

Spatial Aspects of Mobile Ad Hoc Collaboration

by

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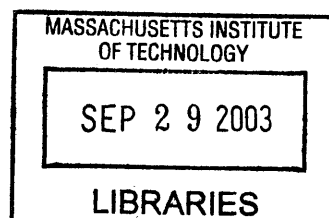
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Abstract

Traditionally, communication devices are designed to overcome distance in space or time. How can personal mobile tools augment local interaction and promote spontaneous collaboration between users in proximity? Mobile ad hoc collaboration is an emerging framework that attempts to answer this question.

This thesis reviews current research in mobile ad hoc collaboration, explores its precedents in art, and examines the enabling wireless communication and location sensing technology. It then proceeds to consider location, proximity and spatial organization as major factors in the development of interfaces and applications within the framework. The importance of seamless transitions between face-to-face communication and mediated communication is emphasized, and the principle of ad hoc communication group formation on the basis of proximity is proposed. The principle is demonstrated in a prototype wearable system for synchronous voice messaging.

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Chapter 1. Introduction

1.1. Rationale and Objectives

On March 10, 1876 Alexander Graham Bell called his assistant waiting in a room downstairs, “Mr. Watson, come here! I want you!” Such were the first words transmitted over the telephone line. According to some accounts, the inventor accidentally spilled acid on his clothes. His words conveyed a sense of emergency to a nearby person. History has preserved a record of the incident, however the telephone was designed to connect people in remote places. Originally conceived as the “harmonic telegraph”, it was intended to link stationary terminals across long distance.

In 1939-1940 Galvin Manufacturing Corporation, a company today known as Motorola, developed the first handheld two-way radio for the U.S. Army Signal Corps. The version that went into production, SCR-536 Handy-Talkie, was widely used in World War II. It is believed that the capability of mobile personal communications introduced by the device was a decisive factor in many Allied victories (M. Hall, n.d.). Handie-Talkie, an AM-band device weighing 2.3 kg, had a range of 1.6 to 4.8 kilometers. To turn a Handie-Talkie on, one would pull the antenna on the radio out. To turn the device off, one would push the antenna back.

The FM-based SCR-300 Walkie-Talkie radio followed in 1943. Switching bands helped increase the range of the radio. More importantly, FM radios were not prone to interference from other radio signals, atmospheric phenomena and electrical noise of artificial origin, which impeded AM communication, where high power had to be used by the radio transmitter to address the problem. The result was better signal quality and a promise of reduced power consumption and improved battery life. The SCR-300, however, was a crude first version of

personal two-way FM communications technology, implemented as a backpack weighing almost 16 kg (Farley, American personal communications, n.d.).

Half a century later cellular telephony has made mobile personal communications ubiquitous. However, to date the effect of the technology on the face-to-face interactions that play an important role in our life and are vital for collaboration and coordination of work activities (Bellotti & Bly, 1996) has been limited. It is well known that one of the primary reasons why mobile telephones are purchased is for safety, and yet they are used to summon help from afar whereas it might be available in the vicinity.

The problem that is addressed by this thesis is the poor service modern communication tools provide their users poorly in situations at the transition between omnimodal face-to-face interaction and conditions requiring mediation. Whereas little about today's radio technology prohibits the employment of a communication tool in such situations, complexity and counterintuitive organization of user interfaces often discourage users from resorting to the tools where they otherwise would be desirable. A good example from daily life is communication within the home. Even though each household member often has a personal wireless handset, to talk to somebody a couple of rooms away, one will typically visit there. This is much simpler than locating the handset, remembering how to use this or that function, recollecting numbers, pressing successions of buttons and holding the device next to one's ear.

A critic might say that this may not always be convenient, but why is it a real problem? As it is often the case with communication systems, existent issues become particularly salient in connection with occurrences threatening public safety. The tragic events of September 11, 2001 have drawn the public attention to the interoperability issues caused

by imperfection in the design of communication systems used by the firefighters, police, and emergency medical service personnel¹.

The reaction of the general public and decision-makers to the suddenly revealed weaknesses has been to invest in replacing existing analogue communication infrastructure and communication devices with new digital ones (see, e.g., Scannel & Davis, 2003, March 17). This will help resolve problems associated with bandwidth congestion in the radio spectrum that surfaced, increasing communication reliability. We argue, however, that this problem is only the tip of the iceberg. Hidden is a plethora of intimately interwoven issues of interface design and network organization carrying paramount importance to the daily life of every individual in the mobile age.

1.2. Thesis Overview

At the center of the argument developed in this thesis are issues of network organization. Taking the decentralization stance, in Chapter 2 we discuss mobile ad hoc collaboration, an emerging research framework concerned with the design of collaborative applications for decentralized self-organizing networks of personal mobile devices where connectivity depends on the distance between the users. As envisioned by Kortuem, Gellersen, and Billingham (2002), the framework emphasizes a human-centric rather than network-centric perspective, therefore we dwell on the manifestation of the network organization at the interface of the mobile communication device.

Developing this line of argument, Chapter 3 considers spatial aspects of mobile ad hoc collaboration. Starting with self, we turn to self in relation to others, then to ways in

¹ An extensive list of news publications dedicated to the problem can be found at the web-site of the Public Safety Wireless Network (<http://www.pswn.gov/newsroom.cfm>), a newly formed U.S. government program aiming “to promote effective public safety communications and to foster interoperability among local, state, federal, and tribal communication systems.”

which the physical environment affects user mobility on different scales. Seeing the excessive complexity of modern user interfaces as a major current problem, we suggest tackling it by taking advantage of the well-established fact that human perception is fundamentally spatial. If the organization of the communication network dynamically reflects spatial organization, the user interface can be simplified. In a sense, we attempt to rethink the idea of cellular tower or micro-cell in the context of user-centered communication. We assume a cognitive perspective on location and proximity in a search for good reference marks to guide “cell” formation.

As a practical matter, we propose to form communication groups automatically on the basis of proximity as it is structured by the spatial organization, while excluding users from mediation where it is redundant because the users are within hearing distance. Chapter 4 presents the concept of a wearable system for proximity-based audio communication and some scenarios where we believe its use can be highly beneficial. We suggest a wearable walkie-talkie augmented with space-sensing capabilities and consider advantages and disadvantages of offloading interface complexity onto the spatial context, touching upon new social situations that would result from the use of such a device. We also describe an implementation of the prototype system called upon to give a quick reality check to the idea, talk about previous prototypes that led to this particular design and challenges associated with its implementation and evaluation. A summary and a list of references conclude the thesis.

Chapter 2. Mobile Ad Hoc Collaboration: an Emerging Framework

2.1. Some Definitions

Mobile ad hoc collaboration is an emerging research framework concerned with augmenting ad hoc interactions and promoting spontaneous collaboration between users of mobile devices. Its special focus is on human factors issues related to the design and evaluation of collaborative applications for mobile ad hoc networks, covering ethnomethodological research into interaction under conditions of mobility and analysis of social impact of developed systems and applications. The framework was first proposed in the Workshop on Mobile Ad Hoc Collaboration of the ACM CHI 2002 Conference on Human Factors in Computing Systems (Kortuem et al., 2002).

A mobile ad hoc network (MANET) is a decentralized self-organizing network formed by mobile devices. Connectivity in such a network is transient as it depends on the distance between the devices. No fixed infrastructure is required for network operation. Some authors prefer the shorter “ad hoc network” to the more descriptive “mobile ad hoc network”. “Ad hoc wireless network” can also be used in the same sense. Such usage blurs the distinction between the mobile and stationary devices forming the network, however the distinction is not necessarily that important. While ad hoc networks will be predominantly mobile, they will clearly incorporate a certain number of fixed nodes to allow for the interoperation between the given ad hoc segment and the fixed infrastructure of the wired Internet (or another wide area network relaying long-distance traffic).

A mobile ad hoc network is usually seen as comprised of autonomous nodes interacting as peers. It is not entirely clear what devices can see (and talk to) what other devices as users

navigate through their day, which makes a peer-to-peer architecture is an obvious choice for MANETs. Moreover, peer-to-peer architecture is more generic than client-server or master-slave and thus can be used to emulate the latter two in scenarios where client-server or master-slave architecture may be preferred.

Technically, scenarios of interaction in mobile ad hoc networks encompass communication between users in different places. Mobile ad hoc collaboration, however, puts an emphasis on local interaction. Chance encounters between humans often spark creative exchanges and cooperation on the spur of the moment. Computers can help promote such unplanned social situations arising out of physical proximity between their users. They can also empower the users to take better advantage of chance encounters.

2.2. Existing Applications

Most work on collaboration is about dedicated meeting places or planned collaboration. Research into the collaborative applications for mobile ad hoc networks proper has so far been limited.

Developed applications alert the user to the presence of friends and colleagues (Holmquist, Falk, & Wingström, 1999), facilitate the exchange of personal information (Kortuem, Segall, & Cowan Thompson, 1999), support coordination tasks like trading delivery tasks and impromptu MP3 file sharing (Kortuem et al., 2001), identify people the user wants to meet using a match making algorithm (Terry, Mynatt, Ryall, & Leigh, 2002), or suggest alternative dining options to a group of people on the basis of individual preferences (McCarthy, 2002).

Holmquist et al. (1999) proposed a mobile interpersonal awareness device serving as “a contact facilitator rather than a mediator”. Four prototypes called Hummingbirds were

created. Using a 433.92 MHz band radio transceiver, each Hummingbird continuously transmitted its identification code, while listening for codes of other devices approximately in the radius of 100 meters. When Hummingbirds detected each other, they started to hum and showed IDs of Hummingbirds they detected on a 2-by-8 character LCD screen. Testing in different settings revealed that users found the functionality of the devices compelling, though they expressed more enthusiasm in new surroundings than in familiar environments.

Lovegety (Bleep at first sight, 1998, May 15), a commercial matchmaking device introduced in Japan in 1998, was equipped with color display lights to indicate the user's mood and a high-pitch bleeper for alerting potential partners when they would find themselves within 4.5 meters from each other. 350,000 Lovegetys were shipped in two and a half months following the product's initial release.

