

COMBINING DATA AND VOICE COMMUNICATIONS ON DIGITAL WIRELESS NETWORKS

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Abstract

Growing demand for access to mobile data and the advent of new digital wireless voice/data services motivate the design of a system that handles both voice and data traffic efficiently. In this paper we describe the design of a system for wireless voice and data communications. On the network side, we enhance a digital cellular/PCS basestation with a direct data connection to provide data services. On the terminal side, we describe a small, light wireless handset that uses a pen based user interface and handwriting recognition for access to data services.

Technical Subject Area: Personal Communication Systems

Secondary Subject Areas: Interactive Communication Systems, Interactive Multimedia Systems

1. Introduction

Recent trends in communications and computing indicate a growing demand for mobile data communications services. In the last decade cellular subscriber growth rates have been between 35% and 60% per year in the United States [Cox96]. Concurrently, prices for cellular service have been dropping. New digital cellular networks that support both voice and data communications are being deployed. They are based on the IS-136, IS-95, and GSM standards and provide data bandwidths of up to 14.4 kbps per user. There are also a growing number of Cellular Digital Packet Data (CDPD) users despite the high cost of terminal equipment. The Personal Communications Industries Association projects 88.3 million subscribers to PCS, paging, cellular, and other mobile radio services by 1998, climbing to 167.4 million subscribers in 2003 [Schn94].

The Internet has experienced tremendous growth in the last few years. Applications include electronic mail (e-mail), electronic bulletin boards, Internet voice telephony and the World Wide Web (the Web). Web browsers for displaying local and remote documents encoded in HyperText Markup Language (HTML) [Musc96] have become the most popular applications on the Internet.

Personal digital assistants (PDAs) such as the Newton MessagePad, 3Com PalmPilot, Sharp Zaurus, and new

Windows CE palmtop computers are gaining in popularity. Their strengths include long battery life, small form factor, and well-designed, integrated applications. International Data Corporation reports that 5.1 million handheld devices were sold in 1997 and projects 1998 sales to reach 8.2 million.

From these developments, we see that wireless service providers are making mobile data access available and that consumers desire mobile data services. This paper proposes a design for the network infrastructure to support data and voice together on the same wireless network and describes applications and a handset design for this network. Section 2 surveys current wireless data access methods and handsets. Section 3 describes the system architecture. Section 4 describes the applications and handset to support the applications. Section 5 summarizes the paper.

2. Previous Work

There are two data-enabled digital cellular telephones and several wireless data services operating today. The Nokia 9000 Communicator [Nokia96] is a sophisticated palmtop computer built into a GSM cellular telephone. It is capable of receiving faxes, e-mail, and short messages. When the clamshell casing is closed, it operates as a regular cellular telephone. When open, it reveals a half-VGA LCD display on one side and a keyboard on the other. Applications include address book, calendar, to-do list, calculator, world clock, Web browser and telnet. The user dials into an Internet service provider just like a cellular modem for Internet access.

The AT&T PocketNet telephone [PCSI96] is an analog cellular telephone with an integrated CDPD modem. A TCP/IP stack is embedded in the telephone to enable applications to access the Internet and display Web pages on its 5 line by 20-character display. A Web browser allows users to view documents formatted in the Handheld Device Markup Language (HDML) [Unwi96].

Advanced Radio Data Information Systems (ARDIS) is a two-way packet data service operated by Motorola. It is suitable for two-way transfer of data files of size less than 10 kilobytes. Mobitex is a radio network for voice and data developed by Ericsson and Swedish Telecom. It operates similarly to a cellular telephone system, except that handoffs are handled by the mobile terminal rather than by the network.

The Personal Access Communications System (PACS) was originally developed and proposed by Bellcore in 1992. It supports voice, data and video for indoor and microcell use. The Digital European Cordless Telephone (DECT) system and the CT2 system are European standards for cordless telephones. The Personal HandyPhone (PHS) system is a micro-cellular system widely deployed in Japan. It supports handoffs only at walking speeds.

