行政院國家科學委員會補助專題研究計畫成果報告

服務品質導向的網際網路費率策略及促成工具

計畫類別：□個別型計畫　■整合型計畫

計畫編號：NSC 89－2213－E－002－080

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本成果報告包括以下應繳交之附件：

□ 赴國外出差或研習心得報告一份
□ 赴大陸地區出差或研習心得報告一份
□出席國際學術會議心得報告及發表之論文各一份
□國際合作研究計畫國外研究報告書一份

執行單位：國立台灣大學電機工程學系

中　華　民　國　89 年 10 月 20 日

網際網路服務品質保障之促成工具(子計劃三)：
服務品質導向的網際網路費率策略及促成工具
QoS-based Pricing Policy and Enablers for Internet

計劃類別：整合型計劃
計劃編號：NSC89-2213-E002-080

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一. 中文摘要

本計畫在執行期間,進行下列三項研究：

(1)差別服務架構中*相對品質服務*(Qualitative Service)之拍賣競價機制設計，

此研究，我們設計一套配合 DiffServ 架構的競價機制，讓使用者的競價行為自然反映了他們的需求且同時把市場帶到一個穩定的運作點。我們的分析證明市場在這一點上，沒有任何使用者會片面更改他的出價。我們設計的市場機制具有兩個合理的特性:「使用者購買行為的均勻性」和「市場邊際效應遞減基本法則」。我們的在一個小型的實驗網路上做了參考實作以驗證我們設計的市場機制。

(2)差別服務架構中*量化品質服務(Quantitative Services)*整合計價與頻寬分配策略之設計。

設計目標是為了誘導使用者的行為並藉此作為頻寬分配的原則使得網路服務提供者獲得最大的利潤。研究中所考慮的量化服務品質為對每個使用者保證其平均傳送速度及封包延遲的上限。研究共分三部份:

a) 歸納整理差別服務網路的架構和描述計價系統設計的基本原則；

b)在單一網路服務提供者的區域下，將計價和頻寬分配的整合問題數學化；

c)發展演算法並探討了所制定的計價策略的特性。

(3)台大宿舍網路差別服務等級之虛擬計價實驗系統。

為促成宿舍網路資源於各個宿舍 IP 間使用的公平性， 紓解網路壅塞，提昇宿網資源使用效率，以及提供有等級區隔的服務選擇，提高服務品質，我們與台大計中孫雅麗教授合作設計完成一套實驗系統，提供宿舍學生二種網路服務等級，並每日給予每個宿舍學生固定的配額來購買優先等級服務。我們將進行實驗，研究以差別計價收費來作流量控制，及使用者的相關需求行為。

關鍵詞：網際網路, 服務品質, 差別服務, 計價收費, 促成工具, 拍賣, 頻寬分配

英文摘要

During the one-year period of this project, research efforts were focused on three parts.

I. Design and prototype implementation for auctioning qualitative service in a single domain DiffServ network.

Assuming a single DiffServ network domain, we designed an auction-based market mechanism. Its pricing scheme drives the market to an efficient and stable equilibrium without requiring a priori knowledge of user demands. Our game theoretic analysis shows that at the equilibrium, no one user will unilaterally change bid. The market mechanism has two desirable properties of "the uniformity of user purchase versus resource provision" and "the law of diminishing returns." A reference implementation architecture of the market mechanism is realized in a small network to validate our market design as shown in Figure 1.

II. Design of an integrated pricing and bandwidth allocation scheme for quantitative service

The objective of this task is to induce users' demand behavior and to guide resource allocation of the service provider so that the total revenue of service provisioning is maximized. QoS items considered are the average rate and delay bound. Three subtasks were completed:

a) Reviewed DiffServ network architecture and identified the foundation for pricing system design.

b) Formulated pricing and resource allocation problem of single DiffServ domain.

c) Developed solution algorithms and investigated properties of the pricing policy (Figure 6).

III. Design and implementation of an experiment system for pricing control of NTU dormitory traffic.

To facilitate the fairness among dormitory users, to alleviate congestion and increase efficiency, and to provide differentiated services, we collaborated with Prof. Y.-L. Sun of NTU computer center and designed and implemented an experiment system as shown in Figure 8. The system provides a two-priority service, and daily allocates to every dorm user a fixed quota to buy the high priority service. We will soon carry out experiments to study pricing control and user demand behaviors.