Kortuem et al. (1999) described Proem, a wearable system supporting informal collaboration between individuals who never met before or don't know each other. Each user defined his or her profile in advance. Proem was equipped with a radio transceiver board sensing other systems within 2-3 meters. When users were physically close, a profile exchange took place. A record of encounters was kept.

The application is similar in its functionality to that of Lovegety described above and "thinking tags" (Borovoy, Martin, Resnick, & Silverman, 1998), wearable devices serving as electronic nametags that use infrared to exchange information about users in a face-to-face conversation in order to determine and display the relationship between them. However, Lovegety didn't keep a record of interactions, while thinking tags were

intended to augment a face-to-face conversation rather than a chance encounter not necessarily implying speech communication.

Kortuem et al. (2001) presented Proem as a middleware system for developing mobile ad hoc networking applications. Among applications discussed were coordination tasks, for instance, delivery tasks trading, as well as ad hoc MP3 file sharing.

Terry et al. (2002) implemented Social Net, an interest matching application inferring a match from patterns of user collocation over time. If user A knows users B and C, but B and C don't know each other, Social Net will suggest it to user A to introduce them if it notices that B and C are often seen "near" each other. The hardware used in the project were Cybiko devices. The multifunctional text-based mobile devices introduced in 1999 by Cybiko, Inc (n.d.) employed a proprietary operating system (CyOS) and a proprietary radio communication protocol (CyRF) allowing the devices to communicate with other devices within the range of 50 meters indoors and 100 meters outdoors.

McCarthy (2002) implemented Pocket RestaurantFinder, a prototype system providing alternative dining options to a group of people on the basis of individual preferences. The system worked in a kiosk and on a handheld (Palm computer). In the handheld scenario, users could exchange their preset preferences by using Palm's infrared beaming capability.

Wiberg (2001) explored ways to provide seamless interaction support in between mobile meetings. To this end, RoamWare was created as an architecture that helped users to integrate spontaneous mobile communication and mediated communication into a series of interactions. Comprising a desktop module and a PDA module with a custom radio

communication board, the system implemented “dynamic addressing” based on interaction histories allowing users to re-establish physical meetings in the virtual realm. Certain applications developed for the virtual realm can be adapted for use in MANETs to augment interaction between mobile users in physical proximity. Yenta, a system developed by L. Foner (1997), was an Internet-based system of distributed agents that clustered users on the basis of their interests and allowed users to send messages to other users as well as to the clusters they belonged to. One of Yenta’s scenarios was promoting collaboration within an organization by matching people a few offices away who were applying similar methodology or working on the same problem without knowing it. While Yenta was a desktop-based application and relied on standard wired network infrastructure, an application for MANETs could be created along similar lines. The same applies to the agent-based mechanism for reputation management proposed by Yu and Singh (2002).

As we will be discussing below, modern wireless networks with broad coverage are not MANETs. At the same time, some collaborative applications designed for cellular phones and other wireless devices can be re-implemented for MANETs.

Pirates! (Falk, Ljungstrand, Björk, & Hansson, 2001) is a mobile game utilizing location information. Specifically designed for users co-present in a physical space, the multi-player handheld game designates every player as a captain of a ship. Possible objectives include finding treasure, trading with aboriginal populations of the islands, and fighting other ships. RF beacons placed in arbitrary spots in the physical space manifest islands forming the archipelago where the game unfolds. As users move through the space, their

handheld computers detect islands and other users in proximity using radio sensors, which triggers game events. Wireless local area network is used for communication.

BotFighters by It's Alive! (n.d.) is a commercial location-based SMS game for GSM mobile phones that takes advantage of Global Positioning System (GPS). Users play against others in their vicinity, chasing them out in the street. Released in 2000 by the Swedish company "It's Alive", the game mixes action and role-play ingredients. It has been highly successful in Sweden, Finland, Ireland, and Russia where mobile operators offer it.

2.3. Precedents in Art

Some of the earliest and truly original demonstrations of the persuasive potential of communication seamlessly conjoining mobility, face-to-face interaction, and mediation were artistic forms. Alien Staff and Porte-Parole, vivid artifacts created by Krzysztof Wodiczko in 1992 and 1994, enabled otherwise marginal and disregarded individuals like immigrants and homeless people to address anyone in the public space (Wodiczko, 1999). Symbolic form of the smart artifact, the pre-recorded multimedia program, and the presence and performance of its owner all attracted attention of passers-by.

Computer augmentation of spatially localized mobile interaction as well as social preconditions and consequences of such augmentation was anticipated in art long before they became technically feasible. Research into mobile ad hoc collaboration and wearable computing was most notably pre-empted by ideas and practices of Situationists International and Archigram, radical art movements popular in the 50's, 60's, and 70's.

Situationists believed that the experience of the urban space is dynamically constructed in the course of its playful and purposeless exploration. They developed and cultivated the practice

of so-called “stroll” or “drift” (French “*la dérive*”). Henri Lefebvre, a formative influence and close friend of the Situationists, described the derive in the following way.

In the city one could create new situations by, for example, linking up parts of the city, neighborhoods that were separated spatially. And that was the first meaning of the derive. It was done first in Amsterdam, using walkie-talkies. There was one group that went to one part of the city and could communicate with people in another area (Lefebvre, 1983).

Guy-Ernest Debord and Jacque Fillon stated in an early Situationist manifesto that the necessity to distinguish between leisure and reality once established in brick and mortar by the functional approach to urban planning was embarrassing (Debord & Fillon, 1954). Attempting to inspire creation of new spatial practices, they called for new games, joyfully foretelling “inevitable” economic and social upheavals that would bring them. Ludic perspective on urbanism was also characteristic of Archigram, a movement formed by six renegade British architects in early 60’s. The group took its name from “Architectural Telegram”, a magazine that served as its voice enunciating that architecture should become an instrument of social progress. The overall direction of the movement as manifested in its then fantastic concepts was toward adapting architecture to the technological and social changes, making it more convenient for the individual. Archigram thus promoted artifacts for nomadic lifestyle, such as Suitalon, a housing one wears on one’s back, or Cushicle, an inflatable body suit containing food and water supplies as well as radio and television. In the end, the city would come to the person and not vice versa, either as a happening simulating urban experience (Instant City), or outright as huge animated forty foot tall building-like structures roaming about on pullout legs (Walking City, NY).

2.4. Social Issues

Interface organization and computing architecture have profound effects on social interaction, but don't tend to be grounded in it. As dramatically expressed in the late 80's by Richard Stallman, founder of the Free Software Foundation, "If I had been developing proprietary software, I would have been spending my life building walls to imprison people" (Moody 2001, p. 29). Deeply personal for Stallman, the comparison between software and brick and mortar walls might have sounded to many as a metaphoric one back then. However, in the last decade its literal character became evident as the triumphal march of Internet and mobile communications stressed the core role that information appliances and networks in their specificity play in reshaping the physiology of the modern megalopolis (Mitchell 1995, 1999, to appear).

To demonstrate the potential impact of collaborative peer-to-peer applications for MANETs, authors who belong to the software world typically invoke the spectacular success story of Napster (see e.g., Left, 2001, January 29). The peer-to-peer Internet-based system for file sharing empowered Net users to make data on their hard drives searchable and available to the network at large without much effort. Its introduction marked drastic changes in the landscape of data exchange on the global network at a speed that surprised many.

Difficulties began when it turned out that a considerable proportion of files people shared contained copyrighted material, such as books, music, video, and licensed software. Organizations representing the copyright owners started a legal campaign against the "piracy" in Napster's network, which culminated in Napster's shutdown made possible by the reliance of the generally decentralized system on a centralized lookup service. New peer-to-peer networks such as Freenet (visited June 26, 2003) have been designed to achieve a

higher degree of decentralization so that they are less vulnerable to unfavorable outcomes of legal proceedings in more austere jurisdictions protecting strictly centralized schemes of information distribution.

It should be noticed that web and ftp offered almost as much freedom for data dissemination as peer-to-peer file exchange networks. The real difference was in near real-time updating of information on data availability, important for accessing files on hard drives of computers that are up and visible to the network only for limited periods of time. Napster's appearance also roughly coincided in time with a manifold increase in bandwidth available to an average Internet user as broadband networks started to be deployed at the "last mile", which opened the option of multimedia and software exchange to a much larger audience of netizens.

This coincidence made the new possibilities opened by the equalization of transient and permanent network nodes at the user interface level more visible, prompting to suggest that decentralized and localized interaction between individuals will play an increasing role in the future.

Adoption of mobile ad hoc networking naturally leads to a serious reorganization of information flow and ensuing changes in social patterns. Mobility as such naturally suggests decentralization and ad hoc interaction. We believe that it is the design of mobile devices more than social convention that significantly influences distance patterns in communication. Interfaces and architectures currently dominant in the world of mobile telephony either don't encourage local interaction or stand in its way.

Everybody these days is all too familiar with the problem of people talking on the cell phone in a public space. They often argue that it signifies the erosion of privacy. A more careful observer can see that it is rather the erosion of public space and its code of behavior by the

private space (Harper 2001, p. 244). However, the apparent lack of consideration to each other on the part of cell phone users is in the end nothing more than the manifestation of a shortfall in the design of communication devices that under certain conditions render their owners socially inappropriate. When loudly alarming the user to an incoming call, the cell phone knows little about the user's current social situation. When it comes to outgoing calls, instead of increasing the user's awareness about the environment, other people in it, and possibilities for local face-to-face interaction, the device encourages the use of the virtual phone book. The phone book is detached from the immediate user's context, and in most cell phones it is the only element of the interface affording easy call setup.

If introduction of new interfaces and architectures for mobile devices leads to the creation of new social situations, appropriate use of technology should warrant that the new situations are as much compatible with previously established norms and practices as possible. One obvious aspect in which smart devices can often be improved is by passing the control to the user when asked. This is Asimov and Campbell's wrongfully ignored second rule of robotics (Asimov, 1942). Regardless of how deep the devices' contextual awareness is, just the time of day or much more than that, their "smart" components are still in the business of intelligence augmentation rather than artificial intelligence. In view of a robot's limited ability of judgement, the application of the first rule should also be ultimately relegated to the user.

