Why Is My Internet Slow?: Making Network Speeds Visible

Marshini Chetty[1], David Haslem[2], Andrew Baird[3], Ugochi Ofoha[1], Bethany Sumner[1] and Rebecca E. Grinter[1]

Georgia Institute of Technology[1]
{marshini, uofoha3, bsumner8, beki}@gatech.edu

Orange Sparkle Ball[2]
david@orangesparkleball.com

Amazon[3]
baird.gatech@gmail.com

ABSTRACT

With widespread broadband adoption, more households report experiencing sub-optimal speeds. Not only are slow speeds frustrating, they may indicate consumers are not receiving the services they are paying for from their internet service providers. Yet, determining the speed and source of slow-downs is difficult because few tools exist for broadband management. We report on results of a field trial with 10 households using a visual network probe designed to address these problems. We describe the results of the study and provide design implications for future tools. More importantly, we argue that tools like this can educate and empower consumers by making broadband speeds and sources of slow-downs more visible.

Author Keywords

Home networks, broadband speed, broadband tools

ACM Classification Keywords

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

General Terms

Human Factors

INTRODUCTION

With increased broadband adoption in the U.S., more households report experiencing sub-optimal internet speeds [9]. Often broadband speed varies because there are more users on larger home networks, frequently using high bandwidth media such as real-time voice and video applications [1,20-21]. Not only are slow speeds frustrating, they may indicate households are not receiving services they are paying for [26]. In the U.S., only 30% of online Americans receive "advertised" speeds, even though internet service providers (ISP) charge higher rates for faster speeds [9]. Adding to concerns over inconsistent home broadband speeds, are ongoing debates about "net neutrality" which would introduce a tiered internet service—paying fees for various types of web traffic [10]. Regardless of which side of the debate one is on, regulators, companies, and consumer groups agree that users need visibility into what performance the ISP is actually delivering for various services [17-18].

For these reasons, households require tools to help them determine their internet speed, diagnose a slow connection and take action to rectify the problem [8]. Our research goals were to make home broadband speeds visible and manageable for users and to study how this informs their thinking. To this end, we created a probe called Kermit to show householders factors causing internet slow-downs. In this paper, we describe results from a field trial of Kermit with 10 households where we also ascertained real consumers' awareness of broadband speed issues.

We have three major HCI contributions. First, we introduce a novel visual tool for home broadband management. Second, we provide insights from our field trial into how real consumers conceive of tiered internet services, broadband issues, and implications for the design of future tools. Our third contribution is showing how such tools can serve to educate and empower consumers about broadband service in general.

We begin by reviewing related work on home networking and broadband issues. We then describe Kermit's design and our evaluation methods. Finally, we discuss our results, and how tools similar to Kermit can help households better understand and manage their broadband connections. More importantly, we call for the HCI community to conduct more research on household broadband tools—to help consumers become aware of, and engage in public debates on broadband issues affecting them, such as net neutrality.

RELATED WORK

Previous studies highlight how setting up, maintaining and troubleshooting a home network is far from straightforward [11]. Not only is digital housekeeping a problem, its resolution depends on the social makeup of the home and how people rely upon each other for help, particularly when technologies fail [24]. Notably, these studies suggest that even technically knowledgeable individuals struggle with home networking. To overcome these challenges, researchers propose that visual tools might better ease the task of digital housekeeping [27].

More specifically, households often create their own make-shift visual representations of their networks (e.g., using

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post-it notes) because they have no unitary visualization easily accessible to them [3]. Moreover, even when information is available in router configuration pages or other equipment, it is not presented in layman's terms. Overall, household members lack conceptual models of their home networks and usable information required to manage and troubleshoot them—advocating a need for tools that provide both real-time and historical data so users can understand changes over the network's lifetime [23].

Recently, not only is managing the home network a challenge, but increased internet congestion means that households also have to deal with varying, and often slow broadband speeds. Slow speeds can be detrimental for the overall internet experience, with 2 Mbps being barely sufficient for TV quality streaming media [1,20]. Speed slowdowns can be caused by factors internal and external to the household [21,28]. Internal factors include bandwidth intensive applications choking a connection, old computing equipment causing stalls or multiple people using the internet simultaneously creating bottlenecks. External factors include the access technology itself (e.g., cable) only allowing for a maximum speed, ISPs shaping internet traffic (i.e. controlling network packets to optimize performance) or peak times when most consumers get online. With a myriad of factors involved, deciding why a connection might be slow is complicated. Moreover, inherently limited last mile access technology, network congestion and traffic shaping, mean speed variances are likely to persist [6,21].

In fact, the gap between actual and advertised speeds is large in the U.S., with overall speeds being quite low relative to other countries. To help improve offerings, in the recent National Broadband plan, the Federal Communications Commission (FCC) outlined minimum download speeds of 100 Mbps and upload speeds of 50 Mbps for all American broadband users [8]. Because of speed variances, certain countries have criticized providers for so-called "headline" speeds in their broadband package offerings. Mostly, the concern is that "up to" (e.g. "up to 1.5 Mbps") does not alert consumers that they may not attain those speeds consistently, or at all [19].

