling in the Differentiated Services Internet", IEEE International Conference on Computer and Communications (ICC 2002), NewYork, USA, April 2002.
- S. Witosurapot, J. Lambert and I. Ouveysi, "Scalable Extension for Per-flow Signaling in Differentiated Services Internet", Technical Report, Swinburne University of Technology, September 2001.
- 4. S. Witosurapot, J. Lambert and I. Ouveysi, "Combinatorial Approach to Optimization Flow Control", Technical Report, Swinburne University of Technology, February 2002.
- 5. S. Witosurapot, J. Lambert and I. Ouveysi, "Combinatorial Approach to Optimization Flow Control", International Symposium on Communications and Information Technology (ISCIT 2002), Pattaya, Thailand, October 2002.

TABLE OF CONTENTS

Abstract	i
Acknowledgement	iii
Declarations	iv
Table of Contents	vi
List of Illustrations	ix
List of Tables	xi
Chapter 1 Introduction	1
1.1 Background	1
1.2 Motivation for Research Approach	3
1.3 Problem Statement	5
1.3.1 Problem of Fairness in Differentiated Services Internet	5
1.3.2 Problem of Discrete Form Utility Functions	<i>6</i>
1.3.3 Problem of Resource Reservation and Connection Admissio	n Control6
1.4 Contributions	7
1.5 Dissertation Outline	g
Chapter 2 Literature Review	11
2.1 Introduction	11
2.2 Optimization-based Flow Control	14
2.3 Approaches Proposed in this work	19
Chapter 3 Price-based Fairness and the Differentiated Services In	nternet21
3.1 Introduction	21
3.2 Background And Related Work	22
3.3 The Proposed Architecture and Assumptions	24
3.3.1 Overall System Architecture	25
3.3.2 REM Optimization Flow Control Scheme	26
3 3 3 Assumption on User Utility Functions	28

3.4 Simulation Results	8
3.4.1 Simulation Setup	0
3.4.2 Experiment 1: Fairness among sources with the same round trip time 3	2
3.4.2 Experiment 2: Fairness among sources with different round trip times 3	5
3.5 Conclusions	6
Chapter 4 Combinatorial Approach to Optimization-based Flow Control3	7
4.1 Introduction	7
4.2 Discrete Form Utility Optimization and its Implications	9
4.3 Background on REM Optimization Flow Control Framework4	1
4.3.1 Network Optimization Sub-problem4	1
4.3.2 User Optimization Sub-problem4	2
4.4 Agent Model and Algorithm4	2
4.4.1 Agent-Network Optimization Sub-problem4	3
4.4.2 Agent-User Optimization Sub-problem4	4
4.4.2.1 Definition of a Piecewise-Linear Utility Function4	5
4.4.2.2 Saparable Programming Model4	5
4.5 Simulation4	6
4.5.1 Fluid Model of TCP Flows and REM Router4	3
4.5.2 Extension to Support User Agent5	0
4.5.3 Simulation Results5	2
4.6 Conclusions	5
Chapter 5 Adaptive Pricing Service for the Differentiated Services Internet5	6
5.1 Introduction5	6
5.2 The Model and Assumptions5	7
5.3 A Proposed Pricing Scheme5	9
5.3.1 Base Price5	9
5.3.2 Congestion-control Price	1
5.4 Related Work6	2
5.5 Discussion and Conclusions	3

Chapter 6 Conclusions and Future Work	64
6.1 Conclusions	64
6.2 Summary of Contributions	65
6.3 Future Work	66
Appendix A Fundamental of Optimization-based Flow Control	68
A.1 Introduction	68
A.2 The Model	68
A.3 Social Welfare Maximization Problem	69
A.4 Outline of REM Algorithm	70
References	71

LIST OF ILLUSTRATIONS

Figure 1.1 Comparison of Service models in the Internet, (a) Best-effort Service,2
(b) Integrated Services (IntServ), and (c) Differentiated Services Internet (DiffServ)
Figure 2.1 Optimization-based Flow Control Framework
Figure 2.2 Utility Functions of different adaptive applications: (a) Elastic utility18
(b) Stepwise utility, and (c) Arbitrary form of discrete utility
Figure 3.1 The architecture of proposed framework in the DiffServ Network25
Figure 3.2 Examples of marking probability in MRED and dsREM routers29
Figure 3.3 Simulation Scenario
Figure 3.4 Experiment 1: congestion window size of 5 TCP Vegas flows with32
the same RTTs sharing a bottleneck link of 48 Mbps, and queue occupancy
at dsREM core router
Figure 3.5 Experiment 1: congestion window size of 5 TCP Reno flows with33
the same RTTs sharing a bottleneck link of 48 Mbps, and queue occupancy
at dsREM core router
Figure 3.6 Experiment 1: congestion window size of 5 TCP Vegas flows with34
the same RTTs sharing a bottleneck link of 48 Mbps, and queue occupancy
at MRED core router
Figure 3.7 Experiment 1: congestion window size of 5 TCP Reno flows with34
the same RTTs sharing a bottleneck link of 48 Mbps, and queue occupancy
at MRED core router
Figure 3.8 Experiment 2: congestion window size of 5 TCP Vegas flows with35
the different RTTs sharing a bottleneck link of 48 Mbps, and queue occupancy
at dsREM core router
Figure 4.1 Comparison of the general optimization flow control framework:39
(a) supporting only applications with concave utility functions and the extension,
(b) accommodating both applications with concave and non-concave utility
functions, and (c) solution approach in (b)
Figure 4.2 (a) User utility value as a function of user rate, and (b) User rate as43
a function of the network price

Figure 4.3 Discrete user utility: (a) Rate preferences of three users,	44
(b) Convex Hull and Concave Majorant for users in (a)	
Figure 4.4 Example of a piecewise-linear utility function and its coordinates	46
Figure 4.5 TCP system model using Simulink block diagram	49
Figure 4.6 Simulink block diagram – REM router subsystem	49
Figure 4.7 Simulink block diagram – TCP source subsystem	50
Figure 4.8 Simulink block diagram – Agent subsystem	51
Figure 4.9 Discrete utilities of 3 classes of user applications within	51
the agent subsystem	
Figure 4.10 Simulation topology	53
Figure 4.11 Simulation Results for REM router (a and b) and TCP flow (c)	54
Figure 4.12 Simulation Results for Combinatorial Agent	54
Figure 5.1 Differentiated Services model	58
Figure 5.2 Example of supply and demand curves	60

LIST OF TABLES

Table 2.1 Time scale of congestion control, and related mechanisms (Keshav 1997) 12
Table 3.1 Simulation parameters	31