Chapter 7

Pricing based Dynamic Channel Allocation

7.1 Introduction:

In last chapter, we have implemented MDDCA in which the channel allocation is done based on global optimization followed by local optimization for call admission and handoff control. To further explore the feasibility of such control, in this chapter, we present a mechanism to integrate pricing along with call admission. A dynamic pricing concept considering the parameters of linear and non-linear pricing system with and without feedback is introduced. Due to pricing based availability of resources, the network traffic gets spread over which results in reduction of congestion, increased utilization of channels and thereby enhancement of spectrum utility.

7.2 Static Pricing and Existing Practices:

Traditionally, wireless service providers have supported static or fixed pricing schemes, where a certain price buys the user a bundle of usage minutes per month and a fixed set of services that can be accessed throughout the duration of the contract. 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. The number of cells in large cities has almost reached its maximum and reducing the size of the cells further would add more overheads than the benefits. Moreover during off peak periods, it would increase the amount of unused resources. Therefore it is important to have a mechanism that will improve overall utilization and performance of the network based on the traffic load. In wireless 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 better use of available resources [23, 177].

In literature review we have seen that, researchers have used pricing integration with call admission control where dynamic peak hour price is applied only when traffic load increases beyond the optimal value. Queueing models are used where users are categorized as premium users and normal users. High paying premium users are served with high QoS than the normal users. Service class based planning is also used where some of the channels are reserved for handoff, to be allocated to the premium users. All such allocations are made on statistical data and observation of user priority and status preference. While introducing such priority based allocation the traffic load intensity at that instance is not necessarily given a due consideration. An orthogonal but critical issue in ensuring QoS to wireless users is the formulation of a mechanism which administers the state of the
network and adaptively controls the flow of traffic into the network. In this work, we have developed a technique for integrating pricing based on the network load applicable throughout the day and not at specific time in order to achieve QoS.

7.3 Dynamic Linear and Non-Linear Pricing Modeling:

Current wireless networks use static pricing schemes, users are charged with constant or fixed rate throughout the time of the day. The major advantage of this scheme 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, cannot react effectively to the dynamic changes in the traffic conditions, and contributes unpredictable variation to the network usage and conditions. In this section we have developed dynamic linear and non linear closed loop pricing model for peak and off peak periods. The developed 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. One of the most important advantages of dynamic pricing will be to reduce call blocking probability, increase QoS and provide prioritized channel access to the user depending upon urgency of call. In dynamic pricing, high demand during peak period will spread over to off peak period which will result in improving overall utilization of system.

In linear pricing, price of a call is proportional to current network traffic and hence the linear pricing is modeled as \( P_L = k\lambda + C \), where \( P_L \) is linear price of a call, \( k \) is proportionality constant, \( \lambda \) is incoming call
arrival rate and $C$ is minimum price applied at no load condition. For nonlinear pricing, the parabolic function is used to model the price of a call as,

$$P_{NL} = \frac{\lambda^2}{4a} + C$$ \hspace{1cm} (7.1)

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, which will result in underutilization of the network. Therefore to optimize the network utilization and user demand, we have modeled non-linear pricing with feedback mechanism as,

$$P_{NL-Feedback} = P_{NL} - \frac{\lambda}{K_f}$$ \hspace{1cm} (7.2)

where $K_f$ is a feedback factor. To analyze effect of dynamic price on $\lambda$ with dynamic pricing, $\lambda_{DP}$, the demand function used in [179] is referred as,

$$\lambda_{DP} = A \lambda_{FP} e^{-\frac{P}{B}}$$ \hspace{1cm} (7.3)

where $\lambda_{FP}$ is $\lambda$ 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 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 $\tau$, and the probability that a call is blocked is given as,

$$P_b(t) = \begin{cases} 
0 & \text{when } \lambda_{in}(t) < \lambda_{cap} \\
\frac{\lambda_{in}(t)-\lambda_{admit}(t)}{\lambda_{in}(t)} & \text{when } \lambda_{in}(t) > \lambda_{cap}
\end{cases} \quad (7.4)$$

