Building a Better Intercom: Context-Mediated Communication within the Home

Cory D. Kidd,[1] Thomas O'Connell, [1] Kris Nagel, [1] Sameer Patil[2] & Gregory D. Abowd[1]

[1]College of Computing & GVU Center
Georgia Institute of Technology
Atlanta, GA 30332-0280 USA
{coryk, thomas, kris, abowd}@cc.gatech.edu

[2]School of Information & CS Dept.
University of Michigan
Ann Arbor, MI xxxxx USA
patil@umich.edu

ABSTRACT

As we enable everyday environments with ubiquitous technology, there are many opportunities to support simple activities in useful ways. We are investigating how an environment made aware of the location and activities of its occupants can better support direct human-human communication. Specifically, we have instrumented a home to explore lightweight, spontaneous hands-free communication between residents in different parts of the home. Our working prototype demonstrates how existing technologies of voice recognition, indoor positioning and audio routing lay the foundation for the exploration of a variety of more intelligent alternatives to the traditional home intercom system. We show how context can be used to mediate the initiation and management of one- and two-way audio connections between residents, supporting a range of within-home conversational patterns. In this paper, we describe a variety of home communication scenarios and the general infrastructure we have built to explore them.

Keywords

Home, audio, ubiquitous computing, computer-mediated human-human communication, context-aware computing

INTRODUCTION

Human to human communication is an essential part of our everyday lives. Advances in communication technology have enabled anytime-anywhere connection between people. There are a wide variety of devices to communicate with family, friends and workgroup members who are distributed geographically. We use cellular phones when stuck in traffic, to advise others when we will be late, or at the store to call home to be reminded of what is needed. Instant messaging services connect us with on-line friends and relatives.

We are interested in promoting communication within a building, specifically a home, which is hands-free and allows for freedom to move about. In a domestic setting, family members will be collocated within the same building, but often will be unable to be heard using a normal speaking voice. In addition, a lack of knowledge of the whereabouts or activities of other family members can hinder effective and civil communication. Many households utilize intercom systems to facilitate conversations between remote parts of the home, but these systems have their drawbacks. They require one or both parties to go to specific parts of the house or hold onto a handset in order to communicate. They also offer little ability to direct communication to a person within the house when the location of that person is initially unknown.

In this paper, we will discuss the design and implementation of a better intercom system that results from the instrumentation of a home to facilitate flexible one- and two-way audio conversations. The intercom is further enhanced to react appropriately to relevant context within the home, specifically the location and activities of the residents. After motivating the need for such a context-aware communication system within the home, we will describe specific communication scenarios that we aim to support. The hardware and software infrastructure for the prototype intercom will be described and shown to provide a fairly general solution to exploring lightweight, hands-free audio communication. We will then show how context is used to mediate the human-human audio conversation. The result moves toward one of the goals of ubiquitous computing — causing the technology to disappear into the environment because of the implicit way it supports an everyday activity.

UNDERSTANDING INTRA-HOME COMMUNICATION

Longitudinal studies of census data on home computer ownership and usage show an increased use of personal computers across all demographic groups since 1984 and that the dominant use of personal computers is communication via the Internet [17]. Similarly, email was found to sustain ongoing relationships and strengthen some weaker relationships in an analysis of

home Internet usage [8]. This quantitative data shows the value of technology in supporting communication at home, but does not provide insight into how technology facilitates more direct, synchronous human-human communication, especially within the home itself.

However, one ethnographic study in the home highlights the value placed on communicative activities between collocated household members, although these are often in small time blocks and dispersed over multiple spaces within the home [10]. Another ethnographic study of home technology highlights the problem of "space overload," which states that when technology is fixed in a particular location, as opposed to being distributed throughout the home, problems can arise over shared use of the space [11]. This localization does not afford the interaction and coordination of activities common in the everyday routine of a household. These intra-home communication patterns and the desire to decentralize technology both suggest that any computationally enhanced communications system should be accessible throughout a home, instead of being centered on the few places that might contain a personal computer or even localized to special-purpose appliances hung on the walls. The social interactions within the household are better served by distributed technology throughout the environment, that is, through ubiquitous computing technology.

