SIMULATION OF A HOSPITAL PICTURE ARCHIVING AND CONTROL SYSTEM (PACS)

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ABSTRACT

The nation's hospitals have long used distributed data processing as a means of reducing operational costs and providing timely service. Radiology Departments are now also taking advantage of these facilities in order to decept the cost of producing and archiving radiological images. Today a typical medium scale hospital consumes large quantities of silver oxide film which, along with attendant labor costs, is expensive compared to costs for digital image processing technology now available. Using this technology large image files can be stored and retrieved through local area networks that can also support the transaction traffic essential in a hospital environment. The evolving systems are called Picture Archiving and Control Systems (PACS).

PACS will include radiology imaging equipment, distributed and central image archiving facilities, and significant numbers of workstation displays. The devices will be interconnected by high speed local area networks capable of distributing information ranging from simple control messages to large image files of several megabytes in a fashion offering most users a response time of several seconds.

This paper illustrates the PACS system concept, present a queuing model approach to analyzing PACS performance, and discuss results acquired for a variety of parametric samples. The IBM Research Queueing Package (RESQ) has been used for the exercise and will be discussed sufficiently for the reader to appreciate its capability.

RESQ simulation results indicate that system response times will be more dependent on the internal architecture and programs of the workstation than on the speed of the transmission media.

THE PROBLEM

Discrete simulation was used successfully to gain insight into architectural tradeoffs for a complex preprototype distributed information system. The application involved the archiving and distribution of radiological image data (X-Ray, Cat Scan, Magnetic Resonance, Ultrasound, etc.) within hospitals. The work was done by the Network Systems Laboratory of IBM's Federal Systems Division.

The data processing requirements of many hospitals make it cost effective for them to implement distributed data processing systems. Hospitals need to track numerous important transactions on large transient patient populations in order to deliver effective health care, perform inventory and staff accounting, and bill for services. Because of the high cost of health care professionals, hospitals were early to recognize the value of providing distributed access to their computers with digital terminal equipment (DTE) provided in or near most work areas.

Today's diagnostic radiological images are being generated in digital form, as well as on film, and can be distributed electronically throughout the hospital. Perhaps even more important, they can be economically archived (digitally) to avoid the large expense of silver-oxide film and attendant labor costs for film management, archiving, retrieval, and display. In addition to reducing costs, Picture Archiving and Control Systems (PACS) offer far more responsive service.

The typical PACS system will consist of radiology source imaging equipment (called modalities), distributed and central image archiving facilities, and significant numbers of high-resolution graphics display devices. The devices could be interconnected by high-speed local area networks (LANs) capable of distributing information ranging from simple control messages (<2000 Bytes) to large image files of several megabytes. Typically PACS traffic consists of either: (a) large files being requested infrequently by operators at workstations throughout the hospital or (b) large image files being transferred from modalities located in the radiology department. The requested image files must be delivered within several seconds with high confidence. Performance standards are being defined in detail by the hospitals, the users, and the suppliers. The National Electrical Manufacturers Association (NEMA), and the American College of Radiologists (ACR) have played an active role in developing these standards.

Delivering large image files throughout a LAN environment within a few seconds in response to multiple users is a challenging problem. To contain costs the solution to this problem must include standard 'off-the-shelf' technology. The IBM Federal System Division's Network System Laboratory has completed preliminary analysis of this problem using discrete event simulation, and some of the results are presented in this paper.

THE IBM NETWORK SYSTEMS LABORATORY

In support of the PACS application and others like it, the Network Systems Laboratory has developed expertise in distributed system design. The Network Lab has pursued a comprehensive effort to define, configure, and analyze LANs that include products from multiple vendors. In 1983 the Lab began a multi-year internal research and development project that included the following major tasks:

- Hybrid network architecture definition,
- Laboratory configuration definition,
measurement technique development,
performance analysis and modeling, and
performance measurement and evaluation.

In work accomplished to date, these major tasks have
been pursued using investigations of CSMA/CD, token
ring, and Hyperbus networks. (Hyperbus is a trade-
mash of Network Systems Corporation.) Based on this
work the Lab has developed approaches (a) for defin-
ing software/hardware threads (single transaction
paths) through LAN architectures, (b) for analyzing
the performance of those threads against a varying
background load, and (c) for simulating the perfor-
man e of specific application architectures like
those anticipated for PACS.

