

Smart Data Pricing: Lessons from Trial Planning

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Abstract—Rapid increases in the demand for broadband data are increasingly causing a growth in costs for communication service providers (CSPs). Yet under the current pricing plans, CSPs’ revenue has not kept pace with these costs. Thus, many CSPs are considering Smart Data Pricing (SDP) as a way to reduce cost or increase revenue. Before offering such novel data plans, however, CSPs must conduct trials of the specific data plans proposed. Due to the complexity of necessary changes in network equipment and a need to carefully design the trial in order to understand customer behavior, planning such trials is not only a critical precursor to SDP deployment, but also a nontrivial undertaking in itself. This paper discusses general principles of trial design and proposes two methods for estimating their effectiveness. We first give an introduction to the goals of SDP research and review three possible SDP approaches. We then discuss the importance of pre-trial participant surveys and some technical considerations of implementing the trial infrastructure for a particular SDP algorithm. Finally, we show how the CSP may extrapolate from the trial results to estimate the SDP trial’s benefits, in terms of changes in traffic patterns and a reduction in spectrum requirements. We conclude with some remarks about future work.

Index Terms—Smart Data Pricing, Spectrum Requirements.

I. INTRODUCTION

To cope with rising demand while still providing adequate quality of service, Communication Service Providers (CSPs) have three options: add capacity, optimize existing capacity, or avoid rising user demand. Yet none of these options completely solves the CSP’s fundamental problem, which is larger than this “capacity gap.” CSPs are also facing a “revenue gap:” their rising costs are not compensated by a commensurate increase in revenue. To bridge these gaps, many CSPs are considering Smart Data Pricing (SDP) practices to create new revenue streams and optimize the costs of existing services [1], [2]. SDP is a general term encompassing many methods of congestion management through changes in pricing, from time-dependent pricing [3] to congestion pricing [4] and the pricing of WiFi access [5]. One theme in these proposals is the goal of reducing peak demand on CSP networks, thus lowering CSP cost and potentially increasing revenue [2], [6]. SDP leverages pricing to change consumer behavior so as to reduce CSP network load.

While SDP’s different pricing proposals have great potential to reduce CSP costs [2], they also depend heavily on user behavior and consumer acceptance of SDP measures. Thus, before any type of SDP can be deployed or offered to consumers, a user trial for assessing SDP’s benefits is essential. Such trials are relatively rare in networking research, in part due to the overhead of recruiting participants and implementing SDP

algorithms in a usable system (notable exceptions include the Berkeley INDEX project [7], a trial of voice call pricing [8], and more recent trials of both time-dependent pricing for mobile data [3] and psychological factors in reducing data usage for financial gain [9]). Some CSPs, however, have recently conducted trials of usage-based pricing, and subsequently offered such data plans to their customers [10]. In light of recent momentum towards investigating new broadband pricing plans, this paper considers some general principles useful in conducting SDP trials.

Though conducting the trial itself is in some sense the “main object” of an SDP trial, we argue that pre-trial design considerations and post-trial benefit assessments are equally important: the results of a trial are heavily impacted by the effectiveness of its design, and the resulting benefit assessment will determine the trial’s long-term success. Designing an SDP trial involves both experimental considerations, e.g., evaluating participants’ bias, and technical considerations, e.g., separating functionalities between a CSP network and users’ personal devices. After conducting a trial, CSPs require precise methods to estimate and extrapolate the true benefits of SDP if deployed for the entire customer base, rather than just the trial subset. This paper addresses both SDP trial design and the estimation of a trial’s benefits.

We first give an overview of different SDP algorithms that could be tested in a user trial in Section II. In Section III of the paper, we discuss the design of an SDP trial, including both pre-trial surveys of trial participants and technical aspects of integrating SDP mechanisms into CSP networks. In Section IV, we give two methods for estimating the benefits of an SDP trial: calculating the reduction in peak traffic given user behavior, and assessing the change in spectrum requirements due to changes in users’ traffic patterns. We use data from previous SDP trials and CSP partners to show example calculations for time-dependent pricing. We conclude with some thoughts on future work in Section V.