where $\lambda_{cap}$ is the call arrival rate corresponding to full capacity of the system, $\lambda_{in}$ is incoming call arrival rate and $\lambda_{admit}$ is admitted call arrival rate at time $t$. The call inter-arrival times are determined by the generation rate, which is a function of the time of the day. The probability of $K$ arrivals in interval of length $t$ is given by the Poisson distribution:

$$P_K(\lambda t) = \frac{(\lambda t)^K}{K!} e^{-\lambda t} \quad (7.5)$$

where $P_K(\lambda t)$ is the probability of $K$ arrivals in interval of length $t$, $\lambda$ is the call arrival rate. Figure 7.1 shows the Poisson distribution.
Fig. 7.1: Poisson Distribution of Calls in Cellular Network

The call holding time (total call duration) is modeled using a negative exponential distribution and is assumed to be dependent on the price.

\[ T_p = T_0 \cdot e^{(1-p)} \] (7.6)

where \( T_0 \) is the call duration of a call following a static pricing, \( T_p \) is the call duration with dynamic price and \( p \) is the dynamic price.

The demand price function is modeled as

\[ \lambda_{\text{price}} = A \lambda_{\text{static}} \cdot e^{(-\text{price})} \] (7.7)
where $\lambda_{\text{price}}$ is the call arrival rate with dynamic pricing, $\lambda_{\text{static}}$ is the call arrival rate with fixed pricing, price is the price charged to users and $A$ is the demand elasticity constant.

The revenue per unit time is calculated as,

$$(\text{Call Price}) \times [\text{Number of calls admitted per unit time } \lambda_{\text{admit}}(t) \times \text{(Average Call Duration)}]$$

If Average Call Duration = unit time, then Revenue per unit time = Call Price x $\lambda_{\text{admit}}(t)$

where $\lambda_{\text{admit}}(t) = \min[\lambda_n(t), \lambda_n^*]$ (7.8)

and $\lambda_n^*$ is the optimum number of calls admitted considering channels for handoff and $\lambda_n(t)$ is the call arrival rate.

**7.4 The System Implementation:**

To implement the dynamic pricing model, we devised an algorithm where the price of a call is determined using current network traffic. 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 Broadcast Control Channel. User can decide to make a call considering the importance of the call and the price level prevailing at that time. Price range is dynamic with a minimum to maximum ratio, which is updated periodically based on the traffic load encountered and acceptable call blocking probability. The maximum price is 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 is selected to attract enough users to make additional calls which helps in increasing the network utilization. We have considered cell with a capacity to support λ (new calls and handoff calls). Once call is admitted into the network, the price prevailing at the time of admission is applied for the duration of the call. When a call is over, the call duration and call charges are calculated. The resource pool is updated and the process repeats for further calls by calculating call price as a function of call arrival rate. The number of call requests and number of calls served in a day are calculated over a period of 24 hours using cumulative sum of call request and calls served at every instance of time interval. 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. 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. It illustrates that the λ does not follow the exact Poissons distribution. The traffic varies throughout the day and is maximum at time called peak hours.

7.5 Results and Discussion:

The traffic pattern considered in reference paper [26] assumes that a call pattern varies uniformly throughout a day and reaches maxima and minima. The actual traffic pattern may not follow the same variation as assumed in [26] and also as shown in Fig.7.1. Hence, it can be seen that there exists a new call arrival rate where the total user utility can be maximized and, therefore, the network resources can be optimally utilized. The standard distribution structure can be
used to analyze the problems in call generation and management during peak and off peak periods in a day. It can also be used to understand how the implementation can be used to optimize the network resources and maintain efficiency by scattering proportion of calls using pricing mechanism. Figure 7.2 shows the empirical traffic data and observations of telephony traffic patterns in wireless mobile network that allows us to model typical variation in call arrival rate with fixed pricing during a 24-hour period (observed from the data at GMSC, BSNL-Chinchwad, Pune). It illustrates that the call arrival rate does not follow the exact Poisson distribution. Hence this traffic pattern is used to analyze the developed scheme.

