WIRELESS TELEMEDICINE FOR NURSING HOMES AND RETIREMENT CENTERS

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by

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On my honor as a University student, on this assignment I have neither given nor received unauthorized aid as defined by the Honor Guidelines for Papers in Science, Technology, and Society Courses.

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ABSTRACT

This project investigates whether or not telemedicine consultations can be successfully carried out over a wireless broadband network connection with a tablet-PC based wireless telemedicine kit. The kit would allow low-cost, virtual medical consultations between doctors and remote patients located in nursing homes and retirement centers for situations where a physical visit to the specialist is not necessary. Fixed telemedicine installations currently in use do not suit the needs of small nursing facilities due to their cost, size, and lack of portability. A portable telemedicine kit would obviate the need for a physical visit for minor consultations for these patients. The kit itself is based on a tablet-PC, which features a stylus that can be placed directly on the screen for additional input capabilities such as handwriting recognition. The software would allow two-way videoconferencing with audio, input from digital medical peripherals, transfer of high-resolution still digital photos, as well as textual input. Establishing the feasibility of telemedicine over a wireless link requires evaluating the tradeoffs in feature set and quality of transmitted video with various limited amounts of bandwidth. This project should illustrate to what degree effective telemedicine can be carried out over wireless links. These findings may pave the way for further development of wireless telemedicine and thus solve the initial problem of extending the benefits of telemedicine to new populations.

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1 Introduction to Wireless Telemedicine

1.1 Telemedicine

The word ‘telemedicine,’ defined by William Darkins as “health care carried out at a distance,” often refers to the use of technology to facilitate virtual medical consultations between remote locations. Telemedicine offers several benefits to patients and doctors alike. Free from the need to travel to see patients, high-demand specialists can save valuable time by using telemedicine technology. Patients, especially those in rural areas, are also freed from the physical, emotional, and monetary burdens (on themselves and on loved ones) associated with traveling long distances to receive specialized medical care. Often these burdens would altogether prevent patients from receiving the expert advice necessary to alleviate a particular ailment. Telemedicine has thus been almost universally welcomed as a tool to increase the reach of medical care.

1.2 History of Telemedicine

The idea of telemedicine is not a new one. The activities now credited as being the forerunners of telemedicine were mainly transmission of medical imagery over communications links to allow multiple doctors to view the images and consult each other. One early instance took place in 1959 when a two-way videoconferencing link was established using microwaves between the University of Nebraska Medical School and a state mental hospital [1]. Until the late 1980’s, telemedicine consisted of similar video links at a limited number of locations. Existing communication networks were not yet able to provide the sophistication needed for a widespread network of telemedicine installations, and computer technology was not yet able to add functionality beyond videoconferencing. A rise in computer technology in the 1990’s allowed telemedicine to grow into a more complex and feature-rich service. Computers capable of using video compression technology combined with deregulation of the telecommunications industry leading to cheaper bandwidth permitted growth in the field [2].

1.3 The Current State of Telemedicine

Presently, telemedicine is used primarily for remote virtual medical consultations and for medical education. A telemedicine consultation typically takes place between a patient and their nurse or primary care physician at one location, and a specialist doctor or team of doctors at another. Some types of consultations are particularly suitable for telemedicine. For example, dermatological checkups and diagnostics can often be carried out with telemedicine due to the external nature of the field. Radiology has also been shown to lend itself well to telemedicine. Telemedicine installations have also been adapted to facilitate remote lectures between doctors for continuing medical education.

The University of Virginia Office of Telemedicine is today the center of a modern telemedicine network encompassing the state of Virginia. With the office in Charlottesville serving as a hub, medical professionals can consult with nurses and primary care physicians across the state. The remote facilities are mainly clinics, hospitals and prisons, and they are connected via T1-class data links. All installations provide two-way videoconferencing, high resolution digital photography, data capture from medical devices (such as digital stethoscopes), and secure transmission of user inputted data. Remote medical consultations carried out using this network have continually gained in popularity since the office began offering them in the mid 1990’s. Patients have responded favorably with words, and government agencies such as the National Telecommunications and Information Administration have shown support in the form of grants. The general usefulness of telemedicine has been asserted in many studies [3].

1.4 Problems with Conventional Telemedicine

Fixed telemedicine installations currently in use do not suit the needs of nursing homes, retirement centers, and similar small healthcare facilities due to their cost, size, and lack of portability. Traditional telemedicine often uses a videoconferencing standard known as H.320 as the basis for communication between the remote sites. The H.320 protocol encompasses the transmission audio, video, and data using Integrated Services Digital Network (ISDN) connectivity. While H.320 is still in wide use, it suffers from several problems. The first of these problems is that H.320 equipment is expensive to purchase and deploy. Not only are the terminals themselves expensive, but the required ISDN line must be leased from a telecom provider at a significant monthly rate [4]. ISDN lines are fixed, precluding the option of portability. H.320, adopted in 1990, is an aging standard, not easily integrated with modern telemedicine devices such as digital medical peripherals. The H.320 videoconferencing standard is thus unsuitable for telemedicine in nursing homes and retirement centers.

Traditional telemedicine installations are usually installed once at a fixed location within a medical facility and are rarely if ever moved. An installation will often monopolize an entire room. The bulk of the equipment as well as the nest of cabling tethering it to the wall prevents these setups from easily being transported within the facility or to another facility with which the equipment might be shared. This lack of portability prevents possibilities such as conducting real-time telemedicine in a patient's room, home, or other remote locations.

