Wireless Wide Area Networking for

Device Monitoring

By

Owen A.L. Zacharias

Submitted in Partial Fulfillment

of the

Requirement for the Degree

Master of Science

Supervised by

Professor Wendi B. Heinzelman

Department of Electrical and Computer Engineering

The College

School of Engineering and Applied Sciences

University of Rochester

Rochester, New York

2004

Curriculum Vitae

The author was born in Boston, Massachusetts on September 24th, 1979. He attended the University of Rochester from 1999 to 2003, and graduated with a Bachelor of Science in Electrical and Computer Engineering concentrating in Computers. He then continued his studies at the University of Rochester in the Master's program in Electrical and Computer Engineering. With the guidance of Professor Wendi B. Heinzelman, he has researched wireless communications protocols with a major focus into wide area networking.

Acknowledgements

I would like to thank my Advisor on my thesis work, Professor Wendi B. Heinzelman. It was a very rewarding experience to work with someone who is so enthusiastic and knowledgeable in her discipline, and who provides continuing and critical feedback.

In addition, I would also like to thank the talented graduate students who make up Professors Heinzelman's research group. They have all provided me with a strong source of information and an excellent outlet for critical thinking and reasoning. I would like to especially thank Colin Goldsmith, who partnered with me on our thesis work with Xerox: without his drive and knowledge this Thesis would not exist.

I would also like to thank those in the Electrical and Computer Engineering department who have helped me along my way over the past five years. Without my fellow colleagues Michael Wieckowski, Jacob Keniston, and Scott Sturdivant, my time in the department certainly would have been lacking in excitement and enthusiasm. I'm grateful for all of our experiences together, and wish each of you the very best wherever the future may take you.

Finally, I would like to thank my parents, brother, and grandparents. Thank you so much for supporting me though my efforts in the continuing of my education over the years. I hope that I can use the skills that I have obtained here to make you proud in the future.

Abstract

This thesis discusses a means of connecting devices over a wireless Wide Area Network (WAN) in order to perform a number of different remote administration functions. These include, but are not limited to automated meter reads, product break notifications, maintenance support, and process automation.

A detailed review and comparison of the available wireless WANs currently in operation was conducted. Out of the numerous choices the best-suited protocol, based on a number of decision metrics, was chosen for the task at hand.

Finally, the system was prototyped in hardware and in software using the Java™ programming language. Simulations using wired networks demonstrated the successful operation of the remote administration functions.

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Motivation

The Xerox Corporation has developed an infrastructure for connecting its devices, located in customer sites, to a central application server located within Xerox. This set of Device-Centric services (DCS) will provide a multitude of applications including automated meter reads, product break-notification, maintenance support, and process automation.

The current implementation of this infrastructure contains a wired network connecting Xerox devices into the backbone of the customer's network, through the Internet, and subsequently into a Xerox application server. Unfortunately, this solution is not always viable given legacy devices, client network security concerns, and the recent emergence of unconnected digital copiers and printers. Therefore, wireless networks can be looked to in order to reduce the number of these stand-alone devices that remain unconnected to the DCS system.

The wireless solution can be broken into two separate parts: local and wide area. The Wide Area Network (WAN) option is explored in this thesis, while the Local Area Network (LAN) solution can found in [7]. The wireless WAN will involve an interface from the device (printer, copier, etc.), located at the customer site, to a third party carrier (e.g., Cingular Wireless, Nextel, etc.), who will then route the data back to Xerox.

One of the goals of this thesis is to determine which wireless WAN best fulfills a number of criteria set forth by Xerox. These include: capital cost, operational cost, security,

10

device scalability, data scalability, network coverage, network reliability, power consumption, and susceptibility to noise. The majority of these metrics are considered for each of the technologies examined within this thesis in order to determine the very "best" solution for the task of Remote Monitoring.

Once a wireless WAN is selected, software and hardware can then be chosen and developed in order to support the DCS over a wireless WAN. One of the major goals here is to use commonly available components, or off-the-shelf parts, in order to minimize the cost of development. This will therefore speed up the time to market of the final system.

1.2 Contributions

This thesis work contributes to the initial development phases of a wireless WAN solution for Xerox's DCS. It presents an in depth evaluation of current wireless WAN technologies being used in the U.S. and worldwide, using a number of decision metrics in order to determine the "best" solution out of the available technologies. This effort also recommends a hardware implementation strategy and software development requirements (including a Java prototype), based on the WAN technology selected to connect remote customers to Xerox's DCS. The work culminated with a presentation to Xerox of the complete specifications of a Wireless WAN system to support remote DCS operation.

1.3 Organization

This thesis is organized as follows. Chapter two gives a general background of wireless WANs. Chapter three details the various technologies that were investigated and considered for use within this project. Chapter four presents the WAN protocol that was finally decided

upon. Chapter five contains the hardware component design. Chapter six describes the

software used to operate the remote monitor over the wireless channel. Finally, chapter

seven presents future work in this area and the final conclusions.

Chapter 2

Wireless Wide Area Networks (WAN) Background

2.1 A Myriad of Protocols

With the wireless communication industry growing at its current rate, it is not surprising that a large number of drastically different protocols have been conceived and developed over the years.. While each protocol has been specialized for a different niche of the wireless market, all have some fundamental aspects in common. These include the transmission of data over a wireless channel (RF, Satellite, etc.) from a low power device (mobile) to a station that receives and propagates data along either another wireless channel or a wired network.

2.1.1 Voice

The most common of all wireless wide area networks carry voice traffic. This is because the first wireless WANs were simple analog cellular systems which attempted to mimic the Public Switched Telephone Network (PSTN). Therefore, these cellular networks were setup and optimized for voice traffic by focusing on a Circuit Switched networking approach. In a circuit switched connection a channel is opened between the two parties attempting to communicate and that same path is utilized throughout the duration of the dialogue. This method of communication ensures that voice data is received (at the receiver) in the same order that it was sent (by the transmitter).

2.1.2 Data

With the overwhelming success of the Internet, and the global need for instantaneous access to data, it became apparent that the primitive methods of transferring data over voice channels (though modem modulation techniques) were not efficient solutions. Therefore, dedicated data-only networks began to appear that had many advantages over their voice-only counterparts.

Most data can be packetized (broken up into small pieces) and sent independently over separate paths in a communication channel. This model is used the world over on wired networks (such as the Internet) and therefore is used in data-only wireless networks. The use of packetization allows the breaking up of data into discrete chunks, and then transmitting the packets out over a link. The packets will not necessarily traverse the same path, but they will arrive at the same receiver. This can lead to data being received out of order; however, the receiving device has the ability to reconstruct the original data in the correct order. This method is not well suited for voice because the out of order arrival is difficult to use in a system involving real-time reception of data.

2.1.3 Combined Networks

The most modern of current wireless WANs recognize that both voice and data transmissions are vital to the global communications market. Therefore, separate protocols have been created that run over the same network. It should be noted that these hybrid networks, by not giving total precedence to either data or voice, might not be considered as powerful as a single specialized network. However, even with the overhead of both voice and data on the same network, these modern standards allow for much more reliable and higher data rate

transmissions then their data-only counterparts thanks to use of cutting edge hardware and software.

2.2 Service Providers

The goal of this thesis was to find a currently established and operating service provider that could give access to one of the types of wireless WANs. Providers range in size from small (city wide) to mid-size (region wide) to the largest, which encompass entire countries. In the case of the United States, the largest, most well known providers include Cingular Wireless, AT&T Wireless, Nextel, Verizon Wireless, and more.

Unfortunately, there are very few providers that can lay claim to multiple countries around the world (with the exception being the European market). Therefore, regardless of the choice of protocol, when it comes time to expand the current design beyond the bounds of the United States, it will be necessary to make use of multiple providers, even if the same technology is used worldwide.

Chapter 3
Technologies

3.1 Overview

With many different wireless protocols and providers available in the United States (let alone worldwide), it was necessary to narrow down the list of options into those technologies that are already available and established within the U.S. This was an important aspect because the total time from the start of the project to initial delivery was around a year, and therefore would need to rely upon current technologies. With this in mind, certain 3rd Generation (3G) technologies, such as the Universal Mobile Telecommunications System (UMTS) and Wideband Code Division Multiple Access (WCDMA) were not considered due to their slow adoption within the United States.

We new review a number of wireless protocols, giving specific consideration to geographic coverage, building penetration, bandwidth, data & device scalability, security, and TCP-IP support.

3.2 Mobitex

Mobitex is one of the largest dedicated data only (not built on top of a cellular system) networks in the world; its coverage includes thirty-one networks around the world in twenty-one countries, with approximately one million subscribers. Of these networks, some are available to the public (through a provider) while others have been developed for private use only. Mobitex coverage in the United States includes ninety-three percent of the urban business population, and is operated by Cingular Wireless. Cingular's coverage map for

16

Mobitex can be seen in Figure 3.1. From this map it can be observed that Mobitex covers the majority of urban areas within the country. However, most rural areas are left completely untouched. Therefore, if it is determined that a significantly large majority of remote devices (located within the client base) are in urban areas, Mobitex will be an appropriate option.
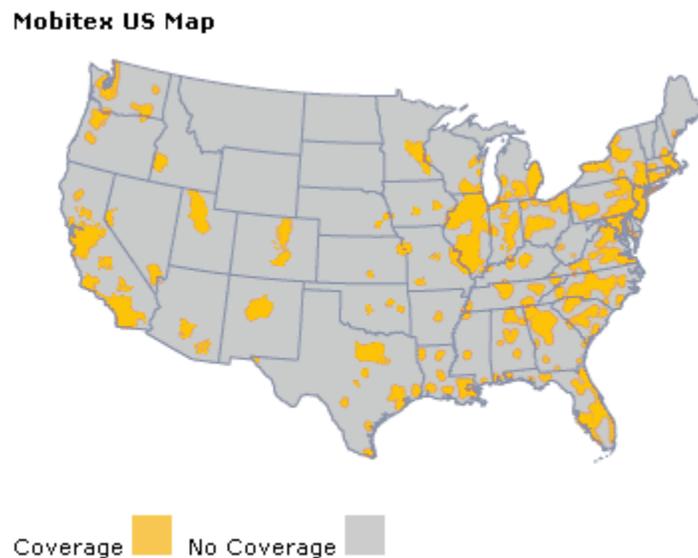
Figure 3.1 Mobitex coverage in the U.S. [5]

Mobitex was developed by Ericsson in the mid 1980s, introduced to the United States in 1991, and remains an open, international standard to date. It has been used for telemetry in the following applications: remote monitoring of control equipment, security alarms, office equipment, vending machines, parking meters, pipes and pumps, utility meters, and more. Therefore, it has already proven itself in remote monitoring applications of fixed installations in buildings for over ten years.

