Eden: Supporting Home Network Management Through Interactive Visual Tools

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ABSTRACT

As networking moves into the home, home users are increasingly being faced with complex network management chores. Previous research, however, has demonstrated the difficulty many users have in managing their networks. This difficulty is compounded by the fact that advanced network management tools—such as those developed for the enterprise—are generally too complex for home users, do not support the common tasks they face, and are not a good fit for the technical peculiarities of the home. This paper presents *Eden*, an interactive, direct manipulation home network management system aimed at end users. Eden supports a range of common tasks, and provides a simple conceptual model that can help users understand key aspects of networking better. The system leverages a novel home network router that acts as a "drop-in" replacement for users' current router. We demonstrate that Eden not only improves the user experience of networking, but also aids users in forming workable conceptual models of how the network works.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Graphical user interfaces.

General terms: Design, Human

Keywords: Home network, human-network interaction

INTRODUCTION

As the home network becomes an essential part of people's daily life, network management has become a regular household task [10, 22]. People need to configure new devices to connect them to the network, set up infrastructure devices (such as routers and wireless access points) for connectivity with their Internet Service Provider (ISP) and with the devices inside the home, manage security in order to defend their networks against unwanted access, potentially configure parental controls to restrict Internet usage for their children, and diagnose and troubleshoot connectivity problems, to name but a few.

However, many home users have difficulty doing such management jobs, and so home networking has become the focus of a growing body of work in the HCI community [5, 7, 8, 9, 13]. Today, the state of network management tools for the home is impoverished at best; most users rely solely on the built-in tools that come with their operating systems and routers (such as the basic Windows TCP/IP control panel, or the web interfaces built into routers and access points). With these modest tools, users must understand aspects of network architecture (that a router is the "central" device on the home network), concepts such as IP addresses (whether to use static or dynamic addresses, for instance), wireless security (SSID, various forms of encryption), and more. Yet many of the essential details of home networking are effectively invisible. Notions such as logical network topology, configuration settings, and traffic flows are ephemeral, and poorly presented to users, when they are presented at all. Unsurprisingly, then, prior work has demonstrated that most home users have poor conceptual models of these notions, impeding their ability to manage, upgrade, or troubleshoot the home network [17].

One approach to addressing the conceptual complexity of home networking might be to create direct manipulation [20] tools that expose a unified visual interface to the now-hidden aspects of home networking. The value of such approaches, with their continuous representation of objects, and support for incremental action and feedback, has been shown numerous times in the past; such systems allow users to form actionable conceptual models about the "model world" interface in which they are working.

However, creating such tools for home networking presents a two-fold challenge. The first of these is the *interaction design* challenge: *what* underlying concepts should be exposed, and *how* should those concepts be represented to users? Simply creating a visual representation of every low-level aspect of the network infrastructure is unlikely to be a workable solution; rather, we must understand the specific management tasks faced by users, and how to create a holistic set of interface abstractions that support these tasks.

Second is the *technical challenge* of creating a system that goes beyond a mere interface front-end, and can robustly effect change in the network in response to user actions at the interface. This involves instrumenting and augmenting the home network infrastructure to provide these management capabilities *while maintaining compatibility*
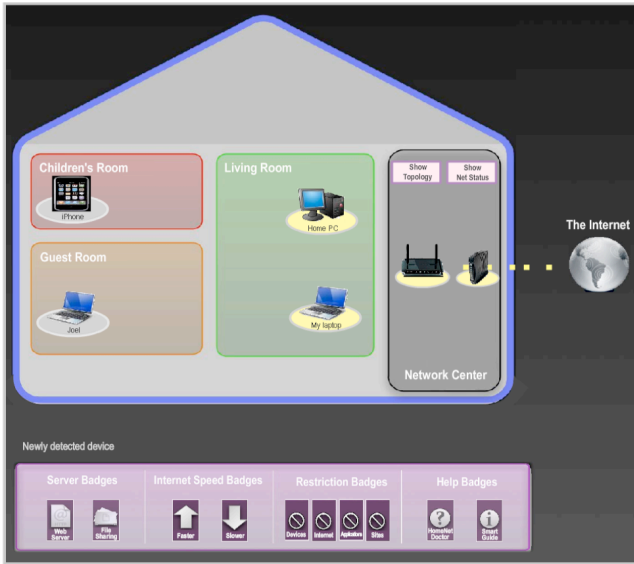
Figure 1. A screenshot of the Eden user interface

with the diverse ecosystem of existing devices and applications that are the reasons home users adopt networking in the first place.

In this paper we introduce *Eden* (Figure 1), an interactive home network management system that exposes a direct manipulation, model-world style of interaction for a wide range of home network tasks. Eden is based on empirical work aimed both at uncovering users' needs, and at developing a coherent set of interface concepts that are approachable and understandable by users. Eden eliminates the need for users to deal with the technical minutia of the network, instead allowing them to perform management tasks with a simple drag-and-drop of visually represented networking devices and network settings. Our evaluations show that not only does Eden perform well at supporting a wide range of common home network management tasks, the visual model presented by the system also helps users form actionable models of the network's behavior—in effect "teaching" them about networking.

Our contributions are threefold. First, we present what is to our knowledge the first fully direct manipulation system designed specifically for home network management, along with the design process that informed this system. Second, we present an approach to actually implementing network policy controls in response to user interface actions, while maintaining compatibility with the diverse, deeply heterogeneous environment in the home network. Finally, our evaluation demonstrates substantial improvements (and user preference) for this tool over alternative approaches.

