The development of an ATM-based Radiology Consultation WorkStation for radiotherapy treatment planning

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ABSTRACT

The Radiology Consultation WorkStation (RCWS) is a multimedia, medical imaging workstation being developed for use in an electronic radiology environment, utilizing a prototype Asynchronous Transfer Mode (ATM) telemedicine network, in support of radiotherapy treatment planning. A radiation oncologist in the Radiation Oncology Department, and a radiologist in the Diagnostic Radiology Department, will be able to consult, utilizing high-quality audio/video channels and high-resolution medical image displays, prior to the design of a treatment plan. Organ and lesion contouring is performed via a shared-cursor feature, in a consultation mode, allowing medical specialists to fully interact during the identification and delineation of lesions and other features.

Keywords: Telemedicine, Multimedia System, ATM Network, Medical Consultation, Medical Imaging

1. INTRODUCTION

The development of the National Research and Education Network (NREN) was one of the five major components mandated under the Federal High Performance Computing and Communications (HPCC) Program, by the High Performance Computing Act of 1991. The Department of Health and Human Services (DHHS) through the National

Institutes of Health (NIH) had the following two charges as outlined in the December 1992 NREN Program Report to Congress: (1) "Provide for medical mission NREN facilities deployment as part of the coordinated Interagency Interim NREN Program"; and (2) "Provide for applications-based gigabit research."

Recently the National Science and Technology Council (NSTC), through its Committee on Computing, Information, and Communications (CCIC), has developed a plan consisting of five Program Component Areas (PCAs) as a broader follow-on to the original HPCC Program. Health Care and Biomedical Imaging is one of the target applications that cuts across virtually all of the five PCAs, but is specifically included in the High End Computing and Computation Area, and the Large Scale Networking Area.

As a participant in the national CIC Research and Development Program, the Division of Computer Research and Technology (DCRT), in collaboration with the Diagnostic Radiology Department of the Clinical Center, and the Radiation Oncology Branch (ROB) of the National Cancer Institute (NCI), are implementing, within their facilities, a prototype high-speed network capable of supporting multimedia communication for medical research and education.

Special-purpose medical workstations are being deployed as nodes to the prototype high-speed network in selected domains within the NIH environment, and these workstations are specifically configured to support the radiotherapy treatment planning goals of the NCI ROB. The RCWS provides for the high-resolution display of medical images and includes a sophisticated mechanism to allow remote consultations between medical specialists. Audio and video are transported continuously through a 155 Mbits/sec (OC-3) ATM link connecting all sites. Two high-resolution Dome/Megascan monochrome display subsystems function as Electronic View Boxes for display of 14 X 17 inch "electronic films."

ATM-based, multimedia software which supports multi-site voice/video conferencing, was developed by the Computer Science Department at the Washington University in St. Louis, and utilized during the initial development stage of this project. Local efforts have resulted in the development of a preliminary version of a customized voice/video conferencing facility, which is specifically tailored to our medical multimedia application.

High-speed networking combined with multimedia technology, in the form of a prototype ATM-based radiology workstation with diagnostic quality imaging, is currently attainable and can assist effective patient therapy. The Quality of Service (QoS) guarantees available with native ATM service make worst-case response times a function of such factors as file server access times and operating system latency, instead of factors related to the high-speed ATM network.

This infrastructure is also designed to support high-performance radiotherapy treatment planning, which is a separate collaborative effort between the DCRT's Computational Bioscience and Engineering Laboratory (CBEL) and the NCI ROB. The DCRT's IBM

SP2 Supercomputer is planned to be utilized to apply the power of parallel computing methodology to the implementation of the computationally intensive calculations required in radiotherapy treatment planning.

The NCI ROB develops radiotherapy treatment plans which involve the utilization of high-energy X-ray beams as the treatment modality. For more than a decade, these plans were developed utilizing a DEC VAX minicomputer, with the required CT scans arriving in the department via sheet film or magnetic tape. A Macintosh-based radiotherapy treatment planning system has been under development by the ROB staff for many years[1,2]. This user-friendly system possesses an excellent human interface, and produces treatment plans in a much shorter time than its predecessor. The addition of the RCWS and ATM network technology offers possibilities for the development of distributed medical consultations and collaborations, throughout the NIH campus, and beyond.

2. METHODS

The DCRT proposed the use of ATM technology as the basis for the prototype high-speed network. The basic approach was to utilize the newest versions of the evolving hardware and software standards, as well as existing application software, whenever possible. This allows us to achieve a rapid and successful implementation of our prototype network and multimedia workstation environment.

With ATM technology, all users have the same high-speed data path between nodes regardless of how many active nodes are on the network at any given time. The ATM channel bandwidth is typically 155 Mb/s (OC-3) or 622 Mb/s (OC-12). This significantly outperforms the popular point-to-point fiber optic transmission services available from the telephone companies: 1.5 Mb/s (T1) or 45 Mb/s (T3).

