Report Number: WUCS-82-2

1982-01-01

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# STUDY OF A DISTRIBUTED PICTURE ARCHIVING AND COMMUNICATION SYSTEM FOR RADIOLOGY

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Presented at the 1st International Conference & Workshop
on Picture Archiving & Communication Systems
January 18-21, 1982, Newport Beach, California

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# Study of a distributed picture archiving and communication system for radiology

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## Abstract

A preliminary design study has been carried out for a distributed picture archiving and communication system for the Mallinckrodt Institute of Radiology. The study develops design equations for three layers of a picture network and examines the estimated flow of digital images between a multiplicity of picture sources, picture archives and picture viewing stations. Application of these data to the design equations leads to some preliminary conclusions. One network architecture consistent with these conclusions is discussed.

## Introduction

The layered approach to the design of computer networks has been well developed in the contexts of distributed data processing and office automation. We suggest an analogous approach for picture archiving and communication systems (PACS). By studying the first three layers (physical, picture link, picture network) several design equations appropriate to PACS can be obtained. These equations combined with estimates of the flow of digital images, provide a methodology for the prediction of the performance of various PACS designs. The rapid response requirements of a department of radiology coupled with the quantity of data, suggest architectures that differ markedly from the popular store-and-forward approach to computer networks. A two-level interconnect utilizing multiple broadcast channels is proposed and discussed. Although this architecture is neither the only alternative nor new, the methodology and the example of its use illustrate a means for analysis and comparison of design alternatives.

The advent of digital radiographic images has revealed the prospect of a picture network. Early reports of the design of such systems have appeared,[1,2] optical disks for archiving images have been prototyped[3,4] and methods for image compression have been suggested[5]. Advantages of PACS have been widely recognized, but the present level of development of computer networks is inadequate for rapid response, high volume systems. Careful design will be required if the anticipated advantages are to be achieved. This study attempts to make a contribution to design methods for PACS.

The basic form of a PACS (Figure 1) includes three classes of nodes interconnected by a high bandwidth digital network. The first class of nodes includes all image sources: computed tomography (CT), nuclear medicine, ultrasound, digital subtraction angiography and eventually chest and other forms of radiology. The picture archive may be centralized or distributed, but seems likely to be heavily dependent on the new technology of optical disks to provide the dense packing of information required. Picture viewing stations that incorporate image processing responsive to the radiologist's needs are the third class of nodes on the network. The functional characteristics of these stations are just emerging, but rapid response seems to be a high priority requirement whether the image to be viewed is in a distant archive or has already been retrieved but needs to be processed before viewing.

PACS engineering design is in its infancy, but one conclusion is clear. Design issues previously studied in the context of computer networks must be reviewed. Specifications for PACS are unique and new models for the networks required must be developed.

## Modeling a picture archiving and communication system (PACS)

We adopt the layered approach to networks. This approach reduces design complexity and conforms to modern practice. The Reference Model of Open Systems Interconnection (OSI) proposed by the International Standards Organization (ISO) has seven layers[6], but in the following we consider only the first three layers. The first is the physical layer corresponding to ISO terminology. Since this study is aimed at picture archiving and communication exclusively, we shall call the next two layers the picture link layer and the picture network layer.

### Physical layer

The design issues for this layer concern the transmission of raw bits over a coaxial cable, a microwave link or an optical fiber. Picture service will require wide band transmission hence neither telephone lines or twisted pair cable are considered.

The physical layer provides a channel with a capacity C in bits per second (b/s) and bit error rate e in erroneous bits per bit transmitted. The channel can transmit D bits of raw data from source to destination in $\tau$ seconds where

$$\tau = \frac{D}{C} \tag{1}$$

The propagation time has been neglected here because signals travel from one point in a local area network to another in times that are several orders of magnitude less than the transmission time $\tau$. Although (1) is disarmingly simple it forms the foundation of the analysis to follow. To emphasize this relationship, the transmission time $\tau$ is plotted in Figure 2 against the channel capacity C with D a parameter chosen to correspond to pictures with 512 x 512, 1024 x 1024 and 2048 x 2048 pixels and with each pixel represented by 8 bits.

For convenience in what follows we have chosen to call a picture with 512 x 512 x 8 bits a standard picture frame (spf). Thus a 1024 x 1024 x 8 picture corresponds to 4 spf and a 2048 x 2048 x 8 picture corresponds to 16 spf. Simple scaling, e.g., 1.25 for 10 bits/pixel adjusts to a specific image characteristic. Other sizes of images may be used by assigning a single scale factor for each different image size. Note that transmission times less than 1 second require channel capacity greater than 2Mb/s for an spf (Mb abbreviates megabit, not megabyte). A 16 spf picture must have a channel capacity of greater than 32 Mb/s for subsecond transmission times.

