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Quality-Contingent Differentiated Pricing for Broadband Services

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Abstract

Even though broadband high speed Internet service has been always attractive choice to Internet users, its deployment has not been very successful. Until very recently most broadband access providers offer a single quality level and price. We propose a definition of Quality of Service (QoS) in a broadband network, present a measurement of the proposed QoS, and discuss its implementability. Further, we show that the idea of contingency pricing can in fact be applied meaningfully to broadband services to assure customers for high quality service. This paper presents our initial work towards a proposal for broadband pricing that addresses the dimension of QoS uncertainty in the context of QoS based pricing, and is designed to be consistent with the technical aspects of data flow and communications infrastructure for broadband service. Our future plans include further development of technical aspects and economic analysis of the proposed QoS and contingent pricing scheme in broadband high speed Internet services.

Keywords: Contingency pricing, quality of service, price discrimination, broadband services.

Motivation

Quality-differentiated pricing, or market segmentation, is a widely used pricing strategy which can yield economic benefits to both sellers and consumers. In the case of Internet access and data transport services, quality-of-service based pricing is considered essential to prevent free riding problems and generate an efficient utilization of the Internet. In the last twenty years, several technical and economic proposals for QoS-based pricing have been introduced, but none widely adopted especially for consumer-oriented services such as broadband Internet access services which offer high-speed and always-on connectivity. Thus, until very recently most broadband access providers offer a single quality level (for home users, at about $45 a month). This policy has limited the adoption of broadband services, because customers who care only about always-on connectivity are not willing to pay the high price for high-speed access.

One critical aspect of quality and pricing for Internet services is the inherent stochasticity in performance level delivered to a user at any time, caused by the best-effort delivery and shared resource utilization in the TCP/IP protocols (up to IPv4). Efforts to introduce QoS-based pricing have focused on reservation of bandwidth for high-priority traffic, differential allocation of capacities for different segments of customers, and weighted routing algorithms. Still, the inherent resource-sharing in packet-switched networks means that throughput rates can only be guaranteed upto some probability of failure. There are also other sources of quality uncertainty, including equipment failure and lack of end-to-end control over resources as shown in Figure 1: an ISP is responsible for traffic and delays between its headend and each end-user's cable modem, but not from the headend to the Internet. In general, most broadband providers offer customers a vague promise of maximum throughput rates, which has little value because communication capacity to the provider system is shared between users.

In the past few months, most broadband providers have announced an intent to offer tiered pricing (Spring 2002). Weber (2002) reported a test for tiered pricing by Cox Communications in Las Vegas (adding a 256kbps tier for $26.95 to their high-speed, $40/month, service). Spring (2002) reports that several broadband ISPs (Comcast, Charter Communications, Cox, Rogers Cable) are testing tiered pricing in some areas. Introduction of tiered pricing is critical to the future of broadband, which is characterized today by excessive capacity and lower-than-predicted demand (for example, Odlyzko (2001) reports that while industry decisions were based on a doubling of Internet traffic every 100 days, in fact traffic has doubled only once a year since 1996, leading to a true annual growth rate of only 100% against an expectation of a 700% annual growth rate).