The Department of Computer Science at the Washington University in St. Louis (WUSTL), and the Diagnostic Division of the Mallinckrodt Institute of Radiology, have previously co-developed several prototype medical workstations with custom ATM interfaces[3], which include multimedia capability and medium-resolution medical image displays. These workstations allow alphanumeric data, graphical data, real-time audio/video data, as well as X-ray, US, CT or MRI images, to be distributed using a prototype ATM network and a campus-wide Ethernet network. The WUSTL ATM switch development effort and the medical workstation design activity are known collectively as Project Zeus[4]. This powerful combination suggests that meaningful real-time consultation sessions can be performed in a medical environment.

The DCRT decided to utilize two developments of the WUSTL, which are both available commercially, as a starting point for our project infrastructure. The first of these is a novel, parallel architecture ATM switching technology, known as Fast Matrix Architecture[4], which was designed and developed in the Department of Computer

Science, and licensed to SynOptics Communications, Inc. (Bay Networks, Inc.) The second is the concept of a specialized MultiMedia eXplorer (MMX) ATM interface[5], which was developed within the Department of Computer Science, and licensed to STS Technologies, Inc. The MMX allows bi-directional signal encoding and transmission of voice and video ATM cells, in the native ATM mode, without encapsulation in any higher-layer network protocol, and without execution overhead on the RCWS's processor.

The DCRT arranged to utilize the ATM multimedia conferencing software, known as VideoExchange[6], that was developed in the WUSTL Department of Computer Science. This application suite is utilized to configure and control the ATM switch and the MMX. The use of VideoExchange initially saved many person-years of training and programming time, and has allowed the DCRT to achieve a rapid and successful startup of the prototype network and multimedia workstation environment.

Ultimately, the DCRT developed specialized paradigms for the distribution and control of multipoint audio/video data streams. The initial version of the DCRT-developed audio/video teleconferencing application, known as Rockville (the NIH is located at 9000 Rockville Pike), is currently being evaluated. Each RCWS includes a Canon VC-C1 Communications Camera, which contains an integral pan/tilt/zoom mount. Software to allow remote control of this camera, in a multi-user conference environment, was developed and integrated into our Rockville teleconferencing application.

An Electronic Viewbox Environment (EVE) medical imaging application, which was developed at the DCRT, provides the capability necessary for consultation participants, distributed at distant locations, to share ownership of a stack of CT scans. EVE initially handles image distribution to all invited RCWS nodes. The conference participants then jointly control the image viewing sequence, the Window/Level adjustments, and the region-of-interest contouring. A shared-cursor paradigm allows each participant to view the other participants' uniquely-shaped cursors during discussions of features-of-interest in the image stack. All control functions are carried-out simultaneously, in real-time, at all invited RCWS nodes.

3. RESULTS

The implementation of the high-speed prototype ATM network and the ATM-compatible multimedia medical workstation nodes, known as the RCWS, was planned to be carried-out in phases, as a series of demonstration tasks, and was intended to explore the extent of a number of applications in the medical environment. The specific tasks selected for implementation directly followed from current high-speed data communication requirements within the NCI ROB environment, and the NIH campus in general.

PHASE 1	• Install two ATM Switches and configure a Prototype High-Speed Network • Design, Configure and Install four Radiology Consultation WorkStations • Develop Electronic Viewbox Environment with Shared-Cursor Control, Image Selection, Window/Level, and Contour Tracing Capability • Develop Rockville Audio/Video/Camera Control Environment
PHASE 2	• Install ATM Switch Connection to the existing NCI ROB Macintosh-based Radiotherapy Treatment Planning System • Install two ATM Switch Connections to the IBM SP2 Supercomputer • Install Sheet Film Digitizer and Image Server at the NCI ROB

The first Phase is complete except for final system testing and evaluation. The fourth RCWS is under construction and has not yet been deployed. The second Phase is currently underway, with all components on-site, and with implementation and software configuration still in progress.

The RCWS is a multimedia, medical-imaging workstation which will be appropriately designed for use in an electronic radiology environment. The block diagram of an RCWS is shown in Figure 1. The RCWS is composed of eight principal components: 1) Scientific-class Workstation, 2) Dual-Screen Medical Image Display System, 3) ATM Multimedia Interface, 4) Servo-controlled Video Camera, 5) Video Monitor, 6) Stereo/Monaural Microphone(s), 7) Stereo Speakers, and 8) Trackball.

A microphone and audio speakers allow bi-directional voice communication, while the S-Video camera and monitor provide video capability. The MMX ATM multimedia interface provides bi-directional, hardware voice/video encoding, JPEG video compression, as well as symmetrical decompression and decoding at the destination. The MMX is interposed between the ATM switch and an ATM network interface card in the Sun workstation. ATM cells containing image data or environment synchronization data, encapsulated as TCP/IP packets, pass bi-directionally through the MMX, to and from the Sun workstation.

The Rockville Teleconferencing Application controls the routing of the S-Video and CD-quality audio ATM cells during the conference session. Rockville sets up and tears down connections in the ATM switches, dynamically, throughout the course of the conference. The message passing paradigm utilized in the EVE Medical Imaging Application, which is discussed later, is utilized by Rockville in order to send stable, non-conflicting commands to all MMXs. Rockville also contains a Camera Control Application which allows the adjustment of the viewing angle and zoom lens settings on the servo-controlled S-Video camera.