## Picture link layer

The second layer takes the raw transmission facility provided by the physical layer and transforms it into a channel that can transmit pictures with a vanishingly small probability of error in spite of the finite error rate e of the physical layer. It transmits information from source to destination in a unit of data that we shall call a frame[7]. Noise may cause a frame to arrive at the destination in damaged condition. The picture link layer at the destination must detect this error and reject the frame. The picture link layer at the source must subsequently retransmit the frame and when the frame eventually arrives at the destination with no detectable errors the picture link layer there must acknowledge its acceptance.

The protocol that accomplishes this retransmission of damaged frames requires the attachment of a prefix and a suffix to the data. The purpose of the prefix is to aid in frame synchronization, to number sequentially the frames and to pass along other control information. The purpose of the suffix is to provide error checking. The destination sends to the source an acknowledgement, which may be a separate transmission or may be "piggy-backed" on data bound in the reverse direction. We assume the prefix and suffix together occupy H bits and the acknowledgement A bits.

The addition of control information and the retransmission of damaged frames increases transmission time. To quantify this effect we introduce the delay factor $\delta$,

$$\delta = \frac{\text{actual transmission time}}{\text{ideal transmission time}} - 1 \quad , \tag{2}$$

the fractional increase in the mean transmission time introduced by the actual channel as compared to the ideal channel. In the picture link layer the number of retransmissions n is distributed geometrically[8] with mean

$$\bar{n} = \sum_{n=0}^{\infty} n\ (1-p)^n\ p = \frac{1}{p} - 1 \tag{3}$$

where $(1-p)^n$ is the probability of exactly n retransmissions preceeding a successful one and where p is the probability of a successful transmission

$$p = (1-e)^H (1-e)^D (1-e)^A = (1-e)^{D_L} \tag{4}$$

assuming independence of errors. In (4) the total number of bits transmitted is $D_L$ = H+D+A, H+D in the forward direction and A in the reverse direction.

On the average there are a total of $\bar{n}$ + 1 transmissions including the successful one. Thus the total transmission time for the picture link layer is

$$\tau_L = \frac{D_L}{C}\ (\bar{n} + 1) = \tau\ \frac{D_L}{pD} \tag{5}$$

The delay factor for this layer is

$$\delta_L = \frac{\tau_L}{\tau} - 1 = \frac{D_L}{\rho D} - 1 \approx D_L\, e \tag{6}$$

where the approximation holds for $H+A \ll D$ and $D_L\, e \ll 1$. Transmission of a complete spf ($2.1 \times 10^6$ bits) does not degrade the transmission time measurably for $e < 10^{-9}$, an achievable error rate for local networks[9].

In summary, easily achieved constraints ($H+A \ll D$ and $D_L\, e \ll 1$) insure that $\delta \approx 0$ and that transmission time at the picture link layer is given by (1) and Figure 2.

Picture network layer

The third layer of PACS interfaces the host computers at the picture source, archive and viewing station to the network. At the source, a set of images from a study is partitioned into a set of frames, routing and control information is added to each frame to form a packet intended for a particular destination, and the flow of packets into the network is adjusted to match network traffic. At the destination this layer receives packets from the network, monitors the flow of packets from the network and organizes the received packets into a set of images that constitute a study.

Model applications. Modeling the picture network layer of a PACS is more difficult than the picture link layer, but some insight can be gained by study of the single network node of Figure 3. Let us assume that the processor executes the protocol of the picture network layer and connects j inbound channels to k outbound channels each with capacity C. The processor may be a node in a store-and-forward network with j inbound and k outbound channels, may be a gateway or bridge between two networks with j=k=1, or may be a channel controller associated with a single host. In the last case the j inbound channels may represent the network traffic destined for the host and a single outbound channel (k=1) represents a DMA transfer to another memory or to disk storage. Alternatively, a single inbound channel (j=1) may represent DMA transfers and the k outbound channels represent the traffic destined for the network.

The model of Figure 3 may be applied in at least one more circumstance. Suppose the outbound channel is a broadcast channel contended for among j processors at network nodes. Furthermore, assume an arbitration scheme for acquisition of the broadcast channel that avoids or limits collisions. The collection of processors at network nodes share a distributed queue that is composed of all images waiting to utilize the outbound broadcast channel. This single outbound channel (k=1) has capacity C.

This interpretation of Figure 3 assumes the time required to acquire the channel is small compared to transmission times. Collisions which are not detected until the entire packet is sent may cause this assumption to be violated. Queueing in ring networks can be modeled in a similar manner, but arbitration must be fair and ring acquisition times small compared to transmission times.