In the following sections, we present an overview of existing network management tools. Next, we provide an overview of our design process, including a formative study to elicit requirements for the tool, as well as evaluation of a range of prototypes. We then present Eden and its basic conceptual model. Finally, we give results of an evaluation of the system's conceptual model and usability, and conclude with directions for future research in home network management tools.

RELATED WORK

Network management has a long history. With tremendous growth in network deployment in the 1980s and 1990s, tools and standards to allow administrators to more efficiently manage large networks became prevalent. Among the most well-known of these are the SNMP [19], CMIS/CMIP [3], and TMN [3]. Based on these standards, many complex management suites such as IBM Netview [1] and HP OpenView [16] were introduced to support management of enterprise-class networks; further, open source tools, such as PacketTrap (www.packettrap.com), provide in-depth features for network analysis, building directly on the underlying TCP/IP network stack. Some of these tools are shown in Figure 2.

However, these tools are intended primarily to help network professionals manage large enterprise-wide networks by centralizing account management, providing unified accounting of network resources for internal cost recovery, measuring performance in complex network topologies, configuring routing policies for networks with hundreds or even thousands of routers, and so on. Not only are home networks generally much *smaller* than the enterprise networks targeted by these tools, the day-to-day tasks of network management are generally far *different* as well (few homes would likely consider implementing centralized account management, or internal billing for printer use, for example). Perhaps most importantly, most homes do not
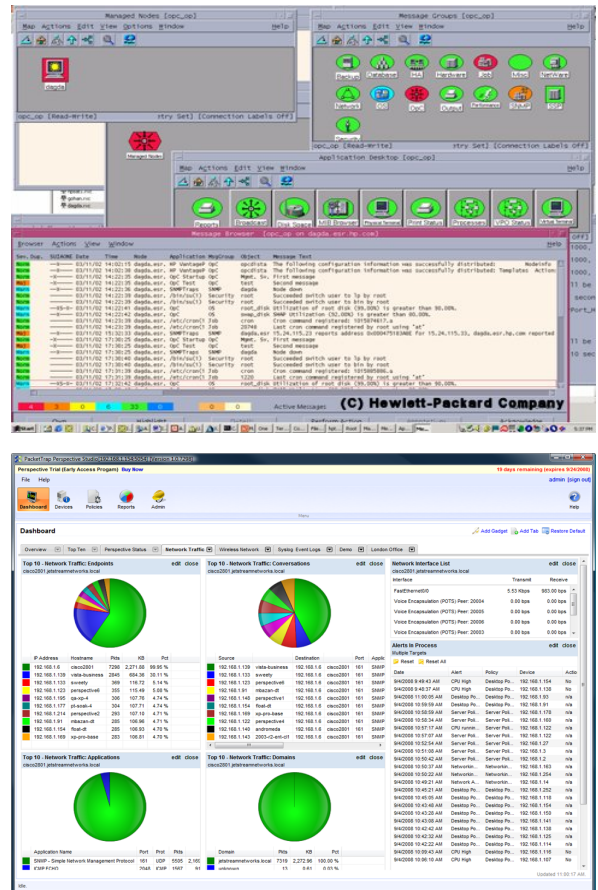

Figure 2. HP OpenView Network Node Manager (top) and PacketTrap (bottom)

have access to professional network managers who can effectively learn and use these complex tools.

The tools and protocols that *are* generally available to home networks typically do not address the full range of home network management. For example, DHCP [6] removes the need for manual configuration of IP addresses and other IP network parameters; UPnP [12] and Zeroconf [4] allow devices in the network to automatically discover each other, easing the sharing of content and services; and systems such as Network-in-a-Box [2], Windows Connect Now [15], and ICEbox [23] remove the need for manual configuration to provision client devices for a secure wireless network. All of these tools, however, only partially address the problems of home network management, focusing only on single aspects of configuration (such as IP address assignment or WEP key settings) rather than providing a holistic model for home network management.

One exception to this is a system called Network Magic (www.purenetworks.com). Network Magic is the work most closely related to ours because, to our knowledge, it is the only purpose-built system designed to provide a high-level interface for network management in the home. Network Magic supports a comprehensive set of household-oriented tasks including device configuration, wireless security, network speed and status monitoring, and troubleshooting through a wizard-oriented interface. That is, although the tool has a graphical interface, the interaction style it presents is wizard-based, not a highly interactive, direct manipulation style of interaction. While the system provides a visual "map" of the home network, interaction with this map is limited to viewing a selected device's configuration, and changing its name or icon type.

While Network Magic is undoubtedly an improvement over rudimentary, per-device tools such as the Windows control panels or router configuration web pages, we were inspired by work that has demonstrated the degree to which highly interactive direct manipulation systems have the potential to increase user performance, confidence, and knowledge over more text-heavy tools. For example, the Sesame system [21] demonstrated substantial improvements in firewall performance over traditional text-heavy firewalls through an interface that provided a coherent, and manipulable, conceptual model to its users. Thus, our goal with Eden was to construct a coherent interactive visual model for the home network to support common management tasks.