At the Network Lab a mixture of laboratory mea-
urements, closed-form queueing models and discrete
simulation are used. Each of these techniques has
strengths and weaknesses that tend to be complemen-
tary. The fundamental approach has been to develop
analytical methodologies where feasible and simula-
tions where necessary. To some extent both can be
benchmark ed against measured data; successfully
benchmark ed models can then be used for extrapo-
ation.

The analytical models developed or used in the Lab
to date either address the LAN channel capabilities
for homogeneous undetailed stations [1,2,3] or
include the device hardware and software details for
at most one particular foreground pair of devices
running against a homogenous background load.
Simulation is being used to look at specific system
configurations, requirements for hybrid data termi-
nal equipment, and mixed traffic conditions.
Simulation was the tool of choice for PACS.

SIMULATING BACKGROUND LOAD

RESQ simulation results have been compared with
results obtained from analytical models. The re-
results of both approaches are now being compared with
measurements. Figure 1 illustrates the results of

The solid curve (theory) represents results obtained
from an IBM PC-based algorithmic model that analyzes
in detail a pair of foreground devices running with a
homogeneous background load. This background load
consists of the usual Poisson traffic uniformly
distributed among a large number of background
devices. Because we were interested in reproducing
such a curve in a laboratory environment, the simu-
lation results were obtained in several runs over
which the background load was spread among different
numbers of devices. In this way we were able to
determine that the typical analytical background
load could be achieved, for this particular case, by
dividing the load evenly among at least twelve
LAN-attached devices. Fewer devices may be required
depending on system parameters.

Other comparison runs were made for Ethernet that
included large numbers of simulated devices.
Laboratory measurements have been made under both
load and no-load conditions, and token ring compari-
sions have also been made. Results are beyond the
scope of this paper but are generally supportive of
the modeling.

THE TOOL -- RESQ

Simulation of the PACS application has been accom-
plished using the Research Queuing Package (RESQ)
developed by IBM's Research Division [4,5,6]. RESQ
is a high-level language designed to facilitate
either numerical or simulation analyses of queueing
systems. For the rest of the paper we will only be
referring to the capabilities of the simulation
'side' of RESQ.

RESQ supports two general classes of queues: active
and passive. Active queues are the normal type of
service oriented queue that represent the principal
system resources. For these queues RESQ provides
several service disciplines and allows one or many
servers. Passive queues are used to represent the
simultaneous possession of resources, such as shared
CPU memory. Both types of queues can be configured
with one or more waiting lines.

The first step in modeling a communication network
using RESQ is to represent the major network re-
sources in terms of the RESQ modeling elements.
This is done with a graphics notation language. In
addition to the active and passive queues, the
principal RESQ modeling elements are shown in Figure
2.

* A trademark of the Xerox Corporation.
In a communication network model, source nodes are used to introduce traffic into the network. Sink nodes are used to remove traffic from the network. Set nodes are used to assign characteristics to messages and to accomplish computations. The primary use for fission and fusion nodes is to model message packetizing. Messages are subdivided at fission nodes, move through the modeled network and are reassembled automatically by RESQ when the pieces reach a fusion node. A split node is often used to model acknowledgments.

RESQ keeps a complete set of statistics about every queue in the network. It gives the user access to a variety of statistical distributions. It provides for flexible routing and offers other user-friendly features. Perhaps its major advantage is its full support for modeling blocking due to resource constraints with passive queues.

For the past 18 months the Network Lab has pursued analytical and simulation models that can be used to address such application environments as PACS. The work leading to the PACS analysis includes the following:

- Developing and validating a RESQ-based Ethernet sub-model,
- Developing and validating a RESQ-based token ring sub-model, and
- Building a PACS architecture and traffic model "around" the two submodels.

Figures 3 and 4 present a simplified version of the Ethernet simulation model in RESQ graphics notation. Figure 5 presents the token ring model in similar notation. Reference 6 discusses examples related to these figures and is thus a source for additional insight into these RESQ diagrams.

