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On Placement of The ACR-NEMA Bus in Picture Archiving and Communications Systems

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Abstract

The ACR-NEMA standard [1] allows different medical devices to communicate compatibly in a Picture Archiving and Communication System (PACS) environment. This paper evaluates the performance of PACSs incorporating the ACR-NEMA standard. The ACR-NEMA standard requires that the ACR-NEMA bus be placed between any medical device and a network interface unit. In this paper, we propose and evaluate the performance of a PACS architecture with a better placement of the ACR-NEMA bus. We show that such an architecture is better suited towards medical imaging applications than the one proposed in the ACR-NEMA standard.

1. Introduction

Medical Imaging encompasses all pictures or images which are obtained from patients at a hospital. These images are used for diagnosis, analysis, treatment, and follow-ups during the patient's hospital care. In the past decade concentrated effort, primarily by radiological clinicians and researchers, has been focused on developing digital image communication and storage systems. In the medical literature [2-4] these are referred to as Picture Archiving and Communication Systems (PACSs).

The objective of a PACS is to allow medical images to be communicated, analyzed, compared and processed singly and with respect to each other in a radiology center or other specialized hospital areas. PACSs are usually intended for hospitals with medium to large number of beds, where (CT) and other digital diagnostic imaging techniques are frequent. PACSs at the very least will consist of the following components: Image Generating Equipment (IGE), workstations, a storage archive and a communications network. IGE's capture images of the different modalities. Workstations with different levels are needed throughout the hospital. The radiologist, for example, will have interactive workstations with array processors, multiple display screens and a large local storage. The storage archive replaces the film library and must be huge to store the annual terabyte loads. The communication network interconnecting all the hospital PACS devices has usually been a LAN.

Recently, there has been a surge in use and acceptance of digital imaging equipment. The need has then arisen for a standarized PACS protocol for interconnecting various devices from different manufactures/vendors. The American College of Radiologists (ACR) and the National Equipment Manufacturers Association (NEMA) recognized the need for such a standard. Their joint work resulted in the introduction of the NEMA standard 300-1985 [1][1] which, in the remainder of this paper, we refer to as the ACR-NEMA standard. The design of the standard with its hierarchal communication protocol is intended to enhance both equipment conformance and performance. The standard is based on the ISORM (International Standards Organization Reference Model) and is briefly reviewed in Section 2.

At the University of Alberta, we developed an extensive and detailed simulation model for evaluating the performance of PACS incorporating the ACR-NEMA standard. In [5], the performance of the ACR-NEMA protocol and its impact on the end-to-end performance, using an 80 Mbps token ring LAN, was investigated. The results in [5] showed that the ACR-NEMA standard is well suited for "today's PACSs", which mostly carry images not exceeding a few Mbits in lengths. However, for future PACSs, carrying much larger images, use of the ACR-NEMA standard, in its current format, results in unacceptably large response time (delay) values.

Several enhancements to the ACR-NEMA standard were proposed in [6]. One enhancement involves increasing the ACR-NEMA bus data rate. It was shown that doubling the ACR-NEMA bus rate can reduce average response time values by as much as 85% for large images.

Another direction for enhancing the performance of PACSs, incorporating the ACR-NEMA standard, is adopted in this paper. It was noted [5, 6] that most of the PACS delay was due to the ACR-NEMA protocol. By also noting that only viewing requests may have real-time constraints, we propose the removal of the ACR-NEMA bus from the archive-workstation path. Therefore, the ACR-NEMA protocol delays would be eliminated from all viewing requests. The ACR-NEMA bus is to be kept at the IGE's to maintain compatibility in the multi-vendor medical imaging systems. As we shall see, such a placement of the ACR-NEMA bus results in reducing average response times by as much as 96%.

