"You're Capped!" Understanding the Effects of Bandwidth Caps on Broadband Use in the Home

Marshini Chetty[1,2], Richard Banks[1], A.J. Bernheim Brush[1], Jonathan Donner[1] and Rebecca E. Grinter[2]

Microsoft Research[1]
{rbanks, jdonner, ajbrush}@microsoft.com

Georgia Institute of Technology[2]
{marshini, beki}@cc.gatech.edu

ABSTRACT

Bandwidth caps, a limit on the amount of data users can upload and download in a month, are common globally for both home and mobile Internet access. With caps, each bit of data consumed comes at a cost against a monthly quota or a running tab. Yet, relatively little work has considered the implications of this usage-based pricing model on the user experience. In this paper, we present results from a qualitative study of households living with bandwidth caps. Our findings suggest home users grapple with three uncertainties regarding their bandwidth usage: *invisible balances*, *mysterious processes,* and *multiple users*. We discuss how these uncertainties impact their usage and describe the potential for better tools to help monitor and manage data caps. We conclude that as a community we need to cater for users under Internet cost constraints.

Author Keywords

Bandwidth, metered use, data cap, Internet, pricing, usage-based pricing, usage-based billing, bandwidth cap

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Human Factors

INTRODUCTION

Faced with increased network congestion from both the rise in bandwidth intensive applications and the growing number of Internet users [19], many Internet Service Providers (ISPs) have imposed a data "cap" or monthly data limit on their subscribers [12]. These bandwidth caps vary from 1-250 GB and exist in nations such as Australia, Canada, Turkey, South Africa, the U.K., and the U.S. [10,24]. Data caps are not restricted to home broadband; they are also part of the pricing model used by cellular providers for mobile Internet users [25]. Since ISPs argue that caps help provide more consistent service to all their users (e.g., [4]), this pricing model is likely to persist. Yet, little work has directly considered the effects of bandwidth caps and costs on broadband users' Internet experiences.

We find this gap surprising because caps have implications for how we design and deploy networked technologies and content [18]. For example, how viable is a data intensive photo-sharing application in a home with a 150 GB data cap? As HCI and related fields increasingly design applications that rely on the Internet, we argue that it is time to re-examine the assumption that for end-users the only cost associated with network use is speed. Moreover, caps are another opportunity to explore how existing infrastructure shapes the ways in which people engage with the Internet, thus providing an opportunity to reflect on assumptions and imagine different future technologies [5].

In this paper, we describe how monthly bandwidth caps affect households' Internet use in South Africa—a country with roughly 480,000 broadband subscriptions for the population of 49 million [9]. We chose this country because prior to February 2010, all South African home broadband data subscriptions were capped so most users' experience of broadband was of a metered connection. Our goals were to learn (a) how bandwidth caps affect households' broadband use (b) how households manage a bandwidth cap during the month, and (c) what tools and information households desire to monitor and control their bandwidth usage.

To do this, we conducted a qualitative study of 12 households living with data caps. We found that households struggle with three uncertainties related to their bandwidth usage: *invisible balances, mysterious processes,* and *multiple users.* To overcome these uncertainties, households described wanting better ways to help them manage their bandwidth. Consequently, in a second study phase we gauged their reactions to designs for potential tools to address the uncertainties they raised. Our contributions include empirical evidence of how data caps shape Internet use and implications for the design of networked technologies and content.

BANDWIDTH CAPS AND RELATED WORK

Bandwidth caps are a form of usage-based pricing where Internet use is billed based on how much data is used rather than providing unlimited data access for a fixed cost. Usage-based pricing is not a new business model [11]. For some early dial-up home Internet plans, customers were

CHI'12, May 5–10, 2012, Austin, Texas, USA.

charged for the connection and every additional hour of use above a certain time limit, on top of the cost of telephone calls [1]. In many countries such as the U.S., the shift from dial-up to broadband led to flat-rate pricing. By allowing users to pay a fixed rate for unlimited use, these plans enabled "always-on" Internet use [23]. Caps, however, pose a potential threat to this usage mode, one that remains under-examined in HCI and related fields.

Several studies have explored usage-based billing as a means of controlling network congestion. For example, Shenker et al. [4] investigated various usage-based pricing models and their effects on network traffic. Examples of pricing models include having a "smart market" where users are only charged for their traffic when the network is congested and priority-pricing where users indicate which packets should be prioritized over others [6]. These studies focused on how well each model managed network congestion and what technical challenges they presented. Most of these studies do not explicitly examine bandwidth caps as a form of usage-based billing. Moreover, the focus has largely been on optimizing pricing for the network infrastructure rather than understanding its effects on the user experience of the Internet.

Some exceptions exist. The Internet Demand Experiment (INDEX) in the late nineties exposed users to various usage-based pricing models including flat-rate pricing and paying per-byte used [18]. They found that people tended to use the Internet less when charged by the byte, as compared to when they paid a flat rate. Yet users embraced the idea of having rates change according to their own use and during times of high traffic congestion. Another report suggests that Internet users alter their behaviors in response to unlimited and limited Internet access [14]. These studies show that caps do cause people to modify their Internet usage, but they do not examine specific household Internet behaviors and practices in detail.

Since these studies, few have tackled the question of how cost as a constraint affects users' broadband experiences. Internet regulatory bodies have focused on how other Internet constraints shape Internet use, such as limited connectivity and slow speeds, or the absence of sufficient bandwidth to conduct online activities smoothly [7,16]. Additionally, some researchers have implemented visualizations for end-users to better manage Internet constraints such as speeds. For example, the *Kermit* system showed home users which devices were using up significant bandwidth and an estimate of the speed from the ISP to help users determine why the Internet was slow [3].

