Evaluation Of Dynamic Pricing In Mobile Communication Systems

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Abstract: *The rapid growth in demand for cellular telephony coupled to the limited bandwidth allocated to the air interface, has encouraged researchers to find technological solutions to increase the number of usable channels. The various techniques developed invariably involve installation of new infrastructure. While such strategies enable the networks to meet peak-hour demand, they inevitably leave the network resources idle in off-peak hours. In this context dynamic pricing (the variation of price according to system utilisation) could potentially offer a "soft edge" scheme for achieving a more efficient use of available resources. This article presents predicted (GSM) network behaviour under a dynamic pricing regime. Simulation results indicate a strong correlation between the shape of the price function, the number of blocked calls in the system and the expected revenue. These suggest that dynamic pricing could be used very effectively to regulate demand whilst offering a sensible means for revenue optimisation.*

1. Introduction.

The mobile cellular telephony market has expanded rapidly over the past decade. In the UK, at the end of the first quarter of 1999, mobile phone penetration was almost 30% - up by 5% compared to the end of 1998[1]. This rapid growth has been mainly due to aggressive marketing and the level of competition between service providers, which has led to a reduction in call charges [1]. In turn, the increased demand for network services has led to substantial investments in the network infrastructure. Given that the radio frequency band allocated to GSM/GPRS and UMTS is limited, the obvious solution to increase the available capacity is through cell splitting and frequency re-use resulting in smaller cell clusters. Hence, urban areas now have far more cells per square kilometre than rural ones. However, the difference between peak and off-peak demand for mobile services tends to be very significant, with only a few very busy hours during the day and much quieter periods at other time. Thus, meeting the peak demand for mobile services is costly and the resulting network capacity remains under-utilised most of the time.

This has encouraged service providers to look at other means for efficient management of the available network capacity. It has been suggested that in GSM/GPRS networks a degree of flexibility in the number of available channels per cell could be achieved by using *dynamic channel assignment* or *alternate routing* [2, 3]. The main disadvantage of such dynamic capacity allocation techniques is the increased computational load on the system and the increased co-channel interference. In UMTS an adaptive cell-sizing algorithm has been suggested as means for relieving congestion [4]. However, this approach fails when traffic is uniform i.e. when in a cell cluster, all cells are busy at the same time.

An alternative approach to the problem is to attempt to modify user demand to "fit" within the available resources in the cell. Currently, most mobile service providers offer cheaper (or free) off-peak calls as a marketing incentive, in an attempt to utilise 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 tariff when the operator *anticipates* high demand. In this context, real-time or *dynamic pricing* (the

[1] Data source at: http://www.de.infowin.org/ACTS on 26.08.1999

variation of tariff according to system utilisation) could potentially provide an additional strategy for encouraging more efficient use of available resources. In this scheme, the price of calls changes as demand fluctuates. It rises in accord with demand, deterring additional subscribers from accessing the network or holding the channel for long periods. During the off-peak hours, the tariff will drop from its nominal level, and this will serve as an incentive to generate more revenue for an otherwise under-utilised network.

The effect of price on users' demand for fixed line calls was investigated by Cosgrove and Linhart [5]. They observed a positive correlation between the increase in price and the reduction in the number of calls made by customers. This was true even for flat rate customers, when the reduction in call frequency had no effect on their bill. They also observed that the estimates that customers made about their telephone usage followed a lognormal distribution, i.e. while a few customers underestimated their usage, a large majority overestimated it and their estimates were widely scattered.

This article begins with the introduction of an algorithm for the application of dynamic pricing to cellular networks. Then a theoretical model depicting user demand elasticity to dynamic pricing is presented. And finally, results from a set of simulations, incorporating the user behaviour model and linear and non-linear pricing functions are presented.

2. Dynamic Pricing For Cellular Networks

2.1 Dynamic pricing algorithm.

A cellular system in which a dynamic pricing algorithm is implemented should be self-regulating and its behaviour in time would be determined by the price charged for the phone calls. This feedback loop maintains the performance as fixed by the pre-set system parameters. The rate of change of the price for the calls would determine the degree of demand regulation in the network.

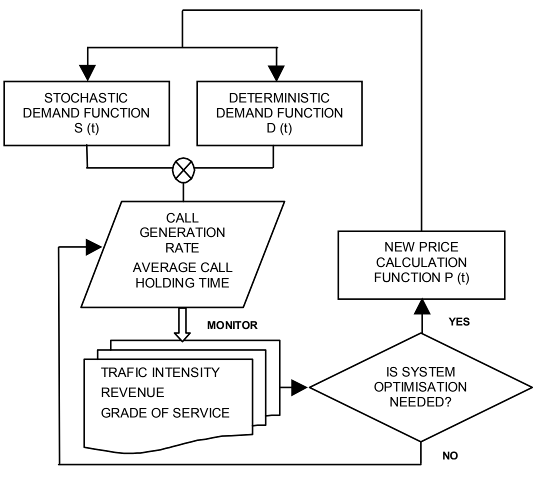

Figure 1 Dynamic pricing algorithm

At time zero, the system would offer users calls at price P_0. User demand is a combination of random demand S(t), caused, for example, by emergencies and deterministic demand D(t), which is a function of the time of day and can be predicted fairly accurately. Depending on the price elasticity of demand, a certain number of calls will be generated. On the basis of these, the call generation rate λ_P, and call-holding time τ_P can be calculated. Operational system parameters such as: traffic intensity (E_p), revenue (R_p) and Grade of Service (GoS) (υ_P), determining the network utilisation and its performance are hence calculated.