The remainder of this paper is arranged as follows. Section 2 provides an overview of ACR-NEMA standard. In Section 3, we describe our simulation model. As well, we introduce the new enhanced PACS architecture. In Section 4, some numerical results of the new architecture are shown and compared to results obtained by following the ACR-NEMA bus placement specification as stated in the standard. Finally, in Section 5, we draw our conclusions.

2. The ACR-NEMA Standard

The ACR-NEMA Standard [1] allows digital medical images and their related data to be transmitted between hetrogeneous devices irrespective of the manufacture or image format used. The standard specifies the hardware interface between an imaging device and a Network Interface Unit (NIU), a minimum set of commands and a set of data formats to be communicated between the two devices.

The ACR-NEMA standard follows the general structure of the ISORM in terms of having seven layers with each layer to a great extent having independent functions. The functions of each layer of the standard are condensed and given next.

2.1 *Physical Layer*

The physical interface consists of a 16-bit parallel data bus (operating at 4 Mbps per line, resulting in a 64 Mbps bus) plus a parity line and 3 pairs of crossed control circuits to support asynchronous transfer, arbitration and interrupts. All circuits are differential as specified in the 485 ANSI Standard. The data and parity lines are bidirectional, whereas control lines are unidirectional. The standard specifies a must-follow-state-diagram, as well as timing signals. It also defines a maximum error rate for the 17 parallel lines (16+parity) of 17×10^{-9}.

2.2. *Data-Link Layer*

The data link protocol defines exchange of data and control frames. Two modes of data-link service are provided; datagram and stop-and-wait. In datagram mode, no acknowledgment frames are required for data frames transmitted. On the other hand, in stop-and-wait mode, an acknowledgment frame is required for every data frame transmitted.

A valid frame check sequence (FCS) must be transmitted with the frame. The FCS is defined as the one's complement of the truncated binary sum of all words in the frame excluding the FCS. The data-link layer also pads a header to the frame (one word) describing the nature of the frame.

2.3. *Network/Transport Layer*

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[1] A modified version of the standard has been introduced in 1988.

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The two main functions of the network/transport protocol are:

(1) Establishing and maintaining multiple virtual channels across the interface. The purpose of the virtual channels is to provide data exchange with several devices simultaneously. The sending (source) node forwards an open-channel- request along with a number indicating the virtual channel number to the destination node. (The source and destination addresses are passed from the session layer). A close-channel-request is used to terminate a message transfer. A close-channel-indication message is required to officially close the channel, thus making it available for future use.

(2) Packetizing large messages into blocks of less than 2K words (32K bits), tagging these blocks and sending them as packets. At the receiving end these packets are assembled to the original ACR-NEMA message. To achieve the above tasks, the protocol adds a two-word packet header to each transmitted packet, a packet descriptor and a block sequence number.

2.4 *Session Layer*

The session layer in the ACR-NEMA standard is responsible for establishing and controlling an end-to-end connection between a sender and a receiver (i.e. an imaging device and a workstation). A major requirement at this layer is that each node must be able to provide its logical address, as well as its network address. It is recommended that such addresses be identical to those used at the application layer.

Unlike the ISORM, where the user has access to the application layer only, in the ACR-NEMA standard, the user is permitted direct access to the session layer.

2.5. *Presentation Layer*

This layer is responsible for building messages out of ACR-NEMA *groups*. The standard defines a number of groups which indicate the type of information contained in a message, e.g. command information, identification, patient information, acquisition details, pixel data, etc. Such groups have a fixed numbering and messages must be transmitted in ascending order of group numbers. Each group is further subdivided into *data elements*. An ACR-NEMA message will thus contain a *group* number, an *element* number, a *length* field and a *value* field. Data such as patient information, images, etc. are to be contained in the value field.

2.6. *Application Layer*

The application layer provides the user interface and runs the application software. The ACR-NEMA standard defines a minimum number of commands that can be used to locate and move files, among which are commands performing the functions: send, find, get, move, dialog and echo. Except for the send request (which may carry data representing images), the application layer commands are usually short in length.

