Mobility Agents: Guiding and Tracking Public Transportation Users

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ABSTRACT
Increasingly, public transportation systems are equipped with Global Positioning Systems (GPS) connected to control centers through wireless networks. Controllers use this infrastructure to schedule and optimize operations and avoid organizational problems such as bunching. We have employed this existing infrastructure to compute highly personalized information and deliver it on PDAs and cell phones. In addition to guiding people using public transportation by showing them which bus they should take to reach specific destinations, we track their location to create spatial awareness to a community of users. An application of this technology, called Mobility Agents, has been created and tested for people with cognitive disabilities. About 7% of the U.S. population has a form of cognitive disability. Cognitive disabilities are limitations of the ability to perceive, recognize, understand, interpret, and respond to information. The ability to use public transportation can dramatically increase the independence of this population. The Mobility Agents system provides multimodal prompts to a traveler on handheld devices helping with the recognition of the "right" bus, for instance. At the same time, it communicates to a caregiver the location of the traveler and trip status. This article describes our findings at several levels. At a technical level, it outlines pragmatic issues including display issues, GPS reliability and networking latency arising from using handheld devices in the field. At a cognitive level, we describe the need to customize information to address different degrees and combinations of cognitive disabilities. At a user interface level, we describe the use of different mission status interface approaches ranging from 3D real-time visualizations to SMS and instant messaging-based text interfaces.

Categories and Subject Descriptors
H.5.3 Information Systems: group and organizational interfaces.

General Terms
Experimentation, Human Factors.

Keywords
Location aware services, geographic information systems, multimodal interfaces, wireless computing, ubiquitous computing, ambient intelligence, agent-based architectures.

1. INTRODUCTION
Typical travelers use complex artifacts such as maps, schedules, labels, landmarks, and signs to access and navigate modern transportation systems. Many of these are confusing enough for the average, non-disabled user; they are nearly impossible for those with limited memory, attention deficits, or limited communication skills. Of these, the individuals who have the ability to work outside their residence and use a public bus, still need intensive training, monitoring, and feedback. This kind of training is highly repetitive and manpower-intensive. The Mobility Agents project takes a multi-faceted approach to this problem. For persons with cognitive disabilities, the project has been developing mobile, personalized, location-aware technologies to provide "just-in-time" memory prompts and cues for what to do and where to go next. For the caregiver communities, the project is developing technologies to allow planning, monitoring, assessment and emergency notification if something goes wrong or if the mobile traveler desires help while traveling.

Increasingly, public transportation systems are equipped with GPS systems connected through dedicated wireless networks with transportation control centers. Several small and big bus systems in the United States use this technology. The primary use of this infrastructure is to efficiently schedule and optimize operations to avoid organizational problems such as bunching. This existing infrastructure can be re-purposed and used to compute highly personalized information that can then be delivered on PDAs or cell phones to persons with cognitive disabilities to help them while traveling. Location aware *Mobility Agents* can transform generic bus position information, i.e., syntactic information, into personally relevant, i.e., pragmatic, information. At the pragmatic level a GPS coordinate can turn into crucial information. For instance, a mobility agent correlating bus and person positions may notify its user that "his/her bus has arrived."

For this research we had defined a theoretical and a practical research objective:

1) **Theoretical**: **Develop the conceptual framework of the Pragmatic Web** [9, 10] that advances the vision of Every Citizen Interfaces [2]. Information consumers should be able to define how they process information. They should also be able to establish a multimodal interaction scheme between themselves and existing information spaces. The goal of information processing in Pragmatic Web applications is to turn generally available *Web information* into *personally relevant information* communicated through *appropriate modalities* that include speech and animation. To fulfill this objective, we need to empower information consumers by giving them control over the information processing process.
2) **Practical**: **Build and assess the Mobility Agents architecture** in a real environment that includes people with cognitive disabilities using the technology. We have set up the necessary hardware and software environment that enabled us to build a usable prototype of the Mobility Agents system. We have used core principles of user-centered design [6, 7] to involve users, namely persons with cognitive disabilities and their caregivers, early and repetitively in the design, implementation and testing cycle. Cognitive disabilities are defined by the U.S. Department of Transportation as limitations of the ability to perceive, recognize, understand, interpret, and respond to information [11]. About 7% of the U.S. population has a form of cognitive disability [1]. This definition includes a wide spectrum of potential problems that makes it impossible to define a single interface for an average person with a cognitive disability. For this reason, we have included the users early in the design and development of the system. We conducted cognitive walkthroughs [5] to create system mockups and used them in several focus group meetings with persons with cognitive disabilities accompanied by their parents.