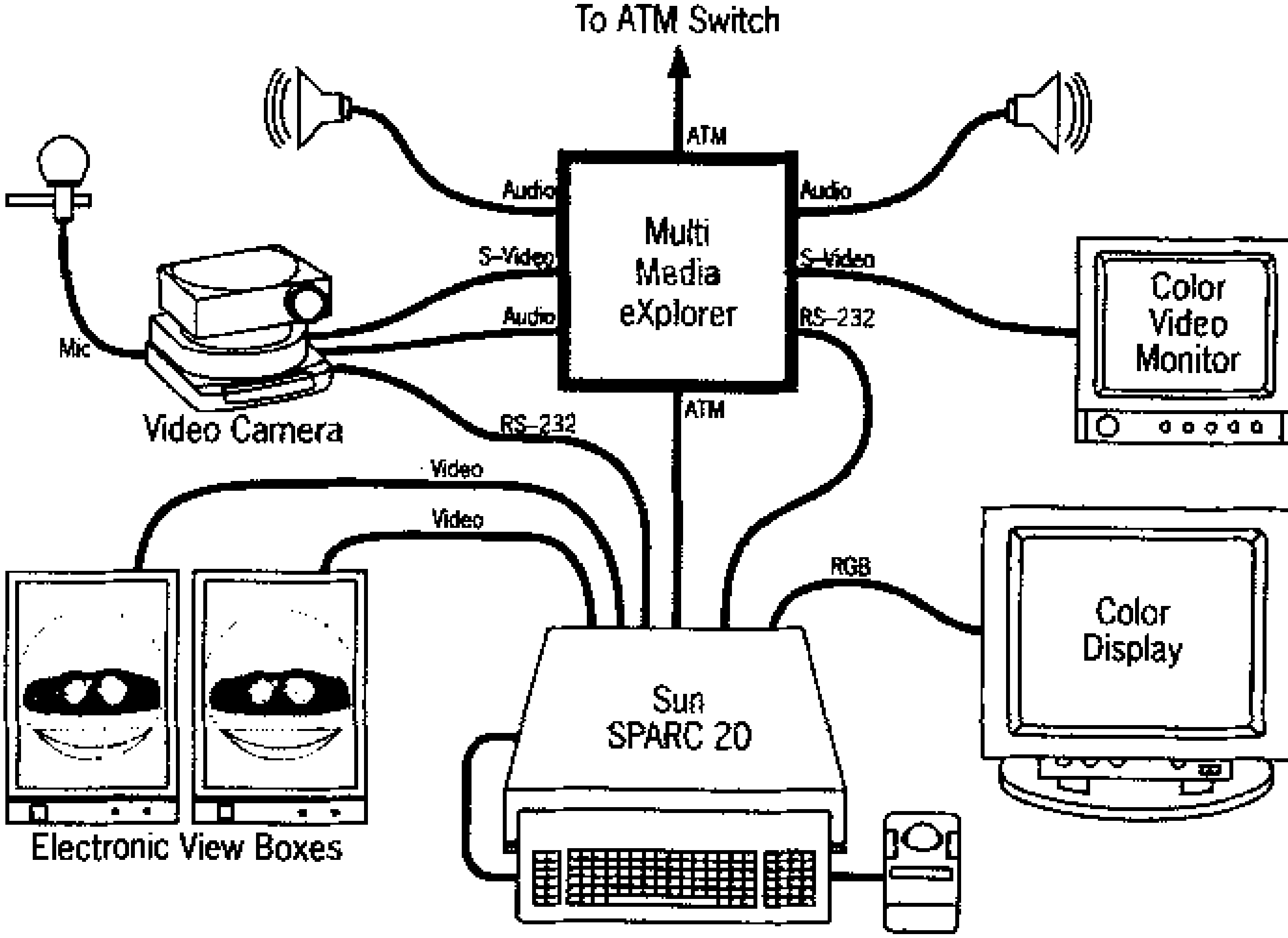

FIGURE 1: DIAGRAM OF THE RADIOLOGY CONSULTATION WORKSTATION

The "Owner" of the image set to be distributed for consultation is assigned the role of "Host", and initiates the consultation session, via a pull-down menu. The "Study" to be selected for the conference is identified, and the participants to be "Invited" to the conference are also selected. As participants "Sign-On" for the conference, Rockville assures that each is connected to the audio and video sources originating at the RCWS node supporting the conference "Host". The "Podium" is passed to participants and they become the "Active Participant", as they click on the Podium button in the Camera Control graphical user interface, shown in Figure 2. This interface also contains the controls used to pan and tilt the camera mount, and zoom the camera lens, in order to locate a participant within the video camera's field of view.

The EVE Medical Imaging Application provides for the transmission of the image-stack to the RCWS processor's main memory, after the RCWS signs-on to the conference. This application then provides for the synchronization of the images displayed on the pair of high-resolution monochrome displays located at each RCWS node. In addition, EVE controls the Viewbox graphical user interface, shown in Figure 3, and provides the multiple, shared-cursor service that is central to the telemedicine conference environment. Each RCWS is assigned an independent cursor shape as it joins the conference (six different cursor shapes are currently defined). Each participant may choose to transmit their cursor to all other participants as the conference proceeds, in order to identify a feature in the image being discussed, or for any other illustrative purpose. As a result, it is possible to have all cursors visible on all RCWS viewboxes at the same time.