The digital cellular networks, particularly GSM, are the most widely deployed worldwide. They offer both voice and data communications and are a good foundation upon which to build a true voice/data mobile communications system.

3. System Architecture

Our system enhances digital cellular and PCS networks to provide efficient wireless access to data communications services. The system distinguishes explicitly between voice and data traffic. Voice traffic is sent via the Public Switched Telephone Network (PSTN) while data traffic bypasses the PSTN and goes directly to a data network. The data network includes an Internet gateway, compute servers and data servers. This architecture is shown in Figure 1. Each wireless basestation supports many mobile terminals. The basestation is enhanced to recognize wireless data packets and send them directly to the data network.

3.1 Data Network

A direct data connection has several advantages over the old architecture. With the old architecture, a wired Public Switched Telephone Network (PSTN) call takes several seconds to set up. Cellular calls take even longer. An application that accesses the network therefore sees a long initial delay. After that, it has a continuous circuit-switched connection even though the radio channel is idle most of the time. With the new architecture, there is no PSTN connection for data calls so the setup time is much faster. This allows the terminal to be very responsive even if the wireless connection is torn down and rebuilt often.

Since the channel is priced by connect time rather than by bandwidth, obtaining data services over the wireless channel can be expensive. One way to alleviate this problem is to tear down the wireless connection after a short timeout and rebuild it when needed. Ideally, the wireless data channel would be a packet-switched multiple access channel rather than circuit switched. New digital cellular packet data standards are evolving for this purpose. For example, IS-657 [TIA96] is a wireless packet data standard for CDMA. These standards will help speed the deployment of packet data capabilities in new digital cellular and PCS networks.

The direct data connection also means that network service providers can become Internet service providers (ISPs). The service provider assigns a semi-persistent Internet Protocol (IP) address to each wireless terminal

when it logs on, similarly to the scheme used by wired ISPs today. This address is independent of the user's ID so that more than one person can use each terminal.

A data network cluster may be shared by several basestations; routers allow communication between clusters. Inter-cluster communication is important when users roam away from their home basestation. Internet access is provided by the cluster serving the remote basestation. User data is retrieved from the home cluster.

Protocols for serving roaming terminals already exist. One such protocol is Mobile IP [Per98]. Mobile IP provides for a home agent on the terminal's home network and a foreign agent on the remote network. The terminal broadcasts a request for service on the remote network. The foreign agent replies and simultaneously contacts the terminal's home agent to request interception of IP packets and tunneling these packets to the roaming terminal through the foreign agent. The home agent informs the sender of the foreign agent's address so data packets can be sent there directly.

Mobile IP has several limitations. It requires a static IP address for each terminal, which is not practical given the scarcity IP addresses. There is no provision for authentication and security. Mobile IP does not specify a billing method for roaming service. Extensions to the protocol are required to overcome these limitations.

3.2 Servers

Clusters of compute servers connected to the wireless basestations support several functions. Parts of Web pages and other documents, such as images, are transcoded or sub-sampled before transmission to conserve wireless bandwidth. Other compute-intensive services are provided to support thin wireless clients (that is, wireless terminals that do not have powerful capabilities). Security servers provide user authentication. Data servers serve as repositories of public information as well as providing storage for user data and backups. One or more Internet gateways provide access to the Internet.

3.3 Authentication

Each user of the system has an ID that is distinct from the ID of the handset, and a password is necessary to authenticate the user. This password may be an alphanumeric string or some form of biometric authentication, such as fingerprints or signatures. Unauthenticated users may access public services such as 9-1-1 dialing; only authenticated users may access private data. Authentication is provided by the security servers mentioned in the preceding section.

Each terminal therefore supports more than one user and each user can use any wireless terminal. For example, a user on vacation would take a lightweight handset with her whereas she would carry a more powerful terminal on a business trip. Of course, she may access her data

from a desktop computer or other wired connection as well.