Constraints on speed and availability have also been a particularly salient part of the research discourse about Internet use in developing countries. For instance, Wyche et al. [26] studied how Kenyan Internet users, confronted with slow and sporadic connections at telecenters and cybercafés, orient to the web differently, with more deliberate, planned, and purposeful online interactions. Similarly, Chen et al. [2] found sporadic Internet connectivity and slow Internet speeds tend to frustrate users (e.g., during long page load times). In another study, Smyth et al. [20] discuss how users create innovative content distribution networks in situations of limited bandwidth and connectivity. They describe how mobile phone shops in India download media (e.g., video or voice clips) and resell it to others for entertainment use on their mobile phones.

In summary, we can draw two conclusions. First, previous work shows that cost affects how users use the Internet. Second, while empirical evidence exists for how certain users manage some types of constraints, the impact of bandwidth caps have not been explored in detail, nor widely discussed in the literature. For example, researchers do not typically consider how much data the applications we design consume or whether our field deployments take bandwidth away from other activities. Nor do studies explore bandwidth as a shared resource that must be allocated and negotiated as part of a family dynamic, with all the complexities of a household micro-economy. Moreover, although Internet usage may be likened to sharing energy resources or cell phone minutes, bandwidth is not a limited natural resource and multiple users and devices make tracking this commodity different than in these other domains. Our study was crafted to address these omissions. We focused specifically on how households experienced bandwidth caps, exploring the challenges they faced, discussing strategies they employed, and considering approaches that might make living with a cap easier.

FIELD STUDY SETTING AND METHODS

At the time of the research, Fall 2010, most South African ISPs offered "use-it-or-lose-it" data plans varying from 1-9 GB per month [15]. If a household did not use their allocation for the month, the unused data portion (which participants frequently referred to as "gigs") did not carry over to the following month. If a household ran out of gigs before the end of the month, they had to purchase additional gigs at higher cost to continue to access the Internet. These additional gigs were also "use-it-or-lose-it." At least one ISP did offer non-expiring "rollover" gigs at a slightly higher price, but only one of our participants mentioned having this type of plan.

To help users track bandwidth usage through the month, most providers such as Telkom[1] offered limited non-real-time tracking tools requiring users to login to their ISP's website. These tools could be configured to send a text message or email notification when the household was close to their cap. However, none of these tools offered a per device or per user breakdown of traffic usage. (Note, third-party tools for monitoring bandwidth usage such as NetLimiter[2] exist. However, these tools usually monitor usage per single machine and do not separate out internal

[1] www.telkomsa.net

[2] http://en.wikipedia.org/wiki/NetLimiter

#	Household Composition	Annual Household Income (USD)	# PCs	Cap	Cost per month (USD)
H1	Mother [self employed], Son (Teen), Son (20s) Roommate (20s)	$35K+	4	U	$146
H2	Mother [Admin Assistant], Twin Daughters (Teens)	$35K+	3	3GB	$81
H3	Couple [sales, self employed], Daughter (Teen), Daughter (20s)	$35K+	3	5GB	$146
H4	Mother [Personal Assistant], Daughter (20s), Son (Teen)	<$35K	2	5GB	$22
H5	Couple [self-employed, finance], Son (20s), Son (Teen)	$35K+	4	3GB	$36
H6	Couple [Admin assistant, Manager], Daughters (2 Teens), Daughter (8)	$35K+	3	5GB	$36
H7	Couple [self-employed], Sons (10, 7), Daughter (2)	$35K+	5	6GB	$91
H8	Couple [Manager, finance], Daughter (12), Daughter (5), Nephew (24)	$35K+	3	3GB	$36
H9	Mother [self-employed], Daughter (Teen)	<$18K	3	3GB	-
H10	Couple [driver, teacher], Daughters (3 in 20s), Grandchildren (2 Toddlers)	<$18K	2	5GB	$146
H11	Couple [self-employed, translator], Daughter (Teen), Son (Teen), Son (8)	$35K+	3	U	$109
H12	Mother [retail], Son (Teen), Grandmother	<$18K	2	1GB	$29

Table 1. Participant Demographics (U is uncapped, Cost is self-reported and varies with phone line rental, data bundle, and ISP charges reflecting participant confusion over DSL vs. top ups vs. phone costs).

home network traffic from bandwidth counts. Exceptions such as NetWorx[3] provide total bandwidth usage for a household but must be installed on every machine to be tracked and do not account for devices that do not support the software (e.g., an Xbox)).

Participants

Our goal was to recruit families reflecting different socioeconomic backgrounds. We recruited 12 households using word of mouth, email distribution lists, and through our network of contacts in the area. We compensated each family with dinner during the interviews and approximately 70 USD in gift certificates. Table 1 shows that our participants had a variety of broadband plans ranging from 1 GB per month to the more unusual (and new to South Africa) unlimited data plans. We interviewed families that tended to fall into higher income brackets and that owned two or more computers.

One household (H8) did not have Digital Subscriber Line (DSL), the main broadband technology in South Africa, and used two 3G (wireless) cards provided by a cellular service provider for Internet access, each with a data cap. Although our families had a range of speeds they paid for out of the offerings of 384 kbps, 512 kbps, or 4 Mbps, we focused discussions solely on their experiences of bandwidth caps.

Study Protocol

The study consisted of two parts. In part one, we visited the households and interviewed them about their broadband usage. We asked them about how they managed their Internet usage, whether they had ever exceeded their cap, and what had happened as a result. The two uncapped households commented on both their experiences living with and without a cap. Since we interviewed families as a group, their responses may have been affected by group dynamics. Each family also filled out a demographic questionnaire. We used these interviews to generate not just our empirical themes, but also to brainstorm concepts for ways to support cap management. We deliberately opted to create abstract low-fidelity designs to solicit feedback on the tool concepts [13].