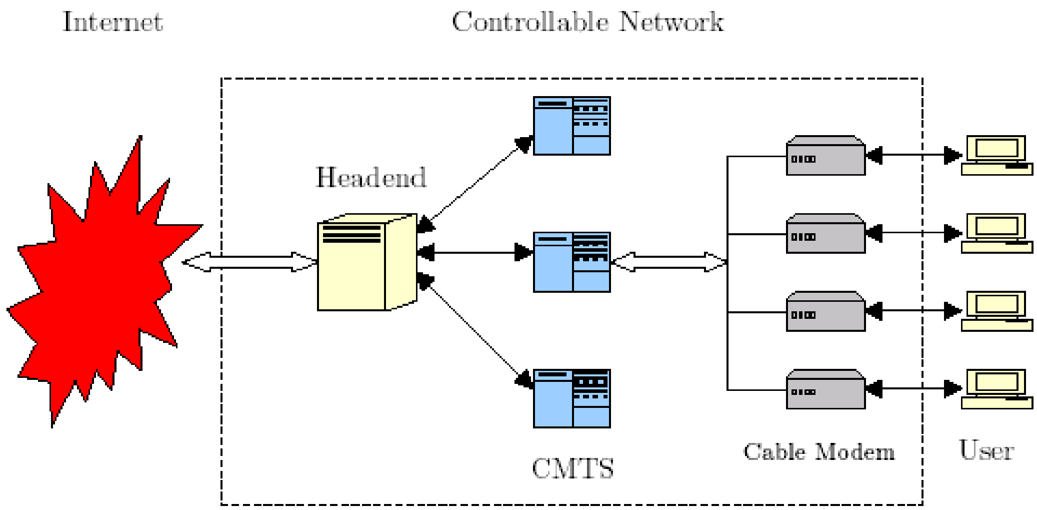

Figure 1. Network Diagram between End Users and Internet

However, introduction of tiered pricing is problematic under QoS uncertainty (potential customers of the higher QoS levels have no incentive to pay the high price unless they can be assured better service) unless the pricing scheme builds in a rigorous mechanism for dealing with quality uncertainty. This is aggravated by the fact that high- and low-value consumers of broadband service have a shared communication channel to the service provider.

This paper presents our initial work towards a proposal for broadband pricing that addresses the dimension of QoS uncertainty in the context of QoS based pricing, and is designed to be consistent with the technical aspects of data flow and communications infrastructure for broadband service. The proposal builds on recent changes in broadband communication standards and recent work of Bhargava and Sundaresan (2000, 2002) who have proposed quality-contingent pricing for IT services characterized by quality uncertainty.

Broadband Service Quality

This section covers three related aspects of broadband pricing: how a broadband service provider can provide differential treatment to users based on their payment levels, how she can examine or analyze the profitability of the proposed pricing scheme, and what kind of quality assurance under uncertainty and quality measurement & guarantees must accompany a tiered pricing approach.

Differential Traffic Control

To implement a tiered pricing policy, a broadband network must be able to offer differential treatment to different categories of users. We discuss two recent proposals in this regard and then offer an alternative approach based on recent changes in industry standards.

Anderson, Kelly, and Steinberg (2002) study a contractual scheme of bandwidth sharing under the congestion marking system supported by the Internet standard on Explicit Congestion Notification (Ramakrishnan, Floyd, and Black 2001). They argue that the proposed "Contract and Balancing Process" can be used as a means of sharing bandwidth in Internet network. This approach is attractive to Internet backbone providers, however we are not convinced that it can be implemented between an ISP and end users because end users usually do not reserve their dedicated bandwidth in advance. Stahl, Dai, and Whinston (2001) study the optimal pricing strategy of end users and the optimal allocation decision of the ISP under the Diffserv architecture and the leaky-bucket (Kuroso and Ross 2001) routing system. They demonstrate that the leaky-bucket approach can not outperform the usage-based pricing structure (i.e., the leaky-bucket approach can not achieve the social optimal allocation of network resources). However, this approach models the Internet as a single node and assumes that there is no uncertainty in the network.

We propose an alternative scheme for differential treatment, inspired by the broadband industry's newest technology specification *Data Over Cable Service Interface Specification* (DOCSIS) 1.1. This standard specifies the functions of the cable provider's Cable Modem Termination System (CMTS) and the end users' cable modems. Under DOCSIS 1.1, a broadband ISP can assign different service treatments to different customers (for detailed information, see Motorola (2001) and CableLabs Staffs (2001)). Unlike the old control specifications (prior to DOCSIS 1.1, the control mechanisms, typically maximum throughput rate, were installed at each cable modem), the management of different allocation of the routing capacity is controlled by the CMTS.

