Int. Computer Symposium, Dec. 15-17, 2004, Taipei, Taiwan.

# Pricing-Enabled QoS Guarantee For Differentiated Service Network

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***Abstract****-By adopting an appropriate economics theory and analyzing a close connection between quantity and price, a service provider will be able to offer the necessary incentives for each customer to choose the service and price that perfectly matches his or her needs without wasting any resource. Our approach enables network service providers to react instantaneously to network congestions and provides customer with high flexibility in service class selection. Economic efficiency is well deployed in pricing strategies to maximize customers' net benefit, provider's surplus and efficiently allocate network resources. To design the differential pricing structures in our researches, we define a DiffServ-based architecture not only to support multiple QoS classes but also allow customers to make personal QoS class selection. However, it also brings about the question of how to provide sufficient quantity and adequate QoS to heterogeneous applications in networking market. In this article, we outline these challenges and discuss pricing strategies*

## 1. Introduction

For years, it has been clear that the integration of multiple services into a single network infrastructure has the potential to generate more efficiency in design, infrastructure and management. Service differentiation brings a clear need for incentives to be offered to encourage customers to choose the service that is most appropriate for their needs, thereby, discouraging over-allocation of resources. In commercial network, resource allocation and congestion control can be most effectively achieved through pricing. Pricing has recently attracted significant attention for the purpose of achieving economic efficiency on the Internet. Many researchers have proposed distinct pricing scheme as mechanisms for managing both resource allocation and network congestion. In our pricing architecture, we are concerned for the production, sale and purchase of network resources that are in limited supply and for how customers and ISP interact in market for them.The purpose of our research is to investigate how pricing depends on the nature of competition and regulation, and whether the price is driven by competition of customer, the profit-maximizing of producer, or the social welfare maximization in the networking market.

### 1.1. Economics Theory

Communication services, such as network resource and architecture are valuable economic products. The prices for which they can be sold depend on factors of demand, supply and how the market operates. The key players in the market for communications services are suppliers, consumers, and regulators. The demand for a service is determined by the value users place on it and the price they are willing to pay to obtain it. The quantity of the service that is supplied in the market depends on the efficiency of their network operations. The nature of competition is among suppliers. How they interact with customers and how the market is regulated all have dependence of the price of network resources. One of the most important factors is competition. Competition is important because it tends to increases economic efficiency: that is, it increases the commercial value of the service that are produced and consumed in the economy. Moreover, the regulator can take account of welfare dimensions that suppliers and customers might be inclined to ignore. For example, a regulator might require that some essential network resources are available to everyone, no matter what their ability to pay. In summary, charging for network resources totally is a essential method to manage elaborate network perfectly. Our researches are to define valuable pricing strategies for our networking market by adopting economics theory.

### 1.2. Differentiated Service Network

The differentiated service network is designed to differentiate IP traffics so that each service priority could be determined on per-hop basis. By using DiffServ, traffic is classified based on DSCP (differentiated service code point). Then the traffic is forwarded according to PHB mechanism defined by IETF. This approach allows applications with similar characteristics to be forwarded with the same traffic guarantees. That is a crucial feature because the current Internet is exactly a network of multiple service provider networks. DiffServ network allows for three main categories of service differentiation such as EF, AF and BE. The DSCP is mapped to the PHB and this technique allows providers to control what QoS class the customers purchase. Switching into different PHB, each time a packet entering a network domain would be remarked.

## 2. Economics Efficiency

An innovative pricing concept has come to our attentions that promise to significantly improve economic efficiency such as customers' surplus, provider's surplus and social welfare maximization. We use economic theory to analyze the relationship between demand and supply in DiffServ network to perform effective network resource allocation and meet customer's application requirements. Theorems of economics can guarantee that demand and supply control dynamically movies the system to an equilibrant point where resources are used efficiently.

### 2.1. The Customer's Problem

Utility is actually an abstract concept rather than a concrete. Utility means the aggregate sum of satisfaction or benefit a consumer gains from consuming a given amount of goods or services in an economy. Although utility usually increases as more of a good is consumed, marginal utility usually decreases with each additional increase in the consumption of a good. This decrease demonstrates the law of diminishing marginal utility. Because there is a certain threshold of satisfaction, the consumer will no longer receive the same pleasure from consumption once that threshold is crossed. In other words, total utility will increase at a slower pace, as an individual increases the quantity consumed.