Response time. In all of the above cases we can consider an abstraction of the problem which includes only the source rates $\lambda_i$ in studies per second, the channel capacities C in bits per second and the study size m in packets per study. We further assume that origination of studies at the $i^{th}$ source ($1 \le i \le j$) can be represented by a Poisson process with rate $\lambda_i$. Although Poisson statistics may not be appropriate in specific cases, other assumptions are mathematically difficult and, at best, equally hard to justify. Calculations with Poisson statistics can give good design information, but may fail if detailed predictions are required. The study size m is assumed to be an integer valued random variable.

The transmission time $\tau_L$ found for the picture link layer (5) applies to each outbound channel and leads to a service time $m\,\tau_L$ for an M/G/1 queueing model[10,11] with Poisson input, random service times and a single server. Note that only one outbound channel can be in service at a time, but the processor may switch channels between studies.

We assume that the control information added by the picture network layer is included in the header and acknowledgement portions of the packet produced by the picture link layer. With these definitions and assumptions the traffic intensity $\rho$ is given by

$$\rho = \lambda\, \bar{m}\, \tau_L \tag{7}$$

where $\lambda$ is the total source rate $\lambda = \sum_{i=1}^{j} \lambda_i$; $\bar{m}$ is the mean study size; $\tau_L$ is the packet transmission time; and $\bar{m}\,\tau_L$ is the mean service time. The mean response time $\tau_N$ at the picture network level is the time a study spends in the queue and in being transmitted (serviced). This time is given by the Pollaczek-Khinchine formula[10,11]

$$\tau_N = \bar{m}\,\tau_L\,(1 + \beta\,\frac{\rho}{1-\rho}) \qquad (8)$$

where $\beta = \frac{1}{2}\,E\,(m^2)/(\bar{m})^2$ is half the ratio of the second moment of the study size to the square of its mean. For example, a geometric distribution for the study size leads to $\beta = 1 - 1/(2\bar{m})$. Thus, for a large mean study size $\beta = 1$, the maximum value possible for the assumed distribution and the same result that would have been obtained had an exponential distribution of service times been chosen. On the other hand, for a constant study size $E(m^2) = (\bar{m})^2$ and $\beta = \frac{1}{2}$. For mixtures of the two cases the coefficient $\beta$ in (8) is bounded by $\frac{1}{2} \le \beta \le 1$.

The delay factor for the picture network layer can now be calculated,

$$\delta_N = \frac{\bar{m}\tau_L}{\bar{m}\tau} - 1 = \frac{D_L}{pD}\,(1 + \beta\,\frac{\rho}{1-\rho}) \approx \beta\,\frac{\rho}{1-\rho} \qquad (9)$$

where the approximation is valid for the same conditions required for the approximation in (6).

Buffer size. The buffer size required for the processor in Figure 3 is determined by $\rho$ and the distribution of study sizes. General results are not available, but Dor[12] tabulates values for a queueing model equivalent to a constant study size. For example, to obtain a probability of buffer overflow of $10^{-3}$ for $\rho = .2$ requires a buffer with capacity four times the mean study size. This is an optimistic result since a random distribution of study size can only increase the probability of overflow under the same conditions.

For this reason store-and-forward networks seem ill-suited for picture service. Note that smaller packets do not improve the situation. Fast response to requests for the transmission of an entire study cannot be achieved if some packets are delayed because they cannot fit into a buffer enroute. Consequently, circuit-switched, broadcast or ring networks seem most appropriate for picture service.

By use of the design equations (1), (5), (6), (8) and (9) we can analyze many features of PACS architectures. To make our conclusions meaningful to MIR we need data on the present level of study generation and utilization.

## Data from the Mallinckrodt Institute of Radiology (MIR)

At the Mallinckrodt Institute of Radiology (MIR), overall activity has grown steadily for the last ten years at a rate of about 10,000 diagnostic studies per year to a level of 250,000 studies performed between July 1, 1980 and June 30, 1981. In early 1970, digitized images from Nuclear Medicine were beginning to find everyday clinical usefulness, and in 1981, 4,408 digitized studies were performed. Other digitized studies such as CT head studies have grown from 682 in 1974 to 7,085 in 1981 and CT body studies have grown from 656 in 1976 to 3,531 in 1981. With new imaging instruments that are available in other radiology disciplines such as ultrasound, digital subtraction angiography, digital chest x-ray units, and digital portable units, the number of digitized images will increase greatly in the 1980's.

### Study size

The studies performed at MIR in 1981 are categorized in Table 1 according to those presently digitized, those that are likely candidates for digitizing, chest x-rays, and other radiographic procedures. The number of images per study is also included in this table, having been obtained by sampling a number of studies of each type. The numbers indicate that about 250 thousand studies or about 1.5 million images were generated in MIR in 1981. The data in Table 1 can be extended using image array sizes for current instruments and estimating future array sizes for chest and other exams. The result is that a study size of about 10 spf's is appropriate as a typical study size, and would have to be increased to about 40 spf's if chest and other exams were digitized with an array size of 2048 x 2048 x 8 bits. These values can be used in predicting the effects on the network model for currently digitized images as well as future requirements if all images in MIR were to be included.