**SCENARIOS AND GOALS**

Figure 6 shows a simplified PACS architecture. The devices on the left represent typical radiological sources: Cat Scan (CT), X-Ray, Magnetic Resonance (MR), and film digitizer (DIG). The host computer in the upper right acts as the archiving file server for the radiological pictures. The workstations in the lower right provide access for doctors to request and observe their patients' pictures. The key analytical assumptions include the following:

- Device speeds and characteristics were educated guesses of generally available products in the 1986 to 1989 time-frame; for example, 4mbps token ring was compared with 10 mbps Ethernet.
- Typical 1/0 software delays were included to accomplish protocol at OSI level 4.
- Acknowledgements and windowing were not modeled.
- Workstations were of approximately IBM PC AT capability, and the host was of IBM 43xx capability.
- Data was transferred on the host channel in 64 kbyte units.
- The transfers were memory-to-memory; no disk delays were included.
- Messages were packetized in place in memory.
- No adapter priority was modeled.

Some of these assumptions are optimistic, but do not interfere with our gaining an understanding of the

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**Figure 3: Ethernet Device Submodel**

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Figure 4: Ethernet Main Model

Figure 5: Token Ring Model
Simulation of a Hospital Picture Archiving and Control System

Figure 6: Simplified PACS Architecture

architectures and media access methods. In the case of acknowledgement and windowing, an appropriate sliding window protocol would minimize any effect on response. Such a protocol might have the destination device acknowledge every two packets and the source device pause only if four sends have happened without acknowledgment. In a well-balanced system using such a protocol, a file-transfer source may never wait. The considerations of archive access and retrieval times were not modelled since both LAN technologies would incur these delays if the same archive was used in each case.

Figure 7 shows a simple picture of a single communication thread. A message only spends a part of its travel time being sent on the LAN's media (B-C). This is true whether this media can transmit 4 or 10 megabits per second. Messages must be built into one or more packets of the proper size and form, typically handled by the source device's processor (A). The packets must be moved from the attached device's memory into LAN adapter for transmission (A-B). Some cost may be paid for acquiring the right to transmit on the LAN (the media access delay). After receipt of the packet(s), the packet(s) must be moved to the attaching device's memory and recomposed into a message (C-D). Often messages have to be moved more than once at each end. Since data movement speeds inside a device (and between attaching devices and the LAN adapters) are typically in the same order of magnitude as the LAN transmission, poor internal device architectures can overshadow efficient LAN methods. We assumed the ideal case of no movement of packets in the attached devices -- that messages were packetized in place.

Hospital image generation and acquisition requirements are well documented [7] and realistic values have been used in these models. Source modality image generation rates are reduced to images per hour based on typical study rates and the number of images per study generated by each device. The frequency of image recall from archiving used in this simulation is also consistent with available literature. We picked numbers of terminals and rates to represent more than peak stress load.

To be useful the RESQ model had to address critical PACS issues, which include the following:

- predicting response time at the workstations,
- sizing the host (file-server) computer,
- finding appropriate number of adapters on the host,
- evaluating different strategies for host/adapter communication,
- comparing results under different traffic assumptions,
- comparing token ring and Ethernet.

These issues were all explored in our study. This paper will present some of the results in depth.

TOKEN RING VERSUS ETHERNET

For our assumptions and anticipated PACS of traffic, both the 4 mps token ring and 10 mps Ethernet LAN could achieve acceptable response times for both the modality image unloading and workstation image retrieval traffic under conservative assumptions.

In scenario 1 (figure 8) no modalities are included. Requests originate from each of 60 terminals twice a minute with a Poisson distribution. These requests were sent to the host; and responses of 1500 bytes, 1/2 Mbyte, or 2 Mbyte were returned with the probability of 0.5, 0.45, 0.05 respectively. This represents office traffic and two different size image files. Response time was defined to be from the start of the request from the terminal processor's memory until the entire message arrived at the terminal processor's memory.

Ethernet allows no more than 1500 bytes of data per packet. Larger messages must be packetized. Therefore, to satisfy a 150,000 byte request from a doctor at least 101 packets must be transferred. (One packet sent out to make the request, and 100 packets returned to satisfy the request). Inside the model, as in the real world, all delays, are for the transmission of packets, but we have to collect statistics on the transaction from the doctors' point of view. Therefore, each outgoing request packet gets a RESQ resource called, in this case, 'LIFE', which is returned with the file transfer packets. RESQ automatically provides detailed

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statistics on the LIFE resource. For this application the token ring model also assumes packets of 1500 bytes of data. Actually the token ring protocol allows significantly larger packets. Since many of the delays in a LAN are associated only with the number of packets, the token ring protocol should be able to do somewhat better relative to Ethernet than this model demonstrated.