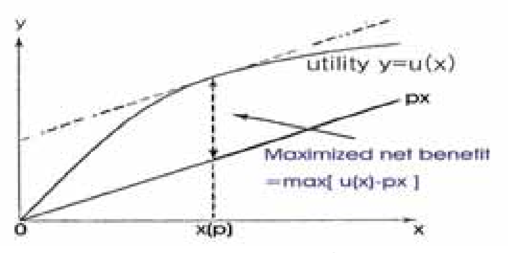

**Fig.1. Net Benefit**

The Fig1 shows that the customer has a utility u(x) for a quantity x of a service. In this figure, u(x) is increasing and concave. Given the price vector p, the consumer chooses to purchase the amount x=x(p) that maximizes his net benefit. Note that at x=x(p) we have $\delta u(x)/\delta x = p$

We can think of u(x) as the amount of money customer is willing to pay in pursuit of products and px means the money customer actually pays. The expression that is maximized is called the customer's net benefit or consumer surplus. It presents the net benefit the consumer obtains as the utility of x minus the amount paid for x.

$$CS_i = \max_x [u_i(x) - p^T x]$$

The Fig2 shows that the demand curve stands for a single customer and a single good. The derivative of u(x), denoted u'(x), is downward sloping, here for simplicity shown as a straight line. The area under u'(x) between 0 and x(p) is u(x(p)), and so subtracting px (the area of the shaded rectangle) gives the consumer surplus as the area of the shaded triangle.

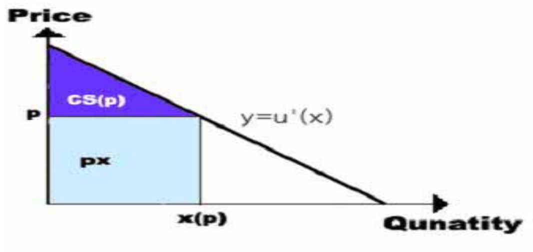

**Fig.2. Consumer Surplus**

### 2.2. The Supplierr's Problem

Profit, or producer surplus, is the difference between the revenue that is obtained form selling these services, say r(y), and the cost of production, say c(y), Denote $y=(y_1,\ldots,y_k)$ the vector of quantities of these services. An independent firm having marvelous profit seeks to solve the problem of maximizing the profit.

$$PS = \max_i [r(y) - c(y)]$$

An important simplification of the problem takes place in the case of linear prices, when $r(y)=p^T y$ for some price vector p. Then the profit is imply a function of p, say PS(p), as is also the optimizing y, say y(p). Here y(p) is called the supply function, since it gives the quantities of the various services that the supplier will produce if the prices at which they can be sold is p

### 2.3. Welfare Maximization

Social welfare (social surplus) is defined as the sum of all consumer and producer surpluses. We speak interchangeably of the goals of social welfare maximization, social surplus maximization, or economic efficiency. The key idea is that, under certain assumptions about concavity and convexity of utility and cost functions. Social welfare should be maximized by setting an appropriate price and allowing producers and consumers to choose their optimal level of production and consumption. This has the great advantage of maximizing social welfare in decentralized way. Suppliers and consumers see these prices and then optimally choose their level of production and demand. They do this on the basis of information they know. A supplier sets his level of production knowing only his own cost function.

$$S = \sum_{i=1}^{N} u_i(x^i) - c(x)$$

The Fig3 shows that a simple illustration of the social welfare maximization problem for a single good. The maximum is achieved at the point where the customer's aggregate demand curve u' intersects the marginal cost curve c'.

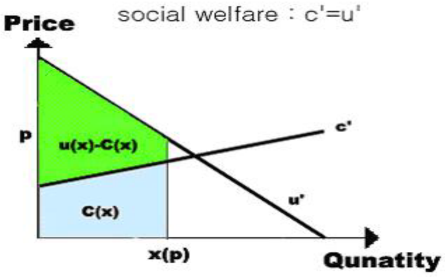

Fig3 Social Welfare

We have the remarkable result that the social planner can maximize social surplus by setting an appropriate price vector p, In practice, it can be easier for him to control the dual variable p, rather than to control the primal variable $x_1,\ldots, x_n$. This price control both production and consumption. Among this price vector, the consumers maximize their surpluses and producer maximizes his profit. Moreover, prices equal the supplier's marginal cost and each consumer's marginal utility at the solution point, we call that price marginal cost prices.