Economic Analysis of the Proposed Scheme

Under the recently announced tiered pricing strategy of broadband ISPs, QoS is promised but it may not be delivered to end users. Moreover, currently there is no rigorous contractual scheme to handle non-performance. The literature on quality uncertainty offers approaches such as money-back guarantees, warranties, and trial periods (see Moorthy and Srinivasan (1995)). In a recent paper, Bhargava and Sundaresan (2000, 2002) propose a quality-contingent pricing scheme and argue that it is especially attractive in the context of IT services. Since the performance can be determined only after using the broadband service, this service can not be returned or repaired, making money-back guarantees and warranties infeasible. Therefore, we build an economic model for our proposal based on Bhargava and Sundaresan (2000, 2002)'s contingency pricing proposal.

We consider an ISP who adopts a contingency pricing scheme with multiple contracts (R_i, R_i): a customer contracts a broadband service at price R_i, and the customer receives a rebate (R_i) if the guaranteed QoS is not delivered. We assume that the ISP has equipment to measure packet delay continuously in small time intervals (e.g., millisecond, second, etc.) for each user. We focus on downstream performance, though the same idea can also be applied to upstream data flow. Since we consider the guarantee within the infrastructure that the ISP is responsible for, we treat the Internet as a single node that sends traffic, destined for specific users, to the ISP.

The ISP's QoS guarantee is only responsible for her own network (i.e., between CMTS to the end users) and consists of two parts (m_{qi}, y_{qi}): given a certain time period, y_{qi} % of packets will be delivered less than m_{qi} milliseconds. Therefore, for the downstream performance, a packet arrival time is stamped at the CMTS, and the corresponding service completion time is measured at the end user's cable modem. We assume that performance is measured by a trusted third party or using equipment & software that has been verified by a trusted agency.

We assume that the ISP serves multiple classes of customers; for example, casual users with email and I-chat, heavy users with multimedia users and large office documents, etc. We also assume that all members in a class share an independent and identical distribution for the number of packet requested per usage (i.e., $X \sim Poisson\,(\lambda_i)$), a distribution for the number of usage during a time period (i.e., $Z \sim Poisson\,(\mu_i)$), and an identical valuation for a packet (α_i) and valuation for the Always-On feature. We note that two main benefits of the broadband services are Always-On feature and High Speed communication. Therefore, expected net surplus of a customer in class i is

$$E[U_i] = v_i + E[\text{Utility of High Speed}] \text{ - } (R_i - E[\text{Rebate}])$$

where U_i is the customer's net surplus and v_i is the customer's valuation for the Always-On feature. Let $h(\cdot)$ be the probability density function of the ISP's performance (this function can be estimated from the industry data or appropriate simulation model). Then, we have

$$E[U_i] = v_i + E[\text{Utility of High Speed}] \text{ - } (R_i - \int_0^y h(\cdot)dy)$$

Now, we derive the customer's expected utility from the High Speed feature. We model this utility as linearly correlated to the customer's packet value and total number of packets, but the customer incurs disutility due to the network delay. Considering these, we have

$$E[\text{Utility of High Speed}] = E[\alpha_i \sum_{i=1}^{Z_i} X_i] - \beta E[\alpha_i \sum_{i=1}^{Z_i} X_i E[m_a]]$$
$$= \alpha_i \lambda_i \mu_i - \beta \alpha_i \lambda_i \mu_i E[m_a]$$

where β is a delay constant per unit time. Therefore, a customer in class i will take the contract as long as her net surplus is greater than 0. Specifically,

$$E[U_i] = v_i + \alpha_i \lambda_i \mu_i - \beta \alpha_i \lambda_i \mu_i E[m_a] - (R_i - \int_0^y h(\cdot)dy) \geq 0$$

