A Demonstration of Medical Communications Based on an ATM Broadband Network Technology

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ABSTRACT

The research and development efforts of several university and industry groups have brought digital imaging technologies into the practice of medicine. Radiographic images based on a digital data set can now be acquired, stored, communicated and presented for both primary interpretation and access by the referring physician. Moreover, conferences between a specialist and a primary care physician can be supported with audio and video links.

A demonstration project at Washington University in collaboration with Southwestern Bell and NEC-America provides a testbed for deployment of ATM (Asynchronous Transfer Mode) broadband network technology supporting both LAN and WAN experiments in multimedia medical communications. A network based on four geographically dispersed ATM switches supports rapid display of high-resolution medical images, patient information, digital video and digitized real-time physiological signals at channel rates of 100 Mb/s. A prototype configuration of an Inquiry & Display station is based on the NeXT computer with auxiliary displays for the medical images. Observations and preliminary performance results will be presented.

1. BACKGROUND

In the 1980s, several of us recognized the important role that communications could play in the delivery of medical information to the community. We were convinced that medical images needed to be included along with more traditional forms of medical information and would require broadband transmission facilities. To bring this vision to life, three organizations at Washington University have collaborated over the last four years to create a demonstration of these future possibilities in medical communications. These organizations are the Electronic Radiology Laboratory (ERL), the Applied Research Laboratory (ARL) and the Office of the Network Coordinator (ONC). The following paragraphs briefly describe the relevant background regarding these organizations and, in addition, mention our sponsors in this project, Southwestern Bell and NEC America, who have made important contributions to the demonstration that go well beyond their financial support.

Electronic Radiology Laboratory (ERL). The goal of Mallinckrodt Institute of Radiology's ERL is to create tools and conduct experiments useful in gaining a thorough and practical understanding of electronic radiology including its software, hardware, communication, psychophysical and operational aspects. To this end, over the past three years ERL has developed a radiology image and information management system (RIM)[1] that supports image acquisition, database management (integrates patient demographics, exam information, diagnostic reports from the Mallinckrodt radiology information system with image information) image servers (high-speed delivery of pixel data) and image-capable inquiry & display workstations as shown in Figure 1. RIM is now in active use as a tool for the investigation of the operational aspects of electronic radiology in the chest service and the emergency department.

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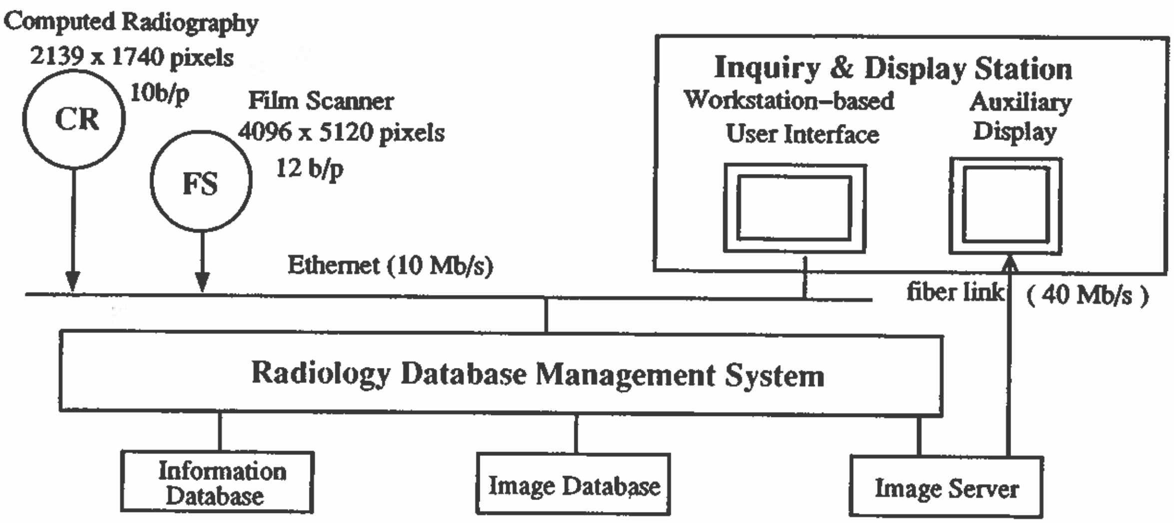


Figure 1. The Radiology Image and Information Manager (RIM) developed at the Mallinckrodt Institute of Radiology coordinates the flow of images and information between multiple scanners, databases, image servers and Inquiry & Display Stations. Although the figure shows a single Inquiry & Display Station, RIM supports many such stations of various kinds.