4. The Voice/Data Handset

We have designed a small, light voice/data handset as part of our system. It is designed primarily for communications applications although it supports personal information management. It uses a pen digitizer and handwriting recognition rather than a keyboard and mouse for text input and navigation. Bitmapped LCD screens support a graphical user interface.

4.1 Applications

Compelling applications are the key to the success of any communications system. The applications on our handset fall into two categories, communications applications and personal information management (PIM) applications. The handset design is optimized for communications applications since it is crucial to support the communications applications well, even at the expense of the PIM applications.

Communications applications such as directory, e-mail, Web browsing, and facsimile (fax) directly support the handset's function as a mobile communications device. The directory enables a user to obtain communications-centered information from the white pages, yellow pages, corporate directory, or personal directory. Multimedia e-mail allows users to send text, graphical and audio messages electronically. The Web browser is a powerful paradigm for retrieving and viewing multimedia documents, whether they are local or remote. Many corporations use Web servers for disseminating information to customers and employees.

PIM applications include appointment diary, expense diary, calendar, world clock, notepad, and calculator. Although these applications are supported, the handset is not optimized for them.

4.2 Hardware

The handset is designed to be small and light yet have a large screen area. It features a clamshell casing which, when closed, looks and functions like a regular cellular telephone (see Figure 2). A dialing keypad on the front contains the usual numeric and control buttons (send, store, recall, answer). Calls are made and received as they would be on a regular cellular telephone. The form factor is about the same as that of cellular telephones.

When the clamshell casing is opened it reveals two contiguous touch screens and operates like a pen-based PDA. Each physical screen has a resolution of 640 by 240 pixels so the pair realizes a full VGA screen. A passive pen is used to press soft keys, manipulate menus, and write on the touch screen.

4.3 User Interface

The user interface is optimized for communications applications. Our prototype uses the Inferno operating system. Inferno is small and fast so a low-power processor and a small memory can be used in the

handset. A graphical user interface (GUI) is supported via the Tk widget set [Oust94], which is a set of graphical primitives such as buttons, menus, and data entry windows.

Applications use a point-and-tap interface wherever possible so most control functions are accessed using buttons and pull-up menus. A writing area is maintained on the lower part of the screen and all handwriting capture is done here (see Figure 3). This minimizes hand and arm movement and maximizes screen visibility during writing since the writing hand does not obstruct the screen. Only one application is visible at any one time to prevent user confusion and eliminate placing and resizing applications. Menu bars are placed at the bottom of the application rather than at the top to minimize navigation from the writing area.

For users preferring a keyboard for data entry, a software keyboard is available. This keyboard may be displayed on the lower screen for the user to tap with the pen. Selection and cursor movement are effected using the pen or by arrow keys on the soft keyboard.

4.4 Handwriting Capture

The common writing area is called the Handwriting Capture Widget (HCW) and individual text entry areas within applications are called Text Entry Widgets (TEWs).

All handwriting capture and editing is done in the HCW. Users print handwritten characters and "electronic ink" traces the trajectory of the pen. Text from the recognizer then replaces the electronic ink one character at a time. If the recognizer makes an error, the user taps on the misrecognized character to bring up a correction menu containing the 5 most likely choices returned by the recognizer. She can choose one of these candidates, Rewrite, or a soft keyboard.

Arrow buttons allow horizontal scrolling. The "Clear" button erases characters. The "Lower" button indicates lowercase character mode, which the user changes to uppercase or digits by tapping on this button. Punctuation symbols are supported in all three modes. When the user taps the "Done" button, recognized text is sent to the TEW possessing entry focus. TEWs are enhanced Tk text entry widgets and are used by applications for all text input. When a TEW receives text from the HCW, it automatically passes focus to the next TEW on the current form without user intervention.

