

Quality-of-Experience in Wireless Pricing: Some Research Directions

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Abstract—One of the most important factors that affects a user’s satisfaction with their network experience is how much they are paying for the service. In this white paper we outline some current and future research questions related to Quality-of-Experience in network pricing.

I. INTRODUCTION

The overall Quality-of-Experience (QoE) that a user obtains when consuming content over a wireless network depends on many factors. In particular,

- What is the content that the user is viewing?
- What is the quality of the network connection?
- How much is the user paying for the bandwidth that is consumed?

In this white paper we discuss ongoing research on the last question, namely how does network pricing affect user behavior and the perception of the service that they receive.

In particular, our work on QoE in network pricing has addressed (or is addressing) the following set of questions.

- How can we use measurements and modeling to determine an end user’s experience of their network payments?
- How can we use network measurements and financial analysis to determine a content provider’s experience of its network payments? (Most of this work is aimed at the study of *sponsored content* in networks.)
- How can we jointly model the experience of content providers and end users with respect to the network performance that they experience vs. the payments that they make?

In examining these questions we believe that the following principles are important.

- One way to discover how end users perceive their pricing plan is via a study of *quota dynamics*, namely the extent to which an end user’s current actions depends on their quota status.
- The network economic ecosystem comprises the network operator, the end users and also the content providers. In order to understand whether the network operator is offering an appropriate quality of experience, the viewpoint of the content providers should be considered in addition to the viewpoint of the end users.

In the remainder of this white paper we shall address some past and ongoing work that is based on these principles and also describe what we believe are interesting directions for further study.

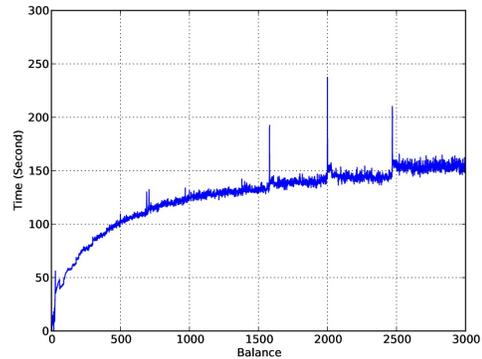


Fig. 1: Voice call duration as a function of remaining balance.

II. QUOTA DYNAMICS

One of the key questions that operators will ask about their end users is whether they feel that they are getting sufficient value from the network services that they are purchasing. One way to do that would be to send out surveys. However, such studies could suffer from low participation rates and would be expensive to carry out. In addition, many end users may not consciously know the internal tradeoffs that they make in terms of network usage vs. network payment. It is better to derive such tradeoffs by observing the actual consumption of data. This leads to a topic that we refer to as *quota dynamics* that aims to understand how much service (and what types of service) users consume based on how much service quota they have remaining and how much they paid for that quota.

An initial study of quota dynamics was presented in [2]. This paper analyzed a set of CDRs from a low cost wireless carrier in Asia and also generated a set of models to explain the observed behavior. This carrier primarily had pre-paid voice+text users (whose quota did not expire at the end of the month). Two main effects were observed in this data. First, as user balances became low, the rate at which service was consumed slowed down. In particular the duration of voice calls became slower. (See Figure 1.) Second, as the user balance gets lower, there is a shift in the type of service consumed. In particular, voice usage goes down but this is partially offset by an increase in texting.

In addition, to the CDR models described above, the paper [2] also offered various models for quota dynamics. One such model aims to capture quota dynamics in prepaid data systems.

We assume that a user has a fixed quota Q for each month and is trying to maximize the aggregate utility it obtains from that quota. In this setting user behavior can be captured by a dynamic program in which users tradeoff the utility they can obtain in a given day vs the utility that they can obtain in future days. The paper [2] shows that in many cases this leads to behavior in which a user holds back some quota for the end of the month, just in case it has a high-utility need for data at that time. Current research is examining how the models change when users have the ability to trade data during the month.

A. Quality of Experience

How do models of the above type connect to user QoE? We believe that they can shed light on whether the end users in a network perceive that the Quality-of-Service that they are receiving is good value. If most users are really holding back from using up their quota so as to avoid paying for a more expensive service tier, this suggests that users feel that the network services are expensive with respect to the quality that they are receiving. If on the other hand, the user does not worry about going over quota (and hence incurring overage charges), or if the user purchases a plan that is much larger than it typically uses, then this suggests that the user feels that she is getting sufficient “quality” with respect to the amount that she is paying.

B. Future Work

Most of the current work on quota dynamics has looked at a single pool of quota for each user. There are a number of ways in which this could be extended. First, there has been little work that looks at payment analytics for shared data quotas. By examining how multiple people in a family consume a shared quota, we can determine who is getting the most perceived value from the network with respect to the amount that they are paying. Second, we would like to couple quota dynamics with deep packet inspection in order to determine what are the types of data transactions that are most valued by the users. This information can then be used to introduce various types of “transaction” pricing in which users no longer pay by the Gigabyte but instead pay different amounts for different types of data.

III. QUALITY OF EXPERIENCE FOR CONTENT PROVIDERS

We believe that Quality-of-Experience for Content Providers is an important goal for network management, in addition to Quality-of-Experience for end users. A major function of today’s networks is to connect end users with Content Providers and so it is important that both sides of the transaction are satisfied with the experience. This is complicated by the fact that a Content Provider’s definition of experience could be different from the end user’s definition.

We have been studying network pricing for Content Providers, especially as it relates to sponsored content. Part of this work relates to the Quality-of-Experience that a Content Provider would receive if it participates in such a scheme.