Limitations of Existing In-Home Intercom Systems

We have looked at several intercom systems to inform our exploration of intra-home communication. Intercom systems may be built into home telephones or operate as a completely separate system, sometimes integrated with a home security system. Intercoms most often support one-way audio connections, forcing an awkward protocol on the users in order to use a half-duplex technology for a conversation. More expensive intercoms incorporate two-way audio and monitoring capability [2]. Some intercom systems have hands-free operation, either through a headset, a foot control, or preset voice commands, such as "talk".

Intercoms directly support place-to-place communication. While this is appropriate for some communication patterns (for example, monitoring or broadcasting), it is not suitable for person-person communication that is very common in the home. To reach a particular person, the intercom requires either a broadcast to all stations or a search through a sequence of stations in an attempt to reach the desired person. This polling through the stations usually requires the caller to press a button for each station (even in most hands-free systems); the call recipient is then able to respond hands-free, as the caller will have already activated the audio connection. Once this connection between two individuals is made, they are tied to those station locations for the duration of the communication; they may not roam from station to station without explicitly resetting the communication path.

Another feature of today's intercom is the monitor mode, where every station may listen to a designated station. Any speaker will automatically be connected to the monitored station. In this mode the entire intercom system is listening to the specified location and is not simultaneously available for conversation between other household members.

We see the main limitations of existing intercom systems, therefore, as requiring too much explicit activity on the part of the caller to establish and maintain a one- or two-way audio connection to another person in the home. It is also intrusive, as the caller has no choice but to make an announcement to a particular location in the house. This can sometimes be a disadvantage, possibly disturbing an individual whom the caller would otherwise not wish to disturb. The caller is unaware of two pieces of important context:

- Where is the intended recipient located?
- What is the recipient doing, and is it OK to interrupt the recipient at this time?

A context-aware intercom system that could provide the caller with this kind of information would enable the caller to initiate only desirable conversations. Such an intercom can use context to automatically or manually mediate appropriate audio conversations. Other context, such as knowledge of ambient sound levels in the locations of the caller and recipient, can be used to set appropriate parameters for the conversation, such as an initial volume.

How people communicate within the home

To inform our design of the context-aware intercom system for the home, we interviewed eight individuals from six families concerning their communication preferences within the home. None of the interviewed families currently used an intercom, but two were prior intercom users. Four families had children at home; the other two were couples only. Four of the households were interviewed to gain insight into communication preferences within the home and past use of intercoms. From these initial talks, four communication scenarios were developed and presented to two other families, who were asked to predict their preferred method of communication interaction for each situation as it applied to their current home life.

We noticed several phenomena across the households:

- People prefer not to raise their voices at home. Four of the families explicitly said they tried not to "yell across the house" or volunteered stories illustrating the problems loud voices create, such as waking a

sleeping baby, inciting a dog to bark, or distracting household members. Sometimes, yelling does not even suffice for communication. A former intercom user regrets not installing one in a new home. In the old home, the intercom seemed redundant because the strong parental voice could be heard throughout. However, in the newer home, the parents' usual voice level was not enough to be heard everywhere, because of the larger floor plan.

- Several family groups reported pairs of family members are either in the same space at regular communication times or know where the other household members are when communication needs arise. This is consistent with ethnographic studies of the home where patterns of day-to-day activity are well defined [11], so that it may be expected to find the children in front of the television just prior to bedtime or in their rooms completing homework just before dinner.
- Intercom systems were not sufficiently valued in the home to justify their expense. This perception may result from the lack of affordance intercoms offer for the type of communication actually valued in the home, communication supporting emotional bonding, not simply assisting in routine tasks [10]. Families spoke of using an intercom to call all members to an activity or to monitor a child, but made no mention of more affective conversations over the intercom.

The last two observations suggest intercom systems are not necessary for facilitating family communication within the home, though the first observation certainly suggests there are times when current communication modes are either impossible or undesirable. Furthermore, one family specifically cited the annoyance of running through each station to locate the person with whom you want to speak. The need for a better intercom is illustrated by this family story in which Jamie wants to speak with Kim in another area of the home:

Jamie: Kim, where are you?

Kim: I'm here.

Jamie: (raising voice) Where?

Kim: (raising voice) In the guest bedroom!

Jamie: (raising voice) In the bedroom?

Kim: (raising voice) In the GUEST ROOM.

This sample exchange related in the interviews illustrates the ambiguity inherent in locating others, often while attention is on another task in the home. Existing intercom systems provide a systematic, yet cumbersome way to locate a person by checking every station.