These will be compared to a set of target system performance parameters (estimated theoretically) and a decision will be reached as to whether an adjustment to the tariff is necessary. If the answer is "YES" a tariff increment ΔP would be calculated. ΔP may be a positive or negative (see Figure 1)

The application of this algorithm relies on the assumption that network users would change their demand for network resources in response to tariff changes. Their demand will increase when price is low and decrease when it is high. As a result, the network traffic carried at any given time would be more evenly distributed both temporally and spatially. Another expected effect of dynamic pricing would be that the average call holding time would be inversely proportional to the price charged by the network. Dynamic pricing acts on both the overall call generation rate and the average call holding time - this correlated combined effect facilitates the algorithm's convergence towards an acceptable level of call blocking probability.

2.2 Implementation of dynamic pricing in mobile systems.

The most suitable position for implementation of the algorithm in GSM/GPRS will be in the Base Station Controller (BSC). The pricing information can be disseminated to the MS in the relevant cell using the Broadcast Control Channel. This channel is only listened to by the mobile stations in that particular cell and it has a spare slot on the Downlink which can be used to transmit the current call price to the mobile stations [6].

3. Simulation Model.

3.1 Demand elasticity.

The gravity model, used originally by Wilson [7] to determine the most probable distribution of number of trips between two regions depending on the attractiveness of the destinations, was adapted to predict the number of calls generated between two cells. The resulting call gravity model is shown in equation (1) and the corrective constants A_i and B_j (sometimes called balancing factors) are introduced to ensure that if the number of users in the cells double the number of calls between the cells does not quadruple.

$$\Psi_{ij} = O_i D_j A_i B_j e^{-\alpha(p_{ij} - p_{static})} \tag{1}$$

$$A_i = \frac{1}{\sum_j B_j D_j e^{-\alpha(p_{ij} - p_{static})}} \tag{2}$$

$$B_j = \frac{1}{\sum_i A_i O_i e^{-\alpha(p_{ij} - p_{static})}} \tag{3}$$

ψ_{ij} - the total number of calls between cells i and j .
O_i - total number of users in cell i.
D_j - total number of users in cell j.
p_{ij} - dynamic price at time *t*.
p_{static} - price at time *t* before introduction of dynamic pricing.
α - elasticity factor.

Thus, the most probable distribution of calls between two cells in a cell cluster at any given price would be as described by equations (1-3).

3.2 Simulation Results

To observe the change in network performance in a cellular network upon implementation of dynamic pricing, a simulation model was developed using the OPNET™ simulation tool. The behaviour of the system was tested for $\alpha \in (-1, 1)$ and two pricing functions linear and non-linear (Figure 2)

Table 1 System performance with different pricing functions

Demand elasticity (Alfa)	Change in revenue (%)		Change in total calls blocked (%)	
	Linear	Non-linear	Linear	Non-linear
-1.0	126	113	35	6
0.0	0	0	0	0
1.0	130	123	-8	- 29

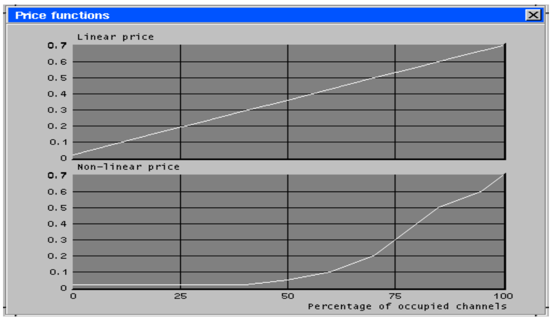

Figure 2 Shape of pricing functions

Results show that the application of dynamic pricing to the system leads to a significant improvement to the revenue to service providers with both linear and non-linear pricing functions. However, the results show that the shape of the pricing function influences significantly the total number of blocked calls in the system. The variance in the expected generation rate and the resulting blocked calls in the system are higher for linear pricing functions.

Figure 3 Generation rate (non-linear price)

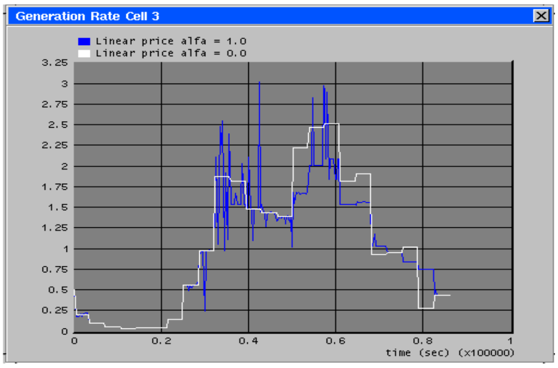

Figure 4 Generation rate (linear price)

4. Conclusions.

It is evident from the simulation performances that as a result of dynamic pricing users suppress their demand for the service when the network is busy and increase their usage at quieter times, leading to an overall reduction in blocked calls by up to 30%. Therefore, it is inevitable that a certain proportion of calls attempted during the busy period and suppressed due to the very high price would never be made again. In effect, these calls are lost and represent lost revenue for the service provider. However, the proportion of calls lost due to suppression during busy periods has to be compared to the proportion of call lost due to call blocking and call dropping. As users will have a choice as to whether to proceed with a call or not, the importance of the call would influence the user's choice. Thus dynamic pricing allows a natural prioritisation of the calls to occur ensuring that only low priority calls are lost. This is an improvement on the current system, which loses calls indiscriminately.

Acknowledgement

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