In the second part of our study, we showed our designs to the families to get their opinions on the concepts. We presented the designs as a PowerPoint slide deck soliciting feedback on each concept. In addition, we provided each participant with printed copies of each design with space for them to add annotations and to sketch their own ideas. To complement the design feedback, we also created an exercise where participants estimated bandwidth costs of different online activities. Specifically we asked (1) how much 1 GB costs in Rands (the South African currency, ZAR) (2) how many times a YouTube video of a well-known song could be viewed with 1 GB of data, and (3) how large this particular song was in MB. Participants filled out their responses on paper and discussed them during a post-exercise interview.

We analyzed all the interviews, the feedback on the tool designs, cost exercise, and field notes, coding the data for relevant phenomena using established qualitative methods [22]. We then merged all the codes and resolved points of disagreement among our team. All of the codes were then arranged into higher-level categories presented here.

FINDINGS FROM INTERVIEW 1: LIVING WITH THE CAP

Participants had broadband for work, school, or their home business. The lower income families (H10 and H12 whose

[3] http://www.softperfect.com/products/networx/

annual income was low relative to the number of occupants [21]) had broadband for safety concerns (e.g., to avoid having to spend time at Internet cafes in unsafe neighborhoods), and as their "luxury" item to organize and do research online. All our families had reached or exceeded their caps, a process most referred to as "being (or getting) capped." For instance, H4 told us they were once capped three times in a month, H6 spoke of often being capped around 23rd or 25th of the month, and H5 had been capped twice in the month prior to the study, and every month before that.

Although our households paid for different speeds, none reported hitting their bandwidth quota any faster on higher speed plans. Instead, all the households always spoke of the cap as the overarching limiting factor on their browsing habits. Interestingly, the two households that had transitioned to uncapped plans spoke of how much slower these uncapped connections were compared to their capped plans. Yet, these uncapped households still preferred limitless consumption to having a fast capped connection.

In this section, we describe how families grappled with three uncertainties related to their bandwidth cap: *invisible balances, mysterious processes,* and *multiple users*. We also comment on the contrasting experiences of our two households on uncapped plans (H1 and H11).

Invisible Balances: Managing Use and Being Capped

Many of the issues our participants raised related to the inability to track their bandwidth balance or what was remaining of their cap at any time. In particular, our participants experienced bandwidth as a finite resource and highlighted the lack of warnings about when their data quota would be reached and the turmoil that resulted from being cut off from the Internet.

Lack of warnings and inadequate tools: Without a method to easily check their bandwidth balance, participants sometimes struggled to determine whether they had been capped. Often, the main sign of being capped was the inability to browse or access non-South African websites because certain providers offered a separate cap for local sites. For example, a participant in H9 told us: "*I can't access my Gmail account but I can go to the website for Telkom [ISP]. That's the only way I've managed to work it out.*"

Those without a separate cap for local sites complained that their "gigs" ran out suddenly, sometimes when they were in the middle of an online activity. To avoid this abrupt disconnection, several participants made an effort to use the existing ISP tools for managing their cap, such as configuring warning emails to alert them as they approached their limit. However, at least 5 households found those websites to be inadequate for their needs and "*not user-friendly*." For example, they complained that these sites required a login, forming a barrier to checking the usage at a glance. Even when warnings were issued, participants said that they came too late when there was insufficient bandwidth left (e.g., less than 5MB) to complete even basic tasks. Sometimes warning messages even arrived after the cap had already been reached when it was too late to prevent being cut off from the Internet.

Turmoil when cut off: Being capped or exceeding the invisible balance led to a variety of negative emotions. For instance, participants were exasperated when they wanted to do something online but then discovered that they were capped. In extreme cases, households felt "*incomplete*" without Internet access as the following participant in H4 said: "*It was awful realizing how dependent we were on technology. It was a big thing that we didn't have Internet. We were all psychotic*."

This feeling arose in part to perceived expectations of responsiveness by friends, family, employers, and other institutions of those with home broadband access. H7 ran a home business and gave an example echoed by others: "*Suddenly I can't get [online] and I'm urgently getting an email, and there's a brief that has to go off now*."

Forecasting and monitoring: Even before the end of the month, participants wanted to know if there was enough bandwidth for upcoming activities such as school projects. H6, a high school student, explained: "*It would be really useful for me, because then I know that I don't have to worry that I wouldn't have [the ability to go] on the Internet for a project or something, because I know I have the gigs.*"

Others wanted to know whether there were freeloaders on their wireless networks. For example, H11 noticed via their ISP usage tool that network activity had taken place at times when they were asleep. Additionally, their ISP told them that their network was insecure, making it possible for others to also use their cap, further depleting it.

Participants explained once they reached their caps they had three options: living with it until the next month, topping up their connection, or getting online via other channels.

Living with it: Those who lived with the cap (and limited Internet) told us they eagerly awaited next month's reset. Living with their cap was bearable for a few days, especially when there was a separate cap for local sites, allowing participants to still do online banking or check local email. However, sometimes constraints, such as economics, forced families to wait for the next month even if it was difficult. Even families who could afford more bandwidth described being tired of being forced to buy more gigs. A parent in H2 told us that she decided that living with being capped was a better option if they were close to the end of the month: "*Yes, initially it was a matter of we get capped, and then I would buy another gig. Until I realized, you know what, "No." So we got to the point of we kept [on going].*" Another mother in H4 said: "*Often I kind of stand firm and say, "We're not going to buy any more cap.*" Finally, the lack of information provided on bandwidth use was frustrating since parents could not use the opportunity to teach their children how to work within the budget.

Topping up: Families that wanted and could afford to, often chose to "top up" their balance or buy additional gigs,

available in 1 GB increments. Topping up became part of a parenting strategy in the face of the invisible bandwidth balance; rules were set as to how many times this would occur. For example, the father in H3 said that he told his daughters to "*go a little bit slow*" with their usage and that he had a "*one top up on me for the month*" rule.