SCENARIOS FOR A CONTEXT-AWARE INTERCOM

People communicate with each other in many different ways in a home. To better portray the communications patterns we hoped to support with a context-aware intercom, we describe some relevant usage scenarios in detail before presenting our prototype that supports all of these capabilities. In all of these scenarios, our model of interaction is made hands-free by providing voice interaction with the house intercom system.

Scenario 1: Broadcasting a message

Dad has finished preparing dinner and wants to call the rest of the family to the dinner table. He requests a broadcast announcement to the whole house by saying, "House, I would like to announce …" There are microphones embedded in the ceiling (or worn by the father) that pick up this request and process it. Dad waits for an audible signal from the house, a simple response, "Go ahead." and continues, "Everyone, dinner is ready. Come and get it!" In every room of the house, the message is heard through speakers embedded in the ceiling or walls. Dad ends the announcement by telling the house, "Stop the intercom."

Scenario 2: Monitoring activity

Often, we want to monitor activity in a remote part of the house. A classic example is the baby monitor. In this case, the parent would initiate the monitoring by asking, "How is the baby doing?" or "What's going on in the baby's room?" When the intercom receives this request, it determines which room the baby is currently in and creates a one-way audio connection from the microphone in the baby's room to speakers nearest the parent. If the parent moves to a different room, the baby monitor audio channel follows along, moving to the speakers closest to the parent who requested the baby monitor. When the parent no longer needs to listen in on the baby, he tells the house, "Stop the intercom."

Scenario 3: Having a conversation

From the kitchen, Mom sends Sally down to the basement to get some items from the pantry. Once Sally gets down to the pantry, she cannot find the items Mom sent her down to retrieve. Sally wants to ask for some clarification from Mom, but Mom cannot hear even if Sally yells. So, Sally instructs the house intercom, "House, I want to talk to Mom." Meanwhile, Mom has set up a baby monitor connection to her younger son, Joey. She can hear Joey crying, so she departs to the family room to care for him. When the house recognizes the request from Sally down in the basement pantry, it then locates Mom, who has now moved to the family room. The house knows that baby Joey is also in the family room, so tells Sally, "Mom is now in the living room with Joey. Do you still wish to speak with Mom?" Sally guesses that Mom is changing Joey's diaper

because he was heard crying before she went down to the basement. Though Mom's attention will be divided, Sally still wants to speak with her, so she responds, "Yes." A two-way audio connection is established between Sally in the basement pantry and Mom in the living room. Sally asks Mom to help her determine which items to bring up to the kitchen. During the course of the conversation, Mom finishes with Joey and returns to the kitchen to see what else she needs Sally to bring up from the pantry. The conversation between Sally and Mom continues uninterrupted as both move about the house. As Sally finally returns to the kitchen where Mom is, the house determines that their remote conversation has ended and automatically terminates the audio connection between them.

Highlights from the usage scenarios

These scenarios highlight the major features of the context-aware intercom. The intercom should:

- set up a variety of one- and two-way audio connections between locations within the house, including multiple connections at once;
- distinguish who is the initiator of a request (the caller) and who is(are) the intended recipient(s);
- mediate the initiation of an audio connection by providing adequate feedback to the caller to help him or her determine whether it would be appropriate to continue with the set-up of the audio connection;
- create audio connections that move appropriately with the movements of the caller and recipient(s); and
- terminate the audio connection based upon explicit request or other appropriate implicit cues.

PROTOTYPE INTERCOM DESIGN

Environmental Instrumentation

The initial context-aware intercom prototype has been installed in a real home on the edge of our campus. The hardware design consists of an electronically configurable audio system with the following components:

- Speakers: There are pairs of speakers mounted in the ceiling of each room throughout the house. This allows audio output of a conversation to any room where a person may be located.
- Microphones: Currently each person wears a wireless microphone while walking around the house. We have ceiling microphones placed in each room, but we require proper echo cancellation, not currently implemented, to address audio feedback for two-way conversations. Once addressed, we will move to the open-air microphone infrastructure.
- Audio Switch: The speakers and microphones feed into an audio switch. This allows us to control the input and output routing through a serial connection to a desktop computer. The audio switch supports simultaneous point-to-point connections (two people speaking or one person listening to another), as well as one-to-all broadcast. We are looking into other available hardware and software solutions that will give us more flexibility in the amount and type of connections we can create within the house (such as multi-party conversations across three or more rooms).
- Positioning system: We are using a positioning system from PinPoint Corporation, the 3D-*i*D® Local Positioning System [12]. This system is deployed over an entire floor of the house, giving readings at a room-level accuracy for tags worn by individuals.