Mobitex operates at a bit rate of 8 kbps with a maximum packet size of 512 bytes. It uses symmetric transmissions (same number of time slots for uplink as downlink) and it employs simple error correction with both Forward Error Correction (FEC) and Automatic Repeat Request (ARQ). FEC allows the receiver to detect and correct small errors, while ARQ allows for the data to be resent by the transmitter in the event that FEC is not sufficient in correcting detected errors. Mobitex uses Gaussian Minimum Shift Keying (GMSK) with non-coherent demodulation and allows support of TCP/IP through the use of a Front-End Processor (FEP) that provides the necessary protocol conversion.

3.2.1 Operating Frequencies

Mobitex worldwide operates on three different frequency bands: 400, 800, and 900 MHz. However, Cingular Wireless in North America operates in the frequency bands of 896-901 MHz for uplink and 935-940 MHz for downlink. These lower frequencies of operation (< 1 GHz) allow for better propagation though materials common in most office buildings. Therefore, Mobitex will have an advantage over its high frequency competitors when it comes to building penetration.

3.2.2 Services & Devices

Users of the Cingular Mobitex network are charged for the amount of data that is sent, not the time a connection is open (hence the phrase: Always on, always connected). As of February 10th 2004, Cingular was charging a $25.00 USD one-time activation fee for its Mobitex data plans. Prices of plans vary by how much data is used per month. The smallest plan yields 100 kB/month for $19.95 USD, while the largest plan offers unlimited data

transfer/month for a fee of $59.99 USD. Of course, these quotes reflect the price for a single device/plan setup and are not applicable to the purchasing power of a large corporation such as Xerox, which would no doubt buy in bulk.

Very few Mobitex modems were able to be located; however, one example was the Ericsson 2100 PCMCIA type III card. Unfortunately, no information could be found on this device through Ericsson, so it is probably no longer in production. Various other DSP solutions exist for Mobitex modems, but an extensive amount of development would be necessary to produce such a solution, and should be evaluated accordingly.

3.3 Cellular Digital Packet Data (CDPD)

CDPD was built on top of the analog U.S. Advanced Mobile Phone System (AMPS) network. CDPD operates by making use of available AMPS channels not currently in use by voice traffic. Due to the fact that CDPD works over an analog cellular system, it does not require the use of digital service, which can greatly increase coverage in rural areas. CDPD is an open specification that adheres to the Open Systems Interconnection (OSI) model; therefore it may have the ability to adapt to future needs.

3.3.1 Established Applications

CDPD has been used in a number of different applications that can be grouped under the umbrella of Remote System Administration. Agent Systems, Inc. conceived a fine example of this. In this case CDPD facilitated communications within a transit fare collection system and could be tied into various different processes, such as the following: Self-service Ticket Vending Machines, fare gates, booth computers, and ticket office machines [2].

The use of CDPD in the transit fare collection system can be observed in Figure 3.2. It can be seen that CDPD is used at the toll collection location (toll both) in order to collect the fare from passing vehicles. The rest of the system requires a combination of CDPD and the Internet to relay data from the survey point to the administration point. This is a very similar application to that of the remote monitoring of Xerox devices, in which a wireless link will represent one of the stages in communication while still relying upon a wired solution (Internet, intranet, Virtual Private Network (VPN)) to relay information to the end destination.
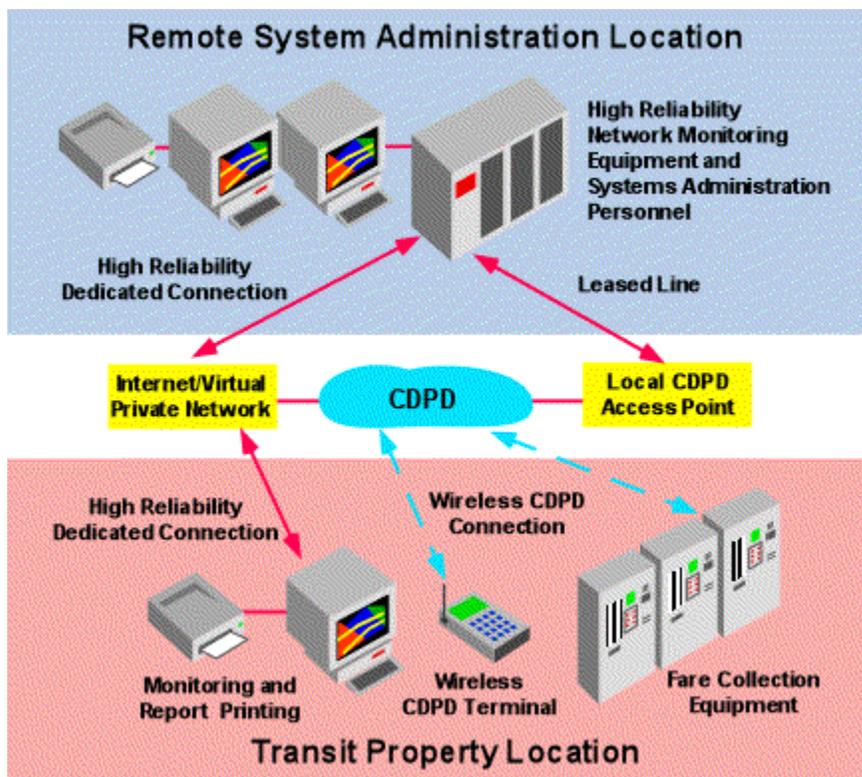
Figure 3.2 CDPD uses in transit fare collection [2]

While CDPD supports fixed-to-fixed communication, it was not explicitly developed with that purpose in mind, and therefore many of its features are optimized for mobile communications, such as routers in the CDPD system that track the movement of mobile devices. CDPD does offer a native support of the IP protocol, so development of systems using CDPD may not differ significantly from wired implementations.

CDPD offers similar error correction to Mobitex (FEC, ARQ) in order to ensure reliable packet delivery. A theoretical data rate of 19.2 kbps exists, but in practice this number is closer to 10 kbps due to packet collisions and other network limitations. Packet sizes range from 24 to 928 bits, with a frequency band based around 900MHz (similar to Mobitex).

3.3.2 Services & Devices

Various manufacturers were found that produce modems for CDPD. Some examples of PCMCIA modems are the Sierra Wireless, AirCard 300 that lists at $499.00 USD and the Merlin from Novatel Wireless, which lists at $299.00 USD. Both quotes are current as of February 10th 2004.

Many different service providers handle CDPD coverage in the United States and Canada. Most operate on a state-by-state (province-by-province) basis. Those with nationwide coverage include both AT&T Wireless (Figure 3.3) and Verizon Wireless (Figure 3.4). However, AT&T appears to be phasing out its CDPD network in favor of pseudo third generation data protocols (GPRS/EDGE). Therefore, pricing plans for AT&T Wireless CDPD were not available.

22

AT&T

Figure 3.3 AT&T CDPD coverage in the U.S.

VERIZON
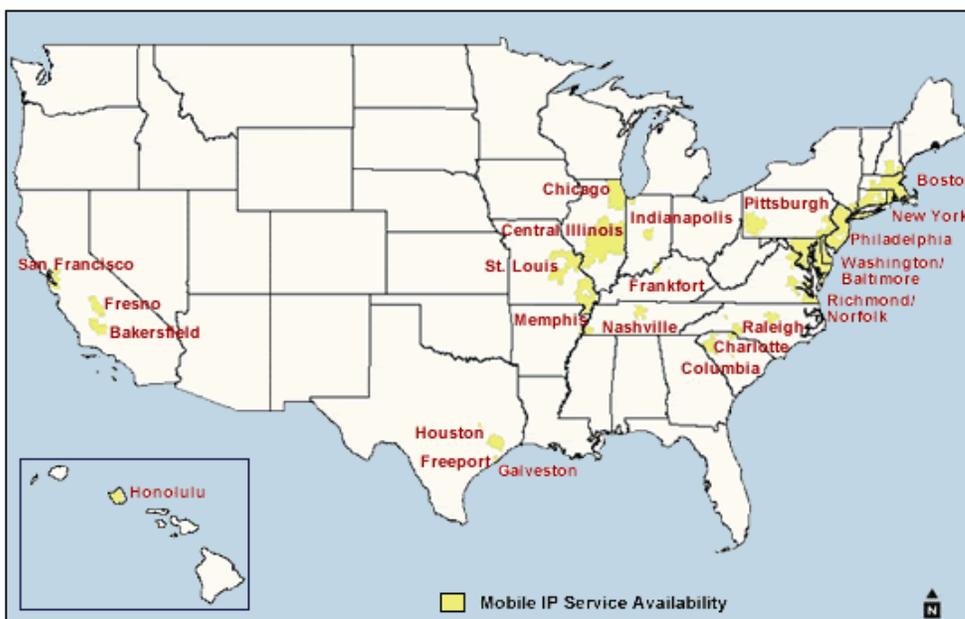
**Figure 3.4 Verizon CDPD coverage in the U.S.**

AirLink Communications, Inc, which was founded by two of the developers of the original CDPD standard, urges clients, on their website, to switch over from CDPD networks to newer, pseudo 3G data networks such as GPRS (EDGE). While Federal regulations provide that analog service (CDPD) be supported until the end of 2005, availability of CDPD hardware, multi-platform compatibility, billing system support, and other technical issues may cause some carriers to migrate from CDPD even earlier [18].

3.4 Advanced Radio Data Information Service (ARDIS)

ARDIS was the first data network of its type in the United States. It was designed by Motorola and IBM in order to facilitate communications with IBM technicians who were operating deep within buildings. During the early 1980's, teams of radio design engineers conducted extensive field tests in virtually every major urban area in the United States in order to determine the best achievable coverage. ARDIS was then designed to provide reliable communications within buildings, on the street, or in vehicles.

In March of 1998 a company named Motient bought the ARDIS name, which is to this day still under the umbrella of the global Motorola network, DataTAC. Motient is now the sole operator of the DataTAC network (known as ARDIS) within the United States.

3.4.1 Coverage

Motient claims to have over 2200 base stations (BSs) and the deepest in-building coverage of any data network available. It includes two-way communications and coverage of ninety percent of the urban areas in the U.S. (Figure 3.5). This is accomplished due to several unique attributes of Motient's network.