3. Simulation Model

We distinguish two parts to our simulation model: a *network* and a *traffic* part. The network part provides a model for PACS architectures. The traffic part models the image workload on the PACS and includes such things as image size, arrival process and arrival rate. The two parts are described below.

3.1. *PACS Model*

The ACR-NEMA standard does not provide specifications of a particular network for interconnecting devices. We, therefore, propose the use of a token ring [7] as the LAN in the PACS. The choice of the token ring network was motivated by the fact that the token ring protocol is a demand assignment one (stations are given transmission rights only upon demand), not much bandwidth is wasted at light offered load and packet transmission access is round robin at heavy load. Moreover, a previous study [8] has shown that Ethernet is unsuitable for such applications. Indeed, most random access LAN protocols would not be suitable for transmission of medical images because of the high offered load and long sequences of packets associated with such applications.

The ACR-NEMA standard requires that an NIU be used to interface to the network and that the ACR-NEMA interface (bus) be placed between any imaging device and an NIU. A PACS architecture, incorporating the ACR-NEMA standard and using a token ring LAN, is shown in Figure 1a. In this paper, we propose an alternate placement of the ACR-NEMA bus. In the new PACS architecture, see Figure 1b, the ACR-NEMA bus is removed from the archive-workstation path. Such a proposition was motivated by the following:

(1) As was shown in [5], the ACR-NEMA protocol was the source of most of the image transmission delay. Removal of the ACR-NEMA bus, whenever possible, is, therefore, desirable.

(2) Real-time constraints are usually imposed by radiologists and physicians requesting images for viewing or while performing interactive processing. Therefore, it is the response time from the archive to workstations that is under real-time constraints, not the one between the IGE and the archive.

(3) Storage devices and workstations already have well-accepted standard physical interfaces. Only the ACR-NEMA image format needs to be kept in such devices.

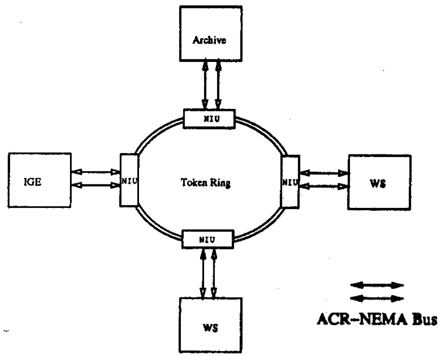
Next, we list the assumptions used in the simulation model:

(1) The Archive is infinitely large. That is, no image is to be lost due to lack of storage space. Also, the buffer sizes at the IGE, workstations and NIUs are assumed infinite.

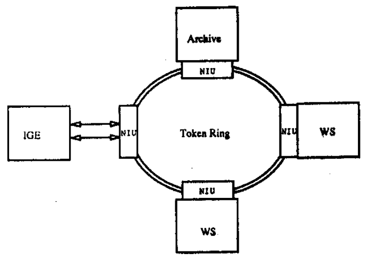
(2) Both the ACR-NEMA bus and the token ring are error-free.

(3) Processing times at the IGE, NIU's, archive and workstation are not considered. The rationale behind this is twofold. First, such processing times are highly dependent on the particular devices used in the PACS and also on the software implementation. Secondly, by allowing the ACR-NEMA protocol to operate in ideal conditions, it is easier to focus on the communication protocol performance rather than implementation details. The reader should bear in mind, therefore, that the performance values obtained in this paper represent bare minimum ACR-NEMA protocol delays.

(4) The transmission rate of the token ring is 80Mbps.[2] The choice of a data rate higher than 64 Mbps (8 Mbytes per second, as specified in



(a) Architecture S: ACR-NEMA Bus At Each Device



(b) Architecture E: ACR-NEMA Bus At IGE Only

Figure 1: PACS Architucture Alternatives

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[2] Such a rate correspond to the commercially available Proteon ProNet.

the ACR-NEMA standard) is obvious, since a lower rate would create a bottleneck at the LAN. On the other hand, a much higher transmission rate is not desirable, since it does not improve the PACS performance, which in this case would be limited by the 64 Mbps provided by the ACR-NEMA bus.

