Who's Hogging The Bandwidth?: The Consequences Of Revealing The Invisible In The Home

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ABSTRACT
As more technologies enter the home, householders are burdened with the task of digital housekeeping—managing and sharing digital resources like bandwidth. In response to this, we created and evaluated a domestic tool for bandwidth management called Home Watcher. Our field trial showed that when resource contention amongst different household members is made visible, people's understanding of bandwidth changes and household politics are revealed. In this paper, we describe the consequences of showing real time resource usage in a home, and how this varies depending on the social make up of the household.

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Bandwidth monitoring, home networks, home broadband

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General Terms
Human Factors.

INTRODUCTION
As global broadband penetration increases and more homes use multiple computers, bandwidth is becoming a new kind of resource that households need to share, understand and manage. This is yet one more aspect of a trend toward households engaging more and more in "digital housekeeping", such as the need to set-up, maintain and trouble-shoot the home network [18]. With more people in a household engaged in on-line activities and more residential real time services (like TV on demand), in-home traffic congestion can cause performance degradation for household members' internet experience, particularly for time-sensitive traffic [3,7,8].

Figure 1: Home Watcher in situ in two households.

Moreover, often residential broadband speeds differ from those advertised, as a recent UK report shows, thus homes are frequently sharing a smaller pipe than they are paying for [11]. Even with planned networking infrastructure overhauls to achieve universal high speed access in the UK by 2012, factors such as cost, distance from the exchange, bottlenecks at different times of day coupled with in-home congestion, mean that a smooth online experience is not guaranteed for everyone in the home [19].

In the face of this growing issue, and perhaps because of its recency, there are very few easily accessible tools to help households understand, diagnose and manage their home bandwidth use [5,13]. In response to this, in this paper we make two contributions: First, we present our design for a tool to address this problem, together with a report on its evaluation in real homes over an extended period of time. Second, drawing from the field study, we discuss the implications of revealing what was previously invisible to a household, and in so doing comment on how this alters its understanding of bandwidth and related issues, affects the dynamics of a household, and reveals its internal politics. All of these findings have implications for building such systems in future which must find their place in households of different kinds, and with their own internal complexities.

To address the first issue, we set about creating Home Watcher—an appliance (see Fig. 1) which aims to show who in the household is using the bandwidth, as well as how much each person is using in a way which is easily understandable and accessible. Additionally, Home Watcher allows household occupants to limit other people's use of bandwidth (and by proxy their internet-related activities) from a publically situated open access display.

To address our second set of issues, we conducted a field trial of Home Watcher in a variety of different households. Our results illustrate design considerations that have been thus far overlooked with resource monitoring systems, which pertain to the social consequences of these systems.

In what follows we begin by situating our research amongst other contributions on designing for the home, explain why bandwidth contention is becoming more problematic and how social issues come into play when designing solutions to this seemingly largely technical problem. Next, we discuss our methods, including the design and implementation of Home Watcher and our field study protocol. Thereafter, we discuss our results, which illustrate that aside from providing a technical solution for residential bandwidth management, Home Watcher also revealed household politics and enabled new forms of domestic contention. Moreover, to accommodate this new type of system, households evolved their own etiquette for using this visual bandwidth monitoring tool.

RELATED WORK

Moving on from the workplace, the CHI community has collectively explored many facets of the home and the design of home technologies through empirical studies of daily life in households and field trials of technology prototypes. Some of the seminal work in the area shows how households create a sense of domestic order and construct an idea of home through both mundane and "high tech" artifacts e.g., [17]. Other work also shows how the relationships, roles and activities of people within the home differ strongly from those in the workplace (e.g., [10],[12]). This means not only that some office-based technologies may be simply inappropriate in a home environment, but also that there may be unexpected difficulties when transferring such technologies across domains. For example, transferring networking technology from the office to the home has uncovered a host of novel difficulties and problems [15].

Yet, as more technologies enter the home, in addition to managing household resources such as energy, food and water, home networks introduce new types of resources that have to be dealt with. Network resources mean decisions need to be made about who uses computing equipment and when, and who should get priority for bandwidth. What is not clear, which our research addresses, is what kinds of tools are needed to help households manage these new types of technological resources and what the consequences are of making network resource usage more visible in a domestic environment. With increased broadband adoption, a particular resource of interest is bandwidth. Bandwidth is an increasingly scarce resource as networked infrastructure buckles under the pressure of more consumers using more bandwidth-intensive applications and because legacy wiring has limited capacity [19]. In the UK, a recent report found that often consumers experience speeds far below those advertised for different internet access bundles [11].

Even if increased capacity through infrastructure overhauls comes to fruition, Internet Service Providers (ISPs) and consumer groups are debating whether tiered access or internet traffic to various services (e.g., Google, BBC, Virgin Media) should be treated or even priced differently [4]. At the networking levels, this already happens to some degree as latency sensitive traffic is prioritized to ensure streaming media services play smoothly [7].

