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Implementation of the ACR-NEMA standard and building towards an
ACR-NEMA test facility at the University of North Carolina

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Abstract

Development of a prototypical medical communications system has been underway at the University of North Carolina (UNC) in Chapel Hill. A major system design choice was the use of the ACR-NEMA protocol for the digital transfer of medical images. Previous papers have described the planning and development of the medical image communications system at the University of North Carolina Memorial Hospital¹ and the development of a limited ACR-NEMA protocol implementation for a Vax 11/730 running Unix 4.2BSD.² This paper details progress during the past year in expanding the network through the addition of new nodes to the ACR-NEMA protocol network and in performing further analyses of image transmission between nodes on the network. Additionally, initial developmental efforts and future plans for an ACR-NEMA test facility at UNC are discussed.

Introduction

Because the digital transmission of medical image data over the communications network at UNC is based on the newly defined ACR-NEMA interface protocol, our primary communications goals have been, first, to test simple image transfers between two nodes using the ACR-NEMA protocol; second, building and studying an ACR-NEMA communications system (i.e. an ACR-NEMA protocol network with many nodes); and third, to develop a test environment to assist in the analysis of ACR-NEMA communications systems and in the debugging and evaluation of ACR-NEMA protocol implementations. The last goal will enable us to evaluate our own network and assist manufacturers in evaluating their equipment's ACR-NEMA interfaces.

The first section of the paper reviews the medical image communications system at UNC and previous ACR-NEMA work at UNC involving testing simple image transfers between two nodes using the ACR-NEMA protocol. Included in the review of UNC's communications system is a description of the radiology broadband cable plant, nodes attached to the cable network, and the communications capabilities of those nodes. The second section of the paper details the addition of more ACR-NEMA protocol compatible nodes to the network, further analysis of ACR-NEMA protocol image transfer on the network, and initial work at developing an ACR-NEMA test facility at UNC. The third section describes ongoing work including connecting other manufacturer's ACR-NEMA compatible equipment to the network, completing the full ACR-NEMA package, developing an ACR-NEMA software testbed system for Vaxes, and the analysis of our ACR-NEMA communications network and nodes on the network using the facilities of the planned ACR-NEMA test facility. The final section of the paper outlines plans for the ACR-NEMA test facility in more detail.

Background on UNC's medical communications system

The backbone of the prototype communications system is the network cable plant consisting of broadband coaxial cable which runs throughout radiology, radiation therapy, the emergency room trauma center, the surgical suite, biomedical engineering, and via a fiber optic extension, computer science. The system is arranged in a linear tree fashion. The coaxial cable system consists of three cables, two of which are designed for multiple analog video signal transmissions through the use of separate broadband channels. Because these two are not utilized for digital image transmission they are not considered in this paper. The third cable is used to support several different channels of digital data communications, including one channel for ACR-NEMA protocol communications, another for a local area network (LAN) of IBM-PCs, and one for a LAN of RS-232 protocol communications.

The cable passes an analog signal between desired points; thus, in order for communications of digital images to occur there must be modems between the digital computer equipment and the cable network to which the equipment is attached. These modems are called network interface elements (NIEs).

The NIEs on the network are prototypes from 3M. The NIEs have a raw bandwidth of 3 Mbits. Experimental results with early NIE prototypes indicated a transfer rate of approximately 10 seconds for a 512 squared by 8 bit image between two NIEs on the network. Besides performing the routing management functions required for an ACR-NEMA protocol network the NIEs may also be configured with additional software to allow them to emulate

an ACR-NEMA compatible imaging device. This ability is very useful in testing new pieces of ACR-NEMA compatible equipment. Details on NIEs and their use in an ACR-NEMA protocol communications network have been discussed in Nelson, et al.³

Regulating communications between the NIEs was the job of the Network Control Unit (NCU). The first node attached to the network was the 3M archive. The archive was connected through an NIE port of the NCU. The 3M-1 archive contained two magnetic disk drives for short term image storage and two optical disk drives for long term image storage. A more complete description of this system and the database retrieval program running on the archive was presented by Creasy, et al.⁴ The second computer attached to the ACR-NEMA communications channel was our diagnostic radiology research computer, a Vax 11/730 running 4.2BSD. Connected to the Vax was our Comtal image processor, which was used for our prototype PACS console experiments.