In this paper we mostly focus on the practical research objective of building and assessing the Mobility Agents work. This paper quickly outlines the main architecture of the Mobility Agents system, and discusses some of our findings arising from testing the system with GPS equipped busses in Boulder, Colorado.

2. ARCHITECTURE

Mobility Agents is [10] a real-world system operating with two independent Boulder bus lines (the Boulder Hop and the University of Colorado Buff Bus). This test platform encompasses 27 buses tracked in real time. Each bus contains a GPS sensor and a wireless transceiver that sends updated information on bus position, direction and speed to a Web server.

The *Mobility Agents Engine* is the main component of the Mobility Agents architecture (Figure 1). This engine serves as a central information hub between transportation systems, caregivers (e.g., parents or professional care providers helping persons with cognitive disabilities) and travelers (persons with cognitive disabilities). *Mobility Agents* inside the engine provide destination options, receive user choices, analyze bus information, and correlate locations of travelers and buses. Mobility Agents turn general bus information at the *syntactic level* into personally relevant information at the *pragmatic level* [10]. This pragmatic information is wirelessly transmitted through a second Web server to a handheld device running the traveler interface. The caregiver gets information about trip progress and can customize user profiles and destinations through a variety of interfaces.

The strong need to have highly specialized solutions for people with cognitive disabilities has been conceptualized as the "universe of one" [3]. Caregivers should have customization mechanisms that control how and when information will be presented to travelers. Additionally, caregivers must be able to