A complete conventional telemedicine setup can be expensive. While conventional setups often feature capabilities beyond what a wireless telemedicine could offer, these capabilities are just as often superfluous for consultations taking place in the smaller medical facilities targeted by wireless telemedicine. The complexity of these systems may also daunt untrained users.

1.5 Wireless Telemedicine

To solve some of conventional telemedicine's problems, modern computing and connectivity technologies afford the possibility of wireless telemedicine. A wireless telemedicine kit will be portable. An individual should be able to transport, set up, and operate the kit with minimal effort. The kit should be easy to use for those with or without medical training. It should be simple for a nurse and patient to connect to a remote doctor and a telemedicine consultation to take place.

A wireless telemedicine kit based on a tablet PC will be relatively inexpensive. A rudimentary kit could be constructed for the cost of a laptop, webcam, and connectivity solution. Additional features can be added as they are needed or become affordable.

To obviate any specific site connectivity requirements, wireless broadband service will link a wireless telemedicine kit to the Internet. Offering data transmission rates comparable to those of conventional cable and DSL-based broadband offerings, wireless broadband can cover an area with a radius of up to 30 miles, depending on line-of-sight (LOS) to the tower. The use of wireless broadband would theoretically allow a telemedicine consultation to take place anywhere within this range.

1.6 Rationale for Pursuing Wireless Telemedicine

Building a portable telemedicine kit and using a wireless broadband service for connectivity can solve some of conventional telemedicine's problems as well as enabling new possibilities for its use. True portability would allow telemedicine consultations to take place anywhere within a nursing home or retirement community, offering flexibility to its users. Additionally, a portable kit could be easily loaned to another facility or even shared between multiple facilities. The use of commodity hardware and inexpensive commercial connectivity where possible will serve to make the kit affordable for smaller medical facilities.

The target patients are those living in nursing homes and retirement centers who require medical attention appropriate for telemedicine. These locations typically have large populations of elderly who may require frequent medical care. It is important to note that this kit is not intended to replace a physical visit for complex diagnoses, but to obviate unnecessary travel inconveniences associated with minor visits. For minor consultations and checkup visits, the travel costs associated with physically meeting with the physician can be daunting. The money, time, and physical efforts required for such trips justify the use of telemedicine if it is suitable for the given need. Small nursing facilities may not have the space, money, or need for a full telemedicine installation. The monthly cost for a fixed data connection would likely not fit into the budgets of nursing homes. An inexpensive portable kit could be easily moved between and shared by multiple facilities.

Hence, the goal of this project is to bring the benefits of telemedicine to nursing home residents in an inexpensive, convenient manner. This goal will be achieved by demonstrating the feasibility of producing a portable telemedicine kit that can be connected to a telemedicine network through a wireless metropolitan area network.

1.7 Overview of Technical Report

This document, having explained conventional telemedicine and its limitations as well as the idea of wireless telemedicine and the rational for pursing it, will now continue to document the project. This project seeks to demonstrate the feasibility of conducting telemedicine consultations using contemporary wireless connectivity. Subsequent chapters will describe a fully featured telemedicine kit, the test-bed used to demonstrate feasibility, the results of testing, and finally the significance of the test results.

2 The Wireless Telemedicine Kit

The kit is comprised of the tablet PC, a connectivity solution, digital medical peripherals, and customized software. This chapter considers each element separately, and also contains a section on information security.

2.1 The Tablet PC

Laptop computers that are today referred to as tablet PC's have their roots in decades of research on pen-based computer input devices. In 1963, MIT student Ivan Sutherland created an early pen-based input device he dubbed the Sketchpad [5]. The following decades saw many products introduced that attempted to allow people to interact with computers in a manner similar to writing with a standard pen. Poor handwriting recognition performance doomed many offerings from large computer manufacturers including IBM [6]. Beginning in 2002, software maker Microsoft began an initiative to advance pen-based computing through the introduction of Windows XP Tablet PC Edition and partnerships with hardware manufacturers. The integration of digital ink and handwriting recognition with the world's most widely used operating system appears to be a major advancement in the field of pen-based computing. Today's tablet PC 'convertibles' running this superset of the Windows XP operating system often resemble standard small notebook computers, until the user rotates and flips the screen down and touches the stylus to the display screen, allowing them to interact with familiar applications in a new manner.

Figure 1: Toshiba Portege M200 tablet PC. Source: www.toshibadirect.com.

The tablet PC is a logical choice as the basis for a portable telemedicine kit. Tablet PCs are as lightweight and easily transportable as any small laptop. They are able to perform nearly all of the functions of a standard laptop, and run any of the many commercially available and custom developed software applications for Windows. Tablet PCs easily connect to other peripherals such as cameras and digital medical devices using the Universal Serial Bus (USB). Most offer wired and wireless Ethernet interfaces, as well as PC Card interfaces for proprietary connectivity devices. When folded to form a tablet, tablet PCs offer additional input capabilities. A user can enter notes or diagnostic data using the stylus while holding the tablet in the manner of a traditional pad of paper. The additional capabilities offered by the tablet PC will serve to make portable telemedicine kits easier to interact with than a standard laptop or desktop computer.

2.2 Connectivity

A fundamental necessity for any type of telemedicine is a data connection between the two endpoints. Before considering the underlying transport, it is important to consider the type and amount of data that will be sent. The features of telemedicine consultations dictate that a substantial amount of bandwidth is necessary. The primary consumers of bandwidth during a consultation are the bidirectional audio and video streams that allow the illusion of a virtual presence to take place. The transmission of high resolution digital still images in a reasonable amount of time also consumes significant bandwidth. Finally, textual and other additional medical data will consume smaller amounts of bandwidth.