While topping up restored Internet access, participants complained that the process was exasperating. To top up, participants either had to call their ISP and wait in phone queues or they went online if that was an option. Some used creative solutions to make the process more convenient. For instance, one household (H10) had two ISP's with two plans and switched to the second plan when the first one was capped. Participants were also unhappy that top up gigs did not typically rollover into the following month.

Finding Internet access elsewhere: Families sometimes resorted to visiting friends and family members to access the Internet once capped. In H2, the mother told us her daughters often went to their aunt's house when it happened, but added that they usually ended up capping that connection too. Families also described using the Internet on their phones or using a 3G card on their computers, linked to their cell phone accounts or a pre-paid data bundle to avoid the cap. For example, the mother in H2 used her 3G card on her laptop to help the family stay within bandwidth limits: "*Before we used that final gig, I would use my phone as a modem. So I buy a data bundle*."

Invisible balances frequently caused disruptions in connectivity, forcing users to either restore the network somehow, or live without it. Having timely visibility into the remaining balance was therefore desirable.

Mysterious Processes: Understanding and Optimizing

Our participants struggled with understanding what mysterious processes or applications and websites were using up bandwidth. In particular, families had difficulty identifying data-intensive Internet applications. For many, Internet terminology did not help. For example, H12 reported: "*With this MB and Kbps, I'm not clued up with it at all.*" Similarly confused, H5 correlated data used with time taken to download: "*Because I think what I understand is that the less time it takes, the less cap you can take*."

Participants did not appear to understand that YouTube or downloading songs used up significantly more bandwidth relative to web browsing. Participants also did not comprehend how background or non-browser based activities consumed part of their monthly allotment. Specifically, they worried about these processes using up bandwidth but not being under their control, such as an application automatically sending usage data back to its manufacturer. To help with bandwidth budgeting, participants wanted to know prior to use whether a site was likely to consume a lot of their monthly data allowance. For example, a school child in H9 told us: "*I want to see—like when you are about to click [something], you can see how many gigabytes is in there.*"

Estimating bandwidth usage: Two households had downloaded third-party bandwidth monitoring tools such as Traffic Watcher[4], to help them budget their bandwidth. The remaining ten households did not use any tools other than the defaults provided by the ISPs. Our estimation exercise illustrated the lack of awareness of costs, both monetary and bandwidth wise. Twenty-two of 51 participants (43%) answered "I don't know" to the question of how much 1GB costs in Rands. Estimates of the number of videos they could watch for 1GB and how large a particular song was in MB also varied wildly.

In some ways, these responses were not surprising. ISPs imposed different charges for top-ups, line rental, modems, and data plans. Similarly, for estimating bandwidth costs, although a few respondents had an intuition that streaming media was more bandwidth intensive than browsing text and images, they were unlikely to know just "how much" a YouTube video would consume in MB, or how long they could surf the net for $10—the average cost of a 1 GB top-up. Data sizes are abstract concepts and in many cases difficult to find. However, forced by caps to create folk theories about how much data different activities consumed, our participants developed strategies to optimize use.

Avoiding updates: One surprising finding was that just under half of our households (H3, H4, H7, H8, and H11) chose not to do software updates because of the bandwidth required, despite the potential security risks. Even the few participants who reported applying updates were somewhat reluctant to use their precious cap for this purpose. A dad in H5 explained: "*Because it just uses up our gigs, so you know you can have three gigs of spin, one of the gigs [used up], downloading the latest version of everything, every month. And so I think I don't have to do it."*

Setting Rules: In addition to software updates, families chose not to download anything they considered unnecessary unless they reached the end of the month and had a surplus of bandwidth. For example, many made a conscious effort not to download music. Others tried to curtail all downloads and prioritized files for work and school over personal or recreational downloads. Often, setting the rules involved negotiating what was allowed and what was not as well as what was prioritized, but there was no technical means to enforce these social rules.

Part of managing the cap was to set rules about home Internet usage in general. Some parents asked their children to stop using certain websites, avoid "*excessive gaming*" and to restrict media downloads and uploads. Other parents even banned certain sites such as Facebook and YouTube. Participants also self-monitored their online activities and purposefully reduced their usage of certain sites and software applications that they believed to be bandwidth intensive. One mom in H9 proudly told us of her child: "*I think [my daughter] is actually very sweet when she said she*

[4] www.codeproject.com/KB/IP/apptraffwatcher.aspx

won't have Facebook and all that because Facebook would suck it [bandwidth]. And I used to Skype full time with my friends in the UK [but] now [I] stopped doing that."

Often, because of the cap, participants became annoyed with family, friends, or colleagues who forwarded them emails with large attachments or images. These participants took care to be considerate when composing emails to their own contacts making sure not to send large files.

Using physical media and informal data sharing networks: Avoiding large email attachments led to increased use of physical media such as flash drives, DVDs, and CDs to send and receive files. H7 explained: "*But [my husband]'s dad for example has been taking photographs of our son. He did pictorials for us and I very much wanted him to upload them and get them to us, but practically he couldn't do that. So those have come through CDs a couple of times, he just popped them in post.*"

With capped usage curbing downloads, many households also spoke of informal data sharing networks. In these networks, friends, or family with uncapped or work connections would download videos, movies, and music to share with others using physical media such as CDs, DVDs, and flash drives. Our participants did not appear to have any qualms about whether this content was downloaded illegally or not. Rather the informal data-sharing network was seen as a type of favor on the part of the downloaders. One teenager in H9 told us she received music from one of her friends because: "*She's the one with the unlimited cap.*"

Maxing out the cap: After spending most of the month avoiding the cap, the last few days would be focused on using all the remaining bandwidth if the household tracked use with third party or limited ISP tools. Families spoke of downloading all the media they wanted (e.g., music), to ensure they used their entire cap. These binge downloads were a special treat and, to guarantee that the "use-it-or-lose-it" bandwidth did not go to waste, participants planned their wish lists. For example, H7's quote typified many we heard: "*If we've had a relatively good month and there's a lot of cap left over, then I'll start looking around at the end of the month for things that I might want to download which previously I would have not gone ahead and done."*

The binge could even be competitive. H4 told us how a brother often did not remind his sister when the end of the month was approaching so that he could use any surplus bandwidth for his downloads. In other words, families swayed between avoiding and trying to reach their caps, depending on the time of month. Caps can and *do* shape usage patterns, creating routines that change over the month and with respect to the amount of bandwidth "left".

