Dynamic Pricing for Congestion Avoidance and Utilization Improvement in Wireless Cellular Networks

G. S. Mundada
PICT, Pune – 411043, India

B. S. Chaudhari
I2IT Pune – 411057, India

A. V. Walke
PVPITBavdhan Pune 411021, India

ABSTRACT
With tremendous growth in the wireless industry and due to scarcity of spectrum, the future cellular network will be limited by the number of channels available in each cell. The solutions like sectoring, cell splitting cannot cope up with the ever increasing demand of the subscribers. One of the other options to control the demand is through the economical means. Cellular users are sensitive to price and it can act as a tool to determine number of incoming calls and control the duration of such calls. In this paper we have studied and analyzed theimpact of dynamic pricing on traffic and congestion in cellular networks. The simulations are carried out using fixed, linear and nonlinear pricing for the incoming calls. The obtained results show that using dynamic pricing strategies in cellular networks reduces the congestion and blocking probability. It increases the system utilization. The results also illustrates that the dynamic nonlinear pricing has better performance than that of dynamic linear pricing.

General Terms
Algorithms

Keywords
Congestion Control; Dynamic Linear Pricing; Dynamic Nonlinear Pricing

1. INTRODUCTION
The rising demand for cellular communication is increasing the importance of efficient use of the limited bandwidth and frequency spectrum. The network planners have put up lot of effort on the channel allocation schemes to improve spectrum efficiency so as to allocate the scarce resources to users more efficiently [1]. In recent years considerable efforts have been made on the channel allocation strategies and many schemes like fixed channel allocation (FCA), dynamic channel allocation (DCA) and hybrid channel allocation (HCA) has been proposed [2], [3],[4],[5].

The frequency spectrum is scarce and an expensive resource. In terms of frequency spectrum usage, frequency reuse is an effective technique to reuse the limited spectrum. With the rising demand for cellular services, the network planners attempt to increase the available capacity through cell splitting, cell sectoring and frequency reuse resulting in smaller cell clusters. However even with the high degree of frequency reuse (micro and pico cells), the network capacity is limited and not sufficient. Such implementations are costly and potentially yield more interference in the system. Therefore there are no efficient ways to solve the limited resource problem and guarantee QoS if the call arrival rate is high during peak hours [1].

The mobile users operate independently and in absence of knowledge of current network load has to act selfishly. The difference between peak and off peak demand for cellular services tend to be very significant with only few busy hours during the day and much quieter periods at the other times. Thus meeting the demand during peak period becomes difficult and on the other hand, network capacity remains underutilized during off peak period. Therefore it is important to have a mechanism that will improve overall utilization and performance of the network based on the traffic load. An alternative approach to the problem is to modify user demand to fit within the available resources in the cell. In public networks, pricing has been suggested as an effective mean to resolve the allocation of the scarce resources to the users. The variation of pricing dynamically based on system utilization could potentially provide an additional strategy for encouraging more efficient use of available resources [6][7]. In such a scheme the price of call changes as demand fluctuates and rises in accordance with demand, deterring additional subscribers from assessing the network or holding the channel for long periods. During the off peak period the tariff will drop and will serve as an incentive to generate more call which will generate more revenue for an otherwise underutilized network.

In [2], authors propose the integration of call admission control with a dynamic congestion pricing scheme in which dynamic peak hour price is applied only when traffic load increases beyond the optimal value otherwise a normal price is charged to each user. Yaipairoj et al. [1] proposed a queuing model where users are placed in either normal queue or high price priority queue and users with high priority queue are served with higher QOS than the users placed in normal queue.

The paper is organized as follows: in Section 2, the proposed system model is discussed whereas the results, discussion and conclusion are presented in Sections 3 and 4IV, respectively.

2. DYNAMIC LINEAR AND NON-LINEAR PRICING
Current wireless networks use flat pricing schemes: users are charged with constant or static rate throughout the time of the day. The major advantage of these schemes is that the billing and accounting processes are simple. However, the price is independent of the current state of the network or any dependence is fixed and is based on decisions that have been made statically and may not correspond to the actual system conditions. Hence, such systems cannot avoid congestion scenarios and further cannot react effectively to the dynamic changes in the traffic conditions and contributes unpredictable variation to the network usage and conditions.