ADDRESSING THE INTERACTION DESIGN CHALLENGE

As noted earlier, one key challenge in providing a visual interface to home network management is that it is not clear what aspects of the network *should* be exposed to users, nor *how* these should be represented. For example, should low-level concepts such as traffic types and flows, NAT settings, TCP/IP ports, and so forth be presented in the interface? Or should the tool only expose high-level details, perhaps such as aggregate bandwidth on the network? There is a trade-off here between potentially overwhelming users with irrelevant details, versus not providing them with enough details to be actionable in problem diagnosis. Further, once these details are decided upon, there is still the question of
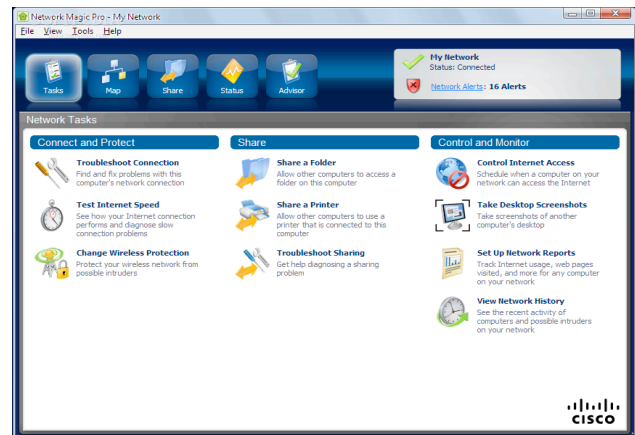

Figure 3. Network Magic's Task Panel

how these are knitted into a coherent, consistent set of interface abstractions that are understandable to users.

We believed that by better understanding users' management needs and desires we could constrain the design space, and from there begin to iterate with alternative interface designs with users. Thus, the initial step in our design process was to create a "catalog" of home network management tasks. After this, we created a diverse range of prototypes and evaluated these with users; this allowed us to experiment with a number of conceptual models for how to represent the details needed to support users' management tasks. The sections below briefly describe our design process

Understanding Home Network Management Needs

Our first step was to create a basic catalog of home network management tasks to provide us with insight into how to scope the system's design. We combined two techniques to gather this data. First, we developed a catalog of the tasks that can be performed now using the tools commonly available to householders—these included the router web page interfaces used by multiple vendors, operating systems' network control panels, and so forth.

This technique yielded the set of actions that are *currently possible* (albeit perhaps not easy) using available tools, but of course could not yield insight into activities that might be *not possible, yet still desired* by householders. Thus, we combined this data with the results from a study designed to reveal householders' frustrations and desires with respect to home network management. Our study included 14 users with a range of networking skills, from completely novice users to a professional network administrator. Our goal in sampling so widely was to understand not only what current tasks novice or intermediate users find difficult, and which we might make *easier*, but also to catalog a range of more advanced tasks performed by experts that we hoped to make *possible* by less experienced users. This formative study included both survey and interview components. The survey contained instruments to collect participants' self-reports of their knowledge of networking, as well as baseline data about their current networks and practices (number of devices on the network, for example, and which tools they currently use to manage the network). Semi-structured interviews were then used to elicit users' desires

for their home network, many of which they reported as not currently achievable given either the state of the tools or their knowledge of network management.

Participants expressed a range of desires in this study, but three categories of tasks stood out as being desirable, yet not currently practical. First among these was network monitoring, primarily to give insight into why the network was behaving in a certain way or to assist in troubleshooting. Participants expressed this as a key frustration, and desired an easy way to see the status of the network at a glance, or check network speed.

A second desired feature was security. Although we had expected general fears or unease about security to manifest themselves in our interviews, a number of participants expressed specific, concrete desires. These included the ability to provide household guests with access to the home Internet connection without implicitly providing that guest with access to all of the resources on the home network. (In most current home networks, any device on the network has unfettered access to all other devices on that network; this behavior is distinct from devices *outside* the home, which are restricted from accessing internal devices through Network Address Translation (NAT) implemented at the router). A desire for parental controls to regulate children's Internet use was also widespread among participants.

Finally, a third desire was gaining more control over network performance, to ensure that network resources were being used for the task at hand. In networking parlance, this is called *Quality-of-Service* (QoS) control. Largely this desire surfaced among participants who made regular use of high-bandwidth, latency-sensitive applications (such as Internet telephony, media applications, or games), and was expressed as a desire that "the important stuff work."

From our analyses, we defined a range of home network management tasks which we group into the following broad categories.

- Membership management: this category includes the tasks associated with adding new devices to the network and removing devices from the network.

- Access control: this includes basic security functionality, as well as access controls for guest machines and parental controls for children.

- Network monitoring: this includes basic visibility of the overall home network, the ability to monitor particular devices' Internet usage, and the overall connectivity to the Internet.

- QoS policy for bandwidth priority: this includes the ability to indicate that certain "important" applications or devices should have priority in the home network.

Interaction Concepts and Prototypes
Based on this data, we next undertook an exploration of a range of design concepts for interfaces that could embody the various management tasks enumerated above. Our goals with this phase of our design process were to explore ways to make necessary concepts visible in a way that supports

users' goals, while omitting low-level, unnecessary, or overly complex details.

We were guided in this effort by prior research that has suggested that users often rely on self-created visual representations of their home networks, in an attempt to lend concreteness and visibility to what may otherwise be an abstract and largely invisible infrastructure [22]. We hoped that by understanding users' visual depictions of their networks, we could gain insight into how *system-generated* visual depictions might echo and support these practices.

There is a challenge here, however, in that prior research [5, 9, 17] that has studied users' visual depictions of their own home networks has indicated that a disparity exists in how householders view the network: the more technical knowledge users have, the more they tend to think of the network from a logical perspective—as a set of technical relationships among networking devices. In contrast, less technically-inclined users tend to view the network from a physical or spatial perspective—based on the locations of networking devices in the built environment of their homes.