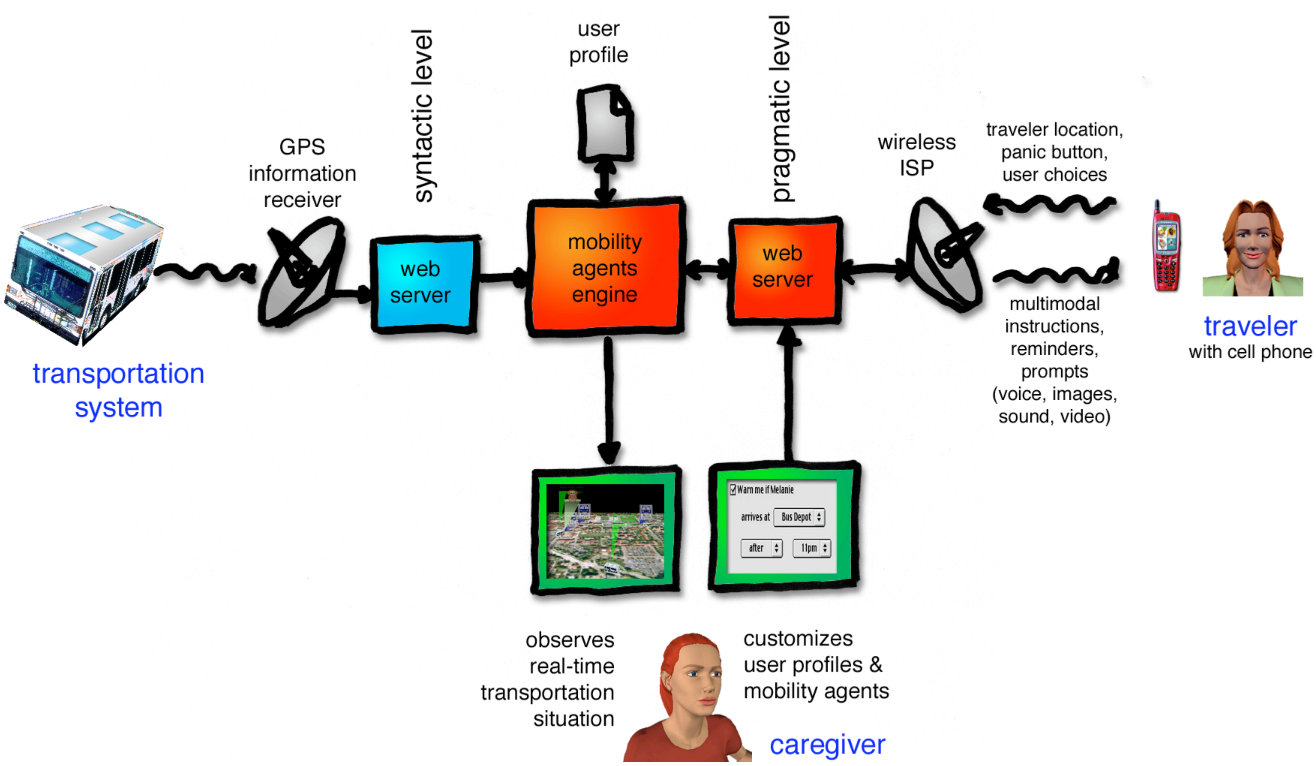

Figure 1: The Mobility Agents Architecture

define how the system interacts with them and how it behaves when unforeseen situations arise. Our interviews with members of the disability communities indicate that most caregivers would like a Web-based interface that lets them set up and maintain these customizations. Consequently, the architecture needs to exhibit a high degree of adaptability; providing such adaptability requires sophisticated End-User Development [4, 8] approaches. End-User Development lets us provide customization mechanisms that range from simple preference specifications (e.g., can the traveler read? if yes, what type of font, color and size are most effective?) to more intricate rule definition (e.g., what should happen if the traveler does not leave the bus at the expected bus stop?).

2.1 Traveler Interface

On the handheld device that travelers interact with, customized attention and memory prompts based on the travelers' goals, user preferences, and cognitive abilities appear. These prompts are manifested as voice, sound, animation, text, and iconic representations, and they perform various functions. For example, specific prompts alert the traveler that the right bus is approaching.

The handheld device used by the traveler needs to be fairly computationally powerful, since it deals with multimodal interaction that includes speech output, animations, and sounds. A suitable device also needs wireless networking and GPS capabilities. The first Mobility Agents prototype ran on an HP iPAQ 5455 handheld device (Figure 2) combined with a Sony Ericson T68i Bluetooth-enabled cell phone serving as a wireless modem and a Navman GPS module. Our current prototype is working on PDAs with built-in cell phone functionality and external (Bluetooth-connected) GPS sensors. Next-generation PDAs are just now appearing in the market that encompass all necessary components (GPS, networking, computing power and performance) in a single device which is a more compact, robust, integrated platform better suited to this application.

Figure 2: Handheld device for traveler

2.2 Caregiver Interface

Caregivers often need to monitor travelers with cognitive disabilities, especially when the traveler starts using a new route. The Mobility Agents prototype includes a version of a *Real-Time Transportation Visualization* (Figure 3) that shows locations of travelers, buses and bus stops. This visualization is a 3D interface that shows object location and state (Figure 4). It also provides users with camera options such as a top-down bird's eye view and object-centric (person or bus) views. It also shows state information of buses approaching, stopping, and departing. Since a specific bus stop may be shared by several different lines, the visualization includes this consideration and provides graphic indicators that differentiate buses.

The Real-Time Transportation Visualization is a combination of a live information browser and an agent-based simulation. Buses are agents that, on average, receive real-time spatial information updates every two seconds. Between live updates the simulation estimates heading, position and speed information

