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Design and simulation of a totally digital image system for medical image applications

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DESIGN AND SIMULATION OF A TOTALLY DIGITAL IMAGE SYSTEM
FOR
MEDICAL IMAGE APPLICATIONS

by

Charnchai Archwamety

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and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

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SIGNED: D. Archwamety

DEDICATION

This dissertation is dedicated to my daughter, Anita, my wife, Angsana, and also to my parents, Kok-Cheng Ow and Siew-Jung Ngow.

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ABSTRACT

The Totally Digital Imaging System (TDIS) is based on system requirements information from the Radiology Department, University of Arizona Health Science Center. This dissertation presents the design of this complex system, the TDIS specification, the system performance requirements, and the evaluation of the system using the computer simulation programs. Discrete event simulation models were developed for the TDIS subsystems, including an image network, imaging equipment, storage migration algorithm, data base archive system, and a control and management network. The simulation system uses empirical data generation and retrieval rates measured at the University Medical Center hospital. The entire TDIS system was simulated in Simscript II.5 using a VAX 8600 computer system. Simulation results show the fiber optical image network to be suitable, however, the optical disk storage system represents a performance bottleneck.

CHAPTER 1

INTRODUCTION

Digital technologies are growing considerably fast in this decade. Hospital equipment and instrument are benefiting from this high technology in several areas. One area is the conversion of x-ray image films into totally digital images. This image information can flow inside or even outside the hospital by using a digital network as a media. Electronic image review and analysis consoles replace the light boxes and connect to the network. All modalities (imaging equipment), such as an Ultrasound (US) and a Computed Tomography (CT) Scanner, patch into the network. The magnetic and optical disks for storing the data of images replace the film library rooms and connect to the network. This operation makes things easier and more convenient to handle for image storaging, viewing, processing, retrieving, and generating. In addition, replacing films with the digital form reduces the cost.

At the University Hospital, Arizona Health Science Center (AHSC), the Department of Radiology is planning to use a Totally Digital Imaging System (TDIS). The TDIS system is viable to replace the x-ray films system. However, the performance of the TDIS system must be carefully determined and investigated. The work discusses the system performance requirements, network topology, review console, imaging equipment, media access techniques, and image archiving for the TDIS.

For the economic environment today, the cost of purchasing equipment is a critical decision. A hospital may want the benefits of a TDIS but cannot initially afford the entire system. It is possible for a hospital to start with a partial system first, then add other necessary components later as needed. So an institution does not need to discard the start-up system. A good system or architecture should be flexible, capable of add-on components, modular, and have a standardization of medical equipment. However, there is no electronic data processing standard in hospital environments. Therefore, a definition of the TDIS architecture is necessary to accommodate custom implementations for various Hospital Information Systems and Radiology Information Systems.

Organizing the materials of this work is necessary, and Figure 1.1 depicts the road map block diagram of this dissertation. Chapter 1 contains an overview of a Picture Archiving & Communication System (PACS), two examples of simulation work, and three examples of PACS implementations. This chapter also has a problem statement, research objective, and approach. The approach section describes the

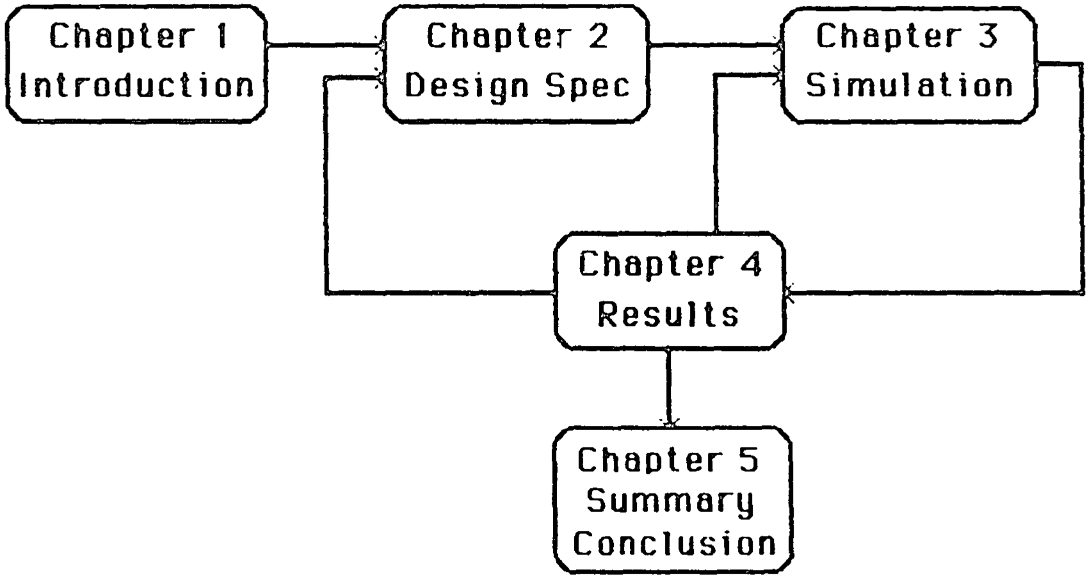


Figure 1.1 Dissertation Road Map

way to design the Totally Digital Imaging System (TDIS) and the use of discrete event simulation language for the simulation.

The second chapter is the TDIS design specification. It comprises the architecture of the overall system including system topology, component interaction and an example of the data transfer rate requirement. This chapter has six subsections corresponding to each subsystem. The subsystems are user workstation, imaging equipment (IE), image data network (INET), control and management network (CMNET), database archive (DBA), and external system. The external system contains the Radiology Information System (RIS) and the Hospital Information System (HIS). In addition, the subsequent section includes system operational scenarios for data generation, storage, and retrieval.

After designing the system specification, one needs to develop the simulation model which is in the Chapter 3. This chapter provides the assumption, user and data flow scenario of the overall simulation system, and the model development of each subsystem. Furthermore, the image migration algorithm also applies to the database archive section. The simulation model uses empirical data for generation and retrieval as the data inputs.

Chapter 4 consists of all simulation results. The simulation processes have four different phases. Phase 1 is the simulation from imaging equipment up to serving processor in the database archive. Phase 2 is up to the first level of data storage. Phase 3 is a combination of data generation and retrieval in a single network channel. Phase 4 has the image migration policy applied in the third phase. The results include image response time with and without queue, the maximum number of requests in queue, and the channel network utilization. This chapter also provides the descriptions of hourly channel utilization and techniques of multiple data creation from the original input data. The results of this section are very useful for Chapters 2 and 3 in order to further develop TDIS specification.

The final section is Chapter 5. This chapter will give the discussion of the results from Chapter 4, summary and conclusion. This section includes system performance evaluation, constraints, improvements, and implementations in the future.

1.1 Picture Archiving & Communication System Overview

Today, most hospitals still use the conventional x-ray films system for patient diagnosis. The Computed Tomography (CT), Ultrasound (US), Magnetic Resonance Imaging (MRI) System are all converted from a digital data format to a film format. These films are then moved to a film library room which needs a large area for storage.

Doctors have to use the film library stations to diagnose, write results and/or consult. The films are not only expensive and unreusable, the are also is time consuming. Everything has to be done manually which makes the system very inefficient.

The Totally Digital Imaging System (TDIS) is a system where the x-rays are processed using digital acquisition, transfer, storage, and retrieval techniques. Image acquisition equipment can transfer the digital examination images and information of the patients directly to database archive through a fiber optic image network. Finally, the database archive system which uses magnetic disks in combination with optical disks keeps all patient's digital x-ray images and textual information. The magnetic disks have fast access and large volume. Optical disks have slow access and very large volume.

The doctors can retrieve any image or sets of images from the database archive for reviewing and diagnosing. In addition, the system can be used to enhance, process (filtering, zooming) the images in fast action for image quality and study as well. All these functions will be performed in automated fashion. Such a system is so-called a Picture Archiving and Communication System (PACS) [Hedge 1986, Fisher 1986]. Figure 1.2 shows the architecture of a

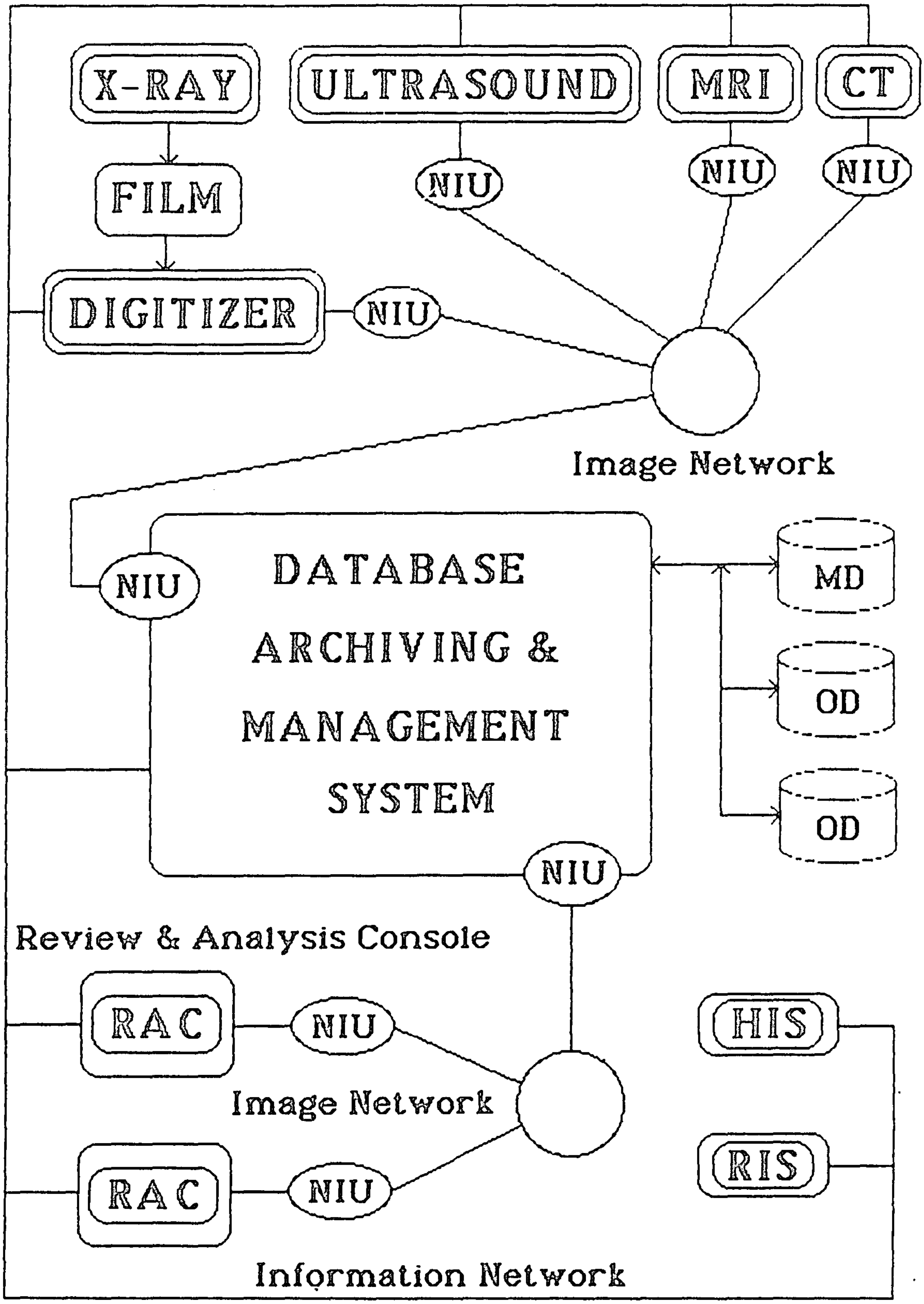


Figure 1.2 Architecture of Typical PACS Radiological Information Environment System

TDIS using high technology radiological information and digital components.

1.1.1 Simulation of PACS

Picture archiving and communication systems (PACS) have been studied from different facets. Previous work in PACS has included simulation studies. The following sections show two different examples of previous simulation work.

a. Lawrence's work [Lawrence 1986] at the IBM Network System Laboratory, Maryland, used two different network types, Token ring and Ethernet. The simulation of simplified PACS environment, using the IBM Research Queueing Package (RESQ), has been performed. The first task is to obtain the response time of workstations only to get the images from modalities onto the channel. The second task used a combination of workstations and modalities with the peak traffic to find the response time. The simulation results showed that system response time was more dependent on the internal architecture and the workstation than on the speed of the transmission media. Either Ethernet or token ring could handle the short transaction traffic and large image data file characteristic of the asynchronous PACS environment. Designers should consider removing the disk accesses and complex workstation processing function from the critical timing path of the operator response times. Figure 1.3 depicts the simplified PACS architecture for the

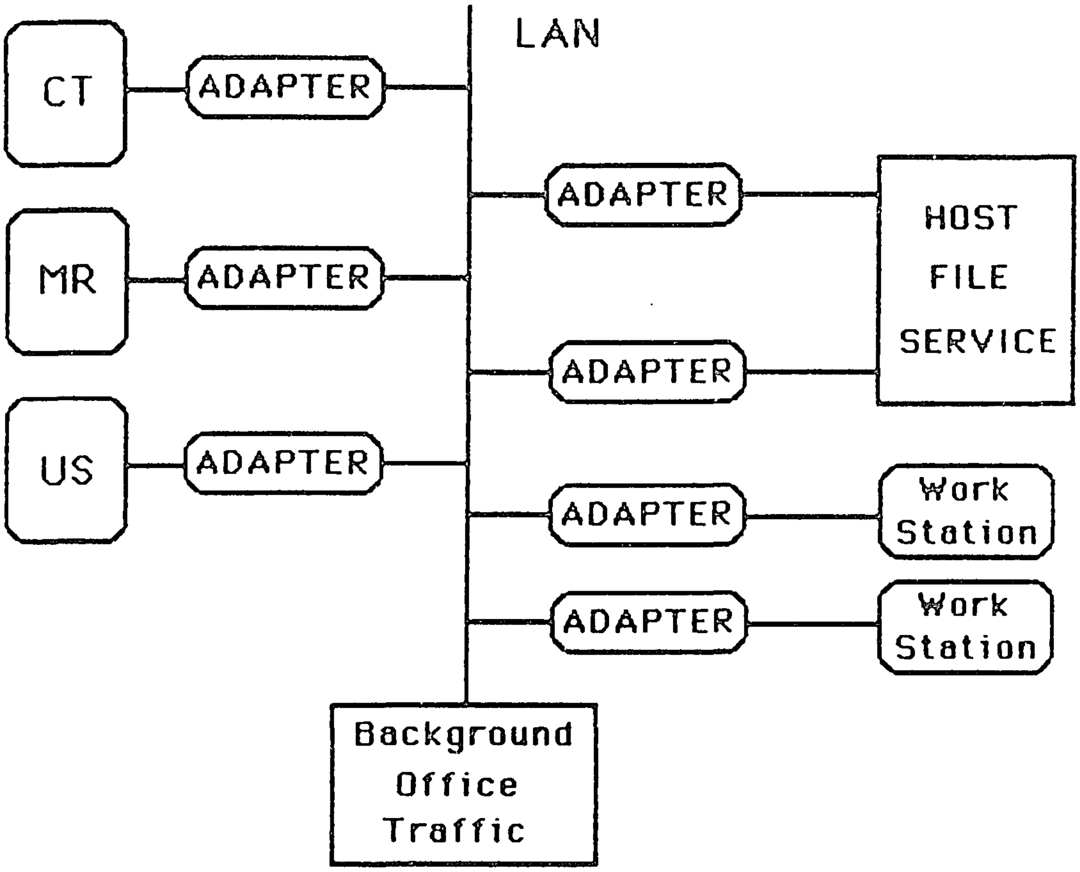


Figure 1.3 Simplified PACS Architecture

Workstations With Ethernet and Simplified Traffic

60 Work Stations Each Sending:
- 1500 byte request
- Twice per minute
- For 180,000 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 I/O Driver Software
- 50 msec at DLC
- 995 msec at Workstation I/O Driver

Figure 1.4 Results for Workstation Traffic Only

IBM study. Figures 1.4 and 1.5 illustrate an example of the output data.

b. The simulation work of Davis [Davis and et al 1986] at the University of Alberta, Canada, simulated a distributed imaging system that was used for storing and retrieving digitally formatted medical images. It used the Ethernet local area network as its communication network. The model also included three modalities, an image processor, an active storage device, an archived storage device, and several workstations. Only the first two layers of the Ethernet as proposed by the IEEE 802 model are implemented. Figure 1.6 shows the Medical Image System with an Ethernet communication bus. Figures 1.7 and 1.8 depict the example results.

The results showed that, for 1024x1024x8 bits images, an Ethernet bus of 10 Mbps capacity will result in response times (related to active storage) of less than 2 seconds even for 24 and possibly 32 workstations. For 2048x2048 images, the 10 Mbps Ethernet channel is clearly not sufficient, however, a 60 Mbps channel might be sufficient. A 100 Mbps channel certainly would allow less than 1 second response time for up to 32 users. For larger 4096x4096 images, a 100 Mbps bus is essential. Even with a 100 Mbps channel, the simulation showed that for more than 3 users it exceeded the 2-second response time.