The Inquiry & Display Station[2] shown in Figure 1 appears as a standard client to RIM whether the station is in a physician's home, in a primary care physician's office, in the emergency department, in an ICU or in a radiology reading room. In each case, the station consists of a computer workstation and one or more auxiliary display screens that are specialized to radiographic images. The means of communication may be different and the resolution and number of display screens may be different, but the RIM interface is the same. In this paper we concentrate on the broadband medical doctor's workstation (MDWS) although other work in ERL has been carried out on a narrowband MDWS[3] and on a diagnostic workstation[4].

Applied Research Laboratory (ARL). The goal of ARL is the transfer of ideas developed by Washington University faculty to industry. ARL provides a conduit for these ideas that adds value by developing prototypes, carrying out demonstrations and conducting applied research. The objective of these activities is to bring the idea to a point that industry can judge its value as a product. We believe that ARL is an important mechanism for reducing the time-to-market of new technology.

Project Zeus, the design of a broadband network and its application on a university campus, is the first such activity for ARL. The Laboratory has taken the research results of one of us,[5,6]created the components of a prototype broadband network and connected these components together to demonstrate the potential of broadband networks in medical communication.

The prototype ATM switch shown in Figure 2 has 16 ports each transmitting 53 byte ATM[7] cells. A five byte header is used to route the cell through a binary switch fabric that is made up of two boards each containing 32 custom binary-switch chips. These boards are identical and function either as a copy network or as a routing network as determined by a programming pin on each chip. An example is shown in Figure 3. Four quad-port processor boards and a switch interface to a control processor complete the seven-board switch. Each switch requires a total of 144 custom chips of five different types, all developed at Washington University.

In the longer range, Project Zeus envisions the design, deployment and operation of a high-speed campus network based on the ATM broadband technology that has been developed in our laboratories over the last several years.[8] The network will support ubiquitous multimedia workstations with high-resolution graphics and video capabilities, opening up a wide range of new applications in research and education. When complete the network will support an aggregate throughput of hundreds of gigabits per second and will be designed to support port interfaces at up to 2.4 Gb/s. The prototype implementation uses 100 Mb/s port rates, with higher rates introduced as the demand arises and as economics permits. Interworking of the campus network with experiments in broadband public networking is anticipated and is central to our medical communications plans.

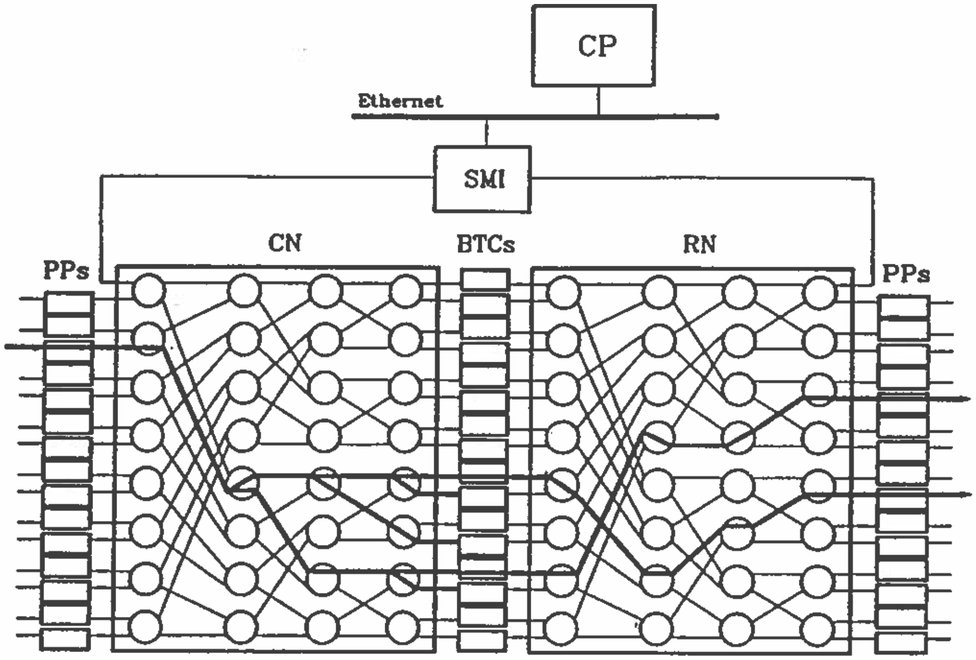


Figure 2. The Washington University prototype switch has 16 full-duplex ports each operating at 100 Mb/s and transmitting fixed-length Asynchronous Transfer Mode (ATM) packets (each packet is a 53 byte "cell") according to a standard international format. The switch architecture can be scaled up in both the number of ports and in port speed. In addition, the switch has the inherent capability to broadcast from one source to many destinations using the copy network (CN) and the broadcast translation circuits (BTCs). The routing network (RN) uses identical 2 x 2 switch elements (shown by the circles). The interfaces to the ATM links are through the port processors (PPs) and control is carried out through the switch module interface (SMI) and the control processor (CP).