Along with concerns about providing sufficient bandwidth to homes, as people use multiple computers and other internet-enabled devices, even with a decent speed connection, different household members may experience slow internet connections depending on others' web activities [3]. For example, if everyone in the house is using high bandwidth, low latency applications for streaming media (e.g., YouTube or BBC iPlayer), it becomes more likely that at least some occupants will experience disruptions to their online pursuits. Given such in-home network congestion, domestic bandwidth monitoring tools will help households fairly distribute this resource more effectively and let occupants know when their online activities will negatively affect others [8]. However, aside from being a technical problem of managing bandwidth, social issues come into play when designing ways to visualize domestic computing activity.

For example, ethnographic studies of home networking underscore the need to make home network usage more visible to everyone in the family, beyond just the so-called 'network guru' or person who primarily manages the home network to help alleviate management and troubleshooting difficulties [5,13,18]. Poole *et al.* call for visual network tools which use non-technical jargon, show information in real-time, provide access to a history of use over time and which seek to improve a household's overall understanding of their network related routines [13]. Tolmie *et al.* similarly suggest making the home network more inspectable through the creation of visual network tools will help people better orchestrate their networking tasks [18]. Others emphasize how the home network is intimately tied up with household routines and ordering of the home [6]. For example, oftentimes the home network is used as a means of parenting, where internet access is carefully monitored by placing computing devices in public areas of the home [2]. In these cases, always-on networking access throughout the home is not desirable.

What these studies collectively show is that the home network is a complex socio-technical system, and the task of making the equipment work as needed is far from straightforward. Further, short of redesigning networking protocols from the ground up, a possible strategy to help households better manage their networks is to introduce more visual networking tools [15] or remove the burden of reconfiguring the network from users altogether [1]. Our work extends previous endeavors by developing a visual home network representation and evaluating how this tool is used in a domestic setting.

Returning to bandwidth management, most existing bandwidth monitoring tools are designed for personally tracking a single computer (e.g., BWMeter or Net Meter Pro) and even at the household level, we could find only one tool, SpeedMeterPro, for multiple home computer bandwidth visualization. Our appliance, Home Watcher, differs from these tools because it shows all household machines' bandwidth use on a public display, in terms which do not require familiarity with the *lingua franca* of networking protocols. Further, Home Watcher is a separate public appliance as opposed to a software application for one machine. Moreover, Home Watcher allows anyone to limit bandwidth usage for any machine in the home from a single display, as opposed to being solely controlled by one network administrator. To sum up, designing for the home brings with its own challenges and with the growing issue of bandwidth bottlenecks, we offer Home Watcher as a contribution in its own right. We also add to existing work on home networks by presenting a field trial to show how these visual tools might find a place in the home.

DESIGN OF HOME WATCHER

We first set out to gather feedback for the tool design, specifically to identify how best to graphically represent individual users' current bandwidth use and history of use over time. We also wanted to determine what strategies people might employ for sharing bandwidth more fairly amongst themselves and whether an appliance or desktop widget form-factor was preferable for the tool. To answer these questions, beginning in 2007 in the Cambridge and London areas in the UK, we conducted one-on-one interviews and a week-long diary study of internet use with three households (two families with teenage children and one shared household with three roommates) to gauge households' current views of bandwidth as a scarce commodity and to identify types of bandwidth management strategies. Based on these interviews, we developed concept prototypes and held focus groups with four additional households (two families with teenage children and two shared households with roommates) to gather feedback and identify which features to implement in a fully functional prototype.

The preliminary work indicated that households might want a current view of their bandwidth use along with some historical data (in the order of minutes) to help diagnose and understand their household's bandwidth use. We also found that users better understood the data when each computer's use was shown as a proportion of the total available bandwidth (which varies constantly). This approach was judged to be best to help users identify who might be causing the internet connection to slow down. The resulting design (see Fig. 2) shows a current view on bandwidth use where each machine is displayed as a circular colored "blob" which bounces up and down the vertical axis of a graph showing the real time changes in bandwidth usage, with a tailing graph spanning about half a minute. When machines are inactive, the icons grey out and then disappear from the display altogether after a period of 10 minutes of inactivity, re-appearing as soon as they come online again. We also separated out upload and download speeds (bottom and top rows in Fig. 2) to give households a more accurate view of activities causing congestion. In addition, because households wanted a longer term comparative history view to understand how bandwidth usage has changed over time, we designed a separate history view accessible from the main screen to show all machines' use over the course of the last 10 minutes, last hour, last 24 hours or last week.