Firstly, the Motient network is not a true cellular network. It contains overlapping cells so that each device will have access to one or more base stations at any one time, thereby increasing coverage. When a mobile device attempts to send data, there are multiple BSs listening within the range of that mobile. Contention for the channel can be avoided as long as mobiles are separated far enough in space. Overlapping cells are made possible through the use of Single Frequency Reuse (SFR). SFR allows multiple BSs to use the same radio frequency, thus creating the overlapping cells. Therefore, even deep within a building users may still be able to communicate with two to five BSs, therefore increasing the probability of successful communication.
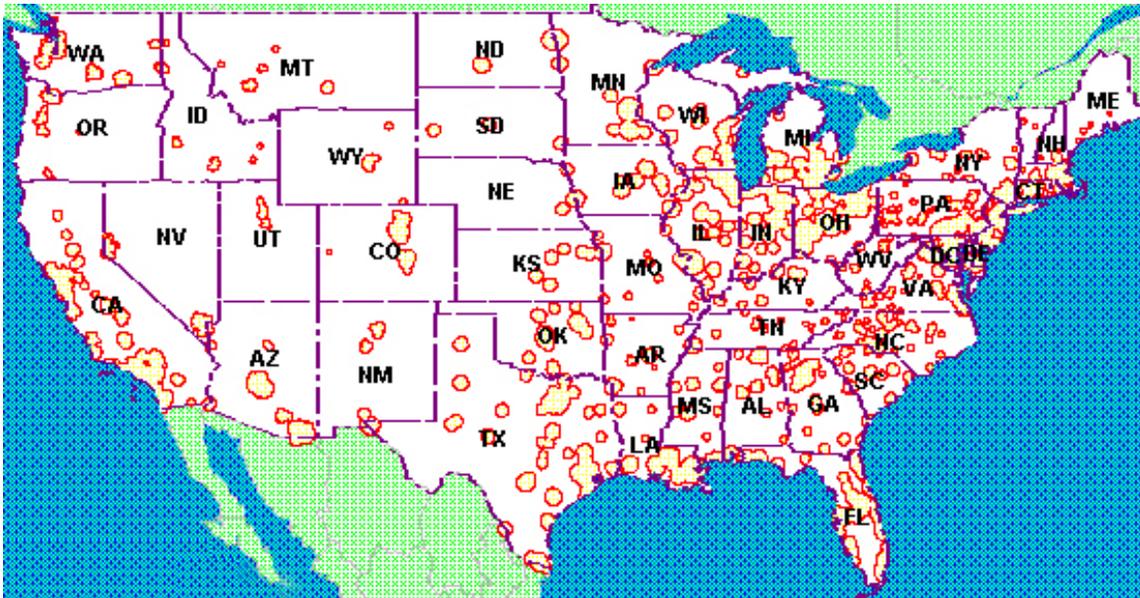
Figure 3.5 Motient's ARDIS coverage in the U.S. [13]

ARDIS is based on the MDC 4800 and RD-LAP (Radio Data Link Access Procedure) developed by Motorola. Short ARDIS messages tend to have low retry rates but high packet overhead while longer messages tend to amortize the overhead but have higher retry rates [1].

3.4.2 Operating Frequencies

The Motient network makes use of the 800 MHz band, claiming up to 19.2 kbps data rates per cell, and allows packet sizes of up to 256 bytes. This packet size is smaller then the previous two standards (Mobitex and CDPD); however, an optimal packet size for the application at hand has yet to be determined. Motient uses FEC along with a form of ARQ for resending messages. Motient does not offer any form of security at the network level; however, it has implemented SSL (Secure Sockets Layer) for sending email across its network, which may be useful in the end application.

3.4.3 Services & Devices

Motient claims 24/7 Customer support and constant monitoring of network health. When a break in communications is identified, data is instantly re-routed via one of many redundant communications paths, making the overlapping cell system very attractive. For these services, Motient charges a $9.95 USD fee for network activation and $49.95 USD/month (up to 1MB/month of data) with $0.10 USD/kB overage charges. There are currently no modems available that support operation on the Motient network. The primary devices that are capable of operation on the network include hand-held e-mailers and a selection of

blackberry devices. Therefore, it would be necessary to develop a new solution for communication on the ARDIS network, which would be costly and time consuming.

It should be noted that Motient filed for Chapter 11 restructuring on January 10, 2002 [9]. Since that time Motient has been built back up into a sound corporation. However, Motient may not be as reputable as some of the larger wireless providers such as Cingular Wireless and Verizon Wireless.

3.5 General Packet Radio Service (GPRS)

One of the more modern of the wireless packet switched data networks is the General Packet Radio Service (GPRS). GPRS improves upon other standards by increasing data speeds (up to 115 kbps), supporting a wide range of operational frequencies, and sending both small data bursts and large volumes. GPRS has almost completely taken over the European and many South American markets for data communications. It has just recently begun to show up on the North American market over the past few years.

3.5.1 Established Applications

Both the United Parcel Service (UPS) and Federal Express (FedEx), two of the world's largest parcel delivery corporations, both make use of GPRS networks to track packages across the globe [3]. Both companies offer the ability of their customers to track the whereabouts of their packages while in transit anywhere on the globe. Therefore, the choices made by these two companies helps to strongly reinforce the presence of GPRS on the global scale.

3.5.2 Coverage

Currently AT&T Wireless and Cingular Wireless offer GPRS support in the US. Cingular's coverage map as of January 23rd 2004 can be seen in Figure 3.6. GPRS has such a large coverage area because it makes use of the entire cellular Global System for Mobile (GSM) footprint. In addition to the U.S. over 500 operators in 207 countries worldwide provide GSM [8], thus making it an excellent global solution. Another aspect of GPRS that can be observed from the coverage map is that the majority of Cingular's coverage is on the 1900 MHz frequency. This is roughly double the frequency that the aforementioned protocols use. This fact alone may make GPRS unsuitable for use deep within buildings.
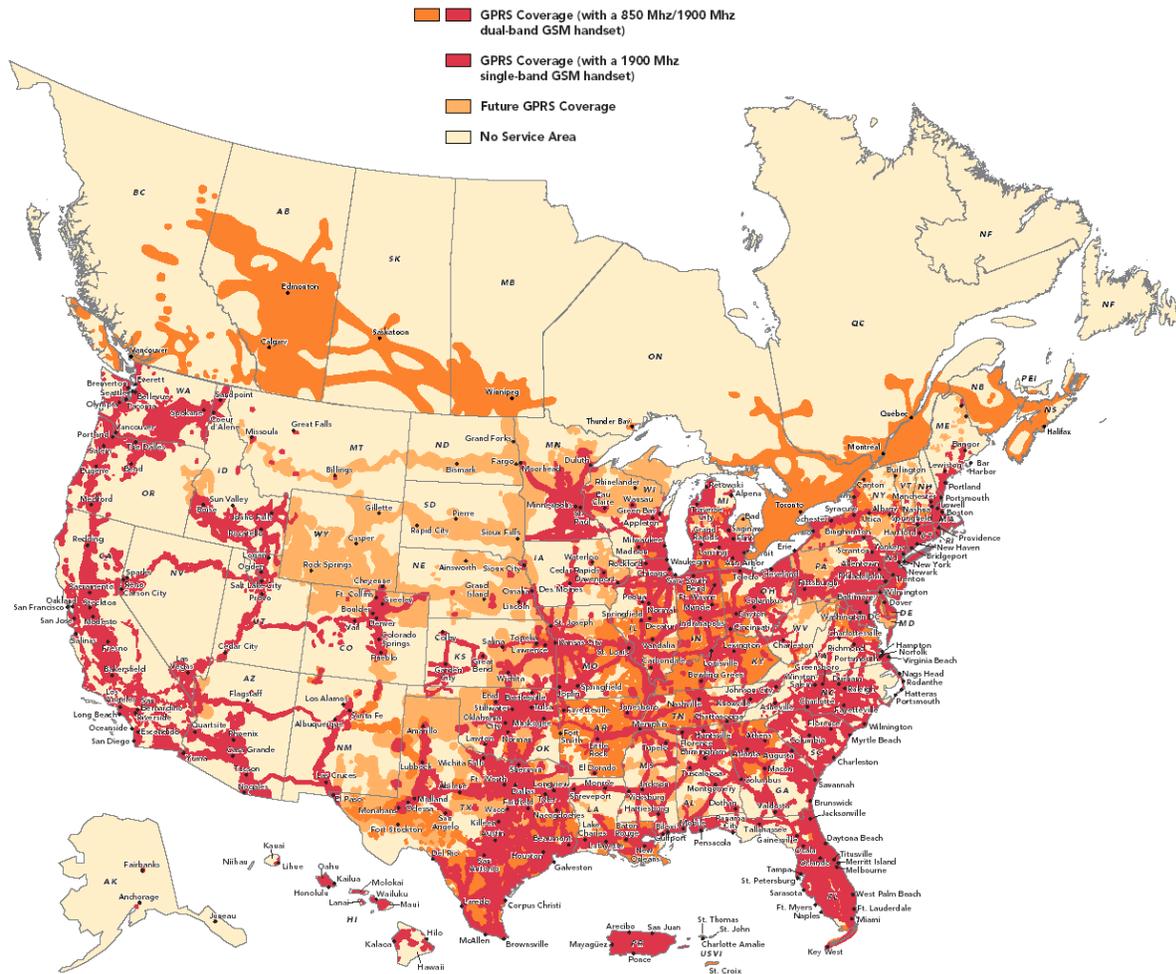
Figure 3.6 Cingular's GPRS coverage as of 1/23/04 [4]

By comparing Figure 3.6 and Figure 3.7, the development of Cingular's GPRS network can be seen over the course of approximately four months. It is worth nothing the headway into the Canadian market and the increased presence along interstate highways in the Southwestern states. Cingular also plans for future expansion across the Western U.S. in Wyoming, Montana, North & South Dakota, and Nebraska. While these states are not urban business centers by any means, it is encouraging to see Cingular's continued development of its GPRS networks across the country, thereby closing the gap on dead zones.