This led us to create a number of interface mockups that spanned the range of representations created by users, from prioritizing the technical relationships among devices, to privileging the physical setting in which those devices are deployed. Figure 4, for example, shows two mockup interface designs, one using a "logical" representation (using a tree-like view common in commercial network management tools, and in the drawings of technically inclined home network users) and one using a "spatial" representation (in which devices are located in the physical space of the home). In addition to these logical and spatial design prototypes, we also generated a number of more "abstract" design ideas. These included a game-like visual representation (reminiscent of prior work using game interfaces for system control [11]), an on-screen fish tank representation (in which devices are represented as fish; interactions among fish represent interactions among devices, and so forth), and a more abstract and "sketchy" version of a house depiction.

In addition to the basic visual representation paradigm, we also wanted to explore alternative interaction styles; thus, we designed two interaction alternatives for each of our visual designs. One was based on a highly direct manipulation-style approach, in which users select, drag, and drop on-screen objects in order to control them; the other was a more "traditional" interface, relying heavily on
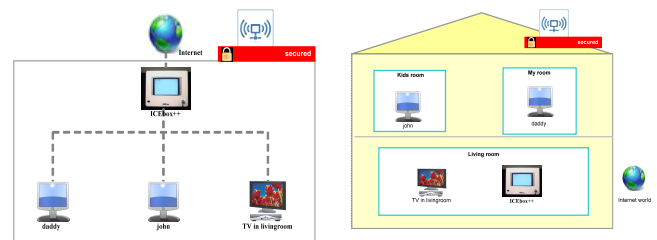

Figure 4. Design alternatives for visual representation paradigms for the home network. Left is a "tree map" representation common in networking tools; right is a spatial representation.

selection to indicate a target object of interest, coupled with menus to indicate a desired action on that object.

Evaluation of Design Prototypes

To gather feedback on our paper prototypes, we performed a basic evaluation with the same 14 study participants as in the requirements gathering phase, using think-aloud as well as questioning them to ascertain their understanding of the various designs, as well as to determine their preferences.

Four knowledgeable users preferred the tree representation due to its simplicity and depiction of topology. However, the users with less networking knowledge overwhelmingly preferred the spatial and abstract representations, with most favoring the spatial depiction (three very novice users preferred the abstract representations; the rest, however, were extremely negative toward the abstract representation, feeling that the mappings between the interface and network concepts were unclear, or that the representation was "inappropriate" for a task-oriented system).

Further, even the technically sophisticated users, who overall preferred the tree representation due to its close correspondance with the actual network infrastructure, saw value in the spatial representation. Users liked the mapping with the physical locations of the devices in home. The use of a physical boundary to represent the logical home network boundary was especially intuitive to users.

This result suggested that a "mixed mode" representation—in which a spatial representation was overlaid with logical information about the network topology and traffic flow—may be a workable visual representation for users of various levels of expertise.

From an interaction style perspective, users overall preferred the drag-and-drop interaction over a heavily tool- and menu-based design due to the "simplicity" of dragging and dropping. This suggested the utility of a highly direct manipulation-oriented interaction style with visually represented devices, and tasks invoked by actions directly on those visual objects.

THE EDEN USER INTERFACE

Based on the formative study results, we created a fully functional implementation of the Eden system, including an overall interface design with interactive elements suggested by our formative studies. In this section we discuss the final Eden user interface; in the next, we discuss the implementation of the system, and our approach to allowing the Eden interface to effect a range of monitoring and policy controls in the home network.

Overall Model: Spatial + Logical

The overall visual and behavioral model of Eden leverages a combined spatial/logical view as shown in Figure 1: space is represented by a pictorial representation of a home, with various "rooms" contained within. Interactive graphical objects that represent users' devices, and various network infrastructure devices, are placed within this representation, and afford dragging and dropping to perform network configuration tasks (more on this shortly). Topology in this interface is represented by visible links that connect devices; these links can be disabled by users.

The Home is a spatial representation of the invisible home network: the physical boundary of the Home maps the logical boundary of the home network, such that devices inside the on-screen Home are those that are "on" the home network, while those outside are not. This depiction provides an at-a-glance representation for users to easily see what networking devices are currently on the network.

Within the Home are a number of sub-regions, which serve to separate user-facing devices from infrastructure devices, and also provide a means for users to create groupings of their own devices for management purposes. Infrastructure-oriented devices appear in an automatically-created region called Network Center, which is located near a wall of the home, adjacent to the Internet icon, which represents the user's ISP; these devices are visually separated from others to indicate their unique roles in the network, as well as the fact that they sit "between" the end-user devices and the Internet, both visually and as a practical technical matter. This region also contains controls to enable or disable the viewing of network status, and the logical overlay of links over the home spatial representation.

Non-infrastructure devices—laptops, game machines, media adapters, and so on—appear in Rooms contained within the Home. The system obviously cannot intuit the physical layout of the home automatically; rather, users create and name their own Rooms in the system when it is first set up. These can be changed later at any time. Devices that are connected to the network appear in Rooms. Again, the system does not automatically detect the locations of devices, but rather allows users to place them within Rooms to reflect their own configurations and semantics, much as in users' own sketches. As described shortly, in addition to providing basic cues for physical locations in the home, certain controls can be applied not only to individual devices, but to entire rooms to affect the behavior of devices organized into that room.