II. REVIEW OF SDP ALGORITHMS

Smart data pricing can take many forms. In this section, we discuss some of the proposed mechanisms that can be used to realize SDP.

A. Variable Data Pricing (VDP)

In VDP, operators charge for bandwidth differently based on one or more metrics such as time of day, usage volume, location, congestion level, application type, etc. These plans can be realized either in a static or dynamic manner. A two-

period (day-time & night-time) time-of-day plan, which is often used for voice calls, is an example of a static plan. But although such plans are easier for consumers to understand, they do not solve the operator's problem with large peak demand because they do not take into account the gradation in the time-elasticity of demand for various mobile applications. In contrast, a dynamic pricing plan can help operators to charge for current congestion levels while allowing users to save on their monthly bills if they use at less congested periods. Similarly, an app-based pricing plan can allow providers to charge based on the bandwidth requirements of different application classes, but such pricing has privacy and network neutrality implications [2].

B. Responsive Pricing

This pricing scheme [4] provides users with dynamic price signals that depend on the current network load. This helps to exploit the users' price and time sensitivity for different applications by dynamically adjusting the prices to reflect the congestion level in the network. Such mechanisms can be realized by using an auction mechanism in which a user places a bid on each packet to reflect their willingness to pay to send the packet into the network and a gateway admits packets in descending order of their bids as long as the network performance remains above some specified congestion level.

C. "1-800" Numbers for Data (Reverse Billing)

The idea of reverse billing for mobile data is analogous to the concept of 1-800 number for voice calls, i.e., the receiver pays for the data delivery. This is a particular form of sponsored access in which the users are subsidized by content providers or advertisers in return for their "eyeballs." Given the rapid growth in demand for mobile data and the harsh overage fees, content providers may want to subsidize a part of the users' access fees to improve their browsing experience. A mechanism like this can be realized using a third-party micropayment system in which users and content providers/advertisers are matched and microcredits proportional to the amount of bandwidth subsidized are made directly to the users' account. Without careful design, however, such a pricing plan may raise network neutrality concerns.

III. TRIAL DESIGN

The challenges of planning SDP trials with CSPs are multi-faceted: CSPs require trials to have minimal impact on their complex network environments, which must continue to serve current customers without interruption throughout the trial. Recruiting trial participants is another challenge, as there is a need to select a demographically diverse set of users, who ideally represent a market segment amenable to the proposed type of SDP. CSPs must then be able to extrapolate SDP's benefits from these users' trial results. In this section, we discuss the grouping of trial participants through pre-trial surveys, technical aspects of the trial design and practical considerations.

A. Pre-Trial Surveys

A unique feature of SDP-like trials, which distinguish them from the simulation or emulation trials more commonly seen in networking research, is that SDP requires interactions with real

CSP customers. Indeed, the principal purpose of conducting SDP trials is to gauge the effectiveness of a given SDP algorithm in the context of realistic user behavior. A crucial element of SDP trials is then to evaluate whether these users' behavior is in fact representative of the general population, in order to gauge the general applicability of the trial results. Thus, SDP trials are often enhanced with pre-trial surveys, which can help identify user biases as well as facilitate a qualitative "before-after" comparison of users' attitudes towards SDP and toward data consumption in general [11]. In some cases, the SDP mechanism is transparent to users, e.g., their device will automatically decide how to react to the prices offered. However, one can still use a pre-trial survey to compare attitudes towards SDP before and after the trial.