Cingular 850 MHz Coverage
Cingular 1900 MHz Coverage
Future Cingular 850 MHz Coverage
No Service Area
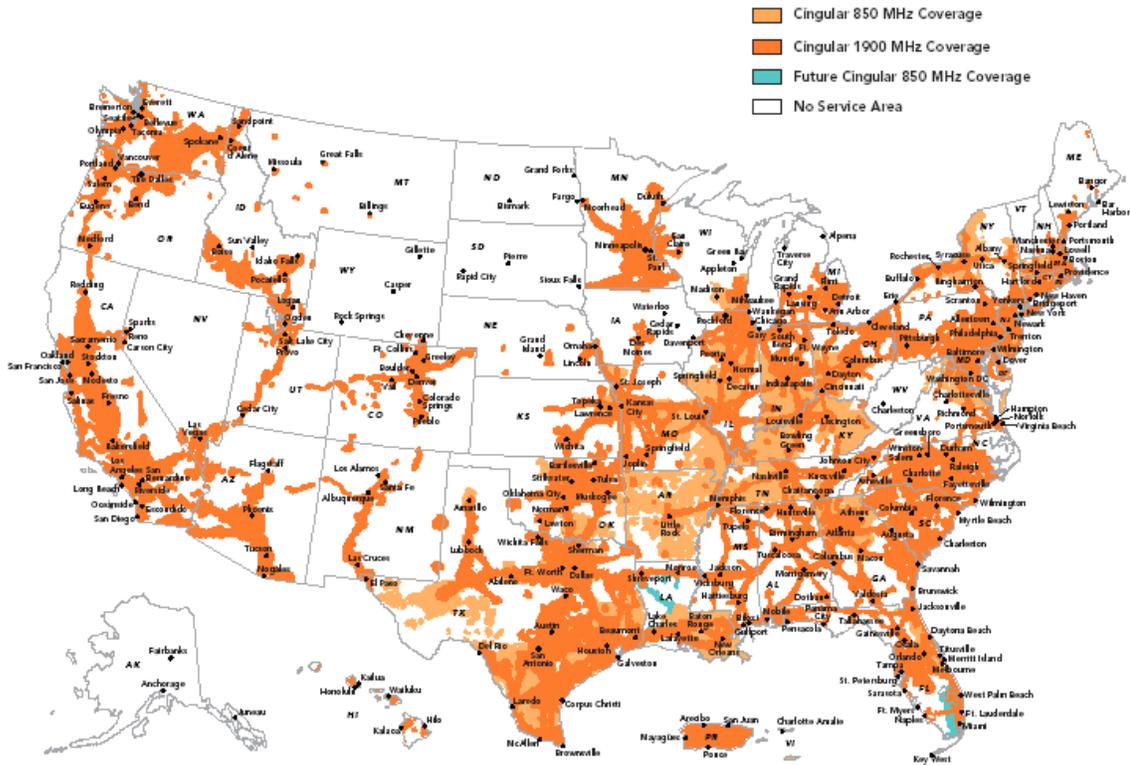
Figure 3.7 Cingular GPRS coverage as of 9/15/03 [4]

3.5.3 Protocol Specifications

GPRS networks are IP-based; therefore, any applications that operate over a wired channel and use IP will work with GPRS. This is very useful in the porting of Xerox's current DCS to a wireless medium. Because of this packet-based, IP approach, devices utilizing GPRS are always online, yet only pay by the amount of data that is sent (making it quite cost effective).

Performance of GPRS greatly improves upon the other data protocols listed above. Theoretical speeds of 115 kbps are claimed possible if all eight time slots are utilized with no error protection implemented. However, this maximum speed is usually not realizable in any practical communication system due to the need for error correction and the competition for

limited resources with other users. Therefore, average speeds of GPRS (on the AT&T Wireless network) are typically within 20-50 kbps on a loaded network.

3.5.4 Devices

Numerous devices support GPRS, such as Sony Ericcson's GC75 PCMCIA card.   This device costs $199.00 USD directly from Sony Ericcson and supports all major Windows operating systems. It operates on a triple band (900/1800/900 MHz), making it compatible across all GPRS networks in the U.S and worldwide. Another PCMCIA card is the AirCard 750 from Sierra Wireless. It supports the GPRS tri-band and lists at $429.00 USD. These prices are current as of February 10th 2004.

3.6 Enhanced Data rates for GSM Evolution (EDGE)

Both AT&T Wireless and Cingular Wireless have recently begun to implement EDGE across their current GPRS networks. EDGE uses a more sophisticated link between the mobile device and the base station (BS) then GPRS. EDGE has the ability to change its modulation scheme "on the fly" in order to adapt to environmental changes that can affect the quality of the channel. Unlike GPRS, which is bound to a Gaussian Minimum-Shift Keying (GMSK) modulation scheme, EDGE uses 8-PSK (Phase shift keying) with the ability to switch back to GMSK. While GMSK was chosen primarily for its ability to lower cost and increase power efficiency, PSK can increase bit rates (3 bits/symbol up from 1 bit/symbol with GMSK) across the wireless channel. AT&T Wireless claims that its EDGE technology can reach speeds of 180 kbps (with a burst of data) and average 100-130 kbps, which is much higher then the actual speeds attainable through GPRS alone.

3.6.1 Compatibility with GPRS

Compatibility between GPRS and EDGE devices allows each device to work seamlessly on both networks. Any GPRS device will be able to operate at GPRS speeds (using GMSK) on both networks. EDGE devices will of course operate at maximum speeds (using 8-PSK) on the EDGE networks and be able to switch back to GMSK for GPRS networks. This is accomplished due to the fact that EDGE technology only affects the physical layer (radio transmission) and the link layer (access control, FEC, ARQ) in the communications protocol stack. However, all other high level protocols such as Medium Access Control (MAC) protocols and IP remain constant across both standards.

3.6.2 Devices

Devices that support EDGE cannot tell whether or not they are on an EDGE or GPRS network. Therefore, applications should be designed so that they will operate within acceptable conditions at GPRS speeds. However, for Xerox's needs, devices will not be roaming. If a device does not see an EDGE network, then it is a safe assumption that it will not see an EDGE network for a very long time (time table for building new BSs). Therefore, EDGE capability might not make sense for the application at hand.

Currently, the Sony Ericsson GC82 PC Card Modem is the only device to offer EDGE support. The PCMCIA card is capable of working on both the 850 MHz and 1900 MHz GSM networks. The card lists for $249.99 USD retail, thus putting it in the same price range as most GPRS compatible devices.

AT&T Wireless is predicting EDGE support to be a standard feature on data-capable devices by the end of 2004. This release date may be pushed back even further, given the

recent acquisition of AT&T Wireless by Cingular Wireless. This is due to the fact that

Cingular Wireless may not put precedence on implementing EDGE and may be more

concerned with getting both companies' current GPRS networks fully compatible. Currently

Cingular Wireless supports EDGE in the Indianapolis area only, while AT&T EDGE

coverage is considered spotty at best.

3.7 Integrated Digital Enhanced Network (iDEN)

Motorola has developed a data network, based on the GSM standard, known as iDEN, which

is comparable to GPRS in a number of ways. iDEN is a proprietary network owned by

Motorola worldwide, with Nextel as the primary U.S. operator.

3.7.1 Transmission Types

The iDEN network supports circuit switched data, packet data, and the Short Message

Service (SMS) [14]. Circuit switched data introduces overhead into the transmission of data

because it is necessary for the network to use equipment outside of the iDEN system. Circuit

switched data also provides low data rates around 4.8 kbps. Therefore, because our data is

already destined for a packetized network (the Internet), this is not a viable solution.

As for SMS, it is used primarily in text messaging operations, and allows for the transmission

of up to 160 characters at one time. SMS could work for the task at hand, however, it was

not designed explicitly for data transfer. Therefore, packet data is left as the obvious

solution.

The packet data network offers the ability to connect a mobile device with a number of different types of networks. These include intranets, VPNs, and the Internet. Any of these would be a feasible option for the monitoring of a remote device. Due to security reasons, the remote device (Mobile) could communicate directly to Xerox's intranet or tunnel in through one of its VPNs. Even without one of these secure connection options, communications from the remote device to an IP address over the Internet would completely fulfill the needs of a remote device monitoring system.

3.7.2 Data Rates

The iDEN standard has the ability to constantly monitor the radio link over which data transmission occurs and make modifications to the modulation technique in use. This technique is useful because as the signal degrades (with the introduction of noise) the amount of data being transmitted can be reduced in order to improve the reliability of data transmission, thereby reducing error rates.

The modulation techniques available to iDEN are as follows:

- 64 Quadrature Amplitude Modulation (QAM) at 44 kbps

- 16 Quadrature Amplitude Modulation (QAM) at 22 kbps

- Quadrature Phase Shift Keying (QPSK) at 11 kbps

However, in order to operate at 44 kbps the mobile device must be high-speed compatible. Therefore, with most devices not meeting this requirement Nextel claims an average data transfer speed of 15 kbps. This is lower then most of the data rates offered by

the aforementioned protocols; however it may be perfectly suitable for basic device monitoring.

3.7.3 Operating Frequencies

The complete list of operating frequencies for iDEN can be found in Table 3-1. The available frequencies for iDEN range from roughly 800 MHz to 1.5 GHz. This wide range encompasses most of the bands that the aforementioned protocols utilize. Given building propagation concerns, the lower end of the frequency choices would be ideal for the task at hand, especially given the wide US coverage provided by Nextel..

Table 3-1 iDEN RF Bands [14]

Range (in MHz)	Channel Spacing	Carrier pairs (MHz)	Link	Spacing	Offset
806-821	25 kHz	806-821	Uplink (from MS)	45 MHz	12 KHz
		851-866	Downlink (to MS)		
821-825*	25 kHz	821-825*	Uplink (from MS)	45 MHz	12 KHz
		866-870*	Downlink (to MS)		
896-901	25 kHz	896-901	Uplink (from MS)	39 Mhz	12 KHz
		935-940	Downlink (to MS)		
1453-1465	25 kHz	1453-1465	Uplink (from MS)	48 Mhz	12 KHz
		1501-1513	Downlink (to MS)		
* Requires Software Release 8.0					

Transmissions from the Mobile Station (MS) to the BS are in the 806-821 MHz band while transmissions from the BS to the MS occur in the 851-866 MHz band. Therefore, we

observe that iDEN may offer a slight improvement in building penetration over the higher

frequency (~1.9 GHz) that GPRS operates on.

3.7.4 Coverage

Coverage for iDEN in the U.S., and worldwide, is governed by the GSM footprint. Coverage

for the U.S. is shown in Figure 3.8, which appears to be very similar to that of Cingular's

GPRS coverage map in which all of the major metropolitan areas are covered. A worldwide

coverage map for iDEN is shown in Figure 3.9. By observing iDEN's complete lack of

coverage in Europe, the strength of the European GPRS coverage shines through.

Figure 3.8 Nextel iDEN coverage in the U.S. [15]
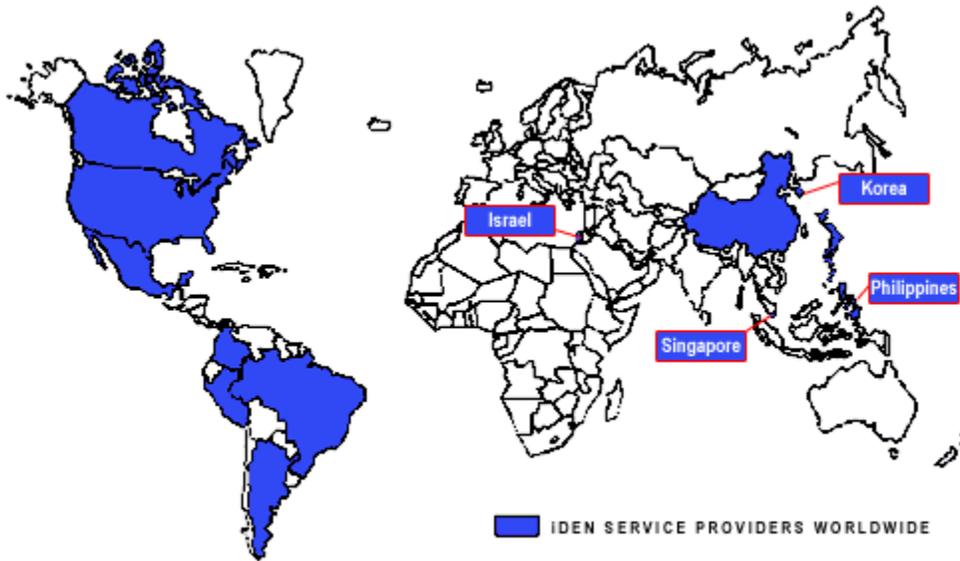
Figure 3.9 iDEN coverage worldwide [16]

3.7.5 Devices

A number of compatible devices are available for operation on the iDEN network. The Motorola iO1000 provides packet and circuit switched data over the iDEN 800MHz network (U.S.) and can be integrated into the following applications: automatic vehicle location (AVL), distributed automation, telemetrics, meter reading, and of course device monitoring. The Motorola iM1100, in addition to offering similar services to the iO1000, has the ability to interface with a standard type II PCMCIA slot [6].