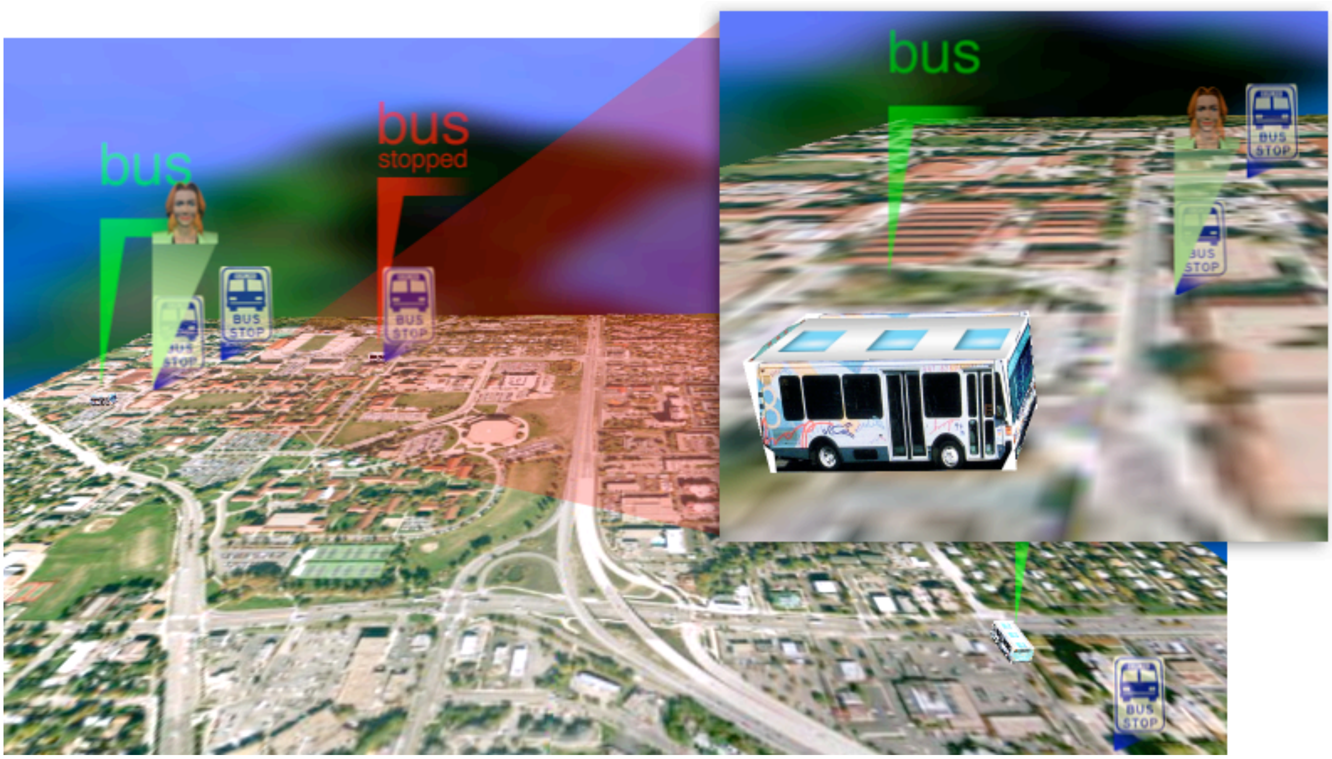

Figure 3: The Real-Time Transportation Visualization prototype: Caregivers see the positions of travelers, buses and bus stops

from previous values. This creates a continuous model in which Mobility Agents represent travelers, buses, and bus stops.

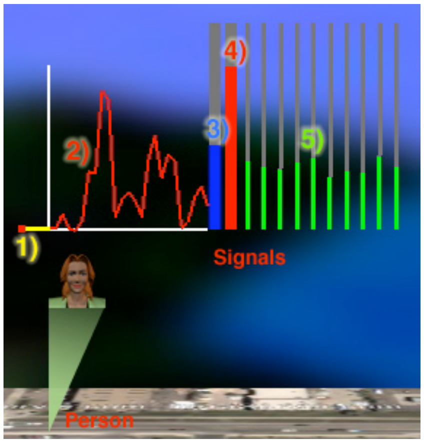

Figure 4: Caregiver interface detail showing signals associated with a traveler: 1) heading: a small arrow indicating the direction the person is moving; 2) plot of network lag time graph: how long it takes the message sent from the device to reach the server; 3) Phone signal level; 4) main battery level; 5) satellites: how many satellites are receiving signal from on the GPS sensor and their signal strength.

2.3 GIS: using spatial information to contextualize messages

The Mobility Agents system includes an agent-based Geographic Information System (GIS) creation and maintenance mechanism. A geographic information database for even a small city is extremely large and cannot be created nor could it be maintained manually. We are using our agent-based Web information extraction technology to create such GIS databases automatically. The agents are given the name of a town and its GPS coordinate range to collect information from USGS databases and web-based Yellow Pages. Having means to automatically gather GIS information is imperative. Businesses such as restaurants move or close down quite often, so the GIS information needs to be rescanned periodically. More importantly, adding new areas of coverage for Mobility Agents requires gathering the GIS information for those areas before they can be incorporated into the system.

Using the GIS information, mobility agents can find out were the person is in relation to known locations or landmarks in a city. Is the traveler close to a restaurant, a hospital, a bridge, a road? The mobility agent can combine all the information he has about the traveler's context and automatically compute a status message to give to users such as caregivers monitoring a traveler. This GIS information is used in the Mobility Agents system in a number of contexts including the generation of the Context Aware Instant Messenger status messages (section 3.3 below).

With the advent of services such as Google Local (http://local.google.com), which allows users to search for places of interest in cities around the U.S. and show the result on high-resolution maps or satellite images, it becomes easier for users to access such location information. For our purposes, we needed to replace the manual labor of searching and reviewing the results with automatic tools that parse the search results and gather the necessary information in a format that is immediately usable by Mobility Agents. We have come up with a simple interface with which one can select the location that serves as a center, the radius of the area of coverage, and which categories and sub-categories of places of interest to search for and gather. The information gets collected in XML-based GIS files that then get loaded into the Mobility Agents system and can be used to provide the useful location references for traveler tracking.

