The Work to Make a Home Network Work

Rebecca E. Grinter, W. Keith Edwards
GVU Center, College of Computing, Georgia Institute of Technology, USA
{beki, keith}@cc.gatech.edu

Mark W. Newman, Nicolas Ducheneaut
Palo Alto Research Center, USA
{mnewman, nicolas}@parc.com

Abstract: Recently, households have begun to adopt networking technologies to interconnect devices within the home. Yet little is known about the consequences for households of setting up and living with these complex networks, nor the impact of such technologies on the routines of the home. In this paper, we report findings from an empirical study of households containing complex networks of computer and audio/visual technologies. Our study finds that home networks require significant household effort not just to coordinate their use, but also their set up and maintenance. We also show how the coordination around networking has to be worked into the routines of the home and the householders.

Introduction

In his CSCW 94 paper "The Work to Make A Network Work", John Bowers reported study findings from a government organisation that deployed and used a network of CSCW applications. At the time, one of the unusual features of the people studied was their degree of familiarity with CSCW. In the 15 years since Bower's study, the general awareness and use of networked collaborative technologies has changed.

One change centres on the use of networked collaborative technologies at home. Today, householders use collaborative applications such as email, WWW, and IM, for recreational as well as for work purposes. However, as domestic computer usage has increased, the difficulty of sharing a single machine at home has lead to a new trend: the adoption of home networking technologies that allow the Internet to be shared among multiple machines. Beyond just the Internet, however, these home networking technologies offer the promise of delivering many more applications to our smart homes.

Yet, little is known empirically about the consequences for a household that has the type of complex network required to deliver such advanced services. This paper reports findings from a study that sought to address that question. Our study found that home networks represent a complex collaborative household endeavour in virtually all of their aspects including design and maintenance as well as use.

This paper begins by reviewing the literature on household collaboration and the role of computing in such collaboration. We then describe our methods and the participants in our study. Our findings are organised around three themes: the myriad of networks that exist in households, the household tensions that emerged because of the clash of individuality and collectivity in the networks, and the collective challenges that householders faced in administration and troubleshooting. The discussion focuses on the collaborative work required to make home networks work, how that coordination is further complicated by the tension between invisibility and comprehensibility, and why it creates an integration paradox in domestic technology.

From Domestic Computing to Domestic Networking

In the last few years, CSCW research has shifted from an exclusive focus on the office to examine collaboration in other settings such as the home. In this context, two lines of complementary research have emerged: studies that focus on domestic collaboration and studies examining the role of computing (which is closely coupled to the adoption of the Internet) in domestic settings. In this section, we review each in turn.

Domestic Collaboration: Routines and Technologies

One theme of home-based CSCW research has emphasised the need to study how people collaborate at home, often with the purpose of informing the design of domestic technologies. This focus of research takes as one of its motivations the belief that computer application development has evolved from a theoretical grounding in paid-labour work, and as a consequence has resulted in design practices that tend to emphasise efficiency and production (Hindus, 1999), which may not be appropriate for the home. Early results from studies in this tradition

have highlighted the nature of routines in the home (see for example, Harper, 2003). Routines can be thought of as the interactions householders pursue in order to organise their domestic life (Crabtree & Rodden, 2004; Edwards & Grinter, 2001).

Studies of domestic routines have had two foci. The first of these is an explication of the routines themselves, often with an eye toward developing insights that could be applied to design. For example, studies of how families coordinate the arrival, processing and output of postal mail show that families need not always explicitly negotiate the division of work (who collects the post from the box or the floor, for example) because they can rely on the visibility of the letters and bills themselves, as well as a shared sense of where various postal items should end up (Crabtree & Rodden, 2004). Another study of routines examined the use of calendars in the home and found that shared orientation to the artefact was essential for family members' explicit negotiation around event scheduling (Crabtree & Rodden, 2004).

The second focus of studies of domestic routines has examined the role that technology plays in these routines. For example, Tolmie and others (2002) highlight how technologies such as alarm clocks play an integral role in complex coordination routines such as "leaving the house," without calling attention to the technologies themselves. They argue that this invisibility in use provides a different criterion than the more usual notions of perceptual invisibility often touted as a principle for designing new technologies.