Software Design

We are interested in rapidly prototyping and easily evolving the context-aware features of the intercom application. To facilitate these design goals, we designed the intercom software using the Context Toolkit [3, 14]. The Context Toolkit provides several useful abstractions for organizing the functionality of the intercom software and greatly eases the incorporation of sensed context. The overall organization of the software is shown in Figure 1.

Context widgets represent abstractions over sensors that hide details of how sensing and interpretation of the environment occurs. In our intercom application, the following widgets are used:

- Location: This widget is a wrapper around the entire PinPoint 3D-*i*D® Local Positioning System, providing an interface that delivers information automatically to interested software components when individuals leave or enter rooms in the house. As we incorporate other ways of getting location information in the house, we can easily add more location widgets.
- Speech Recognition: In the current prototype, each member of the household wears a wireless microphone that is connected to a dedicated PC running the IBM ViaVoice® software. We use the Java Speech Grammar Format [7] to designate grammars that the ViaVoice® engine will recognize. The Speech widget is used for other applications in the home, and for intercom requests it produces formatted context messages of the form: ID: "Jamie" COMMAND: "intercom," and DATA "2-way, Kim" or ID: "Dad," COMMAND: "intercom," and DATA: "broadcast".

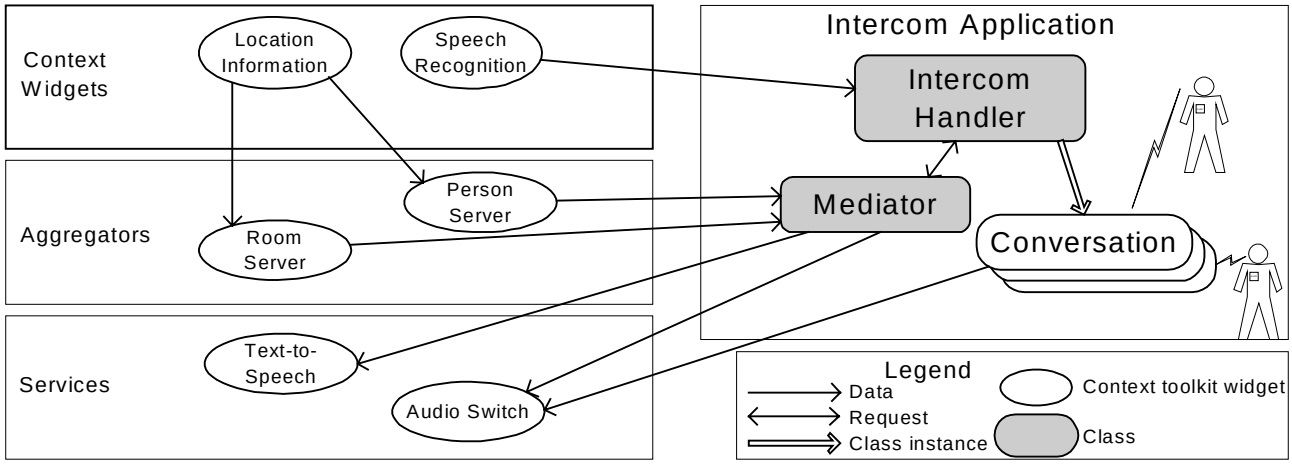

Figure 1 Intercom Application Software Design.

Aggregators collect information for relevant entities of an application. In the case of the intercom system, the relevant entities are rooms in the house (Room Aggregators) and residents of the household (Person Aggregators). The Room Aggregators currently collect information on who is in a given room. For example, the Kitchen Aggregator may know that both Mom and Sally are in the kitchen at the end of the Scenario 3 above. A Room aggregator can also hold other information in the room, such as appliance status, ambient noise level, or even an interpretation or prediction of a high-level activity (for example, dinner preparation). Person aggregators currently hold information about where a person is in the house. The Joey Server, for example, will contain the information that he is in the living room in Scenario 3 above. In that same scenario, the Mom Server would indicate that she is currently engaged in a conversation with Sally.