Amidst concerns over a minimum broadband speed for all, in the U.S and elsewhere, deliberations about creating tiers of internet service continue [28]. These net neutrality discussions (summarized by Jordan [16]), revolve around whether all internet traffic should be treated equally, regardless of where it is from, where it is going or its content.

Proponents of net neutrality argue that a tiered internet with slow and fast speeds would create a new type of digital divide. Opponents of net neutrality argue that tiered internet will guarantee a reasonable quality of service for real-time applications and ensure that content providers are not "free riding" on infrastructure maintained by ISPs. Already violations of net neutrality have occurred, notably with the case of Comcast, a U.S. ISP found to be shaping Bit Torrent traffic in 2007 [15]. In the most recent debates, consumer groups (such as moveon.org and Free Press) challenged the FCC for only considering big business viewpoints—such as net neutrality supporters, Google and Microsoft and opponents, Comcast and AT&T [12]. For consumers, concerns include costs falling on them, high bandwidth users being penalized, and access to certain sites being limited because of additional fees.

With these broadband debates raging on and speed variances, the need for users to be more informed is clear. Yet, there is little data on whether users are aware of the broadband issues at hand, their connection speeds, or factors influencing their internet experience.

To date, the majority of home network tools are geared towards managing and configuring devices [13]. Although broadband speed measurement tools from the FCC, M-Lab, Glasnost and popular sites such as speedtest.net exist [17-18,28], it is unclear how many households are aware of, or regularly use these tools. More importantly, these sites are not tailored to the average consumer, providing tools that are difficult to install, and results that are not easy to interpret without a technical background. Therefore, although these sites are geared towards "enhancing internet transparency", the question of how to create tools for what users desire or need to see, in a language they can readily understand, remains open. One exception to the above, and most closely related to our own work, is Home Watcher. This tool helped households identify bandwidth hogs as a first step towards understanding what visual network tools might do for a home [2].

With Home Watcher's visualization of home machines' bandwidth usage, households were able to learn more about high bandwidth users. However, users wanted more say in how they were personally represented in a network visualization. Our research builds upon the lessons learned from the Home Watcher study. Aside from presenting an alternative network visualization that allows personalization of icons [2], we also provide the estimated internet speed from the ISP. Kermit further differs from Home Watcher because we show all devices connected to the home network as opposed to computers alone; we allow users to prioritize any device's internet traffic instead of just providing a throttle function; and our tool is browser-based instead of a standalone appliance.

With our research on Kermit, not only do we offer a new prototype tool for home networking, we also provide insights into how real residential broadband consumers conceive of issues around internet speed—particularly, when more information has been made visible to them.

PROBE DESIGN

We chose to create and deploy a technology probe called Kermit to determine what households desire in a broadband visualization and management tool, to field test the

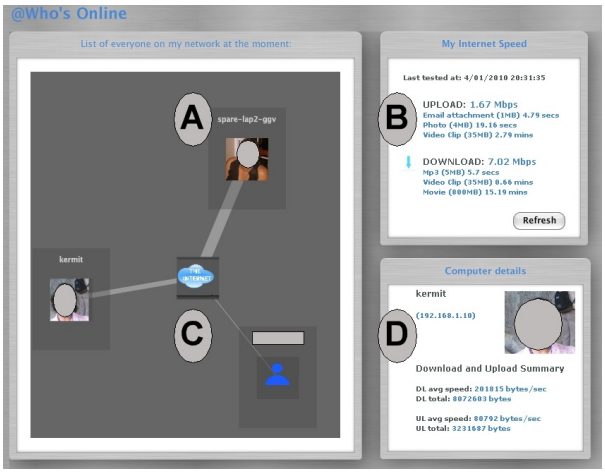

Figure 1: Screenshot of household five's "Who's Online" screen with participants' self-selected photos

prototype in a real-world setting, and to prompt users to think about how they might use a broadband tool, for our own design inspiration [14]. As such our results cover user needs and desires, improvements to the technology in its current form factor and ideas for future tools.

Our three design goals for Kermit are grounded in prior research as discussed in related work. First, we wanted to provide an estimate of the broadband connection speed to help households see if they were attaining advertised speeds. Second, we wanted to show real-time and historical information about bandwidth usage for all household devices on the home network—allowing households to identify bandwidth bottlenecks within their homes. Third, we wanted to provide households with agency to control factors influencing their internet speed.

Probe Features

For our first goal, as shown in Fig. 1B, we created the "Who's Online" screen, where we provided an estimate of the broadband upload and download speed in Mbps, every hour using our own automated speed test. We also provided a "Refresh" button so that users could do a speed test at any point if they desired.

To satisfy the second design goal, we provided a visualization of all the home computers. In this visualization, shown in Fig. 1, users' machines are depicted as little boxes linked to a central internet cloud. Each link changes from a thin to thick line in real-time based on how much bandwidth that machine is consuming, in relation to other machines on the network. The largest bandwidth user (Fig. 1A) always has the thickest line connecting it to the internet cloud with line thicknesses updated every minute. Mouse-ing over a computer icon pops up a bubble showing each machine's average bandwidth use (uploads and downloads) for the last minute. Icons gray out when users are idle for several minutes.