In contrast with Tolmie and others, O'Brien and others' (1999) study of set-top box use showed both the positive and negative impacts that technologies had on household routines. Their study highlighted how use of the television was often intertwined with temporal routines (such as coordinating departure activities) and spatial routines (such as demarking current ownership and control of shared spaces) in the house. Simultaneously, they also discovered that sometimes these technologies overtly dictate the use of the physical areas in the home. For example, in their study of a family with an open plan living room, the use of the television and stereo in that room by any householder not only dictated the use of that entire space, but also limited the possibilities of other householders to access the services provided by those technologies.

These tensions between the use of technology and the use of the space in which it resides have been solved by homeowners in a number of ways. One solution to the difficulties of multiple demands on technology and space noted by O'Brien and others was the purchase of equipment to make the technology more mobile. Televisions on carts, or small enough to be carried to another section of the house, along with portable stereos allowed numerous families to workaround some of the contention of routines. Indeed, as we shall discuss in the next section, similar tensions around computer usage led a number of families in our study to adopt

home networks that, in principle, allowed the resources of the network to be distributed across multiple devices, in multiple spaces.

Domestic Networks: From Internetworking to Networking

An important and related line of research has focused more exclusively on the role of the computer at home. As early as the mid-1980's, a few researchers were beginning to examine computing at home (Vitalari, Venkatesh & Gronhaug, 1986). These early studies reported that the primary use of a computer at home was as an extension of the computer in the office.

Today, studies show that families use their home computer for a variety of recreational activities, many of which are made possible by the presence of the Internet (Cummings & Kraut, 2002; Kraut et al., 1999). For example, Venkatesh and others (2003) groups these non-work activities into shopping, information gathering, learning, and communications. Another area of use for the computer is as a source of entertainment, including gaming (Ducheneaut & Moore, 2004) and also music playing on the machine itself (Brown, Sellen & Geelhoed, 2001; Voida et al., 2005).

For all of these reasons, it is not surprising that some studies of domestic computing comment on the difficulties those householders have in sharing the computer. For example, Frohlich and others (2001) described how families experienced resource contention when trying to share a single machine. They also highlighted how dedicated appliances were not always perceived as the best solution by householders, who often wanted the flexibility that access to a "general-purpose" computer provided.

For those households that choose to invest in multiple home computers, Internet access can become another potential source of contention. Although contention over the management of Internet access from multiple machines via a single landline has not often been reported in studies of home computing use (Rainie & Horrigan, (2005) being a notable exception), it is noticeable that broadband adopters typically have more than one machine in their household (Horrigan & Rainie, 2002).

Broadband adopters also share another important feature in common: their degree of familiarity with networking (Anderson et al., 2002; Horrigan & Rainie, 2002). Perhaps due to this familiarity, it is these families that have taken the next step towards distributing Internet access around the house—as well as potentially solving the problems of sharing computer peripherals such as printers and scanners—by purchasing intra-home networking equipment. Specifically, some households have begun to create and install rich home networks, comprising not just infrastructure technologies such as hubs, routers, gateways, and wireless access points, but also application-oriented devices such as media players and centralised storage.

Whether consciously or not, these networked households represent a step towards realising a commonly touted vision of the "smart home" (Harper, 2003). Visions of the smart home portray home life surrounded by computational devices that varyingly respond, predict, and monitor occupants' activities. Implicit in these notions of ubiquitous and smart home technologies is the assumption of an in-home network that allows the devices and services to communicate with each other as well as the occupants and the outside world.

One version of the smart home begins with a specially designed house that provides the network if not the appliances themselves. As Randall (2003) observed in his own unique study of householders temporarily living in such a smart home, the possibilities of the network were not always seamlessly realisable by the occupants. However, given the dominance of old housing stock, it seems unlikely that many people will experience their smart home as a new purchase (Edwards & Grinter, 2001). Rather, people will more likely attempt to make their homes "smarter" by adapting their existing physical infrastructure (Rodden & Benford, 2003).

This research represents a step towards an empirical understanding of what the consequences are for families who decide to set up and live with a complex network of these technologies. Rather than assuming that the network would produce a set of possibilities, we wanted to understand what options householders sought from their network, and how they collectively set about setting up and maintaining a home network that would provide them with the services of their choice.

Our findings are organised around three themes: the myriad of networks that exist in households, the household tensions that emerged because of the clash of individuality and collectivity in the networks, and the collective challenges that householders faced in administration and troubleshooting. The discussion focuses on the collaborative work to make the networks work, how that coordination is further complicated by the tension between invisibility and comprehensibility, and why it creates an integration paradox.