## 3. Pricing Strategies

To introduce our pricing strategies, we have several main parts to stress. We will introduce utility functions for customers and cost function for provider to construct our pricing models. Our pricing strategies include third-degree price discrimination and hybrid pricing. Third-degree price discrimination is one kind of flat pricing by charging customers the same prices for the same product. Hybrid pricing, a brilliant pricing strategy, changes the price for personal customers in reaction to instantaneous network congestion conditions.

### 3.1. Utility Function

Utility function is strictly increasing and strictly concave, so we define utility function like below. RA is resource allocation, CS means customer distribution and D means personally average delay of each class. Therefore, we define three utility functions for three classes in DiffServ network.

$$u(x) = (\frac{RA}{CS})x^a - D\,, \quad 0 < a < 1$$

There are three QoS classes in our DiffServ network. Since we refer to some ISP companies, the network resource of three classes is allocated as (5/10,3/10,2/10) and the customer distribution is as (24/100,35/100,41/100). The average delay time of each class is (0.004, 0.007, 0.012). In this case, the utility we define for class1 service is more valuable than that we do for class2 service.

Ultimately, we can generate three utility functions for EF, AF and BE such as $U1= 2.083*x^{0.6}-0.004$, $U2=0.857*x^{0.6}-0.007$ and $U3=0.487*x^{0.6}-0.012$.

### 3.2. Cost Function

The cost function we want to find are concerned with the effects of congestion and pricing that take congestion into account. Because users share a common network resource such as bandwidth, we model cost function by supposing that user i has a net benefit that depends on the amount service demanded by other users. That is, he enjoys net benefit of a form like below

$$C(x_i) = \frac{x_i}{1-y}$$

Where $y=\Sigma_i x_i / k$, for some constant k, Here k parameterizes the resource capacity of the system. The intuition is that congestion depends on the load of the system, as measured by y. Full load may correspond to $\Sigma_i x_i= k$, If user i requests a quantity of service that is small compared with the total requests of all users, then y does not vary much with different choices of xi, and so the problem is to maximize producer's profit, with y taken as fixed. We suppose y is not fixed, and consider the problem of determining p so that when the market is in equilibrant we maximize some measure such as social welfare or the service producer's profit

The definition of the load $y=\Sigma_i x_i / k$ is natural for a single link network in which xi is an average flow and k is the bandwidth of the link. In the principle, congestion measures, such as delay and packet loss, can be directly determined given the statistics of the traffic and service discipline of the link. Our cost function is powerful and useful for more general situations, in which we desire to price dynamic parameters of the contract and yearn to find the rules to avoid the occurrence of congestion. Here, D(y)xi is a congestion cost. For example, this congestion cost might arise as the product of xi and the average delay experienced by a packet belonging to user i when packets are served at a M/M/1 queue, Assuming service rate 1 and Poisson arrival at rates $x_1,\ldots,x_n$, the average delay in the queue is 1/(1-y), so we define cost function like that

### 3.3. Third-Degree Price Discrimination

ISP with a degree of monopoly power has the ability to discriminate price in diverse markets. This means being able to charge a different price to different region or market. ISP companies may find that by charging different markets different prices for a common product may actually increase the profits of the firm. This charging of different prices for a particular good is known as price discrimination and is very common in various markets around the globe. Third degree price discrimination can be achieved to design the price for three QoS classes in DiffServ network because the network resources can be segmented and the segments have different elasticity of demand.