Chapter 4
Technology Decision

4.1 Comparison

Given the aforementioned decision metrics, it was not difficult to remove some of the protocols from the running. CDPD was rejected due to the fact that in a few years the nation's providers will no longer support this antiquated analog technology. It was observed that one of the Nation's CDPD access providers, AT&T Wireless, has already begun to phase out CDPD in favor of its newer, digital GPRS data network. As for Verizon, their CDPD coverage appears to be very poor and most likely not worth considering.

EDGE may offer more than is necessary at the current stage of development. EDGE increases data rates over GPRS; therefore, the only way that it will be useful will be if Xerox determines that large capacity and increased data speed will be an important decision metric in the future.

Mobitex claimed very good coverage (~93%), but with a data rate of only 8 kbps (half of ARDIS & iDEN), it may not be sufficient. It is also worth noting that Cingular Wireless (the only Mobitex operator in the U.S.) is also running a GPRS network. Looking at AT&T Wireless we see a progressive switch from older analog technologies (CDPD) to newer digital technologies (GPRS). Therefore, with the recent acquisition of AT&T Wireless, Cingular may follow suit and switch over its data networks from Mobitex to GPRS.

The three remaining technologies are ARDIS, GPRS, and iDEN. ARDIS cannot compare to the other two protocols due to its high cost of operation, lack of data security,

poor device and data scalability, low data throughput, and meager network coverage. However, ARDIS may triumph over these other technologies in one very important factor: deep building penetration. This is what ARDIS was originally designed and operated to do. GPRS typically operates at twice the frequency of ARDIS and cannot reap the benefits of cell overlapping and SFR within buildings. iDEN, while also operating on a GSM network operates on frequencies lower then GPRS which are more similar to ARDIS. Therefore, iDEN, even though it has slightly lower bit rates then GPRS, may be a promising compromise between GPRS and ARDIS.

4.2 Decision Matrix

The complete decision matrix that was used in order to determine the "best" protocol for a Wireless WAN solution can be seen in Table 4-1, Table 4-2, and Table 4-3. For each of the aforementioned protocols these tables show Capital Cost, Operational Cost, Security, Device Scalability, Data Scalability, Data Throughput, Network Coverage, Network Reliability, Modulation Technique, Building Penetration, Network Operators, and TCP/IP compatibility.

Table 4-1 Decision Metrics I

	Capital Cost*	Operational Cost*	Security
ARDIS	Network Activation Fee: $9.95 note: NO PCMCIA solutions exist for Motient's ARDIS network	$49.95/month (up to 1MB/month) $.10/kB overage.	No apparent dedicated security, however Motient does offer SSL for it's email apps over ARDIS
MOBITEX	Network Activation Fee: $25.00. No PCMCIA modems found. Therefore, development of a modem using DSP RF components may become too expensive.	Smallest plan: 100 kB/month for $19.95. Largest plan: unlimited data transfer/month for a fee of $59.99	None
CDPD	Sierra Wireless Air Card PCMCIA 300: $499.00 Novatel Merlin PCMCIA $299.00	N/A	None
GPRS	Sony Ericcson's GC75 PCMCIA card. Tri-band GPRS/HSCSD/CSD (900/1800/900 MHz): $199.00 & AirCard 750 from Sierra Wireless. GPRS tri-band $429.00.	AT&T: $29.99/month for 10MB. $0.0030/kB over. Up to: $79.99/month (unlimited MB)	64-bit encryption key
EDGE	Sony Ericsson GC82 PC Card Modem supports EDGE.	(Same as GPRS)	(Same as GPRS)
iDEN	Motorola: i01000: OEM modem, designed for meter read operations. iM1100 - PCMCIA card, bat powered, ext. antenna available - list price: $349.99 Internet ready phone: i88s, list: $99 + $30 data cable	Plans: Packetstream Gold - $54.99 fixed monthly charge (uses iM1100)	SLL, HTTPS

* Note: Capital & Operational cost represents cost of a single unit or plan, not an entire fleet of devices with corresponding plans.

Table 4-2 Decision Metrics II

	Device Scalability	Data Scalability	Data Throughput	Network Coverage
ARDIS	None	None	Data only network 19.2 kbps (overlapping cells yields 81.6 kbps). Packet size=256 bytes	90% of urban areas in US, best in building coverage
MOBITEX	None	None	Data only network 8kbps, max packet size=512 bytes	93% of urban areas in US, claims largest urban coverage
CDPD	None	NONE: CDPD is an analog data network that will be phased out within the next couple of years	Analog Data Network (operates on top of AMPS). Theoretical maximum=19.2 kbps packet size: 24-928 bits	N/A
GPRS	GPRS devices can be used on the EDGE network (at GPRS speeds)	Next Gen: WCDMA, UMTS	Overlay on GSM (NOT data only) Theoretical max=115 kbps. Avg. speeds around: 20-50 kbps (loaded network)	AT&T claims: 6,500 cities and towns along 30,000 miles of highway.
EDGE	Any EDGE device can be used both on the EDGE network and is backwards compatible with the GPRS network (will operate at GPRS speeds).	(Same as GPRS)	Overlay on GSM (NOT data only) Up to 180 kbps (burst), with avg. speed=100-130 kbps (loaded network)	Includes a subset of the GPRS coverage.
iDEN	Operates in a very popular GSM band (worldwide).	N/A	Overlay on GSM. 64-QAM: 44 kbps, 16-QAM: 22 kbps, QPSK: 11 kbps Nextel claims avg. speeds of 15 kbps.	GSM Footprint includes worldwide coverage.

Table 4-3 Decision Metrics III

	Network Reliability	Modulation Technique	Building Penetration	Nationwide Operators	TCP/IP
ARDIS	24/7 Customer Service. A break in transmission is identified instantly, and data is immediately re-routed via redundant paths	BFSK & 4-FSK	Designed specifically for deep building penetration. (Overlapping cells) Low f=800 MHz	Motient	YES
MOBITEX	Cingular very reliable (however, may be investing more in it's new GPRS network then Mobitex)	GMSK	900 MHz band	Cingular Wireless	YES (through FEP)
CDPD	N/A	GMSK	869-895MHz (downlink) 824-849MHz (uplink)	AT&T Wireless, Verizon Wireless	YES
GPRS	Both AT&T and Cingular are very reputable corporations. They claim the highest degree of network uptime and service.	GMSK	850MHz/1900MHz (high frequencies)	Cingular Wireless, AT&T Wireless	YES
EDGE	(Same as GPRS)	GMSK & 8-PSK	(Same as GPRS)	(Same as GPRS)	YES
iDEN	Nextel-very reliable, Xerox already relies upon Nextel for it's voice services.	64 QAM, 16 QAM, QPSK.	Tx: 806-821 Rx: 851-866	Nextel	YES

4.3 Final Decision

Even though ARDIS is capable of theoretically offering great building penetration, it was concluded by Xerox that this solution would not scale well when it came time to expand operations to include its worldwide clients.

Therefore, a final decision between GPRS and iDEN was at hand. A number of lesser, non-networking aspects, came into play at this point. Xerox noted that it already had established a good relationship with Nextel, who provided the company's mobile voice service. Xerox had been pleased with the reliability of Nextel's voice network, and even used iDEN on a limited basis with some data capable (palm) devices. Another driving force behind the use of the iDEN network was the fact that the Java programming language was well integrated into a number of devices (phones, modems, etc.) supported by Nextel. This fact would help to simplify and speed up development of the software needed to run the DCS platform because Java is very well suited for network applications.

Chapter 5

Component Design

5.1 LAN vs. WAN

With the help of engineers at Xerox, a suitable design overview for how the separate hardware components in the system would operate was obtained. Multiple ideas were debated: one made use of the LAN solution, another the WAN solution, and finally one used both LAN and WAN in the same system.

The case in which both a LAN and WAN solution are utilized can be seen in Figure 5.1. In this figure it can be observed that a collection of Xerox devices will communicate over a LAN to a local access point. These communications are made possible by using a protocol suited for wireless LAN operation (802.11, Bluetooth, etc.) [7]. The LAN controller will then forward data and commands from the LAN to the WAN capable device. From there, data travels across the wireless WAN and then over a wired network (Internet, intranet, VPN) to Xerox.
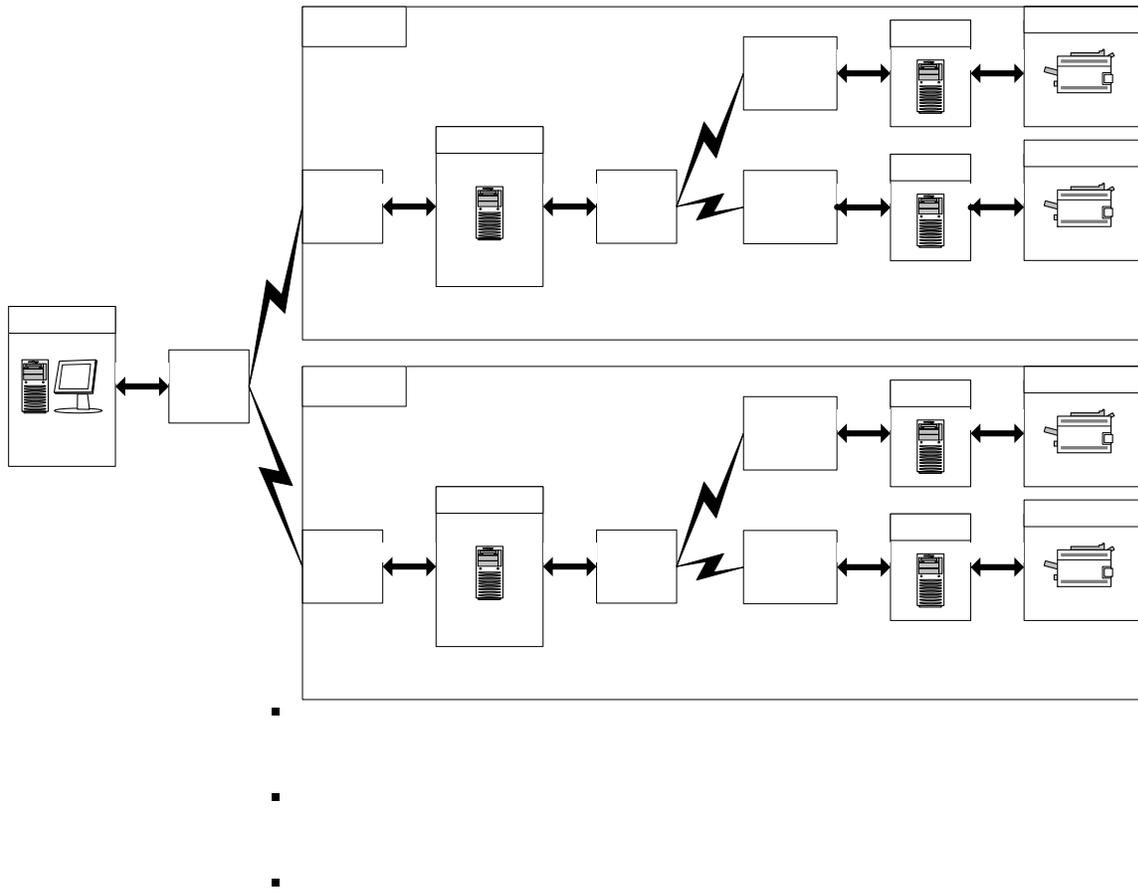
Figure 5.1 LAN/WAN device monitoring [7]