4.5 Biometric Authentication

When the handset is turned on, the user is prompted to write his username and to sign in. A signature verification application authenticates the login locally or using a security server on the network. Signatures are particularly useful for identification because each person's signature is highly unique, especially if they are captured on-line. The feature statistics of a training set of

6 signatures are used to build a template for validating test signatures [Kas96].

The verifier compares global and local features of test and template signatures. Global features capture the overall spatial and temporal characteristics of signatures. We extract local information about a signature using stroke-direction code (SDC), which models hand movements as a time-ordered concatenation of a fixed number of strokes and derives information about the spatial orientation of these strokes. The SDC obtained from a test signature is compared to the model SDC using elastic matching techniques similar to ones used in speech techniques [Sak78]. This algorithm has a 3% equal error rate and needs 150 bytes to store each signature model.

4.6 Handwriting Recognizer

The user interface uses handprint rather than cursive or mixed-mode recognition because the input text consists mainly of non-dictionary words: Universal Resource Locators (URLs) for the Web, e-mail addresses, telephone numbers, personal names, and place names. The use of cursive recognizers is precluded because they require a restricted vocabulary.

The recognizer is based on Hidden Markov Models (HMMs), and supports writer independent recognition of handwritten characters of unconstrained styles [Hu96]. A HMM describes a doubly stochastic process: a process that generates a sequence of states hidden from observation, and an observable process that is dependent on the underlying state sequence. HMMs have been very successful in modeling speech and on-line handwriting. In our recognizer, each character is represented by one or more classes depending on the number of distinct styles observed for the character. Each class is modeled by a left-to-right HMM with a variable number of states and discrete state dependent observation probabilities. For any input character, an N-best decoding algorithm (a variation of the Viterbi algorithm) is applied to find the top 5 closest matches in the alphabet. The HMMs are pre-trained on a large number of character samples from many different writers drawn from the UNIPEN database [Uni96].

5. Summary

We have described a system for supporting both voice and data applications over cellular digital and PCS networks. The system includes a direct connection from

the basestation to a packet data network containing an Internet gateway and various servers. A wireless handset that supports PDA functions and both voice and data communications is also described.

6. References

- [Cox96] D. Cox, "Wireless Personal Communications: A Perspective", in *Mobile Communications Handbook*, J. Gibson ed., CRC Press, Boca Raton, FL, 1996.
- [Gibs96] J. D. Gibson, "The Mobile Communications Handbook", IEEE Press, 1996.
- [Hu96] J. Hu, M. K. Brown and W. Turin, "HMM based on-line handwriting recognition", *IEEE PAMI*, vol. 18, no. 10, pp. 1039-1045, October 1996.
- [Inf96] <http://www.lucent.com/inferno>
- [Kas96] R. S. Kashi, W. Turin and W. Nelson, "On-line signature verification using stroke direction coding", *Optical Engineering Journal*, 35(9), 1996.
- [Musc96] C. Musciano and B. Kennedy, "HTML: The Definitive Guide". O'Reilly and Associates, 1996.
- [Nokia96] <http://www.nokia.com/com9000/n9000.html>
- [Oust94] J. Ousterhout, "Tcl and the Tk Toolkit", Addison Wesley, Reading, MA, 1994.
- [PCSI96] <http://www.pcsi.com/pal.html>
- [Per98] C. Perkins, "Mobile IP: Design Principles and Practices", Addison Wesley, 1998.
- [Rapp96] T. Rappaport, "Wireless Communications Principles and Practice", IEEE Press, 1996.
- [Sak78] H. Sakoe and S. Chiba, "Dynamic programming algorithm optimization for spoken word recognition", *IEEE Trans. Acoustics, Speech, Signal Processing*, ASSP-26, 1978.
- [Schm97] T. Schmidt, "Tim's Personal Devices Journal", *Pen Computing Magazine*, vol. 4, no. 16, pp. 46-47, June 1997.
- [Schn94] R. Schneiderman, "Wireless Personal Communications", IEEE Press, 1994.
- [TIA96] "IS-657, Packet Data Service Option Standard for Wideband Spread Spectrum Systems", Electronic Industries Association, Arlington, VA, 1996.
- [Unwi96] <http://www.uplanet.com>
- [Uni96] <http://unipen.nici.kun.nl>