3. ASSESSMENT

3.1 Traveler Interface

The traveler, a person with cognitive disabilities, carries a handheld device that is either a cell phone or a PDA (e.g., Figure 2). Depending on the abilities of the traveler, the handheld devices need to employ various communication modalities. Some of our Mobility Agents testers were not able to read; some could read but only text with very large font. Others had hearing problems and used hearing aids. While the individual abilities varied widely, there was consensus, established in focus groups, that all travelers wanted to have a small device that would be "cool." Nobody liked the idea of carrying a large, special disability device that would indicate to others that the travelers had special needs. Many travelers already carry a cell phone or MP3 players. Some travelers preferred PDAs to cell phones mostly because of the increased display size.

Testing Mobility Agents was a two-stage process. In the first stage, travelers would just be exposed in a lab situation to an early prototype of the Mobility Agent system. On an HP iPAQ PDA they would see prompts, which they had to interpret. The results of these tests confirmed the need for a highly customizable interface. Messages sent from the Mobility Agents Web server to the handheld client would be interpreted according to end-user definable user profiles. The handheld device would access this profile and react to the reception of a message in a highly specific way. Communication modalities include the use of text, images, animations, sounds, and speech.

The second phase was a field test in which the travelers accompanied by the developers, cognitive disabilities experts and the parents of the traveler had to complete a trip to an unknown location using the system. These trips were video taped and at the same time all message interactions and location changes were collected in a log file on the server side. All experiments used the combination of a PocketPC-based PDA, a Pharos GPS sensor connected to the PDA via Bluetooth, and a Verizon service plan. Getting permissions from institutional review boards and parents is a delicate task since the subjects are indeed exposed to real world, real traffic situations. Because of this we have worked only with four individuals up to this point. With one exception all the trips have worked out, that is, the travelers used the Mobility Agents system to identify the right bus, to board the bus and to exit the bus at the right place. In one instance we had to abort a trip because the GPS sensor no longer worked.

Our findings, while established in the context of exploring interface for persons with cognitive disabilities, are of a general nature that also applies to general audiences using handheld technology in public transportation:

- ***Displays***. The contrast of current PDA LCD display is insufficient for use outside in glaring sunshine. This is a serious problem that effectively can prevent users from using handheld technology. Smaller e.g. cell phone displays, often work better. One can at least speculate that the next generation of handheld devices, perhaps pioneered by some of the new portable game consoles, will improve the situation because they are part of a much larger consumer market that is using these devices in outdoor situations. For instance, the Sony Portable Playstation has a significantly better display than all of the PDAs we have tested and yet costs considerably less.