A successor videoconferencing standard to H.320, H.323, is now in use in the telemedicine field, including telemedicine systems at the University of Virginia's Office of Telemedicine. H.323 defines a standard suite of protocols for conducting videoconferencing using the Internet Protocol (IP). Since nearly every modern computing device understands IP, and more importantly the Internet constitutes an inexpensive, global IP network, H.323 is an appropriate choice for small healthcare facilities wishing to implement a telemedicine endpoint. H.323 encompasses several audio and video codecs of various bit rates. The term 'codec' is short for coder/decoder and 'bit rate' refers to the number of bits transmitted per second. The minimum audio and video bit rates defined within H.323 are 5.3 and 64 kilobits per second (kbps), respectively. In addition to these minimum requirements, networking overhead and other traffic will also require bandwidth. Thus, an appropriate connectivity solution for the portable telemedicine kit will provide a bare minimum of a roughly 100kbps connection to the global Internet. Once this link is established, the available bandwidth back to a fixed telemedicine center is assumed to be of equal or greater quality and capacity.

To achieve the aforementioned metropolitan area portability, the first connectivity option considered is wireless broadband service. The local telecom provider nTelos offers this type of service using a system of base stations and modems called the Ripwave system and manufactured by Navini Networks. They claim a maximum downstream bandwidth capability of 1.5 megabits per second (Mbps) and upstream service of 550kbps. The claimed bandwidth exceeds the estimate of a bare minimum from above; however, these figures are theoretical maximums and do not alone ensure useful telemedicine can be conducted using the nTelos service.

In a preliminary test, Professor Alfred Weaver's research group within the University of Virginia's Department of Computer Science successfully demonstrated a one-way video stream using the Ripwave system in connection with a proposal jointly authored by Dr. Weaver and Dr. Karen Rheuban of the UVA Office of Telemedicine [7]. Before advising an undergraduate student in the undertaking this project, a quick test was prudent since the use of the Navini Ripwave or a similar system offering metropolitan area coverage is critical to achieving the goal of designing a connected telemedicine kit that can be operated in medical facilities that do not provide connectivity.