While our interface strongly leverages the concept of Rooms as a way to convey information about physical location as well as logical groupings, we realize that there are potential problems with this representation—problems that we might term "metaphorical breakdowns." For example, mobile devices might be regularly used in multiple rooms. Since the visual representations of devices in Eden do not automatically update their locations, this can lead to a device-to-room mapping that becomes out of date. There are several approaches one could imagine users might take to manage this breakdown, and which we sought to explore in our evaluation. For example, prior work [17] has shown that mobile devices are often labeled according to ownership in users' network sketches; this might suggest that users place devices in Rooms to indicate ownership rather than strict physical presence (Bob's laptop may be placed in Bob's Room, for instance, regardless of whether it is always used there). Other strategies might be to place mobile devices in the locations in which they are most frequently used, or potentially creating an entirely new grouping for mobile devices. Whether users understood this mapping and could cope with the breakdown was something we aimed to test in our evaluation.

Membership Management

Earlier empirical studies of users' home network management experiences have indicated that managing "membership" in the home network can be problematic. By membership management, we mean the tasks associated with getting new devices onto the network, and (potentially) excluding unwanted devices from the network. For example, adding a new device may require configurations at the new device (setting SSID, WEP keys, perhaps IP addresses and so forth) and potentially at the home network infrastructure (such as changing MAC access controls). Users who run "open" wireless networks (meaning networks without password controls) may find that a neighbor's device has joined their network, whether intentionally or not.

Eden supports membership management through automatic detection of devices, coupled with simple drag-and-drop operations to allow users to signal their intent when a new device is detected. Our system detects when a new device appears on either the wired or wireless home network. When a new device is seen for the first time, it appears in the "newly detected device area" outside the Home. In this mode, the new device is visible to the system, but not yet allowed to connect to the network (meaning that it can neither access the Internet nor other devices on the home network). If a user wishes to add this device to the home network, it can be dragged into one of the Rooms inside the Home (Figure 5). To remove a device from the network, users simply drag it out of the Home.

Viewing Network Traffic and Connectivity

In its default view, Eden only shows the spatial representation of devices within Rooms. However, network topology and traffic information—in a highly simplified form intended for use in common troubleshooting tasks—can be overlaid atop this representation. Controls in the Network Center region allow users to "Show Topology" or "Show Net Status" (Figure 6).

Enabling the topology and network status views overlays a series of visible *links* over the spatial representation. These
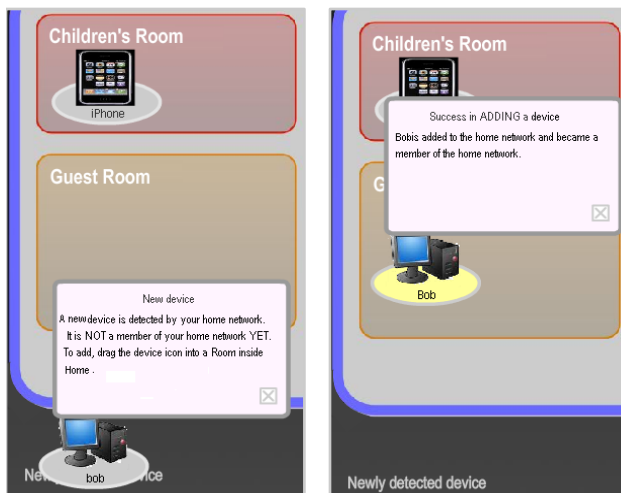

Figure 5. New device's appearing in the newly detected device area (left); Dragging the device inside the Home (right)
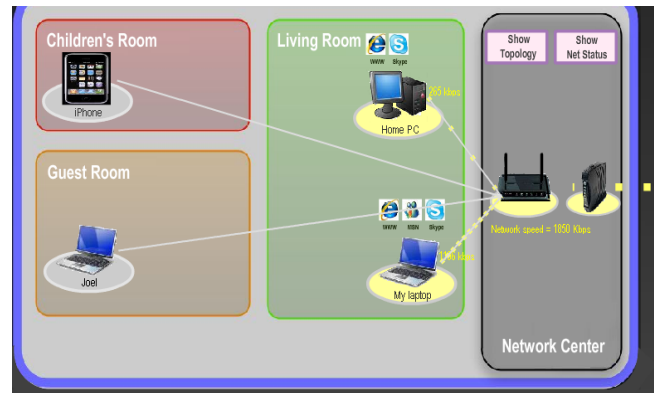

Figure 6. Enabling the 'Show Topology' and 'Show Net Status' options

links are animated flows of dots that indicate the traffic among devices in the network, and make visible the logical topology of the network. They also provide a means to get an at-a-glance view of connectivity and performance; they allow users to tell which devices are communicating, how much they are communicating, and whether or not the home is experiencing connectivity problems with the ISP. The "Show Net Status" enhances this view by showing which specific applications on each device (as determined by standard Internet Protocol port numbers) are generating or receiving traffic; these applications are depicted as icons above the originating devices.

Access Control, QoS, and Server Management

In most current home networks, users have few affordances for managing aspects of networking such as access controls (determining what devices can communicate with which other devices on the network), and quality of service (assigning priorities to devices or applications); even though users in our formative studies expressed a desire for the ability to control their networks in these ways, access control and QoS settings are often buried within complex router setup panels, when they are available at all.

Eden provides access to these concepts through an interface element called a *badge*. Badges are meant to associate particular properties with a device, or group of devices, in the Eden interface, much like people may place badges or stickers on real world objects to convey some property about them (such as price, or "this is broken"). Badges not only provide affordances for this class of network controls, making them visible and draggable, they also provide at-a-glance awareness of the network settings that are associated with client devices.