Multiple Users

Our families also had trouble understanding which household member was using up their bandwidth. Families of three or more especially complained that it was hard to identify heavy users. In many cases, a teenager was suspected of engaging in data intensive activities such as downloading media or playing games. However, the lack of accountability made accusations easy to deny; some children embraced this vague state and others with siblings felt unable to prove they were using only their fair share. While parents differed in the amount of information they desired about their children's Internet use, many expressed interest in seeing if the bandwidth was being used for educational or recreational purposes.

To explain the difficulties of tracking Internet usage, many participants compared it to managing their mobile phone use. Mobile phones, mostly used by a single person, were far easier to comprehend. People with pre-paid mobile plans spoke of checking how much phone credit in Rands (ZAR) or "airtime" they had left, in order to determine whether to call someone. Participants using the Internet on their phone also seemed to better understand the costs of bandwidth on these devices. For example, H10 said of her phone: "*A twelve rand would translate to about six megabytes I'm thinking. But it won't even last a full day, if you…I wasn't doing anything intensive. [If] I was just browsing text*."

One reason participants felt they were able to more easily correlate their phone bandwidth usage with cost was because they tended to just browse or do a few online activities on these devices. Example activities included browsing Facebook, using MixIt (a chat messenger which is cheaper than SMS), or visiting reference sites. A teenage participant in H2, for example, compared the costs of different sites: "*When you Facebook from your phone, when you update, you just tap in then it says "connecting" and then it takes off your air time. And with Twittering, you tap your status and then it doesn't take off any air time even when you post it."*

Overall, our participants appeared to be able to form better conceptual models of the costs of online activities on mobile devices used by a single user accessing a small number of applications. In contrast, multiple users on many devices sharing a broadband connection made it more difficult to correlate usage and costs.

Switching to Uncapped

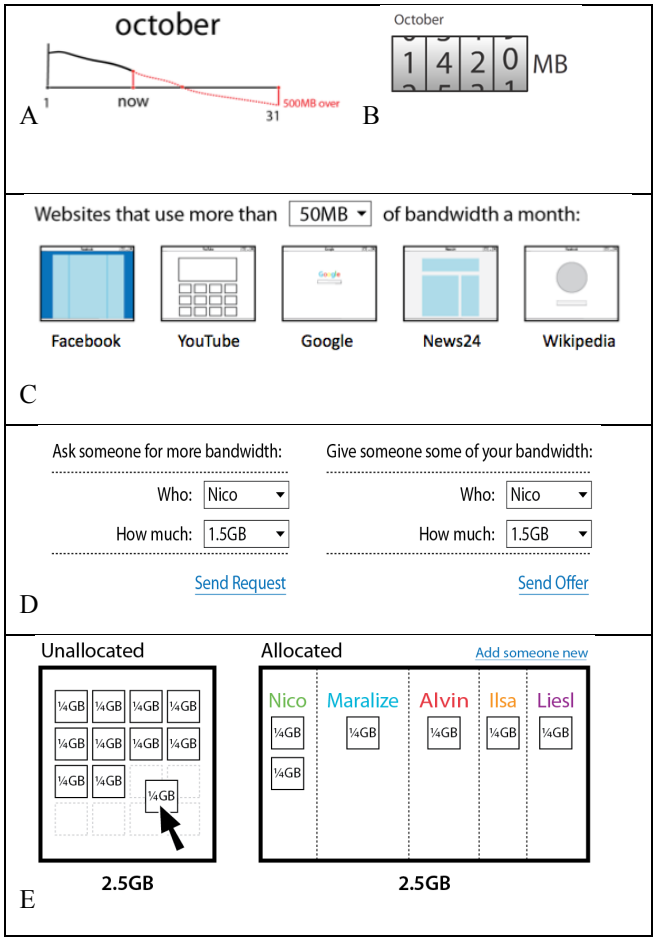
In contrast to the capped households, the two households that recently switched to uncapped plans told us they stopped policing the Internet habits of their children and spoke of downloading more media because the threat of being capped was removed. More importantly, these households reported having fewer Internet related disputes about the cost of access. These differences highlight how capped plans change browsing behaviors.

FINDINGS FROM INTERVIEW 2: MANAGING THE CAP

Based on the themes from the first interview, we created tool design ideas to further explore issues around three uncertainties families were experiencing. Next, we describe the designs and participant reactions showing how difficult users find it to understand bandwidth costs and usage.

Invisible Balances: How much bandwidth is left?