Services provide actuation to the intercom system. In this prototype, we take advantage of two services, the Audio Switch and a Text-to-Speech engine. The Audio Switch service allows us to send commands to the switch in the form of **Route(input, output)** to connect the microphone of one person to the speakers in some room. This service also allows us to adjust the volume of individual connections and remove connections when a conversation is finished. The Text-to-Speech service allows us to send spoken feedback to the users during their use of the system. For example, when a conversation is being requested, the system can tell the initiator "Go ahead" when the connection has been established and "Good-bye" when the conversation has been completed.

Every software component described so far can be shared by any context-aware application. The intercom application itself supplies the appropriate context-aware functionality, and consists of three components, the Intercom Handler, the Mediator and Conversation widgets.

The Intercom Handler subscribes to the Speech Recognition context widget with a filter so that it receives only commands recognized as intercom requests. When an intercom request is received, the Intercom Handler will query the Person Aggregator of both the caller and recipient to figure out which rooms are involved in the connection. The Mediator component then determines whether the connection should be established. If the connection is approved, a Conversation context widget is created to manage the connection.

A Conversation widget requests the Audio Switch service to make the appropriate one- or two-way audio connections. This widget also subscribes to the relevant Person aggregators of the caller and recipient to be informed when either changes rooms. If a room change is detected, the Audio Switch is instructed to alter the connection path in order to follow the caller and recipient. It also informs those Person Servers that each person is now engaged in a conversation by setting the value of an activity context variable. The Conversation widget subscribes to the Speech Recognition widget to be informed when either the caller or the recipient requests termination of the connection. When caller and recipient become collocated in a 2-way conversation, the conversation is automatically terminated.

The Mediator uses available context and simple heuristics and negotiation with the caller to determine whether an intercom request should be approved. Currently, it can query the Room Server where the recipient is located to determine if others people are also located in that room. If not, the intercom request is approved. If the recipient is not alone in the room, then feedback of this context is spoken back to the caller, as illustrated in Scenario 3. The caller is asked whether to proceed with the intercom request. This is an example of

informing the caller of relevant context so that she might apply an appropriate social protocol for continuing with the initial request

Evolving the prototype

The prototype context-aware intercom is a research vehicle for exploring intra-home communication patterns. As such, we must be able to evolve its capabilities as the underlying technology changes and as we gain better insight into how it can and should facilitate domestic communication. In this section, we will discuss how the design of the prototype with the Context Toolkit facilitates a variety of anticipated changes.

We can improve the system through the addition of new and different contextual information. The current prototype uses only location from a single positioning system as a form of context. In addition to the PinPoint 3D-*i*D® system, we plan to expand our location information throughout the house by installing the WEST WIND environmental tracking system [9]. As computational perception techniques for tracking multiple people in the home become available, we will use location systems based on audio and video processing. Any new positioning system can be encapsulated a unique Position widget in the context layer of the house. A resource discovery service in the Context Toolkit will automatically link both the PinPoint and WEST WIND Position widgets to any subscription request for positioning information, resulting in no change to the intercom application.

We currently have created a hands-free interface to the intercom using voice recognition of simple commands. We can explore alternatives to this decision without much difficulty. For example, in situations when speech interaction is more difficult (a crowded room with lots of ambient noise), initiation of a conversation can occur through different modes of interaction. For example, we can mimic the traditional intercom by creating interactive base stations on the wall that allow the caller to indicate a request to talk to some person by selecting their name from a list. A wireless PDA could also be used to provide a portable intercom control unit, in the style of the Star Trek communicator. All of these interaction modalities for initiating a conversation can be added simply by wrapping the functionality as a context widget that produces the standard intercom message, as defined above. The intercom application does not have to change at all, and all of these interaction modalities can co-exist. Similar variety is possible for terminating a conversation.

The most interesting aspect of the context-aware intercom is its ability to use context to mediate the conversations. This occurs during the initiation phase, when a caller tries to connect with some recipient and when a conversation is active and its participants change some part of their context. In the prototype described above, only location information is used to mediate the initiation of a conversation. When the recipient is collocated with one or more other people, the conversation request is not automatically executed, but requires further confirmation by the caller. It is easy to imagine other scenarios in which mediation is required. For example, if Mom is in her bedroom and the door is closed, or if she is on the phone or taking a nap, she may not want frivolous interruptions. If two people are in a room, are they engaged in a conversation, independently reading books or magazines, watching television, or playing cards? In any of these situations, different social protocols exist within the family unit that govern appropriate behavior. Simply informing the caller of this context will allow them to choose appropriately between interrupting the recipient or dismissing the request to talk. For monitoring requests, the relationship between the caller and recipient may also determine whether a child may listen in on a parent or not.