In this paper we propose to use dynamic linear and non linear closed loop pricing model for peak and off peak periods. During off peak periods the price will be low corresponding to low traffic and during peak period price will be high corresponding to high traffic without maintaining queue. The proposed mechanism allocates resources based on dynamic pricing where the price of a call varies based on traffic load on a network. The results are compared with those obtained from the fixed static pricing scheme.

2.2 Benefits of Dynamic Pricing

One of the most important advantages of dynamic pricing will be to decrease call blocking probability and increase quality of service during congestion period and provide prioritized channel access to the user depending upon need, urgency and willingness to pay for dynamic pricing model. Call dropping can be reduced by being able to allocate sufficient guard channels for handoff calls and thus ensure improved Quality of Service (QoS) to users. A network will generate higher revenue because of higher utilization of system. A high tariff during peak period is used to prioritize important and urgent calls and low tariff during off peak period is used to boost demand. In dynamic pricing, high demand during peak period is spread over to off peak period which results in improving overall utilization of system.

In linear pricing, price of a call is proportional to current network traffic and hence the linear pricing can be modeled as PL=kλ+ c, where PL is linear price of a call, k is proportionality constant, λ is incoming call arrival rate and c is minimum price applied at no load condition.For nonlinear pricing, we have used the parabolic function to model the price of a call as below,

$$P_{NL} = \frac{\lambda^2}{4a} + C \quad (1)$$

where'P_{NL}' is a non-linear price of a call, 'a' is variable to control the price of the call. For nonlinear pricing, it is quite possible that increase in price can bring down traffic arrival rate and hence under utilization of network. Hence, to optimize the network utilization and user demand, we propose non-linear pricing with feedback mechanism as below,

$$P_{NL-Feedback} = P_{NL} - \frac{\lambda}{K_f} \quad (2)$$

whereKfis a feedback factor. To analyze effect of dynamic price on λ with dynamic pricing, λ_{DP}, the demand function [8]used is as below,

$$\lambda_{DP} = A\lambda_{FP} \cdot e^{-\frac{P}{B}} \quad (3)$$

whereλ_{FP} is λ for fixed pricing, P is dynamic price charged to the users, A is the constant indicating variation in demand during the day, and B is a demand elasticity constant, implying sensitivity of users to the price.

To analyze, the influence of pricing on blocking probability, we assumed that the duration of each call is equal to the average call duration τ, the probability that a call is blocked is given by following equation

$$P_{b(t)} = \begin{cases} 0 & when \quad \lambda_{in}(t) < \lambda_{cap} \\ \dfrac{\lambda_{in}(t) - \lambda_{admit}(t)}{\lambda_{in}(t)} & when \quad \lambda_{in}(t) > \lambda_{cap} \end{cases} \quad (4)$$

Whereλcap is the call arrival rate corresponding to full capacity of the system, λin is incoming call arrival rate andλadmit is admitted call arrival rate at time t.

To simulate the proposed model, we devised an algorithm as given below:

1. Start with a minimum call price per unit time.
2. Set blocked counter to 0.
3. Calculate the new price as a function of call arrival rate.
4. Broadcast the price level to mobile user using Broadcast Control Channel (BCH).
5. Receive the request for new call and check channel availability.
6. If channel is not available, reject call request and update blocked call counter else accept the call and update network database.
7. When call is over, calculate call duration/ charges and update network database.

In this algorithm, the price of a call is determined using current network traffic. Here we start with a minimum base price and update the price of a call per unit time as a function of the call arrival rate. New price is updated periodically and broadcasted to the mobile users using BCH. User can decide to make a call considering the importance of the call and the price level. Price range is dynamic with a minimum to maximum ratio, which can updated periodically based on the traffic load encountered and acceptable call blocking probability. The maximum price should be selected such that it leads enough users either to postpone their call to less congested period or it will cause users to shorten call period, whereas the minimum price should be selected to attract enough users to make additional calls and talk for longer period of time and increase the network utilization.