![Fig. 7.2: Call Arrival Rate versus Time of the Day](image-url)
Figure 7.3 shows the results for variation of price throughout the day. As the traffic load on the network depends upon time of the day, therefore price varies throughout the day. The result shows that call price is higher in case of non-linear pricing without feedback whereas after using feedback, the call price seems to be minimized. The phenomenon can reduce congestion by controlling the flow of the calls in peak hours along with optimized usage of spectrum.

![Graph showing variation of call price with time of the day](image)

**Fig.7.3: Variation of Call Price with Time of the Day**

Figure 7.4 shows the result for price variation with call arrival rate. The variation of price with time of the day is obtained considering linear pricing, nonlinear pricing and nonlinear pricing with feedback. The call
price is very high without using feedback system. On the other hand, it can be seen that with the increase of traffic load, better results with price optimization can be observed when the system uses feedback. The further optimization with minimization of price can be seen on dynamic pricing system with the increase of call arrival rate or incoming traffic load. Hence, it can be said that the dynamic linear pricing system will be compatible with heavy traffic.

Figure 7.5 (a) shows the calls per hour whereas Fig. 7.5 (b) shows price per unit time with respect to time of day.
Figure 7.5 (a) shows number of call per hour with respect to time of the day where the analysis is carried in context of feedback system. The result shows the numbers of calls generated per hour are minimized when feedback system is not used along with call arrival rate. However, numbers of calls per hour with feedback seems to have more number of calls generated per hour. Figure 7.5 (b) shows the call price variation with respect to time of the day where the analysis is done with respect to feedback scale. The results show that call price is quite high when dynamic non-linear pricing system without feedback is used. The result also illustrates better optimization when feedback system is used with dynamic non-linear pricing system even in peak hours of the day. The results indicates that dynamic pricing system leads to an alternative solution to keep the current network capacity and to make the users demand fit this limited capacity. The consequence will be that the price of making a call will depend on the network load and it can be very high when congestion occurs or very
low to encourage users to make calls during off-peak periods. As a result, the congestion will be decreased while the overall utilization of the system is improved.

Figure 7.6 shows the variation of call arrival rate in static and dynamic pricing in context of linear and non-linear system.

![Graph showing variation of call arrival rate](image)

**Fig. 7.6: Variation of Call Arrival Rate in Static and Dynamic Pricing**

The prime intention of this result is to highlight the impact of static pricing that currently exists now and dynamic pricing on incoming traffic scored by call arrival rate. Static pricing system can be seen with no better control over call arrival rate as illustrated from curves observed in peak hours. However, better optimization of network resources can be seen when dynamic pricing system is used. In a dynamically priced network, pricing function is the most important
parameter, as it influences the demand function and consequently the total revenue and utility of the network. However, dynamic non-linear system is shown to have better performance for a given traffic load as compared to linear pricing system.

Figure 7.7 highlights the results obtained for variation in call duration with time of the day. The results are observed with respect to both fixed and dynamic pricing system. The dynamic pricing system is studied using linear and non-linear pricing. The result is basically an interpretation of network resource utilization by observing the duration of calls.

![Fig. 7.7: Call Duration with Time of the Day](image-url)
It can be seen that call duration in case of fixed pricing is uniform thereby utilizing the maximum bandwidth resulting in network congestion. However, if the system is used with dynamic pricing, the results shows that there is a substantial minimization of active call duration that will assist to cater the needs of massive number of callers during peak hours and thereby ensuring maximum access. Thus a better call admission control can be achieved using dynamic pricing system. It can be seen that dynamic non-linear pricing system has minimized call duration proving to be the best when compared with dynamic linear pricing system and fixed pricing system.