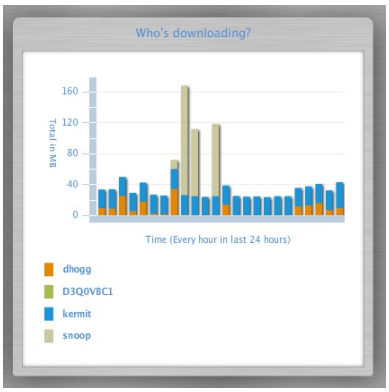

Figure 2: Household seven's download history graph for one day showing four machines usage in MB

For personalization, users can associate pictures with their home computers and change the names used to refer to computers. By default, each machine has a blue person icon (Fig. 1C) and the machine's hostname or IP address is displayed. If users choose to, they can also add a status message to any machine's icon. Double clicking on an icon brings up additional information on that machine in a computer details panel (Fig. 1D). To provide historical bandwidth information, we created the "Who's Hogging the Bandwidth" screen in a separate tab. Users can access a stacked color coded bar chart depicting all home machines uploads and downloads in two side-by-side charts, for the last 10 minutes, one hour or 24 hours. The stacked charts show at a glance which color is dominating uploads and downloads so that bandwidth hogs can be visually identified as shown in Fig. 2.

For our third design goal, users can take actions to influence their speed. Using Kermit, users can limit or prioritize the bandwidth for any machine connected to the network. To do so, a user selects and right clicks the relevant machine icon in the "Who's Online" view and chooses "Limit" or "Prioritize". Once limited or prioritized, a "Limited" or "VIP" is depicted below that computer's name. When a user unlimits or de-prioritizes a machine to return it to its former state, using the same right-click menu, this denotation is removed.

Implementation

Kermit uses data collected from a router flashed with open-source Linux based firmware called DD-WRT [4]. We use a plug-in called RFlow collector to detect packets flowing through the router and to calculate bandwidth counts for each machine, as well as their online status. Since no established methods for determining speed exist, our speed test is based on uploading and downloading a random sized file to, and from, our well provisioned server machine, hosted at a local university. We then calculate the time for the upload and download. When a user limits or prioritizes a machine, the router treats the data packets from that machine accordingly relative to other home network machines' internet traffic.

All back-end information is stored in a MySQL database and accessed using PHP. The Kermit interface was implemented using Adobe Flex. Kermit is deployed by swapping out participating households' routers with a Kermit-router and connecting our server machine to the home network. For data collection purposes, we logged only speed tests results, machines' bandwidth usage, and user interactivity with the probe. We did not collect any privacy-violating data such as urls or packet information.

Kermit Field Trial

We piloted Kermit in two households with 4 adults from December 2009 to February 2010 to ensure it was robust for a larger field deployment and to evaluate our field protocol. Our full field trial occurred between February 2010 and May 2010. We recruited 10 households in Atlanta, a major U.S. city, to participate in the study through word of mouth, snowball sampling, and email lists. We specifically sought households with a broadband connection, at least 2 computers connected to the internet and each other, and a wireless network. Each household was compensated with 100 USD gift card for their time.

We visited each home a minimum of three times during the month long study period. The first visit set the context for the study. Participants completed a basic demographic survey and a week-long diary to indicate their internet usage habits. We also performed a speed test using speedtest.net to collect data about the household's broadband speed. Semi-structured interviews covered questions around home networking roles and routines. To find out more about participant awareness of broadband issues beyond their homes, we asked them about net neutrality and their attitudes towards fee based services. Specifically, we asked participants whether they had heard of the net neutrality debates, provided an overview of the basic premise, and asked for their opinions.

In the second visit one week later, we deployed Kermit. Each household member was given a set of four tasks or "Kermit Homework" to complete for each week of a two week deployment period. All eight tasks were designed to be lightweight to allow participants to test out and reflect on all Kermit functions, for example, "Limit a computers traffic for 30 minutes" or "Who's the biggest bandwidth hog in your house today?". In the third visit, we removed Kermit and administered a final post-study survey. During our exit interview, we asked about Kermit's use as a speed and bandwidth monitoring tool for the household.

All interviews were audio-taped and transcribed, and our surveys were digitized. For the qualitative analysis, three researchers coded the data and the quotes presented in this paper are representative of broad themes of agreement grounded in our data [25]. Our qualitative data was supplemented with descriptive statistics from our surveys, internet diaries, and limited logs of usage. In this paper, we draw mainly from the qualitative data which was triangulated with our other data sources.

Participants

We interviewed 10 households with a total of 21 adult participants between the ages of 23 to 46 years and 2 teenagers aged 15 and 18. Four households comprised families with children between the ages of 2 and 18, three were households with roommates, and three were couples. Participants' occupations were varied, from graduate students, consultants, software engineers to a musician, firefighter and stay at home dad. Six of our households had at least one member with a technical background and four had no members with technical training, so our sample was slightly skewed towards the more tech-savvy user.