All CT slice images in a study are transmitted to all consultation sites during conference initialization, as each participant joins the conference. These images are loaded into local system memory in each RCWS, within several seconds, as a result of distribution via the ATM network. Afterwards, the workstations maintain synchronous image display, user-selected as either a 3 by 4 format, or single-slice 3X enlargement on the right hand electronic viewbox, for organ and lesion contouring. Contouring is performed on the 3X enlargement at a resolution of 1536 X 1536 pixels, which is significantly higher resolution than the 640 X 640 pixel resolution of the display in the Macintosh-based Treatment Planning System (PowerTPS) at the ROB.

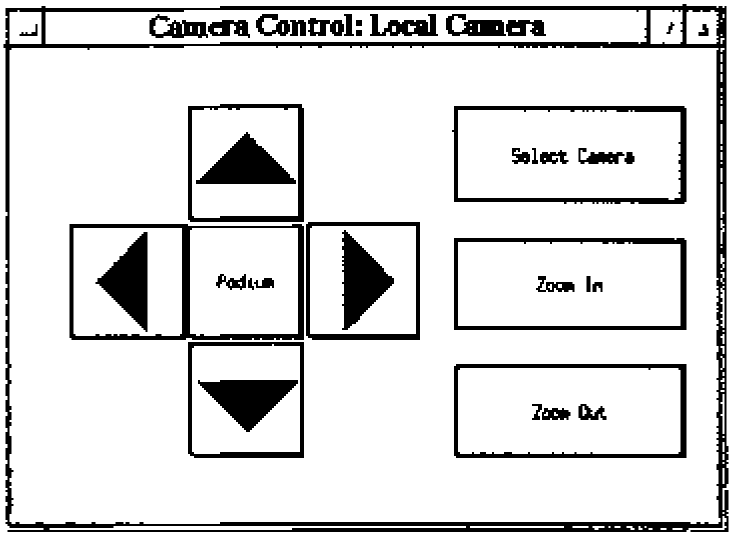

FIGURE 2: CAMERA CONTROL GRAPHICAL USER INTERFACE

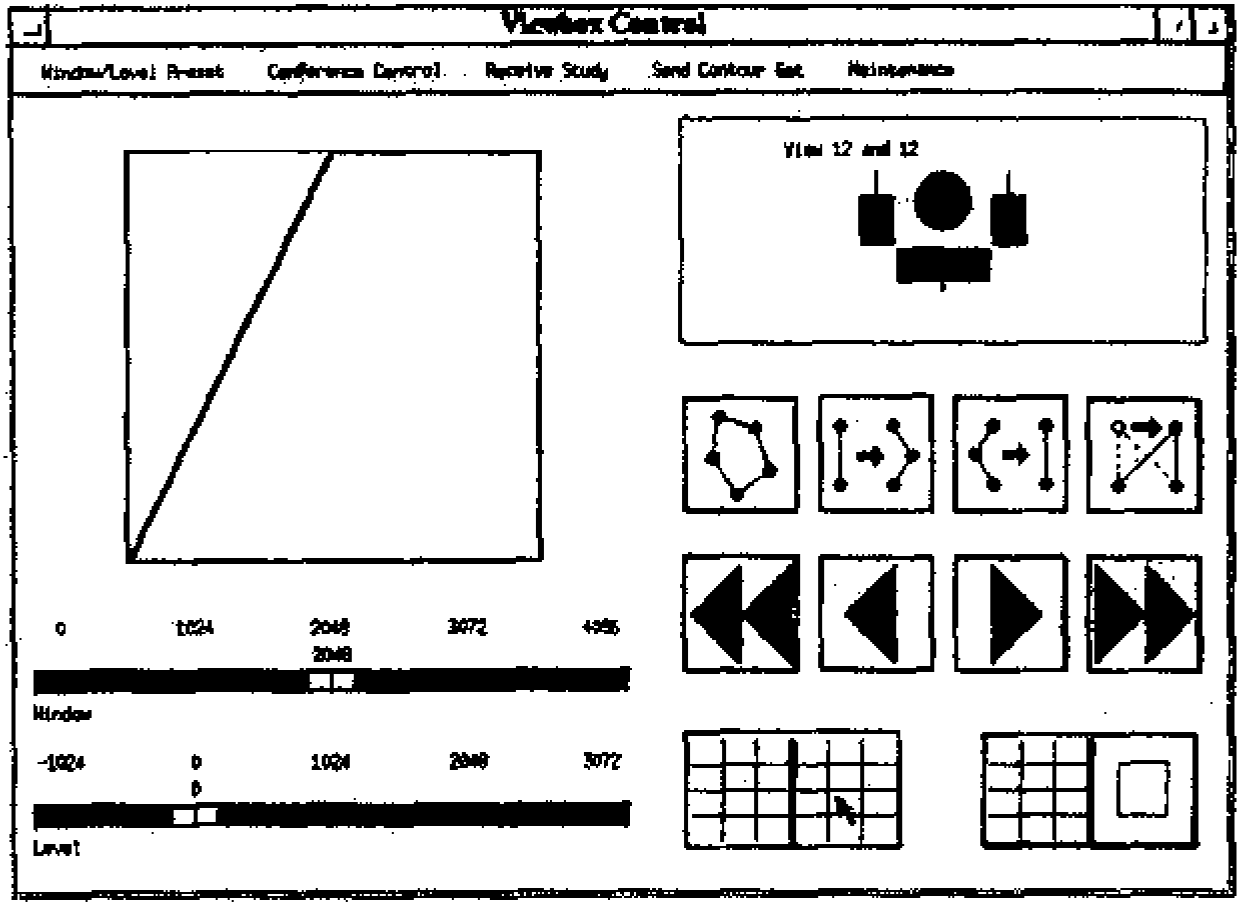

FIGURE 3: VIEWBOX GRAPHICAL USER INTERFACE

The 3X enlargement is performed by simple pixel replication, which is the preference of the ROB Staff, so that image pixels are not modified, and this procedure is performed in real-time. In addition, however, a popular bicubic spline interpolation routine, that is routinely used at the DCRT, has been ported to the RCWS and its execution speed on test data has been evaluated. Unfortunately, the results indicate an execution time of approximately 20 seconds to enlarge a single 512 X 512 pixel image, which is too slow for repeated use in a real-time environment.

Participants may sequentially or randomly sort through the stack of CT images utilizing four shared controls, which are similar in function to those on a cassette tape recorder.

Similarly, Window/Level adjustments, which may be performed at any workstation, are transmitted in real-time to all consultation sites. Three modes of Window/Level control have been implemented: Slider Control, Trackball Control, and Presets via a pull-down menu.

Organ and lesion contouring is also performed through the Viewbox graphical user interface. The contoured regions-of-interest are also transmitted, and displayed in real-time at all consultation sites, as contouring proceeds. Four buttons allow the conference participants to select either Trace Contour, Add Node, Delete Node, or Move Node functions. When any of these four trace function buttons are actuated, the EVE environment prevents other conference participants from interfering with these functions by simultaneously attempting to activate any of them, from another RCWS node. During contouring, only the Window/Level adjustment may be modified from all RCWS nodes, simultaneously.

A simple, continuously updating help feature is shown in the upper right hand corner of the Viewbox graphical user interface. It was modeled after the help capability found in xfig, a popular menu-driven structured drawing tool utilized in UNIX environments. In our implementation, a trackball icon contains three dynamic label lines. Text strings are pasted into these invisible label lines, as the cursor is moved around within the X Windows on either the Sun workstation's color monitor or the two high-resolution electronic viewboxes. The text indicates the result of clicking on any of the three trackball buttons, at that particular trackball-controlled cursor position. In Figure 3, a trackball-controlled cursor is positioned over a button at the bottom right, which selects 12 slice viewing mode on both of the electronic viewboxes. As a result, the trackball icon shows a label next to the leftmost trackball button which states "View 12 and 12".

