Innovation Insights

Optimization of Dynamic Pricing in Mobile Networks

Deriving greater value out of existing network assets
Abstract
Dynamic pricing provides mobile communications service providers (CSPs) a way to derive greater value out of existing assets and improve the financial returns from their investments in new technology. This paper examines the benefits and challenges of implementing dynamic pricing in mobile networks and describes how, in the context of dynamic pricing, CSPs can leverage data analytics and optimization to increase revenue and profits, grow market share, reduce CAPEX, and increase customer satisfaction.

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Introduction

Dynamic pricing in mobile networks is a yield management technique that empowers communications service providers (CSPs) to derive greater value out of existing network assets (Smyk, Applying Yield Management in the Mobile Broadband Market, 2011). Yield management is the umbrella term for a set of strategies that enable capacity-constrained service industries to realize optimum revenue from operations. Dynamic pricing itself is often defined as the process of offering automated variable pricing of mobile services based on real-time analysis of network utilization (Ovum, Dobardziev & Green, 2011).

A number of market trends are driving the growth of dynamic pricing in mobile networks. With mobile users’ growing appetites for mobile services, technological advances in a real-time charging infrastructure, increasing diversification of market segments, and a growing variety of mobile offers, the use of dynamic pricing in mobile networks has become more desirable and feasible. This paper will discuss the value proposition of dynamic pricing, present a high-level description of dynamic pricing solution implementation, and propose several dynamic price optimization techniques that will help CSPs increase revenue and profits.

The Concept of Dynamic Pricing

In general, dynamic pricing refers to the process of fluctuating prices between the buyer and seller. A dynamically priced good or service can be quickly re-priced in response to changing market conditions, such as the current or predicted demand. Prices can vary by channel, product, customer, time, and location using a variety of implementation methods. For example, in the case of a Dutch auction, the auctioneer starts with a high asking price, which is progressively lowered until a participant is willing to pay the auctioneer's price or the seller's lowest acceptable price is reached. For mobile CSPs, the concept is similar, but in this instance, network utilization can be analyzed in real time or near real time to enable quick and informed re-pricing of services such as voice calls, texting, and Internet data access.

Dynamic pricing differs from the static, peak and off-peak pricing techniques traditionally practiced by many CSPs. In the latter, CSPs set their peak/off-peak tariffs solely based on observations of historic, long-term patterns of network utilization. While CSPs do occasionally change the traditional peak/off-peak tariffs, their prices are largely perceived as stable by consumers. Since they are informed about the applicable rates well in advance of their buying decision, their perception of price stability is preserved even though different rates may apply during the peak and off-peak usage hours.

The general concept of dynamic pricing is not new — most likely it is as old as commerce itself. For millennia, merchants have been adjusting their prices on the spot to meet the buyer’s willingness to pay while at the same time assuring a handsome profit for themselves. Automated dynamic pricing in mobile networks is a modern version of this age-old system. With recent scientific and technological advances, CSPs can apply analytical methods to perform automated estimation of demand function, optimize pricing decisions, and deploy the optimized prices in the mobile network in real time.
Types of Dynamic Pricing and Their Benefits

Dynamic pricing is a powerful tool that has strong potential to help CSPs accomplish their business objectives. The tool can be used to increase revenue and/or profits, grow market share, reduce CAPEX, and increase customer satisfaction. Depending on their primary business objectives, the CSP may deploy utilization-focused or revenue-focused dynamic pricing. Utilization-focused dynamic pricing adjusts prices with the main objective of keeping network utilization at maximum levels. On the other hand, revenue-focused dynamic pricing fluctuates prices to maximize revenue and profit, while keeping network utilization within desirable limits.

Since utilization-focused dynamic pricing adjusts prices to ensure maximum use of the network, this approach is especially appropriate for CSPs concentrating on growing market share. Utilization-focused dynamic pricing solutions automatically lower prices upon detection of network under-utilization in order to enable CSPs to monetize unused network capacity, which is a perishable asset that would otherwise be wasted. Lower prices for mobile services will most likely lead to increased customer uptake and satisfaction, and thus, larger market share.

The main objective of revenue-focused dynamic pricing is to increase revenue and profits; the network capacity utilization targets are secondary. Consequently, while the utilization-focused dynamic pricing solutions automatically lower prices upon detection of network under-utilization, the revenue-focused dynamic pricing solutions will lower the prices only if such adjustment will most likely lead to increased customer uptake and satisfaction, and thus, larger market share.