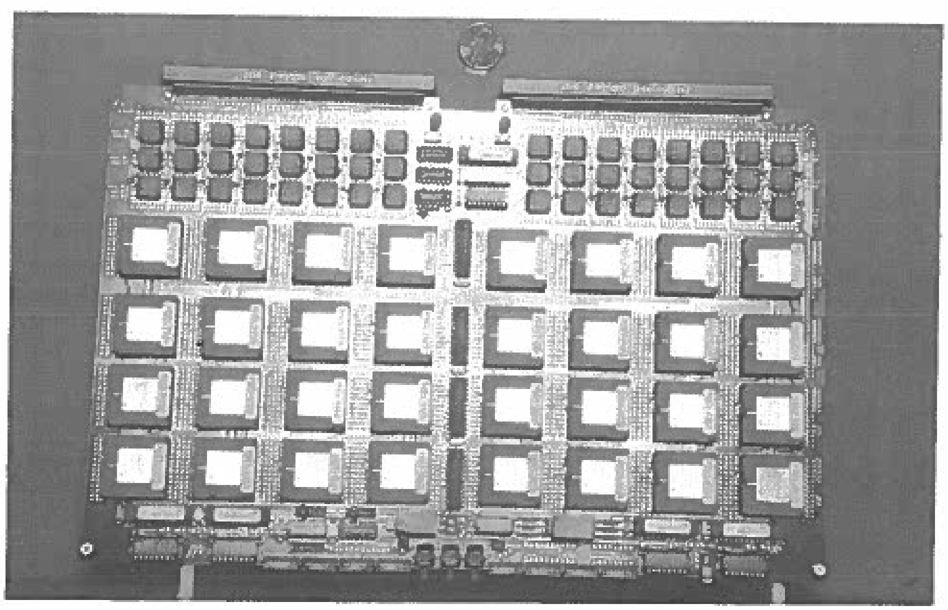


Figure 3. An example switch fabric board. Each of the custom integrated circuits shown is a 2 x 2 switch element capable of automatically directing individual ATM cells to their destination.

Office of the Network Coordinator (ONC). The Washington University campus network began in 1985, has grown to over 2000 nodes on our two campuses and is the most active of all the internet sites nationwide. The network serves ERL, ARL, Southwestern Bell and will be the operational unit supporting Project Zeus. ONC is responsible for the phased deployment of Zeus technology with the first phase getting underway this year. The demonstration described in this paper received both software and technical support from ONC.

Southwestern Bell. Through its subsidiaries, Southwestern Bell Telephone Company (SWBT) and Technology Resources, Inc. (TRI), Southwestern Bell has supported the development of both the ATM and the electronic radiography technology described in this paper. Furthermore, Southwestern Bell has provided the 200 miles of fiber that links the four sites in our metropolitan area demonstration network. Plans for a Southwestern Bell Broadband Image and Information Management (BIIM) testbed are underway that will provide the connectivity to other sites throughout the metropolitan area as our medical communications experiments proceed.

NEC-America. The construction of the prototype switches has been funded by NEC-America and, in addition, NEC engineers resident at Washington University have been members of the ARL team and have been instrumental in the design and construction of digital video and Ethernet subsystems to be used in our demonstrations.

2. MEDICAL DOCTOR'S WORKSTATION

The Medical Doctor's Workstation (MDWS) is an important example of the inquiry and display stations supported by RIM. It is intended to be used by primary care physicians in their offices and homes, by attending physicians in intensive care units and emergency departments and by subspecialty physicians wherever they practice. The design provides for presentation of the complete medical record including laboratory reports, electrocardiograms (both 12-lead recordings and real-time rhythm strips) and high-resolution medical images (both still images and video). In addition the MDWS has the capability to support video conferencing among several participants at scattered locations around a metropolitan area. Depending upon the area of application, the MDWS can be supported by a single auxiliary display in the primary care physician's office or by as many as four auxiliary displays in more demanding applications.

The MDWS is based on a NeXT workstation augmented by one or more Imlogix Image Display Stations (see Figure 4). The block diagram of the MDWS is shown in Figure 5 and includes two specially designed boards. The ATMizer shown in Figure 6 segments the information to be transmitted into ATM cells and, upon reception, reassembles the information into its original form. The multimedia board manages the video, audio and image data streams.