Eight households had cable internet, one had DSL and one had broadband through WiMax. Of our 10 households, only two were paying more than 60 USD per month for their broadband connection. In general, our cable users had faster speeds than the DSL and WiMax households. The cable users upload speed range was 2 to 4.14 Mbps and the download speed range was 11.36 Mbps to an unusually high 52.83 Mbps. Both the DSL and WiMax households reported low upload speeds of between 0.2 to 0.25 Mbps but the WiMax household had a much faster download speed of 6 Mbps in comparison to the 1.61 Mps of DSL. All of our household speeds were well below the FCC's goal speeds with the DSL speeds being the lowest.

RESULTS

We first present baseline data collected before we introduced Kermit. Namely, we discuss our participants' awareness of broadband issues, such as knowledge of their internet speed, their arguments for and against net neutrality and their attitudes towards paying for web content. We then discuss Kermit's role as a broadband management tool to visualize the home network, diagnose a slow connection, identify bandwidth bottlenecks and manage their speeds. Finally, we discuss how, although it was not our intent to design a tool for consumer rights, our participants perceived Kermit to be a technological consumer watchdog.

Awareness of Broadband Issues

Our users had very little prior knowledge about factors causing their varying connection speed. For example, households suspected internal hogs or external service providers to be the causes of slow-downs. Just under half of the respondents had never performed a speed test before. Additionally, half the participants did not know what speed they were paying for. Yet, over two thirds agreed that they would like to know their internet speed to see if they were being charged too much.

Before we introduced Kermit, we also noted a distinct lack of trust in internet service providers. For instance, a 40 year old firefighter in household two declared: "I mean it's hard to know what you're supposed to be getting. And whether or not they're actually telling the truth is a whole other story." (H2P2) and a young project coordinator told us: "Comcast offers those three different packages, three different speeds, and I don't

really necessarily trust that any of them are really faster than the others." (H1P1).

Aside from speed concerns, our participants wondered if their networks were secure. For instance, the firefighter said: "That's our wireless router, and like I said, the only way I can know if anyone is on there…I can come down here. And it's got up to four [lights], and right now the only one that connected is hers. If I'm on, the second one will light up. If someone else is on, the third and the fourth." (H2P2). Similarly, a mother of three, working in insurance, pondered: "I'd like to see if someone unauthorized can get into our bandwidth usage. In other words, somebody sucking up our *air* without our knowledge." (H6P2). Next, we discuss how participants reacted to the idea of a tiered internet service.

Consumer Attitudes for Net Neutrality

More than half of our participants (57%) told us that they had never heard of net neutrality. Even of those that had, most were not entirely clear about what the debate was on or what the effects of a non-'net neutral' policy would have on them. For those that were not aware of the issues, we outlined the basic premise and asked for their opinions.

All our participants were supportive of the current policy, citing reasons such as "I support net neutrality. The internet wants to be free. Free as in speech, not as in beer." (H8P1), "I believe everybody should have the same speed across the board." (H6P1), "It's ludicrous to have to pay different things for different data." (H1P1). The project coordinator explained: "Well, for me, it would be like charging for different power stations that are all feeding into your electricity, and you have to pay a different rate based on where it's coming from locally. It should be a utility, and it should be regulated like a utility." (H1P1). His roommate, a pharmacy technician added: "That's pretty much an ingrained entitlement at this point. Like the question, 'Would I ever pay for YouTube or Google?' It's just the internet. It's free exchange of information. That would defeat the purpose." (H1P2).

Along with strong support for net neutrality, participants were wary of ISPs abusing tiered services. For instance, a mother of two and usability analyst, worried that a tiered service could shut down access to certain sites. She gave the following example: "But the things that concern me that I hear going on about net neutrality. There are some sites, especially, I think ESPN's site, for example, that are only accessible if you are with a particular ISP, and that's a problem." (H10P2). A software engineer added his take: "I think it's too prone to abuse, especially when most ISPs have a local monopoly…Yeah. I mean, they could charge too much or even flat out censor or block sites if they were able to. And since there's no competition around there's nothing really stopping them from doing that." (H9P2).

Aside from worries about abuse by ISPs, our data indicated that participants felt that tiered services could stymie the accidental discovery of new information typical of browsing the web. For instance, a therapist and step-mom in her thirties told us: "I think I'd rather be net neutral. I think it would prevent you from exploring websites that you would never go on…Right? Like, I think people are much more apt to search the web and go someplace new or different if everything is equally accessible." (H7P1).

Consumer Attitudes Against Net Neutrality

Despite the consistent support for net neutrality, our participants expressed views on the fence about the finer details. For example, participants felt that network neutrality is not sustainable because the underlying infrastructure requires maintenance and upgrades. This viewpoint is captured by a parent and software engineer, who explained: "If they ever do enforce net neutrality, no one is ever going to make an investment in improving the network. Because there is no pay off. So it's like well ok, if it is going to kill innovation, or it's…this stuff isn't free. This stuff doesn't build itself. It doesn't maintain itself. So where's that money going to come from unless the government starts subsidizing and we're just back to the same federally mandated or regulated across everything." (H10P1). He explained further, using an online streaming media company called Netflix as an example to show where a non-neutral network could be useful: "I'm a Netflix customer, I only have 1.5 [Mbps], but Netflix pays extra to deliver stuff at 6 megs to me under the hood.".