2.5. Enabling Technology

2.5.1. Wireless Communication

Advances in modulation made since World War II drastically changed the range of technologically feasible scenarios involving wireless communication. Most

widespread wireless communication technologies utilize electromagnetic waves in radio frequency (RF) and infrared (IR) ranges. Although the same information encoding techniques can generally be applied to sound and ultrasound, they have so far seen less use.

The differences in the character of propagation of RF and IR waves make it possible for an application to have a significant control over the distance of communication with RF and the direction of communication with IR that requires line of sight between communicating devices. RF spectrum is scarce, and its utilization is meticulously regulated by international authorities under the umbrella of the International Communication Union (ITU). Historically, the way to work around the technical issue has been to promote one-way radio communication for the consumer market and to impose strict licensing rules for the professional use of radio transmission. Such media forms as radio and television broadcasting in part owe their popularity to such policies that are still in force.

Cellular radio introduced to the American and European markets in 1980's relieved technical limitations on the number of radio transmitters by leveraging the condition of their distribution in space imposed by most applications as well as digital modulation techniques. The developments opened unprecedented possibilities for personal two-way radio communications.

The application that propelled the innovations and was the first to take advantage of them was telephony. A plethora of standards emerged to support the nascent mobile telephone networks, of which the European GSM (Global System for Mobile

communications) was the first one that permitted a cellular user in one country to operate in another country with the same handset.

Pressure on mobile telephony coming from email, other text messaging applications, and widespread adoption of personal computers and the Internet in general led to the appearance of such services as SMS (short message service, initially an extension of GSM). More recently it provoked the development and deployment of the General Packet Radio Service (GPRS) integrating mobile wireless voice and data service, similar in spirit and in bandwidth to the once highly acclaimed but never really triumphant cable ISDN technology.

Meanwhile, in the computer realm there emerged two major competing wireless networking technologies, Wi-Fi (Wireless Fidelity) or 802.11 and HomeRF, both designed to operate in unlicensed 2.4 GHz band. The former gained significant popularity, particularly in the incarnation of the 802.11b substandard devised as an extension of and replacement for wired local area networks and as such offering little beyond basic data exchange capability at the high rate of 11 Mb/s exceeding that of GPRS by orders of magnitude. The latter, providing the same bandwidth, was developed with the idea of facilitating computer augmentation of consumer appliances (primarily those typically found within the home) and wireless communication between them. Encompassing higher level features to facilitate development of specific appliances and applications, HomeRF standard ended up being excessive for some of them and insufficient for others. As a result, it didn't enjoy as much attention as the lightweight Wi-Fi.

Wireless networks created using Wi-Fi technology are by default open not only to their creators but also to complete strangers who happened to be present within up to 100 meters from an “access point”, a device serving as a gateway between the wireless network and the wired one. This security bug turned into an important feature as it put owners of Wi-Fi access points into an indirect competition with mobile telephony providers. Though confined to specific locations that came to be known as “hotspots”, where available high bandwidth Wi-Fi connectivity is clearly preferable to slower and typically more costly cellular connectivity.

Apart from “infrastructure” mode, where the network relies on the use of access points, Wi-Fi also has an “ad hoc” mode, in which nodes connect without access points. Intended for use as a physical layer in MANETs, it had little application in practice until recently. From the perspective of network topology, a pure MANET is a mesh like the wired Internet. It means that many nodes can directly connect to many nodes. Wireless telephone networks have a hierarchical topology with cellular towers serving as a relay for all connections. The same applies to Wi-Fi networks operating in infrastructure mode, where the role of the cellular tower is played by the access point.

Mesh topology offers many advantages. Most importantly, it is highly robust and can better serve users under conditions of mobility. Recently, a specialized IETF (Internet Engineering Task Force) MANET working group has formed with the primary goal of developing an Internet routing standard to support IP-based autonomous mobile segments. Not waiting for the standard to be released, Florida-based startup MeshNetworks (n.d.) already offers an implementation of multi-hop

routing (a routing scheme in which each node can serve as a relay between any two adjacent nodes). In wireless networks there exist a direct relationship between power consumption, range and data rate that became known as the “wireless dilemma”. Multi-hop routing makes it possible to reduce range benefiting in power consumption and/or bandwidth.

Cellular networks and wireless LANs provide long to medium to short range wireless coverage. Named after a medieval king of Denmark, Bluetooth became the first ultra-short range consumer digital RF technology that gained a significant user base. With the range of up to 10 meters and speeds of up to 1 Mb/s, it targets the niche for wireless created by the transformation of the personal computer from a single device into an increasing number of interconnected devices distributed over user bodies as well as over space. From the perspective of the PC evolution, Bluetooth can be seen as a faster and omnidirectional replacement for infrared wireless serial ports, a popular option for notebooks, PDAs and mobile phone handsets.

Bluetooth implemented a master-slave architecture, which in theory allows for a simple and efficient standard. Admittedly, implementing a fully autonomous node in hardware and software results in a shorter battery life and is more expensive overall. However, the long-standing trend for “cheaper, smaller, faster” promulgated by the computer industry would undoubtedly make it possible to develop a competitive peer-to-peer technology. RF transceivers offered by Nordic VLSI (n.d.) could serve as an example of such technology.

Besides, the actual implementation of Bluetooth is plagued with problems akin to those of HomeRF. In an attempt to accommodate for specific types of equipment and manufacturer preferences, the committee in charge of Bluetooth incorporated an excessive amount of high-level details into the standard for what should have been a mere data transmission protocol. The result has been a multitude of technical shortcomings and complications that scared away many developers.

The industry has come to view radio frequency technologies operating in different ranges as complementary. This attitude has been manifested in the appearance of integrated circuits incorporating Wi-Fi and GPRS or even Wi-Fi, GPRS, and Bluetooth (Newstooth, n.d.). T-Mobile, a cellular service provider, has been working together with Intel Corporation to create 2100 hotspots all over the U.S. to offer Wi-Fi and GPRS connectivity in one package (Intel Press Release, 2003, March 3).

2.5.2. Location Sensing

The main source of location information outdoors is the Global Positioning System (GPS) developed and maintained by the U.S. Department of Defense (Kaplan, 1996). The core of the system is a group of Navstar orbiting satellites. GPS receiver device employs radio broadcast from at least four satellites to determine geographical coordinates of its location. Until a few years ago civilian users had access to so-called “selective availability” (SA) mode GPS only. SA users had to reconcile with an error of up to 80-100 meters, an order of magnitude higher than the error for GPS information available to the military.

A system called Differential GPS (DGPS) relying on GPS data and land beacons was developed with the participation of the US Coast Guard to make high precision information available for civilian use. Deployed around major U.S. waterways, as well as in Canada, Australia, and parts of Europe, it requires more expensive receivers.

On May 1, 2000, SA was turned off. DGPS, however, still provided somewhat higher accuracy than GPS, particularly in the urban setting where satellite signal reflections from high-rise buildings interfere with GPS operation.

GPS can be used as a source of location information in mobile ad hoc networks (Ko & Vaidya, 1998), particularly for outdoor applications where device density is low (Patwari, O'Dea, & Wang, 2001). However, it becomes costly to include GPS receivers in every node if the network is large enough. If the device density is high enough, only a fraction of devices can include GPS functionality, with the rest of the devices ranging to them (Pottie, 1998).

Local Positioning Systems (LPS) employ a grid of RF base stations that communicate with the devices on the network. The location of devices in LPS is determined through triangulation using received signal strength, time difference of arrival, or time of arrival (see, e.g., Werb & Lanzl, 1998). Patwari et al. (2001) describe maximum-likelihood estimation of relative location in peer-to-peer networks developed for use in Motorola NeuRFon wireless sensor systems. Nodes with known location can serve as reference points for the others to find out their whereabouts.

Access points on a Wi-Fi network can serve as infrastructure for an LPS, providing accuracy similar to that of GPS, which doesn't work reliably in buildings. Indoor space, however, is typically more densely populated with people and artifacts and in general has a much more complex organization than outdoor space. Better accuracy needed indoors can be provided by combining electromagnetic systems with ultrasound (Priyantha, Chakraborty, & Balakrishnan, 2000), as well as lasers, although costs of required infrastructure are prohibitively high. Ultra-Wide Band (UWB) radio systems present a more viable alternative. Pahlavan, Li, and Makela (2002) give an overview of recent research into RF-based indoor location sensing covering UWB systems and pattern recognition techniques.

With the exception of Wi-Fi triangulation, there are no commercially available indoor location systems using the above principles. A number of simple experimental portable and wearable RF systems have been implemented that provided crude proximity sensing for prototyping (see, e.g., section 2.2 above). Choudhury and Pentland (2002) used infrared for location and proximity sensing in data collection experiments using wearable sensor devices. Starner, Schiele, and Pentland (1998) employed wearable video cameras as a source of contextual information including location.

Radio Frequency Identification (RFID) is a mature technology that has been on the market for over a decade. When a compact tag is detected in proximity by the stationary transponder, the tag's identification number is read. New generations of tags and transponders have a much lower cost and are employed on an increasingly large scale. Objects with RFID tags embedded into them replace subway passes,

plastic charge cards, IDs, access cards, etc. Many building security systems are based on RFID with transponders installed in lieu of or together with regular locks. As a side effect, such systems provide robust user location tracking indoors with the accuracy down to a room.

Chapter 3. Spatial Aspects

3.1. Location and Self

Humans have an “inveterate cognitive disposition to ‘spatialize’ everything” as H. Murray once put it following H. Bergson (Murray, 1951).

M. Weiser was the first to emphasize the importance of location and context for the future of computing in his influential vision of ubiquitous computing (Weiser, 1991). The first location-aware system was infrared-based Olivetti Research Active Badge that integrated a positioning technique with a distributed computing infrastructure (Want, Hopper, Falcao, & Gibbons, 1992). Active Badge then informed the Xerox ParcTab experiment, in which palm-sized personal devices were augmented with location information for mobile access to location-based services (Want et al., 1995, March).