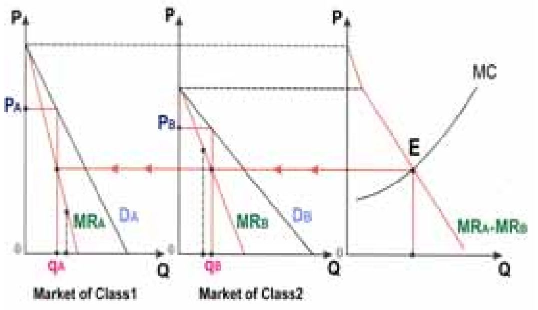

**Fig.4. Calculation of Third-Degree Price Discrimination**

Fig4 illustrates simply the demand and marginal revenue of two different markets and how a provider decides his prices. Demand function, the derivative of utility function, equals to average revenue. In addition, total revenue is the sum of quantity cross average revenue. By equating MC with MR ($MR_A$+$MR_B$), we can generate the equilibrium point (E). By drawing a horizontal line through the MC=MR point until it intersects with the MR curves, like $MR_A$ and $MR_B$, and then reading the price off the respective demand curves $D_A$ and $D_B$ the price in each segment is determined, $P_A$ and $P_B$. In the equation of total revenue, M is the total customers in market1 and N is the total customers in market2.

$$MR_A = \frac{\partial (D_A \times Q_A)}{\partial Q_A} \quad MR_B = \frac{\partial (D_B \times Q_B)}{\partial Q_B}$$

Revenue= $P_A$*$q_A$*M+$P_B$*$q_B$*N

### 3.4. Hybrid Pricing

Airlines are often cited as pioneers in differential pricing. Airline pricing can actually be seen as an example of both price discrimination and product differentiation. It is easy to search for convenient flights, but finding the least expensive rate is cumbersome, because the number of differential tariffs is huge. The third-degree price discrimination is not so flexible that the price too fixed to change. So we define a brilliant hybrid pricing which is the combination of differential pricing and dynamic pricing. The prices customers pay will dynamically change according to the current congestion condition.

In hybrid pricing, social welfare reach maximization. (Through utility function and cost function, they offer truly fairness to consumer and producer) When the derivative of utility function for three QoS classes and the derivative of cost function are equal (when u'(x) and c'(x) intersect) the economy is said to be in equilibrium. At this point, the allocation of network resource is at its most efficient because the amount of network resource being supplied is exactly the same as those being consumed. Thus, both consumer and producer are satisfied with the current economic condition. Table1 shows the tariff charge table for customers.

**Table 1. Tariff In Hybrid Pricing**

| Differentiated Charge | | | | | | |
|---|---|---|---|---|---|---|
| (P) | User 1 | User 2 | User 3 | User 4 | User 5 | |
| Class 1 | 1.2303 | 1.3361 | 1.4407 | 1.5442 | 1.6463 | |
| Class 2 | 1.0374 | 1.0557 | 1.0738 | 1.0918 | 1.1097 | |
| Class 3 | 1.0090 | 1.0135 | 1.0181 | 1.0225 | 1.0270 | |

The money which the first user pay for class 1, called $c_1p_1$, is chapter than that second user pay for the same class service, called $c_1p_2$. When consumers subscribe network service subtly late, they need to pay much money. As congestion occurs, the consumer who subscribe network service pay much money than before. Competition can prevent the occurrence of congestion. Consumers and producers should follow quantity and demand in table 1 to sell and buy. If m flows are served in class 1, the revenue form class1, called TR1. The revenue from class1 is equivalent to $c_1p_1$*$q_1$+ $c_1p_2$*$q_2$+ $c_1p_3$*$q_3$+…+ $c_1p_m$*$q_m$. The total revenue is like below.

$$\sum_{i=1}^{m} c_1 p_i \times q_i + \sum_{j=1}^{n} c_2 p_j \times q_j + \sum_{k=1}^{o} c_3 p_k \times q_k$$

## 4. QoS Class Reshuffle

Note that we are responsible for solving the resource over-utilization and guarantee QoS in the Internet. QoS class reshuffle is created to handle the occurrence of congestion. When there are existing resources in others classes. Customers suffering from congestion problem can choose to switch into higher or lower class just for better QoS service.

### 4.1. Class Reshuffle

The customer has complete control over his choice of network resource, they can see its price on the tariff and predict the charge. However, producer must offer a set of customized services to consumers. Meeting customers' satisfaction also brings in tremendous profits to producer. That is why our system provides three differential classes to customer to choose on their demand. In Fig.5, it shows fairness to some customers to choose their personal service resources and change their classes by modifying the DSCP as their need vary over time.

