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최선형 인터넷 서비스의 유틸리티와 과금

(Utility and Pricing for the Best Effort Internet Services)

李 焄*, 魚 潤*

(Hoon Lee and Yoon Uh)

요 약

본 고에서는 최선형 인터넷 서비스에 대해서 대역공유량의 변화가 가지는 특성을 이론적으로 모델링하는 방법을 제안한다. 그리고 유틸리티에 기반한 요금정책을 제안하고 수치실험을 통해 제안방법의 의의와 효과에 대해 검토한다.

Abstract

In this paper the authors explore the effect of bandwidth sharing to the utility of the customer for the best-effort Internet services and draw a basis for the pricing principle in Internet Protocol networks. Especially, we investigate the behavior of a customer's utility in case an arbitrary amount of additional bandwidth is allowed to each customer for the elastic traffic, which is the typical example of the non-real time Internet data traffic.

After drawing the utility curve, which will be proved to follow the concave curve, we will apply it to the pricing of Internet traffic. Finally, via numerical experiments, we will illustrate the validity and implication of the proposed method.

Keywords : IP network, Best effort services, Utility, Pricing

I. INTRODUCTION

Recently, there has been a growing need for connection to the Internet. As such, the network is shared by many kinds of services from different kinds of applications. Sharing of the network by multiple users results in the increase or decrease of utility to the users depending on the number of active users or the amount of bandwidth.

There exists a few literature which deal with the utility of a shared Internet. Shenker discussed the utility functions for the real-time and non-real-time elastic applications in the future Internet[8]. Even though his discussion is non-rigorous and qualitative due to lack of data in a real field at that time(the year 1995), he found that each type of application has a peculiar characteristic in its utility function. Especially, he intuitively illustrated that the utility of elastic applications follow the quadratic curve. Breslau and Shenker presented a formula for the utility function of the inelastic application in more practical manner than the former one described in [2]. Liao devised the concept of utility generator, which generates bandwidth utility curves by inspecting the

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* 正會員, 昌原大學校 情報通信工學科

(Dept. of Information and Communication Engineering)

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content of the MPEG video[5]. He presented a method to predict the instantaneous and long-term utility curve of the system with respect to the bandwidth increase. Via experiments with several video streams, he illustrated the quadratic properties of the different utility functions. Watanabe et al. compared the utilities of the users provided by the best-effort and reservation-based services in an Internet network[10]. They assumed the variable load condition of Breslau and Shenker to predict the average and worst case values for the utility functions.

One point that we have to point out in those works is that neither paper deals with the relationship between the utility of the users with the pricing of the used bandwidth. On the other hand, in the area of IP (Internet Protocol) network, approaches to determine prices from network operator's point of view such as the pricing for congestion avoidance or for maximizing the total revenue can be found in literature such as [6-7].

However, little work has been done to find a user-oriented pricing model, especially the expected performance(which corresponds to the utility in this paper) from user's point of view. Lee proposed a tariff function for the VPN users based on the usage rate of the bandwidth, which is similar to the concept of the utility of the user[4]. However, the work in [4] does not consider the bandwidth sharing and its impact on the utility of each user. To the best knowledge of the authors, there exists no literature for the pricing scheme based on the utility of each user.

The objective of this paper is to relate the user utility with a proper pricing rate. In this paper we investigate the utility of user for the best-effort Internet services, and propose a pricing scheme that takes into account the utility of each user.

This paper is composed as follows: In Section 2, we describe the utility of shared bandwidth for the elastic traffic in current best effort Internet. In Section 3, we propose a method to determine the price of service based on the utility to the users, which is the function of bandwidth share for each user. In Section 4, we present the numerical results, and discuss the validity of the proposed method. Finally in Section 5, we summarize the paper and give an outlook on the future research issues.