Study: Participants and Methods

In order to study the work to make the home network work, we conducted an empirical study of households with "advanced" technology set-ups. Our choice of such early adopters was motivated by a desire to understand the routines and tensions that result from such complex networks, which we believe will be representative of more and more homes in the near future. For the purposes of this study, the *advanced* qualifier restricted our participation pool to homes that possessed a minimum of two computers, connected both to each other and to the broader Internet.

Further, for the purposes of this study, we considered the *home network* to be not just the computing elements installed in the home, but also the Audio/Visual (A/V) devices installed there. As has been noted many times previously, data and media networks are converging, and are becoming interconnected. This was demonstrated in our sample group, as a number of the participating households had attempted to integrate their computer and A/V networks, for example, to stream MP3s to their stereo. Moreover, studies such as those by Petersen and others (2002) suggest that users already struggle with the complexities of A/V technologies; we wanted to see how the potentially more complex interplay of data and A/V would impact the routines in the home, and the use of the technologies.

Our participants consisted of 14 individuals in 7 homes. Each household was composed of dual-income two-adult family, and all families worked in professional occupations. All but one family lived in old housing stock (ranging from the 1930's to the 1960's), and all of the families lived in houses that did not contain any type of specialised wiring support for home computer networking, such as CAT6 Ethernet wiring throughout the house.

Unsurprisingly, in each household there was at least one person with considerable networking knowledge.[1] In all households network knowledge came from either advanced formal education (undergraduate degrees in computer science that covered networking) or many years of experience as a systems administrator or related profession. This—in and of itself—says much lot about the work required to make a home network work. By contrast, the other members of each household had a much broader range of experiences with networks. Although these other users shared much less in common, one striking feature was that they had all used networked technologies in corporate or educational settings themselves, which was another significant change since Bower's study. While some experienced network use in high-tech industries, others had learned about networks in other professions.

The study consisted of four activities. First, participants were asked to produce a "Home Inventory" of the technologies they had at home. The inventory consisted of three lists. The first asked householders to indicate whether they owned certain types of technology in categories including Home A/V, telecommunications, home automation, and in-home networking. The second asked participants to identify the locations of these technologies throughout their homes. The third list asked the occupants to list their mobile devices such as cellphones, MP3 players, and so forth.

These lists served two purposes. First, they allowed the research team to gain insight into the types of networks and devices that we might see during the later

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[1] Although the general awareness of the possibilities created by networks has grown, studies like Kiesler and others' (2000) reminds us of the usability problems giving networking novices technologies originally designed for systems administrators.

phases of the study. Second, the information allowed us to determine participants' "Tech Home Rating," a system devised by the Consumer Electronics Association (CEA) that claims to help end-users assess the technological state of their home. Surprisingly given our selection criteria, most of our participants (6 of 7 households) scored 3 out of a total of 5, implying that their home was only moderately technological. The one exception was a household that achieved a rating of 4, closer to CEA's "technologically advanced" rating. Despite these middle ratings, the next phases of our study allowed us to assess just how much technology these households owned.

This next phase consisted of three activities that all took place in the context of a home visit; two researchers visited each household. The home visit began with a sketching exercise, where we asked each householder to draw three diagrams: their home computer network, their home audio-visual network, and their vision of what they would like in an integrated home network. We asked the householders not to interact with each other so that their diagrams would reflect their own perspectives about their home networks.

The second activity, which represented the main part of the home visit, consisted of a tour of the home by the householders. The purpose of the tour was to visit the locations of components in the network. At each site, we would stop and discuss what we were being shown, and talk about its purpose, problems that it generated, and also provided an opportunity for the householders to raise issues that they wanted us to know about their networks and its uses.

Finally, the home tour concluded with a short interview designed to review what we had just seen and ask questions about other aspects of the home network that may not have been visible or obvious during the tour itself. In total, most of the home visits took between 2 and 3 hours including the sketching, touring, and interview activities.

At Home with Networking

In this section, we present the findings from our study organised into three topics. First, and as we soon discovered, the apparently simple question of *what constitutes* a home network was much more complex in practice. Second, we learned that there is a tension that householders must balance concerning the individual nature of certain types of devices and the collaborative nature of certain media. Third, the setup, administration, and troubleshooting of home networks required a division of labour in the household; this division of labour was not always completely agreed upon.

What is a Home Network?

The term *network* often conjures up a vision of *a single, well-orchestrated* collection of connected devices. The cohesive singularity implied by term is often used to emphasize the possibilities that fully connected devices can bring to householders—for example, the ability to interact with all devices on the network from any point of contact. Yet, in our studies we found that households embodied a much richer notion of networking, which was at once more pluralistic and less cohesive.