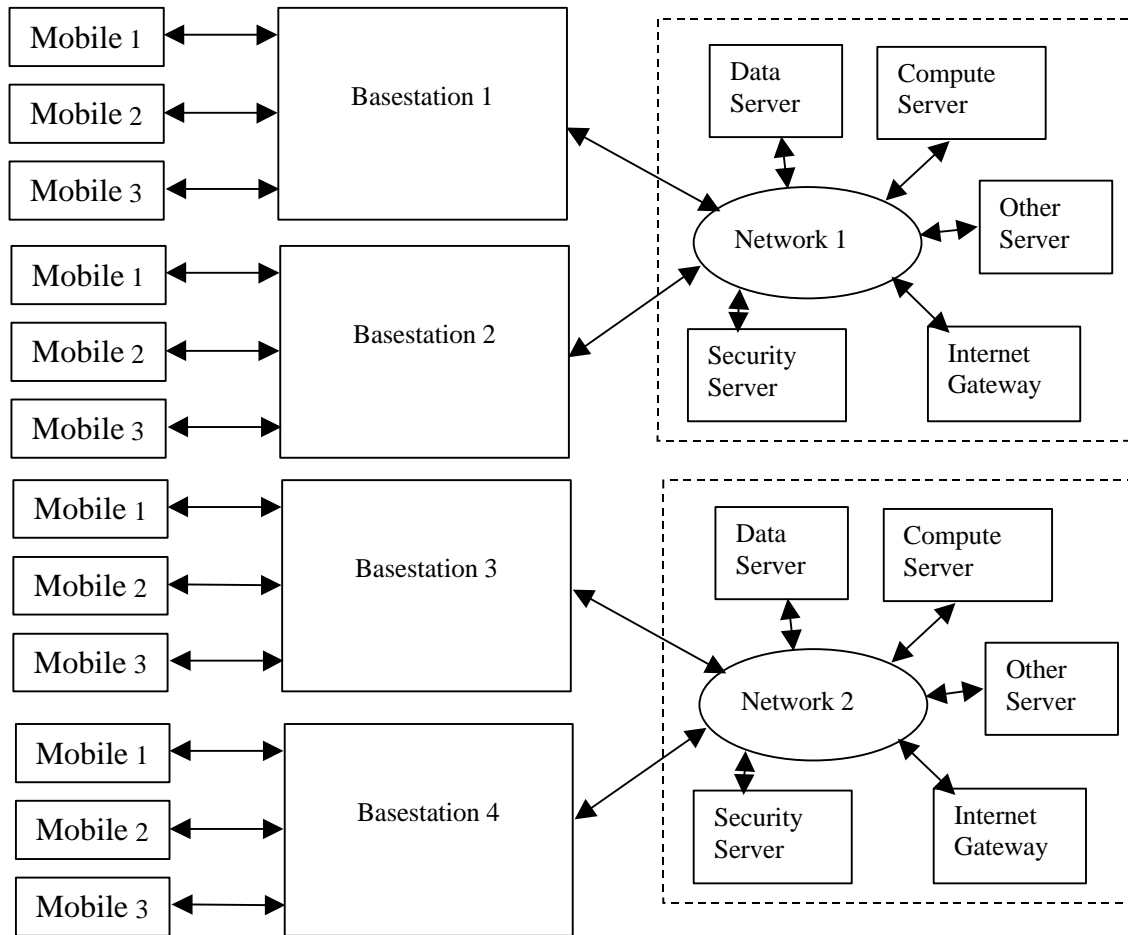
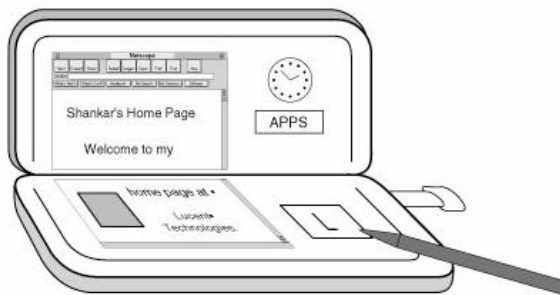