Figure 7.8 shows the variation of call duration with respect to static and dynamic pricing system. The analysis is done with call duration in minutes and price per unit time. The results show that there is no change or variation observed in call duration for static pricing. But, when implemented with dynamic pricing, the call duration per unit time is shown with a gradual descent indicating dynamic pricing system as the best option for conserving the network resources. The result also illustrates that when price is high, only few people will opt for and hence network availability will be high (which is equivalent to low arrival rate) and call duration will be reduced. On the other hand, if price is low, many people may opt, hence high arrival rate. With less call duration time, network availability can be ensured and with more call generated based on low price, the network utilization can be ensured.
Figure 7.9 shows the variations of the blocking probability during the course of the day for static and dynamic pricing. The system is analyzed using call blocking probability with respect to entire day period encountering peak and off peak hours. The result shows minimal call blocking probability for dynamic non-linear pricing system as compared to dynamic linear pricing system. It is to be noted that if the blocking probability is zero percent, the user has the highest level of satisfaction. This means that, when call blocking probability is very high, the user satisfaction is zero. Hence it can be seen that the weighted call blocking probabilities are always lower which means the QoS of the network will be higher.
Figure 7.9 shows the call arrival and call admittance observed in both static and dynamic pricing system. Dynamic pricing system is operated with linear and non-linear pricing system.
Fig. 7.10: Calls Arrived and Admitted in Static and Dynamic Pricing
Figure 7.10 (a) shows that number of calls arrived is more compared to calls admitted in static pricing which usually gives rise to traffic congestion leading to call drop. The number of call arrival is scattered using dynamic linear pricing as seen in Fig.7.10 (b). However, better optimized result can be seen in Fig.7.10 (c) where both call arrival and call admitted are equivalent curves leading to smooth network resource management, call admission and handoff control.

The comparative results of the static and dynamic pricing schemes are listed in table 7.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Static Pricing</th>
<th>Dynamic Linear Pricing</th>
<th>Dynamic Nonlinear Pricing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of call requests in a day</td>
<td>8468</td>
<td>9086</td>
<td>9070</td>
</tr>
<tr>
<td>Number of calls admitted in a day</td>
<td>8018</td>
<td>8800</td>
<td>9027</td>
</tr>
<tr>
<td>Average call blocking probability (%)</td>
<td>0.053</td>
<td>0.031</td>
<td>0.004</td>
</tr>
<tr>
<td>Average system utilization (%)</td>
<td>66.2</td>
<td>72.72</td>
<td>74.60</td>
</tr>
</tbody>
</table>

Table 7.1: Results of Static and Dynamic Pricing Schemes

From the results in table 7.1, it can be seen that with dynamic pricing, congestion is reduced, call blocking probability is decreased, quality of
service is increased, revenue is maximized and fairness is increased as the user has a choice when to make a call considering importance of the call.

The results obtained with dynamic pricing are summarized as under:

- Better channel allocation can be achieved which subsequently will improve call admission process.
- The traffic spread over can be accommodated within the available spectrum which will improve QoS.
- Congestion and thus call blocking probability is reduced.
- The nonlinear pricing method gives better results than the linear pricing approach.
- The developed technique can be used as one of the measures to improve network utilization and fairness.

**7.6 Conclusion:**

In context with static pricing, in dynamic pricing natural prioritization of the calls will occur which helps traffic getting scattered over a time period comprising peak and off peak period. Such traffic distribution can well be accommodated within the available spectrum by allocating a channel effectively, thereby improving call admission. Congestion is one of the most intense problems in current wireless networks. A traditional call admission control scheme that mainly focuses on the tradeoff between new call blocking probability and call dropping probability cannot solve the problem of congestion in wireless networks. Hence we investigated the role of pricing as an additional element to control the efficient use of available resources in cellular networks. The solution integrates call admission control with a dynamic pricing application. The developed scheme works as a traffic shaper which implicitly implements a distributed user based traffic
prioritization. The obtained results indicate that the developed scheme can alleviate the problem of congestion in wireless networks while achieving QoS and efficient use of channel resource by maximizing the system utility compared to static pricing scheme. The results obtained with dynamic non linear scheme are better than those obtained with static and dynamic linear scheme. Thus the developed technique helps in improving the channel allocation and efficiency of the system within a constraint of limited bandwidth and increasing channel demand.