For some of these situations, it is possible to think of simple ways to sense the environment (door switches, appliance status through X-10, ambient sound level) and simple heuristics to combine independent context messages into higher level activity predictions. Other situations are not as straightforward to sense or interpret (Is the ambient noise a conversation between two people or simply the television?). The Context Toolkit supports the creation of Wizard of Oz widgets, the values of which are set by human operators who are able to interpret a situation correctly. To any context-aware application, the Wizard of Oz widgets are identical to widgets connected to real sensors. This allows experimentation in the absence of very sophisticated sensing and perception of human activity. The application developer can evaluate the impact of a proposed sensing technology in advance of it being available, a very valuable prototyping advantage in context-aware computing.

Mediation can also affect the parameters of the conversation, such as setting an appropriate volume level for a conversation based on the ambient sound level in a room. It would even be possible to negotiate whether audio or video connections (or both) should be used based on availability of output services.

RELATED WORK

Our exploration of context-mediated human-to-human communication extends current research in computer-mediated informal communication, audio-only social spaces, and use of context to mediate communication. There have been several desktop conferencing tools to support informal awareness, such as Portholes [4] and Montage [16]. While each of these provides some

situation awareness and a lightweight interface, each is a desktop application designed for distributed workgroups and requiring explicit user interaction with the desktop box, not as appropriate to the home. These systems provide computer-mediated communication through the existing network of computers, but our intercom is characterized by its communication through an aware-environment. Our exploration of human-human communication is influenced by the concept of environment-mediated communication (EMC), where an instance of the real-world physical environment becomes part of the communication sequence [5]. The design space of EMC was motivated by the use of mobile devices providing location-independent computer-mediated communication. While our intercom is not a mobile device, it provides mobile conversations between users within a specific locale, in this case the home. The context-aware intercom design is influenced by the positive social interactions with desktop computer-mediated communication and the environment-mediated communication framework.

Thunderwire, a lightweight and always-on audio-only space, promoted informal and impromptu social interactions [1]. However, the interface to the space did not provide sufficient cues identifying who was present or to remind users to disable the system when privacy was desired. The context-aware intercom is not always on, the connection persists for the duration of the conversation, which can be explicitly (through voice command) or implicitly (as the result of collocation or other context-related activities) terminated. This affords a more private conversation, since those hearing the conversation are those in the same rooms of the house as the users. Our intercom is designed to assist communication within a pre-existing social entity, the household, where the identity of those present is usually known. By providing mediated communication based on location and activity information, our intercom provides a more private connection between users.

Talking in Circles, another audio conferencing environment supporting natural interactions, provides spatial cues to ameliorate some of the problems with group membership [13]. It uses lightweight multi-modal communication to focus on social communications, enabling a cocktail-party-like atmosphere. Initial use shows it enhances the natural fluid aspects of conversation and response to use is favorable as long as the display and audio are synchronized. The spatial cues offered in this desktop environment enhance the moving about between groups and the dynamic aspect of the communication. Our intercom also uses a lightweight communication mechanism. It is not focused on building a social conversation, rather it attempts to enable communication in an existing group. The visual representation of proximity and audio volume may be useful in evolving social interactions, but the intercom's ability to reveal location and activity of a household member better fits the notion of ubiquitous tools in the household.

In addition to the social interaction within audio environments, the use of contextual information to enhance communication has been used in other research. Context-Call provides the caller with context information for the person they want to call [15]. Once the potential caller has this context information, the application allows the caller to decide the mode of communications, continue the call, leave a message, or even cancel the call. Each person explicitly sets the context information, so the accuracy of the context depends upon the person. People may forget to update their situation info or may provide an inappropriate context. Instant messaging applications, such as ICQ [6], also provide various context modes to indicate a person's availability, such as away, busy, or available. Unlike Context-Call, ICQ provides some support for automatic setting of context. It can automatically set the context for several modes, but it ultimately suffers from the same need for explicit user action. Our intercom is designed to benefit from both explicit interaction and implicit cues given by sensed and interpreted context. This context is used by the application to promote more socially appropriate mediation of requests.

