Responsive Pricing Model with Fixed Bandwidth Usage for the Next Generation Internet

Vesna Radonjić and Vladanka Aćimović Raspopović[1]

Abstract – **In this paper we present a model for incorporating responsive pricing scheme in the next generation Internet. We developed an algorithm based on Stackelberg game model with users competing for the fixed bandwidth and the network adjusting the bandwidth price to maximize both its revenue generated from the users and the total user utility. We founded optimal prices for each service class in the network with differentiated services architecture.**

Keywords – **Next generation Internet, Responsive pricing, User utility, Stackelberg game.**

I. Introduction

Pricing issue occupies center stage in the current Internet. Apart from its principal function of revenue generation, pricing also serves as a fairly low dimensional control parameter to optimize system properties and control network congestion [1], [2], [3], [4]. Pricing was also found to be very helpful for encouraging quality of service (QoS) differentiation.

The main idea of all pricing schemes is to stimulate users to behave in a way that improves total network utilization and network performance. Economists have traditionally employed game theory to analyze the behavior of users in markets regulated by supply and demand. The users are modeled as rational agents striving to maximize their individual utility functions. In the case of the Internet, users are computing machines interacting with each other through dedicated communication channels.

It is considered that the introduction of the next generation network (NGN) will result in changes to the existing pricing concepts. In this paper we propose a responsive pricing model for utility differentiated users operating in a connection oriented setting, such as proposed for the next generation Internet. Pricing issue is treated as an optimization problem with network and users behaving as Stackelberg leader and followers.

The paper is organized in the following way. In Section 2 we briefly discuss NGN requirements for pricing, the pricing role in service differentiation and responsive pricing scheme. In Section 3 both users' and network optimization problems are presented and the pricing algorithm for solving these problems is proposed. In Section 4 simulation results are presented and analized. Conclusion is given in the Section 5.

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II. Pricing for the Next Generation Internet

A. Pricing Issue in the Next Generation Network

The NGN concept takes into consideration new realities in the telecommunication industry characterised by factors such as: the need to converge and optimise the operating networks and the extraordinary expansion of digital traffic. The evolution of networks to NGNs must allow the continuity of, and interoperability with, existing networks while in parallel enabling the implementation of new capabilities [5].

It is considered that a pricing issue will occupy center stage in the NGN. NGN requirements for pricing are summarised below:

- Accounting functions, off-line (i.e. post processing) and on-line charging (i.e. charging during the session), shall be available.
- Open mechanisms should be available for charging and billing management.
- Various charging and billing policies should be supported (e.g. fixed rate charging and usage based per-session charging and billing).
- Accounting functions should support services with multicast functionality. The accounting functions should be able to report which user received which information as well as session start and stop times.
- The NGN should enable all possible types of accounting arrangements, including transfer of billing information between providers.

B. Quality of Service Differentiation

The need for a mechanism designed to encourage a socially optimal solution wherein high value bits would be given preference over others has led to the idea of providing QoS in the Internet. The QoS paradigm require a network that could carry out service differentiation with packets serviced depending upon their value. But incentives were necessary to prevent users from inflating their packet values and requesting better services. Price discrimination of services was found to be ideal for encouraging service differentiation with the associated revenues paying for any needed network expansions. It is suggested that the basic best-effort architecture be left intact with QoS schemes solely reserved for resource intensive high quality real-time services.

Congestion can be alleviated by a usage based scheme with users getting charged for the amount of traffic they consume. For maintaining social optimality these charges would have to be set equal to the marginal cost of usage. Since bandwidth scarcity occurs only during congestion, this marginal cost essentially the same as the congestion cost. The notion of congestion pricing was developed to account for the social costs imposed by the user on the rest of the population during periods of congestion.

C. Responsive pricing scheme

The responsive pricing concept describes a dynamic price-setting strategy imposed by the network, illustrating how the network can exploit the adaptive nature of users to increase economic and network efficiency. Price is emphasized as an alternative means for congestion control to ensure proper network operation and in particular to guarantee different service levels.

Responsive pricing is based on the assumption that users are adaptive and respond to price signals [6]. In case of high network utilization, resources are stressed and the network increases the prices for the resources. Adaptive users then reduce the traffic offered to the network. Similary, in case of low network utilization, the network decreases the price and adaptive users increases their offered traffic. In this scheme, both network and economic efficiency are increased.