### Scenario 1 Workstation Side of PACS

**Mean/Maximum Time for Sending Request and Receipt of Image (seconds)**

- 60 Workstations Each Sending:
  - 1500 byte request
  - 30% time (Poission)
  - 1/2 byte response 20% of time

**Assumptions:**
- 1500 byte packets
- No windowing or acknowledgements
- Best estimates delays & architectures

**Results:**

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Media Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Mbps</td>
<td>10 Mbps</td>
</tr>
</tbody>
</table>

| All     | 4.6/1.28    | 4.6/1.28 |
| 1500 byte| 4.2/1.20    | 4.2/1.20 |
| 1/2 byte | 4.2/1.20    | 4.2/1.20 |

**Utilization:** 41.3% 20.0%

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**ETHERNET**

**Adapter Speed**

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today's</td>
<td>19.89</td>
</tr>
</tbody>
</table>

| All     | 3.5/sec*    | 3.5/sec* |
| 1500 byte| 2.15/10.13  | 2.15/10.13 |
| 1/2 byte | 2.49/10.13  | 2.49/10.13 |

**Utilization:** 19.4% 19.7%

*Three host/adapters were required to keep this case stable.

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Figure 8: Workstation Load Results

In scenario 2 (figures 9, 10) no workstations are included. The modalities are simply off-loading their Image files to the host/file server. As a sensitivity test, the nominal, twice nominal, and five times nominal traffic are run. Comparison of the 10 Mbps Ethernet (with 3.5 ms adapter) and the 4 Mbps token ring does not show major difference.

The reason for these results is that Ethernet can not effectively use its 10 Mbps bandwidth because it is paced by the slower speed of its adapters. The PACS traffic predominately includes large file transfers. The nominal traffic rates for a PACS would often see the LAN idle when a file must be transferred. Since a file would be split up into many packets to prepare it for transmission and all of these packets would be sent single file through a single sending and a single receiving adapter, the file could be transferred no faster than these an adapter could fill or empty its buffer. This is demonstrated by figure 11 in which no significant delay is added by additional streams of traffic until the total transmission time of a packet, times the number of devices, gets in the range of the speed of the adapter. In effect, the adapters have picked time slots through collisions and backoffs, and are paced by adapter speeds. Faster (i.e. >10 Mbps) speed token rings, though available, were not modelled. It appears that the LAN media is a less severe constraint than the device or device adapter capabilities (see figure 9). In fact, higher speed token rings (using available adapters) would simply increase the utilization of the media with no gain in throughput within the adapters. Image response times would be reduced by the improved LAN transmission interval.

### Scenario 2 Modality Side of PACS with Token Ring

**Nominal Traffic Rate:** 13.4 Kbytes/sec.

**Mean/Maximum Time to Offload to Host (seconds)**

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Nominal</th>
<th>Twice</th>
<th>5 Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>1.36/4.12</td>
<td>2.72/8.24</td>
<td>5.04/12.48</td>
</tr>
<tr>
<td>CT</td>
<td>1.16/4.32</td>
<td>2.32/8.64</td>
<td>4.64/12.96</td>
</tr>
<tr>
<td>MR</td>
<td>4.07/12.21</td>
<td>8.14/24.42</td>
<td>16.28/48.84</td>
</tr>
<tr>
<td>DF</td>
<td>2.29/6.87</td>
<td>4.58/13.74</td>
<td>9.16/27.48</td>
</tr>
<tr>
<td>DIG</td>
<td>15.99/47.97</td>
<td>31.98/95.95</td>
<td>63.96/191.91</td>
</tr>
</tbody>
</table>

**Utilization:** 1.1% 2.2% 5.4%

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**90 Adapter - 3.5 sec**

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Nominal</th>
<th>Twice</th>
<th>5 Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>1.36/4.12</td>
<td>2.72/8.24</td>
<td>5.04/12.48</td>
</tr>
<tr>
<td>CT</td>
<td>1.16/4.32</td>
<td>2.32/8.64</td>
<td>4.64/12.96</td>
</tr>
<tr>
<td>MR</td>
<td>4.07/12.21</td>
<td>8.14/24.42</td>
<td>16.28/48.84</td>
</tr>
<tr>
<td>DF</td>
<td>2.29/6.87</td>
<td>4.58/13.74</td>
<td>9.16/27.48</td>
</tr>
<tr>
<td>DIG</td>
<td>15.99/47.97</td>
<td>31.98/95.95</td>
<td>63.96/191.91</td>
</tr>
</tbody>
</table>