(5) Images are generated (captured) at the IGE and sent via the ACR-NEMA bus and the token ring to the archive. The archive forwards images to workstations upon request.

(6) A stop-and-wait protocol is used for each frame transmitted.

3.2 *Image Workload*

The medical image load is due to both the size and the number of images viewed. The size of a medical image is given in number of pixels, as well as the depth of information per pixel.[3] In a previous investigation [9] of a hypothetical fully digitized radiology department at the University of Alberta Hospital (UAH), with 3 hospital units (1250 beds) and an outpatient clinic, an estimated range of 0.29 Mbps to 5.93 Mbps is to be generated. Using an average image retrieval rate of 14 times the acquisition rate [10], the offered load on the PACS ranged from 4.35 to 88.95 Mbps.

We consider the following three image loads:

(A) *Small films:* Which include all the current digital modalities (Computed Tomography (CT), Nuclear Medicine (NM), Ultra Sound (US), etc.). The image size is 512×512×8 bits (2.1 Mbits). We call this image size "small" and choose an offered load ranging from 0.07 Mbps to 89.44 Mbps for it.

(B) *DSA & Chest X-ray:* Which include all DSA (Digital Subtraction Angiography) and all chest X-rays. The image size is 2048×2048×8 bits (33.6 Mbits) "medium" with an associated offered load of 4.0 Mbps to 40.0 Mbps.

(C) *Complete Chest X-ray:* Which include GI(Gastro-Intestinal), IVP(IntraVenous Pyelograms) and skeletal X-rays. The image size is 4096×4096×12 bits (201 Mbits) "large" with an associated offered load of 10.8 Mbps to 43.1 Mbps.

Images are modeled to 'arrive' (be generated) at the IGE with an exponential interarrival time. Table 1 shows the corresponding offered load values for some selected interarrival times. In Table 1, the letters A, B and C correspond to the categories above; viewing interval is $1/14^{th}$ the $IS/IT \cdot (14+1)$ where IS is the image size and IT is the interarrival time at the IGE. For example, for case B2, a 33.6 Mbit image is generated every 125 seconds, resulting in an offered load of 4.03 Mbps.

4. Numerical Results

In this section we show and compare performance results from the two PACS architectures in Figure 1. The main performance measure sought is the image viewing response time. The *response time* is defined as the delay encountered by an image from the time it is requested at a workstation until it has completely arrived at the display. Such delay includes: queueing delays, virtual channel setup time, transmission across the ACR-NEMA interface, token ring delay, relevant propagation delays and waiting time for acknowledgments. By measuring the token ring delay, one can then isolate the delay due to the ACR-NEMA by subtracting the token ring delay from the response time. A radiologist sitting before a workstation will tolerate a 2-second response time. Therefore, it is of utmost importance to recognize and specify the conditions under which such a limit can be achieved.

Three workload categories are used: categories A, B and C corresponding to images of size 2.1, 33.6 and 201 Mbits respectively. For each workload category, the offered load is varied to illustrate the performance of the ACR-NEMA protocol under various offered load conditions. High offered loads are used to help detect bottlenecks in performance. Although response times depend on the actual size of the images, the sequence length of the number of packets in an image further impacts delay. For example, a 201 Mbit image consists of over 6000 ACR-NEMA packets.