Figure 1: Network Architecture: PSTN connections not shown



Closed



Open

Figure 2: Handset Design: Open and closed configurations

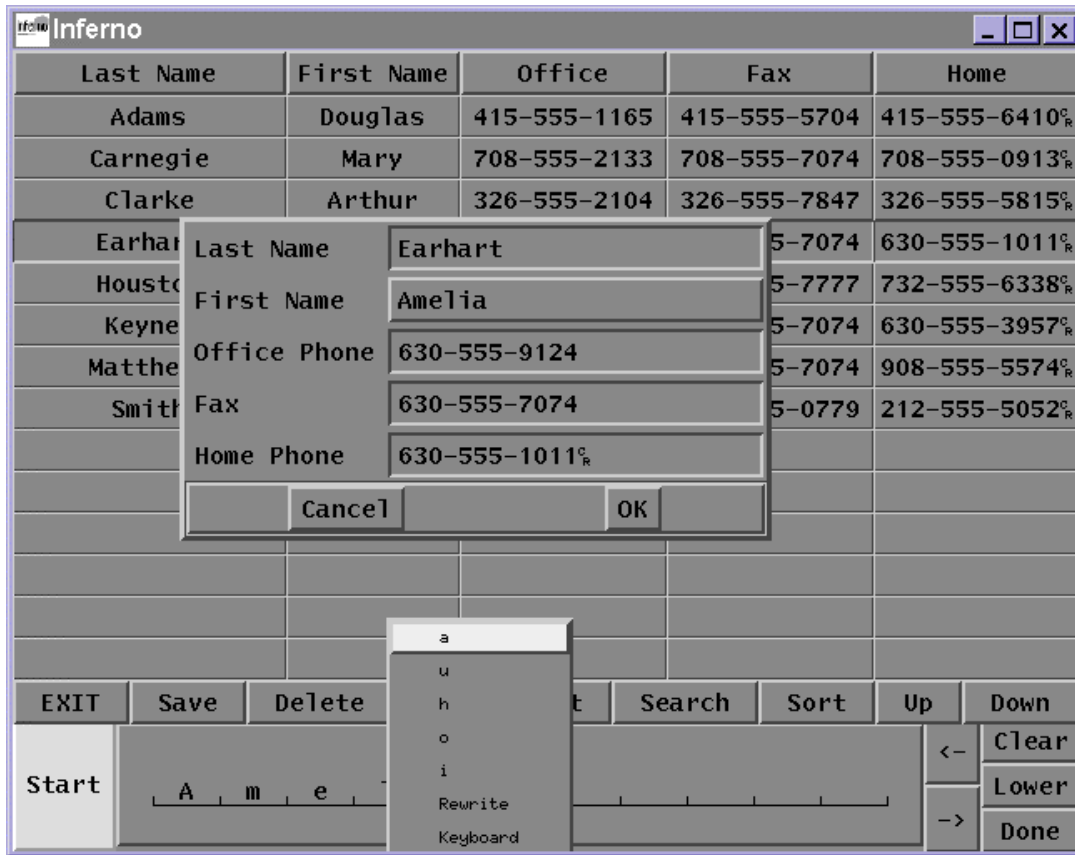


Figure 3: Screen Shot: Handwriting capture widget at bottom with correction menu active