Audio-visual (A/V) systems, which were typically the older of the two types of networks that people had in their homes, illustrated some of those properties. In all homes we found a "primary" A/V network, which typically resided in the living room and included all the most recent A/V component purchases.

Families described this network, and the space that it occupied, as the place that they "came together" to utilise the services that this A/V network provided. Although in the majority of our cases, we found that families generally agreed about how they used the various services this network provided, we were also surprised to learn about difficulties that three of the families were having with television, and how this in turn shaped their A/V networks.

Half a century after the arrival of television into many people's homes, almost half of the families we visited were still actively considering its role in their homes and trying to determine the boundaries of acceptable use. In once case, the householders had developed a shared policy about the acceptable amount of television use, in relation to other activities such as talking to each other, reading or hobby time. This family would routinely decide that they were watching too much television, at which point the television would be disconnected from the network and stored away. Somehow, as they explained, the television always found a way to return—for example, because someone wanted to watch a particular program. Significantly, their network had to accommodate the routine arrival and departure of the television set.

In another case, the householders disagreed about the place of television in their A/V network, with one member enjoying the television and the other believing that television had no place in the home. Their compromise illustrates another common phenomenon in homes: the presence of *multiple* A/V networks. In this case, the television was not a part of the primary A/V network, but was installed in a "secondary" A/V network, a place where this one member of the household could watch.

A number of families had such secondary A/V networks, which were present in a variety of locations, but never in the living area of the house. For example, a secondary network might appear in a master bedroom where family members watched television before sleeping, or in a home office where one family member worked but might still want to watch television or listen to music.

Another common feature of these secondary A/V networks was the age of the components that comprised them. Components typically migrated into secondary networks as householders upgraded their primary A/V network. Consequently, secondary networks had components of dramatically different ages, which as a collection presented significant integration challenges.

In comparison with A/V networks, it was much harder to identify how many computer networks existed in the homes we visited, because generally the structures of such networks are not visually apparent. A/V networks located in specific regions of the house, connected through tangible wires and in a relatively localized topology, were easier to "see" than the computer networks. Visually, much of the computing network often appears to be unified and cohesive, as all components are connected to each other, to the broadband modem, and out to the Internet.

Yet, through interviews and diagrams we came to learn that some households had much more complex data network than were visually discernable. For example, several households needed to create a distinction between their "personal" home network, and their "work" home network (on which corporate machines at home were connected). Whether it was for reasons of taxation (being able to take certain deductions on equipment used for business purposes), or ownership (software developed using corporate resources would belong to the corporation), or data protection (ensuring that personal machines did not accidentally connect to the corporate network), the home computer "network" was rarely as simple and unified as it first appeared.

One distinctive feature we found in some households was an *open wireless network*, providing free Internet access to anyone in the area. Unlike "accidental" open wireless networks, attributed to householders' ignorance about how to secure the network, our householders had deliberately chosen to allow anyone within range to connect to their network, and the Internet. The motivation for doing so was often described in terms of "neighbourliness": these homeowners wanted to offer not just friends and houseguests, but also their neighbours the ability to share their network resources. While householders recognised the potential for network abuse, the opportunity to be neighbourly, with those within wireless range, appeared to make some households feel appropriately part of their community.

Comparing computer and A/V networks also revealed a difference in the degree of personal ownership of devices in the household. Householders frequently referred to computers as belonging to someone, but rarely spoke about A/V devices—even those they used exclusively—as "mine." This difference in orientation towards devices—as belonging to people on a computer network, and as being situated in a space on the A/V network—also influenced how technology migrated in the household. Unlike A/V networks, when new computers arrived, old ones migrated to a new owner, which in turn could trigger location changes,

such as physical desk swaps or network topological changes, that were a consequence of the change of ownership.

Beyond the complexity of the technologies themselves, Home A/V and computer networks illustrate the complex relationships between devices, householders, the services the network provides, and (perhaps competing) household visions of what constitutes acceptable use, all of which in turn is reflected in the devices present on the home network and how their users describe them. The answer, then to our question of what a home network is turned out to be a set of relationships and beliefs, layered over a set of interconnected and disconnected technologies, which was surprisingly complex in implementation and subject to ongoing change by the household.