Table 1

| | 1981 Studies | Cumula-tive study total | Images per study | Array size (bits) | Array size (spf) | Average study size (spf) | Cumulative average study size (spf) |
|---|---|---|---|---|---|---|---|
| Presently digitized | | | | | | | |
| CT head | 7085 | | 27.31 | 256x256x11 | .34 | 9.4 | |
| CT body | 3531 | | 21.67 | 320x320x11 | .54 | 11.6 | |
| Nuclear Med. | 4408 | | 73.01 | 64x64x8 | .015 | 1.1 | |
| | | 15,024 | | | | | 7.5 |
| Soon-to-be digitized | | | | | | | |
| Nuclear Med. | 8008 | | 9.53 | 64x64x8 | .015 | .1 | |
| Ultrasound | 4074 | | 41.00 | 512x512x6 | .75 | 30.8 | |
| | | 27,106 | | | | | 8.8 |
| Chest x-rays | 104,582 | | 1.92 | 1024x1024x8 | 4 | 7.7 | |
| | | 131,688 | | | | | 7.9 |
| Other exams | 118,183 | | 3.92 | 1024x1024x8 | 4 | 15.7 | |
| | | 249,871 | | | | | 11.6 |
| Chest plus other exams | 222,765 | | 2.98 | 2048x2048x8 | 16 | 47.7 | |
| | | 249,871* | | | | | 43.5* |

*This entry is obtained by increasing the array size to 2048x2048 for both chest and other exams.

### Source rates

The other piece of information needed for the network model is the rate of studies that must be carried on the network. Figure 4 is a plot of studies performed per hour at MIR. The actual data are averages for 15 minute periods for seven Mondays in September and October of 1981, Monday typically being the busiest day of the week. The peak rate is reached for the two 15 minute periods between 8:30 and 9:00 a.m. and corresponds to 136 studies per hour (34 studies in 15 minutes). When the less active period between 8:00 and 8:30 a.m. is added the hourly total is 130 studies. These values can be used in the model to predict the delay factor due to competition for the network resource. Only image generation is represented in the solid curve of Figure 4. Images retrieved for viewing must also be included, but no hard data are available to predict this traffic. Some assumptions can be made, however. The average study production for 43 weekdays in September and October of 1981 was 47.6 studies per hour. If we assume that every image generated will be retrieved an average of two times, then the average retrieval rate for studies is about 100 studies per hour. From a study done at MIR on the distribution of times when chest films are read (dashed curve in Figure 4), it can be seen that a six-to-one ratio of peak-to-average activity is not an unrealistic estimate for retrieval rates.

### Network response time

This gives a range of peak network activity from .04 studies per second (rate of 136 per hour generated and currently digitized) to .2 studies per second (rate of 736 per hour for all images either generated or retrieved at peak periods of activity). Figure 5 summarizes network response time $\tau_N$ for this range of activity and for average study sizes of 10 and 40 spf's. A curve for network activity at .4 studies per second is added in Figure 5 to help judge the effects of future growth. We assume a geometric distribution for study size and consequently $\beta = 1$ for each of these curves.

## A proposed architecture

The design equations and the estimates of network traffic for MIR are summarized in Figure 5. Typical average study size is either $\bar{m} \simeq 10$ spf or $\bar{m} \simeq 40$ spf depending on the resolution chosen for chest and other x-ray studies. The total source rates range from $\lambda = .04$ to $\lambda = .2$ depending on the estimate of image retrieval traffic.

Design goals

Modularity. The continued growth of radiological image production and interpretation at MIR is certain. Improved system components will be developed as technology advances. Both of these facts argue for a modular approach to system design. Furthermore, even current estimates of source rates press the performance of present-day technology suggesting design approaches that distribute the network traffic.

Such an approach requires a partitioning of the network into subnets. Clearly this partitioning should be done in a way that minimizes the traffic between subnets. Considerable locality of traffic seems likely for radiology departments like MIR. Most interpretation of radiographic studies is done within a single imaging modality. This may change in the future because of PACS itself, but a preferred modality exists in most cases and collateral studies in other modalities will, even then, probably represent a small fraction of the total traffic associated with the case.

It is important to recognize that network traffic locality does not require geographic locality. At MIR interpretation is usually done on the floor where the study was performed so geographic and traffic locality are likely to be similar. Subnets that overlap geographically are possible, however, permitting subdivision of network traffic along functional rather than geographic lines.