An expanded version of the wireless WAN aspects of the system can be seen in

Figure 5.2. In this diagram an expanded version of the LAN can be seen as containing a

number of different Xerox devices, and a LAN access point. The entire LAN is then pictured

within one of the multitude of cell sites. The wireless WAN operates by choosing the base

station (BS) that has the best ability to detect the mobile, or in this case the WAN/LAN

interface device within the building. The choice of BS can be determined by a number of

different approaches, depending on the protocol being used. In the case of Motorola's iDEN

standard, the BS is chosen when the WAN modem powers up. At this point the WAN device receives signals from all the BSs in its range, and then also transmits a Request for Service. The next step involves determining which BS can offer the WAN device the best service, which usually means the highest Signal to Noise Ratio (SNR) at the lowest cost of power.

In normal operation where a device is mobile, it would be handed off between different BSs as signal quality faded (due to movement away from the current BS or entry into a noisy environment). However, in the case of the stationary Xerox WAN device it will most likely communicate with the same BS for the duration of operation. Exceptions to this rule include the introduction of noise, the failure of a BS, or a Xerox WAN device stationed on the border of different cells [14].
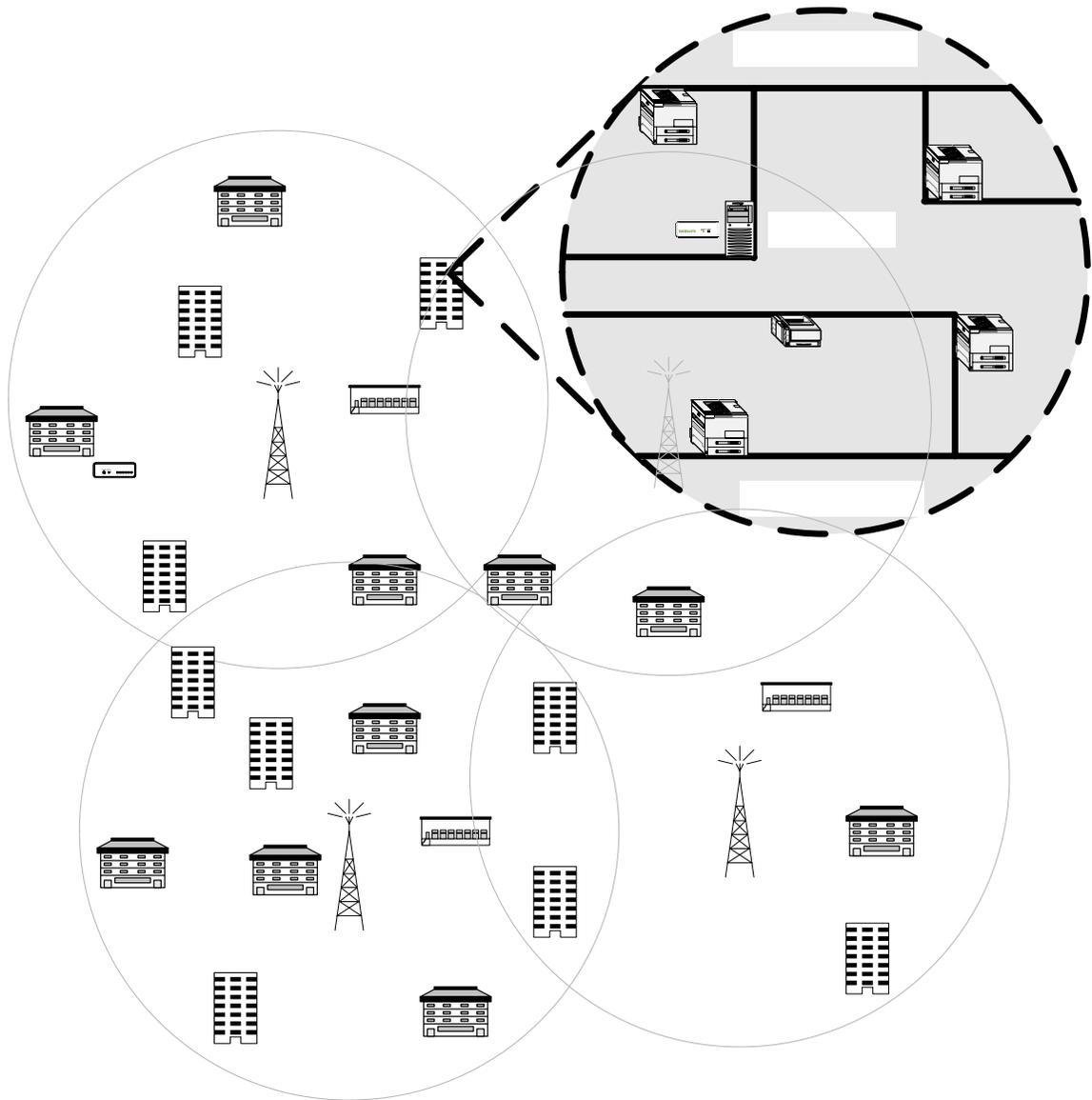
Figure 5.2 Wireless WAN [7]

The other two design cases, which are either strictly LAN or strictly WAN, are very similar to the above scenario. In the WAN case each device will have its own wireless WAN capable modem, and therefore communicate directly to Xerox. Unfortunately, this can become cost prohibitive when a client site contains a large number of Xerox devices to

connect. This is due to the fact that each device would require separate wireless WAN hardware and more importantly would need a separate service plan (from one of the providers) for each device.

In the case of the strict wireless LAN solution all devices will be tied into a wireless LAN and the access point will be connected into the customer's TCP/IP network. This solution is the most cost effective because it removes the reoccurring operational cost due to the wireless WAN provider. However, this solution relies upon the customer granting access to their internal network, which may be very difficult to obtain given the current trend in strong internal security constraints within intranets.

Regardless of which case is chosen, it is necessary to develop two interfaces. The first is between the specific device (copier, printer, etc.) and the wireless hardware, and the second is between the wireless hardware and Xerox's network, which would be responsible for collecting data from the device. Xerox decided to tackle the first of the two interfaces because of their intimate knowledge with how to interact with their own devices. It would be up to our group to develop a solution for data transfer from the wireless device back to Xerox.

5.2 The Final Solution: Strictly WAN

The final solution that Xerox agreed upon was to use the option that involved a strictly wireless WAN solution. This was because the initial development of the product was to be tested at a number of client sites in which only one or two Xerox devices were in operation. Therefore, the overhead of implementing a LAN, which would feed the WAN, was cost

prohibitive. However, Xerox realizes that in future developments the LAN solution will be

vital when dealing with customers who operate a larger number of Xerox devices within a

small radius.

Chapter 6

Software Development

6.1 Prototyping

Development began with the design and pseudo coding of a simple client/server model that fulfilled the following goals: TCP-IP compatible, extremely lightweight software model, a simple communication protocol, an interactive GUI client, and a way to simulate the Xerox device while testing.

6.1.1 Lightweight Client/Server & Protocol

In order to ensure proper operation on a mobile device running the Java Virtual Machine (JVM), it was necessary to make the protocol as small as possible and to design the Server, which would be running on a device with very limited resources, to be as efficient as possible.

In addition to these goals we required a means to simulate the operation of a Xerox device (printer, copier, etc.). We envisioned a design in which a computer running the GUI client would query the Xerox device (server) in order to obtain device specific data. The server software would then query the physical Xerox device (device simulation) for data. This simple model can be seen in Figure 6.1.

Client
Device

GUI

Client Class

Console
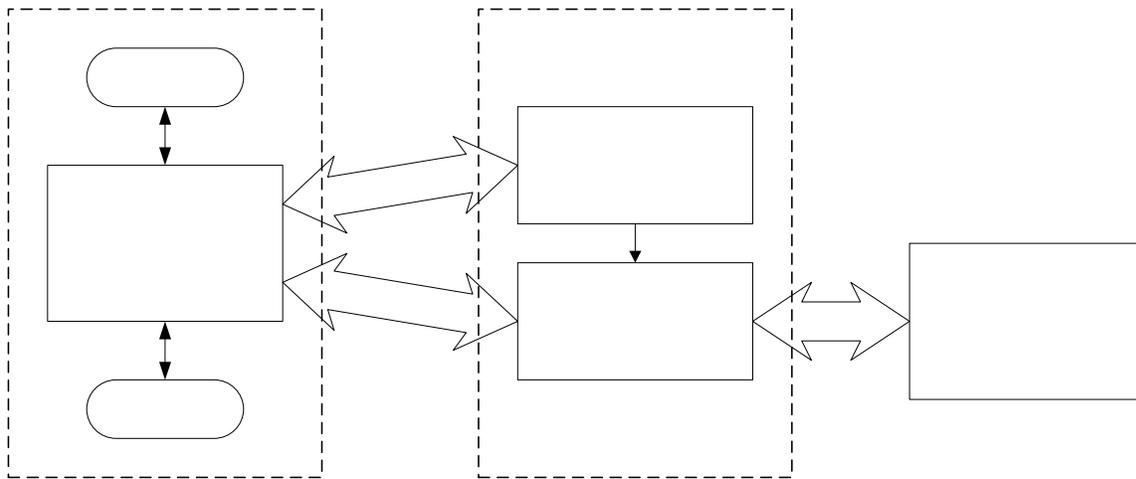
Figure 6.1 Client/Server model

While we were not provided with specific types of data that Xerox would be interested in querying, it was necessary to come up with a number of "sample" indicators that were determined to be useful in device operation.   The parameters chosen were the following:

- Paper Count

- Toner Level

- Device Usage

The first two, "Paper Count" and "Toner Level" were meant to be read-only attributes because the only way to modify them would be a physical change to the device (the filling of a paper tray or replacement of a toner cartridge), which of course would not be possible over the wireless link. Therefore, we were left with an abstract term "Device Usage" which could be thought of as a metric for billing. Usage could be dependent on the amount of paper used,

toner used, or some other device feature that we are currently unfamiliar with. Regardless of how it was measured there would need to be a way to read it remotely and then reset it for the next billing cycle. Therefore, device usage would have read/write capabilities from the client stand point.