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

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

Assumptions same as figures 8 - 10

Results:

TOKEN RING	Media Speed	
Traffic	4 mbps	10 mbps
All	.74/7.43	.40/3.61
CT	1.68/2.19	1.04/1.51
MR	.77/1.15	.55/1.03
DF	3.28/3.28	.99/1.12
DIG	7.43/7.43	3.61
1500 byte	.43/5.61	.17/1.27
1/6 mbyte	.90/4.87	.49/1.49
1/2 mbyte	2.00/5.81	1.08/1.36
Utilization	53.9%	21.6%

ETHERNET	Adapter Speed	
	Today's	'89
Traffic	10 msec*	3.5 msec
All	2.46/15.10	1.56/8.10
CT	4.23/5.02	2.00/2.43
MR	2.41/4.11	1.00/1.39
DF	3.98	1.86/1.86
DIG	15.09/15.10	6.63/6.67
1500 byte	1.63/10.74	1.17/7.40
1/6 mbyte	3.01/11.56	1.94/8.09
1/2 mbyte	5.20/11.32	2.32/3.43
Utilization	20.5%	20.2%

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

Figure 1.5 Results for Full PACS with Peak Modality Traffic

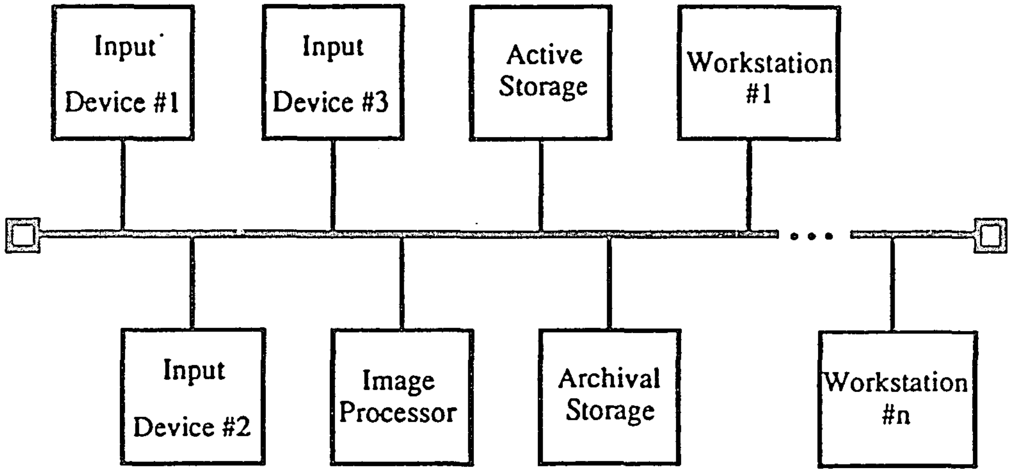


Figure 1.6 Medical Imaging System with an Ethernet Communication Bus

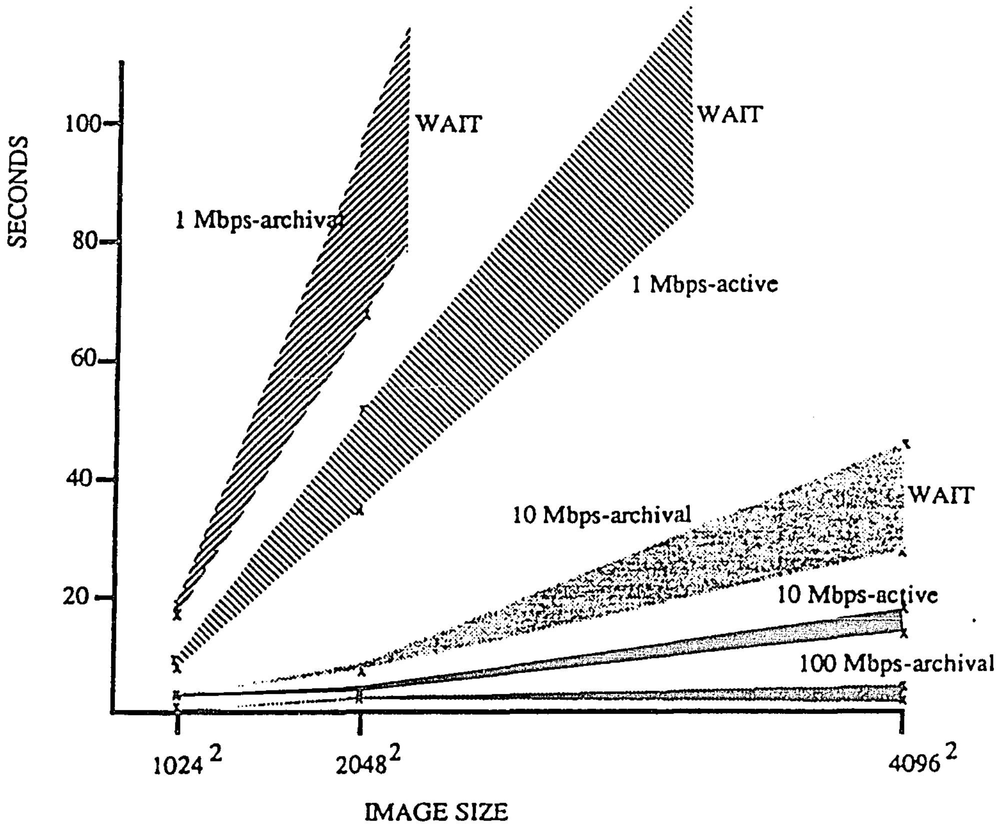


Figure 1.7 One User Average Response Time & Minimum Transfer Time

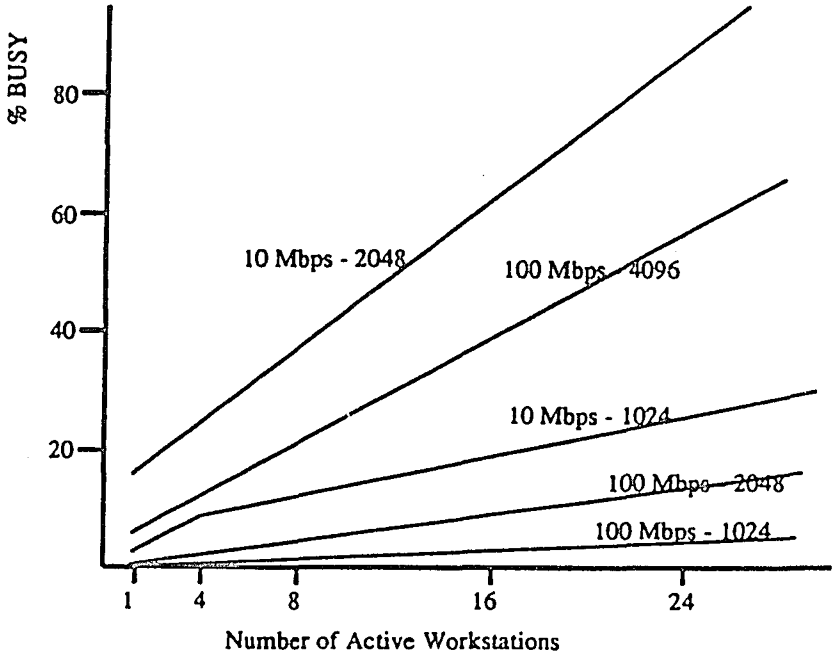


Figure 1.8 Channel-Busy Percentage vs. Number of Workstation

In order to reduce the response time, the system should have some local storage (reducing transmitting images whenever possible) for buffering. The system should not use the CSMA/CD Ethernet for larger image sizes, because an environment of a long sequence of packets results in many collisions, and hence, delays transmitting the images.

1.1.2 Examples of PACS Implementations

Today, a number of hospitals have begun to install and test the commercial and prototype PACS systems. This section summarizes these efforts. Several PACS systems are currently in the R&D phase. One commercial PACS product that is under development in the market right now is the AT&T PACS called CommView [Hegde 1986]. Figure 1.9 shows its architecture. In general, the PACS system has five majors parts. They are:

1. Imaging Acquisition Node
2. Image Network
3. Database Archive & Management System
4. Review & Analysis Console
5. Gateway to External PACS

Figure 1.10 illustrates the interconnections of these major parts, and their architectures are depicted in Figures 1.11, 1.12, and 1.13, respectively. The following sections provide three different examples of PACS implementations.