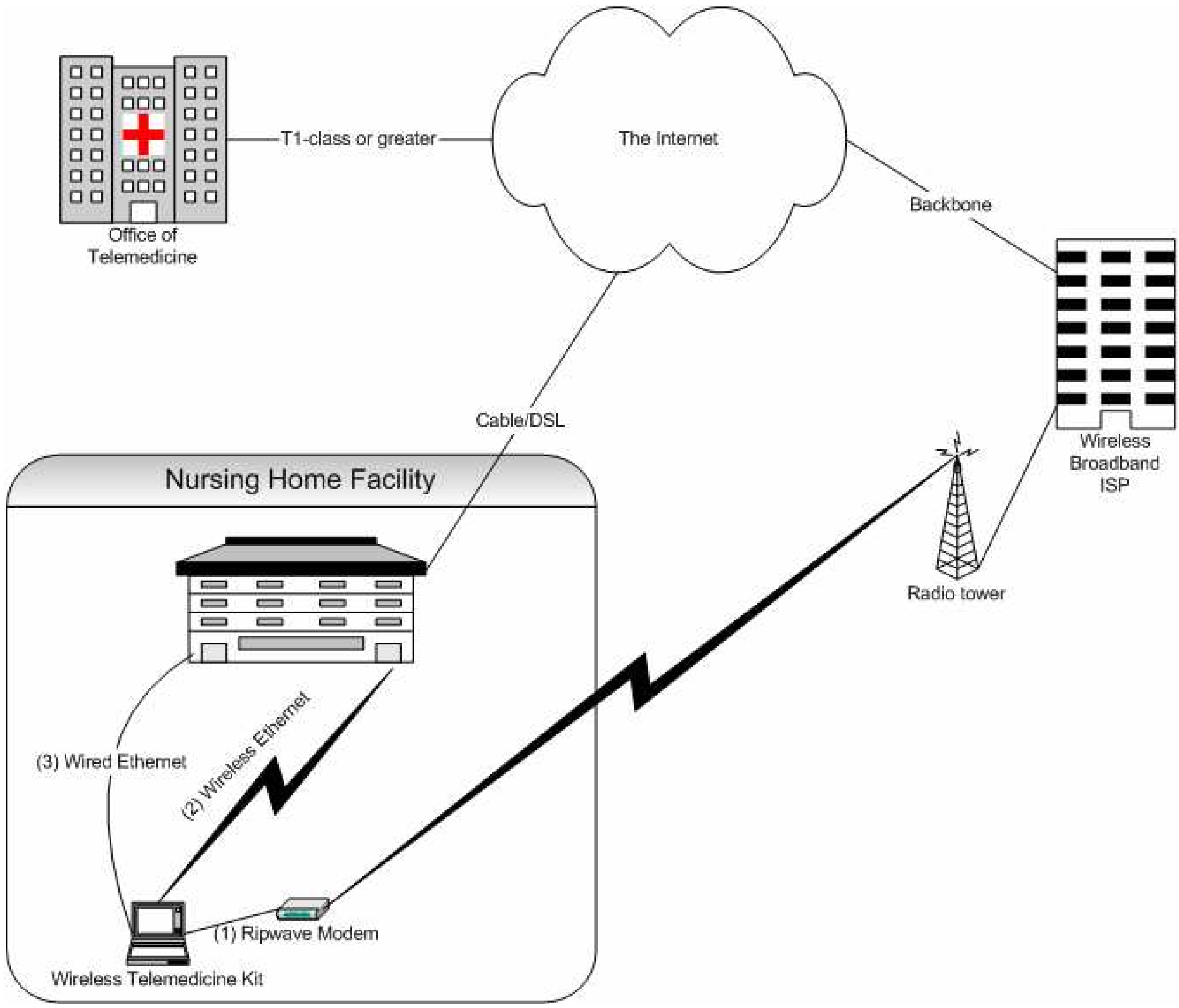

Figure 2: Three possible data paths to the Office of Telemedicine

In addition to wireless broadband, a tablet PC-based telemedicine kit should be able to connect to locally available bandwidth. Most tablet PCs are equipped with wired (IEEE 802.3 standard) and wireless (IEEE 802.11 standard) Ethernet adapters. In cases where wireless broadband coverage is insufficient and a facility has an existing Internet connection, these adapters can be used to connect to the local area network (LAN). A local LAN's connection to the Internet may or may not provide sufficient bandwidth to conduct a telemedicine consultation, depending on the connection type and the number of users sharing the connection. Predicting the success of a using this type of connection depends on many factors and is beyond the scope of this document.

2.3 Software

The tablet PC runs the Microsoft Windows XP Tablet PC Edition operating system. As mentioned above, this OS is a superset of Windows XP and thus runs most software written using Microsoft's Visual Studio .Net development environment. There are many relevant software packages and development kits available that can facilitate rapid development of telemedicine applications. Microsoft's NetMeeting application is a basic H.323 compliant videoconferencing solution. A software development kit (SDK) is available for NetMeeting allowing developers to integrate NetMeeting's capabilities into their own applications. A tablet PC SDK is also available, affording a straightforward manner of integrating pen-based input capabilities into a telemedicine application. Thus, while beyond the scope of this project, it is apparent that producing the software required for a wireless telemedicine kit to interface with the University of Virginia's telemedicine network is feasible.

2.4 Information Security

Due to the sensitivity of personal medical data, ensuring the security of transmitted information is a key requirement of a portable telemedicine kit. Most people consider their medical history and status to be highly private, and any counselor who may come into contact with this information has an ethical obligation to honor their privacy. Additionally, the Health Insurance Portability and Accountability Act of 1996 (HIPAA) specifies standards and regulations with regard to the electronic storage and transmission of medical data that must be adhered to by law [8]. Fundamentally, individuals who access medical data must be authenticated (their identity verified), and authorized for the particular datum. The data itself must be encrypted using strong encryption.[1] Research in various aspects of the field of secure electronic medical data is in progress at the University of Virginia and can be applied to a wireless telemedicine kit.

Wireless transmission of data presents another potential security risk in that data traveling through the air in radio waves is more easily intercepted than data traveling on a wire. While adequate steps to secure wireless connectivity are prudent, most of the security will lie in the strong encryption at the final endpoints of the transmission. Thus, if any information is intercepted as it traverses a wireless link, it will be of little use to a miscreant since it will already be strongly encrypted.

2.5 Features and Accessories

The heart of a telemedicine consultation is videoconferencing, the feature which allows participants on each end to view and hear each other to simulate an actual face-to-face encounter. Providing this functionality requires a camera and microphone on each end. Inexpensive USB-connected webcams featuring a small camera and integrated microphone are thus a perfect hardware addition to the telemedicine kit. These cameras will provide video streams to aid natural conversation. They could possibly be used for minor diagnostic imagery as well. Their limited resolution, combined with bandwidth constraints, suggest that a high resolution digital still camera also be included in the kit.

[1] Strong encryption standards are those which the security community regards to be significantly difficult to break using currently available technology. The Advanced Encryption Standard (AES) with 256 bit keys is an example of a strong encryption standard.

Figure 3: An inexpensive USB web camera with integrated microphone. Source: www.logitech.com.

In addition to audio and visual diagnostic capability, a wireless telemedicine kit will feature digital medical peripherals, allowing for digital recording and transmission of medical data. Digital stethoscopes, sphygmomanometers,[2] and cardio/respiratory monitoring systems are all currently available. Below is a photograph of the leads for a digital respiratory monitoring system. This system features a RS232 serial interface. Although most tablet PCs no longer include a serial port, inexpensive RS232 to USB adapters are commercially available and future medical peripherals are expected to take advantage of the newer USB interface. The system below is an example of one of many peripherals which can be added to the wireless telemedicine kit. Nearly any USB accessory will work with the kit.

[2] A sphygmomanometer is a device used to measure a patient's blood pressure.

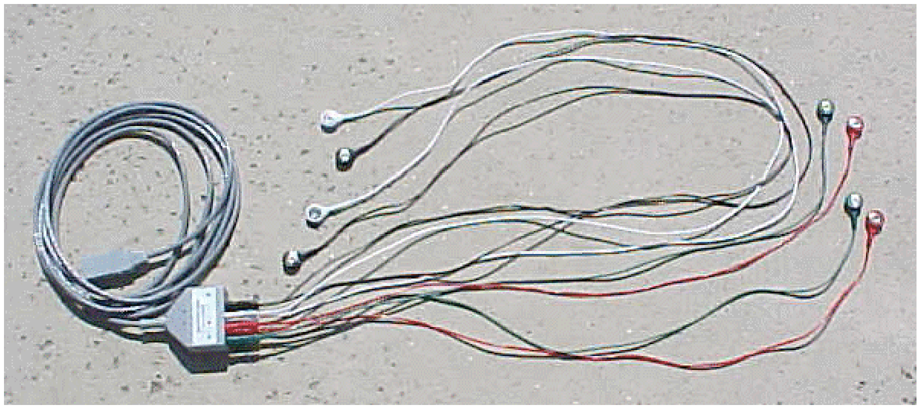
Figure 4: Hemo Sapiens, Inc.'s EXT-TEBCO system. Source: www.hemosapiens.com.