EVE is implemented as a small collection of discrete UNIX processes on each RCWS. Several of the processes are responsible for the control of a single physical device, such as the electronic viewboxes, the video camera, or the multimedia interface. Others control the Viewbox graphical user interface and manage the RCWS's local image cache. Also running on each RCWS is a process known as the Dispatcher. The Dispatcher has two important functions: to coordinate the operations of the processes running on the local RCWS, and to act as a communication agent on behalf of the local RCWS for coordination with other RCWSs participating in the conference.

A Server process runs on a conference management workstation and is responsible for relaying messages between the RCWSs. The EVE Server only communicates with the Dispatcher on each RCWS. The Dispatcher is responsible for forwarding messages from the Server to its local EVE processes and vice-versa. This hierarchical message-passing architecture minimizes the total number of interprocess communication pathways.

All of the above processes use a simple, efficient message-passing library designed specifically for EVE. This library allows processes to exchange messages of various formats, containing a variety of data types. The Dispatcher and EVE Server route messages through the message-passing hierarchy based on the messages' source or content. For example, when a user transmits a trackball pointer from one the viewboxes, that Viewbox process sends a trackball motion message to its local Dispatcher. The Dispatcher relays the message to the EVE Server, which then broadcasts the message to the Dispatchers of each RCWS in the conference (including the originating RCWS.) Each of those Dispatchers then relays the message to the appropriate local viewbox; the viewbox then displays the remote user's trackball pointer.

A critical aspect of EVE's design is the avoidance of race conditions that lead to situations where the display environments at the conference sites become unsynchronized. For example, consider the simple problem of responding to a user's request to change the displayed Window/Level to new values. A naive implementation might first update the local display at the user's RCWS, then send an environment update message to the remote RCWSs, advising them to make the same change. However, if two conference participants request new Window/Level values at the same time, both will momentarily see their own Window/Level selection. Then, each will instead see the Window/Level selected by their partner, after their partner's environment update message arrives. The result is an inconsistent state - the two participants are seeing different displays.