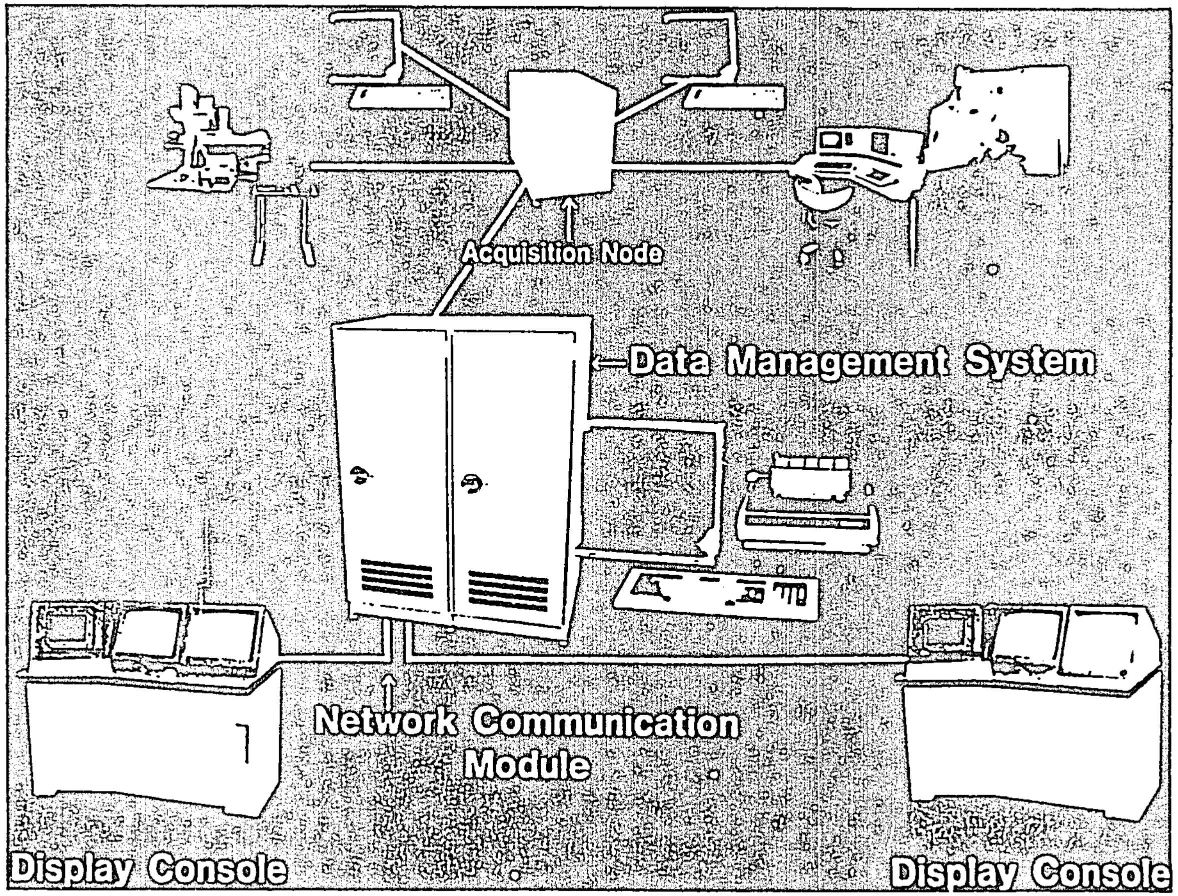


Figure 1.9 CommView Product from AT&T

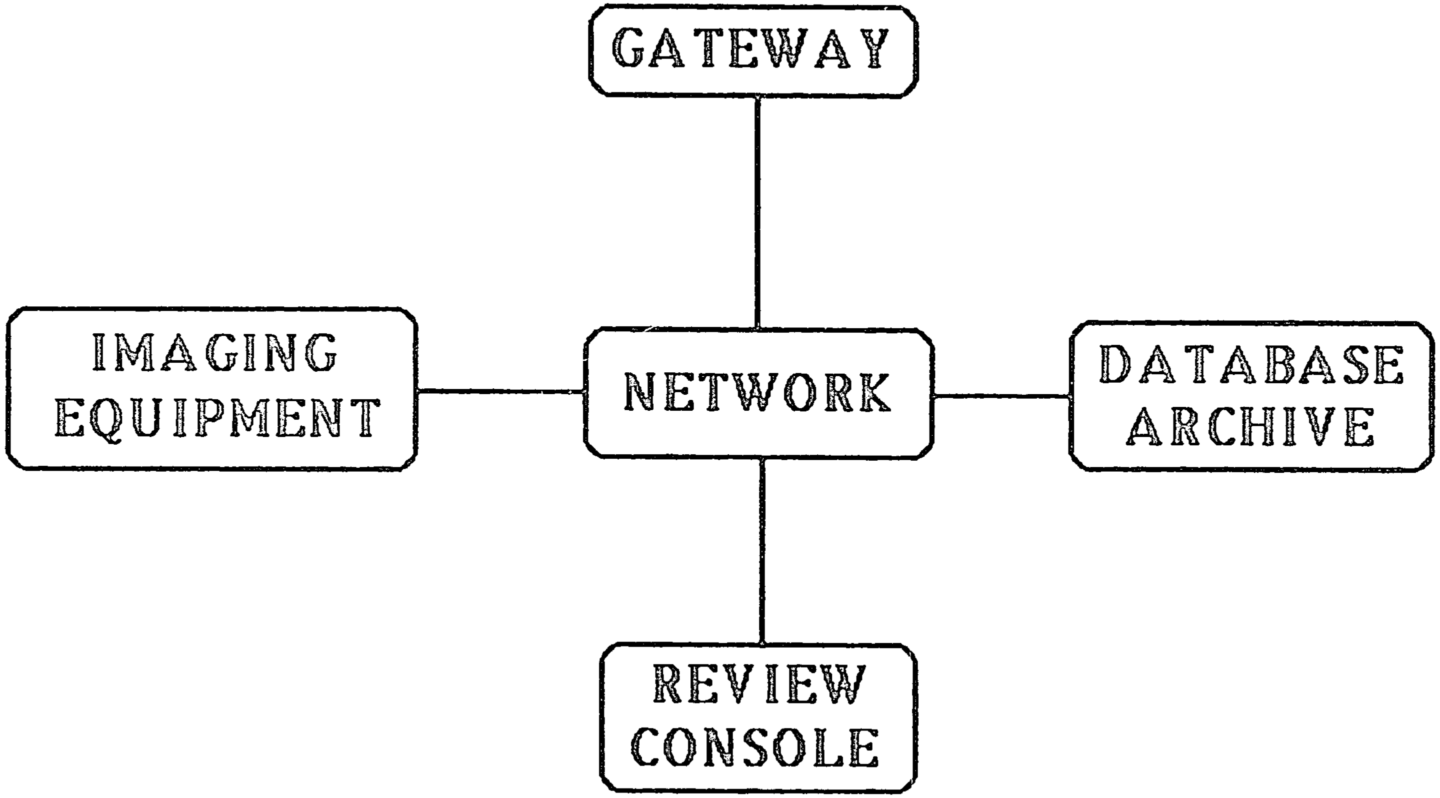


Figure 1.10 5 Major Parts Interconnections of PACS System

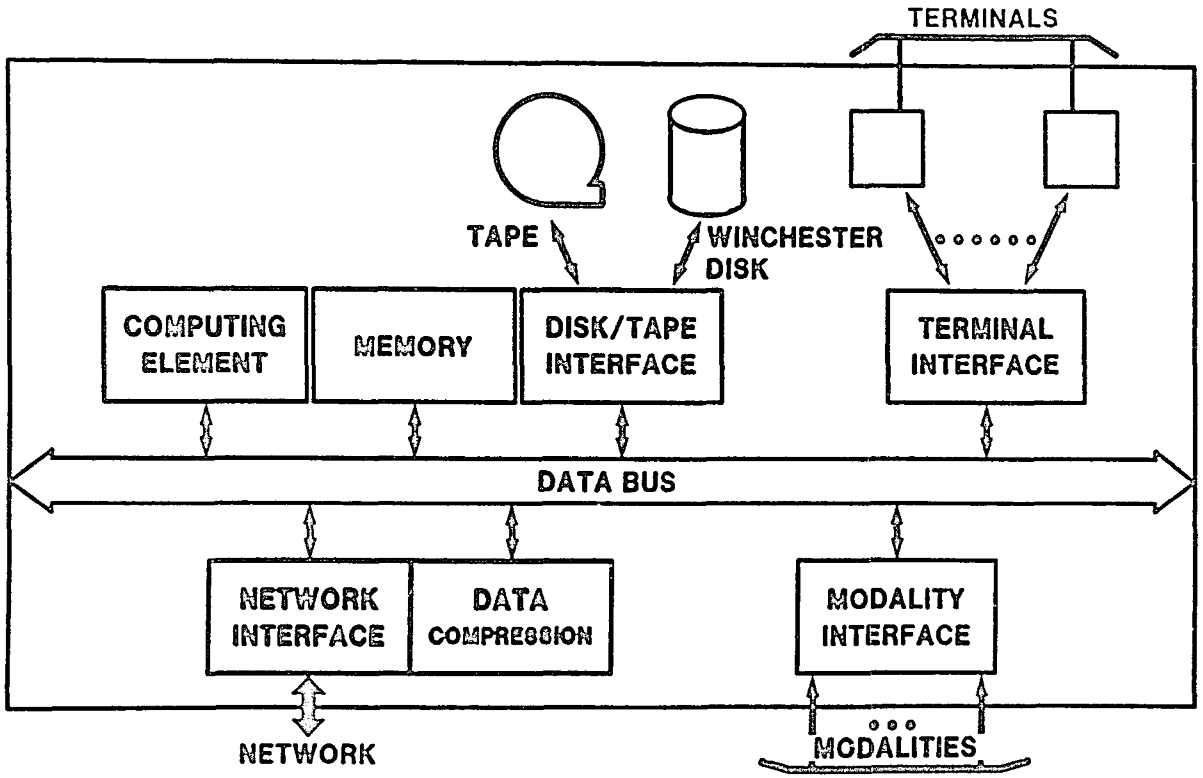


Figure 1.11 Acquisition Node Architecture

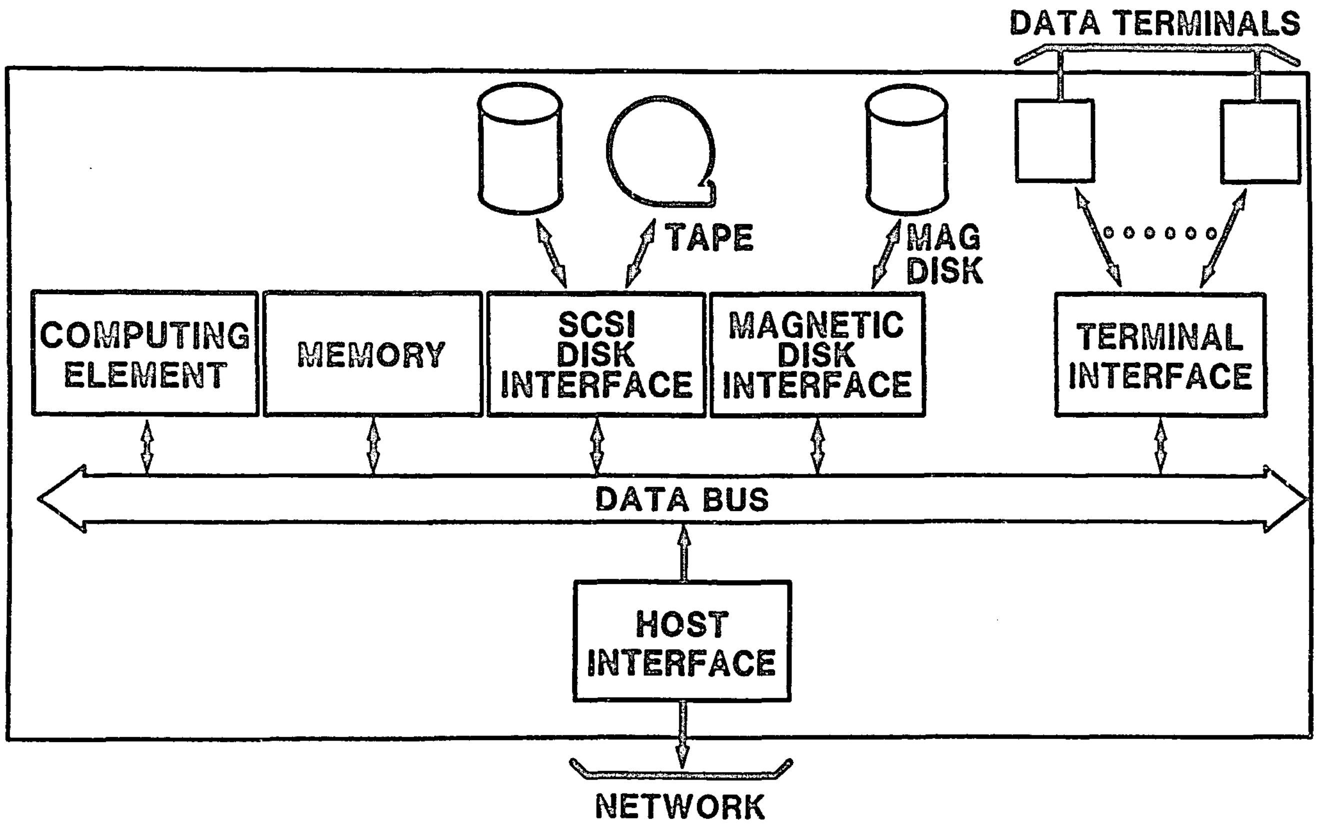


Figure 1.12 Data Management System Architecture

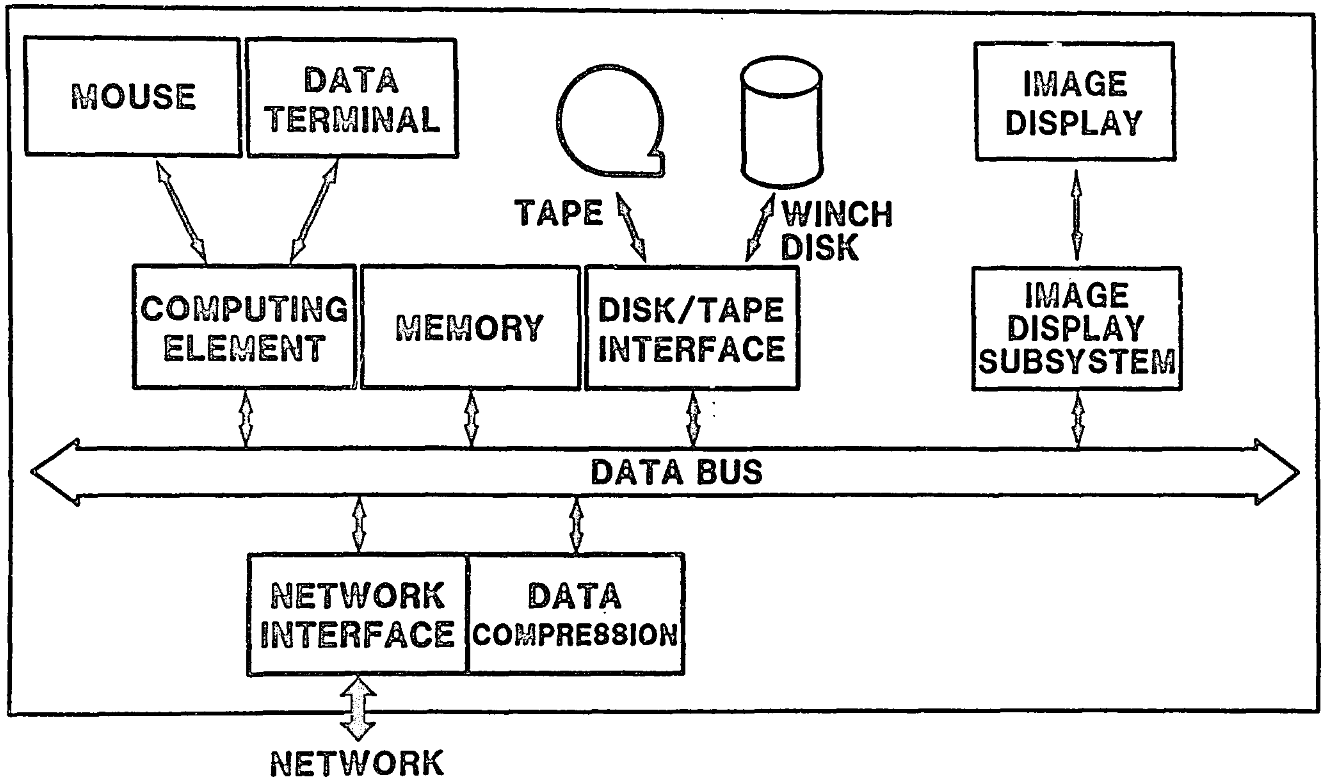


Figure 1.13 Display Console Architecture

a. The Radiology Department at Duke University has CommView installed with a high speed 40 Mbps fiber optic network [Stockbridge 1986]. Figures 1.14 and 1.15 illustrate the Duke PACS and its fiber optic network. There are over 50 clinics, 20 wards, 1000 beds, and a Radiology Department with 45 resident radiologists and 60 staff members. When the system is fully implemented, it will enable physicians to receive patient images in a few seconds.

Images have been transmitted between the Duke South and the Duke North complexes. The fiber optic network provides high coverage of diagnostic image acquisition as well as flexibility through the patch panels. The network provides connections between the Data Management System and Display Consoles selected to serve radiologists, physicians (in-patient), referring clinicians (out-patient). The overall purpose is to help the Radiology department communicate more quickly and more effectively with physicians and clinicians.

b. A prototype PACS (the DIMI project) is currently being developed at the University Hospital at Nantes, France [Bizais 1986]. The image acquisition system acquires 1200 MB per week. Image compression techniques are used to obtain further data reduction. Figure 1.16 shows an acquisition and processing unit (the imaging island). Vinix is a VICOM images processor where runs with Unix System V.

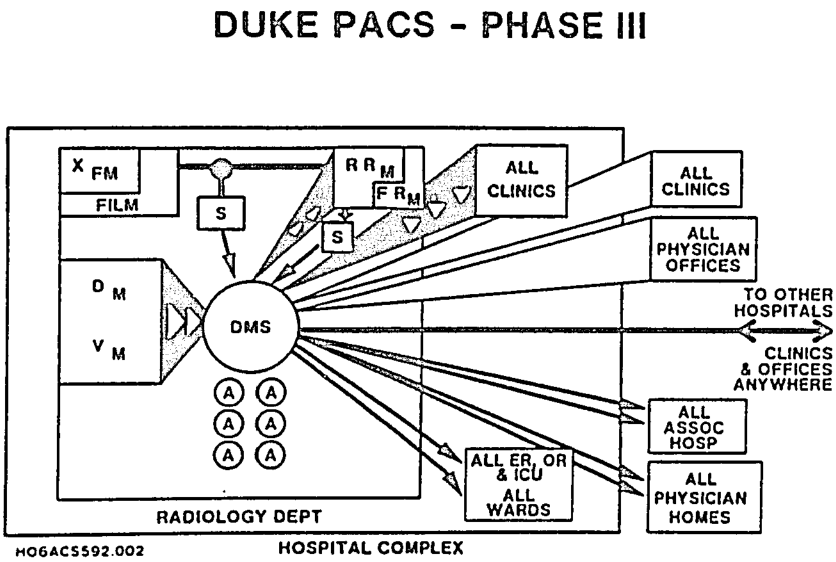


Figure 1.14 DUKE PACS Phase III

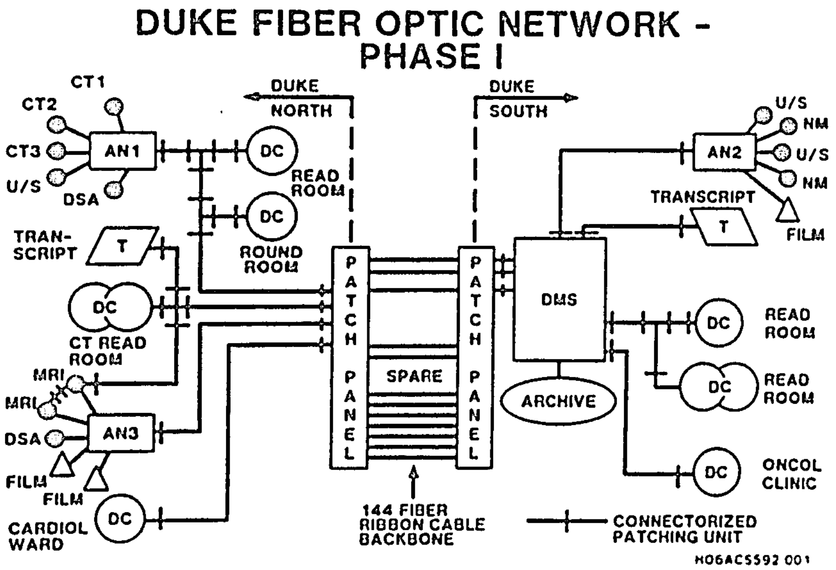


Figure 1.15 DUKE Fiber Optic Network Phase I

A working PACS prototype at the University Hospital of Nantes is being developed. This system has specific features to allow hospital work and applied research. The basic structure of the system is a fast local area network which links an archiving node and four image islands. In each island it is possible to work locally, i.e. to acquire, store, process and display images like with a conventional system. An island also can access remote data about patients and old images like with a true PACS.

Figure 1.17 depicts the DIMI architecture. It consists of 4 Vinixs and a VAX 11/750 running Unix System V with three RA81 magnetic disks and a TU78 tape drive linked together through a double network. Ethernet is for remote login, remote execution, remote interprocess communication, mailing and all necessary functions in a PACS. The Imopnet is for images transmission only with a speed 500 KB per second fiber optic star network. The speed limitation of this network depends mainly on the speed of the host buses.

c. Another commercial PACS system that is available in the market now is CDA (Computer Design and Application, Incorporation) PACS [Birkner 1984]. The CDA PACS consists of a viewing terminal (DELTAview) and user stations (DELTAnode), an archive/distribution machine with both magnetic and optical storage (MegaDELTA), an acquisition

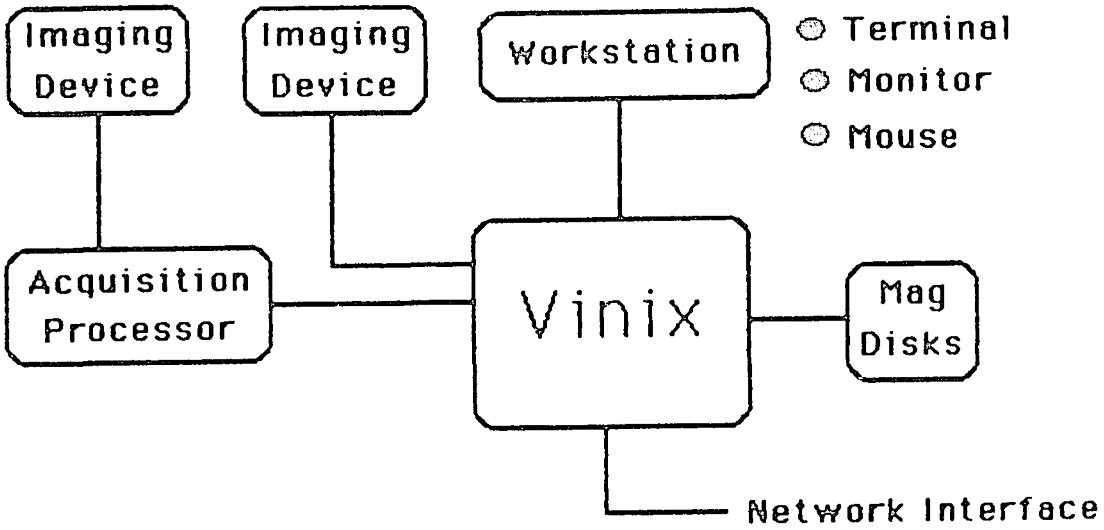


Figure 1.16 Acquisition & Processing Unit : Image Island

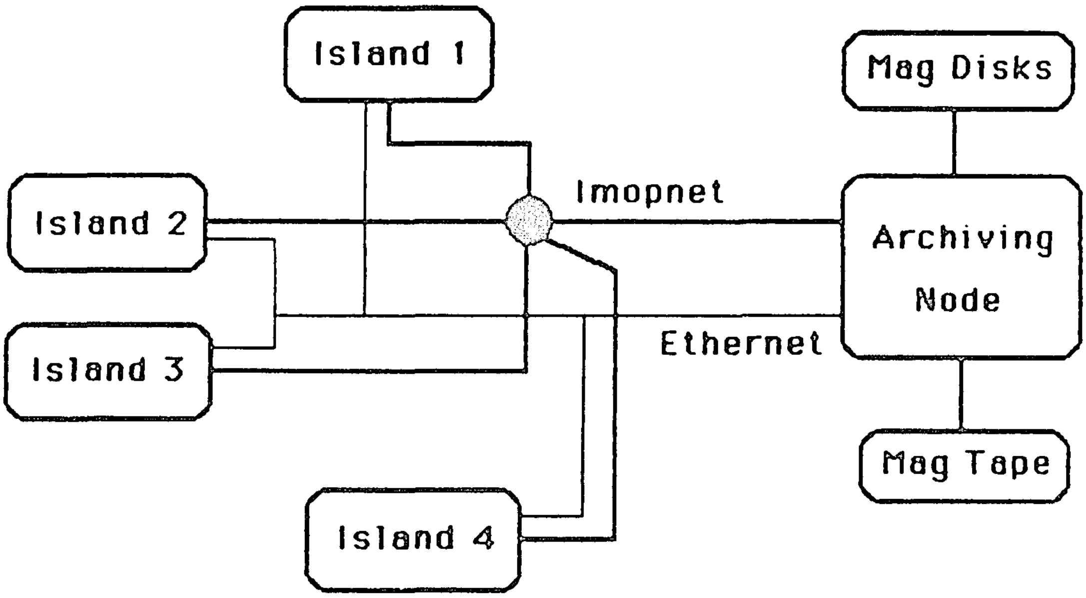


Figure 1.17 General DIMI Architecture

processor (DELTAMaTE) to connect imaging modalities to the archive, and a digital communications network (DELTAnet 2) based on a boardband CATV distribution medium. Figures 1.18, 1.19, and 1.20 show the typical system block diagrams.

1.2 Statement of Problem

The application involves the distribution and archiving of the medical image data, such as X-ray, Magnetic Resonance, Cat Scan, and Ultrasound, in digital format. A PACS must be able to provide an image transfer time suitable for real-time image storage and retrieval. To gain insight into architectural tradeoffs for a complex prototype PACS system, a discrete event simulation tool such as SIMSCRIPT II.5 [Russell 1983] is a good candidate for evaluating the system performance.

Today, most hospitals use the diagnostic medical images (from modalities) in film format. If the hospitals used a TDIS system, it would eliminate or reduce the high cost of silver-oxide film, attendant labor cost, and film developing cost, including the time consumption for archiving (storing), retrieving and displaying images on the light box. The Picture Archiving and Communication System (PACS) or the Totally Digital Imaging System (TDIS) is a good candidate. It offers more responsive service than the film-base manual system of today.