In designing a trial of a particular form of SDP, it is important to compare users' behavior with and without SDP; the use of a control group, as is standard in scientific experiments, is a relatively simple way to do so. The trial administrators can then compare the data consumption of users in the control group (i.e., without SDP) with that of users who experience SDP. In fact, in some cases using three control groups might yield the best results: one group can simply continue with their data plans as is, one can be given a data monitoring app, and another can be given the SDP algorithm, which generally includes data monitoring as a secondary feature (e.g., time-dependent pricing [3]). Yet for a control group to be effective, users should be evenly split among the control and experimental groups. If users in each group have, on average, similar biases towards SDP, then their observed behavior can be credibly compared to discern SDP's effects on Internet usage. We identify three categories of questions to ask in pre-trial surveys:

Awareness of data usage: Since SDP deals with the pricing of Internet data in order to incentivize users to adjust their data usage, users' awareness of their data usage is one major source of potential bias. In general, users who are already more aware of their mobile data usage may be more likely to adjust their behavior in response to SDP. One way to gauge users' awareness is to simply ask how much data they use per month, or whether they employ any data monitoring apps to track their usage. Another indicator is users' current data plans. Users currently on unlimited mobile data plans, for instance, are not accustomed to changing their behavior in response to price signals, and may be less responsive to SDP compared to users with monthly usage caps. Of course, this reasoning likely applies only if the user actually pays for data on the device; thus, one might also ask if the device is shared and whether all parties contribute to paying for its data usage.

Attitudes towards SDP: In addition to awareness of data usage, users may also be affected by their existing attitudes towards SDP, e.g., those genuinely interested in the idea of SDP, versus those just looking to help out a friend who is running the trial. Thus, it is important to ask users about their incentives for participating in the trial, as well as whether they have any experience with the particular form of SDP being trialed (e.g., time-dependent pricing has been offered by some electricity companies in the past). One can also ask whether

users plan to adjust their behavior in response to SDP; these responses indicate users' enthusiasm for the trial. Comparing these results with users' actual behavior during the trial can also be instructive; for instance, if users indicate that they are enthusiastic about the particular SDP idea being trialed, but then do not adjust their behavior in response to SDP, then the implementation of this particular SDP idea may have somehow dampened their enthusiasm. Such information is useful feedback for future trials and deployments.

Demographics: Demographic characteristics such as age, gender, ethnicity, and income level may indirectly affect users' attitudes towards SDP. The principal benefit to collecting this information, however, is that demographic correlations can also aid in extrapolating a survey's responses to a wider population range. For instance, CSPs can apply the results of a survey to another community with slightly different demographics. Since aggregated demographic information is usually easily obtained from census data, at least in the United States, this extrapolation is often easier than extrapolating from factors such as the distribution of data plans offered in a particular area, which is often difficult to obtain.

B. User-CSP Functionality Separation

Traditionally, network control and management have mostly been done at CSPs' core networks for both simplicity and a lack of need for personalized user controls. This rationale, however, is increasingly invalid, with the ubiquity of smartphones and tablets driving a need for "smarter" services such as time or congestion based pricing, app-based pricing, sponsored pricing, and toll-free (zero-rated) access to specific applications [2]. These new requirements challenge the conventional core network architecture: offering personalized services in the core network is not scalable, considering the number of users, devices, apps, and services.

While CSPs have begun deploying sophisticated network policies and deep packet inspection (DPI) devices to control their networks, this still suffers from a limited view of user behaviors. In fact, the smarter services mentioned above can be more easily and accurately performed on users' devices rather than in the core network infrastructure. For instance, it is not accurate and almost impossible for a CSP to offer an app-based pricing only with its core network infrastructure. However, it is rather straight forward if the CSP leverages users' devices; the CSP can charge a user based on the reported amount from a sponsored app installed on the user device.

