Dynamic Pricing in Cellular Networks for QoS Management

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Abstract—In this work in progress paper we describe dynamic pricing strategies for network quality of service (QoS) in cellular networks. Dynamic pricing policies allow the network operator to charge a cost per time unit depending on the availability of network resources; hence it regulates the arrival rate of calls of service to the network. This implies that network service requirements such as performance, availability, reliability, security, bandwidth, congestion, routing, stability, delays, etc are maintained at an optimum level. These are the parameters that define the network QoS both within the network and at the edge access points where customer services are offered, leading to significant improvement in the network management. We model demand for the network capacity as a function of the arrival rate, which in turn is a function of the service price. The aim of this project is to apply a three stage pricing scheme to cellular networks.

Index Terms—Cellular networks, dynamic pricing, optimal price, quality of service (QoS)

I. INTRODUCTION

Today, demand for mobile services has been rising exponentially; however, the bandwidth and frequency spectrum for mobile services is critically limited. To address this limitation problem, GSM service providers need new tools to help them efficiently and effectively optimize their networks [1]. Several methods have been suggested such as cell splitting and frequency re-use [2], dynamic channel allocation or alternative routing [3], and adaptive cell-sizing algorithm. All these methods often imply either an increase in system complexity or a significant degradation of the quality of service.

An alternative approach is to attempt to modify user demands to fit within the available network resources in the cell. Currently, most mobile service providers have implemented static pricing strategy by offering cheaper (or free) off-peak calls as a marketing incentive, in an attempt to utilize the spare capacity. However, a major drawback of the current tariffs is their lack of flexibility and inability to take account of the actual network load, by merely increasing the tariffs when the operator anticipates high demand. In this context, we propose a solution based on real-time or dynamic pricing techniques where prices are adjusted according availability of the network resources, hence making better use of the available bandwidth, and providing the desired QoS to the user as well as greater revenue to the service provider. It presents the user with a price they are willing to pay. It is intuitive that the trend of user demand can be modified by imposing higher rates in the correspondence of peak-traffic time periods and low rates when large network resources are available. Thus, this pricing scheme can be used as congestion control, call admission control and resource management.

II. RELATED WORK

Dynamic pricing has been mainly used to control wired networks supporting Internet-based services [5], [6]. In this case techniques to derive the system optimal rates have been proposed, which charge user on the basis of the congestion they cause to the network. Dynamic pricing on cellular networks is an emergent research domain. In [7] a self – regulated system is proposed and the goal of the algorithm is to maximize both the revenue for service provider and the welfare of the users, that is, to choose the pricing function, which offers the best utilization of system capacity whilst keeping the call blocking probability at a preset level. A new dynamic pricing scheme for cellular networks is proposed in [8]. Unlike [7], [8] introduces the notion of call admission control. This scheme also shows a clear cut between new calls and handoffs. In [9] yet another approach to dynamic pricing in mobile networks is presented. The main goal of this research is to maximize the total revenue by finding an optimal pricing function.

In our paper, we use a novel optimization model based on non-linear mathematical programming presented in [4]. We use an optimal pricing scheme to moderate the demand for connection requests from different classes of service. We develop a three-stage procedure to determine the optimal amount of capacity and the optimal price schedule.

III. NETWORK MODELLING

Network capacity is denoted by c_T, whose unit is the maximum number of packets that can be transmitted over the link per unit time.

A. Service Model for Guaranteed Services:

Let the price per unit time be $p_i(t)$. Call duration being independent on price and is exponentially distributed with departure rate r_i.

Arrival rate of calls for service is given by $\lambda_i[p_i(t),t]$. $\lambda_i[p_i(t),t]$ depends on price at any given time and is Poisson distributed at any given time and price, which means that the number of calls arriving within any period is independent of the number of calls that arrived within the previous periods. This can be modelled as equation (1)

$$\lambda_i[p_i(t),t] = e^{-\gamma p}\left(1 - \cos\left((2\pi t/T) - \tfrac{1}{4}\pi\right) + \varepsilon\right) \quad (1)$$

where $\lambda_i[p_i(t),t]$ is call arrival rate, $p_i(t)$ is price charged per unit time, γ, ε are arbitrary constants and T the time period (1 day).

The number of calls being processed (underway of service i) is noted by $q_i(t)$ and $E[q_i(t)] = \overline{q}_i(t)$. Under the assumptions we made about call arrival and departure process, the rate of change of $\overline{q}(t)$ should be:

$$\frac{d\overline{q}_i(t)}{dt} = (1-\beta_i)\lambda_i(p_i,t) - r_i\overline{q_i}(t) \quad i = 1..., N. \quad (2)$$

where β_i is the blocking probability, $\lambda_i(p_i,t)$ is call arrival rate and r_i the departure rate.