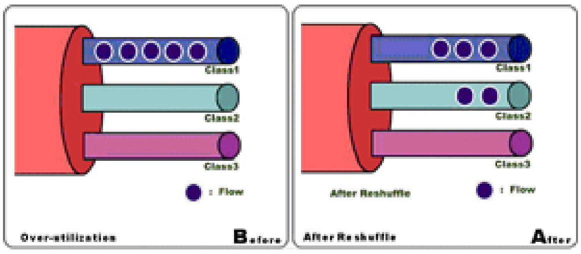

**Fig.5. QoS Class Reshuffle**

### 4.2. Event Trigger

In hybrid pricing, when n flows are served in class 1 and the n+1th flow arrive, traffic congestion occurs and some flows suffer from increasing end-to-end delay time. After the end-to-end delay time of some flows exceed the trigger bound, these flows can obtain better service by shuffling into other classes to obtain more resource to offer. This action is called QoS class reshuffle. This is done by our system, which sort flows in decreasing order of pi*di, where pi is the unit price flow i pay and di is the terrible end-to-end delay time flow i suffer from. If pi*di > pj*dj, this implies flow i come to class 1 later than flow j and get worse QoS service. Therefore, flow i is the first choice to be reshuffled. Our class reshuffle strategy indicated that a later coming flow would use other classes instead and pay less money for the service.

We achieve "we-win" target by introducing pricing concept into our system. It is not only beneficial for customer to get perfect service and pay less money, but also help ISP accommodate more customers and earn much revenue.

## 5. Simulations and Results

Here we conduct simulations to evaluate our pricing strategies, such as third-degree price discrimination and hybrid pricing, and compare them with QoS class reshuffle in DiffServ network. We perform our simulations using QualNet simulator. Fig.6 shows the topology of differentiated network.

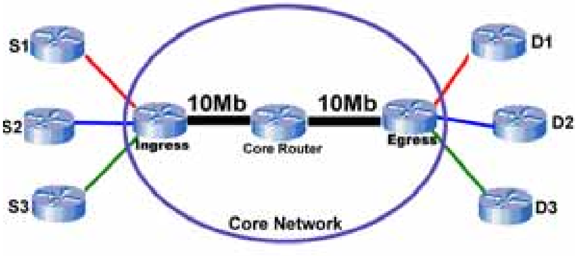

**Fig.6. Topology of Simulation**

### 5.1. Simulation Parameters

To generate two kinds of traffic applications, we describe VoD and VoIP by their characteristics. The table below shows traffic characteristics of them. We model the VoD as CBR flows with constant packet-generated intervals and constant packet size. The VoIP is modeled as VBR flows with constant packet-generated intervals and various packet size of exponential distribution.

**Table2 Simulation Parameter**

| Traffic Application Characteristics | | | |
|---|---|---|---|
| | **Mean Rate** | **Packet Size** | **Trigger bound** |
| **VoD** | 384Kbps | 210Byte | 150ms |
| **VoIP** | 24Kbps | 20Byte | 100ms |

### 5.2. Scenarios

We introduce two scenarios to evaluate the performance. In scenario1, we evaluate QoS improvements of supporting QoS class reshuffle. We start simulation by generating two kinds of traffic applications, such as VoD and VoIP, into EF class, AF class, and BE class in DiffServ network. Among the most excellent improvement of QoS class reshuffle is that each flow could maintain perfect QoS service even with the increase of traffic load.