In addition to the above hardware, a portable telemedicine kit will feature custom software for the viewing and collection of medical data. Firstly, the software must identify the parties involved in the consultation, usually a patient, nurse or primary care physician, and the remote specialist doctor. This information must be recorded and stored in a manner analogous to the particular institution's method of documenting face-to-face encounters. A common task during a medical exam is the reading of the patient's vital signs, heart rate, breathing rate, and temperature. Telemedicine software features forms for these data that can be filled in automatically by digital medical peripherals, or through stylus or keyboard input from the nurse.

Software will likely need to be customized for each particular institution or application. For example, an implementer of a wireless telemedicine kit to interface with the Office of Telemedicine's network would draw upon the software currently in use between fixed locations, tablet PC and videoconferencing SDKs, and secure medical data exchange software projects.

2.6 Using the Kit

To clarify the use of the kit for the reader, below is a typical usage scenario in the form of a list of actions and events:

1. The nurse or primary care physician unpacks the kit, boots the tablet PC, and attaches peripherals required for the consultation.
2. The patient is ensured to be present and the connection is established with the remote physician.
3. The remote physician and the local patient and nurse interact normally using the bidirectional audio and video streams.
4. Textual notes, pen-inputted readings and observations, digital medical peripheral readings, and high-resolution still photographs are transmitted to the remote physician in real- or near real-time.
5. The data for the session is encrypted and stored remotely and possibly locally as well.
6. The session is terminated and the kit is packed for transport.

3 Testing the Kit

3.1 A Pared Down Telemedicine Kit for Testing

A complete wireless telemedicine kit would include many components unnecessary for demonstrating the feasibility of wireless telemedicine. The goal of this project is not to construct a fully functional kit, but to show using appropriate hardware and testing that the construction of a useful kit is possible and should be undertaken. As previously discussed in this document, the primary question to answer to establish the feasibility of conducting a telemedicine consultation via a wireless broadband link is whether the bandwidth offered by such a link will be sufficient. This question can be answered without the purchase of expensive digital medical peripherals or of the costly Navini Ripwave modem and required service contract.

3.2 The Test Hardware

Simulating a wireless telemedicine consultation and testing its bandwidth requirements require several pieces of hardware. The first is a tablet PC running Windows XP Tablet PC Edition to form one endpoint for the simulation and to test pen-based input. Professor Weaver agreed to order a Toshiba Portege M200 tablet PC for the project; the subsequent to the completion of this project it will become available to other research groups under his direction. The M200 has both wired and wireless Ethernet interfaces. The author’s laptop computer running Windows XP filled the role of the other endpoint. Inexpensive Logitech brand webcams with integrated microphones were attached to the USB interface of each PC. A consumer grade Linksys WRT54G wireless access point with integrated Ethernet switch served to connect the PCs. For simulation of various network conditions, a third PC featuring two 100Mbps wired Ethernet interfaces was used as a router to connect the two laptops.

3.3 Test One: Videoconferencing Using Microsoft NetMeeting

With the knowledge of roughly how much bandwidth the Navini Ripwave modem provides, I set out to determine how much bandwidth H.323 videoconferencing requires. This test requires an H.323 client; I selected Microsoft's free NetMeeting client, version 3. NetMeeting is simple to use and allows the user to set various parameters for the session.

To explain the test data, I must first explain H.323 in more detail. The H.323 protocol suite encompasses multiple audio and video codecs which have various levels of quality and bit rate. For audio, NetMeeting prefers the G.723.1 codec, which encodes at a constant rate of 6.4kbps. I use the word 'prefer' here because other codecs are available. NetMeeting prefers video codecs from the H.263 family, which itself is divided into several subclasses based on the size of the transmitted image. The names and specifications of each H.263 codec tested are listed below in Table 1, and screenshots are available in Appendix A. Each H.263 video codec encodes at bit rates in multiples of 64kbps. The efficiency of the compression algorithms they employ depends on the input video. A video stream of a stationary subject will consume less bandwidth than that of a moving one. Thus, the actual transmitted bit rate is variable and unspecified.

Name	**Image Size (pixels)**	**Color Depth (bits/pixel)**	**Maximum Frames per Second**
CIF	352x288	24	30
Quarter-CIF (QCIF)	176x144	24	30
Sub-QCIF	128x96	24	30

Table 1: H.263 Video Transmission Modes. Source: www.cisco.com.

3.3.1 Measuring Bandwidth Usage

To measure the bandwidth usage of each codec, I captured packets from live NetMeeting sessions with the open-source network protocol analyzer Ethereal. I measured the inbound and outbound throughput at the tablet PC for each of the nine possible combinations of inbound and outbound H.263 format. Thus, bandwidth requirements are characterized for various asymmetric setups. Using different stream formats in each direction might be useful since the doctor's imagery of the patient is more critical than the patient's view of the doctor. Establishing the session in this manner might help to meet bandwidth constraints, and thus asymmetric setups were tested. All tests used the G.723.1 audio codec.

For the tests each PC associated to the wireless access point at 11mbps and full signal strength. Each session lasted at least on minute, with sufficient subject movement to simulate an actual telemedicine consultation. Using Ethereal, I set a capture filter to capture only the data from the NetMeeting session, and a display filter to select the direction of data flow and a time window from the middle of the stream. Ethereal's statistical summary then provided the average bits per second for the session. The reported figure includes IP and Ethernet header overhead. Measuring throughput in this manner gives a realistic reading, since network overhead can increase throughput requirements up to 20 percent or more compared to a raw input rate [9].