It is worth noting that even utilization-focused dynamic pricing does not always have to entail decreasing prices. Faced with a large service demand that can overload parts of the network, both utilization and revenue-focused dynamic pricing may respond by dynamically raising selected prices\(^1\) for services that use the overloaded part of the network. Note that using dynamic price increases to throttle back the overload traffic is typically superior to alternative overload handling methods, which involve either broadly degrading the service below an acceptable level (service degradation) or denying the service to selected customers (service rationing). All three methods — dynamic pricing, service degradation, and service rationing — address network overload by ensuring that the CSP continues serving the customers even when network resources are overloaded. However, only the dynamic pricing method leads to revenue increases. If the CSP combines higher prices in an overloaded part of the network with lower prices in an underutilized part of the network, customers may respond by not just throttling their demand in the congested area of the network, but also by shifting their demand in time or space to the less utilized part of the network. Thus, by shaping the customer demand, dynamic pricing may help the CSP to delay or avoid CAPEX expenditures to expand the capacity of the network. At the same time, it can increase customer satisfaction by reducing the frustration typically caused by service degradation and service rationing.

In summary, while revenue-focused dynamic pricing is more effective in growing a CSP’s bottom line and a utilization-focused approach is more useful for growing market share, both approaches can help providers reduce CAPEX and increase customer satisfaction.

\(^1\)In extreme examples, the two approaches may lead to completely opposite pricing decisions. Focus on revenue growth may require a price increase while focus on utilization growth may call for a price decrease.

\(^2\)The price increase does not necessarily imply an increase of a base price. A price increase can alternatively be presented as a reduction of the typical price discount offered to the customers.
The effectiveness of dynamic pricing can be amplified by combining it with market segmentation. Single, “one-size-fits-all” pricing does not meet the needs of all the customers and therefore does not capture all of the possible revenue. By separately pricing services targeted at specific market segments, CSPs stand to gain additional revenues from both low-end customers for whom the one-size-fits-all service was too expensive, and from high-end customers, whose willingness to pay for mobile services exceeded the price of the one-size-fits-all services.

Dynamic Pricing Implementation in Mobile Networks

In general, the end-to-end dynamic pricing solution for mobile networks includes several complementary components. First, an optimization and analytics component collects and analyzes the current and historical network utilization, pricing, and subscriber information. Based on this analysis, the optimization component determines the optimal level of pricing for immediate deployment in the network. Second, a real-time rating and charging component implements prices recommended by the optimization component and reports all the chargeable network activities to the analytics components for further analysis and optimization. Third, a bandwidth management component controls the usage of network resources to ensure that customers receive services for which they paid. It also enables CSPs to offer a variety of services that can be dynamically priced. Fourth, the dynamic pricing solution must include a notification component, which effectively conveys current service prices to mobile network users. Lastly, the dynamic pricing solution must be integrated with the systems implementing mobile services that are to be dynamically priced, e.g. voice telephony or mobile broadband data services.

Figure 1 – Dynamic Pricing Solution
Optimization of Dynamic Pricing

Optimization of dynamic pricing in mobile networks should take into account the following basic characteristics of the problem faced by the CSPs:

- The mobile network capacity is fixed in the short run.
- The available network bandwidth (inventory) is a perishable good — capacity available at a given time will be wasted ("spoiled") if it is unused at the moment when it is available.
- Consumer demand is variable in time and space.

As do most real-world optimization processes, dynamic pricing optimization methods must rely on simplified mathematical models of a very complex market reality. The mathematical formulation of the optimization problem for dynamic pricing in mobile networks will vary depending on the sophistication and complexity of the underlying market model. In general, the market model will reflect the following assumptions:

- **Level of customer sophistication in regard to their reactions to dynamic price changes imposed by the CSP**
  - Simple models assume *myopic customers* who buy as soon as the offered price is less than their willingness to pay (Talluri & Van Ryzin, 2005). In the case of myopic customers, the demand levels in each network cell for each period of time are independent of each other. Thus, the pricing problem can be independently solved for each timeslot in each individual cell (or cell area).
  - More advanced models assume *strategic customers* who will attempt to optimize their own behavior in response to the pricing strategy of the CSP. In particular, based on observed historical prices, strategic customers do form expectations for future prices. In contrast to myopic customers, the strategic customers, who expect lower prices in the future, may decide to postpone their service purchase even if the current price is below their willingness to pay.

- **The CSP’s ability to segment the market**
  - Simple models assume that the CSP sells to a single market segment.
  
  More complex models assume that the CSP provides services to multiple customer segments, each characterized by a different price-response function and willingness-to-pay distribution.

- **Number of network-based products/services competing for customer demand and network resources**
  - Simple models assume a single type of service offered to network users, such as phone calls, texting, or Internet browsing.
  - More complex models assume that CSPs offer multiple services that share the same underlying network. Each service has different characteristics both on the demand side (consumers have different willingness to pay for different services) and on the supply side (each service requires a different amount and type of network resources).

- **Variety of network resources involved in implementing network services**
  - Simple models assume that a single type of constrained network resource is required to offer a particular network service. For example, if wireless access network capacity is viewed as a major bottleneck, then the formulation of the optimization model may include only this particular resource.
• More complex models may reflect that a user of a single service will consume multiple types of constrained network resources.

