The Effectiveness of Time Dependent Pricing in Controlling Usage Incentives in Wireless Data Network

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1. INTRODUCTION

With advances of bandwidth-intensive mobile devices (e.g., smart phones, tablet computers), the data traffic for wireless data network has grown tremendously, and is predicted to further increase by more than 10 times in the next five years. The tremendous increase in transmission demand may cause serious congestions. This challenges network operators to find new ways to improve, or at least maintain their service quality.

There are many solutions to address this problem from a technical viewpoint [1, 2]. In this paper instead, we try to solve this problem using a pricing approach. The rationales are: 1) traffic demand is highly volatile over time, so it is neither physically easy nor economically profitable to purely rely on technology to meet the extreme demand at peak time; and 2) a large amount of traffic do not have real-time requirement, or are unnecessary at all, and pricing has been proven as an effective way to shape users' behaviors [3]. Current pricing models are not well suited for wireless applications: flat rate pricing is dominant in broadband network where bandwidth is usually sufficient, but usually causes congestions in wireless environment. For example, WeChat, a very popular mobile social application in China, uses data network to send text, voice and photos. Under the flat rate pricing model today, people often relentlessly upload photos and "short talk" of trivial errands. As a result, ISPs incur a large burden, and it becomes even worse at peak hours when transmission demand is huge. There are rumors that this application will charge customers due to high pressure from major ISPs in China.

We provide a first step study on pricing wireless services. In general, there are four pricing models to consider: 1) time-independent flat rate, where a single price is proposed for unlimited bandwidth consumed anytime; 2) time-independent metering, where the price is for a unit of bandwidth consumed anytime; 3) time-dependent bundling, where the price is for unlimited bandwidth depending on the time, and 4) time-dependent metering, where the price is for a unit of bandwidth depending on the time. In particular, we study the effectiveness of a time-dependent pricing (TDP) model that shapes users' behaviors. Comparing with time-independent pricing (TIP), TDP has the potential to even out time-of-the-day fluctuations in bandwidth consumption. TDP has been studies in a number of economic literatures, but for wireless network, a number of key problems remain unknown. For example, is TDP always a dominant strategy? When using TDP, should an ISP choose time-dependent bundling or time-dependent metering? Furthermore, what is the optimal price such that an ISP maximizes its profit?

In our study, we model how users make purchasing decisions and compare the above pricing models. Our preliminary findings include: 1) TDP can improve the bandwidth utilization and increase ISP's profit; and 2) in peak hours, time-dependent metering is a dominant strategy by reducing unnecessary traffic while in valley hours, the ISP maximizes its profit by using time-dependent bundling.

2. MODEL

2.1 Users' Valuation and ISPs' Profit Model

A user's decision variable is the amount of bandwidth $x_i(t)$ devoting to each service i at time t, and this decision depends on the user's valuation of the service. We consider three factors that impact the valuation: 1) the user's interest in the service (i.e., user's valuation of per unit bandwidth on the service), which we denote as c_i; 2) the bandwidth requirement for service i to have the standard quality at time t, which we denote as $\omega_i(t)$, and 3) the quality of service, which we denote as a function $f_i(x_i(t), \omega_i(t))$. We assume $f_i(x_i(t), \omega_i(t))$ is strictly increasing in $x_i(t)$ over $[0, \omega_i(t)]$ and equals 1 when $x_i(t) \geq \omega_i(t)$. Users may either choose to pay for bandwidth $\omega_i(t)$ to receive standard quality of service with a valuation of $c_i\omega_i(t)$, or opt to pay less for a bandwidth $x_i(t) < \omega_i(t)$ and receive degraded qualtiy (e.g.,

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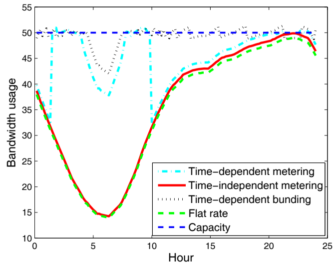