The communications software in the 3M-1 provided support for most of the ACR-NEMA protocol. Some of the areas not covered under that implementation were true point to point communications and also adherence of the software to an older draft of the standard, under which that version of the software had been developed. The implementation on the Vax consisted of a subset of the ACR-NEMA protocol which allowed image transfers to and from the archive using the protocol. Last year's studies characterized transmission times for different types of images between the Vax and 3M-1 archive.²

We chose to implement a specific subset of the ACR-NEMA protocol that would allow the reading and writing of images because, first, it would provide a reasonable test of the ACR-NEMA protocol, and second, it would provide immediate benefit in terms of allowing other PACS research efforts access to remotely stored images. Upon completion of the test prototype, the next step was to complete the development of the full ACR-NEMA protocol implementation for the Vax.

Progress

During the past year, emerging needs required fast access between the various research Vaxes in both radiology and computer science. Additionally, several groups on different machines needed convenient access to output from a newly acquired 4000 by 4000 line film digitizer. As a result the foremost priority became implementing software that would allow image communications between the various machines. With the complete ACR-NEMA protocol implementation for the Vax unfinished, the ACR-NEMA prototype test software offered the fastest transfer times and appeared to be the most desirable short term alternative. However, turning it into a usable tool required several additions to the software. Implementing these changes resulted in our Modified Test Program (MTP) software package. As a result, the majority of work accomplished this year was involved with implementing the MTP package and bringing new nodes online on our ACR-NEMA network. Other work included progress on the full ACR-NEMA protocol implementation and planning towards the implementation of an ACR-NEMA test facility.

The backbone of the original coaxial cable network ran throughout radiology and related departments. The growth of demand for medical data communications is evidenced by the rapid increase in connections to our base system. Connections have been made to the network by radiation therapy, biomedical engineering, the new PACS research facility, and the new MRI building located one half mile away. Additionally, computer science has been connected via 1 mile of optical fiber that acts as an extension cable between the coaxial cable system in radiology and the graphics Vax node in computer science.

The NIEs have been updated several times. Major changes included moving the frame checksum calculations into hardware and modifying the software to allow true point to point communications on the network. The current transfer time between two NIEs for a 512 squared by 8 bit image is now approximately 4 seconds.

In addition to the Vax 11/730 in diagnostic radiology, two more Vaxes have been connected to the network. The first is a Vax 11/750, running 4.3BSD, in radiation therapy. The second is a Vax 11/780, running 4.3BSD, in the computer science department. The digitizer is attached to the radiation therapy Vax, necessitating access to that Vax from the other machines. The computer science graphics Vax is the host machine for one of the largest academic computer graphics labs in the United States. Giving the graphics Vax easy access to a large base of medical images provides the ability to view the image information in several different presentations on any of a multitude of machines.

Additionally, an ACR-NEMA test tool prototype from 3M has been added to the network. The prototype, known as AN-Test-Tool, is an ACR-NEMA plug compatible device. It attaches to the ACR-NEMA connector of a network interface element. The Test-Tool is capable of sending and receiving ACR-NEMA messages and packets. It allows the user to construct and control the sending of specific messages over the ACR-NEMA interface to other ACR-NEMA devices. This greatly simplifies testing and debugging new ACR-NEMA interfaces.

The major software development at UNC was the creation of the MTP package, which is an enhanced version of the original prototype programs that were used for evaluating elementary send and receive operations last year in conjunction with the 3M-1 Archive. The major addition to the function of the test prototypes was the inclusion of arbitrary point to point communications in the MTP package. As described in last year's paper² the

connection between the original Vax and the 3M-1 was accomplished using the default channel 0 from the earlier ACR-NEMA protocol drafts. Transferring images to any of several destinations required the use of the routing mechanisms provided in the ACR-NEMA standard (i.e. Open Channel Request, Open Channel Indication, Close Channel Request, and Close Channel Indication packets, and the Connection Control Packet information). Additionally, work was done to make the MTP package more robust and user friendly than the original test programs so that it could be made generally available to Unix users attached to the network.

Once the MTP package on our diagnostic radiology Vax was completed, the next step was to transfer the package to the other Vaxes and bring them online. The first Vax that the MTP package was ported to was a Vax 11/750 in radiation therapy. Porting the code required some minor changes in the software to allow for differences between the 11/750 and the 11/730. The next step was porting the package to the Vax 11/780 in computer science. Efforts similar to those required for the 11/750 were required. The computer science Vax could not be attached to the network completely, however, because of attenuation problems with the fiber options extension which have required modifications of the transmitter/receiver pairs. The final node that we brought online was the AN-Test-Tool which only required plugging it into one of the NIEs.

In addition to the MTP work the point to point addressing required new software development on the 3M-1 and the NIE nodes as well. Once 3M had updated the NCU and archive software and after the MTP package was finished and ported to the other Vaxes, an examination of image transfers between the different nodes on the network was undertaken.