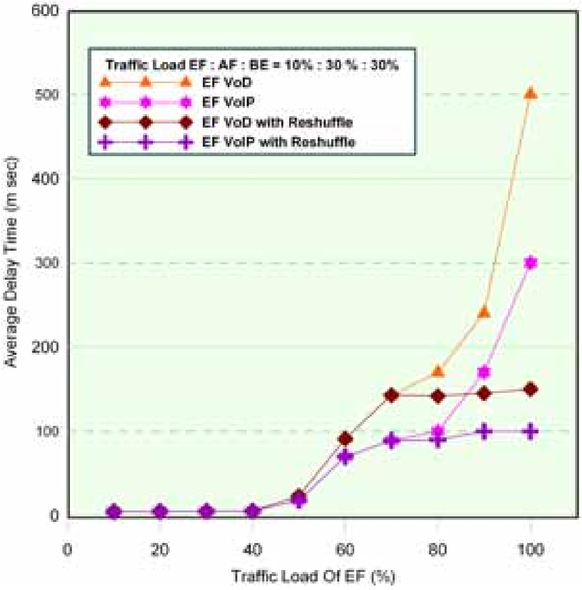

**Fig.7. Average Delay Time**

The Fig.7 shows that average delay times in EF service soar with the increase of traffic load. When the delay time exceed reshuffle trigger bound, our system switch flows suffering bad QoS into other classes and using the rest of resource. After the reshuffle, the delay time deterioration would be solved completely. The Fig 8 shows packet loss is reduced and alleviated by adopting QoS class reshuffle.

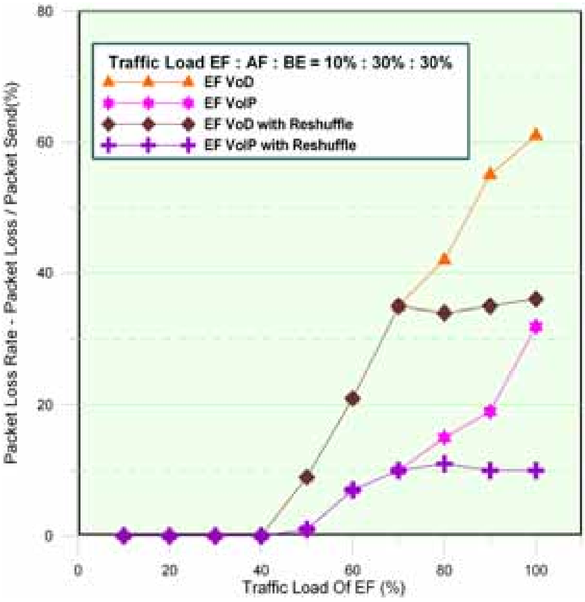

**Fig.8. Packet Loss Rate**

In scenario 2, we are concerned about the economic efficiency in our networking market. The detailed comparison between third-degree price discrimination and hybrid demonstrates the profits provider could receive. Fig.9 implies that hybrid pricing brings more profits than third-degree price discrimination does. After traffic load rises to 80 percent, the growth of revenue gets stopped eventually.

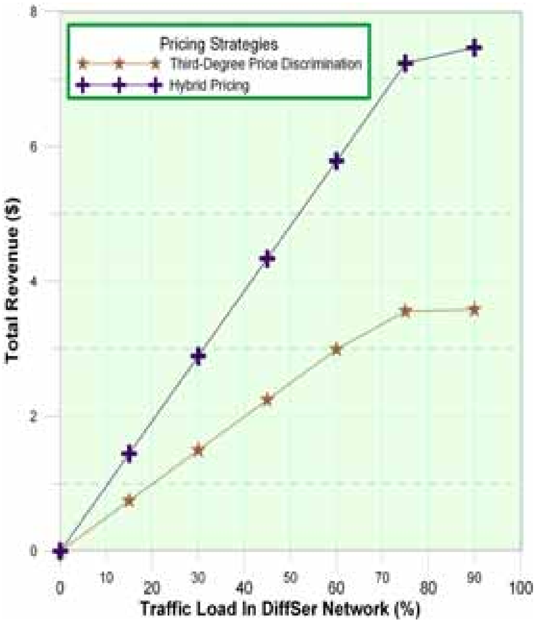

**Fig.9. Total Revenue**

## 5. Conclusions and Future work

In this article, we propose the innovative pricing strategies to achieve economic efficiency for provider and customer to acquire better profit and QoS services in networking market. QoS class reshuffle allots network resources more efficiently and provides guaranteed QoS to maintain the network at stable and good performance. By adopting economic methods to better manage network resources, customers and provider could be in pursuit of "We-Win" excellent outcome.

The future work to is to conduct research on the combination of network and economics. We could develop mechanisms within revenue-maximizing and well-distributed resource pricing architecture for the next-generation network to dynamically formulate reasonable prices to the customers.

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