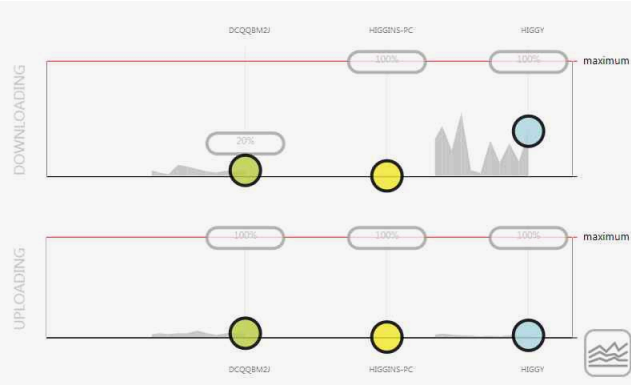

Figure 2: Current view showing real-time bandwidth usage for three home computers in Household D, including an applied download limit of 20% on the computer on the left.

On the basis of the preliminary work, we also discovered that households wanted control over the bandwidth distribution once they had identified whether someone was 'hogging the bandwidth'. We designed a limit feature so that any household member can 'throttle' the upload or download speeds of any other machine in the house, using a lozenge-shaped widget appearing above each machine. Dragging the widget up and down changes the maximum amount of bandwidth that a machine is allowed to use. We set the upper bound for limits to 20% to avoid severe disruptions to anyone being throttled, but no notifications were provided to users who were limited.

HOME WATCHER DEPLOYMENT

Because of feedback in favor of an appliance form factor, we deployed Home Watcher as an information appliance using a mini-touch display attached to a laptop or on a tablet PC. (In Household A, due to technical problems, a standard laptop replaced the mini-display). Participants chose where to place the main display during the installation visit. A client agent was installed on each machine in the home, to track internet traffic statistics and broadcast messages on a secure channel to the main display machine. Our main GUI machine stored all machines' bandwidth upload and download speeds in a SQL database with screenshots of usage and throttles. We did not collect any information about urls, application names or packet headers to preserve privacy because our main goal with the field trial was to see how the tool affected household dynamics. All networking code was written in C# using

various Windows components for rate limiting machines and calculating link speeds. Our GUI used Windows presentation framework to display aggregate traffic statistics to the user at set intervals and for the history view.

Household Recruitment

For our field trial, we specifically sampled households who had experienced bandwidth problems (slow speeds, disruptions etc) to ensure a likelihood that Home Watcher would help these households understand and manage their bandwidth more effectively. In the end, we recruited 6 households (24 occupants) using local mailing lists, bulletin boards and word of mouth from the Cambridge and London areas in the UK to participate in a eight week field trial (with a three week deployment) in June and July 2009. Households were compensated with £100 for the entire field trial (and £10 per child's internet log completed). Three households were families with teenage children, one was a married couple and two were shared households:

- *Household A* included a software consultant and a home executive with five sons aged five to 23, with 10 computers in use. This family complained of severe bandwidth problems and suspected that the 17 year old son, in particular, hogged the bandwidth.
- *Household B* was made up of a software engineer and high school physics teacher with two teenagers and five computers. Overall, bandwidth contention in the house was low but the father was concerned that his daughter was always streaming YouTube for music which added to their monthly download quota.
- *Household C* comprised three roommates and one live-in girlfriend with three computers—two roommates were editors, and the other two were unemployed. These housemates experienced slow connections particularly in the evenings, when some housemates were trying to work and others were suspected of hogging the bandwidth for watching online shows. Relationships were strained within this household.
- *Household D* comprised three roommates each with their own computer, a philosophy graduate student, a healthcare management worker, and a church volunteer. They experienced no significant bandwidth contention and had close, stable relationships.
- *Household E* included two high school teachers and two teenagers with three machines. This household experienced severe bandwidth problems which they attributed primarily to their service provider.
- *Household F* contained a young married couple each with their own computer, an architect and a graduate student. This couple complained of occasional problems with watching streaming media which often resulted in degraded call quality on Skype.

Field Study Protocol

During the study period (over 8 weeks), every household was visited a minimum of three times, with visits lasting between 40 minutes to 3 hours. In the first visit, each household was asked to log their internet usage habits for a week in a paper log we provided. We did this to get a sense of their average computing usage patterns, determine when internet connectivity was perceived to be slow and see what causes participants attributed to these periods of sluggishness. We also interviewed all household members, asking them what they understood about the concept of bandwidth, what kinds of bandwidth related problems they experienced and to learn more about their online activities. Additionally, we collected baseline demographics and asked households to sketch out a floor-plan of their house, showing equipment locations and 'bandwidth hogs'.

In the second visit, we installed Home Watcher and asked participants about their internet logs. In addition, we asked households to speculate on the uses of Home Watcher and demonstrated how the appliance revealed bandwidth distribution and enabled control over others' bandwidth use. In the final study visit, which varied from a minimum of 2 to 3 weeks after installation, we asked participants how they used Home Watcher over time. In total, we performed 25 field visits. Visits were audio-taped, extensive field notes were taken and, where appropriate, photos of usage and video footage was taken.