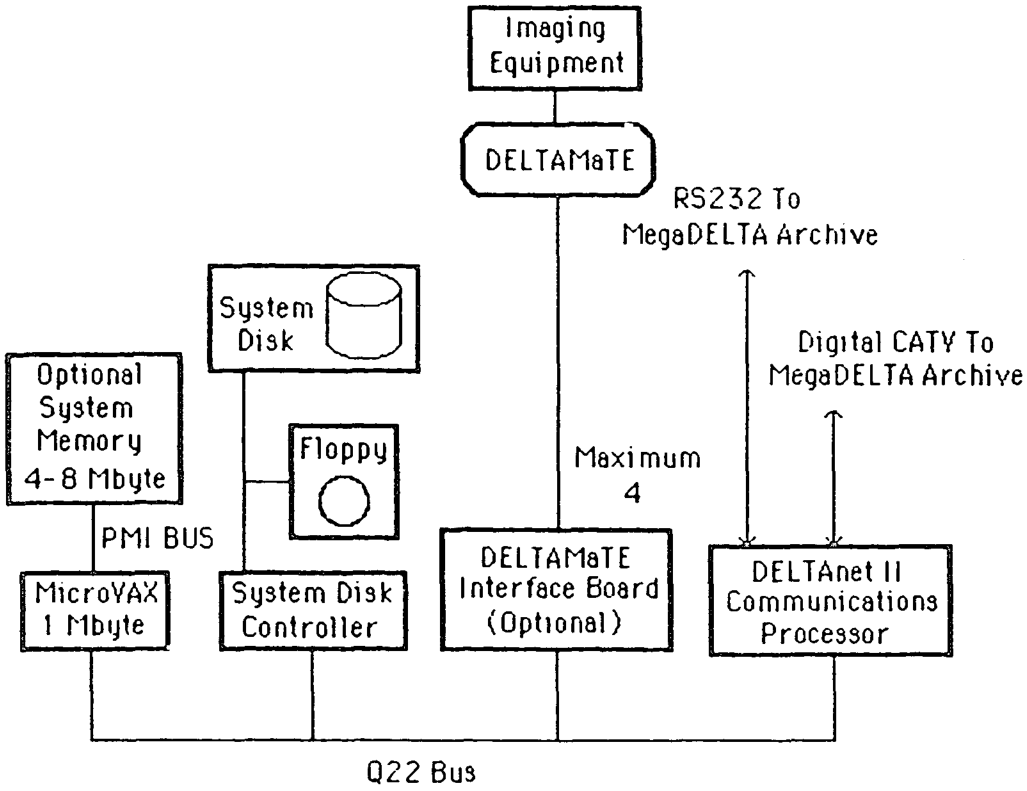


Figure 1.18 DELTAlink : Modality Interface Processor

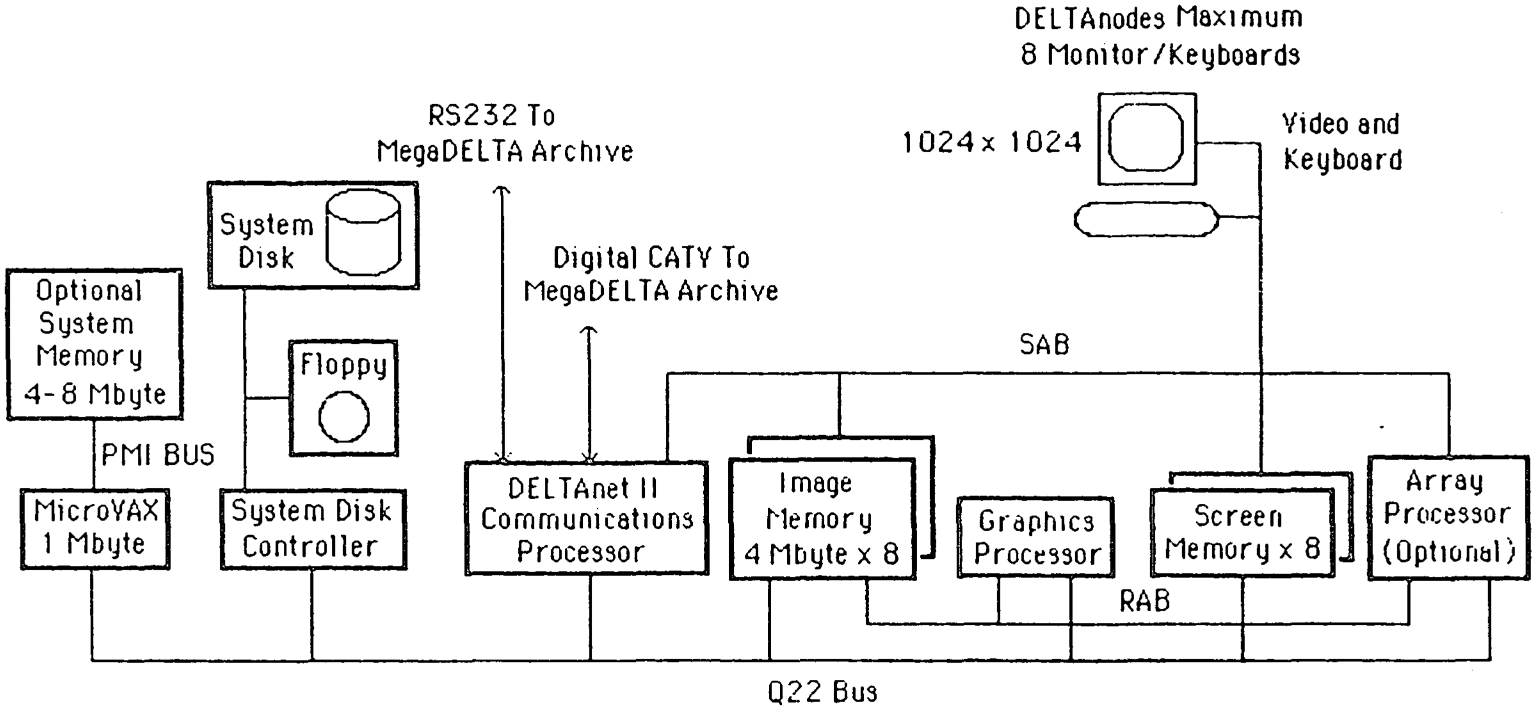


Figure 1.19 DELTAview : Viewing Terminal

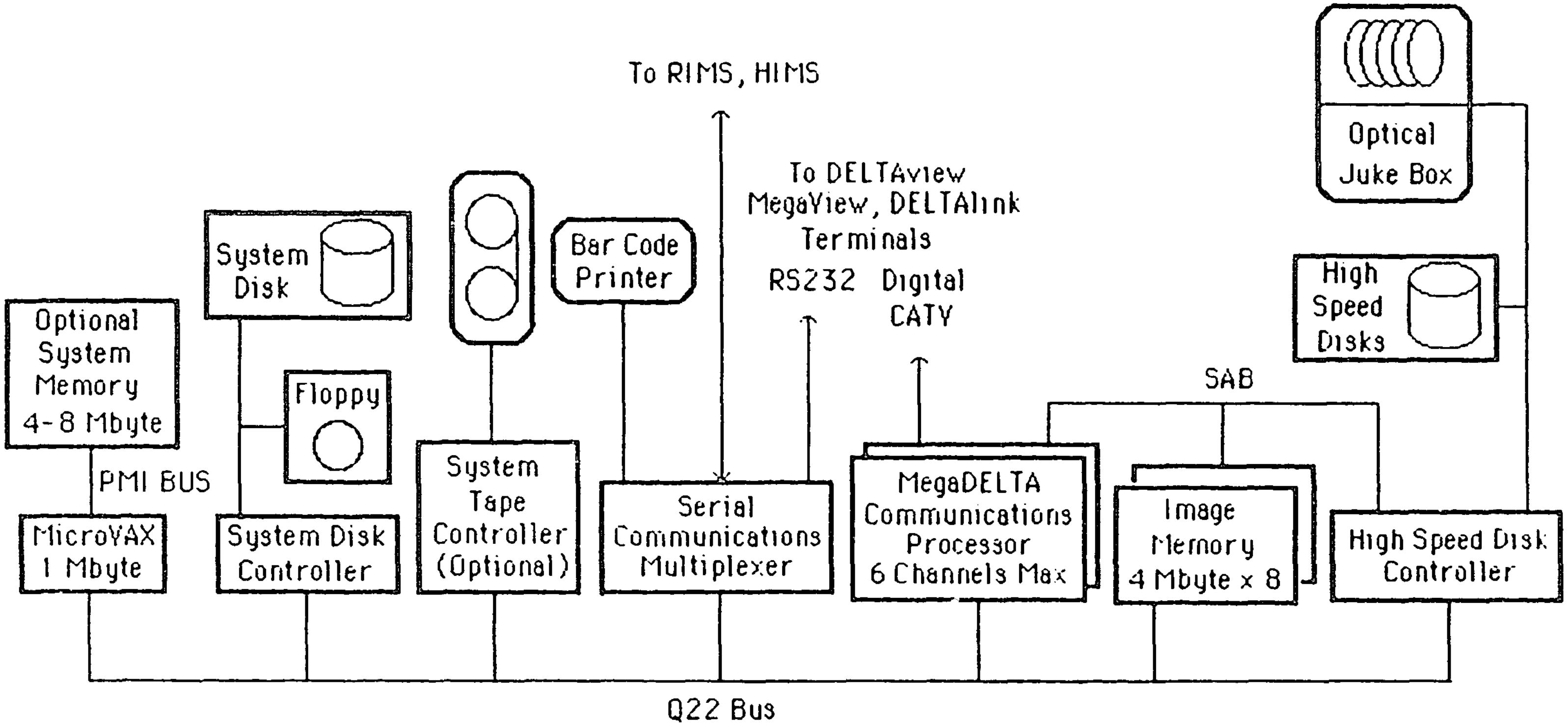


Figure 1.20 MegaDELTA : Archive

In general, the typical PACS system consists of acquisition nodes (imaging equipment or modalities), centralized image archiving system, high resolution digital image display consoles for analysis and review, and a high-speed local area network. The network uses fiber optic network components to distribute the images. The traffic of the network is a function of the number of image requests which generate at review console workstations and acquisition nodes. The review console must receive the requested images within several seconds with a high quality image (low data error rate). Delivering the large data image files within several seconds from the PACS environment in response to the large number of users and requests is a critical and challenging problem. In addition, the design with reasonable assumptions based on present and off-the-shelf technology must be carefully worked out.

The performance standard of this system is being defined and evaluated in detail by the users (radiologists, physicians, technicians), suppliers (manufactures), and hospitals. The National Electrical Manufactures Association (NEMA) and the American College of Radiologists (ACR) play an important role in developing such standards [ACR-NEMA Standards Publication No. 300-1985]. The International Standards Organization (ISO) is developing standards for usage at the application user level.

1.3 Objective of Research

The objective of this research is to develop the specifications of the TDIS and develop a computer model simulation of the image network and data base archive system. The simulation system will determine the performance evaluation of the TDIS system given a multiplicity of parameter values.

The University Hospital, Arizona Health Science Center (AHSC), Department of Radiology is planning to use the Totally Digital Imaging System (TDIS). The system is viable to replace the x-ray films system. The digital image system is necessary and highly required in the near future. The design and its simulation of the totally digital image network and some related portions (such as network interface unit, medical standard equipment interface, database archive) will be carried out. This is totally new and unique to our specific system.

1.4 Approach

1.4.1 Totally Digital Imaging System (TDIS) Design

The requirements of the TDIS network topology, data transfer rates, media access technique, and standard interfaces (such as network, equipment, remote console, data base archive) must be established. After conceptual and functional design of the system, it is required to measure the performance and efficiency of the system with appropriate assumptions. The performance includes channel utilization, response time, and maximum waiting time in queue. The method used is a top-down design philosophy. As part of this work, a TDIS design specification is necessary in order to approach the evaluation task. Figure 1.21 shows the design approach for this work.

1.4.2 TDIS Simulation Using Discrete Event Language

The Simscript simulation language is used as a performance measuring tool. The language provides the capability of developing models for a discrete event system. The models can be driven by empirical data or predetermined data in the language. This discrete event simulation language has been widely used and accepted in most areas, including engineering applications, since early 1963 [Markowitz 1963, Russell 1983]. The VAX 8600 computer at Radiology Department and also the VAX 11/750 computer at Electrical and Computer Engineering Department have the Simscript II.5 language installed.

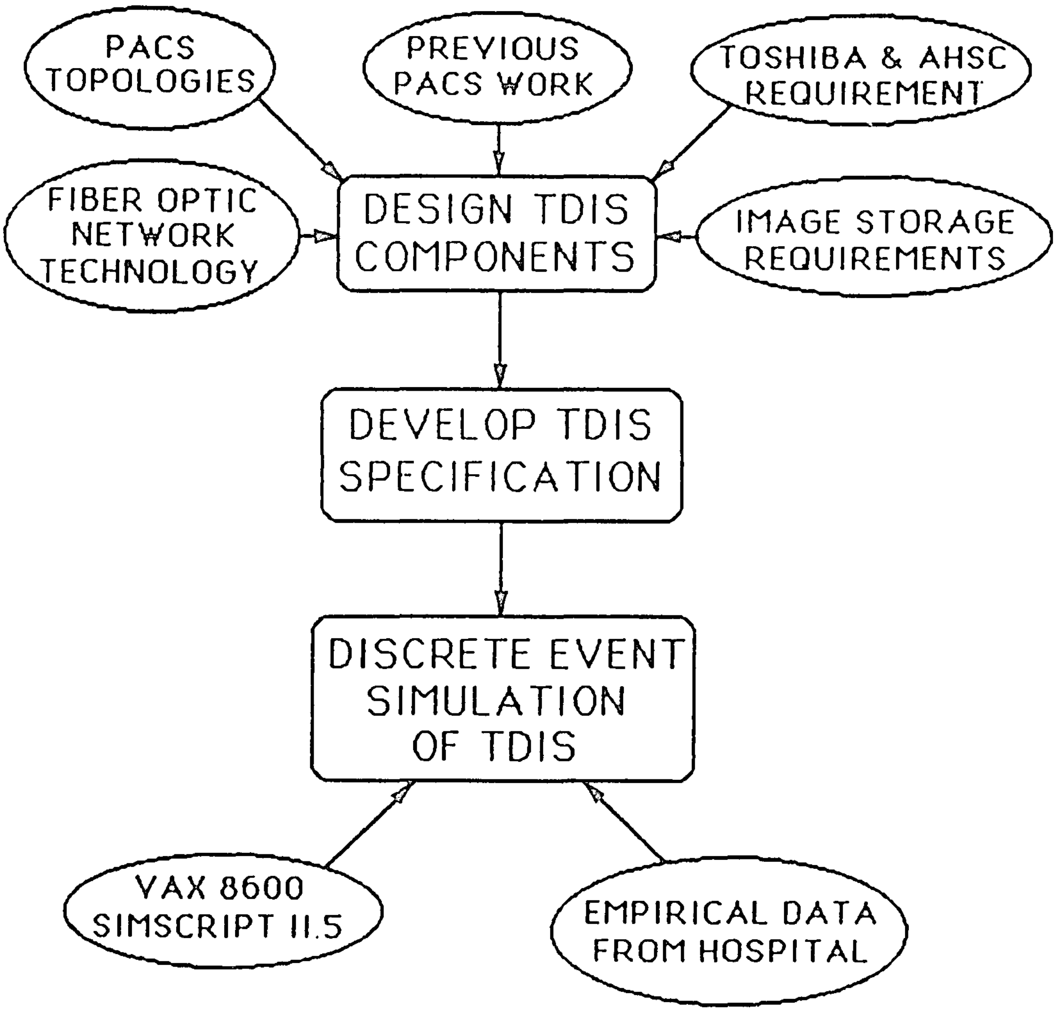


Figure 1.21 TDIS Design & Simulation Approach

CHAPTER 2

TDIS DESIGN SPECIFICATION

In this chapter, the performance, operational requirements and specification of the TDIS System are described. They depend upon amounts of data generated, storage requirements, image size, data transfer rates, user response times, and interfaces to other systems. The operational requirements describe how the TDIS System is used by the users and managed by the Radiology Department staff. The requirements presented in this chapter have been developed and derived by various means. Image data generation and retrieval requirements have been developed from an analysis of current radiological scenarios in the University Hospital, Arizona Health Science Center and hospitals in Japan. The image network and data base archive requirements have been derived from computer simulations performed on the specific architecture. Other requirements exist because of TDIS components already developed, such as the Review Consoles and data generation equipment from Toshiba, Japan. The performance requirements are stated in quantitative items substantiated by real data. The specifications of the TDIS System here which can be used for reference in order to build the system.

2.1 Overall System Architecture

The overall architecture of the TDIS system is a multiple star topology with multiple components. The components, such as data generation equipment and review console workstations, will be on the radial arms of the star. The Data Base Archive (DBA) unit will be at the center of the star. The interconnection mechanisms of these components are provided via a high speed (156 Mbits per second) fiber optic network [Nishihara 1987]. This star topology exhibits a centralized communications control strategy. In addition, this system will have capability to interface to the external Radiology Information System (RIS) and Hospital Information System (HIS).

2.1.1 System Topology

The point-to-point link star network topology is used for the TDIS. Image transfer occurs between the components on the radial arms of the star. There is no need to transfer the patient images from one workstation to the other workstations. Imaging equipment transfers images directly to the DBA. Workstations obtain the requested images directly from DBA. Figure 2.1 represents the TDIS block diagram which consists of:

a. The 3-level hierarchical magnetic and optical disks for images storage and retrieval

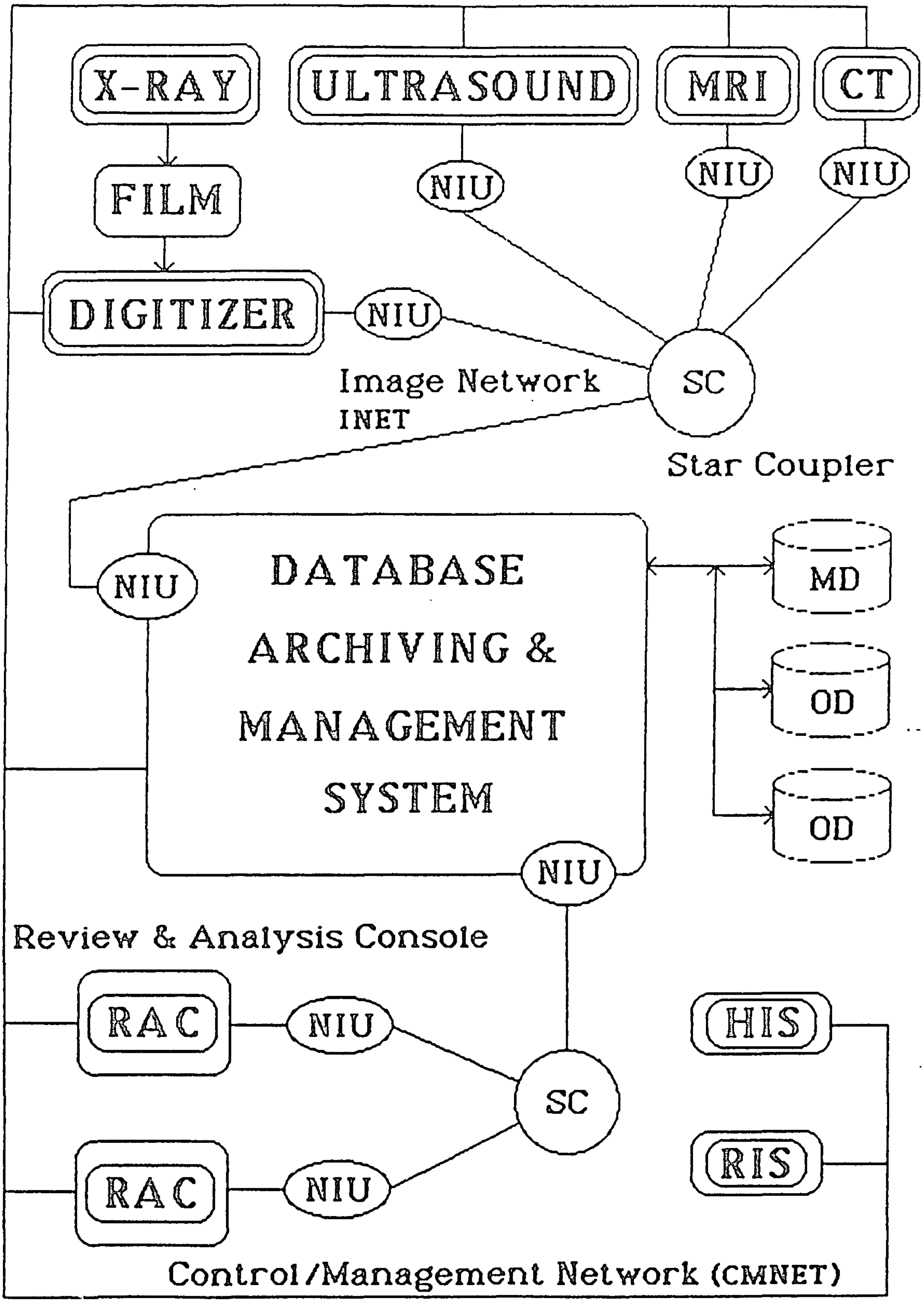


Figure 2.1 TDIS System Architecture

b. Data Base Archive which will manage the data flow among the storage disks, data acquisition nodes and workstations (DBA has 2 fiber optic interfacing nodes)

c. A computer (may use VAX 11/780) inside the DBA

d. 33 nodes for workstations

e. 33 nodes for modalities and imaging equipment

f. Two fiber optic passive star couplers (33 inputs by 33 outputs per coupler)

g. Two fiber optic cables (1 for redundancy/spare line) link to DBA per node

h. Control/Management Network (CMNET), for control and management purposes, connected to DBA and all acquisition and workstation nodes

The TDIS System will reside within the confines of the University Medical Center and the Radiology Department building. The exact locations of the review consoles, and DBA system will be determined at a later time. However, the data generation equipment will stay in the original location. The TDIS components are spread over the geographical hospital complex and within one kilometer.

2.1.2 System Component Interaction

There are five major blocks for the TDIS System. They are:

a. Imaging Equipment

b. Network

c. Data Base Archive

d. Review/Analysis Console

e. External System through Gateway

The network itself consists of two parts: an image data network called INET and a control/management network called CMNET. The INET and CMNET will connect to all components throughout the system. The imaging equipment will send the image data to the Data Base Archive through the image network. The imaging equipment needs to send the request to Data Base Archive through CMNET. The Data Base Archive section will handle the requests from any nodes which can be any Imaging Equipment, Review/Analysis Console. The DBA will also manage the patient images for image data archiving (storing) and retrieving. The Review/Analysis Console retrieves the images from Data Base Archive through INET, again the request must go to the CMNET first. The external systems, RIS/HIS which might be incompatible to the TDIS System, can connect to the existing TDIS System through gateway network.

2.1.3 Example Data Rate Transfer Requirement

ASSUMPTIONS. The following assumptions are used to develop the data transfer requirement.

a. Let 2048x2048 pixels be an image, 2 to 4 hours session, 1 pixel = 12 bits (for 4096 gray levels). Total 48 Megabits (Mb) per image (1 Mb = 1,048,576 bits).

b. Time division technique applied.

c. Reading image at workstation takes less than 5 seconds.

THROUGHPUT CALCULATION. For 2 hours session, or 7200 (2x60x60) seconds.

a. Time for reading an image at workstation is about 5 seconds, 5 seconds per image.

b. For 2 hours, it will have 1440 (7200/5) images to handle with in one day job.

c. Then it will exceed to the AHSC requirement of 1.56E+9 pixels per day or 372 images per day (based on 2048x2048x12 bits per image).

d. The size of an image is 48 Mb per image. Then the total of 69.12x1000 (1440x48) Mb for the data flows in 2 hours.

e. Then we need the data rate of 9.6 (69.12x1000/7200) Mb per second for each review workstation.

f. For 10 active workstations, we need 96 (9.6x10) Mb per second, or 48 Mb per image /0.5 second per image = 96 Mb per second.

2.2 TDIS Subsystems

2.2.1 User Workstations

These are the review and analysis consoles [Dallas 1987] used by the radiologists and physicians to retrieve and view the patients' images. These workstations will connect to the Image Data Network (INET) and Control/Management Network (CMNET). The review console will provide the high speed data transfer of more than 80 Mbits per second [Fisher 1987] through the INET. The spatial resolution up to 2048x2048 pixels and the gray levels up to 4096 levels are necessary for the review console.

The workstation cluster has one 33-port fiber optic passive star coupler. The input node of star coupler patches to the DBA node, the output nodes will connect to each workstation. Each workstation must connect to the CMNET for control and management purposes. Section 2.2.1.1 describes in details for each review/analysis workstations.