**Utilization:** 1.1% 2.2% 5.4%

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**Figure 9: Modalities Only (Token Ring)**

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**Figure 10: Modalities Only (Ethernet)**
Simulation of a Hospital Picture Archiving and Control System

<table>
<thead>
<tr>
<th>Transaction Queueing Times (Seconds)</th>
<th>For 1-Way 525 Byte Transmissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Adapter - 10 msec</td>
<td>Mean</td>
</tr>
<tr>
<td>1 Device</td>
<td>3.96</td>
</tr>
<tr>
<td>2 Devices</td>
<td>3.95</td>
</tr>
<tr>
<td>3 Devices</td>
<td>3.96</td>
</tr>
<tr>
<td>4 Devices</td>
<td>3.96</td>
</tr>
<tr>
<td>5 Devices</td>
<td>5.19</td>
</tr>
<tr>
<td>6 Devices</td>
<td>6.01</td>
</tr>
<tr>
<td>'89 Adapter - 3.5 msec</td>
<td>Mean</td>
</tr>
<tr>
<td>1 Device</td>
<td>1.67</td>
</tr>
<tr>
<td>2 Devices</td>
<td>1.67</td>
</tr>
<tr>
<td>3 Devices</td>
<td>1.67</td>
</tr>
<tr>
<td>4 Devices</td>
<td>1.74</td>
</tr>
<tr>
<td>5 Devices</td>
<td>2.25</td>
</tr>
<tr>
<td>6 Devices</td>
<td>2.65</td>
</tr>
<tr>
<td>Assumes:</td>
<td></td>
</tr>
<tr>
<td>o No windowing or acknowledgement</td>
<td></td>
</tr>
<tr>
<td>o No application or I/O software delays</td>
<td></td>
</tr>
<tr>
<td>o Single buffering in the adapter</td>
<td></td>
</tr>
<tr>
<td>o Each device sending to distinct device</td>
<td></td>
</tr>
</tbody>
</table>

Figure 11: Simultaneous Modality Starts (Ethernet)

CONSIDERATIONS IN ANALYZING FILE TRANSFER TRAFFIC

In mixed file transfer traffic, sample statistics can be misleading. The LAN and adapters act on packets. A large message or file must be broken into many packets. In these systems when one packet arrives at a server, many more are sure to follow. The last packet in a file transfer must wait until all the earlier packets are served. Thus in an otherwise idle system, a large file transfer will tend to have worse per-packet mean queuing times than a small transfer, even if mean packet throughput is the same. In a system with a variety of different sizes of file transfers, sample statistics of average per-packet delay disguise the real phenomenon.

Therefore, in scenario 3 only one type of traffic was tried. Running the model without the modalities and having all the workstations requesting 2.65 byte images (scenario 3, figure 12) produces a 2.89 second delay for Ethernet. This is a transaction delay involving one request packet returning in response. The largest component of the delay was in the workstation I/O software (3.00 seconds of the 2.89 seconds). Packets arrived so fast that the workstation processor fell significantly behind in absorbing them. It is noteworthy that although each of the 120 packets in an image file spent about a second (on average) being accepted at the workstation, all 120 packets are absorbed during the 2.89 second end-to-end delay because of pipelining.

RESQ offers several techniques for generating confidence intervals that depend on assumed normal distribution for means. For this application the RESQ-generated response time confidence intervals are not useful. Most of the time LAN utilization is low and takes about the same amount of time for each occurrence on an idle LAN. Therefore, the minimum response time is also the mode of the response-time distribution. The simplistic assumption of normality often captures only 20% of the observed values in a 95% confidence interval. Also, in heavily utilized LANs there is a great deal of autocorrelation between two packets that follow each other. The assumption of independence can only be used if appropriately grouped mean statistics are used.