To address invisible balances, we developed three designs including a line graph (e.g., Figure 1A), a bandwidth 'clock' and a simple number to answer the question of



"How much bandwidth is left in a month?" We also created animations to elicit emotions around the fact that bandwidth is constantly running out such as a speedometer (e.g., Figure 1B). Participants varied in their affinity for the ways we visualized the bandwidth balance. Some told us that sometimes their use was erratic with lulls and spikes that our designs did not reflect. At least two participants also wondered if the calculations and predictions of when a home might run out of bandwidth were based on average use to date. One participant in H9 said of her daughter: "*It could be just one bad weekend that she spent all the time on Facebook, and then when you put the pie together, it looks like Facebook is the culprit. But it's not a daily culprit.*"

Our interactive animations were also met with varying opinions. The speedometer shown in Figure 1B garnered 22 positive comments, but participants raised concerns that the animations could be distracting depending on where they were shown. Participants for whom spending money on broadband was not an issue felt that the speedometer ticking down could be annoying creating a disturbing sense of urgency. For those who were more economically constrained, the meter ticking away was seen as a positive deterrence, with their goal being to restrict their usage and stay within their bandwidth budget without being capped.

Regardless of which representations participants preferred, they emphasized the need to know their balance in close to real time, when there was still time to change their usage pattern. Several also wished to know how much bandwidth was used in last 24 hours because access to recent data could make it easier to correlate usage with actions. Participants told us this would help them budget their time and prioritize work over recreational activities.

Mysterious Processes: What sites use most bandwidth?

For demystifying online processes and their bandwidth consumption, we created concepts to answer the question of "What sites are using up the most bandwidth?" (e.g., Figure 1C). In total, 19 participants made positive comments about this set of designs. Despite positive feedback, participants suggested that seeing monetary costs as opposed to bandwidth alone might help them curb their usage because it would likely be easier to understand. Moreover, many noted that in practice, costs would only become significant if aggregated over the month because web browsing may not use much bandwidth. One of our most interesting findings is that representing data usage requires careful presentation to show users that the time spent on a site does not necessarily equate to the amount of bandwidth used.

Multiple Users: Who is using the bandwidth?

To help users track multiple users, we created designs to answer the question of "Who is using the cap?" In particular, we focused on how bandwidth would be allocated to family members (e.g., Figure 1D), when this allocation would occur (e.g., Figure 1E), and around redistributing bandwidth during a month. Our designs for tracking use, allocating, and trading bandwidth, provoked the most spirited discussion. The tools we proposed extended beyond merely describing what the machine was doing; they described what its users were doing, and as such, created the opportunities for micro-economic behaviors and negotiations within the family.

Tracking Usage: Participants felt that having bandwidth usage information could become integral to their online habits. One participant from H4 summarizes this feeling: "*It's like always managing [or] the idea you have a battery on your laptop. You would have a battery for your Internet.*"

Yet, several participants were uneasy about the increased monitoring and collection of data about their Internet habits, a realm they previously considered private. One young adult in H4 for instance told us she was paranoid about being tracked and did not like the idea of her mother or brother knowing about her browsing habits or time spent on the web. Interestingly, at least two households did not feel that tool was out of bounds for tracking guests and student boarders or for shared households with roommates.

Our participants were also concerned that sharing bandwidth usage counts could lead to misperceptions about household users. A young adult in H1 gave the example: "*Let's say I'm doing research but you also go on YouTube just for a little bit. YouTube will use up to 50 megabits very, very quickly whereas your research might not even show up.*"

Clearly, making data caps more visible in the home can make household users accountable for their use of a shared resource and how they spend their time in a way that is not possible at present.

Bandwidth Allocation: Families differed in their responses to the idea of allocating gigs to household members. Some parents loved the concept of distributing the bandwidth like allowances, helping their children manage their time, or using it as a disciplinary tool. One parent in H6 told us she liked the idea of her kids being able to "earn more gigs." Allocation also appealed to participants who wanted their own Internet connection to work even if other householders were high bandwidth users. Similarly, those who had guests or boarders wanted to allocate a portion of bandwidth to them to avoid being capped by their use.

A few participants opposed allocation because they felt the feature went against the principles of sharing in the home. For example, the young female bill-payer for the Internet in H10 told us how her preference was that everyone should just use the Internet as they please. Her sisters disagreed and envisioned having an Internet café style home where everyone would be bargaining for bandwidth.

Families also wondered how the allocations would work in practice. Many saw the need for a login or password and felt this may be difficult to implement, given how different family members often get online on the same machines. Some were concerned that bandwidth would go to waste if someone did not use their allocation; others wondered who would be given rights to allocate the resource.

Others suggested assigning a cap for each site but this was usually met by protests from household members who did not want to share a cap for sites with their siblings (e.g., for Facebook (H10)). For some, trying to impose caps on children's website usage as opposed to restricting use by time seemed impractical. A father in H11 said: "*Ja [Yes], you not gonna be able to tell [my daughter] well you can only use 'x' percentage for Facebook. It's just not realistic.*"

Trading Bandwidth: Many of our families, particularly children, responded positively to the idea of being able to "*trade the cap*" with other family members or to "*sell bandwidth to each other*," highlighting how this "*gives you something to bargain with*", as shown in Figure 1D. Several parents felt that allowing trading could mitigate fights if their children could give and take bandwidth from each other. For example, a mom in H6 felt that it would help her family use a shared laptop more fairly and that once she had finished the allocation, it was up to her kids to resolve their disputes. Participants did see downsides to trading including the potential for new forms of disputes: "[*my daughter] would inadvertently ask [my son], 'Can't I just use yours and I'll only use a quarter of a gig?'. And he'll come back and the whole lot would have been used.*" (H11)

"*Just a few megs [megabytes] man. I need my fix, I promise I'll pay you back next month.*" (H5)

Another family felt there would be nothing left to trade since the children would likely each use up their cap (H4). In these responses, it became clear that sharing bandwidth equitably was a major concern for tools to manage the cap.

In summary, exposing families to design ideas highlighted considerations for creating bandwidth management tools because families had to respond to concrete ideas as opposed to interview questions alone. Ultimately, making information about bandwidth balances, what applications, and people use up bandwidth was highly desired to help users form a better conceptual model of bandwidth and manage their caps more effectively. We are currently building a probe to investigate the technical challenges of bandwidth management tools and what the social implications of such tools might be on family relations.