2.2.1.1 Review Console. Figure 2.2 illustrates the review console workstation. Each workstation comprises the Network Interface Unit (NIU) node that connected to the fiber optic star coupler for receiving the image data. The NIU connects to the Network Interface Module (NIM) board with the ARC-NEMA standard interface. The NIM board will connect to the VME bus (slow data rate, 5 Megatransfers per second), or directly to magnetic disk. If there is more than

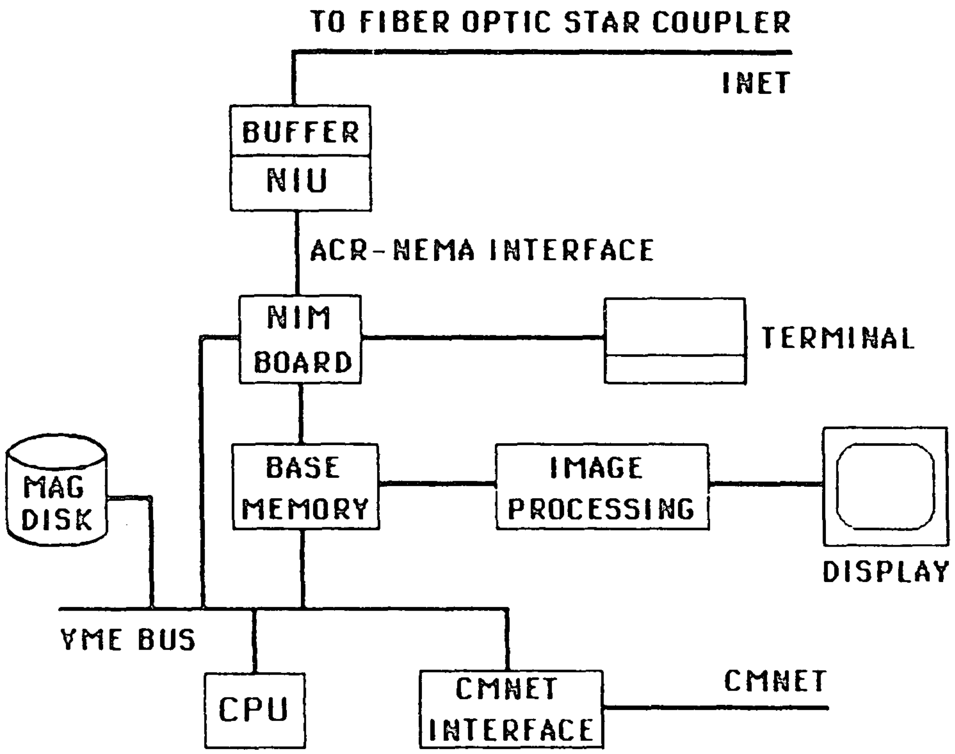


Figure 2.2 Review/Analysis Workstation

one requested image, the local magnetic disk will keep the rest of the images. The base memory (2048x2048x12 bits size) is for immediate viewing, image processing, and operates at high speed (a few seconds per image).

The image processing section is optional for analysis purpose. The processed images in the magnetic disk may be transferred to the DBA section by passing through the INET if needs arrive. Commands, requests, messages need to pass through CMNET via terminal or voice recognition device which connected to the NIM board.

2.2.1.2 Interface to Image Network. Each of the review consoles will have the standard interface which can connect to the same standard interface of network module. Then, the review console can receive the patient images through this connection. The TDIS system will use such a standard interface so-called ACR-NEMA (American College of Radiology-National Electrical Manufacturers Association). However, it will leave the design engineers free to select any standard interface and to make decision for themselves. Section 2.2.3.4 will discuss the ACR-NEMA standard interface in more details.

2.2.1.3 Interface to Control & Management Network. Each of the Review Consoles has a specific standard interface which can connect to the same standard interface of Control/Management Network (CMNET). The interface itself will be the type which depends on the type of CMNET. See more details in Section 2.2.4.

2.2.1.4 Media Access Alternatives for Workstation. There are three proposed alternatives for media access to the workstations.

1. Cluster Ring Technique. This method is one of the three candidates which will be used for the image network media access. In this approach, a token is passed through each workstation to access the media as shown in Figure 2.3. If any station fails, the whole system has to be reconfigured again.

2. Time Division Multiple Access Technique. Figure 2.4 represents time division multiple access technique. This technique will give the time (speed of displaying an image, 0.5 second in this case) equally to each workstation. Whether the other workstations are in use or not, the original workstation must wait for a certain amount of time to get another image. The time in this case is 5 seconds. This time-slice interval depends on the number of workstations and the maximum delay time of each image to the viewer. If a workstation does not need to access the INET media, the system wastes its time slice. Wasted time slice implies a waste of network bandwidth. This is the disadvantage to this technique.

3. Request Poll Technique. In this approach, the system polls to each workstation for its status toward the INET. If a workstation needs to access the INET media, it sends the request to the DBA through the CMNET. The requested workstation is scheduled to access the INET for getting the image. Figure 2.5 depicts the block diagram of this technique. In this case, only workstation number 1,4,5 and 10 are in the schedule to get the images.

2.2.2 Data Generation Equipment

The data generation equipment (imaging equipment or modalities) will generate the image data in the digital form. If the image is in the film format, it will be transformed to the digital format by using the digitizer. These modalities use the ARC-NEMA image frame format [ACR-NEMA Publication 1985]. The standard interfaces of data generation equipment will have two major ports: one for INET, and the other for CMNET. The user, however, can interface to the equipment via CRT terminal in order to send the requests, commands, and messages to the DBA. The other purposes of this equipment are for the equipment itself. The capability of image generation speed should not be less than 64 Mbits per second [ACR-NEMA Publication 1985].

2.2.2.1 Types of Equipment. The examples of modalities are Computed Tomography (CT), Magnetic Resonance

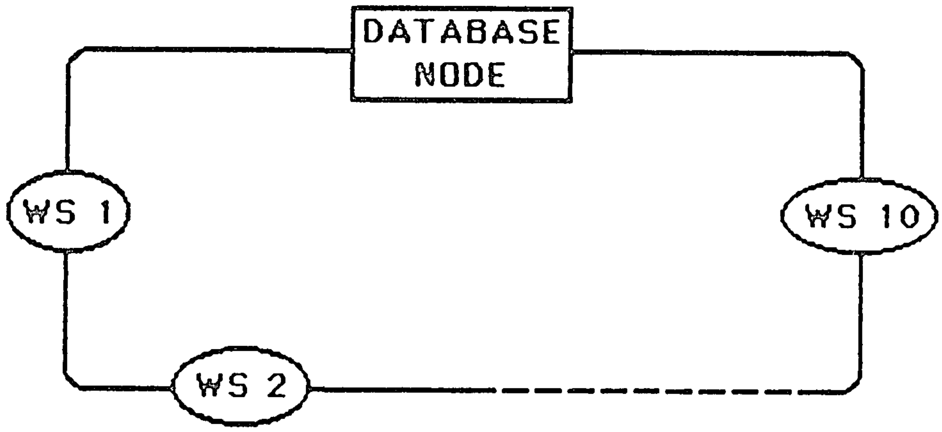


Figure 2.3 Cluster Ring Technique

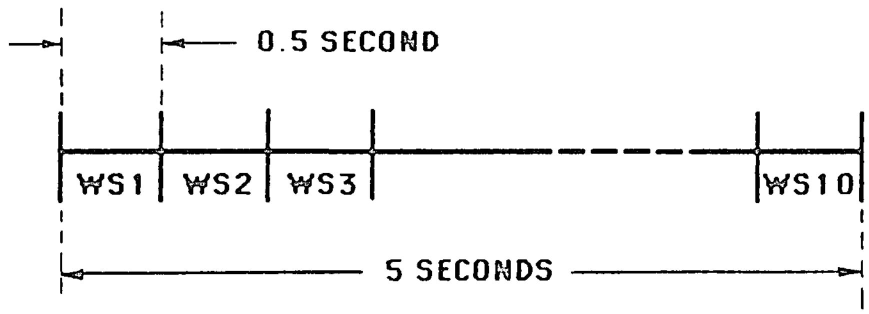


Figure 2.4 Time Division Technique

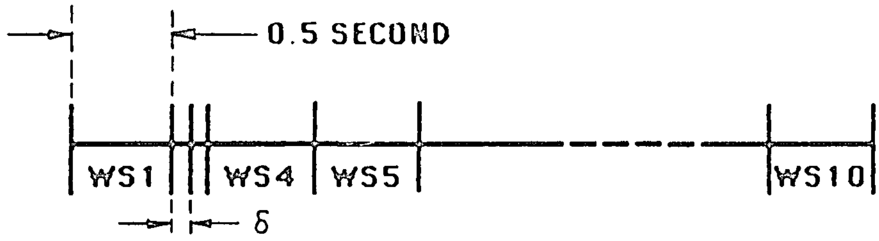


Figure 2.5 Request Poll Technique

Imaging (MRI), Nuclear Medicine (NM), Ultrasound (US), X-Ray, and image digitizer, etc. It includes a Totally Digital Imaging Filing System (TDIF) from Toshiba.

2.2.2.2 Interface to INET and CMNET. Each of these modalities has its own image data standard interface such as GPIB (IEEE 488, American type interface), Seimens (European type interface), and Toshiba (Japanese type interface), etc. There is no unique standard that allows any manufacturers or organizations accessibility to each other today. So it is very difficult to have these modalities connected to the specific image network. An interface converter is needed to do this job. That is one reason why the ACR-NEMA standard interface involved to the TDIS system. Figure 2.8 shows the equipment modules interfaces. See also Sections 2.2.1.2, 2.2.1.3, and 2.2.3.4 for more details.

2.2.3 Image Data Network (INET)

The INET is the image data transfer mechanism among the user workstations, imaging equipment, and data base archive system. This network will be a high speed (more than 150 Megabits per second) fiber optics with a multimode quartz graded index. The network will connect to the Network Interface Units (NIUs) of the workstations, data generation equipment, and storage archive system.

The purpose of this INET is for image data flow only. In this case, it uses only point-to-point flow technique for transferring the images. The TDIS system uses a fiber optic cable for linking this image data because of the fast data rate, high security, less interference requirements. The images are retrieved from magnetic and optical disks and sent to the workstation by passing through this INET. Section 2.2.3.1 describes the detailed specification of the INET. A goal for the INET will be to specify the ACR-NEMA interface where possible.

2.2.3.1 Fiber Optic Network. This fiber optic network uses a high speed data rate of 156.672 (or may be more) Mbps with multimode quartz graded index. The fiber optic cable has 4 wavelengths of 0.81, 0.89, 1.2, and 1.3 micron capability. The network topology will be a star type network, and Figure 2.1 shows its structure.

2.2.3.2 Network Interface Unit (NIU). It consists of 2 buffers (4 KBytes + 6 Bytes + 2 Bytes, for each buffer), parallel/serial data stream converter, a pair of LD-APD diodes optical emission and sensor, 8b-1c (8 data bits and 1 checksum bit) encoder/decoder, optical/electrical signal converter, and an intelligent controller e.g. data flow control. When the NIU uses 8b-1c scheme, the effective data transfer rate will be 139.264 Mbps. The NIU has 2 major ports one for INET, the another for workstation or data generation equipment or data base archive side. Figure 2.6 depicts this NIU architecture.

The data frames from workstation will fill to the double buffer with data rate not less than 64 Mbps. The data will be converted to a serial stream format one buffer at a time. Then the 8b-1c encoder will encode this data stream before converting its electrical signal to the optical signal. Finally, the NIU will send the optical data stream to the DBA side via a fiber optic cable network. The NIU at DBA side will perform like the NIU in the remote side (workstation, for example) but in reverse direction.

This unit is a media between image network and user workstation or imaging equipment or data base archive. The NIU also has an intelligent data flow controller for those of double buffer. This TDIS system will have identical NIU units used throughout the network system.

2.2.3.3 Fiber Optic Cable Plant. There are 68 nodes in total (33 nodes for imaging equipment, 33 nodes for review/analysis workstations, 2 nodes for DBA). It requires a maximum distance of 1 km for each node pair in the hospital environment (see Figure 2.1). However, the designer can use the repeaters when needs arrive (for example, the signal level drops to the inoperable situation). Fiber optic cables will be installed throughout the hospital building

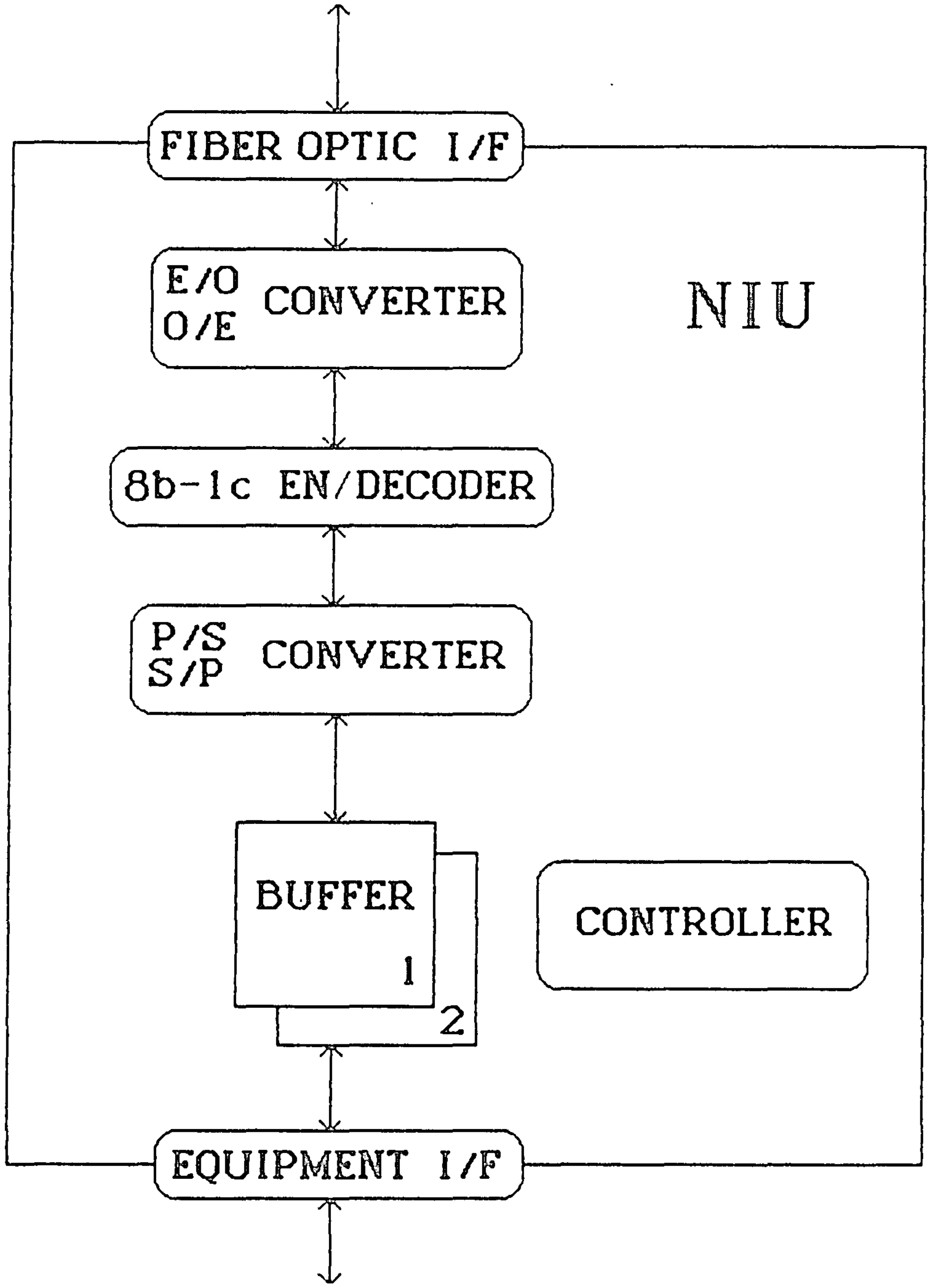


Figure 2.6 Network Interface Unit

where the workstations, modalities and Data Base Archive are necessary.

2.2.3.4 Proposed ACR-NEMA Interfaces. Medical equipment should have a standard interface. Recently, the ACR-NEMA standard interface has a protocol adapted from OSI (Open System Interchange) standard layers (see Figure 2.7). A group of medical and engineering experts proposed this standard interface. The image is broken down into frames. Each frame consists of 2 bytes for frame descriptor, 2 bytes for packet descriptor, 2 bytes for block sequence number, the maximum of 4 kilobytes for image data block, and 2 bytes for frame check sequence (checksum). The data transfer rate should not be less than 64 megabits per second, and it uses a differential circuitry for less interference. However, its evaluation is being done by many manufacturers and researchers.

Figures 2.9 and 2.10 illustrate the session, transport/network, data link, media access and physical layers management of the ACR-NEMA standard. The physical interface consists of 16 bidirectional data lines plus 1 bidirectional parity line, 6 unidirectional control lines [ACR-NEMA Publication 1985].