Our transcribed audio-taped visits and field notes were analyzed using an inductive reasoning approach based on established qualitative techniques [16]. The transcribed data were coded, codes were categorized into higher level themes, and these themes were then discussed with all members of the research team to gain consensus. Multiple field visits afforded iteration on theme development and disagreements were resolved through discussion until a shared understanding of the data was reached. Additionally, the paper logs were used to establish baseline patterns of use, confirm that bandwidth problems mentioned in the interviews matched those reported in the logs and to determine when overlapping computing use occurred between household members. Finally, network traffic data from the database and screenshots of use during the field trial were analyzed to determine system usage patterns, and to confirm points raised in the interviews. In this paper, the excerpts provided represent mutually agreed upon themes drawn from the qualitative data.

Limitations: Heterogeneous Networks

Because home networks are as heterogeneous as the homes they are a part of, we encountered deployment challenges that necessitated additional home visits and remote technical support. Despite these difficulties, because of sustained interaction with our participants over a period spanning two months from the first to the final exit interviews, and their consequent in-depth grasp of how the appliance should work in practice as well as their use of the appliance when it was running smoothly, we were still able

to collect rich feedback around how Home Watcher affected their understanding and management of bandwidth.

FINDINGS

During the deployment period, the system up-time varied amongst households as shown in Table 1 due to a variety of technical difficulties with the system such as client agents being blocked by firewalls or starting in user accounts without administrator privileges, preventing our networking code from interacting with the kernel. Whilst we acknowledge that this is a crude estimate of use since it does not indicate when users actually used the display, we include it to provide an estimation of the extent to which each household had available a working system during the deployment portion of the field trial.

A	B	C	D	E	F
77%	84%	36%	83%	90%	84%

Table 1: Ratio of days of system up time over days of the deployment period

On-line data confirmed that Households D and E used Home Watcher most extensively, including using the throttling functionality to limit other household members on 8 and 24 occasions respectively, with Household F using throttles on 3 occasions. Household B used Home Watcher mainly as an awareness display. Households A, C and F experienced technical difficulties that affected use but still provided rich feedback based on their system interactions.

Reasoning about the Invisible

Before introducing Home Watcher, we asked our households to describe existing bandwidth issues. Participants reported that the most typical issue was that the network often slowed down with visible effects on internet-related activities such as browsing. Other bandwidth-related problems reported included the internet connection dropping, uploads or downloads being slow, streaming media being jittery or call quality using voice over IP being degraded. Slow connections or degraded application and service quality resulted in frustration, annoyance and general unhappiness about the quality of service. In some cases, people who suspected that they were bandwidth hogs felt guilty if they thought their online activities were disrupting others in the home. For instance, in Household A, the main bandwidth user, a 17 year old teenage boy, worried that his downloads might be affecting his dad's working ability negatively. At the same time, he felt somewhat victimized and unjustly blamed for being the bandwidth hog, particularly since he felt he was not downloading excessive amounts of legitimate media.

Existing Bandwidth Theories

Prior to the introduction of our device, because of the lack of visual information about how bandwidth is distributed amongst home computers, our participants attributed the slowness of the connection to several factors: *internal* or contention within the house, and *external* or contention outside of the house, the network connection and equipment, or the service provider (application and network). For *internal* contention, our households suspected that multiple household members were trying to do the same thing at the same time such as streaming media. Other internal contention theories were that one particular person was hogging the bandwidth or that more computers in the house increased the contention. Two households, A and C, speculated about bandwidth hogs in their homes:

A1: Because Daniel is quite a lively lad in the choir so he actually sings and he's constantly downloading tracks and things like that. Downloading tracks. Basically, he's the downloader of the household at the moment. He'll buy tracks off the internet routinely, but really any of us are likely [to be using a lot of bandwidth].

C4: Yeah Paul and I have thought about it. Because sometimes we think, oh maybe Sarah is downloading something at the same time as we are. But we think that actually, there's been times when no one else has been in, but it's been really really slow. So we thought, no, it can't be that.

For *external* contention, participants thought the connection might be slow because of too many people using the network at certain times of day or that there were too many people on the same local exchange, as in Household B: "Well they're all BT. Because BT is the main carrier. All of it comes down one set of copper wires for sort of 50 houses. It's contentious using the one [connection]." (B1). For equipment, people felt their actual hardware might be faulty or that connecting wirelessly caused speed degradation. In some cases, poor speed was attributed to the actual application, service or ISP e.g., a particular real time online player was suspected of being slower and less reliable than others. Whilst all these theories have some truth to them as attested to by [11], without any way to 'see' who is using the bandwidth at any time, there was little households could do to determine what the ground truth was.

Instead, households merely coped with the frustration of slow internet connectivity and bandwidth contention in their own ways. Household E's mom had an ongoing battle with her provider, demanding better service. In other households, such as A and B, children were asked to stop using bandwidth-intensive applications, particularly around times when parents had important online activities to undertake, such as searching for jobs or doing work-related tasks. In Household B, the son and dad complained:

B3: He's always stressing me and saying, 'Oh you probably shouldn't do that because it will use up bandwidth'. So if I try to use a program on remote desktop at school, he advises me against it.