• **Type of the competitive environment faced by the CSP**

The models could assume one of the following environments:

– **Monopoly** – The CSP is an exclusive provider of a given service type. Unlike in the perfectly competitive market, the CSP dominates the market and can dictate prices.

– **Oligopoly** – A limited number of CSPs compete to supply the same, or similar, service. Unlike in monopoly, the CSPs do not operate in isolation, so their pricing decisions impact the demand faced by their competitors.

– **Perfectly competitive market** – In this case, it is assumed that the market includes a large number of CSPs and each supplies only a negligible fraction of the total network services supply. Moreover, customers exhibit no preference over the source of the supply. In such an environment, the CSP is selling a commodity service with no power to price it above the market equilibrium price. Basic microeconomics teaches that in a perfectly competitive market, each firm only has to worry about how much output it wants to produce (Varian, 1992). In such a market, the CSP would sell services at market price and would have no need for pricing optimization.

• **Target market size**

– Total population of potential consumers is, for all practical purposes, infinite. This assumption seems to be un-constraining for the optimal solution space, since typically, at any given moment, the amount of all possible demand from all potential consumers drastically exceeds available network capacity. So it is most likely that any optimal pricing solution will exhaust the network capacity before exhausting availability of consumers.

– Total population of potential consumers is represented by a small finite number.

• **Agility of the CSPs pricing infrastructure**

– The CSP has an ability to quickly implement new prices as determined by the optimization algorithm.

– There is a significant delay between determining the optimal price levels and having the prices take effect in the network.

Based on the above list, it is apparent that the models that could be utilized for optimization of dynamic pricing range widely in sophistication. The more sophisticated models will attempt to better mirror reality and thus often lead to better optimization results. However, it is worth noting that the simple models are not always inferior to complex models. They are often useful in practice because they are easier to implement and frequently provide adequate approximation of the optimal solution.

**Formulation of the Dynamic Pricing Optimization Problem**

A viable practical approach to tackling dynamic pricing optimization relies on an incremental approach to solving the problem. It starts with a basic formulation of the optimization problem and gradually improves its sophistication until practical results of the optimization are adequate. To illustrate this approach, this paper describes a sample basic problem formulation, as well as several possible model expansions.
Basic Formulation of the Optimization Problem

The following sample formulation of basic dynamic pricing optimization makes assumptions that pertain to the underlying market model. The basic formulation assumes that the CSP offers a single service to a single segment with an infinite number of myopic customers. It is further assumed that the CSP offers the service in a monopolistic environment, and that the service utilizes a single type of a constrained network resource, such as a wireless network spectrum.

As to the CSP’s business objective, it is assumed that CSP’s main objective is to increase profits. The profit growth objective is typically represented as maximization of total marginal contribution. Since by comparison to the large sunk costs of fixed network assets the incremental cost of offering a network-based service is relatively very small, the maximization of total marginal contribution is practically equivalent to the maximization of total revenues. Therefore, the optimization objective is to maximize total revenue, and the proposed basic formulation of the optimization problem is applicable to the revenue-focused dynamic pricing.

Since customer demand for the service varies by location, day of the week, and time of day, the optimized price levels may vary in a similar way. Let’s assume that the mobile network consists of N areas, each encompassing a group of one or more network cells. By assumption, the price of service S within the particular area is always the same for all the cells encompassed by the area. However, at any given time the price of service S in cells belonging to different areas may be different. Moreover, it is assumed that for each area and each day of the week, the price of service S can change periodically M times a day.

Let \( p_{ijk} \) stand for the price of the service S in area i during time period k on j-th day of the week, where \( i=1,2,\ldots,N \), \( j=1,2,\ldots,7 \), \( k=1,2,\ldots,M \). The non-deterministic demand for service S in area i during time period k on j-th day of the week depends on the current price of the service and is represented by the stochastic price-response function \( D_{ijk}(p, \xi) \). The price response function specifies demand for the CSP’s service S as the function of the price offered by that CSP and random noise \( \xi \). It reflects service S price sensitivity of customers in the market (or market segment) that is targeted by the CSP for dynamic pricing.\(^3\)

Thus, the basic optimization problem can be represented as follows:

\[
\max_p \sum_{i=1}^{N} \sum_{j=1}^{7} \sum_{k=1}^{M} p_{ijk} E\{\min[D_{ijk}(p, \xi), C_i]\}
\]

subject to

\[
p_{ijk} \geq 0 \quad \text{for } i=1,2,\ldots,N, \quad j=1,2,\ldots,7 \quad \text{and} \quad k=1,2,\ldots,M
\]

where \( C_i \) is the maximum capacity of i-th area that cannot be exceeded by the demand. Note that in order to reserve spare network capacity for handling unpredictable demand spikes, the maximum capacity \( C_i \) used in the price optimization calculation, may be intentionally set to a lower value than the true maximum engineered capacity of i-th area.