Other participants argued a tiered service may be more fair, comparing it to cable TV. For example, a self-employed thirty six year old male said: "From a consumer standpoint, it has its benefits just like cable. I never watch Nickelodeon. Why should I have to be paying for it? Even if it's not a line item, I know it's in there, and somehow I'm paying for it? I never go to MySpace. Why should I have to pay for it?" (H3P2).

Attitudes to Paying for Online Content

When asked on the survey, our participants also told us they objected to the idea of paying additional fees for the privilege of using certain sites. For instance, 70% of respondents did not want to pay a separate monthly fee for any one of the services: Google YouTube, Skype, Facebook, Flickr, or Hulu. Participants were more evenly split on whether paying a fee for a bundle of sites was acceptable with 55% of survey respondents willing to pay a fee for an inclusive package of websites. Despite these responses, participants were not entirely opposed to paying for content provision services. The following quote illustrates this: "And when it's a service like Netflix or something like that where you're getting stuff that people produced and made, and you're doing it for your own entertainment, don't have a problem." (H1P1).

A mother of two and consultant echoed this sentiment: "I mean if you wanted to access certain You Tube videos I understand charging for that. But I don't think as a whole, charging for different bundles [is ok] because the internet is kind of known as free." (H5P1). Other households felt that even switching to a pay-per-use model of bandwidth would be preferable as illustrated by a graduate student in his twenties: "I'd just prefer to just pay for my bandwidth rather than having different prices for different services." (H8P2).

What became clear before we introduced Kermit was that our participants were relatively uninformed about their broadband speed and the net neutrality debates. We found

this surprising, given many were concerned about their rights with respect to the broadband service providers. Even those with technical backgrounds were not certain of what was at stake in a tiered internet service. Yet, all our participants had strong opinions about the issues once we explained the basic premise. Moreover, few were aware of or used tools available at their disposal to help protect their rights as consumers. Many did not even know how to check whether their actual speeds met the advertised ones. In essence, it became apparent that tools that make usable information about broadband speeds more visible, are fast becoming a necessity.

Kermit as a Broadband Management Tool

Now that we have discussed households' prior knowledge of broadband issues, we turn to how Kermit the probe was received. Our data revealed that Kermit was used beyond the tasks we asked our participants to undertake. Specifically, of our 10 households, eight completed the homework tasks and all provided feedback about the probe. On average, based on eight intact database logs (two were corrupted), Kermit was running in each household for 12 days on average, with a mean of 21 automated and user run speed tests per day.

During the deployment period, each household used the limits and prioritize functions for their machines at least three times each. Each household accessed the history pages for the last ten minutes activity on average seven times, for the last hour on average six times and for the last day on average five times. We found that Kermit gave participants a way to visualize their home network, allowed users to diagnose slow speeds, determine bandwidth bottlenecks, and manage their broadband connections.

Visualizing the Home Network

Generally, our data indicated that participants found Kermit easy to use with one teenager going so far as to say: "I think Nana [her grandmother] could use it." (H5P2). Participants told us they liked being able to access Kermit from any browser, as opposed to having a standalone appliance because it allowed them to check Kermit whenever they wanted.

Our findings suggest the most popular feature of Kermit was the household view of machines and networked devices in the home. Eight of our participating households changed the icons for and renamed all the machines in their network, despite only being tasked with doing this for one machine. Names were either descriptive of the machine such as "Xbox", "Small Netbook" or "iPhoney" or included the owner's name and machine type, for instance, "Matt's Desktop". Other labels were nicknames or "funny" names including "snoop" to depict an unidentified machine.

Pictures varied from personal photos of device owners to cartoon characters or famous people. Some participants changed the icon for the Kermit machine to Kermit the frog from the U.S. children's program "Sesame Street". In each case, participants chose pictures to be "funny", directly represent the person in question or a particular machine with a local household reference or inside joke. Status messages varied from expressions of emotion such as, "iHappy", to greetings (e.g., "hi") or messages about activities (e.g., "Really Choking" or "I am the great internet hawg") and finally declarations about the self (e.g., "Too Awesome!" or "The King".)

Aside from being "nifty", more interestingly, participants liked the pictures and labels because it allowed them to form a clear picture of their household's home network. In some cases, households felt more secure as the following quote illustrates: "Because you can change the pictures, you know that 'Hey, that person, that computer is not ours', 'It doesn't belong', 'It's not part of our family'" (H2P2). In fact, one of our families did discover someone else was using their wireless internet from seeing an unknown computer in Kermit when all their devices were already accounted for. In the words of the mother: "Now I know there's a little mouse on the internet. On our internet, stealing our internet." (H7P1).