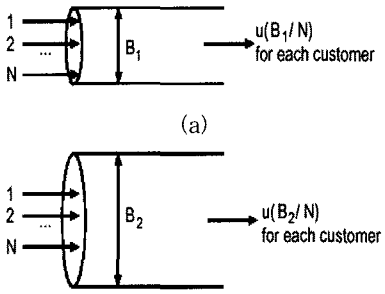
Ⅱ. UTILITY OF THE ELASTIC TRAFFIC

Let us assume that N homogeneous customers are sharing a link of bandwidth B Mbps for Internet applications, and the connection holding time for each customer is sufficiently long enough to ignore the variation of the number of ongoing connections. There exists neither priority control for QoS differentiation nor resource reservation for a specific flows(flows and customers are used alternatively). Thus, the packets from all the users are delivered to the link in FIFO manner from a shared infinite queue, and so they act as best effort traffic.

Under the above assumptions, we can conjecture that the bandwidth is allocated evenly to each user, and a customer can use a share of bandwidth in an amount of B/N in a long term average if we assume that the connection holding time is long enough and the mean rate of a connection is assumed to be the same among all the connections, where the effect of short term fluctuation of traffic dynamics due to the variation of the number of connections is not taken into account in calculating the shared portion of each connection.

The utility is defined to be an amount of data delivered by the network during an observation time period, which is a measure of long-term performance, and it is alternatively represented by the throughput a user can obtain from the network, so utility function represents the utility as a function of bandwidth offered to a connection by the network. The utility is high when there is high throughput, and vice versa. The utility of each best effort connection is represented by u(B/N) and the total utility U(N) is the sum of each utility, that is, U(N) = N×u(B/N). The network operator's objective is to maximize the total utility.

Let us assume that an output link of a router with bandwidth B_1 is shared by a total of N customers with homogeneous traffic sources. Now the network operator decides that, under a certain reason, he/she should increase the bandwidth to B_2, where $B_2 > B_1$, for the same number of connected users. Then we can easily understand that the utility $u(B_2/N)$ is greater than $u(B_1/N)$ from simple intuition, because increased bandwidth can be distributed evenly to each user at least in theoretical view point and the utility of each user will increase, too. Fig.1 illustrates this scenario.



(a)

(b)

그림 1. 대역공유와 유틸리티
Fig. 1. Bandwidth-share and utility.

Here, we can have naive doubts. In what manner the utility function increases? Our purpose is to compare three possible alternatives of concave, linear and convex curves, and verify that the concave one is an optimal form for the utility function from the theoretical point of view. First, let us assume that the utility function is concave. Then, the following Proposition holds.

[Proposition 1] When the utility function $u(B/N)$ is concave, there exists some N such that the total utility function $U(N)=N\times u(B/N)$ has the following property.

$$U(N_2) > U(N_1),\ N_2>N_1. \tag{1}$$

[Proof] Let us prove it by assuming a general function f. Let f: R→R, where R is an open interval of real numbers, bounded or unbounded. Assume that f is concave, that is, f satisfies the following relationship:

$$f(ax+(1-a)y) \geq a\times f(x)+(1-a)f(y) \tag{2}$$

for all x, y ∈ R and all a ∈ [0,1][1].
For simplicity and in order to fit the formula into our purpose we can assume that y=0 without loss of generality. Then, eq.(2) reduces to

$$f(ax) \geq a\times f(x). \tag{3}$$

First, let us map the functions and variables as follows: Let f→u, x→B and a→1/N. Then from the concavity property of the utility function with respect to B, we obtain

$$u(\frac{B}{N}) \geq \frac{1}{N}u(B). \tag{4}$$

Next, let us prove the monotonic increasing property of the total utility function with respect to N. Assume that $N_2>N_1$. Then the monotonic increasing property of the total utility function gives us the following relationship.

$$N_2\times u(\frac{B}{N_2}) > N_1\times u(\frac{B}{N_1}),\quad N_2>N_1 \tag{5}$$

From simple manipulation, we obtain

$$u(\frac{B}{N_2})/u(\frac{B}{N_1}) > N_1/N_2. \tag{6}$$

Now it remains to prove whether the last formula holds or not. Let $\beta=N_1/N_2$, and let $M=B/N_1$. Then, we can find that $B/N_2=\beta M$. Substituting these variables into eq.(4) with an assumption that $N\neq 1$ gives us the result described in eq.(6). Therefore, the monotonic increasing property of the total utility function holds.