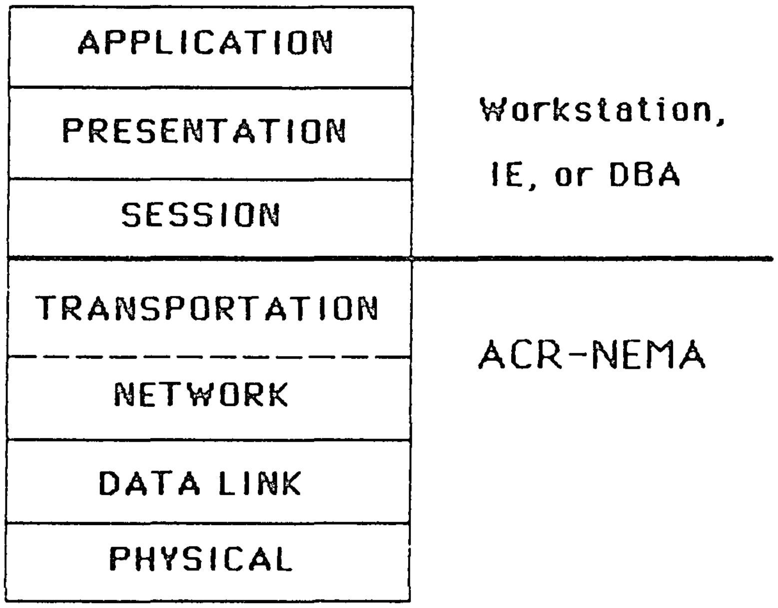


Figure 2.7 ACR-NEMA Standard Layers

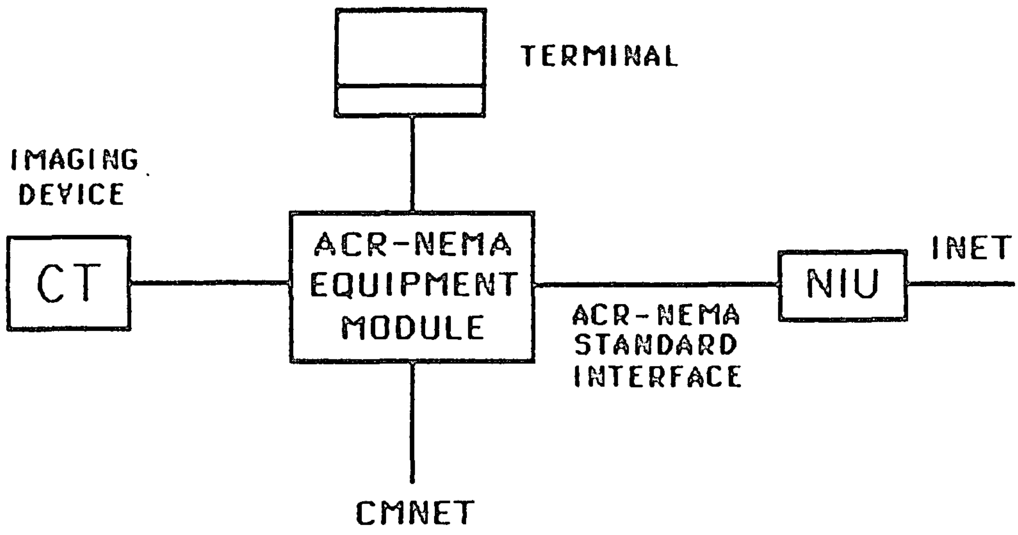


Figure 2.8 ACR-NEMA Equipment Module Interfaces

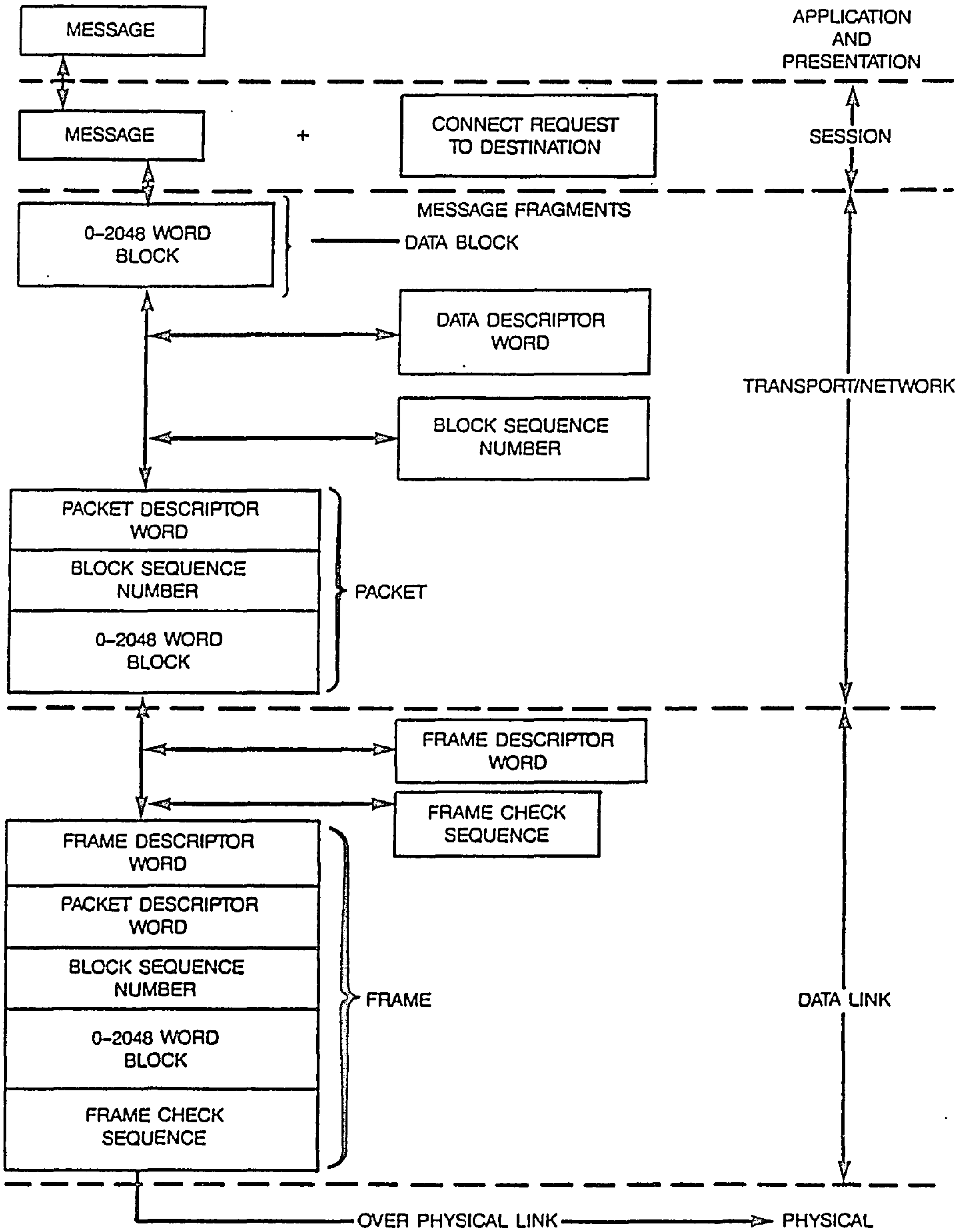


Figure 2.9 Session, Transport/Network & Data Link Layers Management of ACR-NEMA Standard

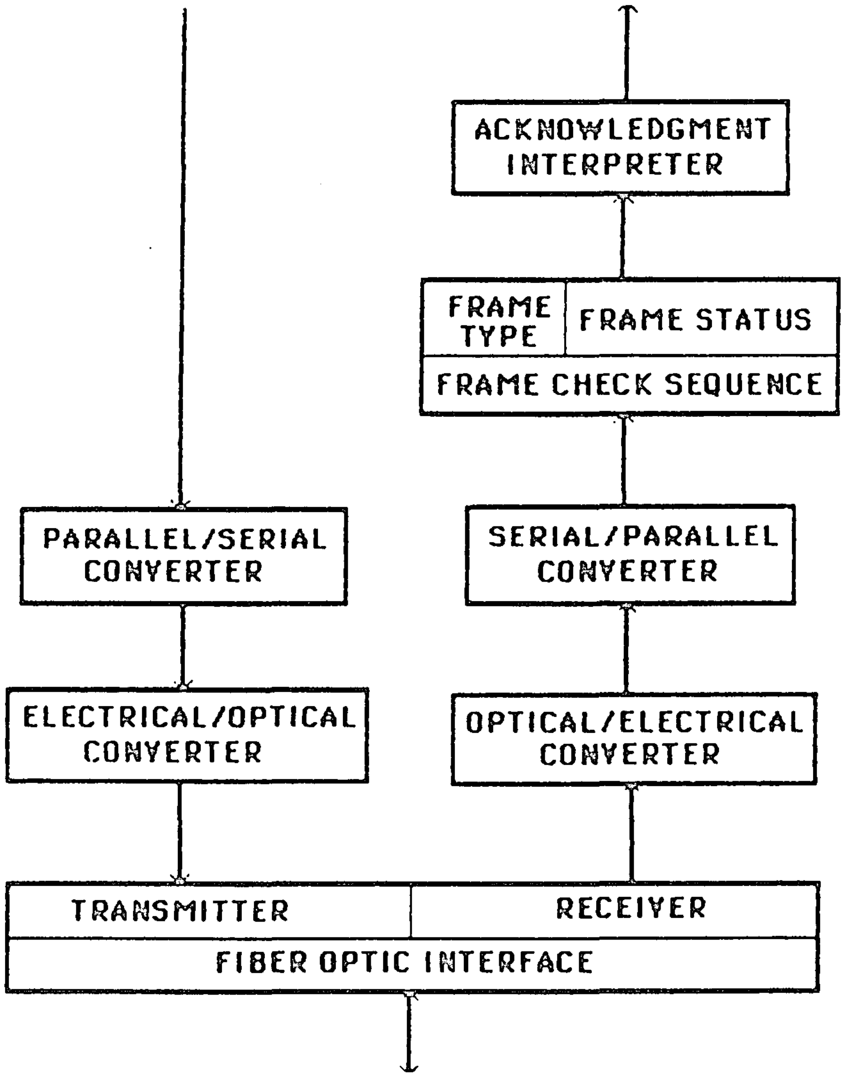


Figure 2.10 Media Access & Physical Layers Management

2.2.4 Control/Management Network (CMNET)

This CMNET is for the command and management purpose. The requests which are from data generation equipment and/or from review consoles will pass through this CMNET. These requests then go to the queue buffer (inside DBA) for being served as first come first serve or priority basis. Any time the viewer wants to review the images, he places the command through CMNET via the terminal or voice recognition device. This command will flow to the computer which is inside the DBA. Whenever the network channel is ready, the DBA will send the acknowledgment to the requester via this CMNET for establishing the connection. Then the DBA will send the requested image(s) to the viewer via INET. In addition, the users can communicate to every workstation by using this CMNET. The user from workstations also can retrieve the patient information from the RIS through this CMNET. Intelligent controller providing the user from this CMNET will reside in the data generation equipment, user workstations, and database archive system. The following sections will provide the detailed description of the CMNET specification.

2.2.4.1 CMNET Architecture. The TDIS system has the CMNET network placed among the workstations, modalities and the DBA. The data which flows through the CMNET is basically a command form called request. So that a low data rate network is accepted. The workstations send the requests to the DBA via CMNET. The DBA processes the requests and responds to requesting workstations through CMNET. This communication continues until the DBA and the requesting workstations are ready to transmit or receive the images. This CMNET may be broadband (Sytek) or baseband (Ethernet) or token-pass ring network ranging from 128 Kbps to 10 Mbps data transfer rate. Which one is the most suitable for the specific applications, the designers will soon make decision for themselves.

2.2.4.2 On-line Image Request. The on-line image request can be either a retrieval request or a generation request. The retrieval request notifies the DBA that the remote workstation needs to retrieve one or more images from the DBA. The generation request is to inform the DBA that there is one or more images ready to store in the DBA.

2.2.4.3 Off-line Image Request. The retrieval request actually has taken place in advance before the generation request arrived into the DBA. Most of the advance image requests are retrieval requests for old images. This is because the doctor knows in advance which previous images he wants to review before sending the patient to the examing room. The duration time between the retrieval request and generation request can vary from a few minutes to hours depending on the situation.

2.2.4.4 Patient Information Request. The doctor can retrieve the patient's via CMNET. The information can reside in the DBA magnetic disk or in some other storage in the same network (CMNET) or different networks. The patient's information will not be included in the images, but it could be the interpretation or description correlated to the images. If the patient information is in a different network other than CMNET, then a gateway is required to bridge the two networks. A summary of the images is also part of the patient information.

2.2.4.5 Interface to System Components. This type of network will connect to all components of the TDIS system. The type of interfaces among the components will depend on the type of network.

2.2.5 Data Base Archive System (DBA)

Data Base Archive (DBA) plays an important role in the TDIS system. The DBA system is a storage center for all of the images and related data which are from the Radiology Department. The DBA will provide for the structured storage of all the images in the TDIS System. The DBA will receive requests from a user at the imaging equipment unit and allocate the storage required for that patient session. A user at a workstation, on the other hand, will request a certain patient's images from the DBA. The DBA will retrieve the images from the storage system. Then the DBA sends the images to the requested user console.

The DBA is also responsible for the migration of images in the storage system according to a migration algorithm. The DBA contains a database management and records system (DBMS) which can keep track of the patient images efficiently. The DBA system requires a data management system to store/retrieve images and patient data, and communicates with the DBA users properly. The DBMS should have high guaranteed space utilization, rapid searching, expandability, and a fast insertion and deletion processing. Figure 2.11 represents the DBA architecture. The following sections will describe further details of the DBA.

2.2.5.1 DBA Computer System. The DBA computer system has INET and CMNET interfaced. The requests of the users arrive in random time to the DBA via CMNET. The computer system in the DBA should be able to process the requests by either taking the patient images from INET and storing them in the DBA storages, or retrieving the requested images from the DBA storages and transmitting them to the requesting workstations via INET. In the initial

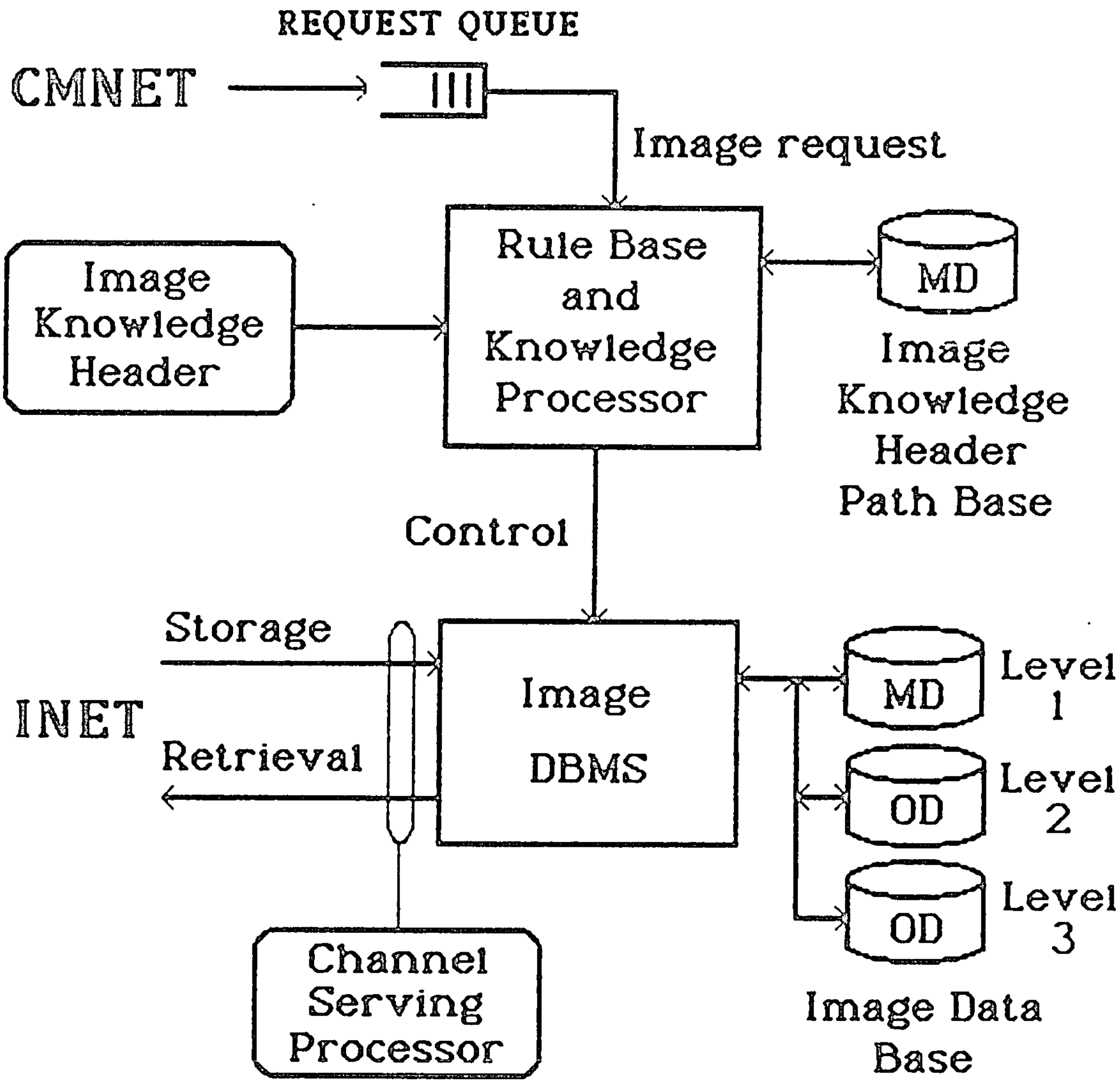


Figure 2.11 Database Archive Architecture

stage, the TDIS system may use the computer VAX 8600 or VAX 11/780 system for a testbed purpose.

2.2.5.2 Hierarchical Storage System. The storage system in the DBA consists of two types of data: patient textual data and patient digital x-ray images. A small and high speed storage will keep the patient information, and a 3-level hierarchical storage keeps the patient images. The archive section has 3 levels of images storages. The first level maintains the images up to 7 days with a high speed data transfer rate of magnetic disks operating in parallel. The level-1 storage is an on-line storage which maintains examinations during periods of high demand by users. A short working period from the patients previous examinations, for example one week, was selected for length of level-1 on-line storage. Level-2 and level-3 maintain the images from 8 days to 1 month and beyond 1 month up to 3 years, respectively. Both levels use optical disks which have lower data transfer speed than the magnetic disk in level-1. The level-2 storage is also an on-line storage, but it maintains the images for a longer time, one month, for example. The level-2 storage is larger in capacity, and storing/retrieving activity time is also longer than level-1 storage. The level-3 storage maintains all of the images generated for a long term (3 years). The storing and retrieving activity of the level-3 storage is very slow. The images that are from 3 years to

10 years old will be stored in the off-line cartridge storages. However, the system needs to move the image cartridges in the storage level manually to level-3 whenever needed. The images that are more than 10 years old will be discarded.

Each optical disk interface, is composed of data path, which is bidirectional for input and output, and control path. We intend to use this optical disk system for only image data storage and retrieval handling, and not for any other data.

2.2.5.3 Requests Handling via CMNET. The DBA receives and transmits the requests through the CMNET. To achieve such a task, the higher layers of OSI model of CMNET must be implemented in the DBA. The following paragraphs will discuss the interpretation of the received requests and response to a request.

All three classes of requests may arrive into the DBA system via CMNET. They are on-line image request, advance image request, and patient information request. Each class consists of two types of requests, retrieval and generation request. The DBA should be able to decode the arrived requests, distinguish the classes, and interpret the data of the requests.

Once a request arrives into the DBA and the class and type of the request is configured using a request decoding method, the DBA allocates the required resources and servers, for example, a channel serving processor, to service the request. Several requests can share some of the resources at the same time. When a generation request arrives at the DBA, the DBA should provide a space location to the incoming images. The database reserves the physical location of the images for referring to the future retrieval.

As soon as the CMNET receives the image retrieval command request from the user workstation, the computer will search for the patient data which is in the knowledge header as shown in Figure 2.12. This patient data consist of all information of that patient. This information will link to that patient image location, then the DBA passes this image location information to the disk storage system. The disk system (refer to Figure 2.13) receives the control signal which is the image location information from DBA. When the DBA receives the image data from the disk system, the DBA will divide the image data into blocks. Each block has 2046 words (16 bits per word) except the last block which contains only the rest of that image i.e. 1026 words. It assumes that the image size is 2048x2048x12 bits (see Figure 2.14). At this point we call it the session layer handling. Further management will belong to the image handling through INET.