C. User Interfaces

In placing some functionality on users' devices, a CSP must take into consideration users' experience in interacting with the SDP client on their device. On mobile devices, this generally takes the form of an app. Such a client has two functions: to collect relevant data for transmission to the CSP, and to enable users to adjust their behavior according to the SDP algorithm offered. The latter function especially requires some user engagement with the SDP client. We can separate this engagement into two types:

Educating users: The Apple App Store and Google Play both offer several apps that monitor data usage and display that

information to users [12—14]. Since SDP aims to change users' data usage behavior, an SDP client can often benefit by including such information displays. For instance, users might view the amount of data that they use on cellular and WiFi networks at different times of the day and at different locations. Such information can help increase user awareness of their data usage, which can make them more amenable to SDP [11].

Offering SDP: The main purpose of an SDP client is to allow users to change their behavior in accordance with SDP's economic incentives. To do so, the client should display the information required for the SDP algorithms. For instance, in a trial of VDP users might be able to view the prices offered for data or for different applications. Depending on the particular form of SDP being trialed, the client might also include an automated response mode that makes decisions for users, in accordance with pre-specified user preferences. For instance, users in an auction-based responsive pricing trial could set upper bounds to the bids they are willing to offer and have their client automatically bid for them, in order to improve user convenience.

In fulfilling the two purposes above, the design of an SDP client plays a crucial role—for instance, if usage statistics are not clearly displayed, users may not pay attention to them, rendering the education part of the app essentially useless. Thus, iterations with focus groups can be valuable to improving the design and usability of the SDP client [11], [15]. Moreover, if clients make decisions based on the SDP incentives displayed (e.g., data prices at different times of the day), the client must alert users to these changes, in a way that is both effective and convenient for users. One way to do so is to install a small indicator at the top of the device home screen; just as a battery indicator shows the percentage of battery left, this indicator can show the user the price being offered. We note, however, that these design choices must also account for the device's development platform—for instance, Apple's iOS platform has limited development functionality, which may hinder the implementation of some desired features.

D. Integration with CSP Networks

Implementing trials requires integrating an SDP system with a CSP's production network. The operation and revenue of a CSP hinges on its production network and a user trial is usually deemed more of an endeavor than a necessity. Hence any SDP trial should be viewed risk-free before it can be considered for adoption. From our experience in implementing trials we learnt three guiding principles.

Privacy and security: Customer privacy is of paramount importance throughout a trial. Thus, if the collected logs include customer's browsing activity, customer privacy needs to be protected. For instance, a hash function may be used to map customer identities to randomized integers, preventing any tracking back to customer identities. CSP security personnel generally are required to confirm and approve remote access and the processing of logs.

Compatibility: Integration is technically challenging because of the wide range of standards and protocols used by different CSPs. For usage monitoring purpose, the network infrastructure of CDMA and UMTS networks exchange Charging Data

Records (CDRs) through the RADIUS protocol, while cable network operators usually use the Internet Protocol Detail Record (IPDR) protocol [16]. Integrating SDP with CSP networks mean the SDP system in question should also communicate in these protocols and standards.

Modularity: Any SDP trial is temporary, and any changes to a CSP’s infrastructure have to be reverted after the trial ends. An SDP system should be modular to make it easy to attach and detach from the production network.

E. Practical Considerations

For over two years, we have been involved in planning and conducting trials of various types of SDP with four CSPs, including two major ones in US, and another large one in India. Based on our experience, we found the following three considerations to have practical significance in putting together the trial implementation:

Time granularity: The time granularity of SDP is limited by the reporting time interval of a CSP’s network equipment, which in turn depends on the access technology used. In LTE and 3G networks, the update interval of RADIUS records can be in the order of minutes, but too frequent updates may be undesirable due to communication overhead. For cable networks using the IPDR streaming protocol, the reporting interval is typically at least 15 minutes.

Platform dependency: Implementing SDP involves software development on a range of platforms. For client devices, there is more flexibility, e.g., in user interface and usage monitoring, with those running open-source operating systems like Android, but one cannot ignore the market of devices running on proprietary operating systems like Windows and iOS. For home gateways, one can develop on Linux-based open-source firmware such as OpenWrt. At the network infrastructure level, there are also open source options such as OpenFlow, but one has to prepare to work with custom and proprietary network equipment.