DISCUSSION AND IMPLICATIONS FOR DESIGN

Our study findings show that families struggle with three uncertainties related to their bandwidth caps. Firstly, *invisible balances* make it hard to know when a cap will be reached and families must plan for inevitably losing connectivity. Secondly, *mysterious processes* mean that it is not easy to determine which applications are using up bandwidth. In the absence of this information, families have evolved strategies to avoid being capped. Thirdly, tracking *multiple users* sharing a data plan is difficult and exacerbates the process of dividing up the bandwidth. Overcoming these uncertainties is complicated by families' lacking a conceptual model of bandwidth as illustrated by their reactions to our designs. Thus, they desire improved ways to monitor and control their bandwidth caps.

To complement our findings, future research could explore how cost affects mobile broadband usage, particularly given that in resource constrained settings, Internet users are more likely to get online on their phones under this pricing model [17,23]. Other studies could examine whether users in countries with higher data caps react similarly to the users we studied. Despite the differing culture and context of use, we believe bandwidth intensive users with higher data caps may be subject to the same frustrations, even though cost may be less of a constraint. Next, we discuss the implications of our study for the HCI community.

The Case for Bandwidth Sensitive Design

At a minimum, our findings suggest capped users desire bandwidth management tools that show how much bandwidth is available and what users, devices, and applications are using up this resource both in near real-time and historically. This information could help users on usage-based pricing plans develop an improved mental model of bandwidth costs informed by real data and enable them to decide how their household wants to prioritize online activities. Presenting usage information that is easy to understand is challenging but offers new opportunities for creative user interfaces. For example, our participants struggled to comprehend that the time spent on a website does not correlate directly to the volume of data used.

Most importantly, we believe these tools need to move beyond simply visualizing information, instead allowing families to have more active control of the allocation of bandwidth to users, devices, and applications if they wish. For example, users could be given improved control over how "chatty" an application is, i.e., to configure how often it retrieves or sends data, or even calls its creator for updates. This model is akin to turning off data "push" notifications on a smart phone to avoid roaming charges. Users on capped or metered plans may also want to know upfront about bandwidth-lite content and how to consume only the most salient content without using too many 'gigs'.

Moreover, much like how developers account for access on a small screen or conditions of slow speeds, we believe there is value in creating content to save users bandwidth and associated monetary costs. For example, certain websites and services such as Netflix[5] (a streaming video service in the U.S.) already suggest a low-resolution version when a slow Internet connection is detected. Extending these design optimizations to users with data caps would be valuable. A trivial example might be to offer text only advertisements to reduce unnecessary bandwidth consumption. Other optimizations could be to delay downloading content immediately or to turn off browsers pre-fetching algorithms, all to minimize costs for those on the smallest of bandwidth plans.

Similarly, in the home, we could leverage the home network to share content. For example, in-home servers that download, store, and share content could make the roll-out of security patches, audio-visual content, and large software updates more efficient, e.g., by centralizing the distribution of one copy of a file to all machines requiring it. All of these features would enable families to make decisions about setting rules and priorities for content access, sharing access fairly, and budgeting monthly Internet costs.

While bandwidth sensitive design would make networking more usable for those with caps, it is important to consider why organizations would be motivated to provide such services. Although ISPs may actually profit from additional revenue when users buy more bandwidth, our suggestions could ultimately benefit them. Specifically, they will gain insight into whether their plan offerings match demand, whether the cap sizes they choose are within reason for average use, and whether users are being treated fairly across the board. In addition, they can more proficiently load balance their network resources and offer enhanced tools to decrease technical support costs.

On the consumer side, given the increasing network congestion from the rise of bandwidth intensive devices and applications we believe that practicing bandwidth sensitive design will provide a competitive advantage for operating systems, browsers, and application developers. As more and more users face the capped situation our participants struggled with, we expect given the choice people will seek out services that are respectful of bandwidth caps.

It is worth mentioning that bandwidth sensitive design also has social implications. As observed in participant reactions to our probes, households may or may not like having detailed usage charts made visible. For some, these charts may serve as a resource for discussions about managing Internet use. Others prefer the ambiguity around their consumption habits. Precisely how increased Internet monitoring and management affects household relationships is a topic for future research.

Moving Past Assumptions of "All You Can Eat" Plans

Aside from potential interventions, our study has highlighted how Internet pricing challenges the assumption that data is an unlimited resource and that what limits our activities is just the speed of the pipe. This has two sets of implications. Firstly and pragmatically, it may cause researchers to reconsider the types of interventions we make in the home. When we deploy probes and prototypes, we offer compensation to participants in part to offset both expenses and inconveniences of the system. Caps ask us to consider how our system interacts with their other data usage and how best to compensate for it. It may also encourage us to consider how our deployment uses the Internet and design in order to minimize that.

But the second and far more important take away is how caps press upon the pervasive assumption of "all-you-can eat" data consumption. Our families were mindful consumers of data, as they were about other consumables; decisions about today's use were considered in the light of what would happen tomorrow and for the rest of the month. Applications and people were in competition for the right to consume data from the network and data was perpetually scarce. Given this mindset, consider two examples of the implications of caps: smart homes and cloud computing. Visions of smart homes conjure up spaces filled with many interdependent networked technologies [8]. Yet, how would the occupants feel if their smart home and its devices cap their network? Would the home even function if capped, and how would we design it to be robust to this situation?

Caps and other forms of usage-based pricing also push on the idea of cloud computing. Pushing data into the cloud adds to competition for network access and with capped billing, storing data locally becomes a more attractive choice. Cloud computing also creates more complications for home users. For instance, households have to juggle data allocations increasingly, between people and devices such as Personal Video Recorders (PVRs) that call their manufacturer to update their television schedule. What alternatives can we envision instead?