\(^3\)Customers’ price sensitivity, and consequently the price response function faced by the CSP, may vary widely between markets. For example, it has been observed that, on average, mobile users in the developing world are almost twice as price sensitive as those in the developed world (Dewar, September 2011).
Accounting for the CSP’s Competitors

The basic problem can be extended to accommodate additional market considerations. For example, the basic model assumed that the CSP has a monopoly on service S. However, in oligopolistic markets, the CSP must take into consideration that drastic lowering of prices may cause an adversarial reaction from competitors, and possibly lead to a detrimental price war. On the other hand, drastic price increases may cause en masse customer migration to competitors. To reduce the likelihood of encountering such adverse effects, the CSP may desire to impose limits on price changes. Such an approach could be accommodated by adding additional constraint to the basic dynamic pricing optimization problem:

\[ p_{i,j,k}^{\text{max}} \geq p_{i,j,k} \geq p_{i,j,k}^{\text{min}} \quad \text{for } i=1,2,\ldots,N, \quad j=1,2,\ldots,7 \quad \text{and } k=1,2,\ldots,M \]

where \( p_{i,j,k}^{\text{max}} \) and \( p_{i,j,k}^{\text{min}} \) are maximum and minimum allowable price values in i-th area during the time period k of the j-th day of the week.

Accounting for Strategic Customers

Strategic customers make their buying decision based not only on the current service price but also on their own prediction of the future service prices. As a consequence, even if the service price is set below the customer’s willingness to pay, a strategic customer may decide to wait until an even lower price is offered some time in the future. This customer may expect that the future lower price will be offered in the same cell or in a different cell. Thus, based on their expectations of future prices, strategic customers may decide to shift their demand in time and/or space. Such behavior should be reflected by the price response function modeling the behavior of strategic customers in dynamic pricing optimization problems.

Since strategic customers’ demand for service S is driven by both current prices and their predictions of future prices, and because their price predictions are formed mostly on the basis of the observed historical prices, their demand for service S in area i during time period k of j-th day of the week can be represented by the price-response function \( D_{i,j,k}(p, p_{i}^{h}, \xi) \), where \( p_{i}^{h} \) is a matrix of historical prices for time periods preceding period i in all cells.\(^4\)

Accounting for Real-Time Utilization Spikes

Individual consumers’ demand for mobile services is random in nature. Therefore, the resulting aggregate market demand, which is a sum of individual consumer decisions, fluctuates widely. The price-response function \( D(p, \xi) \) is used by the basic model to predict mean market demand in response to particular price p. However, the actual demand observed in the network will fluctuate below or above the expected demand level. In extreme cases, the upside fluctuation may cause network overload, which will result in customer dissatisfaction caused by dropped calls or slow network response times. Dynamic pricing may address such situations by raising the prices (or reducing discounts) and thus throttling the excess demand.

The throttling effect can be accomplished by introducing real-time or near-real-time price adjustments in response to real-time or near-real-time observations of the network load approaching overload levels. Price adjustments triggered by overload considerations would overwrite the prices determined by the revenue-maximizing algorithms described above.

\(^4\)In practical implementations, the optimization problem may be simplified by assuming that the matrix represents only limited price history, e.g. it includes historical prices only for areas adjacent to area i and the history goes back only for a small number of periods on a given day of the week.
Accounting for Behavioral Decision Making

Traditional economical quantitative optimization models largely assume that consumers are “rational” and well-informed decision makers concerned exclusively with maximizing personal gains as measured by the expected utility of the purchased good or service. However, psychologists have discovered that despite the numerical nature of prices, price-related decisions usually have a strong intuitive component. For example, rational economists are baffled by the observation that consumers do not always prefer lower prices even for non-luxury goods — consumers are frequently more likely to buy an item that costs $1.99, than an identical item priced at a lower price of $1.87. Consumers are also frequently more likely to purchase an item priced at $4 minus a 25% discount, than the same item simply priced at $3, even though in both scenarios the out-of-pocket expense is the same. Thus, purely economical quantitative price optimization should often be balanced with psychological considerations, taking into account behavioral economics theories in decision making. One way of achieving this balance is to expand the optimization problem formulation to include additional constraints and enhance the price-response function to reflect psychological aspects of the target market.

Summary

Dynamic pricing has been successfully used since the beginning of commerce. Due to recent technological advances, CSPs are in a position to deploy automated dynamic prices in mobile networks. Combining dynamic pricing with data analytics and optimization will enable CSPs to increase revenue and profits, grow market share, reduce CAPEX, and increase customer satisfaction. These objectives can be accomplished by formulating and solving pricing optimization problems to reflect each CSP’s unique goals and market environment.
Bibliography