Overlay billing: Trial participants are usually customers of a CSP under some existing billing plan. It is crucial that an SDP trial does not interfere with the CSP’s billing infrastructure, and we address this issue by overlaying SDP on top of existing billing systems. During a trial, in addition to their usual bills, trial participants receive reimbursements or coupons so that the net effect of the bills and the rewards are the prices charged by SDP.

IV. ESTIMATING TRIAL BENEFITS

To complement the trial design considerations discussed in Section III, we next present two methods for estimating the benefits expected from the trial. These can aid an operator in evaluating the expected success of both an SDP trial and a future deployment.

A. Estimating User Behavior

Since SDP involves real users adjusting their behavior, an estimate of user behavior is essential to predicting the benefits of an SDP trial. While the exact estimates necessary will vary depending on the type of SDP under consideration, generally one needs both a set of usage measurements and a guess from

users as to how they will respond to the prices offered. In this section, we give an example from time-dependent pricing. The goal of time-dependent pricing is to offer lower prices at less congested times, which incentivizes users to shift some of their traffic to lower-price periods, thus relieving the peak congestion on the network.

There are two ingredients to estimating the effects of time-dependent pricing: users’ willingness to shift their usage and save money, and the discrepancy in usage volume between peak and off-peak periods. We estimate the first factor by administering a survey asking users how long they would be willing to wait for different applications (e.g., streaming or software updates) if given a fixed (e.g., 30%) discount in return. These answers could also be inferred from measuring the actual changes in usage during a time-dependent pricing trial. We separate traffic into different apps because users’ willingness to wait depends on the type of traffic being considered—for instance, users will likely be more willing to delay software updates than streaming. These survey data can then be used to calculate the probability that users will wait for different amounts of time, e.g., a 20% probability that they will wait up to 30 minutes to stream a YouTube video, in exchange for a 30% discount on that traffic after 30 minutes. One can then construct “willingness to delay” curves as a function of the time waited for different types of applications.

Given users’ willingness to delay different applications, we next compute the percentage of traffic by volume corresponding to each application, and thus calculate the total amount of traffic that can be deferred for a given amount of time. For instance, data from an SDP trial with 50 different users showed that, on average, 37% of traffic comes from streaming, 14% from media downloads, and 12% from file downloads [3]. From pre-trial surveys, we find that streaming can be deferred for one hour with a 19% probability, media downloads with a 62% probability, and file downloads with a 61% probability [16]. The overall amount of traffic that can be delayed by one hour is then $0.37(0.19) + 0.14(0.62) + 0.12(0.61) = 23\%$. Figure 1 shows a graph of the fraction of traffic that can be delayed for a given amount of time.

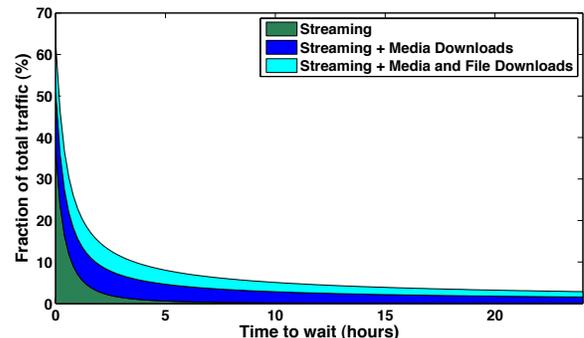


Fig. 1: Fraction of traffic users are willing to delay.

Given these estimates, we can then examine the average CSP traffic at different times of the day. Assuming that the fraction of traffic willing to wait a given amount of time is as shown in Fig. 1, we can then calculate the amount of traffic that can be shifted

from peak to off-peak times. We note that this depends on the observed traffic curve—for instance, if several consecutive hours have similar, large traffic volumes, then offering discounts in off-peak hours will not have much effect on the peak traffic, since little traffic can be shifted from the first peak hour to the nearest off-peak hour. At the other extreme, if a peak hour is immediately followed by an off-peak hour, then a much larger amount of traffic can be shifted from this peak to off-peak time.