Here we report our preliminary results from a special case of our proposed contingency pricing scheme where there is only one customer class. Under this case, it is obvious that the ISP will choose a contract so that the customers' net surplus is equal to 0. Hence, we have the ISP's profit as

$$\pi(R_i, m_{qi}, y_{qi}) = N_i (R_i - \int_0^y h(\cdot)dy)$$
$$= N_i (v_i + \alpha_i \lambda_i \mu_i - \beta \alpha_i \lambda_i \mu_i E[m_a])$$

Given this profit function, we see the following results:

Proposition 1. *If there is only one customer class, then*
a) the ISP should utilize all capacity to maximize the profit, and
b) as long as $\int_0^y h(\cdot)dy = \frac{v_i + \alpha_i \lambda_i \mu_i - \beta \alpha_i \lambda_i \mu_i E[m_a]}{R_i}$ *, any combination* (R_i, m_{qi}, y_{qi}) *generates an equal profit.*

We are currently attempting to extend our analysis to multiple classes of customer.

Applicability of Proposed QoS Guarantee

To answer whether the proposed QoS guarantee and measurement is practical, we need to answer several important issues for the proposed scheme. These issues include implementability, verifiability, efficiency, and moral hazard problems from ISP and end users.

Unlike the other specifications of broadband services, the new DOCSIS 1.1 provides broadband ISPs ability to set service levels for different types of customers. Furthermore, the new DOCSIS 1.1 requires that CMTS handle this various allocations to end users and store usage information. Therefore, our proposed measurement algorithm can be installed easily at CMTS. In terms of each user's cable modem, it will not be difficult or big burden to implement a system that captures packet delays of the end users.

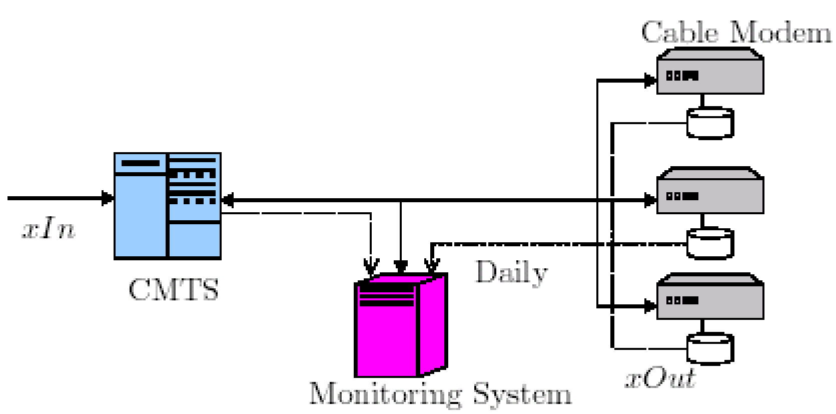

Figure 2. Monitoring of QoS level between CMTS and Cable Modems

To verify the QoS level, the ISP can install a machine between CMTS and all end users (see Figure 2). This machine can communicate with CMTS and each cable modem in a certain time interval (e.g., 10 minutes, 30 minutes, or 1 hour, etc.) and record both CMTS and each cable modem's QoS information. This machine can be operated by third party to increase its credibility.

Conclusion and Future Research Direction

In this paper, we study QoS for packet delay in broadband services. Specifically, we discuss the lack of QoS guarantee and the need of rigorous contractual schemes in broadband network. Further, we show that the idea of contingency pricing can in fact be applied meaningfully to broadband services to assure customers for high performance services. To this end, we propose a definition of QoS for packet delay (by implication throughput rate) in broadband and a way of measurement of the QoS. By separating the entire network communication into two parts (ISP controllable and uncontrollable), this QoS guarantee can be adopted by broadband ISPs. Also due to the new DOCSIS 1.1, which enables an ISP to set different service levels to different end users, our proposed QoS can be implemented easily.

In this paper, we limited our discussion to a definition of QoS for throughput rate in broadband network, a measurement of the proposed QoS, and its implementability. Our future plans include further development of technical aspects and economic analysis of the proposed QoS and contingent pricing scheme in broadband high speed Internet services.

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