Race conditions such as this are much more likely to occur when the conference participants are connected by a high-latency wide-area network. EVE avoids these race conditions by sending all user requests to the EVE Server without acting on the request locally; the server receives and serializes the requests, then broadcasts them to the conference participants in the same order. Thus, when a user requests a change of the environment, the display is not updated until the request has been sent to and received back from the Server. Receiving the request from the Server implies that all other conference participants are receiving the same request, and the consistency of the conference-wide environment is assured.

The block diagram of the NIH Prototype ATM Network is shown in Figure 4. This ATM network provides connectivity between the RCWS nodes, the Consultation Server, the ROB PowerMac TPS, the Sheet Film Digitizer, and the IBM SP2 Supercomputer. The contoured regions-of-interest are available for transmission, via the ATM Network, to the PowerTPS at the ROB, after they are completed for all images in the stack.

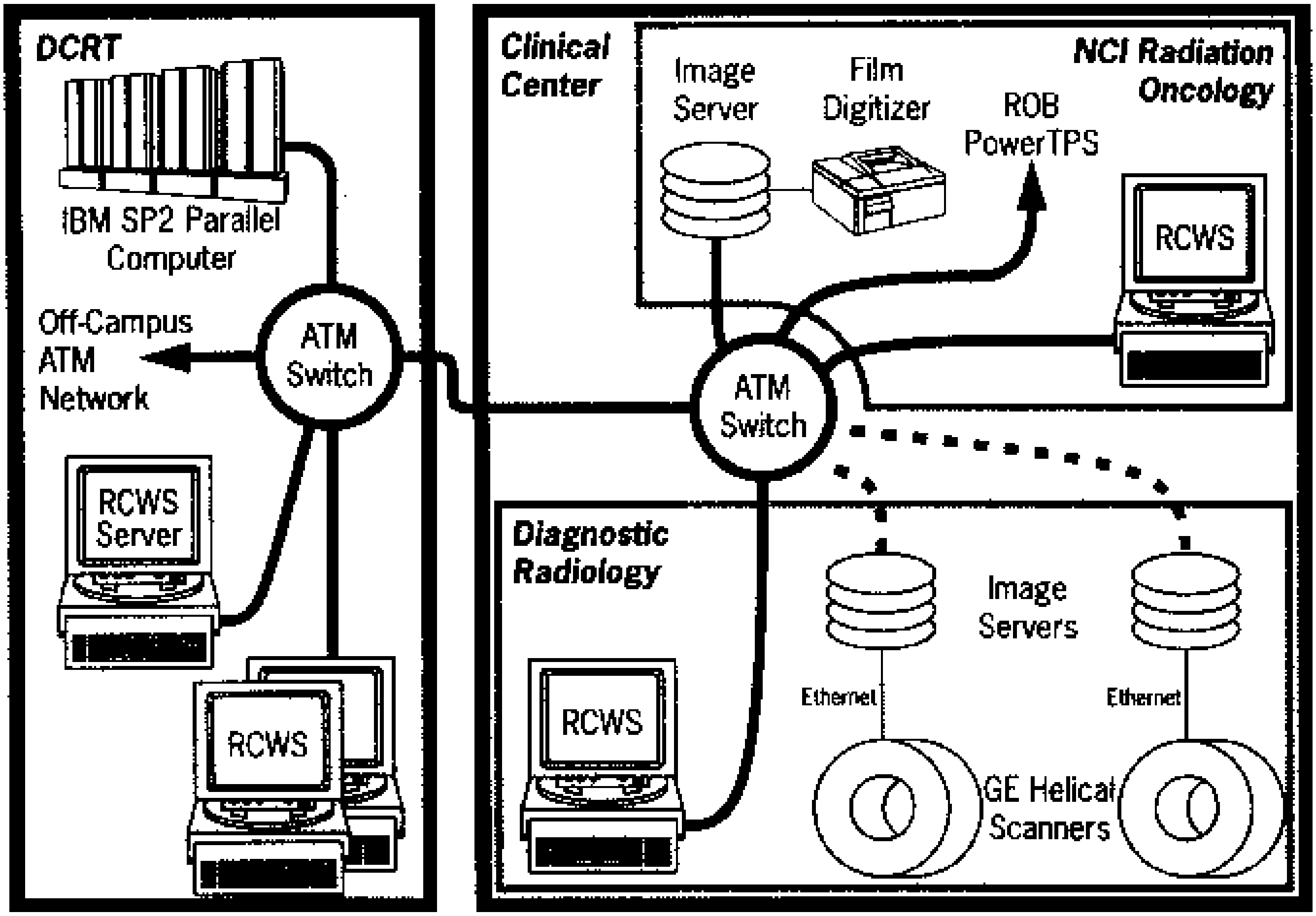

FIGURE 4: DIAGRAM OF THE NIH PROTOTYPE ATM NETWORK

Further extensive processing on the ROB PowerTPS will utilize Beam Placement Data and Wedge/Block Data, to produce Iso-Dose Curves, which together, define the treatment plan. The Sheet Film Digitizer is to be utilized to send Simulation Films and Port Films from the ROB facilities to the members of the consultation session. Additionally, computationally intensive calculations may be off-loaded from the PowerTPS to the IBM SP2 Supercomputer at the DCRT central computer facility.