III. Stackelberg Game between Users and Network

A. User utility function

Pricing issue is treated as an optimization problem with network and users behaving as Stackelberg leader and followers [7], [8], [9]. Users respond to price per unit bandwidth imposed by the network, demanding bandwidth according to their individual utility functions. The solution of the problem encompasses the optimal bandwidth allocation and the optimal price for that allocation.

QoS requirements induce each user i to request a bandwidth of θ_i from the network. The network employs a usage based pricing policy by charging M per unit bandwidth consumed. Both the network and the users are rational, profit maximizing entities. Further they are assumed to be noncooperative and refuse to reveal their utility functions to one another in the fear of being exploited.

Since users are observed as entities designed to maximize their individual utilities, it is important to develop a utility function to model user behavior. This is a generalization of the popular logarithmic function employed, tailored for a connection oriented setting. QoS is defined by bandwidth obtained from the network. Depending upon the quality of service requested, each user would require a minimum bandwidth γ. Fewer bandwidth than γ on average are of no utility to the user. The law of diminishing marginal utility ensures that the user derives the same amount of satisfaction from any bandwidth more than the maximum π (Figure 1).

It is considered that the user is willing to pay a maximum m per bandwidth per service class per unit time. When the network price M equals the maximal price m, the user will desire only the minimum acceptable bandwidth, γ. Any price beyond the maximal price reduces the user's desired bandwidth to zero. Over the interval $m\gamma / \pi \le M \le m$ the desired bandwidth θ decreases logaritmic with price with π. Dependence of desired bandwidth with price for arbitrarily choosen user is shown on Figure 1.

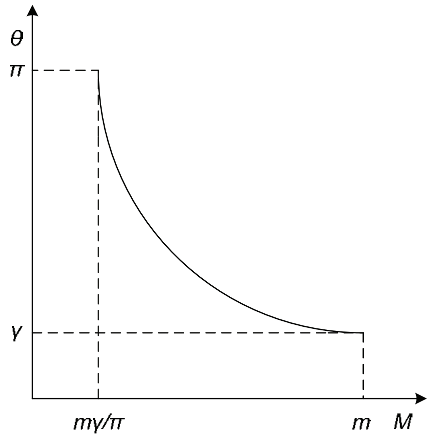

Fig. 1: Desired bandwidth

According to [10], user utility function can be shown to be:

$$U(\theta) = \begin{cases} m\theta, & \text{if } 0 \le \theta \le \gamma \\ m\gamma\left(\log\left(\theta/\gamma\right)\right)+1, & \text{if } \gamma < \theta \le \pi \\ m\gamma\left(\log\left(\pi/\gamma\right)\right)+1, & \text{if } \pi < \theta \end{cases} \tag{1}$$

This utility function (Figure 2) is concave and nondecreasing. Also, U is strictly increasing on $[0,\infty)$ only when $\pi \to \infty$. The case of users that can't tolerate loss, but can postpone traffic (elastic users) can be recovered by setting $\gamma = 0$ and $\pi \to \infty$, thereby rendering U strictly concave on $[0,\infty)$. Therefore, the utility function encompasses a wider spectrum of user behavior by incorporating the range of user bandwidth requested.

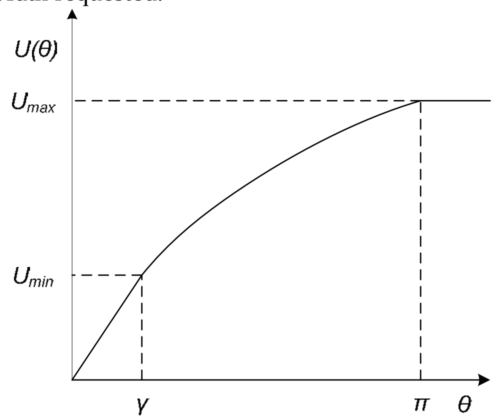

Fig. 2: User utility as a function of bandwidth

We suppose that the shape of these functions (shown in Figures 1 and 2) is the same for all users, but parameters γ, π and m are different.