Keywords: Internet, QoS, DiffServ, Auction, Pricing, Enabler, Bandwidth Allocation

二. 研究緣由, 目的與成果

I. Design for auctioning qualitative service in DiffServ network

Network providers will provide network transport service with different QoS in the future. To achieve such goal, it is intuitive to separate the service into several classes. Packets with some classes should be transferred in a higher priority in order to achieve better QoS. The relative QoS concept is called qualitative service. The class-based QoS provisioning is the basic idea of Differentiated Service (DiffServ) Architecture proposed by IETF.

I.1 Network Infrastructure for Market Mechanism

To realize a market in the DiffServ domain, functional elements additional to normal DiffServ infrastructure such as purchasing agent and pricing server should be constructed. These additional elements offer the functionality of pricing, accounting, and bidding. A user needs a purchasing agent in his PC to help him communicate with the market. The DiffServ domain needs a pricing server to integrate bidding information, making resource allocation, and recording billing data. All functional elements in the infrastructure to facilitate our market operation are introduced below:

Purchasing Agent

Since our market mechanism is auction based, the users needs to bid in the market. The purchasing agent should have the following functions:

1. Send the user's bid to the network provider;
2. Receive market information from the network provider; and
3. (Optional) Help the user to make bid decisions.

The purchasing agent may be a socket-based process running in the user's computer or a web browser interface (Fig.1).

Pricing Server

The pricing server is the holder of the market It plays the role of integrating bidding information and making resource allocation. When users make bids through the purchasing agent, the bid message is transferred to the pricing server. The response of the pricing server should be fast in order to reflect the instant floating price of the market. Pricing server has the following functions:

1. Calculate the resource that should be allocated to each user.
2. Inform the bandwidth broker of the DiffServ domain to give router commands in order to make the new bids effective.
3. Return necessary information back to users in order to let users know the new market situation
4. Recording billing and accounting information

The functional block diagraph of the pricing server is given as (Fig.2).

Bandwidth Bandwidth and DiffServ Router

The roles of bandwidth broker and DiffServ routers are the actual service providers. The bandwidth broker received the resource allocation information from the pricing server. It transfers the information into router commands and sends the commands to domain routers. The domain routers receive the command from the bandwidth broker and add new control entries following the commands to execute the QoS control.

When bandwidth broker receives the new resource allocation from the pricing server, it gives command to domain routers to make the new resource allocation take effect. When the new inter-domain contract is re-negotiated, the bandwidth broker should tell the pricing server about the new forwarding rate of the whole domain so that the pricing server can calculate the new resource allocation and inform all market users about the market resource variation. When the domain boundary routers receive the command from the bandwidth broker, they change their traffic policing parameters in referred TCB(s). Through the cooperation of bandwidth broker and domain routers, the resource allocation from the pricing server can be executed successfully.

I.2 Pricing Policy for Qualitative Service: Auction

In the auction-based pricing mechanism, there is no distinct tariff about the Qualitative PHB capacity. The market price is determined by consumers' behavior when they compete for limited resource. Every user can bid at any time and cause the market situation to change. When the network is lowly utilized, the competition for limited resource is light and the market price falls. When the network is heavy loaded, the price will be driven high because of violent resource competition. So the unit price of the resource is floating over time.

I.3 Market Operation

there are two trading modes for market operation: asynchronous trading mode and synchronous trading mode. The difference between the two modes lies on the resource allocation time spot. The market operation under both modes are introduced below:

Asynchronous Trading Mode

When our designed market is in the Asynchronous Trading Mode, any user can bid at any time and the bid takes effect instantly. Figures 3 and 4 show the Flow chart and sequential diagram respectively.

Synchronous Trading Mode

The synchronous trading mode is similar to asynchronous trading mode except the pricing server will not calculate the new market distribution and resource allocation instantly. The pricing server only takes the job of resource allocation calculation and signaling periodically. The bids announced between two calculation time spot will be held until the next time spot takes place.

I.4 Market Property Analysis

This research also proves the existence and uniqueness of Nash Equilibrium Point in the designed market mechanism through mathematical analysis. The mechanism assures the stability of the designed market. We also show that our market design has the properties "The uniformity of user purchase versus resource provision" and "basic economic law of diminishing returns". The first property is that when the capacity provisioned by the market increases, every active user in the market favors to purchase more qualitative service capacity. The second property is that when the available capacity in the market increases, resource unit price at market equilibrium falls. The two properties show that our market design behaves reasonably when the provisionable market resource varies.