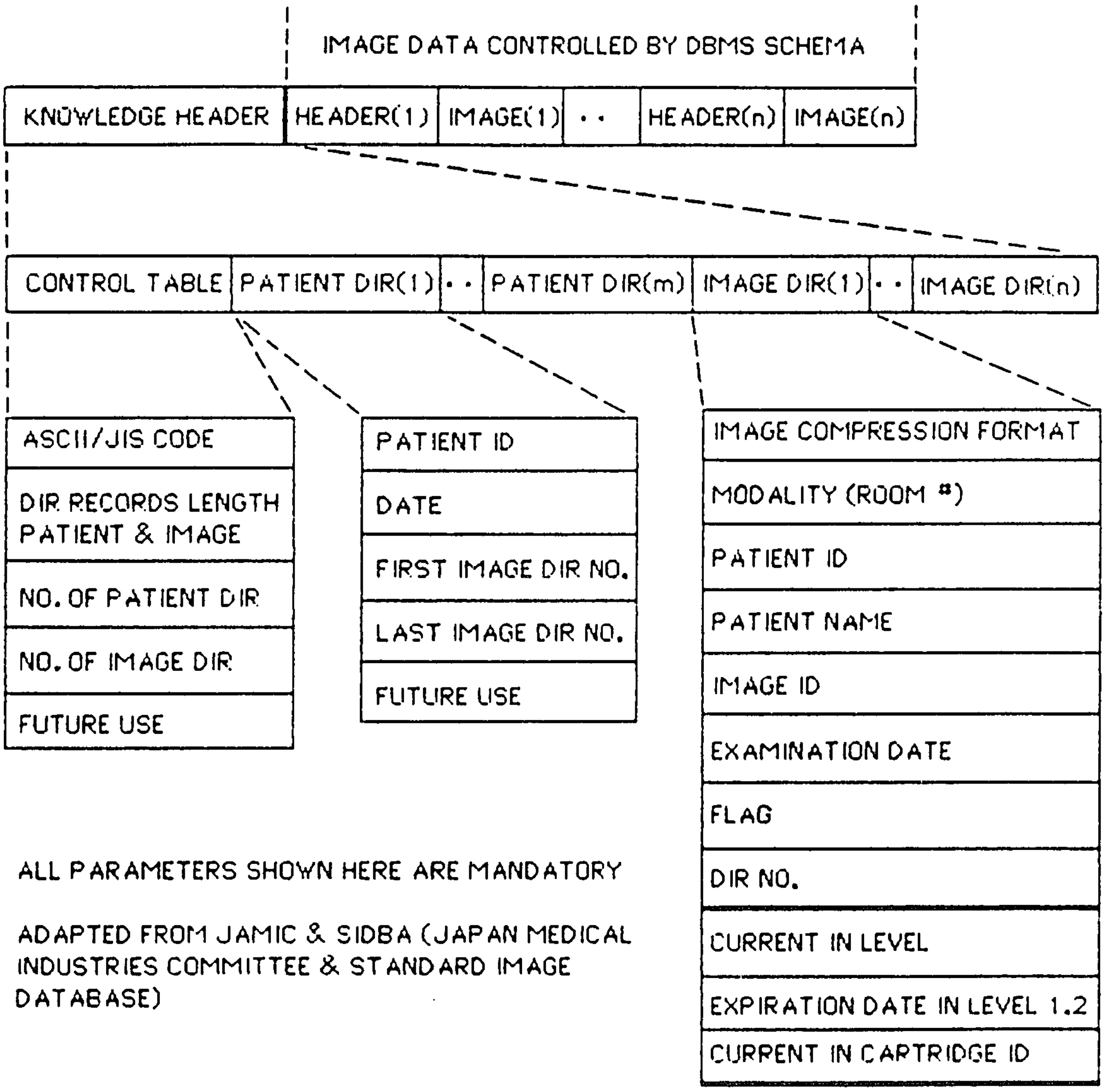


Figure 2.12 Knowledge Header of Patient Image Information

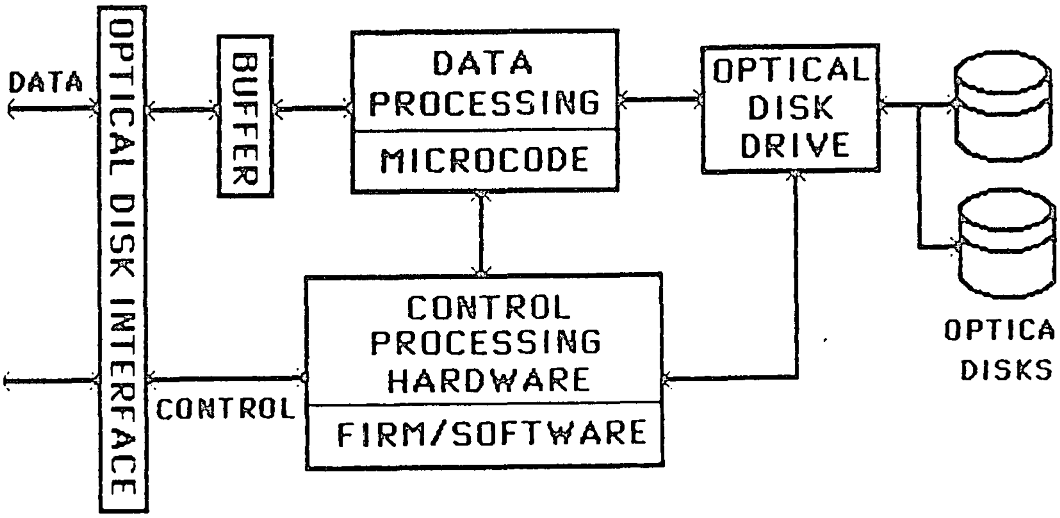


Figure 2.13 Disk System

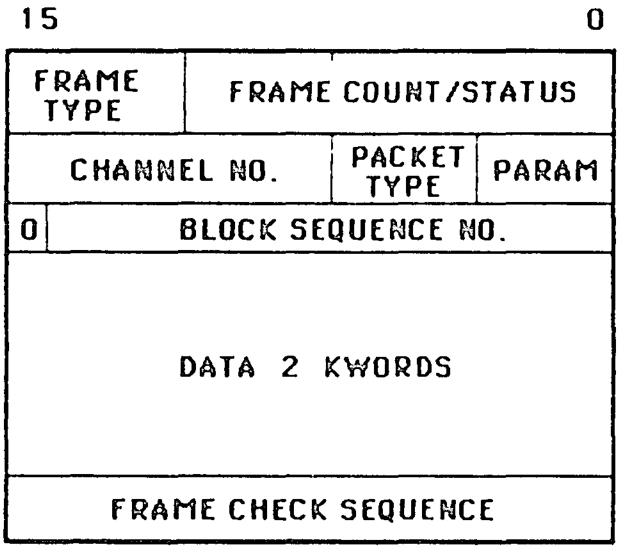


Figure 2.14 ACR-NEMA Frame Format

2.2.5.4 Send/Receive Image via INET. When a request arrives into the DBA, the DBA locates the requested images by referring to the physical location database. If the request is a retrieval request, the DBA prepares transmitting the images and acknowledges the workstation to prepare receiving the images. Then the DBA transmits the images through INET. After transmitting the requested images, the DBA expects to receive a positive or negative acknowledgment from remote side via CMNET. For generation request, the DBA takes the images from INET and stores them in the preassigned location. It performs the acknowledgment action as in a retrieval process but in reverse direction.

2.2.5.5 Image Migration Algorithm. The image migration algorithm function regulates the transfer of images among the storages. It controls the allocation of the on-line database storage so that the requested images from review workstations remain available. It should also keep track of each patient's activities.

By the end of the day, the image migration algorithm checks the expiration date of images for each level. The system then moves the images to the correspondent level. Furthermore, the system also provides the retrieving images for on-line (emergency), off-line or advance (non-emergency) to the review workstations. The system copies the images from level-1, level-2, and level-3 directly to the workstation in case of emergency request. Copying the images from level-2 or level-3 to the level-1 first is necessary when the network channel is busy. Then the images from level-1 go to the review workstation later when the image network channel is available. Section 3.5 will describe in more detail.

2.2.5.6 Interfaces to INET and CMNET. The DBA has 2 network interfaces: one for INET, the other for CMNET. The DBA can interface to the INET via NIU which has the ACR-NEMA standard interface. The interface of a ACR-NEMA module to the NIU is a ACR-NEMA standard with a data rate of 64 Mbps. In contrast, the interface of a ACR-NEMA module to the DBA is defined by the manufacturers. This ACR-NEMA module can stay inside the DBA, then the DBA will have a ACR-NEMA standard interface for the NIU.

The INET is going to be the point-to-point network protocol. Because the TDIS system uses the ACR-NEMA standard, we can use the same NIU throughout this TDIS system. Section 2.2.3.2 has discussed this NIU module for image transfer handling. The CMNET can be the local area network broadband type i.e. the Sytek localnet system to which the VAX computer is connected. The CMNET is used primary for control and management purposes. The DBA module can use the system Unibus for communication between a VAX 11/780 and data storage archive system. The CMNET network will act and/or respond to any requested commands from any users workstations. It also handles or manipulates any information data except image data. Figure 2.15 depicts the DBA interfaces.

2.2.6 External Systems

2.2.6.1 Radiology Information System (RIS). The Radiology Department usually keeps all patient information such as the diagnostic results from the doctors and/or radiologists. The results are also linked to the patient's identification number (patient ID no.), and name. This related information allows easy access to any patient's history. Furthermore, the Department will also keep other information which they may need, such as imaging equipment, film developing & service facilities.

2.2.6.2 Hospital Information System (HIS). The hospital database will store a large amount of information on all employees, all patient billing accounts, related doctor specialist information, and doctor identifications, etc. This database will be easy to access and take less time when searching for needed information.

2.2.6.3 Other Systems. The information mentioned above is just the internal information on the hospital. If outside hospital information is needed, a network protocol converter in the gateway should be added. This would allow

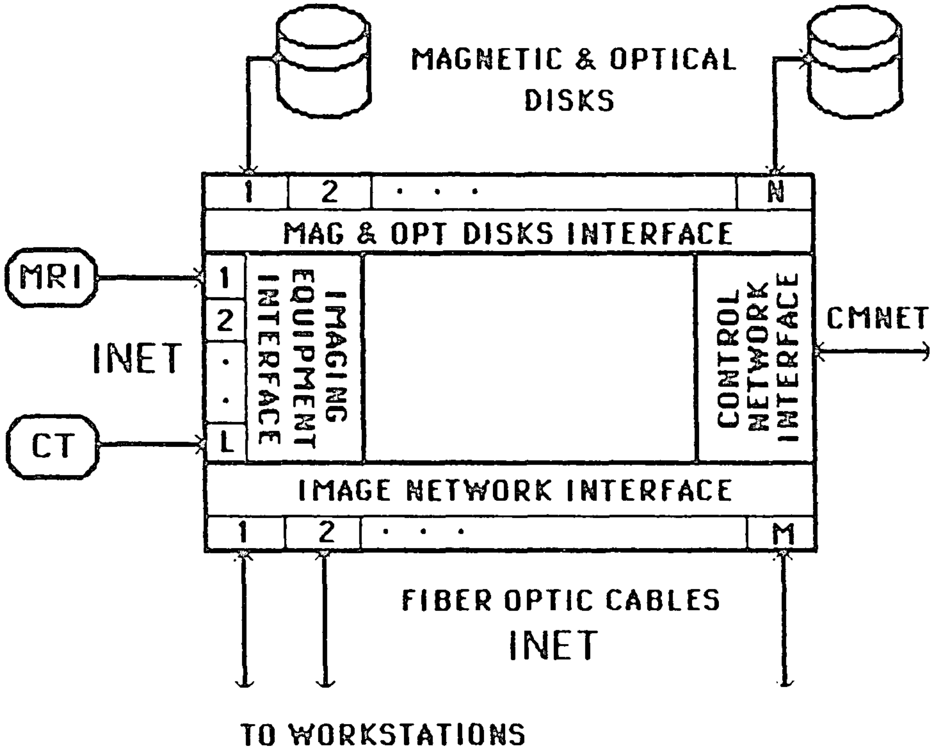


Figure 2.15 Database Archive Interfaces

accessibility to needed information among the hospitals. The end result would be a long hual networking system which would be very useful throughout the nation and even to the world.

2.3 System Operational Scenarios

Suppose we have ten images from a patient to look at. First, the viewer will request the list of images through the terminal or voice recognition device which is connected to the CMNET. The archive system will retrieve the image data from the disk and pass through the fiber optic cable to the destination (review workstation). The review console will display the first image on the screen, the local storage disk will store the rest of 9 images. The review console uses the internal bus, for example VME bus, for passing the images to the local disk for further use.

For an analysis workstation, the image processing section will process (enhance or filter) the displayed image. Afterwards, the processed images in the review console local disk may be transferred to the database archive system disk through INET. This depends on the user. The size of the base memory may be 96 Mbits or more for image processing with the size of an image at 2048x2048x12 bits.

2.3.1 Data Generation

The Radiology Department, Arizona University Medical Center, generates the image data approximately 1.1-3.1 gigabytes per day. The sizes of images will distribute as the following, 1024x2048, 1170x1200, 1460x1450, 2048x2048 pixels with 12 bits per pixel. The image data from user workstation(s) will be transferred to the magnetic disks located at database archive via INET upon request. Section 2.2.5.4 discusses in more detail.

2.3.2 Data Storage

When an image arrives at the DBA, some data comes along with it from the user over the image generation workstation. The received data is basically about the patient and the generated image information. The DBA also creates more data for each image to ease house keeping. This data is not useful or accessible to the users, only to the DBA system. Sections 2.2.5.2 and 2.2.5.4 have more details.

2.3.3 Data Retrieval

When a user turns on the review workstation, he/she has to know some information about a patient and the images. This part of the process may be achieved by a menu-driven process which provides questions about the patient and images. The workstation makes up a meaningful message using the user's answers then sends it to the DBA via CMNET for further processing. Sections 2.2.4.2, 2.2.4.3, 2.2.5.3 and 2.2.5.4 have described this in more details.

CHAPTER 3

TDIS SIMULATION MODEL DEVELOPMENT

The details of the image network (INET), control/management network (CMNET), network interface unit (NIU), review/analysis workstation, imaging equipment, and database archive system were given in the TDIS design specification in Chapter 2. These data are used to establish the models. Simulation of these models will develop the characteristics and performance of the overall TDIS system. Actually, the models will be in the form of the simulation program model. The details of these models are contained in Appendix A. However, this chapter will show the models in terms of block diagrams, process data flow, and simulation flow charts.

3.1 Overall Simulation System

The TDIS simulation system consists of data generation node, review/analysis console node, image network, control/management network, and a database archive system. Figure 3.1 represents the interaction of the simulation models. The images from the imaging equipment model will go to the INET model, and then to the DBA model for generation process. In retrieval process, the images are

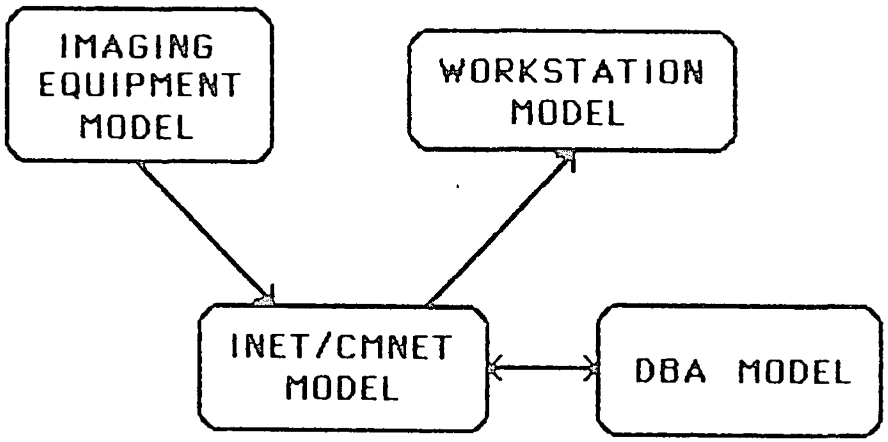


Figure 3.1 Interactions of Simulation Models

transferred from the DBA model to the INET model, and then to the workstation model. The requests and acknowledgment use the CMNET model for communication among three models (IE, WS and DBA). Figure 3.2 shows the overall simulation block diagram.

In general, the input data for the simulation model is of two data types: mathematically generated data and empirically generated data. The mathematical type of data uses a mathematical function, such as the poison distribution function. In contrast, the empirical type of data uses the actual measured data from the hospital. The TDIS simulation uses the empirical data type for input data. The reason we use this type of data is because the simulation results will give the realistic data in an actual hospital environment. In addition, it meets the Toshiba requirement for using the empirical data. Accurate outcomes will result in an improvement to our design of the TDIS system and to the study. Section 3.7 gives the examples of simulation data inputs.

3.1.1 Assumptions for Simulations

This section describes assumptions used in performing the simulations of the TDIS.

a. Because we are designing the system which has 4 channels for our fiber optic image network (INET), four Channel Serving Processors (CSP) are necessary.

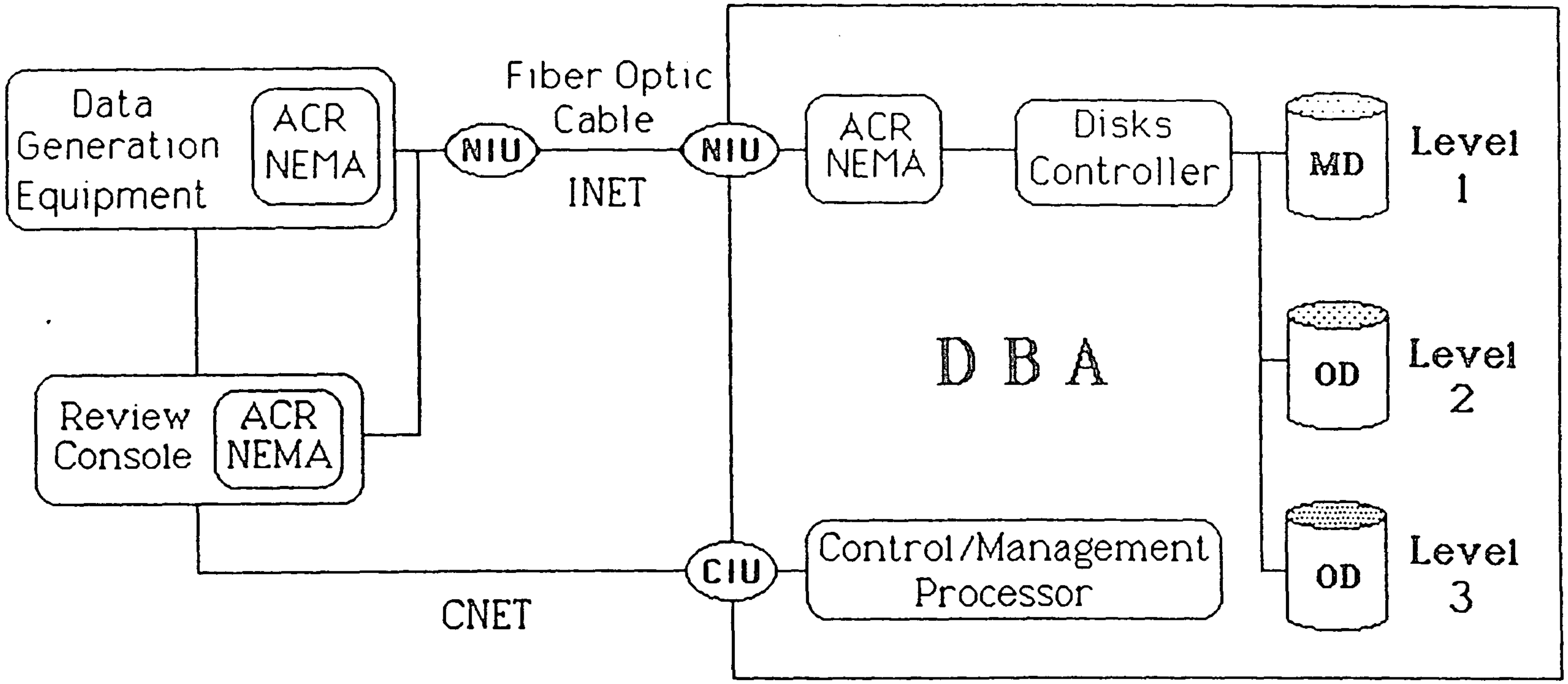


Figure 3.2 TDIS Simulation Block Diagram

b. Any CSP can occupy any channel.

c. In order to process the job in parallel, the system can use all 4 channels simultaneously at any time.

d. The imaging equipment generates the request which has requesting time, room number, and number of images in different sizes. The equipment can be attached to any data generation station.

e. Each NIU has a double buffer and handshake for controlling data flow.

f. The ACR-NEMA module has a finite frame processing time.

g. The INET uses fiber optic high speed data transfer rate.

h. The Control/Management Network (CMNET) uses Ethernet type or Broadband type network.

i. The Data Base Archive has a 3-level hierarchical disk storage system: the first level is for magnetic disk, the second and third level for optical disks.

j. The assigned INET channel can be used for sharing a data path in both directions.

k. The network channel utilization is an average of the sum of each channel that is busy in the desired time period.

3.1.2 User & Data Flow Scenarios

DATA GENERATION: Each unit of Imaging Equipment (IE) produces the request which will pass through CMNET. All the requests go into the DBA request queue. The number of images in different sizes corresponding to the request are also the input data for our specific task of simulation. The activating (requesting) time is strictly in ascending order from top to bottom.

Once the request in the Channel Serving Processor (CSP) queue is accepted by one of the CSPs, the CSP will assign the channel number to the data generation node, then the data transfer begins at the assigned activating time. The size of the image at this moment is broken down into packets. The size of one packet is 4 KB plus 6 bytes for header and 2 bytes for checksum. See ACR-NEMA standard, Publication 300-1985 for detailed specification of the ACR-NEMA interface. The size of the last packet may be less depending on the image size.