Today, location is considered to be the best-studied type of context in the context-aware computing (Gellersen, Schmidt, & Beigl, 2002). In context-aware applications location is usually used not by itself, but as an indexing device from which other contextual parameters can be inferred (Dix et al., 2000).

Location is a point of reference to the self in the environment. Whether the natural landscape populated by our nomadic primogenitors or the maze of modern buildings inhabited by our fellow cyborgs, peculiarities of the environment define ways humans connect to, disconnect from, and reconnect with co-present others in cycles of mobility. Even in such applications as location tracking, location information is used to derive characteristics of place. For instance, with a commercial product like the GPS Child Locator watch introduced in 2001 by Whereify Wireless, Inc., children and other at-risk

individuals wearing the GPS watch can be instantly tracked via the Internet or telephone (Conabree, 2001, February 28). Here the focus is on safety of the place referred to by location.

3.2. Proximity

Proximity is a state of closeness. Etymologically, it is also a state of mobility, since the English “proximity” stems from the Latin verb “proximare” meaning “to approach”. Proximity is usually interpreted as co-location and as such is inferred from the location of users. Alternatively, it can be seen as relative location.

However, coordinates, whether absolute or relative, are often redundant and insufficient. Proximity sensing does not necessarily imply location sensing. For instance, users whose bodies have almost identical coordinates cannot be considered to be in proximity if a wall separates them, even though they are in the same location.

For the user, location doesn't exist. What does exist is place, confines of which arise out of the spatial organization. There can be significant variations in the definition of context in context-aware computing, emphasizing either the computer model of the user's situation or the user's perception of the situation (see, e.g., Dey & Abowd, 2000). One way or another, in so far as context-aware computing is about the interface, it has to take the latter into the account.

From the user's perspective, other people and objects co-present in the same place and places adjacent to it are in most situations more relevant than people and objects in other places because they can be interacted with directly. Distance as a metric of the user's proximity to the people and objects is a very crude metric. Separation or length of the path through space is more adequate.

Obviously, the word “distance” is employed in such sense. If the distances in question are short or very long, it is easy to overlook the distinction altogether. In the first case it is blurred since the question of measurement is usually brought up because there are no obstructions preventing communication from happening to begin with. For instance, Edward T. Hall uses distance ranges in proxemics, the study of “perception and use of space” by humans, covering spatial structure as a means of communication (E. T. Hall 1968, p. 83). Hall’s organizing model of space (E. T. Hall, 1966) includes four interpersonal distance levels and associated voice levels that Americans use when dynamically structuring space for communication under conditions of mobility. Intimate space extends from physical contact to 1 foot, personal space from 2 to 4 feet, social space from 4 to 12 feet, and public space from 12 to over 25 feet.

If distance is long enough, it doesn’t matter whether it’s the distance between places A and B from a bird’s eye view or cumulative length of road segments connecting them. Orders of magnitude become important. Bradner and Mark (2002) discovered that communicants were “more deceptive, less cooperative and less persuaded by their partner if they believed that he/she was in a distant city.” At the same time, cooperation increased over time. Difference in media had no effect on cooperation, deception or persuasion.

In the case of medium distance ranges, it becomes important to draw the line between distance and separation. For example, T. J. Allen concludes that the probability of face-to-face communication “declines to an asymptotic level within the first 50 meters of separation” (Allen, 1997).

He also finds that while it appears reasonable to expect that the probability of mediated communication would increase as the probability of face-to-face communication decreases, "near field" use of media in fact declines with distance. A number of other studies confirm the observation, showing that "between 40 and 50 percent of the telephone calls originating from a household are made within a two-mile radius" (Mayer, 1993). Even before the Internet boom Biksen and Eveland presented evidence that the usage of electronic mail declines with distance as well (1986).

Different spaces structure the separation hierarchy differently. It is difficult to arrive at ranges equally meaningful with respect to a hockey rink and an office space full of opaque cubicles. Some theories, like proxemics, focus on face-to-face proximity, while others may not be as interested in it. However, whichever model of separation levels we adopt, the granularity will tend to be finer in the immediate proximity and become coarser as the distance, number, and scale of physical obstructions increase. In the office space, such obstructions could be, say, tables, offices, and floors. On the shop floor, obstructions to vision are minimal for significant distances, while obstructions to hearing and movement in the form of rattling machines are densely scattered all over the floor.

Proximity may seem to be best defined as omnimodal perspective. However, while spatial perception and navigation skills are very basic in humans, they clearly belong to the supersensory level. Experiments have shown that behaviors involving spatial location and navigation activate the right hippocampus. As London taxi drivers learnt how to find their way around the city in the first two years of their

career, their hippocampus became enlarged (Maguire et al., 2000). Navigation activates the right caudate nucleus of the basal ganglia (Maguire et al., 1998).

3.3. Spatial Organization

Humans strive to impose rigorous order on the space surrounding them, actively redefining its natural pre-arrangement. Spatial organization in both its statics and dynamics exposes the state of technology, cultural peculiarities, and government system, while reflecting the character of the landscape. Waterworks, drainage, transportation, electricity and communication networks are all intimately intertwined with the spatial organization.

Coming in a multitude of layers, from clothing up to the room, car, house, city, and beyond, overlapping elements of the artificially reshaped space vary in the degree of autonomy, mobility, density, scale, and longevity. Interaction between the layers and transitions from one layer to another often have specific patterns, some of them strictly regulated and enforced by brick and mortar or by law.

Patterns of face-to-face interactions in a building are to a large extent defined when architects differentiate spaces in it for distinct functions and organize circulation between the spaces.

Investigating the organization of architectural space in the modern city and its perception by its inhabitants, K. Lynch, a classic writer on urbanism, points at such elements of city image as paths, edges, districts, nodes, and landmarks (Lynch, 1960). Recent research on enabling ad hoc collaboration through schedule learning and prediction arrives at similar elements for its Bayesian user location model based on GPS data (Ashbrook and Starner, 2002).

3.4. Spatially Motivated Design for Mobile Communication

3.4.1. From Tool Boxes to Caskets

The relationship between the development of technology and demands imposed on technology by society is anything but a simple causal link. At the very least, it is bidirectional. Mass wireless communication technology fulfils a latent need for mediation in nomadic situations. Interfaces of communication devices influence the character of mediated communication that in turn impacts face-to-face contacts, forming new social patterns.

A choice in emphasis between usability and functionality seems inevitable in product design. Historically, functionality was at the forefront in communication engineering, driven by the urgent need to provide connectivity where interaction was thought otherwise physically impossible.

Currently, we find ourselves in the situation where the assumption of ubiquitous connectivity with instantaneous delivery and unlimited bandwidth becomes increasingly practical. At the same time, in the wireless world there exists a grave disbalance between the advances in the engineering and the state of the interface. Prevalent legacy designs are overly complicated and spatially agnostic, and as a result they serve the needs of mobile users poorly.

3.4.2. What Mobile Users Still Can't Do

First of all, it is necessary to recognize limits of what humans can accomplish on the go. For instance, it is hard to believe that such activity as composition of texts of any considerable length is going to take place when the author's attention is divided, which is

almost always the case in the mobile environment. The desk and the study were invented for writing not by accident, and they still are very well suited for this purpose.

It is also hard to expect that mobile devices will turn into a fully automated secretary or perform other tasks like filtering that ultimately require full-blown artificial intelligence, creation of which still remains an elusive goal. J.C.R. Licklider proposed at the dawn of computer age that one of the classes of man-machine systems should be “man-computer symbiosis” (1960). By augmenting human intelligence rather than replacing it, computer can render a human secretary unnecessary.

Modern mobile devices have the raw processing power to run most applications ever devised for the computer. Yet, nomadic environments put particular emphasis on the support of basic interactions each characterized by its “what”, “who”, “when”, and “where”.

If “what” belongs to the realm of content, the other three “w”s constitute the logistics of interaction enabling it. “Who” is nothing else but the address book. “When” translates into schedule management. “Where” falling in the same domain, while remaining largely neglected, despite the fact that calendars in general receive a fair amount of attention being considered a business application.

Address books keeping names coupled with contact information probably served as the prototype of the “/etc/hosts” file on Unix systems on the ARPANET that was once used to resolve symbolic names of machines on the network into their IP addresses. A distributed Domain Name System (DNS) was ultimately created for computers on the Internet to eliminate the necessity to keep up individual databases on every host. Users of

Personal Digital Assistants and mobile phone address books, however, continue to live under the pressure to update their contact lists religiously.

A centralized system like DNS would probably be a bad fit for fundamentally localized and ad hoc human interactions. The work of Terry et al. (2002) cited in the Chapter 2 hints at a more adequate organization for the future of the User Name System, particularly in so far as it ties proximity and contacts.

Face-to-face interaction and proximity constitute immediately relevant context. Putting the interaction in context is the way to provide augmentation on a much higher level of integration than the one achieved in modern mobile devices. Localization of this sort can also serve as a partial remedy to the problem of filtering, since remote events will be de-emphasized.

Today the industry is on a sharp lookout for killer applications for the mobile device. Applications that made the industry possible to begin with like the telephony proper are for some reason not considered to be good enough any longer. It is our firm belief, however, that the industry should be looking for killer interfaces for old applications instead.

3.4.3. Mobile Interfaces and Form Factors

To be mobile, personal devices should be wearable or portable. Strapped on the wrists of many, the watch can serve as an example of a wearable that gained wide popularity. Late 19th century army officers wore their mechanical chronographs in this fashion for easy access. Today, ancient systems of belts still utilized by itinerant nomads and military in the field to carry arms and belongings make their way back onto the streets of city, with mobile telephones and PDAs having replaced spears and daggers of old.

Mobile devices have to be designed up to a considerably higher level of durability requirements than their stationary counterparts, since they should be able to sustain heavy use. Not only can they get damaged, they can also get lost or stolen.