In some ways, Kermit made household members feel more connected to each other as exemplified by a participant who lived with her brother: "It's kind of like a community feel. Like what is he doing? What have you been uploading? What are you downloading so much of?…But it's interesting just to see. Maybe I could make a joke to him." (H9P1). These participants saw Kermit as conversation piece.

In summary, our data indicates that participants found Kermit easy to use and understand. Households took time to personalize their representations to form a clear picture of their home network. They also used Kermit to express their identity to others in the home. For these reasons, Kermit was a precursor for an internal household social network.

Diagnosing a Slow Connection

Our data showed that Kermit confirmed for some participants that they were getting the speeds they were paying for. A male participant living with his sister said: "It did. I mean I thought we were getting pretty good speeds and it quantified and confirmed what I suspected so." (H9P2). A full time dad and home maker similarly found: "We're paying for 12 Mbps high-speed. I pay you know, 25 bucks a month. Literally 25 dollars a month. And it's a separate bill. I know, for the most part, right on the spot I've gotten 12 or better every day. So that much I do know from looking at the Kermit system." (H6P1).

Participants also learned other things about their broadband connection, such as a participant who discovered that his internet speed varied from hour to hour (H2P2). In another example, the stay-at-home father told us: "I did learn that bandwidth just isn't about uploading and downloading. It's a lot more. It's not what I do by myself, it's what everybody in the house does. And it's not just the little bit of difference that I make on my computer. It's the collective and being able to put all that together, that was really cool". (H6P1).

Even though participants learned more about their internet speed, several were confused about the types of information shown. For instance, a usability analyst was not sure about

the difference between "the total pipe coming into the house" from the provider, versus what each computer was getting. She categorized the different notions of speed as such: "You had those three things so it's the household speed, what's maximally available at a given time. And then how it's been allocated. And then what my current usage of it is." (H10P2).

Additionally, participants desired more context about the quality of the speed they were getting as well as how their actual speed compared to their advertised speed. For example, a female therapist, suggested a rating system for the speed similar to the U.S. financial score of credit worthiness: "So, if you're gonna do a graphical representation, I think you also need to have a rating system for that. Kind of like your credit score. Like over 700 is really good." (H7P1). Others added that a color coded indicator or having an anchor point for the average speed would provide more context. More importantly, our data revealed that participants were not sure what recourse they would have armed with Kermit's information. Essentially, participants lacked confidence that the service provider would take action if they were alerted about the mismatch between actual and advertised speeds.

Finally, we noticed that several participants found the automatic speed tests somewhat intrusive. In particular, the tests occasionally disrupted normal browsing activities because of the need to upload and download a large file. Having the ability to more easily set the parameters of the speed test, such as how often and when they occur, would improve this aspect of a broadband management tool.

Identifying Bandwidth Bottlenecks

Participants liked the real-time bandwidth visualization to see "how much juice everyone is getting" (H2P1). A teenager in high school told us: "I found myself actually checking it while I was online to see when mommy was down here on the computer. And I'd be upstairs doing homework, to see who was using more bandwidth". A student with a design background exclaimed: "When I did the bandwidth hog test, it was me by a mile because I had five YouTube windows up and those use a lot." (H11P1). For others, the information was surprising as in the case of a parent in household six who discovered he was the biggest hog despite suspecting his son of using the most bandwidth. Participants also learned more about the bandwidth usage of different devices: "I was really, really surprised by how much bandwidth the Xbox takes relative to other things. I think it may just be that it's consistently being used, whereas other machines are sitting around a lot." (H1P1).

Our participants also suggested several improvements to the bandwidth visualization. For example, a mother of two told us: "There's nothing explicitly shown about remaining bandwidth. I mean do I have an excess right now or is everything being pegged? So something like that. Is there any to spare right now? Versus no everything is being maxed out" (H10P2). To address this concern, showing the sum of bandwidth may be better as captured by the quote: "It might be more useful if I could see the, oh, he's using up this much of the whole pie." (H9P1).

A male parent's quote encompasses a common suggestion: "If somebody is sucking up a little bit more bandwidth, maybe they need to rotate up to the top so that you see who's got the priority on sucking the bandwidth right now." (H6P1). Participants also repeatedly told us they wanted to see bandwidth use by applications (e.g., Skype versus Facebook). Such information could help them decide which applications to shut down to speed up their connection. In addition, participants suspected they could identify whether machines have been compromised. For example, high traffic on a machine may indicate that it has a virus, or someone has infiltrated the network.

Generally, participants found the historical information less useful than the real-time visualization. In some of our households, the history views displayed the Kermit server machine as the main bandwidth culprit due to a software bug—a common challenge in deployment studies. Even with this bug, all our participants were able to easily identify the bandwidth hog in the color coded stacked graphs. Some joked that Kermit was installed to do music downloads for the researchers. More seriously, our participants were still able to learn from the history views. A participating software engineer managed to identify that uploads caused significant bottlenecks: "I actually did learn something. Basically doing uploads actually greatly affects overall experience. Or basically has the biggest effect on the network in general—At least going to the internet" (H10P1). To improve this type of view, participants desired a history of internet speed and network connection drops in addition to machine's bandwidth usage, all over longer time periods.