6.2 Component Design

The design could easily be broken up into components, and because we were using the Java programming environment, this led directly to the use of separate Classes for each component. The general outline of our software development can be seen in Figure 6.2. It shows how a client will connect (over a wireless channel) to the Server (Xerox device). Once the connection is established the Server will surrender control of the client to a RequestHandler object, which is responsible for servicing all needs of the client. Once the Server has passed control to the RequestHandler it will continue to listen for other client connections, thereby being able to serve multiple clients from the same device simultaneously.

Each RequestHandler is responsible for querying a DeviceSim when attempting to fulfill a client request. By using a global DeviceSim, our model kept a single simulation running for all connections to the server. This most likely mimics the real world counterpart where the Server is running on an actual device and each RequestHandler must query the device hardware.
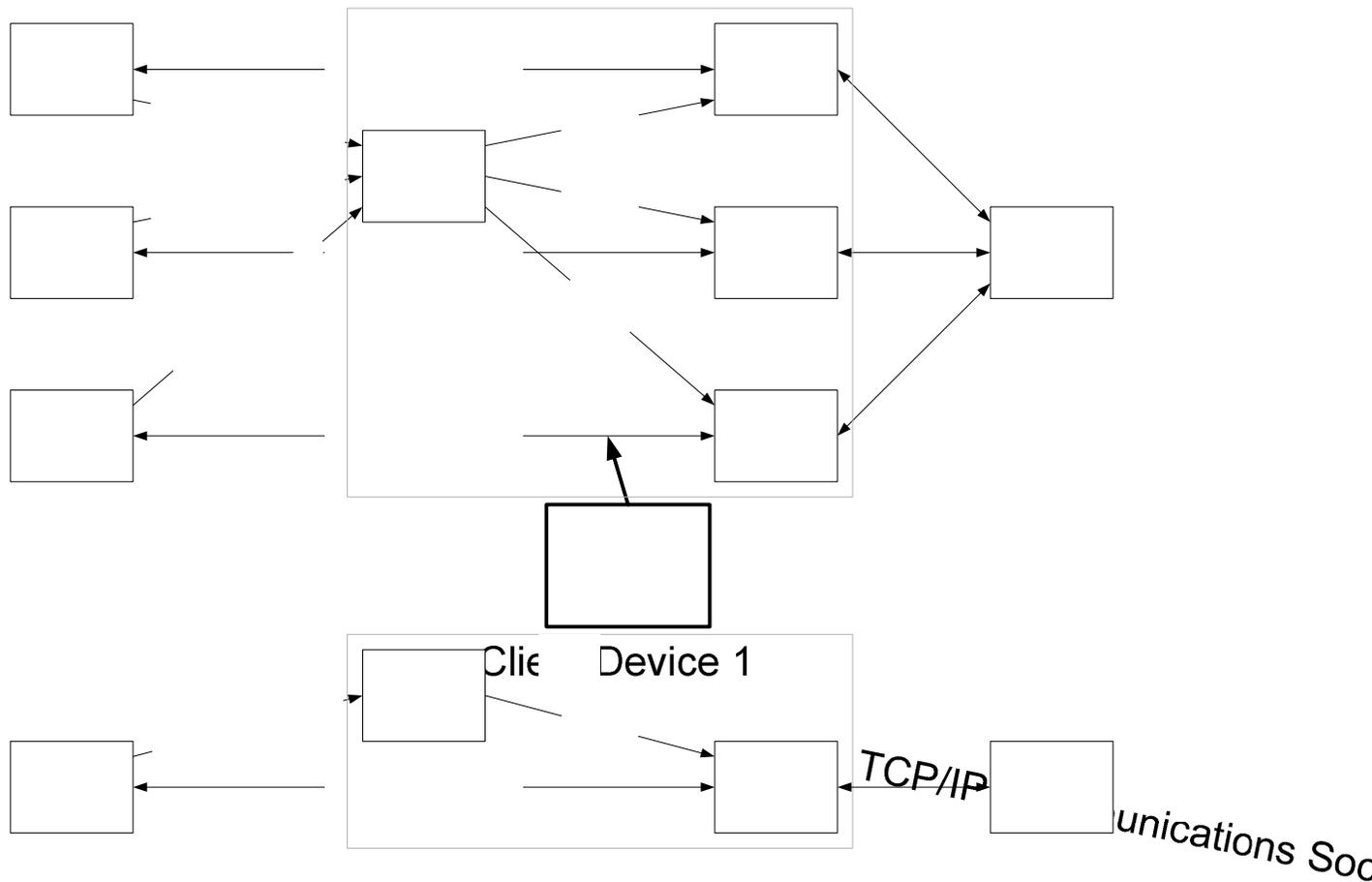
Figure 6.2 Communication paths among the software

6.3 Server-Side

One of the primary goals for the remote device (Server) was that it be extremely lightweight with regard to both the memory footprint and processor usage. Therefore, the Server was kept simple. The chosen method of communications was through Java TCP-IP Sockets. The Java Socket class would allow us to communicate reliably over any TCP connection and also keep upgrade paths available for the future, such as security (encryption with SSL). The prototype sent commands and responses over a TCP Socket connection using plain text. Therefore, there was absolutely no security implemented.

The simple handshaking protocol between the client and server can be seen in Figure 6.3.
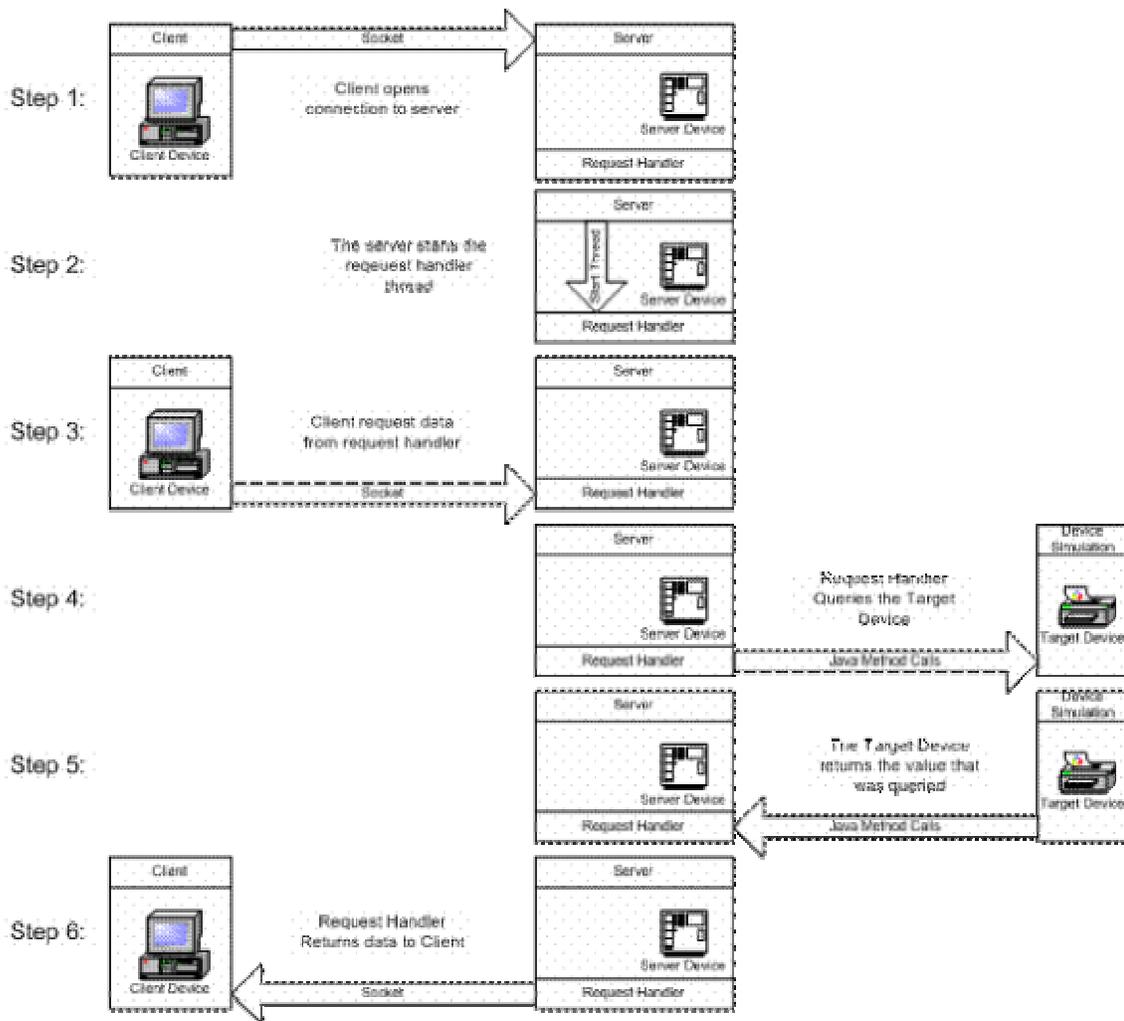

Figure 6.3 Handshaking protocol

6.3.1 Server

The server consists of a Java ServerSocket, which accepts connections from a client. With each new client connection the Server creates a new instance of a RequestHandler object to

do the actual servicing of client requests. The Server will then wait and listen on its port for future client connections.

6.3.2 RequestHandler

The majority of the server operation is handled through the RequestHandler. When a new RequestHandler is created, it begins by opening up a two-way communications channel with the client. This allows the Handler to read any commands from an InputStream and then to respond by "pushing" text out to the client on an OutputStream.

A list of commands and their actions that could be run by the RequestHandler can be seen in

Table 6-1. The list of available commands was kept small in order to facilitate a lightweight protocol. Most of the commands are read-only, while only two of the commands influence data on the server. These are "reset_usage" and "shutdown_server". The first command is self-explanatory, while the second one was used for testing purposes in order to shutdown servers that were running remotely and were no longer needed for demonstrations.