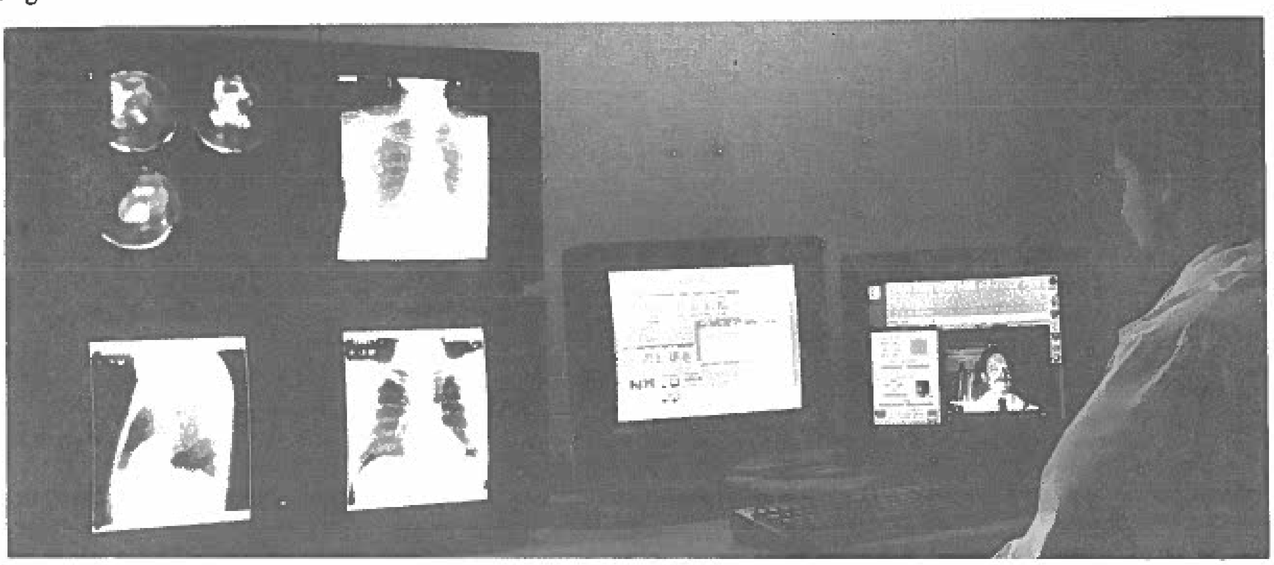


Figure 4. An MDWS as it might appear in the emergency department or in the office of a subspecialty physician. Here the four auxiliary displays can be used to present several images simultaneously as may often be required for more complex cases. Each auxiliary display has frame-rate zoom, pan and contrast adjustment.

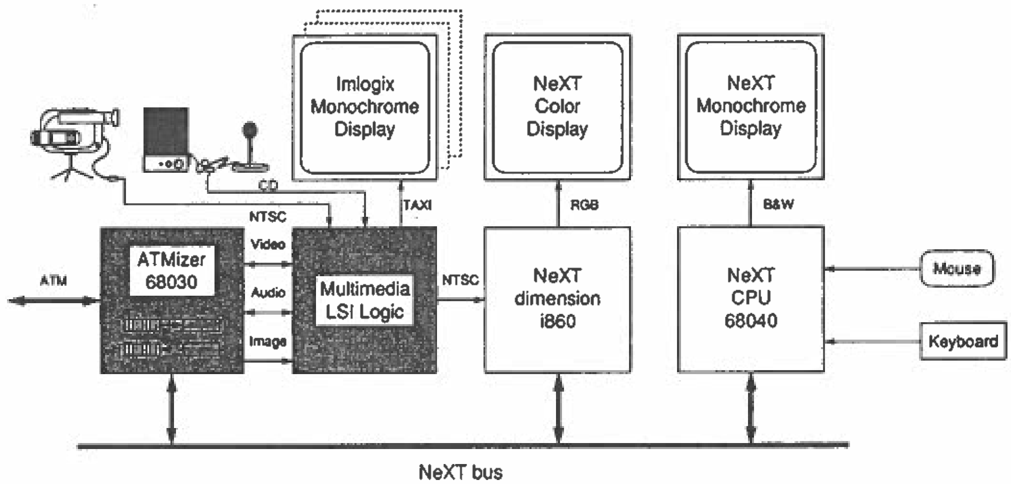


Figure 5. Block diagram of the medical doctor's workstation (MDWS). The shaded blocks were designed and constructed at Washington University. The remaining blocks are commercially available from NeXT and Imlogix. In the Multimedia board video, audio and image data streams are converted between their segmented form (ATM cells) and their continuous forms (NTSC, CD and TAXI, respectively).