As in the studies performed last year, the size and content of the image transmissions were initially varied. In agreement with last year's results, the content of the images had no effect on image transmission. Additionally, the size of the images transferred had the expected proportional relationship to the length of time required to transmit the image. That is, an image of length $2n$ took twice as long to send as an image of length n . The table below shows the average amount of time required for the transmission of a send message, where the image in the data field was a 512^2 by 8 bit image. Each transfer included the opening of a channel from the source node to the destination node, the sending of a command packet, the sending of the image data packets, and finally the closing of the channel. In each case the recorded transmission times were measured from the user's selection of an image to send, while within the applications program on the source node, to the receipt of the entire image and the closing of the channel on the destination node.

Table 1: Summary of Simple Image Transmissions

from	to	average transfer time (secs)
11/730	archive	35.81
archive	11/730	33.63
11/750 (S)	archive	26.44
archive	11/750	17.66
11/730	11/750	40.15
11/750 (L)	11/730	38.75
archive	test tool	19.83
test tool	archive	16.71

①

full debugging on.

Notes: (S) means the software required the use of a Short delay

(L) means the software required the use of a Long delay

The delays were required to avoid handshake problems with the NIEs when the NIEs were more heavily utilized.

Transfer times between the 11/730 and the archive were faster than last year's times. The speedup was due to the enhancements that occurred to the test prototype software when developing the MTP package, as sections of the software devoted to providing debugging information were eliminated and additional code optimization was done.

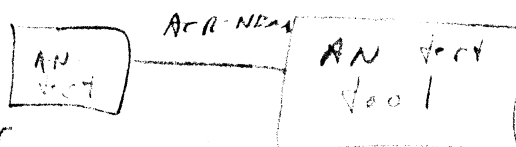
A noticeable improvement is seen in transfer times between the 11/750 and the archive as compared with transmission times between the 11/730 and the archive. This improvement was due to faster disk access speeds and a more powerful CPU on the 11/750. Transfers between the archive and the 11/750 were slightly slower because handshaking between the NIE and the 11/750 required delays between frame sends on the 11/750.

In communications between the 11/730 and the 11/750, the 11/730 is the bottleneck,

② 1/4 Mbyte takes < 1 sec

between AN test tools.

③ Archive → NIE 9-10 secs



driving transfer times upwards, in the range of 40 seconds.

The fastest transfer times occurred between the AN-Test-Tool and the archive. The advantage the AN-Test-Tool has over the other devices is that all of its outgoing image data consists of test frames that are created in RAM, thus avoiding the slow access to disk that is required by the other devices whenever they access the image data.

Similar to last year, the key bottlenecks appeared to be slow access to disk and slow processing capability. Slow disk access slowed down either the retrieval or storage of the image data, while slow processing capability would slow down the checksum calculation.

Additional tests were performed to study the simultaneous sending of images from multiple nodes to the archive. Two different nodes would simultaneously start the task of sending an image to the archive node. Preliminary results were obtained for the transmission times of send messages of the same format as described in table 1. These results are compiled in table 2.

Table 2: Summary of Concurrent Image Transmissions

from	to	average transfer time (secs)
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11/750 (L)	archive	37.81
test tool	archive	17.27
11/730	archive	36.87
test tool	archive	20.37

The major finding of the concurrent image transmission studies was the similarity of the resulting averages with the results from the single image transfer tests. With the exception of the 11/750 sending to the archive, the time required to transfer an image to the archive while another node was sending an image to the archive was only one to two seconds greater than the single image transfer time. Thus, for the current network configuration, sending two images to the archive at the same time does not cause overloading problems at the archive or at the NIE through which the archive communicates to the network. The reason for the increase from 26.44 to 37.8 seconds to transfer an image from the 11/750 to the archive was due to the increased software delay required (a long delay instead of a short delay was required).

Continuing ACR-NEMA work

ACR-NEMA work at UNC continues in two principal areas: adding more nodes to the network while performing further analyses of the network, and development of an ACR-NEMA test facility at UNC.

The next ACR-NEMA node expected to be attached to the network is the MRI machine. This will allow moving images to and from the remote MRI building, hopefully in the future saving radiologists and physicians from making the one half mile journey when they are called upon to (re)view images acquired by the MRI machine.

Eventually, connections will be made to the University of North Carolina's university wide cable system and to the Research Triangle Institute in Research Triangle Park. Connecting to the University's cable system would allow the sharing of information and computer facilities with other groups that deal with two dimensional images (e.g. physics, astronomy, medicine, geography, etc.). Connections to the Research Triangle Institute will facilitate communications with fellow researchers and provide unique opportunities for remote teleconferencing in conjunction with the transfer of image data to a remote location.