Case	Generation interval (sec)	Viewing interval (sec)	Transmission load (Mbps)
A1	450	32	0.0702
A3	45	3	0.746
A4	22.5	1.5	1.49
A7	1.5	0.1	22.36
A8	0.75	0.05	44.72
A9	0.55	0.04	56.24
A10	0.45	0.03	74.57
A11	0.37	0.025	89.44
B2	125	9	4.00
B3	52	4	9.03
B4	28	2	18.0
B5	21	1.5	24.0
B6	15	1	35.8
B7	12.5	0.9	40.0
C1	280	20	10.8
C2	140	10	21.6
C3	100	7	30.8
C4	70	5	43.1

Table 1: Image Workload

In Figure 2, we compare the average and maximum response times of the two PACSs in Figure 1, referred to as architectures S and E, respectively. The offered load used in Figure 2 is a combination of all three image workload categories and ranges between 4 and 43 Mbps. The response time values reported include both the cases where an image is requested at a workstation from the archive and where a generated image is transferred to the archive for storage. The following observations are made:

(1) For the combined averaged workload, both the average and maximum response time values of PACS architecture E are mostly below the 2-second limit. Whereas, for architecture S, response time values are almost always above the 2-second tolerance limit.

(2) Response time values are dramatically reduced for PACS architecture E. For example at an offered load of 35.8 Mbps, the average response time is reduced from 33.5 to 1.35 seconds (a 96% improvement over PACS architecture S).

In Figure 3, we show the impact of the ACR-NEMA protocol on image response times for both PACS architectures. Here the delay values are given separately for all three workload categories. For architecture E, the archive and workstations are directly connected to the token ring, and hence ACR-NEMA overheads are eliminated from all viewing response times. The following observations are made:

(1) For small images (category A), the impact of the ACR-NEMA protocol on the performance of the two PACS architectures is not substantial and is always less than 0.5 seconds. In fact, the average response time, which includes the token ring delay, is always around the 1-second mark. That is, the response time is below the desired limit of 2 seconds.

(2) For medium size images, the impact of the ACR-NEMA protocol is much more apparent. For an architecture S PACS, such an impact is relatively low at light offered load. As the load increases, however, the impact of the ACR-NEMA protocol increases exponentially. For example, at an offered load of 35.8 Mbps, the delay due to the ACR-NEMA protocol is 5.38 seconds. (This constitutes about 89% of the response time). On the other hand, for architecture E, the average ACR-NEMA delay never exceeds 1.5 seconds (keeping the average response time, including the token ring delay, below the 2-second limit).

(3) For large size images, the delay due to the ACR-NEMA protocol is not, and indeed cannot be, below the 2-second limit. However, it is obvious from the Figure that architecture E has a much lower ACR-NEMA protocol delay.

The above results quantify the obvious advantage of placing the ACR-NEMA at the IGE only (PACS architecture E), rather than at every NIU as recommended in the ACR-NEMA standard (PACS architecture S). In fact, the results in Figures 2 and 3 suggest that PACS architecture S is only suitable for transmitting small images (less than 2 Mbits).

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[3] Such information may correspond to the number of grey levels in an image.