B1: Basically working on PowerPoint in remote desktop and dragging images around seems a stupid thing to do. It seems like he should copy the file home, work on it locally, and it will be quicker anyway.

If equipment was deemed the problem source, householders sometimes tried local solutions such as moving closer to the router to get a better signal (as in Household C) or rebooting equipment, as in a quote from the paper logs of Household E: 'No connection - took out all leads and rebooted -

got 9.47 mbps. Best ever!!'. Others just resolved that the contention was beyond their control and did nothing in particular to rectify the situation as in Household D and F.

Expectations for Home Watcher

Many of our participants were curious about the speed of their outgoing connection to see if their provider was shaping traffic. Participants also wanted more visibility to confirm their suspicions about bandwidth hogs within the home as in Household E:"I can see how, you know, if it did show up that somebody was using a lot of the bandwidth that, how we would then reconcile that within the family." (E1).

Some just desired a better understanding their usage so they could better calibrate or optimize their connection plan as in Household F: "I was wondering whether we actually get to 8GB per month" (F1). From the initial descriptions, it became clear that our households were experiencing bandwidth contention within their homes, but that without any way to confirm or refute suspicions about the cause of contention, they resignedly made the best of poor connectivity at times.

Getting Familiar with Home Watcher

For all our households, when we introduced Home Watcher, we observed a similar pattern of householders trying to understand how the appliance worked, and as importantly, how it mapped to people's behaviour in the household. First, participants experimented with the display to see how playing a YouTube video or streaming internet radio resulted in spikes in the graphs or a constant stream of bandwidth. Participants also conducted their own experiments to see how their actions affected the display, such as unplugging machines, changing from wireless to wired connections, or even putting machines into different low powered modes.

From subsequent interviews, we discovered that using Home Watcher, participants were also more generally learning about different patterns of use within the household. For example in Household E, the son noticed his sister (who mainly used Facebook) did not use a lot of bandwidth. His mom took note of the same pattern. Once participants were familiar with the mappings of the display, they could then adjust their behaviour and make optimizations as necessary. Many of our households mentioned that they would like the display to also be available on their computers so that they could more easily check their activities to learn the mappings, without having to go to the main display.

Interestingly, because of the appliance-like form of the display and simplified presentation of the abstract concept of bandwidth, those in the household who were less inclined to engage with the home network or fix technical problems started to grasp what this resource was and how it affected the speed of their internet connection. In initial interviews, not all household participants were clear on what bandwidth was, but by the final interviews for instance, a philosophy student, stay-at-home mom and an architect were talking confidently about sharing bandwidth as if it was any other more tangible household resource, such as hot water or food.

Examples illustrating their new found understanding include Household E explaining how bandwidth intensive sites with streaming media tend to cause spikes in the Home Watcher current view graphs: "Anything that's got video, like websites, which has video streams in it that seemed to spike very very quickly" (E1). Similarly, in Household D, one roommate explained how lowering his already limited machine to 20% caused his live Wimbledon stream to stall: "That's me. About 33%. It's running Wimbledon live, and you can limit me, say to 20%, and that will decrease my bandwidth. You should see that start to stall" (D2). These examples collectively illustrate how household occupants learned to 'read' the display and then formed a mental model based on their learnt mappings between the display and their activities.

Reinforcing and Revealing Patterns of Home Life

Home Watcher's view of domestic bandwidth activity either reinforced existing patterns or revealed new patterns of home life through showing people what others in the home were doing. In one case, seeing bandwidth activity on the glance-able display afforded reassurance about computing tasks that were going on in the background on the computer. For instance, the dad in Household A explained how because the display was adjacent to his main work computer, he could glance at his computer "blob" bobbing up and down to check that his background downloads were working from the "solid block of grey".

Reading the Activities of Others

Home Watcher also had the indirect effect of presenting a view of the household that was not previously available, showing computing activities for all the machines in the house, which were usually linked to one individual occupant. Coupled with each home's knowledge of their routines, and the display of computing activity, Home Watcher provided additional information about what household members already knew their family members or roommates might be doing. For instance, in Household E, the mom knew it was safe to invade her daughter's room since her computer appearing on the screen indicated she had woken up. In Household B, the computer blobs' presence alerted the dad that the kids were awake beyond their bedtime or that some machines were not shut down properly. In Household C, one roommate was able to confirm that his roommate was downloading games, from the sustained high spikes in his bandwidth usage.

Home Watcher also revealed new information about household activities, allowing householders to "read" what was going on. For example, in Household B, based on the intensity of the bandwidth traffic shown on the display, the dad could get a sense of whether the kids were doing homework (low traffic) or not (e.g., playing YouTube videos and doing streaming media which caused spikes in traffic). He was also able to see that his daughter was uploading large files to school and chat to her about optimizing this aspect of use.