Subdivision of the picture archive is an important design objective to facilitate modular growth and to prevent a traffic bottleneck at the interface between the archive and the network. The age of the study, the imaging modality and the patient identifier are three possible keys on which to classify studies into disjoint archives residing on separate subnets.

The subnets themselves can be organized in two ways: 1) point-to-point channels or 2) broadcast channels[7]. In the first case, the network contains numerous links connecting pairs of network nodes. In the second case, a single communication mechanism is shared by all nodes. There are, of course, architectures in which these two cases are combined or hard to distinguish.

At the subnet level point-to-point channels seem poorly suited to the task since resource expansion requires substantial rewiring and concentrated patterns of usage place heavy traffic loads on one or a few nodes (the archives). Broadcast channels, however, have a relative advantage under expansion and such concentrated usage patterns.

Reliability. The design goal of a reliable system is obvious. Modularity helps here through partial operability in the face of failure. The layered approach to system development makes protocol design and verification more systematic.

Errors introduced during transmission are likely to be infrequent if modern local area net technology is used[9]. Studies to be archived should be transmitted with vanishingly small probability of error. For retrieved studies a few pixel errors may be tolerated. Error detection and retransmission protocols seem well-suited to the task of error-free transmission and the delay factor expression (6) for the picture link layer indicates a negligible cost for this procedure. In fact, there seems to be little reason to take advantage of the relaxed error criterion that may be tolerated on retrievals.

Response time. Retrieval of an entire study, not part of one, is the most concrete and challenging of the design goals. Until the radiologist makes a preliminary review of the study, he finds it hard to begin detailed interpretation of a single image. For this reason, we have concentrated on the study as the unit of transmission to be provided by the picture network level to the higher protocol levels.

Figure 5 shows that reasonable study response times (one or two seconds) require wide band channels even for low traffic ($\lambda \approx 0$). No amount of local ingenuity can overcome the limitations imposed by a network with inadequate channel capacity.

The requirement for wide band channels is most severe for retrievals. The picture sources have internal buffering for studies and considerable leveling of the uneven generation rate (Figure 4) can be achieved by delaying archiving. The retrieval traffic is greater, however, both in its average value and in its peak-to-average factor. With delayed archiving source rates of $\lambda = .02$ would be adequate. Retrievals cannot be delayed, however, and raise the activity an order of magnitude to $\lambda = .2$ .

### Design choices

Figure 6 is a sketch of an architecture for a proposed PACS designed for our setting at MIR. The specific design choices underlying this architecture and some of the reasons for these choices are listed below.

Two-level interconnect. The physical and functional separation of resources at MIR suggests a natural subdivision into several local subnets for CT body, CT head, bone/joint, chest, gastro-intestinal, nuclear medicine and cardiac studies. A second level interconnect linking these subnets imposes a penalty associated with extra handling of internet traffic, but locality of traffic within a subnet minimizes the effect of this penalty. "Bridges"[13] between the subnets and the second level are utilized that take advantage of a shared address space and a shared protocol throughout the collection of subnets. The address and protocol translation facilities associated with "gateways"[13] are minimized.

Local archive. A local archive within a subnet handles most retrieval requests. A study at MIR shows that 42% of film retrievals are for studies done on the day of the request or on the previous day. Thus a plan that sends the least recently used studies to a central archive would seem to provide satisfactory locality to retrievals within a subnet.

Circuit-switched discipline. The large buffers required for a store-and-forward discipline would surely escalate the cost of a PACS. Each node would be required to store four or more studies to hold the chances of overflow to acceptable values (see section above entitled Buffer size). We propose that virtual circuits be set up in advance for all study transmissions. This decision requires uniform channel capacity throughout the virtual circuit. Buffering for a portion of a study will be necessary at a processor serving rotating disk storage to accommodate disk seek times and network acquisition times, but the channel capacity to and from disk should also match the network. We anticipate that the overhead associated with the establishment of a virtual circuit will be small compared to the total transmission time for a study.

Broadcast subnets. The single communication mechanism shared among all nodes in a broadcast subnet can be a bus, a cable network, or a ring. In all cases the model of Figure 3 applies with $j$ nodes on the subnet and a single ($k = 1$) communication mechanism with channel capacity C. Choices between coaxial cable and optical fiber may be made on a local basis according to detailed engineering studies providing that uniform addressing and protocol standards are adopted. Even a star network with a single central processor may be used as a subnet providing it has sufficient channel capacity. For initial implementation we prefer coaxial cable and an arbitration scheme that avoids or limits collisions.

Some other observations. The volume of data associated with the picture is much larger than that associated with control of the network. Thus, a small fraction of the bandwidth devoted to control is adequate. Both time-division or frequency-division multiplex are possibilities for merging data and control.