A fixed set of different types of badges are available (Figure 7). A number of access control badges allow users to restrict a device's access to certain resources on the network, and can be used for parental controls as well as more complex management of access controls. For instance, a parent may block all Internet access by a child's computer by dragging an *Internet Restriction* badge to the child's device; this badge then is visually attached to the icon until it is dragged off. Parents can also restrict certain websites, or certain networked applications, from being used via *Sites Restriction* or *Application Restriction* badges. When these badges are added, a pop-up window asks the user to

configure which specific websites or applications will be blocked. Finally, a *Devices Restriction* badge prevents the device it is attached to from connecting to *other* devices in the home network; this is useful, for instance, for guest machines that may need a connection to the Internet but should not have access to other devices in the home.

A different set of badges are used to alter QoS settings in the network. If a user wants to ensure that a particular applications (such as World of Warcraft, or Skype), or a particular device (such as a streaming media adapter) is not interrupted by other traffic, users can place a *Faster* badge on the device; similarly, low-priority traffic (such as peer-to-peer downloads) can be assigned a *Slower* badge to ensure that they relinquish bandwidth to other applications. These badges effectively group devices into three classes: high, low, and default. Each device within a class has the same priority as others in its class (thus, two devices with a *Faster* badge will be prioritized over ones with no badges, but have the same level of priority with each other).

Badges also leverage the spatial and grouping mechanisms in the Eden interface to allow users to express different granularities of control. The above badges, for example, can be placed on individual device icons, on a Room, or on the network itself. Placing a badge on a specific device only conveys the associated property to that one device; on the other hand, when a user puts a badge on a Room, all the devices in that Room are controlled, and when a user places a badge in the Network Center, all the devices in the home network are controlled. This allows, for example, users to easily prioritize the "work" traffic by dropping a badge on the home office Room depiction.

Eden uses badges for one other feature, intended primarily for advanced users. On current home networks, running any type of server at home (such as a web server, or simply sharing a folder of files outside the home network) is very complex, involving configuring firewall rules, configuring Network Address Translation (NAT) to pass traffic from the Internet to a certain machine in the interior of the home network, and so forth. Thus, Eden provides "server badges"—including *Web Server* and *File Sharing* badges—that users can associate with a machine on the home network. Doing so automatically configures NAT port forwarding and firewall rules to make the requested application on that machine visible to the external network.

While these badge types were suggested by our catalog of management tasks, we foresee badges being a useful interface element for possibly other tasks, such as media management between UPnP devices. We have not yet explored this notion further, however.

ADDRESSING THE IMPLEMENTATION CHALLENGE
As noted in the introduction to this paper, our goal with Eden was not merely to create a home network management *interface*, but also to create a fully functioning network management *system* that reliably and robustly implements the range of policy and monitoring controls exposed by the interface. There are, however, a number of challenges inherent in actually implementing the controls provided by the Eden interface.
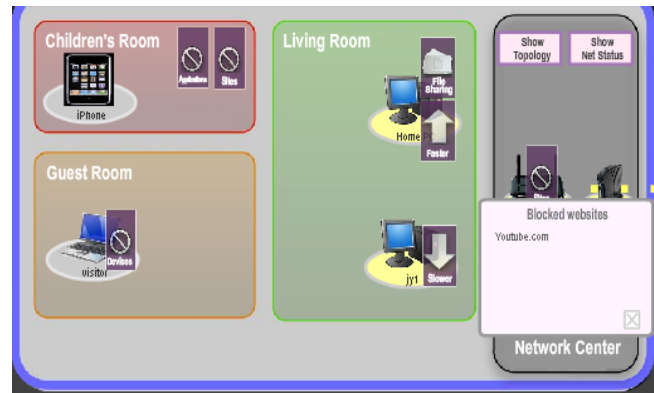

Figure 7. Placing Applications and Sites access control badges on the Children's Room, a Device access control badge on a visitor's device, and QoS badges on devices

One challenge arises from the deep heterogeneity of the home network. Unlike in corporate networks—in which support departments may have some control over the sorts of devices that are deployed onto their networks—home networks are a site of great diversity and experimentation. This means that a wide range of different device types are present—not just computers, but media devices, networked gaming consoles, digital video recorders, and WiFi-enabled mobile phones. This diversity immediately negates one of the possible implementation avenues common in the corporate world, which is to rely on specialized middleware running on each client device (such as an SNMP agent [19]) that allows it to be managed from a centralized tool; homes are unlikely to have such software installed, and creating it for every platform (including embedded devices and gaming consoles) is unworkable.

A second possible implementation approach is to allow Eden to control the settings on the existing home router, perhaps by "screen scraping" the web-based interfaces provided by such routers. This approach is also unworkable, however, largely because Eden provides a much richer set of policy controls than are available on most home routers. There is no way, for example, to implement high-level features such as Eden's access control policies using the rudimentary features available in most routers.

Thus, we implemented Eden as a custom Linux-based wireless router/access point, intended as a "drop in" replacement for the existing home router; the software we developed for the system can also run on PCs, as well as be flashed to the firmware of common consumer routers based on the Broadcom chipset, such as the popular "WRT" routers from Linksys. This system is fully compatible with existing IP-based applications and devices, and requires no special support from clients—indeed, it is transparent to other devices on the network.

By instrumenting the router—a privileged point on the home network—we can not only monitor all traffic in the network, but also enforce policy controls centrally. For example, the device has the ability to drop or restrict flows in response to access control settings, limit the routability of certain devices on the network, or throttle flows in response to QoS requirements. By exploiting this privileged position

in the network, Eden has access to—and the ability to control—not just traffic between devices and the Internet (both upstream and downstream traffic), but also between devices *on* the home network, all of which must communicate via the router, using either its wired or wireless interfaces. Note that while this implementation strategy cannot address every problem that exists in the home (misconfigured hosts, incompatible software versions, and so forth), it does provide an approach to addressing a wide range of management needs that can be implemented in the network.