NetMeeting has several bandwidth profiles for adjusting to the connection on which a session is taking place. The first set of test runs were conducted using the "Cable, xDSL, or ISDN" profile. The results (available in Appendix B) showed that average throughput in either direction never exceeded 67kbps, well below the claimed capacity of nTelos's wireless broadband service. NetMeeting had reduced the bandwidth usage far below the capabilities of H.323. Sessions using this profile consume bandwidth well within the published capabilities of the Navini Ripwave system. To investigate higher quality sessions, the next set of test runs were conducted using the "LAN" profile, which limits throughput much less aggressively.

3.3.2 Test Measurements

Test Run	Tablet Outgoing Video	Tablet Incoming Video	Tablet Outgoing Throughput (kbps)	Tablet Incoming Throughput (kbps)
1	Sub-QCIF	Sub-QCIF	226.31	143.36
2	Sub-QCIF	QCIF	261.12	346.11
3	Sub-QCIF	CIF	221.18	599.04
4	QCIF	Sub-QCIF	287.74	148.48
5	QCIF	QCIF	284.67	323.58
6	QCIF	CIF	319.48	576.51
7	CIF	Sub-QCIF	508.93	185.34
8	CIF	QCIF	523.26	297.98
9	CIF	CIF	543.74	501.76

Table 2: Test 1 Measurements, H.323 Average Throughput.

3.3.3 Preliminary Analysis

The data in Table 2 demonstrate the, admittedly predictable, trend that the larger image formats consume more bandwidth than the smaller ones. QCIF and sub-QCIF streams never exceed 346.11kbps, with one QCIF stream averaging only 284.67kbps. These figures represent 63 percent and 52 percent utilization, respectively, of the theoretical Navini Ripwave 550kbps upstream capacity. These utilization figures leave enough additional unused capacity to transmit significant amounts of textual and numeric data. CIF's average bitrates fall in the 500kbps neighborhood, which although technically below capacity are likely unusable as an upstream codec from the tablet PC. They leave no buffer room for additional data or decreased network performance. The

Navini system's theoretical downstream capacity of 1.5Mbps would support any of the above formats with surplus capacity for additional data or to compensate for decreased network performance.

3.4 Test Two: Simulating Network Conditions

The results from Test One demonstrate the raw bandwidth requirements of H.323 compliant videoconferencing sessions on a LAN. However, the network performance of a LAN is significantly higher than that of a wireless broadband network. IP networks send data in discrete packets of information, each of which travels from the sender to the receiver independently. Several characteristics of IP networks are factors in a network's performance. Packet latency, usually measured in milliseconds, represents the time between the packet leaving the sender and arriving at the receiver. Packet loss represents the percentage of transmitted packets that are lost or dropped, requiring retransmission. Due to the independent routing of each packet, it is also possible for packets to arrive at their destination in a different order than they were sent. Packet latency, loss, and reordering can all degrade the performance of an IP network.

3.4.1 A Method for Simulating Degraded Network Performance

To simulate a wireless telemedicine session more realistically, videoconferencing needed to be tested using a network with higher packet latency, and some packet loss. Such a network can be simulated using a PC running the Linux operating system and configured as an IP router. Stephen Hemminger of the Open Source Development Labs maintains a kernel option available in newer 2.4 and 2.6 series kernels called netem [10]. Netem, short for "network emulator" allows the user to simulate the above network characteristics realistically using a normal distribution (bell curve) to vary the latency and loss in a stream of packets.

With a method of simulating a network at hand, I needed some realistic figures for latency, loss, and reordering to use for the test. While Navini Networks does not publish latency specification for its equipment, a dslreports.com forum post from a wireless ISP employee indicated that latency added by the Ripwave system is typically 90-120ms [11]. From my own experience with wireless networks, I interpret this figure as reasonable and thus selected a normal distribution of 110±15ms added latency for the test. Published figures for packet loss are also unavailable; I used a normal distribution of 3% loss, variable from 0% to 6% over time. This figure is also consistent with my experience with long range wireless networks.

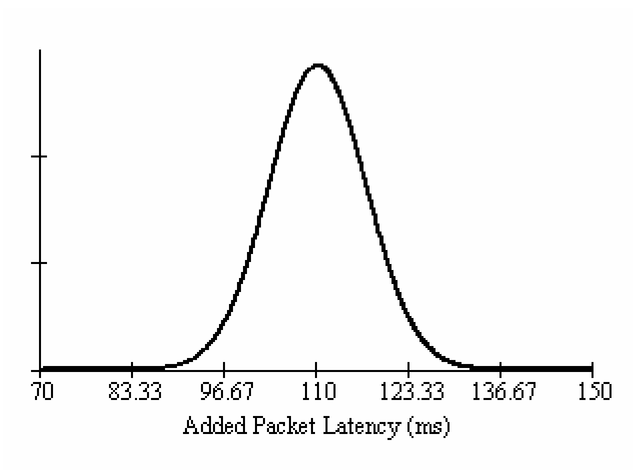

Figure 5: Distribution of Added Packet Latency

To set up the test, I installed the White Dwarf Linux [12] distribution on a PC with two Ethernet cards. I compiled and booted a Linux kernel, version 2.4.29 with the netem option enabled. I also compiled and installed the iproute2 package which includes the commands necessary to specify the above parameters. Finally I connected the tablet PC and laptop to the wired Ethernet interfaces, configured routing to allow them to communicate, and disabled wireless Ethernet.