The hardware and software components of an RCWS, the Prototype ATM Network, and some additional equipment are described in the Appendix. These items are readily available from commercial sources, with the exception of the Electronic Viewbox Environment and the Rockville Audio/Video/Camera Control Software, which were developed at the NIH.

4. DISCUSSION

There is a major fundamental difference between the combination of EVE electronic viewbox and Rockville audio/video control paradigms, and other multimedia conferencing environments (including the VideoExchange audio/video control software developed at the WUSTL). The unique architecture of our environment includes the concept of synchronization vectors, which are transmitted from each RCWS to a central conference server, as any participant initiates selections via the two central graphical user interfaces. The central server contains a specialized message passing interface developed specifically for this project, and designed to maintain synchronization between all RCWS nodes participating in a conference.

Messages are distributed from the message passing interface to the Sun workstations in all RCWS nodes, and through the ATM network to all switches. Within the Sun workstations, synchronization vectors are separated into commands specific for the graphical user interfaces, the image loading and Window/Level modules, the MMX control interface, and the camera servo control module. An appropriate synchronization vector must return to the originating RCWS node before any action is seen by the operator of this RCWS. Within the ATM switches, permanent virtual connections are set up and torn down as necessary to route the required audio and video ATM cells to the appropriate RCWS nodes, so that they may be extracted from the cell stream within the MMX, and delivered to the local S-Video monitor and stereo audio speakers.

The RCWS configuration is currently optimized with a palette of features designed to serve the radiotherapy treatment planning community. It can easily be upgraded to provide additional capability for mammography screening, nuclear medicine procedures, cardiac color Doppler studies, oropharyngeal/laryngeal examinations, and dental examinations, to name a few. In fact, any video-based physical examination can be performed, utilizing the RCWS in conjunction with a microscope, ophthalmoscope, otoscope, laryngoscope, or any endoscope with attached S-Video camera or internal image-forming optics and CCD array.

Utilization of an S-VHS cassette player as the video signal source, instead of the S-Video camera, has shown that it is feasible for recorded dynamic video studies to be transmitted through one RCWS to another system. It is, therefore, possible to produce diagnostic-quality video images in either real-time from a live video camera, or reproduced from a S-VHS tape, at 30 frames per second, and to transmit these images through an RCWS and over the NIH prototype ATM network.

The RCWS makes extensive use of the TCP/IP protocol suite. Using TCP/IP over ATM networks is not entirely straightforward, and a number of issues were carefully considered to avoid potential pitfalls. At the ATM layer, drivers and software, on both the host and the switch, were selected to conform to compatible signaling standards. At the IP layer, there are two different IP-over-ATM standards from which to choose, both with strengths and weaknesses. There are also a number of serious performance issues to be considered; some problems are inherent to running TCP/IP at high data-rates, and some are inherent to ATM itself. Each of these issues must also be considered in conjunction with the realities of which technologies are immediately available.

The first IP-over-ATM standard, "Classical IP and ARP over ATM," was published by the Internet Engineering Task Force[7] in RFC 1577. This January 1994 standard (usually referred to as "CIP") specifies a method of using IP over ATM networks, including an encapsulation of IP datagrams into an ATM Adaptation Layer (AAL) 5 data frame, and the operation of an Address Resolution Protocol (ARP) Client and Server to resolve IP addresses into ATM addresses.

The second standard, "LAN Emulation", was published by the ATM Forum[8]. This January 1995 standard (usually referred to as "LANE") is a different, more recent standard which specifies protocols and methods for generically using ATM as a datalink-layer LAN. LANE has two variations: one to emulate Ethernet and one to emulate Token-Ring networks. Similar to CIP, LANE defines standards for encapsulating data that comes from higher-up in the OSI stack, into AAL5 data frames. Unlike CIP, LANE provides additional features that emulate traditional LANs.

The intent of LANE is to allow every protocol that has traditionally been implemented on top of Ethernet and Token Ring to be easily implementable over ATM. IP is one of those protocols, so LANE obviates the need for CIP. Additionally, since LANE is designed to generically replace Ethernet and Token Ring, it has the advantage of supporting every other current and future OSI layer 3 network protocol, such as Novell's IPX, Apple's AppleTalk and AppleShare, and dozens of others.

Clearly, the motivations for CIP and LANE were different. CIP came from the Internet community, whose interest is promoting IP and thus developed a method for using IP over ATM. The ATM Forum, on the other hand, is interested in promoting ATM and therefore developed a method for using ATM as a LAN, on which all higher-layer legacy protocols can be transparently deployed. LANE is not, and does not claim to be, anything other than a local-area networking protocol, and thus will probably never be used in globally connected networks such as the Internet. However, depending on the implementation, it may be appropriate for enterprise-wide (1,000's of machines) deployment.