[Corollary 1] If the utility function $u(B/N)$ is concave, the total utility is maximum when $N=\infty$.

[Proof] Corollary 1 is deduced from eq.(5).

[Proposition 2] When the utility function u(B/N) is convex, there exists some N such that the total utility function U(N)=N×u(B/N) has the following property.

$$U(N_1) > U(N_2),\ N_2>N_1. \qquad (7)$$

[Proof] Using the same analogy that has been used in Proposition 1 except that the property of the convexity of the function is assumed.

[Corollary 2] If the utility function u(B/N) is convex, the total utility is maximum when N=1..

[Proof] Corollary 2 is self-evident from eq.(7).

From the above two Propositions, we can arrive at the following conclusions : When the utility function of a customer u(B/N) is concave, the total utility U(N) is maximized at $N=\infty$. This indicates that the total utility of the users increases monotonically as N increases, which illustrates that the network never get overloaded. In this case, only the pie of the bandwidth available to each user is decreased as N increases. This corresponds to the generic property of the best effort service for the current Internet.

When the utility function of a customer u(B/N) is convex, the total utility U(N) is maximized at N=1. This indicates that the total utility of the users decreases monotonically as N increases, and this indicates that the network is overloaded as N increases. This corresponds to the QoS-sensitive application of the future Internet, where the connection admission control have to be invoked in order not to degrade the performance of each user by over subscription. Finally, we can easily find that the linear utility function is not suited to our purpose, because the inequality in eq.(6) is replaced by an equality when the utility function u(B/N) is linear.

Summing up the above discussion for the curvature for the utility function, we conclude that it is most natural, at least in theory, that the utility function for the elastic Internet traffic follows the concave function. Shenker has argued that there being a diminishing marginal rate of performance enhancement as bandwidth is increased, so the utility function is strictly concave everywhere, and the total utility is always maximized when no users are denied access to the network[8].

In order to verify whether the law of diminishing marginal utility really holds for the increase of bandwidth, more experiments have to be carried out for the various Internet applications. However, we do not have enough data at this time, because it is not easy to obtain such data from the operating commercial network. The curve illustrated in Fig.2 is obtained from the traffic trace of the access link of KORNET leased-line[3]. The x-axis represents the speed of the access link, and it corresponds to the peak rate the users can send packets to the network. The increase in the link speed corresponds to the increase in bandwidth the user can send his data, whereas the increase in y-axis corresponds to the marginal increase in the throughput the user can obtain.

Note that Fig.2 does not tell exactly the principle of diminishing marginal utility with respect to the increase of the available bandwidth for each connection, because the link in that case is devoted to a user rather than shared by many users. However, we can observe from the result that the users with high link speed can use the available bandwidth with diminishing marginal utility than those with low speed of the access link. Therefore, this phenomenon can be applied to the users of shared network

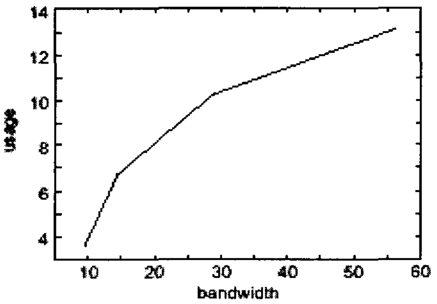


그림 2. 가용대역과 실제사용량
Fig. 2. Available bandwidth and usage.

environment.

To be more rational, and from the above-mentioned propositions, we can argue at least in theoretical point of view that it would be reasonable to assume the utility function to be concave if we apply the best effort service which shares the bandwidth with the other connections as a natural architecture for utility maximization to the network service provider.