The most important challenge introduced by mobility though is that of the interface. The cognitive load of attending to the environment leaves users without enough attention resources to operate a keyboard, whether a full-blown or a chorded one that only has 18 keys. Displays showing a multitude of text symbols and bright color pictures are in general overly distracting. At the same time, it should be acknowledged that for certain tasks like way-finding access to a map is very helpful.

Under constraints of mobility, sound re-emerges as the communication modality of preference. However, for a human to communicate a request to the mobile device, touch is still preferable. Speech recognition technology is not robust enough in noisy environments, while speech is not acceptable in certain social situations. Humans can exchange glances or nods. The user has to interact with its device in a more direct way. Touch commands, however, are difficult to enter, because no perfect mobile touch control exists.

Single button is perhaps the best solution available in terms of simplicity and ease of concealment, but it offers little expressive power. Multiple button devices don't reach the ideal tradeoff between simplicity and expressiveness, which once led to the introduction of mouse and similar pointing devices in the interface of the stationary computer. Touchpads and touchpoints are hardly fully usable when they are worn or carried around in the pocket.

As high frequency words in natural languages retain old roots for the longest time, the most widespread mobile device can boast one of the oldest touch interfaces. Even gone mobile, the telephone still carries the calculator keypad that once replaced analogue rotary dial. It happened over fifty years ago at the famed AT&T Bell Labs.

Rotary dial, in turn, complemented in 1894 the automatic switch that A. B. Strowger invented in the 1880's. According to popular legend, Strowger, an undertaker in Kansas City, Missouri, invented it after he became enraged at a Southwestern Bell operator who was directing calls for his service to her relative, a competitor mortician (Farley, Telephone history, n.d.).

The blending of the phone with the Personal Digital Assistant (PDA) offers a high level of functionality integration, but from the interface perspective it is still problematic. Bright screens may attract buyers and increase sales, but screen-based interaction is a task requiring complete dedication on the part of the user and excluding simultaneous mobility. Stylus input, while offering high precision in pointing, has been criticized for the lack of tactile feedback characteristic of writing on regular paper. It should be added that handhelds with stylus input suggest two-handed interaction, which can be inconvenient for the user in many situations.

The industry has recently picked out an important new direction in the series of prototypes announced by frog design and Motorola. Proceeding from research in pervasive computing, creators of the prototypes distributed the functionality usually contained within one device such as PDA with phone capabilities over a number of wirelessly interconnected devices including an augmented watch, pen, buttons, and goggles (frog design Press Release, 2003, March 10).

3.4.4. Space Qualified Communication

As Townsend (2000) remarks, citing Pool (1973) and Gottman (1973), the wired telephone had a major impact on the urban space. For instance, it enabled the decentralization of factories through taking manufacturing activities from a single floor and making them more distributed. It also allowed the emergence of such an architectural phenomenon as the modern high rise office building. Without the telephone it would be unthinkable, as elevators could never support armies of couriers incessantly travelling from floor to floor with messages.

The logic of mobility requires that the telephone or its successor reciprocate by incorporating dynamic awareness about spatial organization into its design. So far the major change that mobility added to mediated speech communication has been in unpredictable shifts in the spatial context of interlocutors, celebrated by the eternal question “Where are you?” opening most every cell phone conversation.

Ad hoc networking invites transparent cognitive mappings where interfaces reveal certain aspects of the underlying technology. A user’s self can be seen as a central node in the communication network with links to other human nodes temporarily activated in face-to-face and mediated interactions. The interactions will tend to cluster in the vicinity of user’s current location and “important locations” (Ashbrook & Starner, 2002) frequented by the user. By reflecting the spatially relevant part of the ad hoc communication network at the interface of the communication device, it is possible to decrease the interface complexity and promote unplanned face-to-face collaboration.

The interface of modern communication devices is centered on their architecture and that of the network. Instead, it should be user-centered. In ad hoc nets the network

architecture is centered on the user. If the interface is to be centered on the user as well, it should be capable of handling transitions from face-to-face situations to mediation and back, integrating physical and virtual interactions seamlessly (Ishii & Ullmer, 1997). Spatial organization and environmental conditions, as well as the user's behaviors, structure such transitions uniquely, as obstructions to different senses rarely appear and disappear synchronously, creating modality "shifts".

Hearing usually penetrates furthest, unless the environment is noisy.

Vision, as a rule, comes second in densely packed environments such as modern office buildings. However, it may come first in environments such as savanna. Touch typically comes last. Smell is a sense estranged by modern culture, but smell still communicates presence powerfully, and at significant distances at that, if the wind blows in the right direction.

Human culture codifies many aspects of transitions from face-to-face conversations to mediation and back, particularly when it is not something that happens on the go. Disembodied voices, though no longer inspiring awe and fear as they used to (Ronnell, 1991), rarely hail you before their possessor appears, and a physical handshake may precede or immediately follow greeting. Eye contact tends to be meticulously regulated and the end of a conversation is usually followed by the physical separation of interlocutors getting out of each other's sight, or at least by their turning eyes away from one another.

There are many situations, however, in which different conventions about entering and leaving somebody's presence apply. Perhaps the easiest to notice among them are shared space situations, where room, office or compartment is shared. Another set of situations

is chance encounters on the go, where the code is more relaxed out of necessity, since it is often impossible to follow regulations. By bringing the density of space population up to an unusually high level, we arrive at a room where a cocktail party is under way.

Mobile devices can become invaluable in creating and augmenting face-to-face interactions, if they respond correctly to changes in spatial context resulting from the locomotion of users and their peers. To achieve this end, it is necessary to focus on the support of local communication and interaction.

Chapter 4. Wearable System for Proximity-Based Audio Communication

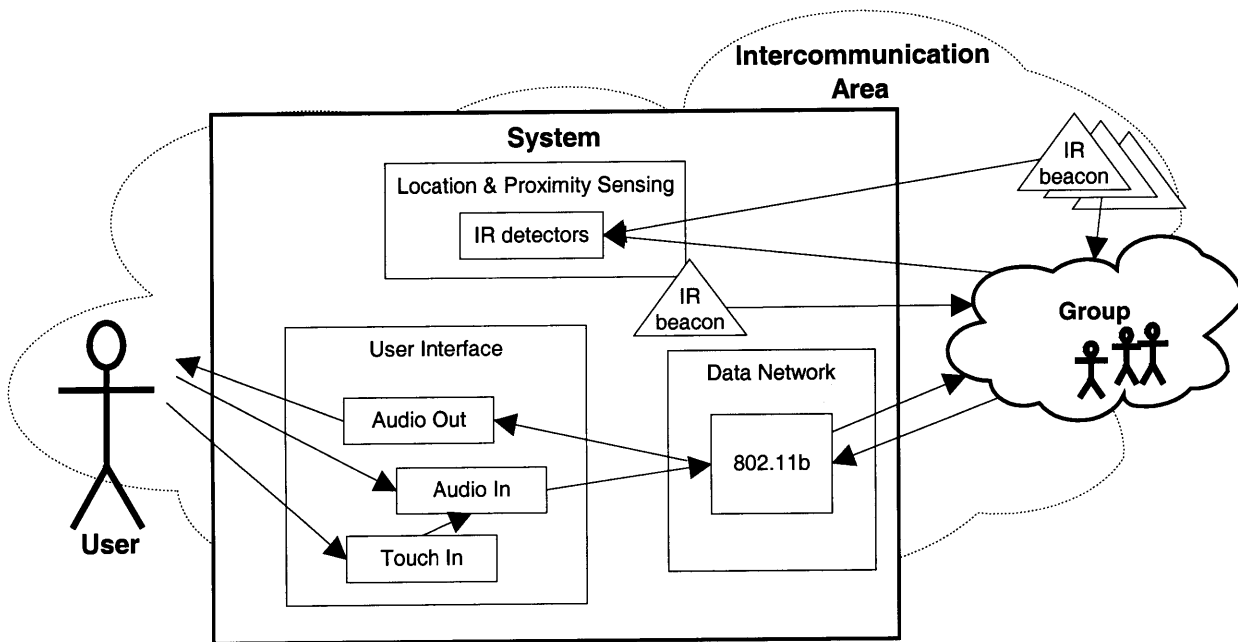
4.1. System Concept

The approach proposed above is a result of the experience in design and implementation of a prototype system for proximity-based ad hoc communication. One of the primary design objectives was to demonstrate how personal mobile communication tools could handle the transition between face-to-face conversation and conditions requiring mediation. As the system was intended to support mobile groups, we chose wearable walkie-talkie as the basic concept for the prototype.

While serverless, the system didn't have to be fully autonomous. For space sensing our prototype devices rely on the infrastructure deployed in the testing space instrumented to inform them about the intercommunication configuration of spaces within and outside it. Essentially, such a configuration serves as a software definition of proximity for communication purposes, dividing the testing space into a set of potentially overlapping areas that we call intercommunication areas. The primary purpose of the division is to reflect the architectural organization, however the two are inherently independent.

Walkie-talkie radios remain the communication tool of preference for groups of mobile users. However, the higher the number of people talking on the same channel, the more difficult it gets for a specific user to discern a message that requires the user's response. To avoid the problem, the size of the group utilizing the same channel should be controlled. Typically, radios are manually configured for operating only on the channels employed by pre-defined groups to which their respective users belong. The necessity to afford such a configuration significantly complicates the interface of the device.

Figure 1. System Concept.



Resulting inflexibility in updating one's communication group membership can lead to group interoperability issues.

If a walkie-talkie knows what other walkie-talkies are in the same space and adjacent spaces, communication groups can be automatically formed in an ad hoc fashion on the basis of proximity between users as the users move through the building. Inflexibility in updating one's communication group membership is eliminated, interoperability is increased, the interface complexity is reduced, and beneficial new ways for user interaction are opened.

Below we discuss three groups of scenarios, in which the idea of proximity-based ad hoc group formation can possibly be advantageous. Then we describe a prototype wearable system for audio communication implementing the idea. In the prototype we confine ourselves to this functionality. We suggest, however, that the ad hoc group formation that

the prototype illustrates should not altogether replace policy-based manual creation of groups. Rather, we see the two mechanisms as mutually complementary layers.