Problems with data skew when packets are transmitted within a subnet that may have dimensions of hundreds of feet foreclose the possibility of parallel transmission. Thus serial transmission rates limit the channel capacity.

Disk transfer and seek times are becoming available that are consistent with the network architecture. IBM 3380 technology (24 Mb/s)[14], optical disk prototypes (50 Mb/s)[15,4], VAS disks (160 Mb/s)[16] all have useful transfer rates. Seek times in each case are well under the study transmission time and can be neglected.

Viewing stations should have a fixed set of image manipulations most useful to the radiologist. A central viewing station may be the appropriate place to locate custom processing of images and developmental activities.

Some improvement in response time can be achieved with image compression (up to a factor of 4)[5] and with the transmission of an index image for a study. Preliminary experiments at MIR indicate that up to 16 reduced resolution images can be displayed on a single viewing screen in a 4-image by 4-image array for the purpose of image selection. The transmission of the detailed images can proceed concurrently with the radiologist's examination of the index image. The values of $\lambda$ obtained for each subnet by partitioning the network into 7 parts are certainly greater than 1/7 the total. We expect, however, no more than 1/3 the total traffic on an individual subnet. Thus the response time under overloaded conditions can be reduced substantially (see Figure 5).

## Conclusions

There is no way to predict precisely what the number of radiology studies will be in the years to come, but certainly radiology volume is increasing. Particularly striking is the rate of growth of the digital imaging modalities, and we believe this trend toward digital image growth will continue. But to obtain the maximum clinical advantage of storing images in digital form, a digital imaging network is required to distribute images so that all of a patient's clinical image data is available for immediate review.

A proposed architecture has been suggested to meet the design goals of such a network. It has been designed against the background of a set of design equations for PACS and estimates of current image generation and retrieval activity at MIR.

Some of the conclusions of this analysis include the following:

1. Systems with great bandwidth will be required to handle the retrieval of multi-image studies during peak periods of retrieval activity. Image retrieval must be accomplished quickly and, for a system to be practical, response times must be comparable to those of any interactive computer system, a maximum of a few seconds.

2. Protocols for error detection and retransmission can be accomplished at little cost given currently achievable bit error rates.

3. Of the various network architectures considered, a store-and-forward discipline seems ill-suited to PACS design. By comparison, broadcast local networks have some important advantages for picture service.

4. Modular network architectures, capable of reacting to growth and changes in traffic patterns are essential. Partitioning the network into subnets will reduce bandwidth requirements and increase response time by distributing network traffic.

5. Much work remains to be done including the physical and conceptual design of an archiving system capable of supporting optimal response times, the evaluation of suitable data compression algorithms, the design of inexpensive image display stations, and the design of efficient network interface units to buffer data as it is transferred between the network, source, and archive.

The layered approach to the design of computer networks has been applied to a picture archiving and communication system for radiology. The first three layers (physical, picture link, and picture network) have been analyzed. The resulting equations have been applied to typical data obtained from the Mallinckrodt Institute of Radiology. The two-level interconnect described seems well-suited to our needs, but much work remains to be done.

## Acknowledgements

This study was supported in part by NIH Grant RR00396 from the Division of Research Resources. The authors thank Don Snyder and Ken Wong for helpful discussions. We also thank the students in our 1980 graduate seminar on computer networks. They contributed much to our thinking through their study of PACS as a term project.

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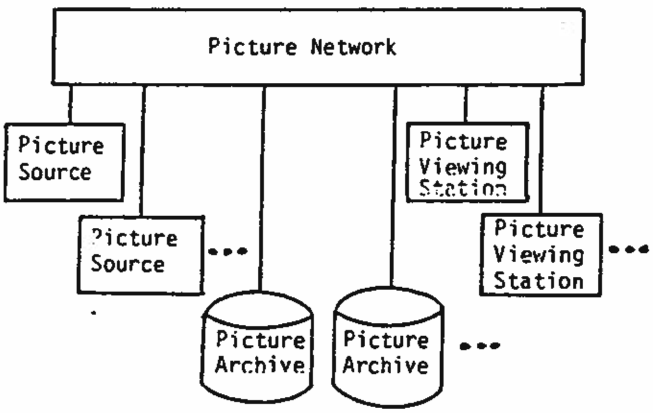



Figure 1. Picture archiving and communication system (PACS) block diagram. Networks should be designed so that growth in the number of picture sources, archives and viewing stations can be accomodated.