Table 6-1 Server Commands

Command	Action
get_deviceID	Gets the ID of the device
get_tonerLevel	Gets current toner level
get_paperCount	Gets current paper count
get_usage	Gets the current usage
reset_usage	Sets the current usage to zero
quit	Disconnects from the server

shutdown_server	Shutdown the server, disconnecting all clients
help	Displays the help text

6.3.3 DeviceSim

The Class responsible for simulating the operation of the Xerox device was called

DeviceSim. This class makes use of random number generation to initialize the device (upon

server startup). It also runs independently of the server so as to further emulate the operation

of a Xerox Device. DeviceSim is responsible for varying the query-able characteristics of

the system, such as paper count, toner level, and usage.

6.4 Client-Side

The client side is based upon a Client Class that communicates (over Sockets) with the

Server and the RequestHandler. In order for the Client to be used it is necessary to bundle it

with either a console or Graphical User Interface (GUI). The console was originally intended

to be used for testing Server operation, and now the GUI is the preferred method of client

control. A standard telnet client can also be used to connect to the server, and is useful for

testing purposes.

6.4.1 GUI

The GUI provides an intuitive means for accessing the remote server. It allows the full

functionality that the console or a telnet client would provide. The actual graphical display is

quite primitive; however, the development of a sophisticated GUI was not the focus of this

project.

Figure 6.4 shows the state of the GUI client when it is unconnected. Figure 6.5 is the connection dialog box, which allows the input of the host to connect to and the port to connect on. If the server is running on the same computer as the client (useful for testing) "localhost" may be used for the host argument, and if the default port value is used (by the Server) the port will be 8189.

Figure 6.6 shows the GUI in the connected state. The Frame title changes to reflect the connected state by listing the host and port. The device ID, usage, paper count, and toner level will all be updated. In order to update these values there is a button listed as "Update". In order to reset the usage of the remote device, the "Reset Usage" button is available.
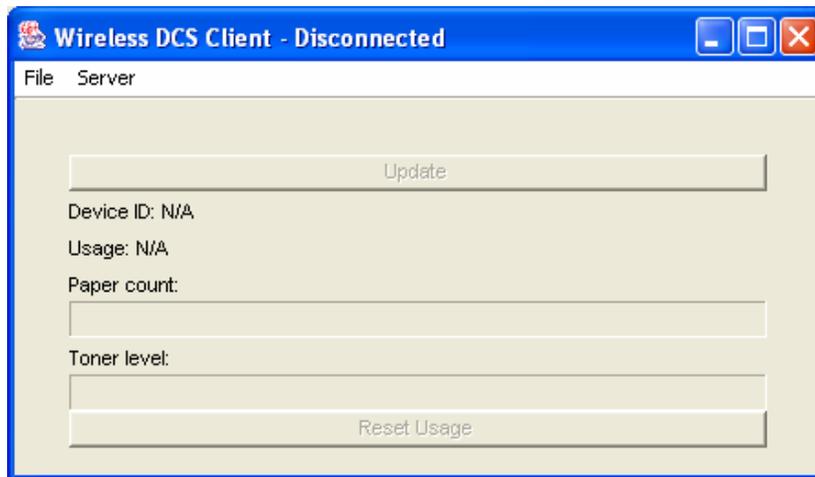

**Figure 6.4 Disconnected GUI Client**
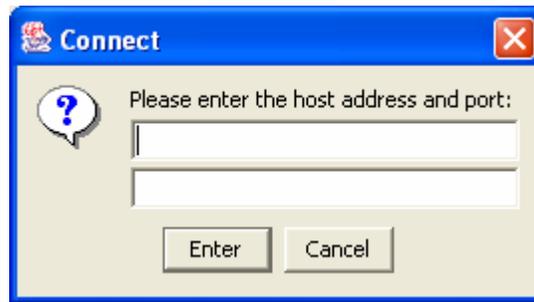
**Figure 6.5 Connection Dialog Box**
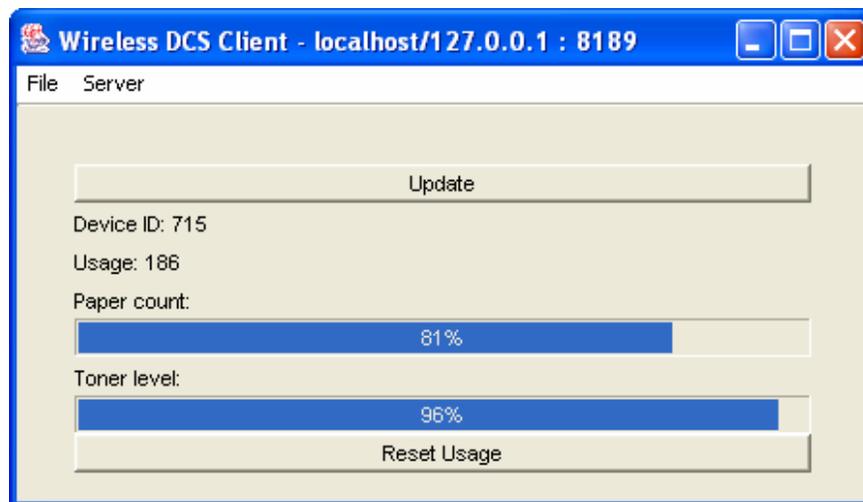
Figure 6.6 Connected GUI Client

6.5 Testing

The software was thoroughly tested using telnet, console, and GUI clients. The server was run on the same computer as the client, on a remote computer (on the same LAN), and also on a remote computer across metropolitan distances. Multiple, concurrent connections to the same server were attempted, and successful.

The next steps in testing will involve the use of the server and client model over a wireless interface. This will be accomplished by porting the current Java™ code to a device that supports the Nextel iDEN network.

Chapter 7
Future Work & Conclusions

7.1 Future Work

The next step in the development process is to port the Java™ code from operating on a PC

to operation on a wireless WAN device that is compatible with Nextel's iDEN network. In

this case, the Motorola i730 Handset, which has a built-in JVM for ease of running Java™

applications, will be used.

In order to migrate to the i730, the Java™ code, which was originally written using

the Java™ 2 Platform, Standard Edition (J2SE) must be modified to use the Java™ 2

Platform, Micro Edition (J2ME). The necessary changes are not too intensive, and for the

most part involve the use of similar library calls to classes and methods with slightly

different names.

Once the code has been successfully ported, the operation of the client-server model

should not differ at all from the PC tested versions. This is due to the fact that the Java™

code does not distinguish between wired or wireless operation. The final step in the

development process will be to integrate the wireless device (in this case the Motorola i730

handset) with one of Xerox's devices (printer, copier, etc.). Much of this work is left up to

Xerox and is highly dependent on which Xerox device model is to be used.

7.2 Conclusions

This thesis work covered a very wide range of activities. It began with research into existing

Wireless WAN technologies. The resulting data was then combined with a number of

decision metrics, set forth by Xerox, in order to determine the "best" choice for the needs of the DCS. Having decided upon a specific Wireless WAN, it was necessary to select appropriate hardware and system architectures that would be compatible with both the WAN and the DCS. Lastly, software was developed and thoroughly tested to run on top of the Wireless WAN in order to facilitate communications between the Server and Client.

The end result of this thesis leaves Xerox with a complete solution for communications between a remote device (located at a customer site) and their DCS system. With further development (beyond prototyping), and a drive to include customers outside the U.S., Xerox will be in a position to reap the benefits of a global system of interconnected devices.

Appendix A

Java Source Code

The source code contained within is organized using the following package structure:

- EDU
  - ROCHESTER
    - ECE
      - DCSClient
        - Client.java
        - Console.java
        - GUI
          - ConnectDialog.java
          - Gui.java
      - DCSServer
        - DeviceSim.java
        - RequestHandler.java
        - Server.java
      - Tools
        - ConsoleInput.java

Note: all Java code was developed using JDK 1.4.2_01

Appendix B

Glossary Of Terms

A list of abbreviations and acronyms used in the paper:

3G	3rd Generation
AMPS	U.S. Advanced Mobile Phone System
ARDIS	Advanced Radio Data Information System
ARQ	Automatic Repeat request
BER	Bit Error Rate
BS	Base Station
CDPD	Cellular Digital Packet Data
DCS	Device Centric Services
EDGE	Enhanced Data rates for GSM Evolution
GMSK	Gaussian Minimum Shift Keying
GPRS	General Packet Radio Service
GSM	Global System for Mobile
GUI	Graphical User Interface
iDEN	Integrated Digital Enhanced Network
IP	Internet Protocol
J2ME	Java 2 Platform, Micro Edition
J2SE	Java 2 Platform, Standard Edition
JDK	Java Development Kit
JVM	Java Virtual Machine
PSK	Phase Shift Keying
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
SFR	Single Frequency Reuse
SMS	Short Message Service
SNR	Signal to Noise Ratio
SSL	Secure Sockets Layer

TCP   Transmission Control Protocol

VPN   Virtual Private Network

WAN   Wide Area Network

Bibliography

[1] ARDIS, DataTac 4000, Software Developers Reference Guide, Revision 2.0, January 1997.

[2] Cellular Digital Packet Data and Remote System Administration An Agent Systems White Paper. Agent Systems, Inc. January 1, 2000.

[3] Brewin, B., UPS to spend $127M on tri-mode wireless driver terminals. http://www.computerworld.com, April 15th, 2003.

[4] Cingular GPRS coverage maps: http://www.cingular.com/business/voice_data_map

[5] Cingular Mobitex U.S. coverage Map. http://www.cingular.com/business/mobitex_map

[6] IDEN Data Modem iO1000 Application and Integration Developer's Guide. Motorola, Inc. October 31st 2001.

[7] Goldsmith, C., Wireless Local Area Networking for Device Monitoring. University Of Rochester, Rochester NY. May 2004.

[8] GSM World. http://www.gsmworld.com/roaming/gsminfo/index.shtml

[9] Haskin, D., Motient Files for Chapter 11.   http://www.internetnews.com January 11th, 2002.

[10] Heinzelman, W., "Lecture 20, Wide Area Wireless Networks." Wireless Communications (ECE 437), University Of Rochester, 2003.

[12] Mobitex Operators Association (MOA), http://www.mobitex.org

[13] Motient (ARDIS) National Coverage Map. http://www.motient.com/find/national.asp

[14] Motorola iDEN Technical Overview. Motorola, Inc. Network Solutions Sector. August 8th, 2000.

[15] Nextel iDEN U.S. coverage map: http://www.nextel.com/services/coverage/index.shtml

[16] iDEN worldwide coverage map: http://idenphones.motorola.com/iden/where_to_buy.jsp#

[17] Rappaport, T., Wireless Communications. Upper Saddle River, NJ: Prentice-Hall, Inc. 2002.

[18] The switch from CDPD to GPRS. http://www.airlink.com/

[19] Java Resources. http://java.sun.com

[20] Eclipse Java Development platform. http://www.eclipse.org