Ideally any resource allocation between competing users should ensure that the total user utility is maximized. The optimal bandwidth allocation is obtained by solving problem:

$$\max_{\Theta} \sum_{i=1}^{N} U_i\left(\theta_i\right),\ \sum_{i=1}^{N} \theta_i \le C \tag{2}$$

Because of the noncooperative setting assumption, we need to develope a distributed algorithm which can be used by each user to update its spectrum allocation without revealing utility information to other users or the network. In practice, the user will try to choose its throughput θ so as to maximize its net benefit (i.e., utility minus cost), $U(\theta) - M\theta$. Thus individual users can solve the simpler problem:

$$\max_{\theta_i} U_i(\theta_i) - M\theta_i \tag{3}$$

The value of θ maximizing utility function (under conditions $0 \le M \le m$ and $\gamma \le \theta \le \pi$) is:

$$\theta^*(M) = \frac{m\gamma}{M}. \tag{4}$$

On the other hand, the network's utility $T(M,\Theta)$ depends on the total revenue generated and hence is a function of the market price and the bandwidth allocated to the various users. It is assumed to be monotonically increasing and strictly concave. The network chooses an appropriate market price by solving the optimization problem:

$$\max_M T(M,\Theta^*) \equiv T\left(M\sum\nolimits_{i=1}^{N}\theta_i(M)\right)$$

$$\max_M M\sum\nolimits_{i=1}^{N}\theta_i(M),\ \sum_{i=1}^{N}\theta_i \le C,\ M \ge 0 \tag{5}$$

User's utility function can also be shown as a function of price. Substituting (2) in (1) for a previous condition, we obtain:

$$U(M) = m\gamma(\log(m/M)+1) \text{ if } m\gamma/\pi \le M \le m \tag{6}$$

In Figure 3, user's utility as a function of price, for an arbitrary user, is presented.

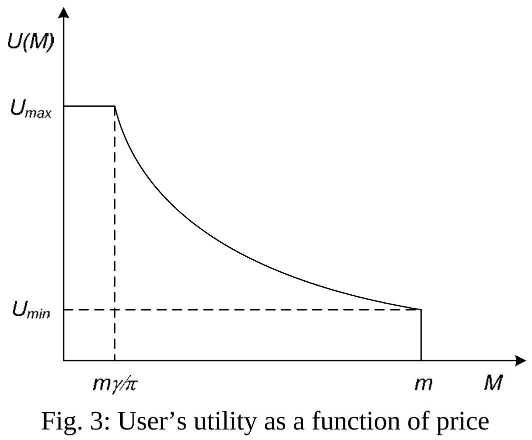

Fig. 3: User's utility as a function of price

This scenario reduces to a Stackelberg game with the network being the leader and the users acting as followers. The network initializes its algorithm by assigning an initial price M^0 randomly or based on historical data.

B. Pricing algorithm

We developed an algorithm for the responsive pricing scheme where users are charged for fixed bandwidth usage. Prices optimization is performed for each service class in a network employing differentiated QoS model. A single critical resource link in a communication network is considered. We assumed existence of the perfect information.[1] On the observed link, the total number of users is N. Algorithm consists of S rounds and in each round s, l_s iterations are performed, where $s = 1,2,\ldots S$. Each round s consists of the following iterative steps:

Step 1: For the fixed bandwidth θ_j, provided to every service j class user, network price is proposed by the network: M_j^{0s} for $s=1$ and $M_j^{0s} = k_s M_j^{\min(s-1)}$, where $M_j^{\min(s-1)}$ is a minimal considered price for class j in a circle $s-1$ for $s = 2,3,\ldots S$ and $M_j^{0s} > 0$.

Step 2: For the price M_j^{0s}, each user i independently calculates desired bandwidth for a desired class of service j, θ_{ij}^{0s}; $j = \overline{1,J}$, $i = \overline{1,N}$.

Step 3: After his needs, user i chooses one class j and is willing to pay M_j^{0s} for service of choosen class if $\theta_{ij}^{0s} \le \theta_j$; user i is not willing to pay M_j^{0s} for the same service if $\theta_{ij}^{0s} > \theta_j$ and he applies for a service of class j' such that $\theta_{ij'}^{0s} \le \theta_{j'}$ and $\theta_{ij'}^{0s} = max\left\{\theta_{i1}^{0s},\ldots \theta_{iJ}^{0s}\right\}$; $j' = \overline{1,J}$, $j' \ne j$.

Step 4: For each class j we calculate $N_j^{0s}\theta_j$, where N_j^{0s} is the number of users such that $\theta_{ij}^{0s} \le \theta_j$, $j = \overline{1,J}$.

Step 5: If $\sum_{j=1}^{J} N_j^{0s}\theta_j < k_e C$, total sums $T^{0s}(M^{0s}) = \sum_{j=1}^{J} M_j^{0s} N_j^{0s}$ and $\sum_{i=1}^{N}\sum_{j=1}^{J} U_{ij}(M^{0s})$ are calculated; after that, new prices for each class j, M_j^{1s} are calculated: $M_j^{1s} = kM_j^{0s}$, $0 < k < 1$ and it crosses over to a new iteration with new prices $M_j^{1s} < M_j^{0s}$.