In sum, our data suggests participants were able to learn from the bandwidth information provided. They also proposed improvements to a bandwidth display, such as knowing if there is left over bandwidth and having a history of speed tests to plan when to go online.

Managing the Connection

Our logs showed that participants made use of the limit and prioritize functions and they also spoke of using them in our interviews. In particular, they embraced the concept of prioritizing a machine's internet traffic. For example, three participants who worked primarily from home felt their machines could be prioritized during their work hours. In household two, a wife limited her husband's machine and prioritized her own because she worked from home. Similarly in household six, a father limited his son and ensured his work machine was the "VIP" because he suspected his son was using up too much bandwidth. In household seven, a business consultant working from home limited his girlfriend's machine and his son's Xbox and prioritized his own machine.

A stay at home dad told us: "I think that limiting and prioritizing are great. Having general control for just an average user is a good option, having a bit more detailed control over it for an advanced user great option as well. And there again, like I said earlier, having the option to totally cut somebody off or setting up a time restriction. And being able to throttle it down to zero for internet usage overall." (H6P1).

Even though participants used the limits and priorities, many neglected to undo those actions because they forgot they had applied them. In one example, a mother had limited her daughter's machine to slow down her time on Facebook and had forgotten about it. To remedy this situation, our participants suggested that there be a notification for the person being limited or the limiter. Moreover, participants suggested that a limit or priority should expire and provide an option to renew.

Our data revealed other improvements. For instance, participants wanted to schedule priorities and limits much like a thermostat. For example, a father of two suggested that Kermit should allow families to create different groups of machines to denote children's', parents' and household devices such as media centers. He envisioned these groups could be treated differently depending on the time of day. He talked about prioritizing a media center when the family is watching a movie and similarly, prioritizing a backup machine late at night. In fact, all of our participating parents requested that there be a mechanism to shut off access completely to the internet on a particular machine. Specifically, parents in our study wanted to control internet access and schedule when their kids could go online. Kermit was therefore seen as a tool for what Rode describes as "digital parenting" [22].

Our participants did not always know exactly what the limit and priority actions did, as highlighted by this quote: "Well, to me priority just means that your packets get sent out first. But throttling, it can either be the inverse of that, or it could be that you have a bandwidth cap or something like that." (H8P2). Participants also expressed similar confusion in our interviews about how multiple machines could be "VIP"s or prioritized or how these slots were determined in practice.

Because there was often no perceptible effect after applying a limit or priority, participants did not know how well Kermit was working. One quote from a software engineer illustrates this frustration: "I don't think prioritization was actually working or I could not observe an effect. If I was running traffic, I'd set the machine with priority, or not priority. And it was still running traffic on another machine and my responsiveness was still good". Others, who were less technically inclined, were content even with a placebo effect: "Psychologically, it's kinda nice to just click 'Prioritize my bandwidth'. And it's one more thing I can do to make my Hulu video load more smoothly." (H8P3).

In summary, participants enjoyed being able to take control of factors influencing their broadband, and the ability to prioritize machines was often viewed more favorably than the ability to limit machines. However, participants wanted more control over the parameters for setting priorities and limits. Additionally, participants desired a perceptible or visual indication that an action was having an effect.

Kermit as Consumer Watchdog

Although we did not specifically design Kermit as a tool for protecting consumer rights, our data showed participants perceived Kermit as technological consumer "watchdog". For instance, one participant in his twenties, a project coordinator at a research institute told us of the hassles of getting his service provider to fix network drops. He spent hours on the phone being shunted between the manufacturer of the router he purchased and the cable company, as they sought to determine why his network connection was not working. He complained of how his service provider always ran their own tests on his line and never picked up problems even though his network connection was faulty.

In our last home visit with him, we serendipitously observed him on a hour long technical support call. At this time, we witnessed first-hand how difficult participants find it to communicate details about the nature of their connectivity problems to their providers. The participant in question joked of the provider's typical tests which were run remotely on his machine in a standard troubleshooting call: "Apparently my computer is not complaining the way that I want it to." (H1P1). His frustration was that he could never get the ISP to respond or deal with his problem. Instead, he had to fumble through the ISP's scripted troubleshooting routines despite knowing the real nature of the problem.

For him, and other participants, having a log of network drops or a neutral speed test in Kermit would be good fuel for discussions with providers. In particular, such information would be useful for troubleshooting and protecting the consumer. He explained further: "But, you know a lot of times they'll say…you know you'll have connection issues and stuff. And you'll just call them and they'll say, "Well, I tested your connection and it's fine right now.' But, you know if it's a re-occurring problem, then if you have a log of 'Yeah, we went down at this time.' We went down at this time. We went down at this time. And there's something that keeps track of it, then I think you'd just be more likely to be able to get support if you have that. Rather than just saying, 'Yeah, my internet connection goes out all the time'." A self employed thirty six year old, also saw Kermit fulfilling this role for consumer rights so that he could say: "Hey, my software told me the system was down even though I wasn't here to [see it]" (H3P2).