CONCLUSIONS

We have presented the design and implementation of a human-to-human communication system modeled after a home intercom system. This intercom system has been designed to support an extended research agenda on intra- communication. The main contributions of this work have been:

- the motivation for a better intra-home communication system than traditional intercom systems;
- the use of context sensed from the environment to mediate the initiation, management and termination of human-human one- and two-way audio conversations;
- the development of a research prototype that can easily endure the changes in technology and mediation strategies that are expected to result from future evaluations in the context of real use; and
- a demonstration of how ubiquitous computing technology can be targeted toward a more invisible interface supporting an everyday activity.

Our immediate research goal is to subject the prototype intercom system to user evaluation in domestic settings, so that we can learn quickly what changes in mediation

strategies are appropriate and what forms of context we need to automatically incorporate into our home setting. There is no reason to limit the intercom application to intra-home communication and we can see many opportunities for a context-aware intercom that works between homes and even within and between office buildings.

REFERENCES

1. Ackerman, Mark, Debby Hindus and Scott D. Mainwaring, (1997). "Hanging on the 'Wire: A Field Study of an Audio-Only Media Space. *ACM Transactions on Computer-Human Interaction*, Vol. 4, No. 11, March 1997, pp. 39-66.
2. Colombo, Allan B., (2000) Get Connected. *Security Distributing & Marketing*, Newton, March, Vol 30, 4, pp. 51-52.
3. Dey, Anind K., Daniel Salber and Gregory D. Abowd. (1999) A Context-based Infrastructure for Smart Environments. In the *Proceedings of the 1st International Workshop on Managing Interactions in Smart Environments (MANSE '99)*, Dublin, Ireland, December 13-14,. pp. 114-128.
4. Dourish, Paul and Sara Bly, (1992) Portholes: Supporting awareness in a distributed work group. In *Proceedings CHI '92*, pp. 541-547.
5. Gellersen, Hans-Werner, Michael Beigl and Albrecht Schmidt. (1999) In *Proceedings of SAC (SAC '99)* San Antonio, Texas, pp. 416-418.
6. ICQ ("I Seek You") homepage. Available at: http://www.icq.com/
7. Java Speech Grammar Format Specification. Available at http://java.sun.com/products/java-media/speech/forDevelopers/JSGF/index.html.
8. Kraut, Robert, Trdas Mukhopadhyay, Janusz Szczypula, Sara Kiesler, and William Scherlis. (1998) Communication and Information: Alternative Uses of the Internet in Households. In *Proceedings of CHI '98*, pp. 368-375.
9. Lyons, Kent, Cory D. Kidd and Thad E. Starner. (2000) WESTWIND: Georgia Inst. of Technology GVU Center Technical Report GIT-GVU-TR-00-15. September.
10. Mateas, Michael, Tony Salvador, Jean Scholtz and Doug Sorensen. (1996) Engineering Ethnography in the Home. In *CHI '96 Companion Proceedings*, pp. 283-284.
11. O'Brien, Jon and Tom Rodden. (1997) Interactive Systems in Domestic Environments. In *Proceedings of Designing Interactive Systems (DIS '97)*, Amsterdam, The Netherlands, pp 247-259.
12. PinPoint Corporation. 3D-iD® Local Positioning System. http://www.pinpointco.com.
13. Rodenstein, Roy and Judith S. Donath. (2000) Talking in Circles: Designing A Spatially-Grounded AudioConferencing Environment. In *Proceedings of CHI '2000*, pp. 81-88.
14. Salber, Daniel, Anind K. Dey and Gregory D. Abowd. (1999) The Context Toolkit: Aiding the Development of Context-Enabled Applications In *Proceedings of CHI'99*, pp. 434-441.
15. Schmidt, Albrecht, Antii Takaluoma and Jani Mäntyjärvi. (2000). Context-Aware Telephony over WAP. Springer-Verlag, London, Ltd., *Personal Technologies* (2000), 4. Short paper presented at *Handheld and Ubiquitous Computing (HUC2k)*, September.
16. Tang, John C., Ellen A. Isaacs and Monica Rua. (1994) Supporting distributed groups with a Montage of lightweight interactions. In *Proceedings of CSCW '94*, pp. 23-34.
17. Venkatesh, Alladi, Eric Shih, and Norman Stolzoff, (2000). A Longitudinal Analysis of Computing in the Home. In *Proceedings of International Conference on Home Oriented Informaics and Telematics, (HOIT 2000)*, Wolverhampton, UK, pp. 205-215.