3.4.2 Testing and Results

The test runs using the above setup were similar to the NetMeeting tests from the previous section. I viewed sessions using both of NetMeeting's bandwidth profiles and using various codecs. The transmitted bandwidth values did not change appreciably from those of Test 1; the each endpoint is still sending roughly the same amount of data. The difference lies in the fact that the other end is not receiving that data as quickly or reliably as before. The primary result is a subjective loss of video quality.

H.263 video codecs employ compression techniques to reduce bandwidth usage and requirements. The nature of the algorithm is to send the entire image at preset intervals, and only sending updates for pixels that change, or deltas, in the interim. Large movements of the video subject cause a large number of deltas to be dispatched. When testing with downgraded network performance, the result is that the receiver's image becomes blurry and artifacts appear. This lapse in video quality persists until either the deltas 'catch up' or a complete refresh of the current image is transmitted. At this point, in the absence of additional motion, the image becomes as clear as any from Test One. Figures 6 and 7 demonstrate this behavior.

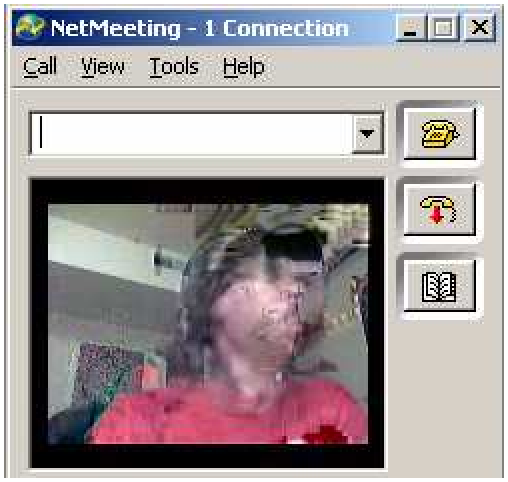

Figure 6: QCIF stream blurred and pixilated due to subject motion.

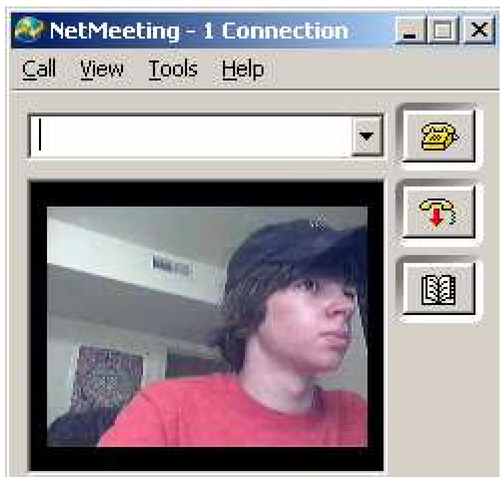

Figure 7: QCIF stream stabilized.

3.5 Analyzing the Test Results

As stated earlier in this document, the primary concern for the feasibility of mobile telemedicine with a citywide range of connectivity is the ability of wireless broadband to deliver sufficient bandwidth to support real time videoconferencing. Test One demonstrated that several H.323 standard configurations for a bidirectional videoconference have bandwidth usage characteristics within the claimed capabilities of the Navini Ripwave system. Test Two showed that decreased network performance still allowed the sessions to take place, although with greater incidence of video artifacts due to motion. It is the author's opinion that these tests demonstrate that the construction of a wireless telemedicine kit is a viable project that should be further pursued.

With the capabilities defined, the question becomes a subjective one of whether these capabilities are sufficient to make doctors and patients want to use the system. I argue that if users accept certain limitations of the system, they will find great usefulness in it. To conduct a wireless telemedicine consultation using an imperfect video stream may require the users to rely on the stream more for human interaction than for diagnostic imagery. Another concession to the limited bandwidth would be the requirement that the session be paused to upload digital still diagnostic images. While the future should provide better connectivity, the system as described will not support a timely large file upload and concurrent video stream. A possible solution to this problem could be to transmit the photos slowly using a small amount of bandwidth alongside audio and video streams. Despite reduced capabilities compared to a full featured telemedicine installation, my testing suggests nothing to preclude the possibility of a rudimentary diagnostic session using a wireless telemedicine kit. Acceptance tests with potential users, while not part of this project, would clarify whether the current capabilities of the kit are sufficient.

4 Completing the Kit Based on Test Results

This project, as a feasibility study, should provide direction for future students and researchers desiring to work towards the realization of a working wireless telemedicine kit. The results of this project shed light on initial bandwidth concerns. The next logical step would be to perform similar tests using a Ripwave modem. Determining the operating characteristics of videoconferencing over the Ripwave under various conditions could constitute such a project. The project would consider variations in signal strength and weather, as well as differences between line-of-sight and non-line-of-sight operation.

With connectivity concerns alleviated, a subsequent project would be to work with the Office of Telemedicine to develop tablet PC software to interface gracefully with their current systems. Activities for this project would include determining the requirements and features of the software, integration of currently used software and medical data security projects, and the addition of tablet PC capabilities using the tablet PC SDK. Once working software is constructed, laboratory and field acceptance testing would evaluate the working kit and allow for further tuning. The completion of this project would likely bring the wireless telemedicine kit very close to being ready for deployment at area nursing homes and retirement centers for regular use.

Upon the advent of portable, wireless telemedicine being used in the field, further studies would evaluate its effectiveness. Many questions would need to be answered: How well is the wireless telemedicine kit working? In what areas is it most useful? What are its limitations? Is it accomplishing the goal of extending quality healthcare to more people? Is it accomplishing the previous goal in a cost effective manner? In much the same manner as conventional telemedicine has been studied since its inception, wireless telemedicine would be carefully scrutinized.