One important issue, and the issue that initiated our investigation of these alternatives, is an implementation issue rather than a standards issue. At the time when it was necessary to finalize a decision with regard to ATM Network Cards for use with the ROB PowerMac Treatment Planning System, FORE Systems appeared to be the only source of PCI-Bus Network Cards with drivers offered for Macintosh support. The current FORE Systems drivers, however, will only support the LANE paradigm, which is apparently the default in the PC and Macintosh environments. As a result, all RCWS nodes will be switched from their present CIP configuration to a LANE configuration, in order to allow the ROB PowerMac to interoperate with them. Currently, a LANE server is being selected for implementation on our prototype ATM Network.

Even if the selection of a standard was not forced by the lack of availability of CIP support for the PowerMac platform, LANE would still be a superior choice. Its most attractive feature is that only the LANE paradigm is compatible with the concept of a Distributed LANE Server. This is critical for the RCWS because current plans involve the eventual deployment of RCWS's into geographically disparate regions---and more importantly, regions which will only have occasional ATM network connectivity to the NIH site.

Both Local Area Networks and Wide Area Networks can be implemented with ATM technology. Such ATM Islands can be interconnected via standard point-to-point communication solutions, such as the Synchronous Optical Network (SONET) with bandwidths of 1.2 or 2.4 Gb/s. SONET/ATM interfaces will be necessary, regardless of individual SONET or ATM channel bandwidths, since SONET is a highly-structured, frame-based communication standard, while ATM is a less-structured, cell-based communication standard. It can be expected that ultimately SONET pathways will lead from city-to-city, while ATM islands will be the predominant means of connectivity within and between enterprises in each metropolitan area.

If a LANE Server were installed in each part of the network that can potentially be isolated from the central NIH site, then every RCWS, network-wide, will always be able to see an operational LANE server. This exactly mirrors the intended strategy for EVE Server development, which is to eventually deploy RCWS nodes and a Distributed EVE Server in geographic regions outside of the local Washington area. Those regions can then have local conferences without connectivity to the NIH, but multiple EVE Servers would automatically elect a leader when they see more than one contending for control on a single network.

5. CONCLUSIONS AND FUTURE WORK

The combination of real-time voice/video integrated into a synchronized medical imaging environment, utilizing a multiple shared cursor service, can be feasibly developed and deployed today. Currently available off-the-shelf components and current ATM standards are sufficiently robust to allow the necessary assurances of connectivity, interoperability and reliability, to ensure the successful development of a multimedia, image-based medical consultation system. Outside of the medical arena, this multi-user, image-oriented, distributed conferencing environment can probably find successful application in the areas of cartography, meteorology, and military intelligence.

A number of enhancements to the RCWS are planned for the next year. Automatic contour following algorithms will be implemented to speed the organ and lesion contouring process. ACR-NEMA DICOM 3.0 communication between the RCWS and image sources will be added. High-resolution video recording and playback capability will be added to the RCWS as a routine feature, along with video-based patient physical examination capability.

Additional RCWS nodes are planned, as well as connections to ATM pathways off the NIH campus. Our ultimate goal is the connection of the prototype ATM network on the NIH campus, to the Project Zeus ATM network on the campus of the WUSTL. We have also experimented with the Whiteboard developed at the Lawrence Berkeley National Laboratory, and plan to include this software, or a similar whiteboard package.

In the long-term, we would like to integrate into the RCWS a multi-user image processing package, which would support 3D reconstructions from parallel-sliced datasets, as well as allowing orthogonal and oblique re-sectioning. We would also like to link the RCWS to the Hospital Information System in the host medical centers, in order to allow the patient's electronic medical record to be included in the medical consultation session, in addition to medical images.

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APPENDIX

Radiology Consultation WorkStation

Hardware

1. Sun SPARCstation 20 Workstation
2. Dome Md4/Sun Display Boards
3. Megascan DG 4820-P High-Resolution Monitors
4. STS Technologies MultiMedia eXplorer
5. Sun 20" Color Monitor
6. Panasonic BT-H1350 Color Video Monitor
7. Canon VC-C1 Communication Camera
8. Efficient Networks ATM S-Bus Network Card
9. Advent 570 Stereo Speaker System

Software

1. Solaris 2.5.1 Operating System
2. Aruba 3.3.0 ATM Network Card Drivers
3. Dome Display Driver 3.0.6
4. Dome XIL Libraries 3.0.0
5. EVE 1.0 Medical Imaging Application
6. Rockville 1.0 Teleconferencing Application

10. ITAC Systems BSUNMD Trackball

ATM Network

Hardware

1. SynOptics LattisCell 10114-SM ATM Switches
2. Sun SPARCstation 10 Workstation
3. Sun 20" Color Monitor

Software

1. Solaris 2.5.1 Operating System
2. SunNet Manager 2.2.2
3. SynOptics Connection Management System 1.2.1
4. SynOptics Network Management Application 1.2

Additional Equipment

Hardware

1. FORE Systems MCA-200E Network Cards for the IBM SP2 Supercomputer
2. FORE Systems PCA-200EMAC Network Card for the PowerMac
3. Vidar VXR-12 Film Digitizer