In summary, the case of families living with broadband caps challenges assumptions of unlimited Internet and make clear the necessity of introspection in our community about limiting and prioritizing Internet activity, and the

[5] http://www.netflix.com

development of more bandwidth sensitive designs. Reflecting on caps offers an example of how the "messy" world of technology can inspire alternate futures for computing, and suggest that we attend to them if we are to have a truly global reach with our systems [5].

CONCLUSION

Bandwidth caps are likely to persist as ISPs and other Internet providers use tiers and limits to manage infrastructural constraints. In this paper, we explored the effects of data caps on home Internet usage in urban South Africa to show that users have three uncertainties with regards to their bandwidth usage: *invisible balances*, *mysterious processes,* and *multiple users*. Our results demonstrate the specific ways in which users orient to and manage their Internet access under cost constraints. Moreover, we suggest that the HCI community rethink assumptions about unlimited bandwidth in how we design our applications and devices to accommodate those who experience the Internet via usage-based pricing.

ACKNOWLEDGMENTS

We thank our participants. This work was supported by Microsoft Research and NSF IIS-090443.

REFERENCES

1. Andrew Odlyzko, "Internet Pricing and the History of Communications," *Computer Networks 36*, 5-6 (2001), 493-517.
2. Chen, J., Dhananjay, A., Amershi, S. and Subramanian, L. Comparing Web Interaction Models in Developing Regions *ACM DEV*, ACM, London, UK, 2010, Article 6.
3. Chetty, M., Haslem, D., Baird, A., Ofoha, U., Sumner, B. and Grinter, R.E. Why Is My Internet Slow?: Making Network Speeds Visible *CHI 2011*, ACM, Vancouver, Canada, 2011, 1889-1898.
4. Comcast. FAQs about Excessive Use, http://customer.comcast.com/Pages/FAQViewer.aspx?seoid=Frequently-Asked-Questions-about-Excessive-Use.
5. Dourish, P. and Bell, G., *Divining A Digital Future: Mess and Mythology in Ubiquitous Computing*. MIT Press, Cambridge, MA, 2011.
6. Falkner, M., Devetsikiotis, M. and Lambadaris, I., "An Overview of Pricing Concepts for Broadband IP Networks," *IEEE Communications Surveys Second Quarter* (2000), 2-13.
7. Federal Communications Commission, *Connecting America: The National Broadband Plan*, 2010.
8. Harper, R. (ed.), *Inside the Smart Home*. Springer-Verlag, London, 2003.
9. International Telecommunications Union. ITU Free Statistics, 2009.
10. Lasar, M. It Could Be Worse: Data Caps Around the World, Ars Technica,, 2011.
11. MacKie-Mason, J.K. and Varian, H.R., *Pricing the Internet*, in Public Access to the Internet, MIT Press Cambridge, MA, USA, 1995, 269-314.
12. MacKie-Mason, J.K. and Varian, H.R., "Some FAQs about Usage-Based Pricing," *Computer Networks and ISDN Systems 28*, 1-2 (1995), 257-265.
13. McCurdy, M., Connors, C., Pyrzak, G., Kanefsky, B. and Vera, A. Breaking the Fidelity Barrier: An Examination of our Current Characterization of Prototypes and an Example of a Mixed-Fidelity Success. *CHI 2006*, ACM, Montreal, Quebec, Canada, 2006, 1223-1242.
14. Middleton, C. and Chang, S., "The Adoption of Broadband Internet In Australia and Canada," in Dwivedi, Y.K., Papazafeiropoulou, A. and Choudrie, J. (eds.), *Handbook of Research on Global Diffusion of Broadband Data Transmission*, IGI Global, Harrisburg, PA, 2008, 818-840.
15. Naidoo, R., Kaplan, D. and Fransman, M. The South African Telecoms Innovation System and the Diffusion of Broadband *Globelics Africa 2005*, South Africa, 2005.
16. Ofcom. UK Broadband Speeds May 2010: The Performance of Fixed-Line Broadband Delivered to UK Residential Consumers, 2010.
17. Otsuka, Y., *Mobile Broadband: Pricing and Services*. OECD Publishing, 2009.
18. Public Knowledge. Letter to Federal Communications Commission, http://www.publicknowledge.org/letter-to-FCC-on-ATT-Data-Caps.
19. Shapiro, R., *The Internet's Capacity to Handle Fast-Rising Demand for Bandwidth*. US Internet Industry Association, 2007.
20. Smyth, T.N., Kumar, S., Medhi, I. and Toyama, K. Where There's A Will There's A Way: Mobile Media Sharing in Urban India *CHI 2010*, ACM, Atlanta, GA, USA, 2010, 753-762.
21. Statistics South Africa, *Income & Expenditure of Households 2005/2006*, 2008.
22. Strauss, A. and Corbin, J., *Basics of Qualitative Research Techniques and Procedures for Developing Grounded Theory*. Sage Publications, London, 1998.
23. The Berkman Center for Internet & Society, *Next Generation Connectivity: A Review of Broadband Internet Transitions and Policy From Around the World*. Harvard, 2010.
24. Wallsten, S. and Riso, J.L., *Residential and Business Broadband Prices Part 1: An Empirical Analysis of Metering and Other Price Determinants*. Technology Policy Institute,, 2010.
25. Wortham, J. As Networks Speed Up, Data Hits a Wall *NYTimes*, NYC, 2011.
26. Wyche, S.P., Smyth, T.N., Chetty, M., Aoki, P.M. and Grinter, R.E., "Deliberate Interactions: Characterizing Technology Use In Nairobi, Kenya," *CHI 2010*, ACM, Atlanta, GA, USA, 2010, 2593-2602.