II. Design of integrated pricing and bandwidth Allocation Scheme

In this thesis, we study and design a resource-based pricing scheme for quantitative services in DiffServ networks. Design objectives are to induce users' demand behavior and to guide resource allocation of the service provider so that the revenues of the provisioning is maximized. There are three stages in our research:

(I) Review DiffServ network architecture and identify the foundation for pricing system design;
(II) formulate Pricing and resource allocation problem of single Internet Service Provider (ISP) under the DSA and
(III) develop Solution algorithms and investigate properties of the pricing policy.

Our study is focused on pricing transport service in a single service management domain, for example, the management domain of an Internet service provider (ISP).

In a DiffServ domain (Figure 5), there are three kinds of network devices: boundary routers, core routers and a Bandwidth Broker (BB). The BB manages the domain resources and negotiates service contract with users. A boundary router is the first router through which some users access the domain. User packets flows are classified and policed according to individual service contract. Core routers mainly forward packet flows according to their classification among routers. Boundary and core routers and BB together aim at providing two kinds of services in a DiffServ network: qualitative service and quantitative services. The former only provide relative differences in service quality among services classes but the latter provides quantitatively guaranteed quality to individual service classes.

Our research is focused on a quantitative service, where the average transmission rate and the delay bound of each service class are guaranteed. Obviously since these QoS indicators are absolutely assurances, the resource allocation certainly has the specific relationship with these indicators. Within these quantitative services we has defined, the relationship between the delay bound and the resource allocation will be derived based on the traffic description, a simple token bucket.

In formulating the pricing problem, we first model all the users into an aggregate user for simplicity. In describing a user's behavior, we adopt the "log-log" approximate model of the INDEX project [INDEX], which quantifies the user's connection time with respect to price structure. The proportion of the connection time of a class to the total connection time serves as an estimate of the probability that a user chooses the specific service class. Based on these analysis and approximation, the users' reaction is described with the changes of price structure. In addition, the business model of the network supplier (e.g. ISP) and the operation of the basic market are both announced. With two-side models, user-side and supplier-side, we can formulate the pricing problem step by step. First, the objective function is to maximize the revenues of the service provider. Some constraints must be considered, which are the delay bound constraints of different service class because of the absolute QoS differentiation, the total link capacity constraint, connection time constraints, and the range of prices constraints. As mentioned above, the pricing and resource allocation problem under DSA has been established completely.

In developing solution algorithms, two methods are adopted for solving the pricing problem that is non-linear; one is Sequential Quadratic Programming (SQP) method, and another is Exhaustive Search (ES) algorithm. Compared to the two methods, we figure out that when the constraint about the range of prices is extended, the solution by SQP method easily falls into the local maximum, which results in incorrectness. However, the solution by ES algorithm always approaches the optimal value in spite of the changes of the constraints. But unfortunately on adding the service classes, ES algorithm becomes inefficient. Thus, it is not suitable for too many service classes. In addition, we consider an example of two service classes with a view to investigate the properties of pricing policy. The result shown in Figure 6 indicates that when the connection arrival rate is lower, the prices of different service classes almost are equal. The results induce users to choose the service class with higher QoS. Instead, when the connection arrival rate is higher, the prices are differentiated. Users are forced to choose adequate service classes due to the finite resource. But some drawbacks also appear like the fact that if the connection arrival rate is much too low, the prices still are differentiated. However, most properties of pricing policy are rational and intuitive.

III. Virtual pricing system of differentiated service network for NTU dorm

III.1 Experimental Architecture

The experiment architecture include (1) swith router "Accelar", (2) packet Engine, (3)router "7513" (4) data collection server, (5) traffic control and accounting server and (6) web server. System home page and network architecture are shown in Figures 7 and 8.

III.2 Pricing model

The supplier (NTU network managers) gives every user (male-3 dorm student) a fixed amount of daily quota to enforce the fairness for using high priority service.

Then, a peak-load pricing scheme is designed for traffic control. A game theoretic analysis is performed. A user, arranges his demand and buy the network services to maximize his utility of one day under the budget constraint. For simplification, the supplier regards all users as identical users according some empirical statistic data. By solving the two-person game problem, we get the peak and off-peak prices to maximize total users' utility. Experiments (Figures 7 and 8) have been designed to study users' demand function and traffic control by pricing.