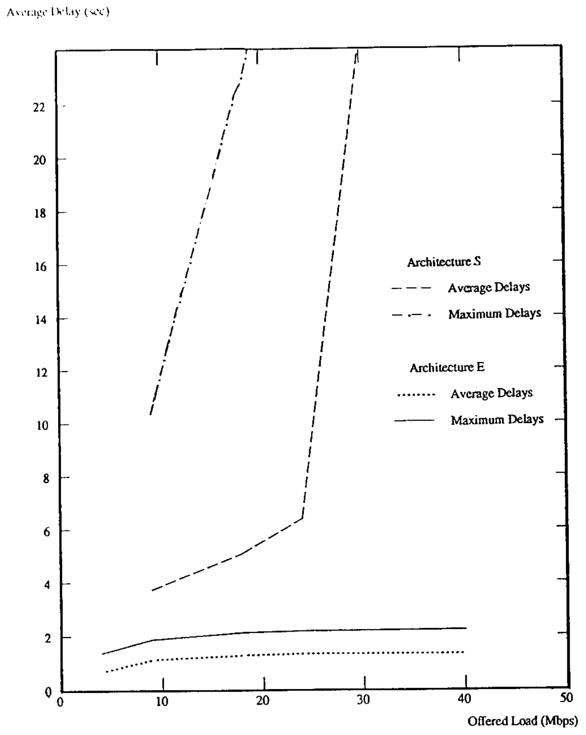

Figure 2: End-to-End Response Time of the Two PACS Architectures

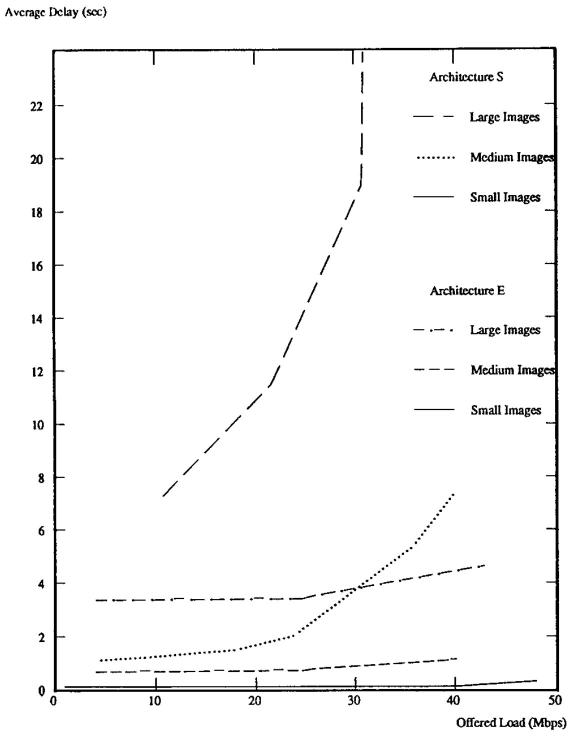

Figure 3: Impact of the ACR-NEMA Protocol

Again we must emphasize that the response times reported here are bare minimum values and do not include the normal overheads of processing, storage/buffer management and screen display. However, since such overheads are common to both architectures, the comparative performance results above are still valid.

5. Conclusions

In this paper, we evaluated the performance of two PACS architectures incorporating the ACR-NEMA standard. A simulation model has been developed through which we studied the performance of the ACR-NEMA protocol and its impact on end-to-end PACS performance. Three different workload categories were used. For each category, the offered load is varied from light to heavy to test the ACR-NEMA protocol at its limits.

The work in this paper have demonstrated the following:

(1) Following the ACR-NEMA standard specifications by placing the ACR-NEMA bus between every imaging device and its NIU, the ACR-NEMA protocol is, then, only suitable for small medical image transmission. For larger images, the response time either always exceed the desired limit (category C) or exceeds it whenever the load increases (category B).

(2) By noting that the ACR-NEMA bus is the bottleneck, it can be seen that it is unsuitable for devices with high bandwidth requirements (storage archive), or devices with real-time constraints (interactive workstations), to connect to the network via an ACR-NEMA bus. Such devices should be connected to the network directly.

(3) By using the ACR-NEMA bus only at the IGE's in a PACS, the delay of the ACR-NEMA protocol is eliminated on all viewing requests and only impacts the image transmission to the archive. Thus the average response time is reduced dramatically, in fact, by as much as 96%.

In summary, the ACR-NEMA standard, with its bus placement at every PACS device, is suited reasonably for today's PACSs which mostly carry small images (category A). However, for future PACSs, carrying larger images (categories B and C), use of the ACR-NEMA results in unacceptably large response time values. This paper proposed a placement of the ACR-NEMA bus that is much more suited to the medical image flow and PACS devices than the one recommended in the ACR-NEMA standard. It has been shown that such a placement, indeed, reduces the ACR-NEMA protocol overhead, allowing the transmission of larger and more frequent images.

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