![Table](attachment:image.png)

Scenario 3
Full PACS with Peak Modality Traffic
Nominal Traffic Rate: 13.4 KB/sec/sec.
Mean/Maximum Time to Offload to Host (seconds)

Traffic includes:
- 60 workstation traffic (figure 8)
- Five times normal modality traffic (figure 9 or 10)

Assumptions same as figures 8 - 10

Results:

<table>
<thead>
<tr>
<th>TOKEN RING</th>
<th>Media Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 mps</td>
</tr>
<tr>
<td>All</td>
<td>1.68/2.19</td>
</tr>
<tr>
<td>CT</td>
<td>0.10/1.51</td>
</tr>
<tr>
<td>MR</td>
<td>0.09/1.92</td>
</tr>
<tr>
<td>DF</td>
<td>0.07/1.27</td>
</tr>
<tr>
<td>DIO</td>
<td>0.05/1.12</td>
</tr>
<tr>
<td>1/6 Mbyte</td>
<td>0.03/0.51</td>
</tr>
<tr>
<td>1/2 Mbyte</td>
<td>0.02/0.35</td>
</tr>
<tr>
<td>Utilization</td>
<td>53%</td>
</tr>
</tbody>
</table>

ETHERNET | Adapter Speed | Today's '89 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic</td>
<td>10 mscx</td>
<td>3.5 msc</td>
</tr>
<tr>
<td>All</td>
<td>2.46/2.65</td>
<td>1.56/2.10</td>
</tr>
<tr>
<td>CT</td>
<td>4.23/5.02</td>
<td>2.00/2.43</td>
</tr>
<tr>
<td>MR</td>
<td>2.41/4.11</td>
<td>1.96/1.39</td>
</tr>
<tr>
<td>DF</td>
<td>3.98</td>
<td>1.68/1.85</td>
</tr>
<tr>
<td>DIO</td>
<td>15.09/15.10</td>
<td>6.83/6.67</td>
</tr>
<tr>
<td>1500 byte</td>
<td>1.63/11.74</td>
<td>1.77/7.40</td>
</tr>
<tr>
<td>1/6 Mbyte</td>
<td>3.03/11.56</td>
<td>1.92/0.90</td>
</tr>
<tr>
<td>1/2 Mbyte</td>
<td>5.20/11.32</td>
<td>2.32/1.43</td>
</tr>
<tr>
<td>Utilization</td>
<td>20.5%</td>
<td>20.2%</td>
</tr>
</tbody>
</table>

*Three host/adapters were required to keep this case stable

Figure 12: Full PACS with Peak Modality Traffic

Trying to mix frequent and infrequent traffic requires long computer runs to get enough observations of the infrequent traffic to understand its effect. The workstations have on the average two transactions as second. The modalities average only slightly more than one event a minute. Further, the workstations are a uniform population, while the modalities have different characteristics. To get a significant number of modality events, one could run the full model for more than an hour of simulated time at a large cost in processor utilization. To get around the problem one can run the uncommon events separately to understand them (figures 8, 9, 10) or run them at several times their normal rate with the full model since they are unlikely to occur coincidentally even at higher rates (figure 13). Neither of these techniques is completely satisfactory.

![Table](attachment:image.png)

Workstations With Ethernet and Simplified Traffic

| 60 Work Stations Each Sending: | 1500 byte request |
|                               | - Twice per minute |
|                               | - For 380,000 byte picture |

10 Adapters Available At Host(s)

Results

Round Trip Time (W/O Application Delay): 2.89 Sec.

Includes (Per Packet):
- 27 msec at Host I/O Channel
- 37 msec at Host 1/O Driver Software
- 56 msec at DLC
- 995 msec at Workstation I/O Driver

Figure 13: Workstation Traffic Only
Utilization of resources in a complex communication model needs close watching. In many parts of such a system there can be no queueing delay. For example, in the real world packets arriving at an adapter must be read immediately into a available buffer or be lost. Data loss does happen in the real world, thus knowing how many packets are dropped is useful. Assuming an infinite number of available buffers and calculating the distribution of buffer in use is a valuable way to help system architects pick the appropriate number of buffers for a system that is only in the planning stage.

CONCLUSION

Simulation showed itself to be a useful tool in analyzing the PACS architecture and traffic. We were able to show that given our assumptions either Ethernet or 4 mbps token ring could handle the short transaction traffic and large image data files characteristic of the asynchronous PACS environment. The LAN media (i.e. OSI layers 1-4) was shown to be far less critical to the message propagation delay than the device high level software, especially when accompanied by a disk access requirement. Modelling of the 10 mbps token ring illustrated the constraints being imposed by the device technology. Workstation architectures, internal buses, and software efficiencies became more significant issues in this environment. Wise PACS designers would be well advised to remove disk accesses and complex workstation processing functions from the critical timing path of the operator response times.

REFERENCES


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