Individuality and Collective Action

Our home visits suggested that home networks generally, and certain types of devices specifically, created a coordination challenge around online media such as photographs. This challenge arose because of a tension between the desires of householders to organise media collaboratively, versus the fact that this media was stored on individually owned devices. We first observed this tension in a household where all the householders had their own personal digital cameras and photograph repositories. This household experienced acute coordination difficulties in trying to manage their online photographs as a shared family collection—something that worked well with their traditional physical photo collection that lived in a box—because their images were stored on separate machines owned by the individual who had taken the picture. An aborted attempt to integrate these individual collections was made even more painful by the fact that each householder's private collection was organised differently, and the sorting scheme of each collection was not comprehensible to the householder trying to merge them together. Householders worried that they would some how "lose" the their collective experiences as they were scattered across machines and potentially subject to deletion or inaccessibility (such as if one individual took their machine off the network).

We found similar concerns in other homes. In most households media coordination problems extended beyond photographs to include other types of media, including collaboratively produced content such as music and letters. We also noticed that two devices seemed to especially exacerbate the tension between individuality and commonality: iPod and TiVo.

The iPod, Apple's portable music player, must be associated with a specific computer from which it gets its music. However, since most computers in the households we visited were individually owned, each iPod tended to gather one person's music only. This would not have been a problem if each iPod had been used exclusively by that person, but it was often used in conjunction with a secondary A/V network, either at home or in the car. Householders without iPods

resented the difficulty in listening to their music in contrast to the convenience of the iPod owner.

TiVo is a brand of Personal Video Recorder (PVR), a specialised computer used in an A/V network that allows people to record television programs to a hard drive, replay them, and skip advertisements.[2] TiVo also collects data about the programs users record, in an attempt to produce a model of viewing habits that can be used to make recommendations about other programs a user might like to view. While all the homeowners were enthusiastic about TiVo's core features, a number of households experienced problems with TiVo's recommendation system.

This problem stemmed from the fact that multiple people used a single TiVo, TiVo has a single viewer model of recommendation—in other words, there is no way to separate usage data in such a way that different recommendations can be made for different people in the home. This tension manifested itself in a number of ways. In one household that had two TiVo's (one for each member of the household), each person "owned" one TiVo. Unfortunately, only one householder's TiVo was connected to the primary network, so it was that person's recording habits that tended to influence the programs that got watched on the primary network even when the other householder was present and wanted to watch TV. Another household, with a single TiVo, attempted to resolve this problem socially, with one member of the household being the only person "allowed" to operate the TiVo and influence how the TiVo generated the data that it would use to make recommendations. The most common model was that any divergent viewing habits among the owners were overloaded into one TiVo, and householders either competed to "turn" TiVo into their own, or accepted that its suggestions were going to be an eclectic hybrid of various householders interests, sometimes right, and mostly representing an alien middle-ground.

In all of these cases, tensions existed in both the computer and A/V networks, where individually owned devices, or services that assumed individual use, conflicted with householders' desires to collectively share and manipulate media.

Administration and Troubleshooting

One dominant theme in all the households we visited was the ongoing challenge of setting up and troubleshooting their networks. Again differences emerged between A/V and computer networks. Although the cables and remotes belonging to the primary and secondary A/V network presented problems, it seemed to be the home computer network that generated the worst difficulties. Of course, one can argue that these problems are the result of trying to migrate technologies such as TCP, IP, DNS and NAT, which were designed to be used by skilled systems

[2] In the USA, where this study took place, the brand TiVo has become synonymous with PVR. Even the few families who owned non-TiVo PVR's referred to their device as a TiVo.

administrators, into people's homes. Yet it seems likely that these technologies will persist in their dominance, and in turn the work to make the home network work will involve meeting the challenges presented by these technologies.

From a collaborative perspective, one feature of the set-up and troubleshooting work was the emergence of a complex and sometimes contested division of labour among the householders. Typically, the person with most networking knowledge was responsible for setting up and maintaining the network infrastructure. In the majority of households the person responsible for setting up and maintaining the computer network was also the same person who supported the A/V networks.

This particular division of labour was accepted in most households, especially given the typically significant difference in knowledge among householders about how computer networks work. The sketching exercise revealed this difference vividly, with one person usually producing detailed network diagrams while the others produced diagrams that contained only a small subset of the devices in the network. Unsurprisingly, the devices that were most commonly missing from sketches included infrastructure devices such as routers, firewalls, hardware VPNs, and—less commonly—the broadband modem. When such devices were sketched by the less knowledgeable householder they were often labelled something like "network doodads." And yet, of course, without knowledge of these devices, infrastructure maintenance is unsurprisingly difficult.