Making the invisible visible in this case had the effect of reinforcing existing beliefs about household occupants' computing activities but it also added a new dimension to people's awareness of household routines and activities, alerting household members as to when people were online and indirectly showing others what they might be doing.

Personal Representation in the Home

In addition to the many ways in which participants in the trial were able to read others' activities, our participants expressed concerns about how they, in turn, would be read by others. In other words, they were concerned that their personal portrayal through Home Watcher might show them in a bad or inaccurate light. For example, some participants worried their legitimate computing actions might be misinterpreted as lower priority activities which were not worthy of bandwidth, for example, if their usage spiked when watching a video, e.g., one child complained: "But occasionally you watch videos for homework!" (B4).

In our shared households, roommates were concerned about how everyone in the house would prioritize who gets more bandwidth but again, suggested that face-to-face resolution of contention would be better than using the tool alone such as Household C: "But you'd need to have the device. Because what if you had something really important to do and they're just downloading music. Or they've gone to the shops or something like that. There needs to be some kind of priority, like maybe some way of speaking to each other online or face to face." (C1).

With revealing individuals' resource usage in the home, notions of identity and personal representation are called into question when deciding how to represent individual's resource consumption. People are wary of how they are represented in their personal sanctuaries and how those representations affect household routines and relationships.

The Politics of Visibility and Control

Aside from the increased visibility affecting people's perceptions of bandwidth, and how they viewed others and themselves in the home, Home Watcher also revealed household politics because of the ability to control other people's use of bandwidth. When we first introduced Home Watcher as a situated public display with publically accessibly controls for limiting other household member's bandwidth directly, all our households also expressed some glee at being able to limit each others' bandwidth and by proxy their computing activities.

Different concerns emerged for family and shared households. Our family households (A, B and E) were concerned about fights that might erupt around bandwidth contention, with children limiting each other or using the tool for manipulation. By contrast, the shared households (C and D) viewed the idea of limiting other people's bandwidth more playfully. And in actual use of the tool, we saw that in Household D, the roommates did exactly that: "'Cause the funny gag is, Jason is upstairs. And you put him down to 20%. And he doesn't know about it and you know." (D1). However, despite expressions of delight at this tool for manipulation of other's computing activities, in practice, we observed a complex etiquette emerging for accommodating and making Home Watcher at home.

Foremost, our participants were very concerned about who gets to decide when it is appropriate to limit someone. For example, one roommate in Household C worried that the application itself does not reflect the person's purpose for using it. For instance, she wondered whether prioritizing Skype over YouTube was unfair if the former was used for maintaining social connectedness with remote friends and family, and whether this activity takes precedence over watching YouTube videos for work purposes. Participants in C and E felt that a status message could be used to indicate what someone was doing but overall households questioned whether nuanced automatic activity classification by a tool would be reliable, because of the blurred boundaries between activities for work and play.

Participants also realized that the severity of limiting someone depends on the application they are using and the purpose of their activities. For example, in Household F, a participant talks about the implications of limiting someone's computing activities: "If you're talking about someone that's using a lot, why is he using a lot? Either you know, he's using some application with like video conferencing or something. And he's using a lot. Well then. Obviously then rate limiting him essentially just means you can't use an application properly, so that's very aggressive." (F1).

Additionally, participants spoke of how limiting someone's streaming experiencing, e.g., a Skype call, was thought to be quite rude, whereas limiting a download was acceptable since it meant just waiting longer for the file to download (in Household D for instance). Participants also wanted to limit based on the time of day, per user for shared machines and based on the purpose although nobody could come to a consensus on what was a legitimate purpose. Notifying the other person to let them know they were being limited and *why* was thought to add a level of justification to one's actions (e.g., in Household C and E).

However, there was also a concern in both shared and family households about *gaming* the system or putting in a false or ambiguous status which would not accurately reflect one's true activities to avoid being limited by others, as in Household C: "but they'd still have to just say 'work', and then no one could put yours down. You could just pretend you're doing work, but you're not" (C2). Parents also expressed concern about limits being overcome by industrious teenagers. For example, the father in Household A predicted: "Yes, because if it doesn't remember the limit it could be bypassed by switching it off and on again" (A1).

All these examples illustrate how open access to a means of controlling household resources can create confusion when these controls appear to be at odds with the social order of the home. Essentially, those most concerned about the controls were worried that existing tensions and power relations in the home (e.g., between parents and children) might be threatened by the option to control another person's use of the internet as a resource.

Leverage and Fodder for Negotiation

Yet, even despite these concerns, most of our households agreed that the increased visibility of resource usage was a good thing. Participants felt that being able to see who was causing the internet connection to slow down opened up avenues for negotiation and conversation with other household members. Elaborating on this, participants spoke of how they could use Home Watcher's visualization to see if their suspicions about household bandwidth hogs were founded, implicitly trusting that the software provided an 'accurate' view of what was happening on the network. In Household A, the parents illustrate their appreciation of the increased visibility into resource contention:

A2: I don't think it would cause rows (arguments). I think it's more important, there would be less rows because people would be able to see what, you know. For me, there is less rows.