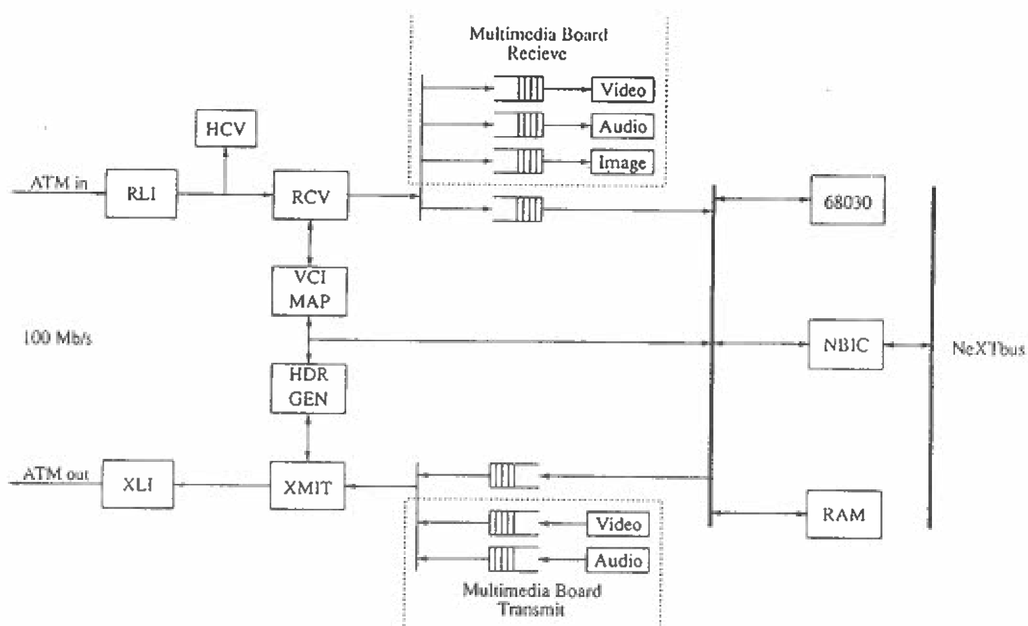


Figure 6. Block diagram of the ATMizer. The Receive and Transmit Link Interfaces (RTI and XLI) provide the interface between fiber (multimode) or copper (shielded twisted pair) links and the ATMizer logic. Many different virtual channels may be carried over a single ATM link, each distinguished by its own virtual channel identifier (VCI). The RCV (receive) and XMIT (transmit) blocks handle bytes in parallel, stripping or adding header (HDR GEN), verifying the header error check character (HCV) and routing (VCI MAP) or accepting data to or from the proper virtual channel (video, audio, image or embedded processor). The embedded processor is a Motorola 68030 which controls transmission over the NeXTbus via the NeXTbus interface chip (NBIC).

The multimedia board compresses outgoing video to about 1 bit/pixel according to the JPEG still image standard[9] at 30 frames per second. The multimedia board also reconstructs incoming compressed video data and displays the resultant high-quality images at a resolution of 640 x 480 pixels. The JPEG algorithm distributes reconstruction errors so that they are largely imperceptible to the eye. A synchronization buffer decouples the rate at which lines are displayed from the rate at which they are received. This choice eliminates concerns regarding the synchronization of scanning rates at the source and destination.

The audio channel on the multimedia board is compact disc (CD) quality and is sampled at 44.1 kHz in each of the two stereo channels. Perfect synchronization of the transmitting and receiving clocks is not required as a result of an algorithm that discards or duplicates occasional samples to make fine adjustments in the number of samples reproduced. This algorithm also adjusts for occasional lost cells.

Each 12-bit pixel is transmitted by the image channel in two bytes even though this format wastes 4 bits. The image display system cannot accept more than 2.5 Mpixels/s so no increase in performance can be obtained by packing two 12-bit pixels in three bytes (assuming link transmission rates of at least 40 Mb/s). Images are distributed to auxiliary displays over fiber links using a simple TAXI-based protocol proprietary to Imlogix.

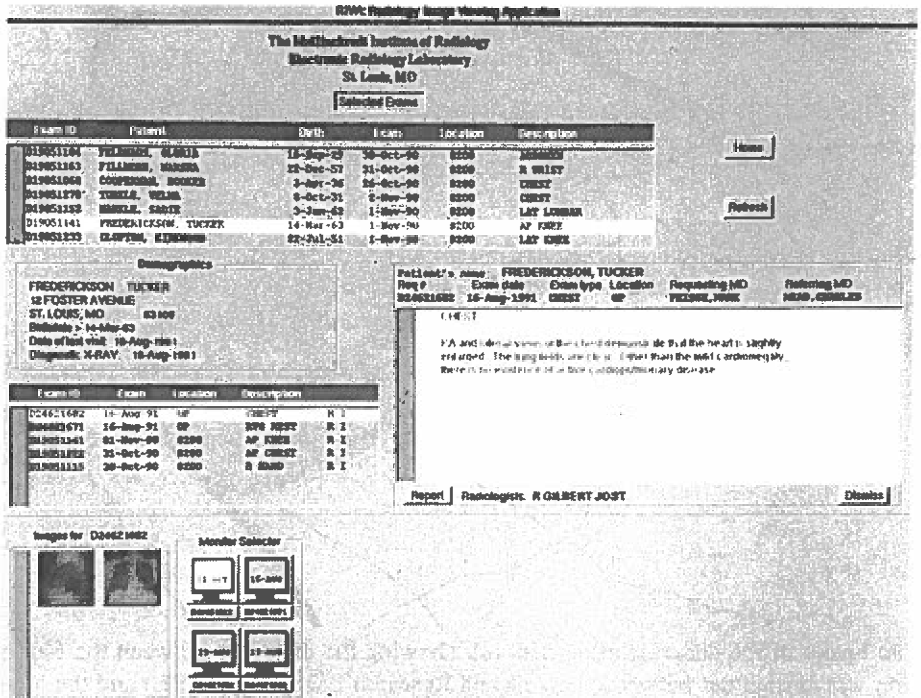
The MDWS can display video, high-resolution images and a variety of information from the medical record. Figure 7 shows a view of the two windowed displays on the MDWS.