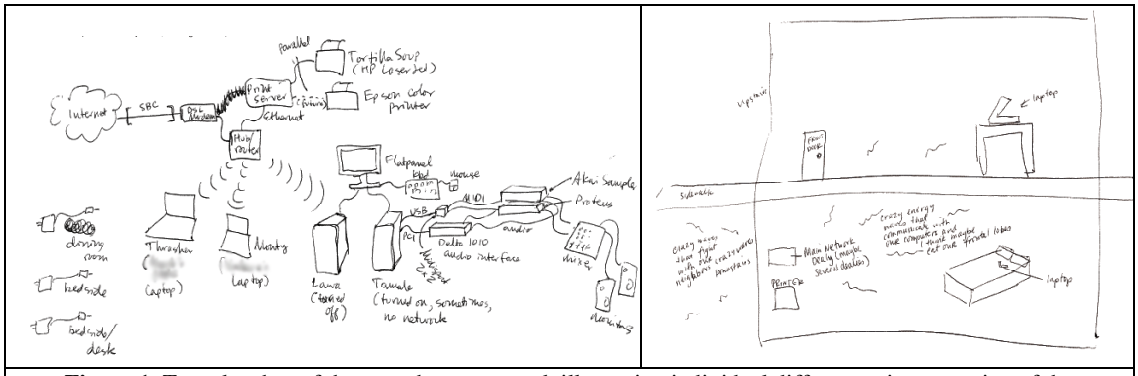

Figure 1: Two sketches of the same home network illustrating individual differences in perception of the structure of the home network. The sketch on the left is by the home "systems administrator," while on the right is by another home resident.

This difficulty manifested itself most clearly when these householders needed to troubleshoot the network and the "systems administrator" was not home. For example, one householder described a week in which he did not have Internet access, because the other person was out of town. Although his troubleshooting skills included rebooting not just his machine but also the DSL modem, they did not extend to considering the actual solution, which was to reboot a router. In other words, without the ability to understand the whole network, troubleshooting the network—let alone installing or modifying the network—becomes virtually impossible.

For some non-systems administrators in the household, troubleshooting the network got increasingly difficult as the home networks evolved. For example, in one household we found a person who did not typically administer the home network infrastructure, but regretted that fact. In particular, this person felt that they had the skills to take on some, if not all, of this responsibility, but because they had not been involved in the initial network setup or subsequent changes, now felt that they did not understand the network well enough to troubleshoot it.

Ultimately in our households, one householder typically recognised the need to take full responsibility for the network infrastructure; these householders unanimously resented the amount of time they spent adding, reconfiguring, and debugging the network. Almost all the systems administrators described instances where trying to provide new functionality in the network—like network printing for Windows machines, or debugging something that had gone wrong—took days of their "leisure" time.

The task of administration includes not just infrastructure support but also device support; often, the device support division of labour caused more tensions than the infrastructure support division of labour. In particular, where householders ascribed ownership to a device, there was confusion about whose responsibility it was when it went wrong. Even householders who did not desire or did not feel capable of troubleshooting their own machines would often administer the look and feel of their computers, as well as make decisions about the organisation of files and the installation of software onto their machines. This made that same machine much harder for the systems administrator to understand, and potentially troubleshoot. Many of our householders felt a sense of uneasiness when discussing the division of labour associated with the machines that made up the network.

Two other challenges for those responsible for the network came from the need to coordinate with outsiders, and the need to understand history. One episode illustrates both of these well. One household described how they kept losing their Internet access. One of their earliest attempts to solve this problem involved calling the local telephone company to see whether they had faulty equipment or a bad telephone line.

This first step in troubleshooting oriented us to the presence of numerous outside parties involved in the setup and maintenance of home networks. Satellite, cable and Internet providers needed to be engaged to provide the basic infrastructure of the A/V and computing networks. Then, other companies providing specific services, such as IP-based telephony or the TiVo PVR's recommendation subscription service were involved. When we asked householders to list how many companies they paid regular bills to in order to make their network work they often listed between 3-7 outside entities.

Unfortunately, having outside agencies involved in the provisioning of the network increased the likelihood of network related problems for these

households. For example, people who came out to install various pieces of equipment tended to have installation scripts that drastically under-estimated the complexity of the networks into which they were adding functionality. Assuming that the television (rather than the receiver) produced the sound in the primary A/V network was a common mistake made by satellite installers; these installers would not leave until they had "correctly" set up the dish work with the television, consequently disabling the receiver.