Proposed ad hoc mechanism makes it possible to relax the limitations of the manual “policy” mechanism in some situations and thus turn it into a tool for reconfiguring proximity in software rather than simply connecting team members. For instance, if the team in area X often collaborates with the team in area Y, the policy could state that authorized users in the areas belong to the same communication group.

An important limitation of the ad hoc mechanism itself is revealed when the density of users in the space drastically increases, say, in the cocktail party scenario. Too many people are next to each other, it is impractical to put them all in the same group and the only way to tell who belongs to which group is to use presets of some kind, i.e., a policy.

A real-world system implementing the concept that we propose would feature a presence awareness module. Since our focus is on audio interaction, auditory presence awareness mechanism of some kind would have to be implemented. For instance, personal auditory cues could be played whenever a new user enters or leaves an intercommunication area. Although, for navigation it can be advantageous to have the presence information available as a map, which could be delivered, for instance, via a head-mounted display.

A number of issues arise in connection with the concept. What metrics of proximity should be used? What is the maximum density that renders the utilization of the ad hoc group formation principle unfeasible? When and how are the groups terminated? While we believe that the first two issues should be addressed in the scenario-dependent presets, one of possible solutions for the last one could be that there is a default of dropping group members when leaving their vicinity that the user can override when necessary. This

issue is in fact tangled with that of participation in multiple spatially overlapping groups. If broadcast mode is utilized, as in walkie-talkie, a message can be considered an answer to the group from which the message last received by the user came unless the user directs it to another group.

4.2. Usage Scenarios

4.2.1. Emergency Response

Imagine firefighters in a burning building. The building is instrumented with special autonomous smoke detectors transmitting the configuration for an emergency situation. The configuration is different at each smoke detector and is stored locally.

A wearable system for proximity-based synchronous voice messaging is employed for communication. The firefighter's wearable receives the definition of the current intercommunication area from the nearest smoke detector as a sorted list of adjacent smoke detectors. A firefighter is considered to be in the same area as another firefighter if the closest smoke detectors in their lists are the same. By default, voice messages are broadcast to all firefighters in the same area. As firefighters move to a different smoke detector, their area definition is updated.

Using the communication system, firefighters can effectively coordinate the sharing of bulky tools, locating typical hazardous objects and neutralizing them or reacting to dangerous changes in the environment. They can also summon help from proximity and are notified when another firefighter enters or leaves the area.

At any given moment they can see on the head-mounted display in which areas other ad hoc groups have formed. Possibly, a coarse building plan can be inferred after seeing a number of smoke detectors if a complete map is not readily available. Anybody can contact any firefighter, any given ad-hoc group or the support group outside at any time.

Elements of such a decentralized command and control system could be used in the home, office, public space, or in a hostile environment. Home would probably tend to be defined as a single area as it is usually not a large place. One could think of elaborate intercommunication configurations for the workplace or public space. If the intercommunication areas are defined for mobility, they are highly likely to be overlapping. There can be different configurations for specific users or groups. Areas will tend to be continuous, but they can also be discontinuous. A default proximity metric can be used in environments where the intercommunication configuration is either unavailable or cannot be trusted.

The simplest scenario that falls into the emergency response category though is calling for help. While in some cases a professional team sent by 911 is indispensable, under many circumstances the person who needs help can get it those in the vicinity.

4.2.2. From Place to Virtual Space and Back

On a winter evening the author had an engaging professional discussion with a guest at his place. At some point the flow of the vivid exchange on mediated communication, wearable computers, implants and similar topics fashionable on the MIT campus was interrupted rather abruptly. The guest realized that he had to leave right away to attend to his business elsewhere. Conversations, however engaging, are commonly terminated under such circumstances. The one in question was no exception to the rule. What made it remarkable was a shrewd concluding observation on the part of the guest. It would take him at least ten minutes to get to his next destination, and the time could be better spent had we been able to keep talking as he would be walking down the street.

At first glance, nothing prevented us from implementing the idea. The guest had his mobile phone with him, and I had a phone in my apartment. Still, neither of us rushed to

deliver a call to the other party. People just don't do that. However, a driver who just left home will occasionally call back if caught in a traffic jam.

Mobile phone users tend to call home or their significant other whenever they have time on their hands, for instance, when commuting to or from work. While one might explain this phenomenon away by saying that people are simply attached to their loved ones, another explanation proposes that the reason for such behavior is the ease with which one activates a frequently used entry in the phonebook. While both explanations suggest that humans share an addiction to communication, the second one prompts the thought that home is a preferable place to call for people on the move because it is only a couple of button presses away.

In the situation that my guest and I found ourselves, however, establishing a telephone connection would take an intimidating number of steps. First of all, we would have to agree about who calls whom. For instance, I could be designated as a callee. Then I would invoke the incantation of the ten-digit number for the line in my apartment to him. He would draw his mobile phone out of the pocket, holster or bag where it was contained and type in the number to initiate the call. With no typos on his part, we would hear a disturbing ring of the classic AT&T telephone on my desk. I would approach it and pick up the receiver. It would be somewhat embarrassing for us to trade traditional "Hello" greetings, as they would be resounding both in the receiver and in the room. Then I would put the receiver down, show my guest to the door and come back to the phone to pick up the receiver. The next ten minutes would see a continuation of our conversation. We would both be grasping our handsets for the duration of the time.

The idea of the system we propose in this thesis was born that evening. The device would make the transition from a face-to-face conversation to a mediated one and back

seamless. Meeting unexpectedly on the elevator or in the street just for a moment, busy users could walk away talking. Such a system would also be used by inhabitants of a big house or an apartment with high ceilings and large rooms where sound of speech gets dampened as it travels from one end of the room to the other.

4.2.3. Community Building

It is often challenging to make unfamiliar people who are present at the same space at the same time to get to know each other. Whether in the office environment, at a café, or in a pub, users interested in meeting new people could make themselves available for public addressing. The ability to talk to co-present others will help users get to know each other. In old times the pub was the heart of a local community and most everybody in the neighborhood assembled there. The publican served as a meeting facilitator, introducing rare newcomers to the relevant members of the crowd of regular customers who were anything but strangers (Stivers, 2000). Spatially aware communication devices can provide this service in today's world, making it less fragmented.

4.3. System Implementation

4.3.1. Interface

In a nutshell, the prototype system implementing the described concept is a fully wearable walkie-talkie. Functionality of the prototype is limited to synchronous voice messaging with the delivery based on the length of the path between users in space with three types of situations being distinguished. Users in a face-to-face situation don't need communication aids; users in proximity are automatically included in the same communication group; remote users don't communicate.

The emphasis on wearability and sound in the system design stems from the focus on minimization of cognitive load associated with the system's use on the go. The system relies on audio as the primary modality for both output and input, supported by a simple push-to-talk button to activate the transmission of the audio. Each time the button is pressed or released, a bell ring audio cue is played to provide the user with feedback regarding the recording status of the device.

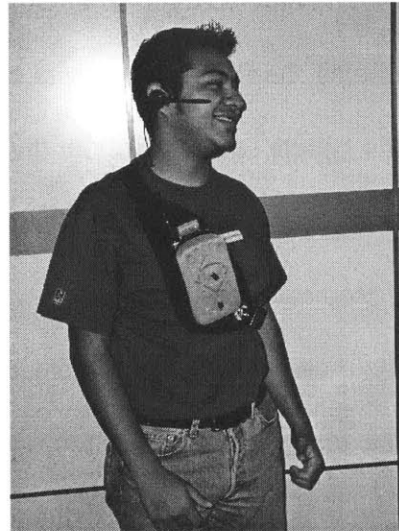


Figure 2. User Wearing the System.

Synchronous voice messaging is easy to adapt to the transitions from one zone to another. The necessity to hold the push-to-talk button pressed while the message is being recorded and broadcast limits the duration of a message to the time that a hand can be dedicated for the task. Thus every message can be delivered according to the arrangement of users in space existent at the time when the message broadcast began without imposing redundant mediation on users as they come into face-to-face range moving through the space.

The choice of synchronous voice messaging as the audio interaction style in case of our implementation was in part dictated by technical characteristics of the development platform. Since the system introduces an audio delay of at least 500 ms, it was not suitable for telephony-style audio interaction, requiring delays below 250 ms. While asynchronous delivery can be desirable under many circumstances, at moments when users are open to opportunistic interactions, synchronous communication is preferable.

Some implementations of voice messaging systems are half-duplex, i.e. if a user is holding the floor, other users cannot start speaking until the floor is cleared (Kim, 2002; this system is interesting in that it keeps a history of voice messages that can be browsed at different speeds). With large groups, this is the only possible approach. Our implementation is full-duplex, and messages coming in simultaneously are mixed, since in our case the size of the group is dynamically controlled by the spatial context.

The touch input was intentionally made as simple as possible so that the user could operate it without getting distracted. Apart from a push-to-talk button, we also considered “push to start and stop talking” button and energy activation. These two approaches free the user for activities where both hands are needed. The former can be preferable, though we couldn’t fully test it because of the problem with the delay. Problems of false triggering plague the latter.

It is interesting to notice that if a communication device reconfigures proximity in software, the modality through which the user activates this device (in our system, touch) can be seen as unobstructed. It is used to remove obstruction in the primary communication modality (sound).

ComTouch, a device converting hand pressure on the mobile phone handset into vibrational intensity for interaction between users in real time (Chang, O’Modhrain, Jacob, Gunther, & Ishii, 2002), implemented the metaphor of unobstructed tactile channel literally. In ComTouch, however, mediated touch augmented audio rather than activated and deactivated it.

4.3.2. Hardware Implementation

The prototype system comprises the Sharp Zaurus PDA, a Wi-Fi card, a headset, a serial board interfacing a button and two IR detectors to the PDA, and an autonomous IR beacon. It is packaged in the Nintendo GameBoy Advance shoulder holster.