- ***Networking***. Cell phone networks have been treating data as low priority compared to voice. Unlike voice information, which is highly intolerant to lag times exceeding even just a couple of seconds, data is delivered with often embarrassingly high lag times. We have found 20 seconds of lag time quite common and times exceeding one minute also do occur frequently. This is a clear indicator that cell phone network providers differentiate between voice and data information. Our messaging system establishing communication between client and server is based on short XML strings sent via TCP/IP sockets. Lag times such as the ones we have experienced can seriously impede real-time applications. Especially in high-density urban situations, a message that arrives a minute late may be quite useless or worse, completely confusing especially to persons with cognitive disabilities. We experimented with data plans from several providers including T-Mobile and Verizon and found them all surprisingly bad for a "wired" city such as Boulder. In the best case scenario there was no problem with lag times being around 2 seconds but the enormous variance of lag time depending on location and time of day indicates that most of existing cell phone networks are running at their maximal capacity.
- ***GPS***. GPS can be surprisingly unreliable. We ran experiments in Boulder, Colorado, and Seattle, Washington. Even in the low average building height environment of Boulder we found that our GPS sensor often was not able to get a GPS fix. This can be the case if the number of satellites received is too low or if the signal to noise ratio is too low. We quite frequently experienced these situations even with no high buildings nearby. In our trip logs we include for each location the number of satellites received and their signal to noise ratios. Further analysis is required but even at this point we can conclude that cheap consumer-level GPS sensors such as the Pharos sensor are really at the threshold of usability for applications such as Mobility Agents. Research has produced new high sensitivity GPS sensors that are able to get GPS locks even inside buildings. These sensors are not commercially available yet and even when they will be their price will probably be too high for this kind of application.
- ***Battery***: PDAs tend to drain their batteries quickly compared to cell phones. This is especially pronounced when PDAs need to run networking, display at high brightness, and run Bluetooth or built-in GPS sensors. Mobility Agents include the tracking of the battery charge level, but some devices can run out of battery already after a small number of trips.
- ***Audio***. Built-in speakers cannot typically produce the kind of volume necessary to alarm travelers in a noisy bus. To make matters worse, some travelers have hearing problems and wear hearing aids. It is possible and necessary to feed the output of the PDA into the hearing aid. Some hearing aids have additional analog inputs that can be connected by wire to external devices such as phones and radios. Newer devices are using wireless approaches, most notably Bluetooth, to interface with external audio sources. We found that all of the PDA and cell phones used in our test included the ability to vibrate which was a very effective way to alarm travelers.
- ***Pens***. Using pen-based interface in a public transportation context is not a good idea. It is virtually impossible to operate a PDA with only one hand. The pen gets easily lost and is not practical when the device needs to be used standing at a bus stop while holding bags or coats. Additionally, some people with cognitive disabilities have motor skill problems that can make the device hard to use even with two hands. As much as possible we tried to eliminate the need to use the pen. We used large buttons allowing users to tab the display with their fingers. Cell phones, in contrast, can be used with one hand and many people with cognitive disabilities are already using cell phones. However, some of the newer types of cell phones feature a very large number of small buttons that can be confusing.
- ***Representations of Progress***. Waiting can be frustrating. Progress indicators are essential. Some people with cognitive disabilities have a very limited sense of space and time. We found that display information that textually represented distance and time was not helpful. A progress bar including a visible representation of a bus moving towards the person did help, but introduced a new set of challenges. Our progress bar represented the distance left between the traveler and the bus. Because of traffic, busses make sometime very sporadic progress. For instance, a bus may stop for quite some time at a traffic light. This can be confusing and even frustrating for a user because it becomes clear that the bus is not moving but it is not clear when the bus will move again.

3.2 Advanced Traveler Interface

For advanced travelers, we included a tool called the Urban Radar (Figure 5) to find bus stops by pointing out the relative position of nearby recognizable landmarks such as restaurants. Tourists exploring an urban environment can use the Urban Radar to find interesting spots. The Urban Radar uses the current location of the traveler and a specified interest, e.g., the interest in food, to find nearby locations. The radius of the search sweep can be constant but can also be switched to automatic mode. In automatic mode the radius will be adjusted until the number of interesting spots lies in a user defined range. In areas with a low density of interesting targets the radius increases. In areas with high density the radius decreases.

The radar representation displays relative locations taking the current heading – determined as the traveler is walking – into account. The Urban Radar is not a replacement for long-range GPS maps. Instead it is a short-range orientation device that helps a traveler to find locations without a potentially confusing map simply by referring to locations that are typically in plain sight.

The Urban Radar can display static locations such as restaurants derived from USGS and Google local GIS information. In addition to the name of the location a travel can access more meta-information including the postal address and the Web page (if there is one) correlating to the location.

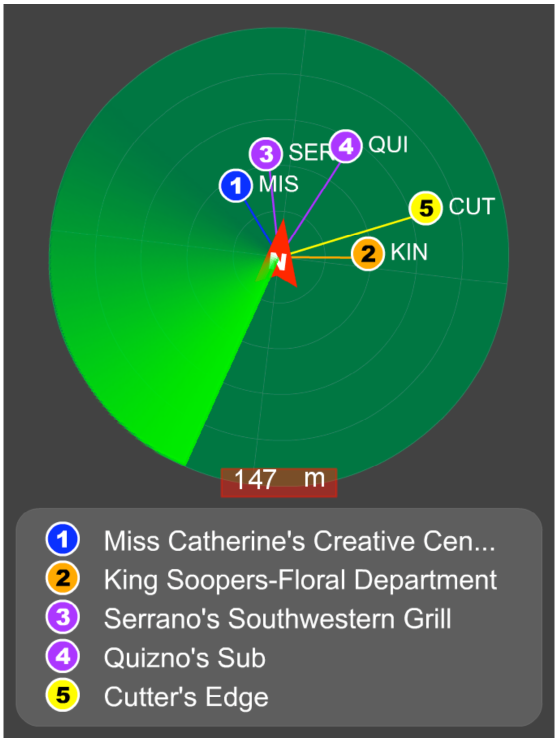

Figure 5: The Urban Radar advanced traveler interface

The Urban Radar can also display dynamic information such as busses heading toward a bus stop inside the search radius or even the location of other travelers in the vicinity.