From Erlang the B formula [4], we derive the network demand. We set prices such that the reserved capacity can never go above total network capacity. In general,

$$A[\overline{q}_1(t),...\overline{q}_N(t);\beta_1(t),...\beta_N(t)] \le c_T \quad (4)$$

B. Service Model for Best Effort Services

We let $p_b(t)$ be the for best effort services, which is a function of both current buffer occupancy and predicted willingness to pay values of future incoming packets. Let B_s be the buffer size. If we assume that at time t, the arrival process of packet of best effort service is Poisson with expected value $\lambda_b(0,t)$ the acceptance of packets is also Poisson with expected value $\lambda_b(p_b,t)$. Define $s_b(t)$ as the instantaneous transmission rate of best effort service at the time, then

$$s_b(t) < c_T - s[q_1(t), q_1(t),...q_N(t)] \quad (5)$$

where $s[q_1(t), q_1(t),...q_N(t)]$ is instantaneous transmission rate of all guaranteed services, which is a function of the number of calls in progress.

Define $v(t,\Delta t)$ as the number of packets actually admitted into the buffer during the interval $[t, t+\Delta t)$; then the instantaneous admission rate can be defined as

$\omega_b = \lim_{\Delta t \to 0} \frac{v_b(t,\Delta t)}{\Delta t}$, ω_b is a random variable,

$E[\omega_b] = \varpi_b(t), \quad \Rightarrow \quad \varpi_b(t) \le \lambda[p_b, t].$

Define $q_b(t)$ as the number of packets in the buffer at time t, then

$$\frac{dq_b(t)}{dt} = \varpi_b(t) - s_b(t) \text{ and } \quad s_b(t) \le q_b \le B_s \quad (6)$$

IV OPTIMAL PRICING PROCEDURE

We formulate an optimal control model to derive the ω_b pricing policy and discuss how to solve this model through a three-stage procedure.

A. Stage 1: Optimal Investment

At this stage we formulate and solve an optimization problem to determine the optimal amount of total bandwidth, c_T and the desired blocking probability of each guaranteed service at each time, $\beta_i(t), i = 1..., N$.

We assume that the traffic load in any period has no influence on the traffic in succeeding periods. Also the arrival rate is constant with time.

B. Stage 2: Optimal Pricing

Given the amount of bandwidth c_T, optimal blocking probability $\beta_i(t), i = 1, N$ and ignoring the assumptions in stage one, we can simplify the model .We then solve for the optimal pricing schedule for guaranteed services.

C. Stage 3: Spot Pricing

Given the prices for guaranteed services obtained in stage 2, the distribution of available capacity for the best-effort service as a function of time can be determined as $c_T - s[q_1(t), q_1(t),...q_N(t)]$. We solve for $p_b(t)$ which is the spot price for admitting packets for best effort service into the buffer to maximize revenue.

Optimal price policy is reached by iterating the second and the third stage until $p_i(t)$ and $p_b(t)$ stabilizes.

V. CONCLUSION AND FUTURE WORK

Due to the fact that a discrete-time approximation of continuous-time optimal control problem description in [4] results in suboptimal performance, one of the aims of this study is to develop a description of the problem in discrete-time solution of which is expected to yield improved performance. The pricing scheme will then be simulated to show the effect of dynamic pricing on QoS.

VI. REFERENCES

[1] R. Abiri, "Optimizing service Quality in GSM/GPRS Networks," In Focus, September 2001.

[2] M. Bouroche, "Meeting QoS Requirements in Dynamic Priced Commercial Cellular Network," Masters thesis, University of Dublin, September 2003.

[3] K. Ahmad, E. Fitkov-Norris, "Evaluation of Dynamic Pricing in Mobile Communication Systems," University College London, 1999.

[4] Q. Wang, J.M. Peha, M.A. Sirbu, "Optimal Pricing for Integrated-Services Networks with Guaranteed Quality of Service," Carnegie Mellon University, Chapters in Internet Economics, MIT Press, 1996.

[5] I.C. Paschalidis, J.N. Tsitsiklis, "Congestion-dependent Pricing of Network Services," IEEE/ACM Transactions on Networking, vol.8, No.2, pp.171-84, April 2003.

[6] J.M. Peha, "Dynamic Pricing and Congestion Control for Best –Effort ATM services," Computer Networks, Vol.32, pp. 333-345, March 2000.

[7] E.D Fitkov-Norris, A. Khanifar, "Dynamic Pricing In Mobile Communication Systems," In First International Conference on 3G Mobile communication Technologies, pp 416-420, 2000.

[8] J. Hou, J. Yang, P. Symeon, "Integration of pricing and call admission for wireless networks," In IEEE 54th Vehicular Technology Conference, Vol. 3, pp 1344-1348, 2001.

[9] E. Viterbo, C.F. Chiasserini, "Dynamic Pricing for Connection Oriented Services in Wireless Networks," In 12th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Vol.1, pp. A-68-72, September 2001.