3. RESULT AND DISCUSSION

For simulation of the proposed model, we have considered cell with a capacity to support λ (new calls and handoff calls) of 100. Average call duration is assumed to be unit time duration. Once call is admitted into the network, the price prevailing at the time of admission is applied for the duration of the call. The number of call requests and number of calls served in a day are calculated using cumulative sum of call request and calls served at every instance of time interval over a period of 24 hours. Average call blocking probability is average of call blocking probabilities over a period of 24 hours. Since every call is of unit time duration, revenue generated in a day is calculated by cumulative sum of number of calls served multiplied by call charges at that time instance over a period of 24 hours. Average price per unit time is average of price at every instance of time over a period of 24 hours. Average system utilization is calculated as a ratio of total calls served and total calls that can be supported by the system over a period of 24 hours.

Empirical traffic data and observations of telephony traffic patterns in wireless mobile network allows us to model typical variation in λ with fixed pricing during a 24-hour period as shown in Fig. 1.It illustrates that the λ does not follow the exact poisons distribution. The traffic varies throughout the day and it is maximum at peak working hours. The variation of price with time of the day considering linear pricing, nonlinear pricing and nonlinear pricing with feedback is plotted in Fig. 2. It shows that the price of a call in nonlinear pricing is less than the linear pricing when traffic is low and is more when traffic is high.

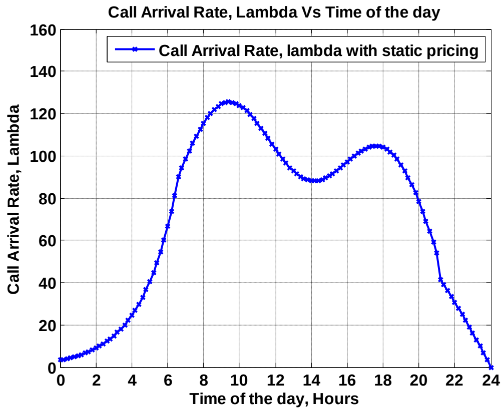

Fig.1 Call arrival rate Vs time of the day

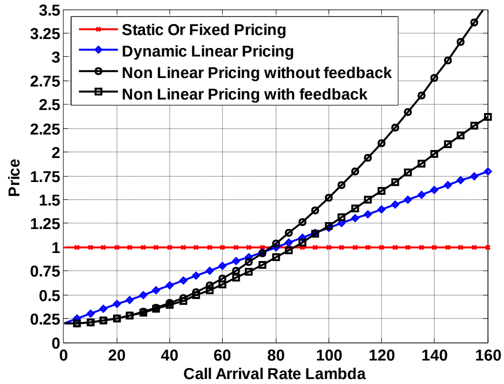

Fig.2 Variation of price with call arrival rate, λ

The traffic load on the network depends upon time of the day and accordingly price varies throughout the day. Variation of price throughout the day is computed and is as shown in Fig.3.

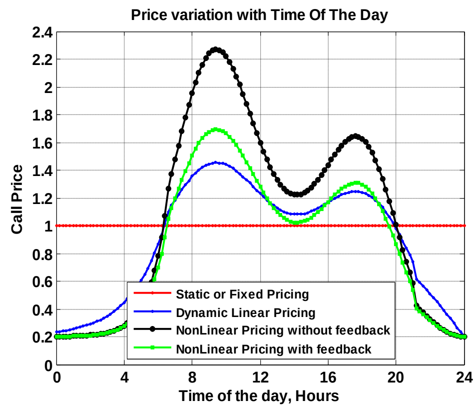

Fig.3 Variation of price with time of the day

When dynamic pricing is applied, call arrival rate is affected. Fig. 4shows the variation in call arrival rate with fixed pricing, and also with linear and nonlinear pricing.