Internally, the system uses common, low-level network management tools to effect changes; for example, the system uses *tc*-based traffic shaping to implement priority badges; server and access control badges are implemented via *iptables*, along with NAT and firewall rules. These facilities are exposed to the front-end interface through XML-RPC based communications channel built using Ruby. Requests issued by the interface are executed by reconfiguring *iptables* and *tc* and so forth.

The user interface portion of Eden is implemented in Adobe Flash CS 3 and ActionScript 3.0, and embedded in an HTML file that is served by our router. We pursued this web-based management approach for several reasons. First, it allows universal access to the management interface, since users can access it from any device in the network capable of running Flash: users simply enter the word *eden* in the address bar of any browser running on the home network; this request is detected by the router and returns the Eden user interface. Second, and although we have not explored this feature fully, a web-based approach offers the possibility of remote family, friends, or network professionals to participate in management of the home network, a practice that is followed by many householders [18]. Of course, whichever device attempts to load the Eden user interface must be able to connect to the router in the first place; however, this is no different than current systems that require that the router be accessible via a web browser in order to configure or troubleshoot it.

EVALUATION

In our evaluation of Eden we wanted to focus particularly on two related but separate issues: first, how well users grasped the overall user interface concepts provided by the system, and second, how usable and effective the system was in comparison to existing management tools.

Study Participants and Evaluation Methodology

We recruited 20 participants of ages ranging from 20's to 50's by word of mouth and by emails to a number of local organizations. We recruited mainly users without strong technical backgrounds, since they are the primary target of our system. Among these 20, five were self-described novices with no technical knowledge of networking nor experience with management; the devices they used at home had been set up for them by others in their households. Twelve were self-described intermediate users; they reported having informal knowledge of networking and could connect devices to their home network. In addition to these novice and intermediate users, we also included three self-described experts, with some form of

formal technical training; we added these users to better understand how well our tools would address the needs of those users who currently are most likely to undertake management and troubleshooting of the network.

For the experiment, we built a home network environment equipped with Eden and a range of client devices in our lab, which allowed us to conduct the evaluation in a controlled setting. One drawback of a lab experiment is that it does not allow evaluation in real home network settings, with the devices and configurations that participants are used to. Nonetheless, we chose a lab experiment because individual variation in home networks would have made it difficult for an in-situ evaluation to control for different device types, topology, and uses of the home network.

Conceptual Evaluation

In our conceptual evaluation, we wanted to get a qualitative sense of, first, whether users understood the overall structure of the interface and its various representations, and second, whether exposure to the Eden interface changed users' understanding of the network itself. For this, we used open-ended questioning about the conceptual and operational model of the home network. We then used a think-aloud protocol while users performed a set of basic management tasks with Eden. Users had no pre-evaluation instruction on the Eden user interface.

Overall, the basic spatial organizing concept of the Home worked well in conveying the home network and in facilitating management. Novice users in particular found the Home concept very familiar and intuitive; P7, for example, noted that the design was favored "Because I think of it [the home network] in very physical terms."

All 20 participants understood the intended association between device icons in Rooms and the physical locations of devices in the real house. However, two users (P1 and P3) inferred an association between device placement and access rights that did not exist. For instance, when a device was in a specific bedroom, these users thought it was only accessible by the owner of that bedroom; but when the same device was in a public space such as a living room, these participants viewed it as being accessible by anyone in the home.

With regard to our earlier questions about metaphorical breakdowns associated with mobile devices, all users except one preferred ownership-based placement for mobile devices, rather than common use-based placement or other approaches. However, one user noted that creating custom categories such as "mobile devices" or "general miscellaneous" might be useful.

Our participants largely grasped our intended mapping of the spatial boundary of the Home as the logical boundary of the home network, inferring that the devices inside were a part of the home network and that devices outside were not. However, several users had an overly literal interpretation of the spatial representation. For instance, P2 and P3 mentioned that devices appearing outside the Home might be wireless devices outside the house, perhaps in the yard or on the deck.

When asked to add or remove a device from the network, most users immediately moved the device inside or outside the Home based on their analogies of the on-screen representation with the home network. However, for several users, the fact that a device was inside the Home was not sufficient to indicate membership; these users emphasized the role of the topology display in giving a clear indication of the connectedness of a device.

All users liked the visual traffic map of the home network. This visual map contributed significantly to "teaching" the users about the basic structure of the network. During our study, ten users reported that exposure to the system showed them how network traffic is transferred from a computer in the home network to the router and then to the Internet, and believed that this knowledge would help them in "fixing" the network in the future. P1, for example, noted, "I feel like I (can) master home networking now. I can imagine how home networking works in my mind." Further, all five novice users and several intermediate users also learned the concept of bandwidth as a shared resource among devices on the network. For instance, an intermediate user, P9, stated, "I didn't realize that the router carries the total amount of the speed and the total amount of the speed breaks down depending on the number of computers that are using it." P7, a novice user, stated, "I'm so disappointed. I thought I had (an) infinite amount of network available to me".

Users used the badges effectively, although several initially tried ways other than drag-and-drop to associate a badge with a device, such as right-clicking a target device or a badge at the first trial. All users stated that they liked the easy visibility of the badges as a way to convey available functionality, and the ease of dragging and dropping badges to activate them.