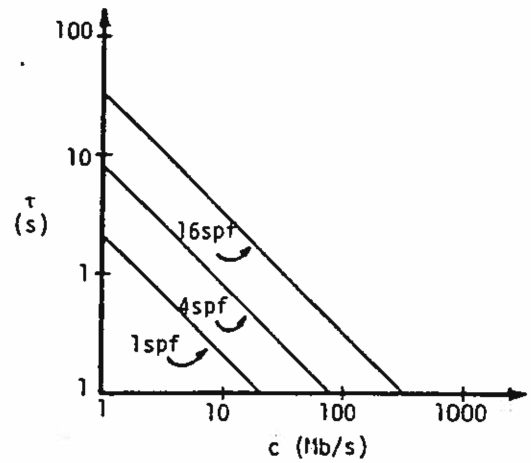



Figure 2. Transmission time in seconds versus channel capacity in megabits per second for the physical layer. Several curves are plotted for 1 standard picture frame (spf) corresponding to 512 × 512 pixels of 8 bits each; 4 spf corresponding to 1024 × 1024 pixels of 8 bits each; and 16 spf corresponding to 2048 × 2048 pixels of 8 bits each.

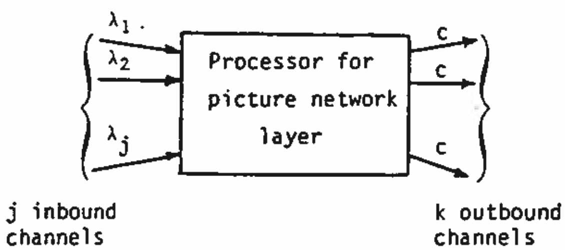



Figure 3. Block diagram of a single network node at the picture network layer. A total of j inbound channels contend for use of the processor to transmit a radiographic study on one of the k outbound channels.

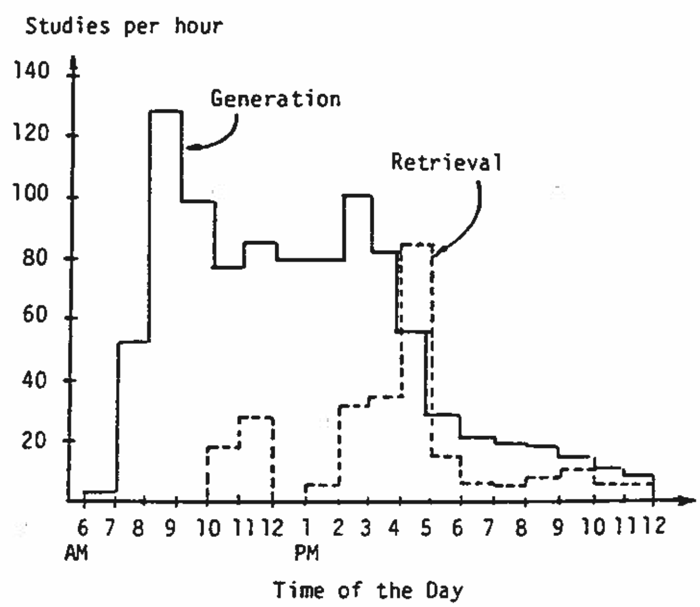
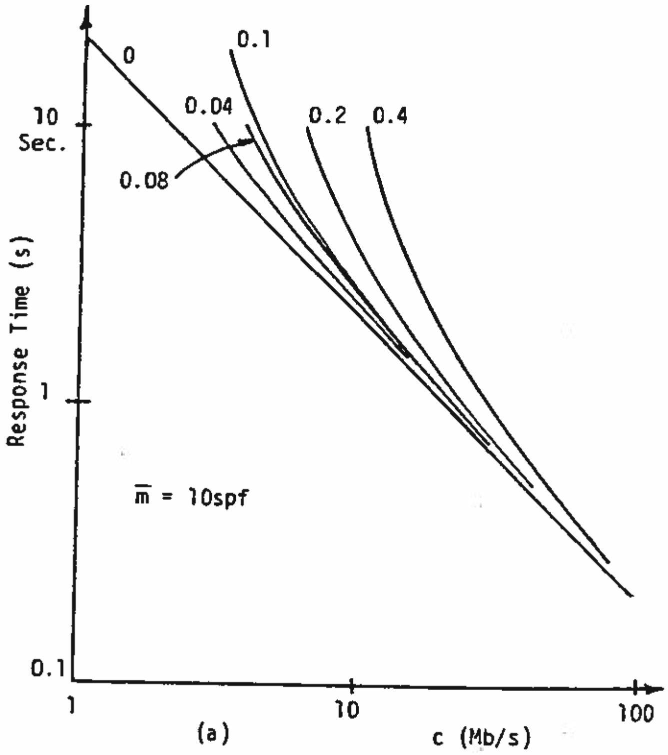



Figure 4. Average rates for study generation (solid curve: seven Mondays of September, October 1981) and study retrievals based on a limited sample of chest film interpretations (dashed curve: July, 1981).