3. DEMONSTRATION

A demonstration scenario was carried out for the purpose of showing our sponsors and others the potential of broadband medical communication in a metropolitan area. It was not a demonstration of a practical medical workstation. Much more work is necessary, but we believe the accomplishments to date show clearly the technical feasibility of this mode of communication.

Figure 8 shows the geographic layout of our demonstration network. The script of our scenario included a patient undergoing an exercise electrocardiogram at the Barnes Hospital stress lab near ERL, a primary care physician at ARL observing the patient via video and consulting with a cardiologist at ERL also via video. The locations of the two physicians were unrealistic and the entire scenario was fabricated, but it does demonstrate the ability of the technology to cover substantial distances within our community.

Not only was the primary care physician able to monitor the patient and converse with the ECG technician, but he was able to call up patient records, 12-lead electrocardiograms, a thallium scan shown as a cine loop and various other radiographic images stored on an image server at ERL. Furthermore, the primary care physician was able to consult with the cardiologist who also was able to view the same patient information from his MDWS. A future demonstration network is planned which will allow a more elaborate scenario and more realistic locations of the MDWSs. Figure 9 shows our plans for this network which include a number of MDWSs and diagnostic workstations[4] (DXWS).



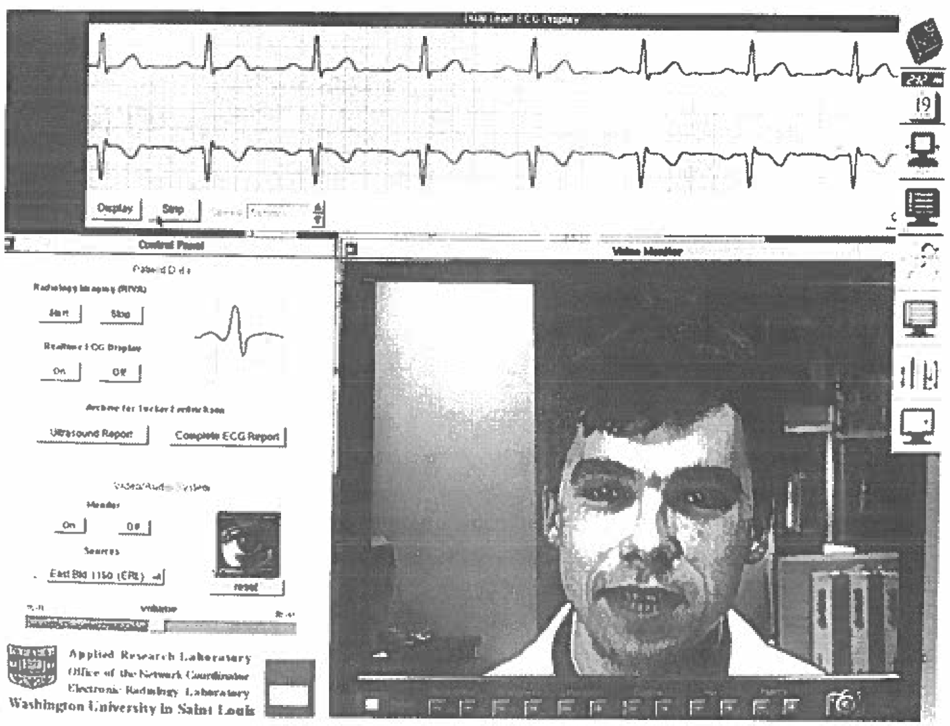


Figure 7. Examples of display screens on the MDWS. The top photograph shows patient information, a radiology report and icons of images and displays available on which to present them. The bottom photograph shows a real-time electrodcadiogram, a control panel and a video image from another MDWS.