Sharp Zaurus SL-5500 personal mobile tool is an inexpensive Linux-based 206 MHz Strong Arm consumer device. It is equipped with a color touch screen, built-in keyboard, Compact Flash slot, Secure Digital slot, RS-232 port, and audio in/out jack. Each Zaurus resides on the Wi-Fi network, to which it is connected by the D-Link DCF-660W compact flash adapter.

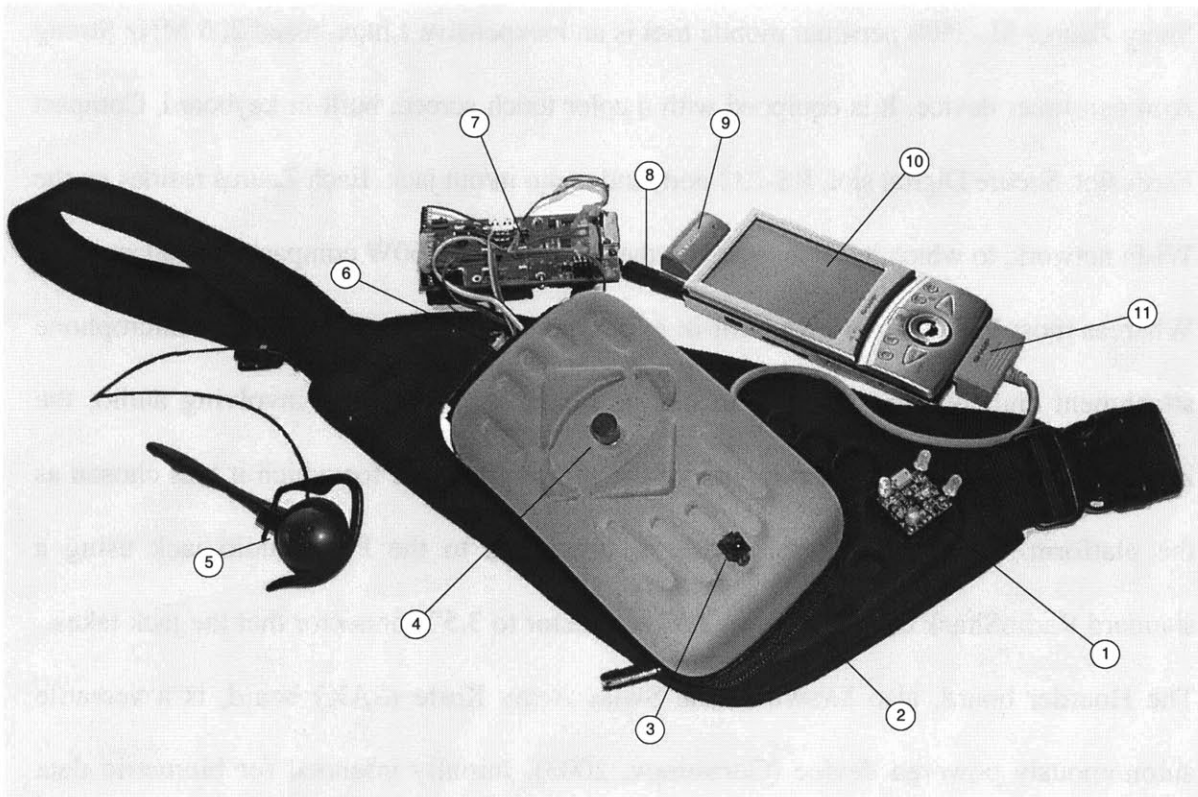
Whereas most PDAs come with built-in microphone and no jack for external microphone attachment and thus are difficult to use in wearable prototyping involving audio, the Zaurus is an exception to the rule, one of the primary reasons for which it was chosen as the platform. A regular phone handset is connected to the PDA audio jack using a standard RadioShack converter from 2.5" connector to 3.5" connector that the jack takes.

The Hoarder board, also known as the Swiss Army Knife (SAK) board, is a versatile autonomously powered device (Gerasimov, 2003). Initially intended for biometric data collection, this board, utilizing a PIC microcontroller, can be used to connect various sensors such as biosensors, GPS, accelerometers, or buttons to any computer with a serial port. Microcontroller code in C programming language was specially customized for the project in order to accommodate for the Sony IR remote control protocol employed by the transmitters.

Generally, a device like the Hoarder is excessive for connecting IR detectors and a button to the serial port as it is used in the system described here. At the same time, it is

advantageous in the sense that it provides a solution allowing for easy addition of new sensors to the hardware architecture should it be deemed necessary.

Figure 3. Hardware Implementation.



- | | |
|--|--|
| 1. IR Transmitter. | 7. Hoarder Board. |
| 2. Nintendo Game Boy Advance Shoulder Holster. | 8. Standard Stereo Converter (3,5" female to 2,5" male). |
| 3. IR Detector (Proximity). | 9. Wi-Fi Network Adapter (D-Link DCF-660W). |
| 4. Push-to-Talk Button. | 10. Sharp Zaurus SL-5500 Personal Mobile Tool. |
| 5. Standard Telephone Headset. | 11. Serial Cable to Connect the Hoarder Board. |
| 6. IR Detector (Location). | |

IR detectors receive signal from autonomous beacons mounted on other prototype systems and installed on the ceiling in the testing area. Each system includes such a beacon permanently broadcasting a unique ID via four low powered IR transmitters, creating an IR cone diverging from the beacon. This IR setup was developed by

Choudhury and Pentland for the Sociometer system (2002). We utilized the same equipment in our system.

Nintendo GameBoy Advance shoulder holster includes a strap going over the right shoulder and to the left with a flat area positioned on the wearers chest, to which a holster with a zipper is attached. The Zaurus PDA and the Hoarder board are placed inside the holster; the button and IR detectors are mounted on the outer side of it. The IR transmitter is secured on the strap under the holster. Velcro and glue provide necessary fixture.

Figure 4. Prototype Systems.



Battery lifetime of the prototype is limited to that of internal battery in the Zaurus. The exact lifetime depends on the utilization and typically is approximately an hour with Wi-

Fi card and headset installed. Hoarder is powered from 4 AAA batteries. The IR transmitters installed on the systems are powered from a coin 3.0 V lithium battery. IR transmitters installed on the ceiling in the testing space are powered from the mains. Both the Hoarder and IR transmitters far exceed the PDA in battery lifetime.

4.3.3. Software Architecture

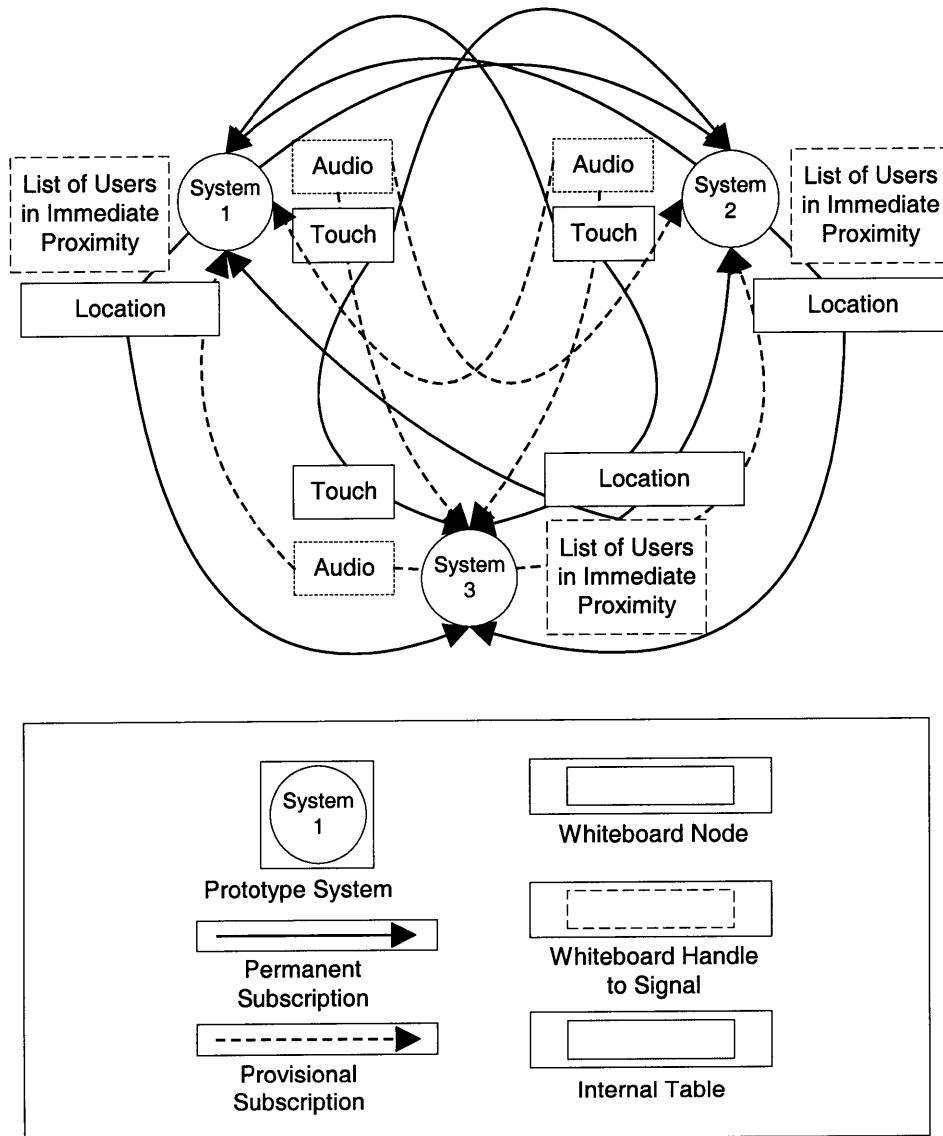
Software written for the Linux operating system in the C programming language implements a modular decentralized architecture for proximity-based audio communication. The choice of Linux as a platform for the project let us take advantage of the open source code base. While the use of Linux was tremendously beneficial, Sharp's incomplete implementation of the audio driver for the Zaurus made it impossible to regulate the audio recording delay on the device. This issue mentioned above in section 4.3.1 was thoroughly documented by Kosmidis (2002).