In particular, participants found Room-based access control to be intuitive and very useful in real situations for managing groups of devices. For instance, P6, who has two children, stated that "For a child's room, let's suppose that there are three laptops. Then you don't have to do one at a time and one at a time. Sometimes, my child's friends come in. So I'm gonna put this guy right here [place the friend's laptop in the child's room] so that automatically all those controls that I've done are applied so I don't have to reconfigure for these kids."

Most users gained a sense of how to assign badges at different levels of granularity as they worked with the interface. For instance, P11 said "Before, I didn't know I could block an individual computer. Now if I put a badge here on a computer, I don't need to block the whole router and I can block an individual computer or I can block a living room (for a group of computers)."

Functionality and Usability Evaluation
In our next evaluation, we wished to test the effectiveness of Eden versus existing home management tools. Thus, we compared Eden with Network Magic (the only comparable home network management tool at this point), and with the tools built into a router and the Windows OS (specifically, the Linksys Wireless-G Broadband Router web interface

and the various network connection wizards and tools built into Windows). We selected tools built-in to the router and the OS since they were found to be the tools that most users relied on from our formative study.

To compare usability, we cataloged the tasks supported by the three tools and categorized them as described earlier. Then, we asked users to perform one or two tasks per category. Users had a 10-minute instructional session and a brief explanation of each tool. In this paper, due to page limits, we only briefly discuss the overall usability comparison results.

Figure 8 shows the tool preferences of the users from the usability evaluation. Seventeen out of 20 particpants strongly preferred Eden over the other tools. Two users preferred a hybrid of Network Magic and Eden. One novice user preferred Network Magic. The tools included with the OS and router were the last choice of every user.

The main features that led to this wide preference were the visual nature of the interface, and the lack of technical jargon: Eden is the most graphical of the tools, and thus seemed to provide better feedback and affordances for users' actions. In contrast, the OS- and router-supplied tools are almost entirely structured around text-based forms, with much technical jargon (this was noted by participants as an especially weak aspect of the Linksys router interface). Network Magic occupies a middle ground between these tools and Eden—it provides a visual map of devices, but all management tasks are done through text-based menus and dialog boxes that require several steps to accomplish a task.

The users who preferred Eden noted the integration of the device map and tasks as an advantage; the ability to group controls, by associating badges with rooms rather than individual machines, was a strong point for many of these users. These users also preferred the visual, drag-and-drop approach over Network Magic's wizard style. For instance, P6, an expert user who felt comfortable with both Eden and Network Magic, emphasized the visual feedback of Eden as its best part compared to the other tools. The wizard-based approach of Network Magic was described as "ineffective" and often "inefficient." Novice users had problems with task completion; for instance, four novice users failed to complete the wizard for adding a new device; for those who did accomplish the task, the time ranged between 30 seconds to several minutes. On the other hand, all users accomplished the task with Eden within five seconds.
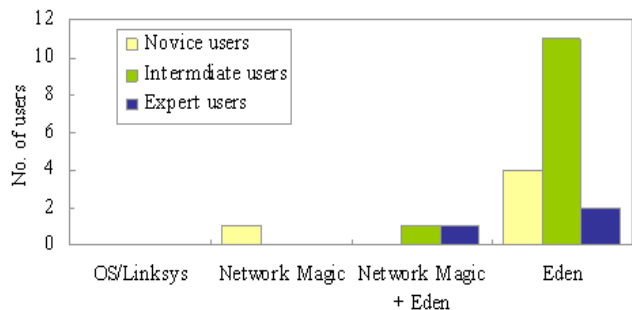

Figure 8. Users' tool preferences

Even though Network Magic removes some technical jargon (e.g. referring to devices by name instead of by IP or MAC address), it still was considered too complex by all but one of the novice users in our study, as well as by many intermediate users. For instance, intermediate user P11 said, "I don't like Network Magic because I have to read something that I don't understand." On the other hand, the three users who preferred either Network Magic, or a combination of Network Magic with Eden, liked the procedural nature of the tool's wizard-oriented interface.

Users had a stronger positive response to the access control features of Eden than we'd initially anticipated. In fact, Internet access control was the primary concern for study participants with children. These participants greatly valued this aspect of Eden, which gave them an ability they did not have at all before. P9, a self-described intermediate user and a mother of three, did not know of any technical means for restricting Internet usage by her children; her approach was to put the family desktop in her own room so that she could make ensure that it was used for appropriate purposes. Other users, such as P7 who has a 17-year old high school student, used access control for punishment, and suggested badges as a way to communicate among householders: "Badges could be different colors. There could be pink badges for Mom and blue badges for Dad that could actually indicate who did the blocking."

DISCUSSION AND CONCLUSION

In this paper, we have explored the challenges of exposing a largely invisible, infrastructure-layer technology using a highly visual, direct manipulation interface; these include the interaction challenge of producing workable interface abstractions for networking, as well as the technical challenge of providing control and instrumentation in diverse home networks. Eden provides a range of mechanisms for supporting end user management of home networks while retaining compatibility with existing IP-based applications and devices. While our evaluation demonstrates the advantages of the system, we envision a number of ways that this tool may be extended in the future; in the near term, we aim to explore the utility of the system for *remote* home administration, to support practices of family and friends in managing each others' networks.

The results from our formative study and our evaluation point to several areas that we think require further research. Perhaps most importantly, users' reactions to the access control features in Eden suggest that a better understanding of the dynamics of parental control—as well as tensions in the power relationships in the home—could provide insight into new ways to support home network access controls.

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