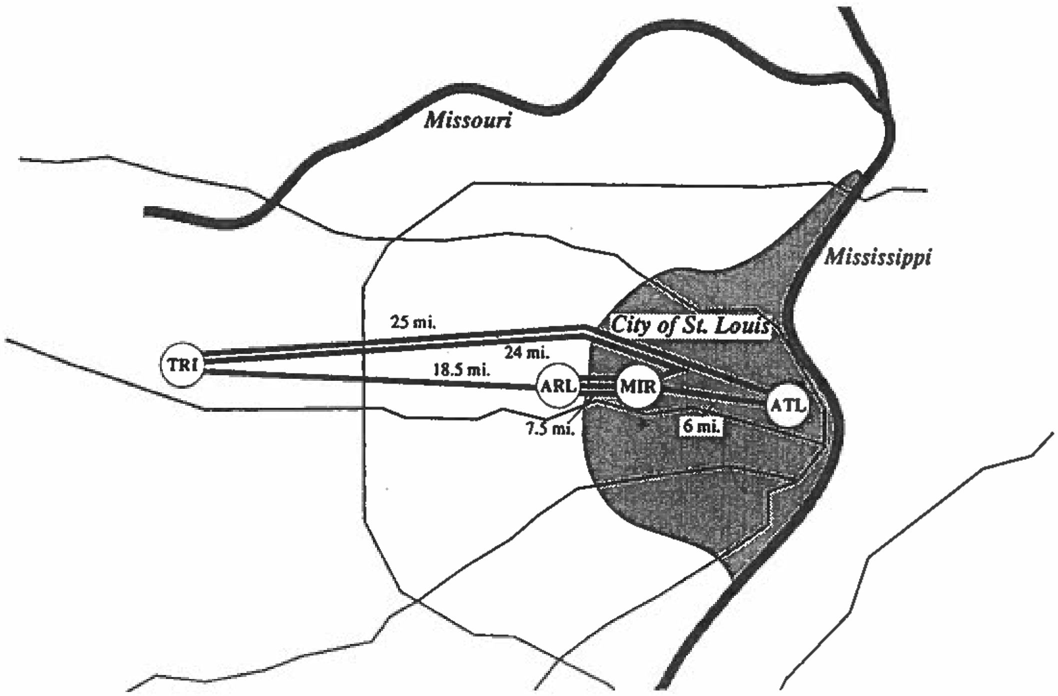


Figure 8. Geographic layout of the demonstration network showing the distances between the four connected sites. The MDWS demonstration was carried out between the Applied Research Laboratory (ARL) and the Mallinckrodt Institute of Radiology (MIR). Two other sites on the network are the Southwestern Bell Technology Resources, Inc. (TRI) and Advanced Technology Laboratory (ATL).

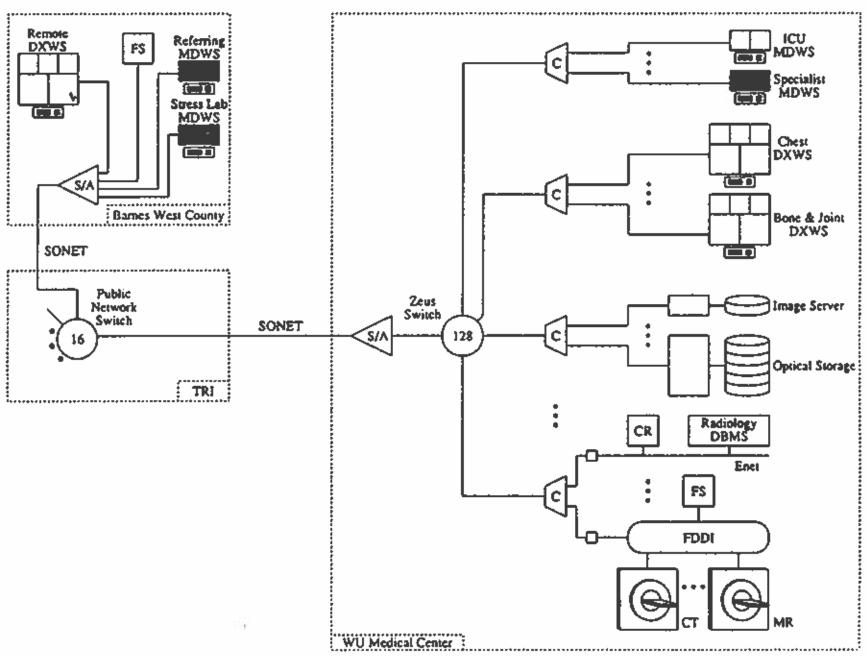


Figure 9. Demonstration network planned for the future with MDWSs (shaded) located at a patient laboratory at Barnes West County Hospital, the nearby office of a primary care physician and the office of a specialist at the Washington University Medical Center. The switch located at TRI is a proposed public network switch which will interwork with a future Zeus 128 port switch (128) and several traffic concentrators (C). A film scanner (FS), a CT scanner and an MR scanner are shown on an FDDI ring that is connected to the Zeus ATM network by a gateway. A SONET-to-ATM interface (S/A) is also shown linking the Zeus network to a public network testbed and a remote radiology site at Barnes West County Hospital.