Currently, the majority of research machines in the radiology and computer science departments that are concerned with image display are connected to the network. The next major step is connecting equipment from outside manufacturers. This step requires commercial equipment to have ACR-NEMA interfaces. At this time we are not aware of any ACR-NEMA plug compatible equipment; however, several manufacturers expect to have interfaces in the near future and this should provide opportunities for testing new nodes on the network.

In anticipation of an increased load on the ACR-NEMA network as more nodes become attached and access to medical images becomes more convenient, the modems in the NIEs will be upgraded from 3 Mbits to 10 Mbits.

After providing a working, albeit limited, implementation of the ACR-NEMA protocol for

Vaxes running Unix to meet current needs, the next step is to finish the development of the complete ACR-NEMA package for Vaxes. This step will allow each of the Unix machines to handle multiple concurrent image transfers with other nodes on the network. The complete protocol implementation will provide a framework on which the ACR-NEMA Vax testbed portion of the test facility could be built. The test facility is described in the next section of this paper.

UNC as an ACR-NEMA test facility

One of the goals for the next year is to continue the development of an ACR-NEMA test facility in the radiology department of the UNC Memorial Hospital. In addition to establishing a viable medical image communications system for the radiology department, plans include analyzing the performance and behavior of an ACR-NEMA network and providing an open arena in which vendors of medical imaging equipment can test their ACR-NEMA implementations. All of the above goals require a working ACR-NEMA network and a test facility of some sort for examining characteristics of nodes attached to the network and the network itself. UNC currently has an ACR-NEMA network; what remains is to develop a testbed system on the network. A first step in this direction is the use of the AN-Test-Tool. To complement the AN-Test-Tool, plans call for the development of a testbed on the Vaxes that will be interfaced to our complete ACR-NEMA implementation. Thus our initial task is to finish the development of the complete ACR-NEMA protocol communications package for Vaxes running Unix and to design a test framework that will help accomplish the above goals.

Outline of planned test facility

In order to study such issues as performance and reliability of the network, some mechanism must exist on the network for generating specific test conditions and recording information on how both individual nodes and the network itself perform. The simplest mechanism would be to manually perform simple operations like sending and receiving images between nodes and verifying the correctness of the transmission and recording how long it required. Although such information is important, in almost all cases potential users of a network will want a more realistic picture of how the network will appear when in actual use (e.g. overloaded, machines down, etc.). In order to provide such a picture we would like to develop a software package that will allow the tester to define any arbitrary sequence of events to be generated at the ACR-NEMA interface of that node and to record responses to that node along with timing information. Unlike normal applications programs on our Vax that would make use of ACR-NEMA connections, this software package would have special access to the full range of control of the ACR-NEMA interface package, enabling the tester to specify events ranging from a send message to the timing between events at the frame level. Thus in addition to being able to calculate statistics on the average transmission time for fifty 512^2 by 8 bit images under normal load conditions, the tester has the capability of defining a sequence of frames to be sent to a node in order to test that node's handling of specific circumstances (normal or error). Such sequences, or scenarios, may be stored and run non-interactively (i.e. batched). This will facilitate the creation of a battery of tests that may be applied when examining a new node on the network. Ideally, the tester would be able to examine a new node by first running a battery of tests specific to the function of that node (e.g. acquisition node), then proceeding to more specific groups of tests depending on the results of the initial battery, and perhaps finally to selective interactive tests resulting in a fairly complete description of the node's responses to normal and abnormal events.

Expected use of the facility

After the development of an ACR-NEMA test facility at UNC, our first step would be to examine the ACR-NEMA protocol implementation on Vaxes in radiology using batteries of tests as described above. After modifying the implementation to make it as correct and robust as possible, we would be able to assist in providing similar analyses of other nodes attached to the ACR-NEMA protocol network. Additionally, we could begin gathering empirical data on the performance of the network under different conditions. This could be accomplished by running various test package scenarios concurrently on several of the Vaxes attached to the network.

Conclusions

A medical image communications system is a fundamental part of a PACS system. UNC has made rapid progress in building and testing the newly defined ACR-NEMA protocol for the digital transmission of medical images. After accomplishing preliminary testing of two

nodes using the protocol, several more ACR-NEMA compatible nodes were added to the network. Parallel work has involved beginning efforts in building an ACR-NEMA test facility at UNC. Ongoing work will extend the network to include more nodes and more involved testing of the network and the nodes attached to the network, while at the same time continuing efforts to enhance the capabilities of the test facility.

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