A1: But it's only when you suspect people of things and they are not doing what you think they are doing, and then you get a row.

Similarly, in Household F (married couple), a participant talks about the technology providing additional information for resolving social contention: "Because when you're in a situation and people can change things' direct influence on other people, then it seems like it's not about the technology anymore. It's about trying to find a good compromise between a group of people." (F1). In these examples, it becomes clear that showing real-time resource usage can open up discussions for household members because it provides fodder for negotiation or even leverage for convincing others to change their behaviors.

Bandwidth Etiquette and Household Dynamics

In terms of actual usage of the limiting functionality of Home Watcher, we observed different reactions in households where the members are on equal footing as opposed to those where members are not. Similarly, in the households with stronger social ties where household members where blood relatives or had longstanding friendships, different reactions were observed to the ones where home occupants were not necessarily on good terms or friends outside of being roommates. Because of the public display and accountability for one's actions in our shared households where everyone was considered equal, people were more inclined to be considerate in their limiting actions, fearing a 'tit for tat' response should they try otherwise. In Household D, the roommate who suspected he was the biggest bandwidth hog in the house said: "For me, I would try to make a point in the future if I'm going to download something. Like maybe just if I'm going to download a game. Just leave my computer on overnight. Turn it on at 11, letting it download between 11 and 6 in the morning when no one else is using it. 'Cause then, it just makes the whole thing easier for other people. So I guess in that sense, I've learned to be more considerate <jokes>. Home Watcher has made me a better person you could say." (D3).

Further illustrating how power relations affect perceptions of the open controls, all three roommates collectively explained how Home Watcher's open controls are subject to the regular power plays in the home using the metaphor of the hot water controls for their shower:

D3: Not really. I mean in our house you can control the shower from outside the shower. So being able to control someone's bandwidth isn't much worse!

D1: Well in a household that has, 'cause we're all single blokes of about the same age, so there's complete, as it were 'equality' between all of us. And so you're nice to others because that's the nice thing to do really.

D2: 'Cause when you're in the shower they're outside.

D1: Because if you turn the shower off when they're inside, they're going to do it to you. And so obviously if you play funny gags on each other, then there's complete vulnerability.

In a contrasting example, in Household C, with the strained household relations, one roommate debated about whether she would ask her roommates permission to limit their bandwidth or just use the tool as a conversation starter: "If it was late at night, I would probably just do it. But then they might do it back to me, so I probably would ask them permission. Maybe if they were just downloading something, but not watching it? Or if that's the case, they might just turn it off for me, if that was the case?" (C1). Yet, when asked about how she would respond to being limited, she expressed how she would retaliate if others were being more inconsiderate: "Well if someone was doing that to me, I think I would do it back".

In our family households we observed slightly different etiquette for limiting other people's bandwidth, where families initially were worried about siblings using Home Watcher to aggravate or poke fun at others in the house. In practice, sometimes these concerns were realized as illustrated by an exchange in Household E. First, the mom explained her selfless limiting of bandwidth prior to the arrival of the rest of the family for the final interview: "I did it once actually, when I noticed that one of the kids was using it a lot. I turned my bandwidth down in favour to allow them to use bandwidth—very altruistic of me" (E1). Yet, later much to her horror, it was revealed that the son had been limiting everyone on the sly: "It made it quicker every now and then if I sacrificed someone else's internet." (E3). He attempted to justify his behaviour but his dad was quite surprised at this as well: "Is this why I couldn't get the Internet?" (E2). In the end, the mom, expressed her mortification, "You see he's to blame for it all. He's been pirating everybody's bandwidth, and not telling everyone!" And later when asked if they understood more about bandwidth because of Home Watcher, her son agreed but she piped in, "Now you're king of the bandwidth".

Clearly, different parenting styles and the power differential between children and parents become more evident as resource usage is revealed and children were aware of this aspect of the tool. As mentioned earlier, teenage children in all three family households (A, B and E) were delighted about the idea of limiting their siblings. Yet, in Household A, both parents were concerned about password controls to limiting so that only the older children and themselves could limit others. Even one of the younger children in this

household, felt a password would be necessary to maintain order in the home: "Because sometimes when I am on the internet and it goes on and off every now and again, I just get really hacked off and I have been 'Oh right, everyone's coming off the internet' because I want to use it right now, and I would limit it all. So it would be better like for a password." (A5).

Similarly in Household E, the teenage son, said he would expect his mother to be more fair with the bandwidth distribution. Clearly, families with their different parenting styles and power imbalances react differently to open control and resource use visibility. Finally in contrast to the family and shared households, in Household F, a married couple expressed dismay when the husband talked about how he may try to limit his wife. His wife felt slighted given that he would use a tool for manipulation even though there were only two of them in the household:

F1: Yeah, well I remember a few times where, there were very very little, where we had issues where you were watching a video where I could not even go on the [internet] and do web browsing.