Figure 1: Bandwidth usage for four pricing models

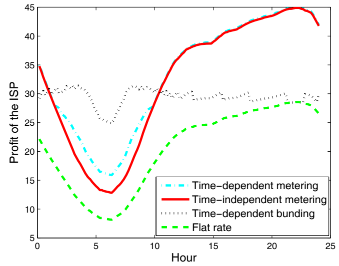

Figure 2: Profit of the monopolistic ISP

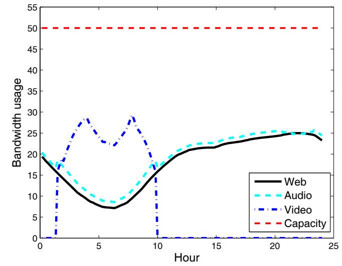

Figure 3: Bandwidth usage for three types of data

lower reservation video or delay of instant messaging), with a valuation of $c_i\omega_i(t)f_i(x_i(t), \omega_i(t))$. Finally, a user's utility is her valuation on the service minus the total bandwidth fee paid to the ISP.

An ISP's decision space is to determine which is the best pricing strategy and what is the optimal (bundling or metering) price to maximize its profit. We consider a monopolistic market consisting of only one ISP with a fixed amount of bandwidth capacity. Since the major cost of an ISP is on infrastructure constructions, we ignore its marginal cost for delivering the data, so its profit is the total service fee charged from all users.

2.2 A Stackelberg Game Model

We model the interactive behavior of the ISP and users as a two-stage Stackelberg game. In particular, we have the following settings.

- *Players*: The ISP and all users.
- *Strategies*: The ISP chooses the pricing strategy (e.g., bundling or metering) and the corresponding service price(s). Each user decides her bandwidth usage $x_i(t)$ for each service i at time t.
- *Rules*: The ISP is the first mover who decides its pricing strategy price(s) and announces it to all users. Users are the second movers and decide their bandwidth consumptions. Each user makes her own decision independently.
- *Outcome*: The outcome can be determined by backward induction. In particular, given any pricing strategy, each user decides her own bandwidth consumption by maximizing her utility. Based on this knowledge, the ISP decides its pricing scheme that maximizes its profit. Both users' utility and ISP's profit functions have been described in Sec. 2.1.

3. PRELIMINARY RESULTS

By solving the above Stackelberg game model, we can determine the equilibrium of users and the ISP under various scenarios. Here, we demonstrate some preliminary results via simulations. We consider three types of mobile contents: web, video and audio. In general, users have the highest valuation per bit for web and the lowest for video. We set c_i as 2, 0.5 and 1 respectively. We assume the bandwidth requirements, ω_i, follow Gaussian distribution with means 25, 100 and 30 in peak time. This setting is to cope with the proportion of total mobile usage of Asia. Requirements at other times are obtained by multiplying a discount function in terms of time.

We observe in Fig. 1 and 2 that the TDP has a higher bandwidth utilization and thus increases the ISP's profit. This is due to the time varying feature of the pricing strategy that can fluctuate the demand at different times. Fig. 2 shows that when the capacity is enough, the time-dependent bundling leads to a higher profit than time-dependent metering and vise versa. The underlying reason is that the bundling pricing can even out the varying valuation for different services. When the capacity is enough, bundling pricing can attract more users and consume more bandwidth, leading to a higher profit. However, when the capacity is insufficient, an ISP only aims to attract a small amount of customers with high valuations where metering can achieve the goal. Fig. 3 demonstrates the bandwidth usage for the three types of data under time-dependent metering pricing. When the capacity is enough, video data transmissions occupy the major part; when it is not enough, video data is minimum due to low unit valuation by customers.

4. CONCLUSION AND DISCUSSION

We address the current wireless data network congestion problem using a *pricing* approach. In particular, we focus on time dependent pricing scheme where prices are time varying. This feature not only leads migration of usage from peak to low times, but also remove a number of low valued or unnecessary usage. Our findings show that 1) time-dependent pricing dominates time-independent pricing; and 2) time-dependent metering or bundling should be chosen based on sufficiency of ISP's bandwidth capacity.

We plan to apply our model to real data analysis obtained from industrial collaborators, so as to gain a deeper understanding on user traffic pattern and the real impact of pricing on shaping users' behaviors. In addition, we are interested to explore the impact of competition on the market outcome when multiple ISPs coexist in the same region.

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