Step 6: If $\sum_{j=1}^{J} N_j^{0s}\theta_j > C$, the network set prices, M_j^{1s} for each class j, $M_j^{1s} = kM_j^{0s}$, $k > 1$ and it crosses over to a new iteration with new prices $M_j^{1s} > M_j^{0s}$.

Step 7: If $k_e C \le \sum_{j=1}^{J} N_j^{0s}\theta_j \le C$, it crosses over to a new circle $s+1$.

The network initializes its algorithm by assigning initial prices based on historical data. In the each next step, initial prices are decreased by factor k_s, so in the circle $(s+1)$: $k_{s+1} = rk_s$, $0.8 \le r < 1$. C is the total capacity of the critical link. Factor k_e points to high level of utilization of total capacity C and $0.95 \le k_e \le 1$. After S circles, diagrams T

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[1] Perfect information is understood as all the users are aware of each others arrival rates.

and U for values θ and M satisfying condition $N_j^{ls} \leq C_j$ are created. The point where both functions T and U reach the maximum gives optimal prices.

IV. Simulation Results

For the purpose of carring out simulation of the pricing algorithm, we developed software in C Sharp. In figure 4, application for determining optimal price maximizing total network revenue and total users utility on critical network link is presented. Total network revenue and total users' utility graphes for one simulation based on chosen parameters in aplication in Figure 4, are shown in Figure 5. According to Figure 5, optimal price and total network revenue for that price can also be determined.

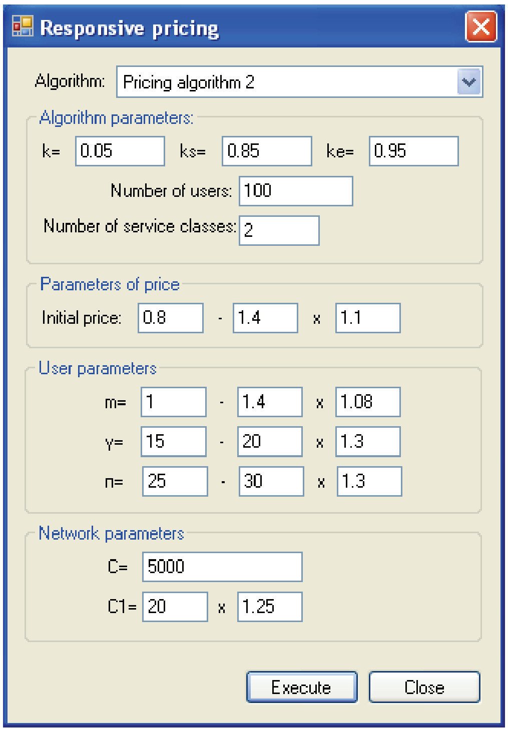

Fig. 4: Pricing algorithm application

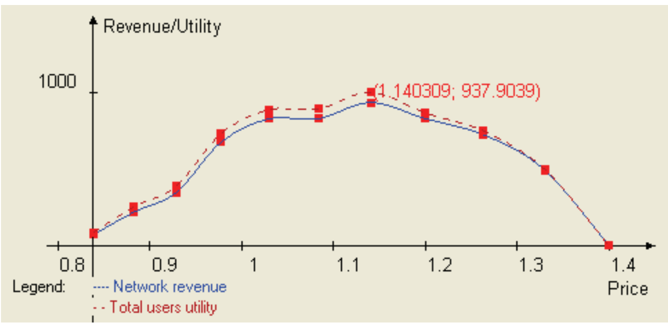

Fig. 5: Output functions

After executing a number of simulations, we can conclude that for fixed number of users the marginal value of total network capacity of the critical link can be determined. Increasing that value network revenue doesn't increase. Future research will encompass analysis of economic profitability in function of critical network link capacity.

V. Conclusion

This paper describe one possibility for implementing responsive pricing scheme in the next generation Internet. We developed an algorithm where users are charged for fixed bandwidth usage. Prices optimization is performed for several service classes in a network employing differentiated QoS model. Pricing issue is treated as an optimization problem with network and users behaving as Stackelberg leader and followers. We verified the proposed model through simulation with software solution.

The important advantage of presented pricing model ensures a high level of network utilization. That can be achieved by congestion control and traffic management. The advantage is also in stimulation each user to choose the level of service to be charged for and network considering users preferences. For solving that problem, Stackelberg game with the network being a leader and the users acting as followers proved to be a good scenario.

Acknowledgments

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