Sponsored content is a mechanism in which a Content Provider contracts with the service provider so that mobile users who are accessing their content do not get charged against their data quota. This creates a complex 3-sided economical structure in which the pricing needs to be carefully designed in order for each participant to benefit from the scheme. Such a win-win-win situation is possible since the Service Provider benefits from additional views of its content, the Content Provider benefits because it receives more views of its content and the end users benefit since they are able to access some content “for free”.

A number of models have recently been developed (e.g. [5], [7], [6]) that aim to capture all the interactions and provide a way to develop optimal pricing. However, all these models make use of many parameters, e.g. how much extra benefit the Content Provider obtains from each additional view of its data, and how much additional traffic the Content Provider will receive if its content is sponsored. Each of these parameters directly impacts the QoE that the Content Provider receives when participating in a Sponsored Content scheme. The paper [3] addressed the derivation of the first such parameter. In particular, the benefit to the Content Provider for each additional view of the content was estimated via a detailed comparison of financial statements and traffic statistics. The paper also addressed methods for estimating the second parameter. In particular, this can be done via a comparison of the amount of traffic to the Content Provider before it is sponsored, versus the amount of traffic that occurs after the sponsoring is put in place. The methods of [3] were illustrated via a case study with Yelp and BuzzFeed. In particular, it was estimated that:

- Yelp’s revenue is roughly \$105 per GB of mobile bandwidth. Therefore it would make sense for Yelp to sponsor its traffic at a rate of \$15 per GB as long as sponsoring increases its traffic by at least 17%.
- BuzzFeed’s revenue is roughly \$19 per GB. Hence sponsoring would not make sense at the \$15 level but it would at the \$5 per GB level as long as the increase in traffic is at least 33%.

We believe that there are many other opportunities for studying QoE from the perspective of the Content Provider. For example, there are many studies that show that user engagement drops off as network conditions degrade. Another consideration was addressed in the paper [4] which showed that the design of the content itself affects how people perceive network performance. It would be interesting to perform a study of how both content design and network performance combine to affect the overall profits of a Content Provider. On the topic of sponsored content there are still many unresolved questions related to how users should be informed that certain types of content can now be viewed for free.

IV. PLACING QUALITY-OF-EXPERIENCE FOR WIRELESS INTO A COMMON FRAMEWORK

One feature of wireless pricing research in recent years is that much of it has focused on a single mechanism for pricing. A model has then been generated to study how that

mechanism performs. However, there has not been much work that examines a multitude of different pricing schemes and compares which ones provide the best Quality-of-Experience for the network participants. We are currently engaged in a project to perform this type of comparison [1]. In particular, we create a utility maximization framework in which the interests of all the network participants are represented. We then describe an *idealized* pricing scheme which carries the optimal set of traffic in terms of maximizing the benefits that the network participants receive. Such a pricing scheme would be prohibitive to implement in practice. However, it provides a framework for comparing any candidate scheme in terms of the benefits it provides for the overall network ecosystem.

More specifically, we assume that there is an underlying set of potential requests for network service. The idealized pricing scheme would charge all network participants based on the utility they receive from the request. We then compare many existing schemes against this ideal. In particular we study fixed monthly quotas, pre-paid schemes, shared data plans, quota trading, transaction pricing and sponsored content plans. Two example results are:

- Sponsored content plans can create higher overall utility than schemes that do not charge content providers. This is because there may be some transactions (e.g. advertising) that have much higher utility for content provider than they do for an end user.
- Shared data plans can create higher overall utility than non-shared plans since the aggregate demand for multiple users is more predictable than the demand for a single user.

In some sense both of these results are “obvious” which is why these types of pricing schemes have been introduced into the market. However, by putting multiple types of pricing plans into a single framework we can more easily quantify the differences between them.

V. OTHER FUTURE WORK

We now discuss some possible broader directions in Quality-of-Experience for network pricing. First, there is the overall question of how pricing information should be presented to the end user and what sort of menu of choices they should see. Although in an idealized world it might make sense to price every possible transaction separately, it is also better to make things simple so that the user is faced with fewer choices. Some questions of this type were considered by [6] in their work on Time-Dependent Pricing. In particular, one thrust of that work was to try and make as many of the decisions as possible transparent to the end user.

However, there is a broader question of how many decisions a user should have to make when choosing a pricing plan. Broadly speaking, the current trend is that pricing options are more complex in developing markets where wireless data charges are larger in comparison to most users’ monthly salaries. For example, many Indian plans are notorious for constantly bombarding the users with multiple offers for reducing their monthly bill. In contrast, plans in more mature

markets tend to distract their users with offers a little less frequently. Ultimately, we would like to be in a situation where the end users specify only a few pieces of information regarding how much they want to pay and what types of service they value, and the network automatically determines how they should be charged for the network actions that they perform. This would also help with transaction pricing since it would make it easier to charge differently for different types of transactions. However, users would need to be confident that they are not being cheated with such a scheme.

VI. SUMMARY

The amount that end users pay is one of the main features that affects whether they are satisfied with the Quality-of-Experience that their plan provides. Research in network pricing has started to look at various types of QoE-centric questions. Typically this work has focused on wireless pricing rather than wireline since wireless networks are capacity-constrained and hence schemes that work best for the end user (such as flat-rate pricing) are not viable from the perspective of the content provider. In this white paper we have described some work currently in progress that relates to understanding quota dynamics from the perspective of QoE, bringing Content Provider QoE into the picture, and also creating a unified framework for understanding the QoE provided by different pricing schemes.

From a collaboration perspective this work would clearly benefit from more interactions with traditional research efforts in QoE. If a network provides better performance with respect to common QoE metrics (e.g. video quality, page download times) then the end users will be willing to pay more for the use of that network. This is mostly clearly illustrated by the cellular coverage maps that Service Providers use when advertising their services. Tying traditional network QoE to the study of quota dynamics is a potentially rich area of study that so far has not received any attention.

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