The second step of troubleshooting for the family with Internet connectivity problems—once they had determined that the telephone line and DSL equipment was not at fault—was to begin to search for problems inside the house. They identified a list of potential problems sources and addressed these in turn. Ultimately, a decision to move a computer and its monitor to a different room caused them to realise that the true source of their problem was that their electrical circuitry was old enough that the quantity of equipment on a single circuit was degrading power to the DSL modem to the point that it was dropping the network connection.

These householders, like many others in this study, lived in housing stock that came from the first half of the 20th century; in many ways the design of these houses caused additional challenges for householders. Another home visit revealed how network complexity increased due to the fact that telephone jacks were not located near the site of the primary A/V network. However, devices in that network required a telephone line so that they could routinely make connections over a dial-up modem connection to receive information, such as television schedules and service upgrades. This led the family to add another network: a wireless connection that allowed their devices located in the living room to communicate outside the house using the telephone jack in the dining room.

Setup, administration, and troubleshooting the home networks revealed a complex division of labour among householders. Two somewhat overlapping divisions of labour seemed to exist in most households: these divisions of labour concerned separation of infrastructure and end-user device responsibilities. Adding to the difficulties for the householders were the relationships they had to manage with outside agencies required in the setup and ongoing maintenance of the network. A final complexity came from the lost knowledge about what previous outside agencies had done, and whether it was adequate (electricians/telephone engineers and the electrical/telephony infrastructure).

Discussion

In this section, we explore some of the broader themes that emerged from our examination of the routines surrounding home networking.

The Collaborative Work Required to Make the Network Work

Much like studies of single device usage in the home, our study has highlighted the importance of ownership, space usage, and routines around the applications that networks provide. With regards to the home network, there is a tension between ownership and the utility promised by the network. For example, the tendency of computers to be personally owned conflicts with desires around collaborative ownership and management of family photos.

Beyond such tensions, however, our study has highlighted how much collaborative work is required simply to make the network work—to let householders get to the stage where they can begin to incorporate the services offered by their network into their lives. Further, our study reveals that the work required to make the network work involves not just the householders themselves, but also parties outside the home, with whom the householders must interact and rely upon in order to realize their vision of useful home networking.

Troubleshooting revealed the many types of collaboration clearly. Householders turned not just to each other—according to their respective divisions of labour—but also to people outside the house when they needed help debugging their network. The sheer number of outsiders, and the potential that problems could involve coordination among them, was daunting to many householders, and something that would, as one person said "keep the network on the to-do list in one form or another for months."

Still more parties were often represented in the design of the home networks. Often these parties appeared in the "social network design" of the household. For example, neighbours and houseguests influenced some households to provide open networks. The corporations that householders work for, as well as potential hackers, influenced people to close off sections of their networks. Even the government could shape a home network by encouraging technical separations based on tax reasons.

Householders took all these outsiders' potential and actual needs and then combined them with their own internal desires for their network. While families' needs are often framed in utilitarian terms ("I want to connect to the Internet") our interviews with families revealed strong moral imperatives involved in home network design: our families' "values" drove the selection and configuration of services and devices on the network. Indeed, in aspiring to open and close networks from various outsiders, the same type of moral order was also being used.

The balance between individuality and collectivity played out in the maintenance of the home network and the devices on it as well. Even though one householder typically was responsible for the network infrastructure itself, many of the devices on that network were "owned" by a particular person in the home. Successfully troubleshooting the network often required breaching normal

practices, for example, to change settings on a machine owned by another person in the home, so that it could function appropriately on the home network.

Finally, and most problematically in some ways, notions about the functionality desired in a home network often made coping with the network difficult, as new desires brought about evolution of the home technical infrastructure. This constant evolution of the network, while bringing new functionality, also changed the way that current work, created tension among the householders. This surprisingly (almost frighteningly) constant evolution of the household networks also fed into problems with invisibility and comprehensibility, which we discuss next.

Invisibility and Comprehensibility

Computing infrastructures are often described as invisible (for discussion see Chalmers, (2004)). Whether because networks are physically hidden, or because they have become so embedded into practice, these technologies seem to disappear (Star, 1999). Invisibility, and the need for comprehension, played out in very complex ways in the households we studied.

First, there were empirical challenges for the researchers. Diagrams helped to capture some of the complexity of home computer networks that was not apparent from their physical appearance. In particular, in the case of data networks, there is no outward sign of the logical structure or of the "reach" of these networks.