3.3 Caregiver Interface

Feedback from focus groups indicated that while caregivers were impressed with the 3D simulation/visualization of the monitoring interface, they needed to have also a simpler, less intrusive interface for daily use. All of the caregiver participants were parents of children with cognitive disabilities. Many participants worked at a job involving using computers. Any kind of interface competing with their regular work duties would be problematic because it takes up a lot of screen estate or requires regular attention. The ideal application would allow a much more *peripheral sense* of observation that requires only a small amount of screen space and provides a concise representation of the location and/or situation of the traveler. In addition, travelers as well as their caregivers wanted to have control over who could access their data.

We experimented with a number of interfaces but found that we could leverage Instant Messaging (IM) technology to fulfill all of the above requirements. The resulting concept is an extension to Context Aware Instant Messaging (CAIM) frameworks combining GPS-based location awareness with Instant Messaging services. Millions of people worldwide already use IM at home or at work to stay in touch with their friends or to collaborate with their peers. Moreover, IM includes all the necessary mechanisms of data protection and visibility control.

An IM-based interface has several components. A *buddy list* (Figure 6) is a list of people including their name, picture, a status indicator (the green dot shows that they are currently online), and a status message, which is an arbitrary piece of text controlled by a buddy. An increasing number of people is putting a lot of information about their work status into the status message for instance "teaching, " "writing progress report", "at lunch." These status messages can be quite informative for observers as they allow them to judge the availability of a person.

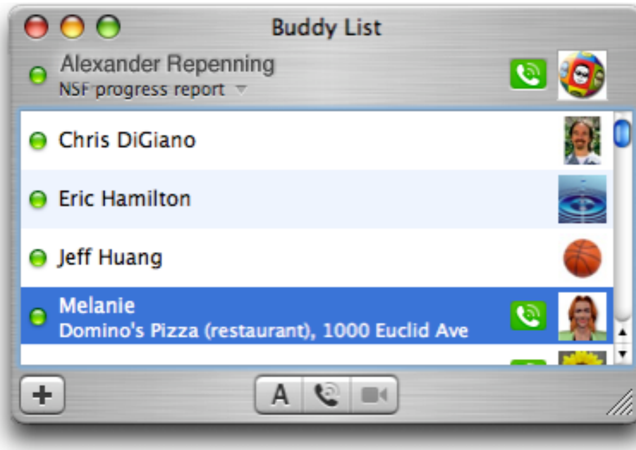

Figure 6: The Instant Messaging buddy list includes tracking information. The mobility agent dynamically updates the status line of Melanie. The agent uses Goggle Local to convert GPS coordinates into mnemonic location.

Each mobility agent is associated with one IM buddy. We have created a piece of software that allows the mobility agents to become a remote controlled buddy. This control includes the ability to set the status message programmatically. The mobility agent tracks the location of the traveler via network and GPS. Using the Geographic Information System (GIS) the agent can find out were the person is. Is the traveler close to a restaurant, a hospital, a bridge, road, etc.? That information is used to automatically create and update a status message. The mobility agent can combine all the information he has about the context the traveler is in to compute a status message. In the example Figure 6 above, the traveler Melanie is represented through a Melanie buddy. The status message includes "Domino's Pizza", the name of a restaurant, and "1000 Euclid Avenue", a street address in Boulder, Colorado. This real time information is typically sufficient to describe Melanie's location to her caregiver. By adding more custom information into the GIS, the description would also be more personalized. For instance, instead of using a generic building address, the system could know where Melanie's doctor is and could use a more descriptive label as part of the status message.

Conceptually speaking the use of the status message is the equivalent to a broadcast mechanism. Any number of people who are allowed to "see" Melanie, no matter where they are located, will be able to read her status message and will be able to see it change in real time.

The status message-based interface works well for peripheral information such as the tracking information. Melanie simply shows up on a buddy list that may already be used to stay in touch with friends and collaborators. However, the status message interface is not sufficient for information that may require actions from the caregivers. Also, many of the specific events concerning Melanie's trip may only be relevant to a very small number of people. To that end, we are also using the messaging part of IM. Events such as Melanie entering or leaving a bus automatically trigger messages sent to a caregiver. Unlike the status message these are messages that are being sent to specific people. These messages show up in an Instant Messages window (Figure 7). In contrast to the status message these messages have the intention of getting the immediate attention of the caregiver. Depending on the specific settings, a sound or other forms of alerts will be produced to make sure that the caregiver notices the message being sent.