B. Spectrum Requirement Calculations

Our second approach to evaluating the trial’s success is to estimate the reduction in spectrum requirements from using SDP. To estimate the spectrum requirements, we adapt the methods presented in the ITU (International Telecommunication Union) Recommendations [18–21] and use the online tool SPECULATOR [22]. These estimates depend on the following parameters:

- User density (users/km²),
- Session arrival rate per user (sessions/sec per user),
- Mean service bit rate (kbit/sec),
- Mean session duration (sec/session)
- Mobility ratio (a proportion given for the classes stationary, low, high, and super high).

We use data from a large CSP trial partner to calculate the session arrival rate per user, mean service bit rate, and mean session duration. We find that the session arrival rate is 1.5 connections/user/hour, while the mean service bit rate is 94 kbits/second for downloads and 16 kbits/second for uploads. The mean session duration is 1800 seconds; though this is fairly long, it is typical for, e.g., tethering or 3G-dongle traffic.

We next use these parameter values to estimate the change in spectrum requirements resulting from time-dependent pricing. During peak hours, time-dependent pricing will likely decrease the average number of connections per user, as users delay some of their usage (e.g., large sessions such as file downloads) to less congested, lower price times. Thus, to estimate the benefits of time-dependent pricing, a CSP would look at the decrease in spectrum requirements as the average number of connections per user decreases. Such a calculation could also help in determining the market (e.g., 3G or 4G) where time-dependent pricing gives the most benefit.

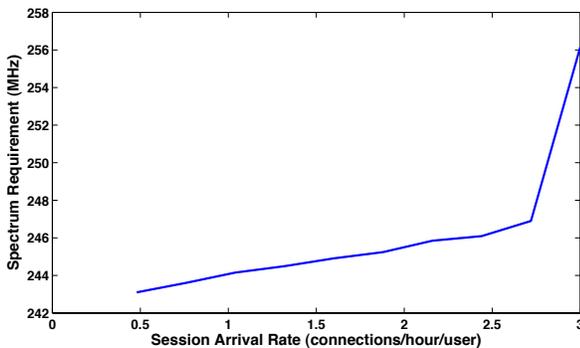


Fig. 2: Spectrum requirements versus the session arrival rate.

Figure 2 shows the changes in spectrum requirements resulting from varying the average number of connections per

user in a low-density user environment. We vary the arrival rate from 0.5 to 3 connections per user, per hour. We use a model of the 4G market in 2015 provided by the SPECULATOR tool [22] for the predictions. We see that a decrease of the session arrival rate from 3 to 2.72 connections per user yields a sharp decrease in the required spectrum, with a more gradual decrease as the session arrival rate decreases further.

V. CONCLUSION

This paper discusses several methods to assist the planning of SDP trials. We first give an introduction to the purpose of SDP research, and then give a short review of three typical forms of SDP. We then discuss several aspects of trial design, both in terms of participant engagement and technical considerations in working with CSPs. Finally, we present two methods for estimating the benefits of an SDP trial in terms of both network traffic and CSP cost. However, this short paper is far from a complete description of the planning and analysis necessary for conducting SDP trials. The many additional dimensions essential in trial planning include the following:

- Balanced sampling of trial users to verify/validate SDP practices.
- Developing a deployment plan combining multiple SDP practices (e.g., time-dependent pricing + cellular traffic offloading).
- Extending the spectrum requirement analysis to different service categorizations.
- Strategizing 3G-4G transition plans with appropriate SDP practices.
- Linking our results to a CSP’s CAPEX model for a more comprehensive estimation of SDP’s benefits.
- Modifying the ITU market models [17] to accommodate missing factors, e.g., differentiating market predictions for different device types.

We are currently pursuing these extensions with CSP partners.

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