三、計劃成果自評

This project has closely followed the original research goal of designing QoS-based pricing policies and enablers for Internet. Pricing policies of both qualitative and quantitative services under a single domain DiffServ architecture are designed and analyzed. There are two experimental implementations to demonstrate enabling technologies, one for the auction-based market design and the other for campus network management. Results have been partially published as listed below and more will be submitted to international journals for publication.

四、Publication List

1. C.-C. Liu, S.-C. Chang, H.-H. Cheng, " Pricing and Fee Sharing for Point to Multipoint Multicast Services with Quality Guaranteed, " *Proceedings of the Seventh International Conference on Parallel and Distributed Systems: Workshops 2000,* Iwate, Japan, July 4-7, 2000, pp.255~260.
2. H.-I. Wu, S.-C. Chang, "Design of Resource Management at IP Router," *Proceedings of ICOIN-14,* Hsin-Chu, Jan. 26-28., 2000, pp. IC-4.1~ IC-4.8.
3. 鄭新禾,"Design for Auctioning Qualitative Service in DiffServ Network", Master thesis, National Taiwan University, 2000.
4. 朱紹儀,"Design of Integrated Pricing and Bandwidth Allocation Scheme", Master thesis, National Taiwan University, 2000.

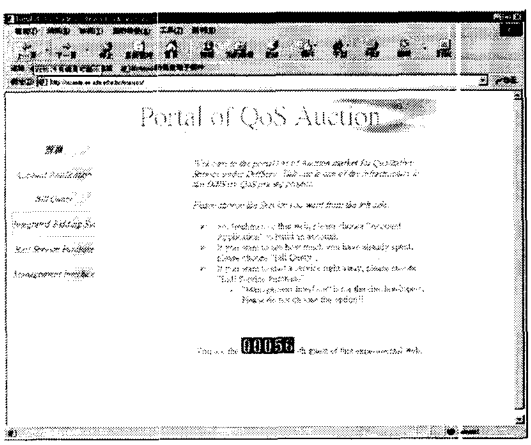

Figure 1: Agent Interface: Homepage

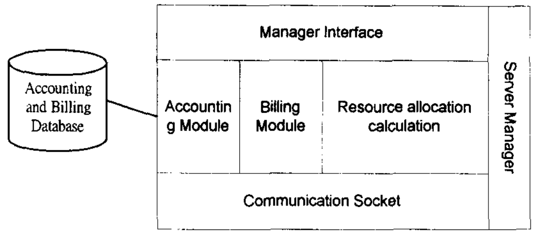

Figure 2: Functional Diagraph of Pricing Server

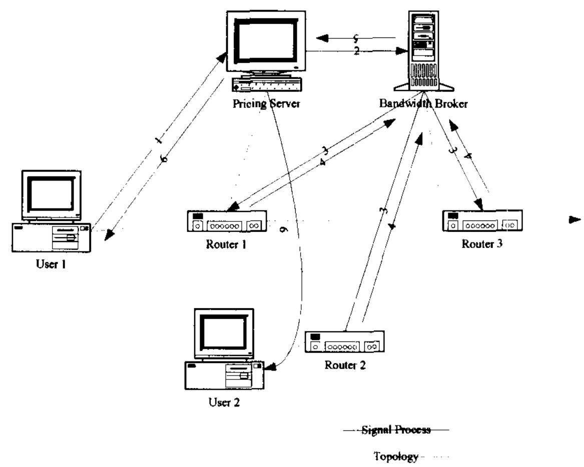

Figure 3: Flow Chart of Asynchronous Trading Model

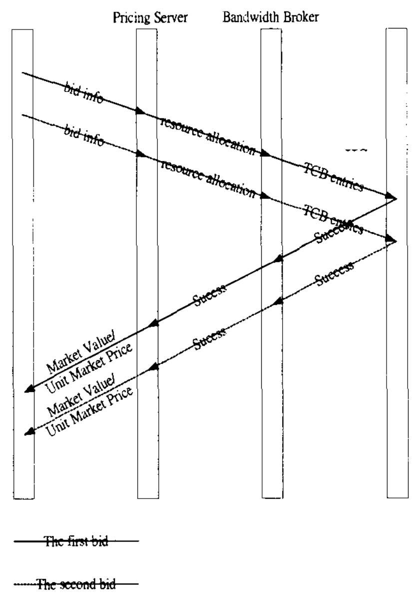

Figure 4: Sequential Diagraph of Asynchrounous Trading Model

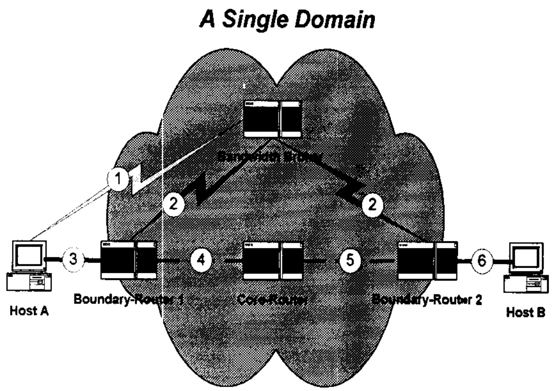

Figure 5: Packet Delivery in a Single DiffServ Domain

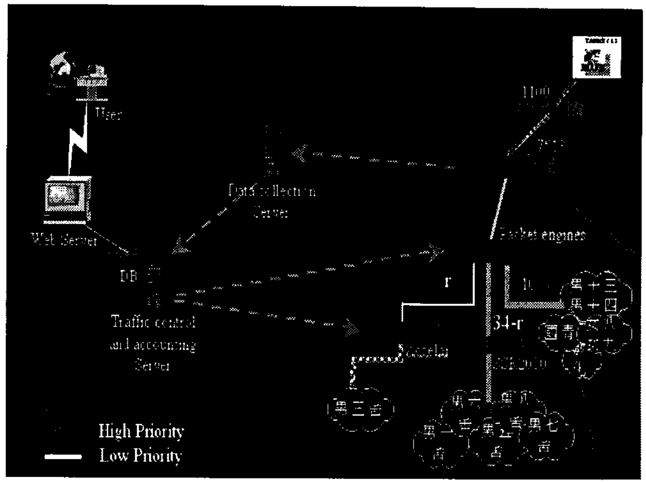

Figure 8: The experiment network Architecture

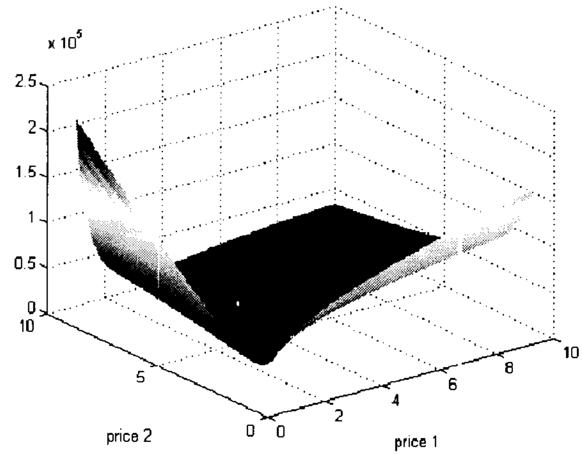

Figure 6: Total Revenue with respect to Price Structure

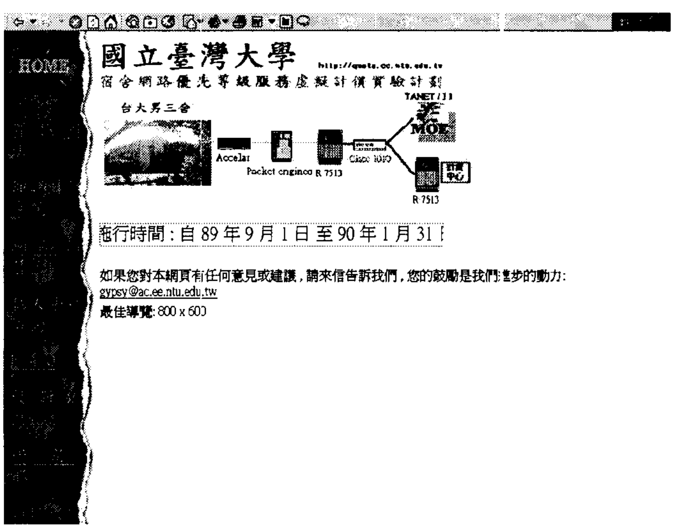

Figure 7: The Home page of virtue pricing system for NTU Dormitory