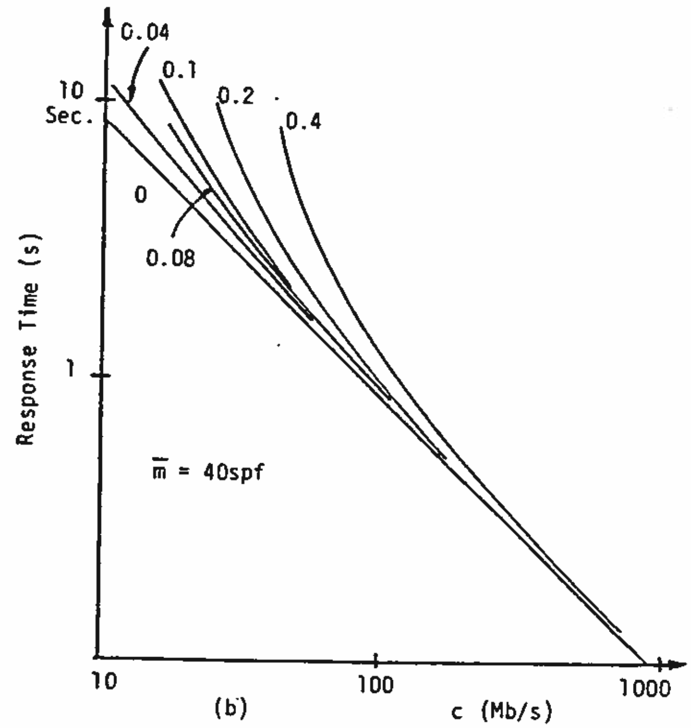




Figure 5. Response time of picture network level versus channel capacity for various values of source rate $\lambda$ in studies per second. Figure 5a is for a mean study size of 10 spf (about 20 Mb) while Figure 5b is for a mean study size of 40 spf (about 80 Mb). Peak values of study generation rate are now estimated at $\lambda$ = .04 while peak values of the sum of the study generation and interpretation rates are estimated at $\lambda$ = .2. Future levels of activity may push rates to $\lambda$ = .4 and beyond.

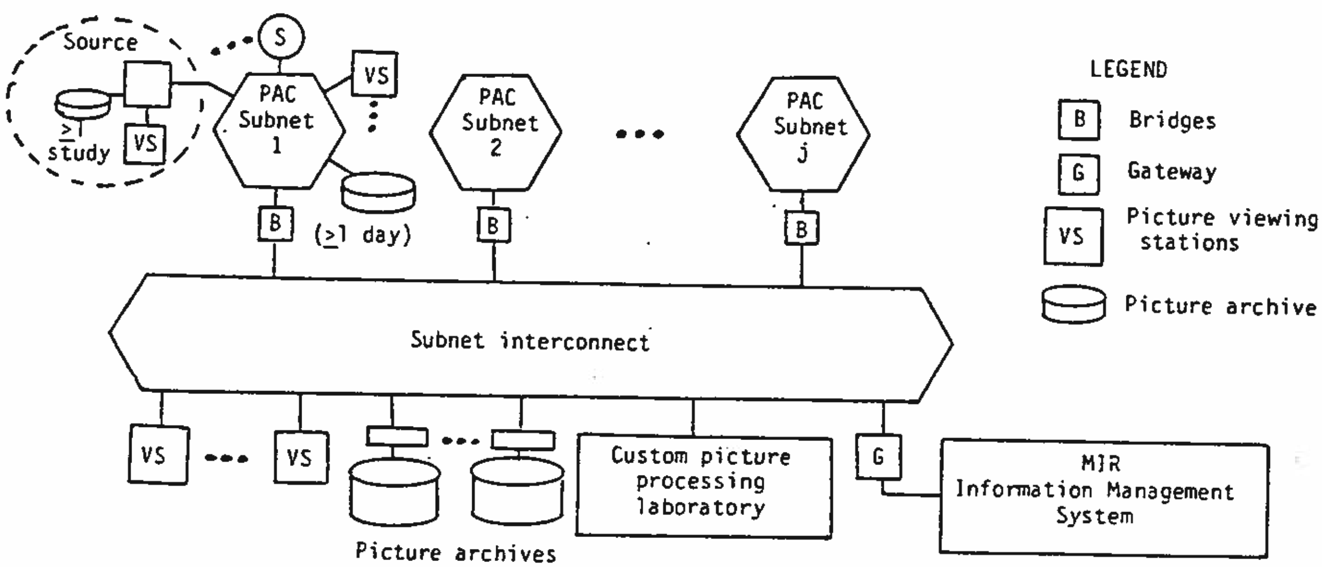



Figure 6. A two-level PACs architecture to support Mallinckrodt Institute of Radiology picture generation and retrieval.