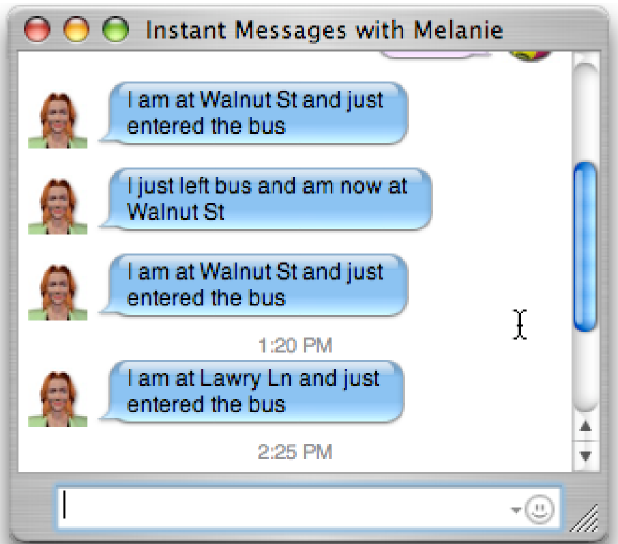

Figure 7: Trip information messages and alerts sent to caregivers through instant messages.

Leveraging IM technology has additional benefits. IM clients (software including the buddy list and the message window) exist on virtually every hardware/software platform including regular desktop computers, handheld devices including PDAs (Palm, PocketPC, BlackBerry) and even cell phones. This allows caregivers to monitor progress of their travelers not just at home or at work, but also on the road. Additionally, many clients are highly customizable. Virtually any kind of status information change can, at the request of a user, trigger new events. For instance, a caregiver may choose to have new messages being spoken or to trigger other kinds of alert signals.

4. DISCUSSION

When we have accurate GPS information from the sensors and the GPRS network connection (for data over the cell phone network) works on the traveler's device, our client software is virtually impeccable. We have produced a robust networking protocol for our client software to communicate with the server, by moving from HTTP type protocols (which are stateless) to TCP/IP sockets. This has enabled us to build stable communication protocols and minimize latency in the client/server communications. However, GPS is not always obtainable and accurate with small consumer GPS sensors. With some cell phone providers, we have experienced some difficulties recovering from losing the GPRS connection. In some instances, after losing GPRS connection (because of heavy loads on the cell phone network), it was hard to regain any kind of connectivity on the device (not just for our software, but any kind of internet connectivity, such as browsing in Internet Explorer for the PocketPC). We have moved to more efficient and reliable cell phone providers, but the current state of networking through cell phone networks (e.g. unacceptably high lag times) provides enormous challenges to the deployment of a reliable Mobility Agents system.

Our early analysis based on all the sensor values indicates that these service problems are only somewhat correlated to location and time. Cell phone service providers currently seem to have a much stronger commitment to voice services compared to data service. By and large, the data service is a “best effort” service, which according to our experience includes the possibility that sometimes data connections cannot be established at all. In other words best effort degrades bits for data if they are not used up for voice. This kind of service quality may be acceptable for casual users but would not be acceptable for critical applications involving persons with cognitive disabilities depending on this service. To a large degree, we believe this problem is the result of the existence of few safety-critical wireless data applications for handheld computers at the present time.

The business model of most wireless service providers is to keep cost high while at the same time keep their data service quality low. These problems with private companies have resulted in early attempts to explore federally funded projects such as the Wireless Philadelphia project. Wireless Philadelphia goal is to strengthen the City's economy and transform Philadelphia's neighborhoods by providing wireless Internet access throughout the city. The quality of the envisioned broadband-based service would be higher *and* cheaper. The city of Philadelphia and Verizon are currently negotiating terms to settle the disputes that have emerged from this project. It is to hope that the federal involvement will result in nation wide improvements over the wireless network situation.

5. CONCLUSIONS

We have created a working wireless guiding and tracking system that helps people, with or without cognitive disabilities, to use public transportation. The combination of current wireless networking and GPS is still posing a number of significant technical issues that make location-aware services not yet usable for mission critical applications. City-wide WiFi and WiMax networks, in due time, will address most of the networking issues. High sensitivity GPS sensors will increase the feasibility of urban applications. PDAs will have to go a long way before they become completely suited for urban use. Finally, it is not necessary, or even desirable, to create all new interfaces for location aware services. For instance tracking applications can be built on top of existing communications tools such as Instant Messaging to create location aware Instant Messaging applications.

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