5 Wireless Telemedicine for a New Type of Health Care

5.1 Significance for Patients

Medical care is a huge industry in the United States and indeed the world. Humans suffer from a wide array of medical problems and have sought to cure these problems using technology for many centuries. The sheer numbers of people working in the healthcare industry and trillions of dollars being spent on healthcare technologies are powerful indicators of the value we as a society place on wellness. Telemedicine was created to bring the benefits of advanced medical care to more people. It provides a means for patients to receive the care they and their families feel that they need in a situation where care might not otherwise be available or would be burdensome.

Wireless telemedicine will extend the breadth of this service by making telemedicine consultations more accessible to more people. Allowing nursing home residents to receive this care will more easily allow the benefits of healthcare, health and happiness, to be realized. Achieving that goal satisfies a desire that is apparent in our culture.

5.2 A Decreased Burden for Nurses and Family

In addition to providing new opportunities for patients, using wireless telemedicine will also reduce the burden on the families of nursing home residents and caretakers working at those facilities. The cost in time, money, and effort required to transport a patient to a specialist medical facility can be quite significant. For wheelchair-bound or otherwise physically impaired patients, the scheduling of and payment for van rides to and from the facility is a necessary burden for a hospital visit. These costs increase with the distance traveled. The time costs of navigating a hospital and waiting for a specialist are significant as well. For simple diagnostic consultations and scheduled checkups, telemedicine can obviate many of these burdens. Portable wirelessly connected telemedicine simplifies the process further by bringing the telemedicine kit directly to the patient.

5.3 Bringing Telemedicine to More People

The primary long-term goal of this project is to bring healthcare to residents of nursing homes and retirement communities through wireless telemedicine. While these populations generally have access to specialist care already, they often must endure the aforementioned burdens to receive it. Wireless telemedicine is a relatively inexpensive way to make specialist consultation available wherever sufficient Internet connectivity can be obtained. The addition of portability to standard telemedicine's offerings will allow these new populations to be reached.

To consider a larger scale, by providing a method for medical care to easily traverse large distances, telemedicine might serve to democratize the delivery of medical care in the future by reducing the disenfranchising effects of the uneven geographical distribution of medical resources [13].

5.4 Social Effects and Concerns

It is important to consider the long-term societal effects of telemedicine and other communication technologies. Telemedicine, like email, telecommuting, the cellular telephone, is a technology that tends to foster a virtual presence instead of a live one. It is not difficult to imagine a scenario where this trend is carried out to the point where live human interaction is rare. This setup should be approached cautiously with regards to medicine. Subtleties in diagnosis that might be missed during a virtual consultation could prove to be important in treatment. We must be careful to limit telemedicine only to situations where it is appropriate. This type of personal disconnect could also have farther reaching social implications by changing the nature of human interaction completely, changing the way we interact and organize ourselves.

5.5 Can A Wireless Telemedicine Kit Bring Telemedicine to More People?

Extending the benefits of telemedicine to the populations of nursing homes and retirement centers would provide a convenient and useful service to many medical patients. A portable, wirelessly connected telemedicine kit based on a tablet PC is a potential vehicle for bringing telemedicine to these patients. Constructing a wireless telemedicine kit that is useful depends heavily on the quality of the Internet connection. Presently available wireless broadband should be able to provide sufficient bandwidth to conduct a telemedicine consultation, but these consultations will not equal the quality of full featured telemedicine installations. As with conventional telemedicine, the uses of telemedicine in lieu of a physical visit must be limited to those which are appropriate for the capabilities the kit provides. Complex diagnoses and procedures will still occur in a hospital. Despite these limitations, the potential benefits of wireless telemedicine justify continued research on a tablet PC-based kit.

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Appendix A: Screenshots of H.263 Video Sizes

Image 1: Sub-QCIF

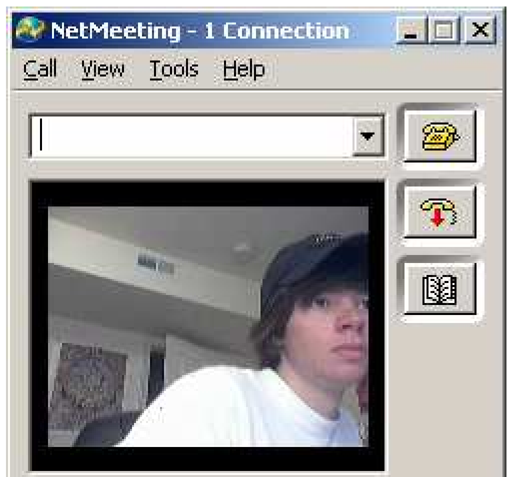

Image 2: QCIF

Image 3: CIF

Appendix B: Test One Results: “Cable, DSL, ISDN” Profile

Test Run	Tablet Outgoing Video	Tablet Incoming Video	Tablet Outgoing BW (kbps)	Tablet Incoming BW (kbps)
1	Sub-QCIF	Sub-QCIF	50.18	47.1
2	Sub-QCIF	QCIF	50.18	50.18
3	Sub-QCIF	CIF	49.15	62.46
4	QCIF	Sub-QCIF	51.2	46.08
5	QCIF	QCIF	51.2	51.2
6	QCIF	CIF	52.22	67.58
7	CIF	Sub-QCIF	62.46	47.1
8	CIF	QCIF	64.51	54.27
9	CIF	CIF	63.48	66.56