4. PERFORMANCE AND OBSERVATIONS

A prototype of the MDWS first operated in August 1991. All of the features described in the previous section are now operational except that the video, audio and image channels have not yet been packaged together on one board. Furthermore, uncompressed digital video (99 Mb/s) rather than JPEG video, has been used to date. Informal assessments of the quality of the video and images in the prototype have been excellent (see Cox et al[2] for details on the image channel). The audio channel of the prototype has, however, been judged less satisfactory. The dynamic range and the sampling rate were comparable to voice-grade telephone audio because the prototype's audio has been carried along with the video. The multimedia board's implementation will utilize a separate channel achieving CD quality audio.

The response time for the presentation of images is good. Each request for an image makes a query to a database containing information about an image's size and its location on a high-speed image server. When returned this information is used by the MDWS to request an image directly from the image server. The image data is then served from a parallel disk array (Storage Concepts), segmented by a specialized unit we call the miniATMizer, transmitted over ATM links at about 40 Mb/s and reassembled for viewing on the Imlogix Display. Figure 10 shows a timing diagram that indicates typical performance for the delivery of a 1k x 1k pixel images. In general, such images are presented in under 2 seconds, while 2k x 2k images require about 4 seconds.

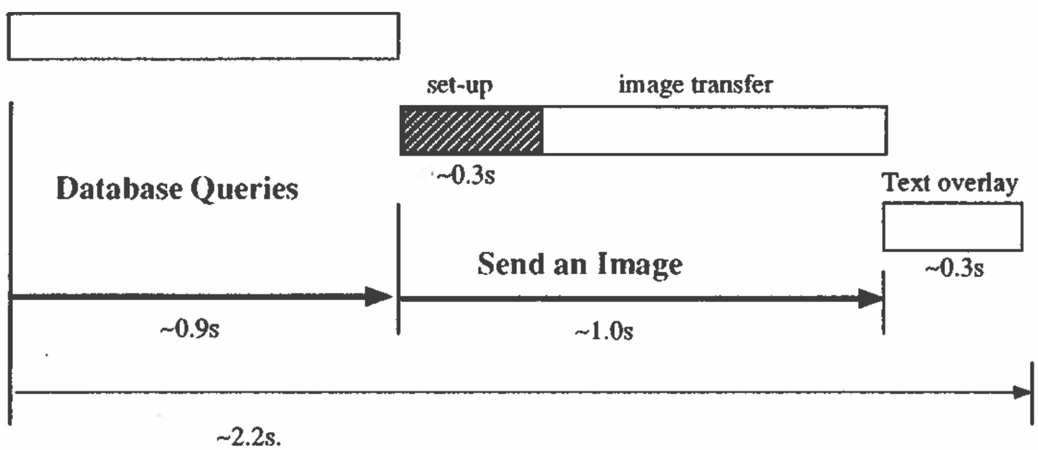


Figure 10. Timing diagram for the delivery of a 1k x 1k pixel image to the MDWS. This diagram includes a database request for information about the location of the image on a high-speed image server. This database search could be done in anticipation of the user's selection of an image to reduce the perceived latency of image delivery. The time associated with the delivery of pixels to the MDWS consists of an initial phase during which the MDWS communicates with the image server followed by the actual image transmission time. Text is delivered to the MDWS during a final phase resulting in the presentation, by way of an overlay, of an exam identifier and an exam time.

5. CONCLUSIONS

There is much yet to do, but the demonstration described has given us encouragement that the MDWS and Project Zeus can be used to investigate the future of medical communications. Our present demonstration uses software that is not very rich in the options available to the user. Although the underlying capabilities are present in the Zeus network technology and the MDWS, more application software is needed to fully exploit those capabilities. We have already found that Interface Builder in NeXTstep is extremely valuable in the rapid creation of these user interfaces.

The ATMizer board also will require considerable software development for both the NeXT processor and the embedded processor. The integration of functions on the multimedia board is not complete as of February, 1992. The video channel is being debugged and audio and image channels have yet to be integrated. We expect these steps to be completed in the next few months.

We have had the opportunity to demonstrate the MDWS and the technology of Project Zeus to many visitors over the last six months. It has generated much interest because of the rapidly mounting enthusiasm throughout industry for ATM broadband communication, but also because of the potential for new approaches to the practice of medicine exhibited by the MDWS.

6. ACKNOWLEDGMENTS

We would like to acknowledge the generous support for this project provided by Southwestern Bell and NEC-America. The development of RIM and many aspects of the MDWS were funded by the Mallinckrodt Institute of Radiology through the continued support of its Director, Ronald Evens, M.D. Digital Equipment, Eastman Kodak and Imlogix provided equipment and technical support. We wish to give special thanks to Tim David, Greg Hassen and Tom Monsees of Imlogix for help in the testing and integration of the image server. Students and staff who have worked on the project during the past year were Deepak Bhargava, Wei Chen, Pete Flugstad, Jason Fritts, Brian Gottlieb, Tom Leith, Dick Olson, Bob Whitman, Steve Wimmer, David Zar and the entire staff of the Applied Research Laboratory.

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