Ⅲ. APPLICATION TO PRICING

Let us return to Fig.1. As we have stated in Section Ⅱ, the increase of bandwidth that has been shared by N customers from B_1 to B_2 introduces the increase of pie to each customer, which is distributed evenly to N users if we assume that each user acts in a fair manner. Thus, if the bandwidth shared by N customers changes from B_1 to B_2, each customer can use an amount $(B_2-B_1)/N$ of additional bandwidth.

In order to investigate the effect of increased bandwidth to the price levied to a customer, let us assume some parameters: Let the price levied to each customer for additional bandwidth be P, and let T be the price of unit bandwidth(unit: Megabits). The determination of T depends on the market and policy of the network provider, and a detailed discussion on the factors influencing the value T is beyond the scope of this paper. Let us simply assume it arbitrarily.

There exist a number of methods for levying charges to the usage of the bandwidth. If we do not care about the principle of the decrease of the marginal utility with respect to the increase of bandwidth, the most typical and simple method to levy additional price to each customer from the increased pie of bandwidth would be described as follows:

$$P_1 = \frac{(B_2 - B_1) \times T}{N}, \tag{8}$$

where the unit of price is Dollars per second. Let us denote the pricing policy using eq.(8) as P_1.

On the other hand, if we take into account the principle of the decrease of the marginal utility with respect to the increase of bandwidth, the price should be a function of the utility, which is also a function of the increased amount of the bandwidth. We propose the following formula for a price that represents the effect of increased bandwidth to the utility each customer can obtain:

$$P_2 = \{u(\frac{B_2}{N}) - u(\frac{B_1}{N})\} \times T, \tag{9}$$

where u(·) is defined in Section Ⅱ, and let us denote the pricing policy using eq.(9) as P_2.

Ⅳ. NUMERICAL EXPERIMENTS

In order to investigate the implication of the proposed pricing method, let us carry out experiments under the following environment. N users have been provided with B_1 amount of bandwidth from the network provider for a long time. The network operator has a history data for the utility $u(B_1/N)$ under that condition. Now, the network operator decides to increase the bandwidth to B_2 from B_1 under the same number of users because the processing power or the utilization of the Router has reached to a certain level. After the network reached to an equilibrium state, the network operator measures the utility under new condition, which corresponds to $u(B_2/N)$. Repeating this procedure for B_x, x=1,2, ⋯, we can obtain a graph for the utility curve $u(B/N)$ for a number of different bandwidth values allocated to the N users who share the bandwidth.

There exist a few results that deal with the behavior of the Internet user traffic under different access speed[9], which includes a number of factors in terms of the marginal utility with respect to psychological and economical effect. Unfortunately, we do not have data for $u(B/N)$ at present due to the short history of the commercial public Internet services. However, we have to assume a utility function in most realistic way.

We can infer that the marginal utility u increases in proportional to the marginal bandwidth W, which is represented by

$$\frac{du}{u} = p\frac{dW}{W}, \tag{10}$$

which has a solution given by

$$u = CW^{p}, \tag{11}$$

In eq.(11) p is statistically estimated by mean opinion tests from the users and it usually has the value in the range of [0-1] from the property of concavity of the elastic traffic. On the other hand, C is determined by the network operators to balance the revenue and the cost. Note that neither parameter can be easily obtained at this stage. Let us assume that C=1 and p=0.5 for simplicity.

Note that the amount of bandwidth provided to a connection is B/N, which corresponds to W, so that W=B/N.

$$u(\frac{B}{N}) = (\frac{B}{N})^{p}, \tag{12}$$

Let us assume that a total of N=10 customers share the initial bandwidth B_1 of 10Mbps at the beginning of the experiment. After that, the network increases the bandwidth in an amount of(B Mbps, where $\Delta B=B_2-B_1$, at the period of interest. Fig.3 illustrates the utility function as a function of B_2 with p=0.5.

The author's subsequent paper given in [11] describes a framework for obtaining the parameters C and p from the observed real traffic data. The authors use a curve fitting method between the measured traffic data and the equation (11).