F2: But then you would just ask me, like 'Can you close it?'.

F1: Yeah but that's kind of annoying right. That didn't happen. I said, 'Watch a movie, I'll check my stuff later'.

F2: But then you would've wanted to just limit my bandwidth? To annoy me so I couldn't keep on watching <laughs>?

Our examples illustrate the way that surfacing something as seemingly innocuous as real time bandwidth usage in a home reveals the complex social order and power relations in the household. Questions arise around who has control over computing activities, how to use the tool to change resource distribution and how the tool itself fits in line with the way power is distributed between different members of the household. We noted differences in the shared, family and couple only households, each with its own natural order based on relations between the home occupants.

DISCUSSION

We set out to create a home bandwidth management tool and found that Home Watcher made the concept of bandwidth more accessible to our participants. Moreover, participants found the overall tool design to be aesthetic and visually engaging. More importantly, our tool opened up avenues for households to contemplate bandwidth as a resource and provided them with ways to redistribute this resource amongst themselves.

Whilst deemed useful, our participants suggested the tool could be improved by providing features to allow users to input their self-declared purpose for activities, adding a desktop accessible version so that people could also view the display from their own machines and by tweaking the underlying networking architecture to better deal with sometimes complex settings and customizations on home machines. Moreover, showing the varying speed from the ISP would add more context to the display and integrating the main display with other always-on devices such as the router may reduce the energy and costs for this appliance.

Overall, we achieved our first research goal of creating a technical solution to a known and growing problem. However, more interesting is our second contribution, which relates to how revealing who is using resources in the home has unexpected and surprising social consequences.

Social Consequences of Visibility

First, showing people how others in the home are using a resource may confirm existing theories about resource usurping or it may reveal new information about how others are spending their time in the home. Such real time usage visualization systems may provide a new awareness for households and indirectly reveal information that was previously private. For instance, certain spaces in the home may attain a sacrosanct status, such as the teenage bedroom (previous research highlights this tension with teenage use of IM and SMS [9]), often replete with 'do not disturb' signs. Because we found that householders began to be able to "read" Home Watcher, despite its apparent lack of detailed information, we found that parents are offered a view into this world, gaining an awareness of when their children are online, and what kinds of activities they may be performing e.g., downloading illicit content or watching movies instead of doing homework. When plausible deniability for such actions is removed, the homes more private spaces may be slightly altered as private sanctuaries.

Further, even with presenting something as innocuous as bandwidth usage, people are concerned with their personal representation on such a system, and what it may reveal or even misconstrue about their activities. In non-family households such systems can be tools of manipulation or may force an egalitarian system for bandwidth distribution depending on whether the relations between household members are pleasant or strained. In these cases, public visibility could be divisive or encourage negotiation. For systems which reveal the consumption of household resources, we should at least be aware of how these devices surface household politics and alter notions of privacy in the home even when the information shared deliberately hides the details of activities.

Control through Visibility

Second, revealing individuals' resource usage in the home enables new forms of control because it can confirm or enlighten occupants about their household habits. Moreover, openly accessible controls reveal complex household power relations because they do not necessarily map onto a household's social order. Taking this to an extreme, if Home Watcher arbitrated traffic by itself, this would still affect how people use the home network, their perceptions of what others in the house are doing and their usage patterns. For example, systems which place more intelligence in the network (e.g., NetPrints [1], a system that learns how to resolve mis-configurations of home networks on the users behalf) or that automate application prioritization or even change domestic energy use, will ultimately affect household dynamics as certain people's habits are prioritized over others.

To summarize, we demonstrated that visual home networking tools can help households better manage their network resources. More importantly, our work shows that even with the CHI community's increased interest in helping households more effectively manage resources, to date most research has focused solely on the functional requirements of these systems, such as what, how often and how information should be displayed. However, thus far overlooked are the social aspects of these systems which affect design (similarly observed in social awareness system design e.g., [14]). First, we could investigate further how to best represent household members in these and similar resource monitoring systems, particularly those that reduce resource use to the individual level e.g., room level energy monitoring systems. Second, because of each households natural power structure if the tools are not to cause unnecessary contention, we could focus on creating better methods for access control for resource monitoring and redistribution—ones that offer an alternative to password protection alone, for control that more closely mimics how households manage access and sharing with social relations and rules.

CONCLUSION

We presented a visual home network tool to address the growing issue of residential bandwidth management. Our tool helped households better grasp the abstract concept of bandwidth and showed where improvements for similar tools could be made. More interestingly, we showed how revealing resource usage in the home affects different types of households, by surfacing household politics and enabling new forms of contention. Our results imply that individual representation and questions of how to provide control for household resources are important design considerations for resource monitoring systems.

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