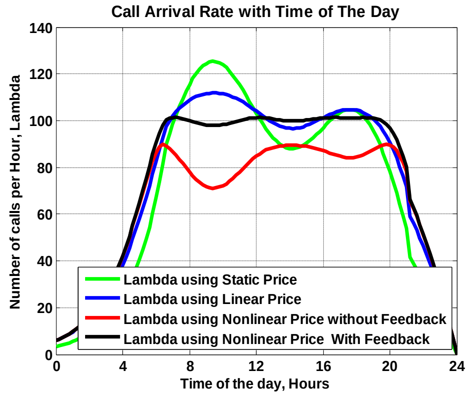

Fig.4 Effect of price on call arrival rate

It shows that with dynamic pricing the traffic will flatten out and system will be utilized more efficiently. Nonlinear pricing works better and use network efficiently and to reduce congestion than fixed and linear pricing.

Figure 5 shows the comparison of revenue generated for different call arrival rate with fixed and dynamic pricing. When traffic is low, the revenue generated by dynamic pricing is less than fixed pricing, but when traffic is high revenue generated by dynamic linear pricing is more than static pricing and revenue generated by dynamic non linear pricing is highest among static, linear and nonlinear pricing. It shows that non linear pricing gives more revenue opportunities for the operators.

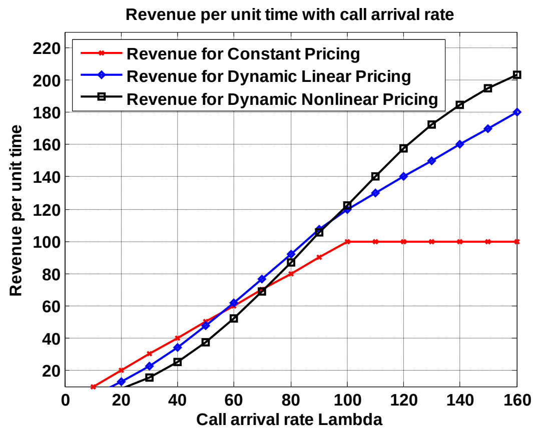

Fig.5 Revenue generated with static and dynamic pricing

Fig. 6 shows the variations of the blocking probability during the course of the day for static and dynamic pricing.

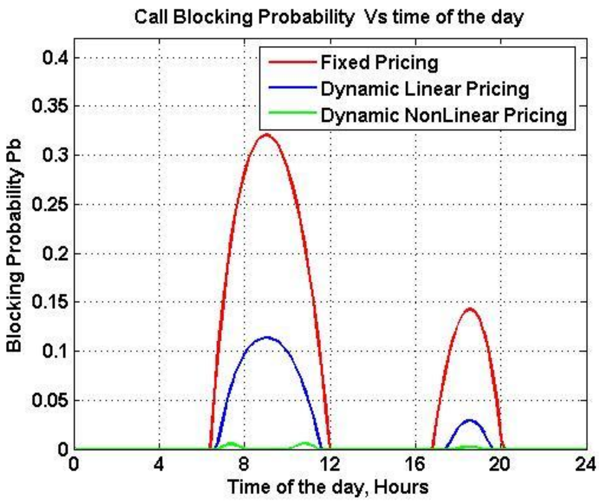

Fig.6 Variation of the blocking probability with time of the day

Table I summaries the simulation results obtained.

Table1: Summary of Simulation Results

Parameter	Fixed Pricing	Dynamic Linear Pricing	Dynamic Nonlinear Pricing
Number of call request in a day	8468	9086	9070
Number of calls served in a day	8018	8800	9027
Average call blocking Probability	0.053	0.031	0.004
Revenue generated in a day	8018	9589	9727
Average call charges per unit time	1.00	1. 09	1. 08
Avg. System Utilization over 24 Hrs	66.2%	72.72%	74.60%

4. CONCLUSION

With increasing number of users of cellular network, it is necessary to deploy effective measures to ensure network availability at all times for all the users of the network. The proposed dynamic pricing method can be used as one of the measures to improve network utilization and fairness while addressing the issue of avoiding congestion. It will ensure a competitive use of spectrum, revenue generation for the infrastructure development and incentive schemes for the network users. Simulation results shows that with dynamic pricing, congestion is reduced, call blocking probability is decreased, network utilization is increased and revenue is maximized while keeping the prices low for off peak hours. The scheme provides the user a choice to make a call based its importance pertaining to the price. The nonlinear pricing method gives better results than the linear pricing method.

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