Second, there was an interesting tension between householders' desires for invisibility and comprehensibility in their home networks. All the households we visited made an effort to minimise the physical visibility of their networks. Cables were typically hidden behind and underneath furniture and often were referred to as the "rats nest". Other families replaced cables with wireless solutions, and then proceeded to hide the antennae in plants around the house. We found speakers, hubs, DSL modems and even computers hidden in cupboards, behind family pictures, inside desks and even under the couch. Families seemed to largely do this for aesthetic reasons: hiding those "little blinky lights" out of view, or "trying to be tidy".

Yet, this physical disappearance did little to help householders, particularly those less familiar with the networks, engage in the setup and maintenance of the network itself. In particular, not being able see devices or their relationship to others in the network reinforced householders' senses that their home network did not contain a variety of technically essential components. This disappearance prevents some from considering infrastructure technology (hubs, routers) as potential sources of problems when troubleshooting.

Of course, visibility alone does not guarantee comprehensibility. In this study, discussions around media usage illustrated how householders could see other devices and content on their networks, and still not make sense of it. Pictures, spread across multiple machines, could not be bought together in a family archive,

because householders could not make sense of others' organisation schemata. TiVo added another dimension to content management. Homeowners could readily cope with the basic functionality of these systems, but the tension that arises through a device used in a shared setting that provides individually oriented recommendations caused homeowners to try to control recommendations through both technical and social means.

Ultimately, this study suggests that invisibility and comprehensibility are both desirable aspects of home networks. Currently, however, these goals are often conflated in the physical embodiment of the device itself. Once a device is out of sight, it is often out of mind. Tools that provide views of the network oriented around the services the network provides—rather than the devices that comprise it--might greatly aid householders in working together on family solutions to not just media sharing problems, but also the set-up and administration of the devices and infrastructure itself.

The Integration Paradox

The difficulties in administrating and troubleshooting the home network led to something we term the *integration paradox*. Integration—whether through single devices embodying a variety of functions, or pre-integrated collections of components—seemed very attractive to householders experiencing the challenges of administering diverse networks.

Yet, while integration seems like a potential solution, integrated devices have their own problems. This is well illustrated by the following quote

> Oh, yeah, if someone would sell me an integrated box, I would buy it. Really. In fact, *we'd buy two of them*." [Emphasis added]

The paradox of integration turns on the simultaneous desire to have integrated components that reduce the work to make the network work, while achieving the same flexibility of functionality potentially provided by non-integrated components.

A similar type of paradox also played out in households around the remote. Most families showed us their large collection of remote controls, most of which arrived in the home as components were purchased. Several households also had a universal remote, purchased to reduce the number of remotes required to operate the system; the goal of such a purchase was to achieve integration of device control, if not of components.

Again, the paradox of integration arose in these cases. In practice, universal remotes worked for a few members of some households—typically those who told us that they understood the programming model of the remote itself. A surprisingly large number of householders, however, used the universal remote in conjunction with *at least one other remote*. Typically the universal remote would be used most often, and a secondary remote would be needed because it contained a few "key buttons". Again, the flexibility provided by the remotes in

combination seemed to override any potential interface benefits that might be had by using one remote alone.

Conclusions

In this paper, we have sought to empirically begin the process of exploring the question of what it means for households to set up, live with, and support complex networking technologies. Moving beyond some of the usability issues with the technologies themselves—and there are many—networks raise many issues for households, most of which involve ongoing collaboration among householders to resolve. Networks not only make the collaborative production and consumption of media and services possible, but they take coordination to produce and consume themselves.

Of course, this study can only be a beginning point in a larger empirical and design research program. Our findings, while emerging from data about end-users experiences of networking in the wild come from a small portion of the population. In particular, our data was drawn from USA residents' homes, belonging to more-affluent-than-average middle-class families, and consequently represents one part of the population being targeted by corporations that have visions of networked homes and a myriad of services that will be delivered into those houses.

Yet, despite potential limitations of this study, it has already surfaced key problems with visions that networked homes. Most particularly, technical networks—as well as the technologies that they connect—enter into social networks that connect householders to each other, and to the outside world in a complex set of coordinated relationships. Future work exploring how other kinds of families, in other places and with other types of technical and social collaborative agendas, set up and live with networks of technologies has much to offer our understanding of precisely what it means to design devices for home networks.

Acknowledgements

We'd like to thank the people who participated in the study. Thanks to John Bowers for an inspirational title for this paper. We appreciate all the helpful comments and suggestions from the reviewers.

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