The cornerstone of our architecture is the Enchantment system. An integral part of the MIThril wearable computing research platform (DeVaul, Gips, Sung, & Pentland, to appear), it was designed with the idea of sensor data exchange and processing in mind.

The Enchantment system comprises Enchantment Whiteboard and Enchantment Signal.

The Enchantment Whiteboard implements a network-transparent inter-process communication (IPC) system for distributed embedded applications. As opposed to traditional IPC systems like RMI and Unix/BSD sockets, Enchantment is based on a client/server model. This makes it possible to avoid the complex logistics of establishing point-to-point communications.

Figure 5. Software Architecture Outline.



Clients post and read information on a whiteboard server using a tree-based hierarchical addressing scheme akin to that of a file system or a web server document tree. An address is referred to as a Universal Network Locator (UNL), analogous to the web Universal Resource Locator (URL). Clients can also subscribe to receive any updates made to the content of the whiteboard, its specific branches, or terminal nodes. The Enchantment

Whiteboard has many other interesting features, but they didn't find use in our specific application.

The Enchantment Whiteboard is not suitable for bandwidth intensive applications like real-time audio. To compensate for this, the Enchantment Signal complements the Whiteboard with a point-to-point communication system. The network transparency is retained through posting signal "handles" on the Whiteboard. Both Whiteboard and Signal APIs are designed in such a way that there is no need for data producers to know information about consumers a priori.

Unfortunately, neither Enchantment Whiteboard nor Signal provides encryption at this point, and data travels on the network in the open. In all other respects Enchantment is a very appealing solution for developers of distributed embedded systems.

On top of Enchantment Signal sensor-specific data generators and readers can be implemented. For our architecture, we have used Signal implementations of an audio recorder, player, and mixer.

The current implementation of the architecture is limited to three prototype systems. All three systems reside on a wireless TCP/IP network (802.11b) and have fixed IP addresses. Each of them runs three separate programs:

- 1) The Enchantment Whiteboard server.
- 2) The Enchantment Signal audio recorder.
- 3) The main application.

The main application monitors the serial port for push-to-talk button events and updates from IR detectors, publishes push-to-talk button status and detected location on the Whiteboard, monitors Whiteboards on all systems to keep track of the status of their

push-to-talk buttons and changes in their locations. It also starts and stops the Signal audio player when it is necessary to receive and play back an audio message.

Unlike many Linux audio drivers, the Sharp Zaurus driver doesn't implement a mixer. Therefore when two messages from different clients arrive simultaneously, the Signal audio mixer is spawned prior to the player to allow simultaneous playback. Current implementation of the mixer can only handle signals from two sources, which restricts the number of systems in the architecture to three (no local audio feedback is presented to the user).

When system A learns that a push-to-talk button on system B was pressed, it decides whether to play back the message from system B based on the data previously obtained from IR location and proximity sensors. If system B has been seen in immediate proximity (face-to-face) in the last 5 seconds, the message is ignored. Else it is played back unless the location of both system A and system B is known, and location of system B doesn't belong to the list of locations considered to be in the same intercommunication area as the current location of system A.

The program has access to the locally stored definition of intercommunication areas for the testing space. For every location (ID of beacon on the ceiling in the testing zone) there exists a list of other locations in the same intercommunication area.

4.4. Evaluation

4.4.1. System Testing

Limited testing of the prototypes conducted in internal exhibitions at the Media Laboratory and in Wearable Group meetings revealed serious problems with IR communication. It worked, however both the location and proximity IR detectors

received ID numbers broadcast by IR transmitters far less frequently than the application required.

One of the possible reasons for the poor performance could be that the positioning of the IR detectors on the body was suboptimal as compared to that in the Sociometer device described by Choudhury and Pentland (2002). At the same time, Sociometers were used for data collection, while our system was intended for real time interaction. The frequency of detection sufficient for obtaining a meaningful amount of data points may be different from that required for updates in collaboration scenarios.

Improvements in detection could possibly occur at a higher speed of IR modulation, which was lowered in the transmitters we used to increase the battery life. Alternative solutions might involve combining IR with RF.

4.4.2. Interface Issues

During system trials users and observers including experts in human-computer interaction and members of general public who represented different industries found it easy to grasp the demonstrated concepts. Both the principle of proximity-based group formation and the idea of seamless transition between mediated and face-to-face conversation received general approval, however a few people challenged them on economic grounds, suggesting that their application for communication at home may not be financially justified.

Trial participants found the prototype too bulky for use on daily basis. The shoulder holster required a significant amount of strap adjustment to sit in place. Female users complained that the positioning of the package on the chest was uncomfortable for them.

Inadequate location and proximity detection prevented us from carrying a more formal evaluation of the prototype with a significant number of users.

4.4.3. On Methodology

No established evaluation methodology currently exists in the framework of mobile ad hoc collaboration (Kortuem et al., 2002). Below we set forth our vision of potential approaches.

Qualitative evaluation appears less problematic as its general principles apply to mobile ad hoc collaboration as much as to any other area. Researchers could query prototype system users on qualitative criteria such as technical effectiveness of trial equipment, perceived utility, and economic value. In the case of our system, additional questions might concern the impact of the architectural space instrumentation and comfort with using technology involving unsolicited communication.

Simple heuristic calculations can be used for quantitative evaluation. Perhaps the most widespread basis for such calculations is the “seven plus or minus two” limit on information processing by humans (Miller, 1956), long renounced by psychologists as a simplification, but still commonly used in both theoretical and applied work in different fields, from humanities to engineering.

More rigorous quantitative evaluation in human-computer interaction presents a difficult task, since evaluation methodology often needs to be area-specific and even application specific. This applies to mobile ad hoc collaboration to the full extent. Besides, it is simply hard to organize a study in which many people simultaneously partake in testing of a prototype mobile device under realistically ad hoc conditions. The best way to conduct such a study is to use the prototype in a real environment as users go through

their day. This effectively means that prototype implementation should be close to that of a consumer grade device. Experimenters undertaking this type of study should also be able to supply enough prototypes, which can be expensive.

For some types of scenarios, such as emergency response scenarios, testing of early prototypes under real conditions can be difficult to arrange, even though it might be possible through training facilities. A mobile game, such as an Easter egg hunt, could be modified to test a communication tool or application (A. P. Pentland, personal communication, January 29, 2003).

While based on the presently contested assumption of human rationality, game-theoretic simulations offer another possible approach to quantitative evaluation for mobile ad hoc collaboration. Recent research in evolutionary economics involving local interaction and mobile players (see, e.g., Ely, 2002) might serve as a basis for such simulations that would have the potential to show large-scale effects of decentralizing mediated communication.

Chapter 5. Conclusions

5.1. Summary

This thesis presented a study of spatial aspects of mobile ad hoc collaboration, an emerging research framework concerned with the design of collaborative applications for ad hoc networks augmenting face-to-face interaction and promoting chance encounters. It reviewed existing research and commercial applications developed within the framework, established its precedents in art, and discussed underlying wireless communication and location sensing technology.

Location, proximity, and spatial organization were then considered as major factors in designing user-centered interfaces and applications conjoining mobility, face-to-face interaction, and mediation in a seamless way. The principle of ad hoc communication group formation on the basis of proximity was proposed, and the implementation of a prototype wearable system for synchronous audio communication demonstrating it was described. Results of the prototype testing were examined and possible approaches to evaluation in the framework of mobile ad hoc collaboration were investigated.

5.2. Discussion

In some respects modern production communication systems gradually converge around concepts similar to the one we propose.

NEXTel phones incorporate a walkie-talkie, but they don't take spatial organization into account and feature complex interfaces preventing them from becoming fully wearable. This complexity could be offloaded onto the spatial context by introducing proximity-

based ad hoc group formation. Decentralized network organization would make the system more robust.

Conventional walkie-talkies that evolved into systems like Motorola Fireground are often wearable, but still have complex interfaces for channel setting and switching. They, however, tend to have a common broadcast channel for high emergency situations. The Fireground comes with central command and control units for a firefighter squad boss supporting more advanced communication functions. We question the efficiency of maintaining hierarchy in the field in the age of mobile communication tools.

Systems like the frog design prototypes mentioned above show that the market probes the concept of distributed wearables forming a wireless body area network.

Vocera (n.d.) wireless badge, essentially putting a speaker and a microphone on the Wi-Fi network in a small wearable package, is a much more compact hardware analogue of our prototype, differing from it only in location and proximity sensing capability.

Few systems enable seamless transition from face-to-face communication to mediated communication and back. At the same time, there exists no readily available proximity sensing technology adequate for the task.

5.3. Future Work

Lack of indoor location and proximity sensing technology remains the stumbling block in the implementation of many applications for in-building spaces. From the days of early prototypes such as the Olivetti Research Active Badge mentioned in Chapter 3, there have been many attempts to bring the technology to a resolution below room level. Wi-Fi triangulation so far has been the one closest to success. Although, if compatible with that of GPS, the resolution of a few meters that it offers appears to be overly coarse for indoors. At the same time, the sensitivity of Wi-Fi triangulation to changes in the

number, location, and settings of Wi-Fi access points as well as to space reconfiguration precludes it from being robust.

With UWB solutions in prospect, robust high resolution location sensing is now in sight. Whether the gain in resolution can be used to infer user and object orientation remains to be determined. Infrared technology that we attempted to use for this purpose is largely inadequate for any purposes but research experiments.

Beyond the basic problem of location and proximity sensing, an important task to be addressed is the establishment of standard evaluation methodology for applications developed in the framework of mobile ad hoc collaboration. Such methodology would provide criteria for comparing applications and their implementations. It would also provide means of assessing their market potential.

A major challenge lies in integrating principles proposed in the thesis into a general wearable architecture. An existent wearable computing research platform such as MIThril could serve this purpose. Meeting the challenge implies, among other things, consideration of different types of spaces, transitions between stationary spaces and mobile transit spaces, from elevators to cars to other vehicles of transportation.

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