Our data also showed how participants wanted Kermit to help them identify the source of internet slow-downs so that they could take appropriate actions. For instance, deciding to call their ISP in the first place, shutting down offending applications or limiting a bandwidth hog. A mother told us: "Like when [Daughter] can't get on the internet and I'm on the internet, why is she not getting on? What is there a problem with the [Cable ISP] server or is there a problem with the router or is there a problem with her computer?" (H5P1). Many of our participants also wanted to print or email a record of Kermit's collected data to their ISP to complain about their service or help the provider solve their problems.

In sum, our participants viewed Kermit as more than a tool for managing broadband connections. For them, Kermit was a trusted instrument for providing valuable information on whether they were getting advertised services.

DISCUSSION

Our study findings are applicable to HCI designers and researchers creating residential broadband management tools. First, we summarize the most important aspects of our results and discuss implications for the design of home broadband management tools. Second, we describe broader implications of our work for the CHI community.

Summary of Findings

We found participants were not aware of broadband issues which were external to their homes but have a direct effect on them. Yet, they were keen on having their rights as consumers protected at all costs. When we introduced Kermit, they were able to learn about their speed and security because it allowed visualization and personalization of their home network. Moreover, participants were able to exercise direct control over how bandwidth is used in the home. Participants particularly enjoyed the concept of prioritizing machines and found a browser based application more useful than a separate appliance. Kermit was also seen as a consumer watchdog, especially in the face of concerns around net neutrality. Finally, Kermit allowed us to elicit design inspiration for future broadband management tools.

Designing Broadband Tools for the Home

Building on the experience with Kermit, several improvements could be made for designing future household broadband management tools. First, visualizations that can handle more devices would allow for a less cluttered display as a home network grows. Second, adding more personalization options would offer users more flexibility for depicting themselves on a tool display and further scaffold understanding of a home network layout. Third, providing more context around the concepts of uploads, downloads, bandwidth and speed would help households know whether their usage is normal and if their speeds are within a defined range—for example, specifying a rating of the quality of the connection helps consumers know if their line speed is poor or excellent.

Fourth, for limit and prioritize functions, households need to perceive a visual difference to understand how their changes are taking effect and be given more control over the schedule and parameters of these limits. For example, setting a schedule of how to treat various machines at different times of day or being able to shut down internet access for certain machines totally. Fifth, for a tool similar to Kermit to fulfill its role as technological consumer watchdog, showing the speeds that a household is supposed to be receiving compared to actual speeds would be helpful. Additionally, allowing consumers to print or email historical speed test logs or network drops could be added. Moreover, tools could also show information about speeds in one's general neighborhood or for similar service providers to show household variance in service delivery.

Finally, designers need to consider how to store the massive amounts of traffic data to power such tools— perhaps it is better to offload this data into the cloud. Determining points at which the data is no longer useful, and what types of aggregate data is most appropriate for users, may pose solutions to avoid requiring significant storage capacity. One caveat is that home users may be wary of the security of this data. Moreover, these tools and speed tests need to be efficient and as unobtrusive as possible.

Empowering the Consumer in Broadband Debates

More broadly for the HCI community, the experience with Kermit suggests that households need more tools that give them a voice in broadband and internet issues extending beyond the home, for example, the net neutrality debate. Our participants told us about the lack of trust in their service providers and generally had misconceptions and concerns about the looming introduction of a tiered service. For them, Kermit was not just about viewing or controlling online activities in their homes but also having a means for collecting irrefutable proof of service mishaps, drops, or well below advertised speeds.

This genre of broadband tools falls into the realm of other technologies created for user empowerment. For example, the HCI community has recently seen a surge of research geared towards environmental sustainability to give households the ability to take control of energy and other resources in their homes. The driving force behind these applications is to encourage households to be green or lobby for change in policies in their locales around energy use [5]. Yet, Dourish, for example, discusses how HCI has not yet addressed questions of scale in sustainability research. He makes the case for tools that do not depend solely on individual motivations but also empower society to take charge of environmental issues as groups, consumers and corporations [7].

We see Kermit and other tools in this vein as potentially performing a similar function of scale for broadband issues, if the speed information data they collect can be made public to enable community level views of internet speeds in various locales, neighborhoods, and by different service providers. This information could be used by government agencies and consumer rights groups to influence internet policy. Even at the scale of individual households, these tools can educate consumers about what the issues are and what is at stake—in this case, bandwidth and speed variance and factors influencing a broadband service. With better tools, consumers are not only more informed, but also given mechanisms by which to take their own experiences into the debates.

In sum, better broadband tools could pave the way for creating a data set that can better inform internet debates and keep consumers informed about speed issues affecting them. More importantly, such tools are invaluable in the face of uncertainty around net neutrality and because the ever-increasing demand for bandwidth means speed issues are likely to persist.

CONCLUSION

Because of concerns around minimum broadband speeds to American homes, we designed and deployed a probe to show households their broadband speeds and bandwidth usage. Our probe was well received, and suggests the need for more tools that give consumers advanced control over their broadband connections. More importantly, such tools can serve as a technological consumer watchdog and can empower households to have a voice in debates around broadband speeds.

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