Fig.4 illustrates the price per customer as a function of ΔB using the same parameters as assumed in computing Fig.3. In Fig.4, T is assumed to be 0.2 Dollars per Mega bits.

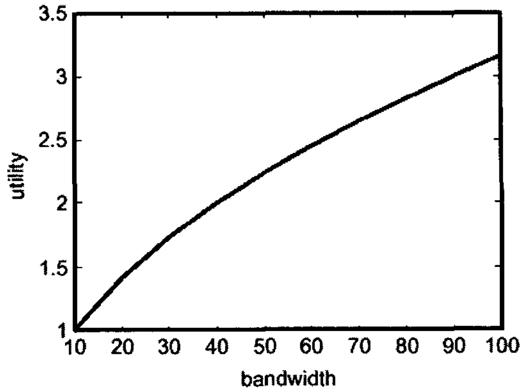


그림 3. 유틸리티 함수
Fig. 3. Utility function.

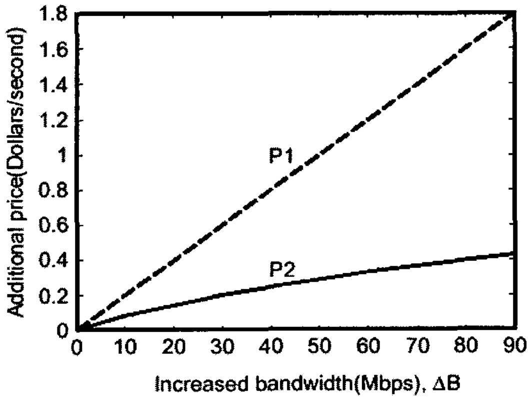


그림 4. 두방법에 대한 요금
Fig. 4. Prices for two schemes.

Note from Fig.4 that the pricing by linear utility, which corresponds to the pricing scheme P_1, levies much higher price than the pricing scheme by using the concave utility, which corresponds to the pricing scheme P_2. Note that P_1 runs counter to the spirit of the benefit of the increasing total utility of the best effort Internet by sharing the network resources. Therefore, we can conclude that the users whose Best Effort traffic follow the concave curve for the increased bandwidth can be benefited from pricing scheme P_2 by the concave utility function.

The result can be used in a priori estimation of a tariff for a flow submitted to the router with complete sharing of bandwidth by a number of connections when the usage-based pricing scheme is introduced in the future IP network.

V. CONCLUSIONS

In this paper the authors investigated the effect of bandwidth increase to the obtainable utility of a customer for the best-effort Internet services that share a limited bandwidth. Via theoretical analysis we could find that it is favorable for the utility function of the elastic applications to have the concave form, which implies that the marginal utility of a customer decreases in quadratic manner as the amount of the available bandwidth increases.

Using the utility function we proposed a pricing scheme for the best-effort Internet services under the condition that the available bandwidth for each customer increases in concave manner.

Via assuming a concave utility function with arbitrary parameter values we carried out numerical experiments, and illustrated the remarkable effect of decreased marginal utility to the amount of price levied to the customer.

Our future research work includes the collection of data in the real commercial Internet, via which we can estimate a more practical utility function from the real data. The problem of revenue maximization is one of the future research areas.

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저 자 소 개

李 焄(正會員)

B.E. and M.E. from Kyungbook National University, in 1984 and 1986, respectively. Ph.D. from Tohoku University, Sendai, Japan, in 1996. From February 1986 to February 2001, Korea Telecom. From March 2001, Assistant Professor of Changwon National University. Current research interests: network design, performance analysis and provision of QoS for high speed telecommunication networks. Dr. Lee is a member of IEEE, KICS and IEEK.

魚 潤(正會員)

B.E. and M.E. from Hanyang University, in 1982 and 1986, respectively. Ph.D. from Tohoku University, Sendai, Japan, in 1994. From January 1986 to July 1987, LG Electric, LTD. From September 1987 to June 1998, ETRI. From September 1998, Assistant Professor of Changwon National University. Research interests : digital communication systems and coding theory. Dr. Uh is a member of IEEE, KICS and IEEK