One of the two buffers in the NIU receives each image frame. Each buffer can contain of maximum of 4 KB + 6 bytes + 2 bytes of data. Once the buffer is full, the NIU sends the 'ready' signal to CSP. At the same time the next frame is put into the available buffer. After checking the buffer status (full/empty), that particular buffer then draws the data from that buffer and sends it to the INET. The INET has the effective data rate of 139.26 Mbps. The buffers in the NIU at DBA act in the same manner as buffers in the NIU at the equipment side. Each frame now goes to the ACR-NEMA model in the DBA with the data rate of 64 Mbps. The ACR-NEMA model performs frame deforming process, and then sends frame to the level-1 storage at 64 Mbps data rate.

After completing the packet transfer, the CSP issues the 'done' signal to NIU, which in turn, changes that buffer status to be empty. The process goes on until the last portion of the image has done its job. The system examines the maximum of bit-error, if it exceeds the threshold value (not decided yet), then the image is useless. The system then performs the next image transmission.

DATA RETRIEVAL: The data flow scenario of the retrieval process is similar to the generation process but now in the reverse direction. Moreover, the process includes review workstations (sending requests, receiving images) and all 3 levels of disk storage. The need of the number of previously requested examinations depends on the doctor. These examinations can be found at the specified level in the 3-level hierarchical disk storage depending on the examination age. Each exam may have several images.

This simulation model requires three input files and produces one output file.

1. The first input file contains the major parameters that are necessary for this simulation module. The

parameter(s) can be changed easily to fit the assumption(s) without recompiling the simulation program. The header of the output file contains these parameters.

2. The second file consists of the data generation information such as process name, requesting time, room number, patient identification, number of films corresponding to its size and request termination code.

3. The third file comprises the retrieval patients information which is used to extract the images in the 3-level hierarchical disk storage. The number of retrieval images depends on the previous examination requirement from the assigned patient's doctor. The file includes patient identification, doctor identification, request priority, examination date examination code, number of film(s), and data field termination code.

4. The output file contains all the required input parameters and simulation results, such as the results of hourly utilization and maximum queue of the requests. Chapter 4 will describe the simulation results.

3.2 Data Generation & Review Workstations

3.2.1 Imaging Equipment (Data Generation)

This model has four major ports. The first one is for any data generator equipment (such as CT, MRI, US), the second is for NIU attachment. Figure 3.3 shows this data generation model. The third port is for CMNET connection,

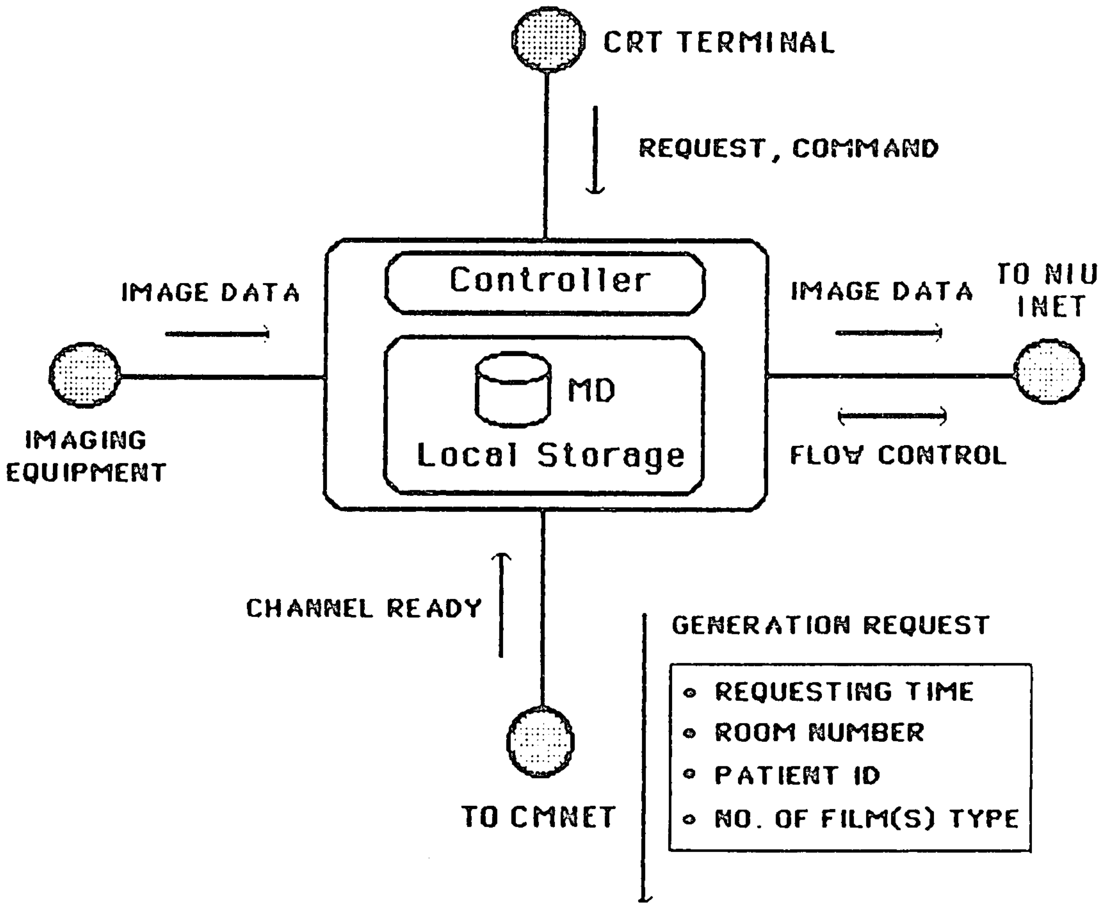


Figure 3.3 Data Generation Node Model

and the last one is for, of course, the terminal. In addition, whenever the image network channel is busy, the local magnetic disk storage will keep the patient image data until the image network channel is available. Then the imaging equipment module will release the patient image. This will make the system more efficient.

Any request (with requesting time, room number, patient identification, number of film(s) type) will pass to the CMNET via terminal. The image data from data generation equipment passes through NIU whenever it receives the channel ready acknowledgment. However, the flow control which is from NIU is needed. The data transfer rate is 64 Mbps, but it can be any value by setting this parameter in the data input file.

3.2.2 Review & Analysis Workstation

This model also has four major ports, the first one is for image display, the second is for NIU attachment. The third port is for CMNET connection, and the last one is for a CRT terminal. Whenever the image network channel is ready, the local magnetic disk storage can keep the series of patient images from DBA first. Until the current image processing or base memory is available, then the unit will perform any desired process. This will make the TDIS system much more efficient.

Any remote commands and/or requests (with patient ID, doctor ID, request priority) will pass to the CMNET via CRT terminal. The image from DBA passes to the base memory via NIU and INET whenever the unit receives the network channel ready acknowledgment. However, the flow control from NIU to review console is needed to control the flow of images. The data transfer rate is 64 Mbps, however, it can be in any value by setting this parameter in the data input file. Figure 3.4 depicts this review/analysis console model.

3.3 Image Network (INET)

3.3.1 ACR-NEMA Standard

The ACR-NEMA standard layers also apply to this TDIS simulation model. The details of how the system distributes the image packet including header and checksum can be found in Section 2.2.3.4. The next chapter will perform the simulation for this part. The ACR-NEMA standard module assumes 500 microseconds delay time for frame processing. The reader can select any value of this delay time in the data input file. The reader also can find the packet type and frame type descriptions of the ACR-NEMA standard frame in the ACR-NEMA Standard Publication 1985.

3.3.2 Network Interface Unit (NIU)

Figure 3.5 shows the developed NIU which can be data transmission and reception. The buffer can be bidirectional

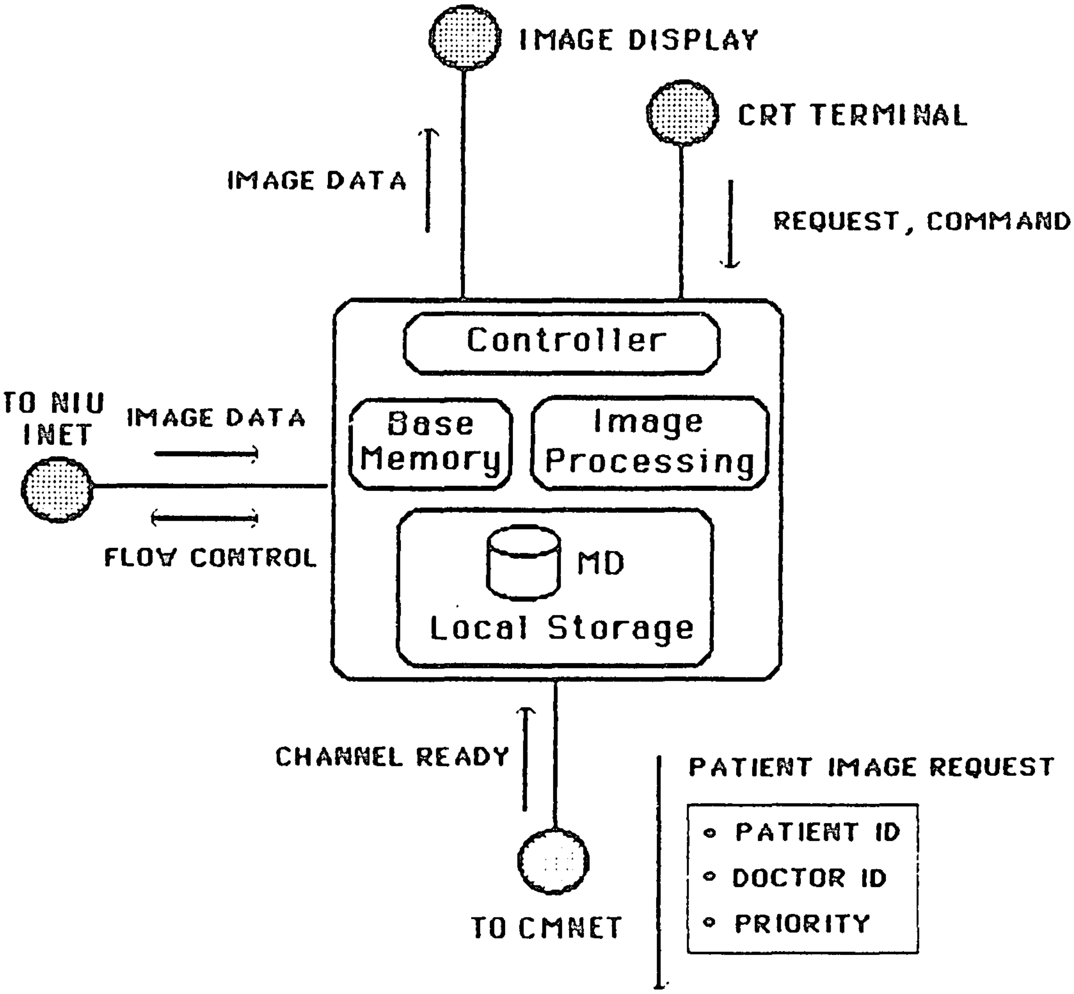


Figure 3.4 Review/Analysis Model

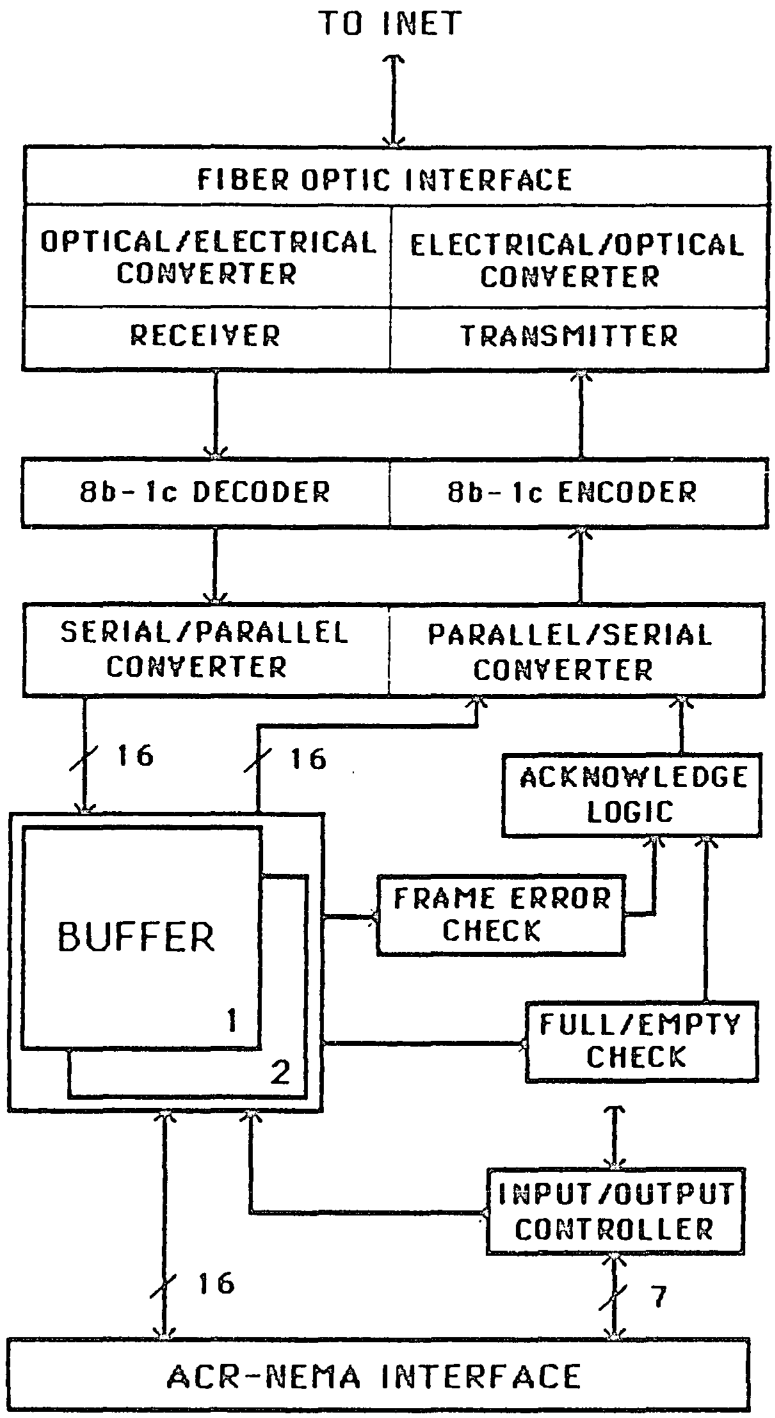


Figure 3.5 Network Interface Unit Block Diagram

data flow which is controlled by the input/output controller. The data flow rate of incoming buffer side (ACR-NEMA standard interface) is much slower than the outgoing buffer side. For transmission mode (from ACR-NEMA standard interface to INET), the buffer size is not as large as in the reception mode. The beginning of the Chapter 4 will show the buffer size evaluation.

According to the TDIS specification, the TDIS system uses the same type of NIU throughout in the image network. If the buffer is full/empty, this NIU can handle the data flow control through INET and ACR-NEMA standard interface. We assume that one image has 2048x2048 pixels, 12 bits per pixel, 16 bits per word, giving a total of 50,331,648 bits (48 MBytes). When we use the ACR-NEMA standard, an image will consist of 1538 frames. Each frame has 2050 words including 3 header words and one trailer word except the last frame which has 1030 words. We adjust the number of words in one frame because we also need the frame in term of number of pixels. That is, 3 words equal 4 pixels. On the other hand, we have a choice to use full 4 Kilobytes (2 Kilowords) for one image data packet. The DBA side forms the format of these frames, and sends them to the review workstation through fiber optic cable.

The ways that NIU handles the flow of these data will be explained as the following (also see Figure 3.5):

1. The Optical/Electrical (O/E) converter receives an image frame which is an optical signal. Then the O/E converter changes the optical signal to be electrical signal bit-by-bit serially. Then the 8b-1c (8 bits with 1 checksum bit) decoder decodes this electrical signal to be pure 8 bits data. This decoder checks the checksum bit for data reliability, and discards the checksum bit.

2. The Serial/Parallel (S/P) converter converts this serial signal to be parallel signal in words (16 bits wide per word).

3. At this point, we assume that the data can flow to the buffer with the rate of 140 Mbps, or higher.

4. On the output side of the buffer, we assume that the transfer data rate is 64 Mbps according to the ACR-NEMA standard.

5. The checksum sequence module will check each frame that comes into the buffer. If there is any error, the Acknowledge Logic module will inform the DBA by sending the status frame (4 words) through INET. The status frame must be in optical signal format. The P/S converter, the 8b-1c encoder and E/O converter will perform this status frame signal. Then the DBA starts sending the frames beginning from the bad frame over again when need arrives.

6. If the frame has is no error, the controller will check to see whether the ACR-NEMA interface is busy. If it

is not busy, the frame in the buffer is transferred to the review console through the ACR-NEMA interface. If it is busy, the NIU will hold the frame until the handshake signals detect the ready signal.

7. In this case the data rate at incoming buffer side is faster than the data rate at the outgoing buffer side. The buffer will be full at one point of time, then the buffer cannot accept any more frame. At this point, the full/empty check module will notify the DBA by sending the 'full' acknowledge. The DBA will stop sending the data frame immediately. With the exception of the last frame of an image, the full/empty check module will report to DBA if the buffer is empty or full.

8. However, the next design approach determines the optimal size of this buffer. This can be accomplished by using the idea of water sinking into a tank which is a buffer while water drains out from the bottom of the tank at the same time. See simulation result for buffer size evaluation in Chapter 4.

9. If the DBA sends half of an image at a time, the buffer will become full eventually. The DBA does not need to receive the 'full' acknowledge from the buffer to stop sending the data if there are no errors, assuming that the buffer is large enough to handle half of the image. However, the DBA needs to get an 'empty' acknowledge from the buffer

to start sending the another half of image. Once, the DBA has completely sent the last frame of an image to the requested workstation, it immediately starts other jobs.

3.3.3 Fiber Optic Cable Network

This model is for the image data transfer and flow control linkage between DBA and workstations. The maximum ideal data rate is 156.672 Mbps; however, the effective data rate will be 139.26 Mbps. By using the encoder/decoder 8b-1c technique, the effective data rate becomes 139.26 Mbps. So the INET uses this effective data transfer rate at 139.26 Mbps for image data transfer. In spite of this, the simulation program can have any value for this data transfer rate in a data input file. It can also handle 4 channels for each fiber optic cable.

3.4 Data Base Archive (DBA)

The DBA system basically consists of a CMNET interface unit, multiple NIUs, and multiple magnetic & optical disks. The user requests arrive in random fashion via CMNET to the DBA system. The DBA system should be able to take the images from IE node and store them on the magnetic disks via INET. In addition, the DBA can retrieve the images from 3-level hierarchical storage and send them to the workstation via INET.

3.4.1 Hierarchical Disk Storage

We have developed a hierarchical disk storage architecture and adapted the architecture to the simulation model. The architecture consists of 4 levels image data storage that can intercommunicate only by means of controlled message through the disk controller. The images from the imaging equipment will actually go to the magnetic disks level-1 with the capacity of 2-3 gigabytes per day. The storage level-1 will keep the images for 7 days with the examination date stamped. A total of approximately 21 gigabytes of data us necessary for this level-1.1 (level 1 set 1). If the images expired in level-1.1, they will be moved to the second level which is a set of optical disks. The optical disk at level-2 has a slow data transfer rate, huge storage volume, and auto cartridges changer capability. This second level requires a data storage capacity of approximately 90 gigabytes to keep the images up to 1 month.

The system examines the expiration date of the images for all levels everyday. If the system finds expired images in level-2 , it will transfer those images to the third level. Level-3, which also uses optical disks, holds images for up to 3 years and has a manual cartridges changer feature. Level-4 stores the images that are beyond 3 years old and up to 10 years in a cartridge storage cabinet. Any images which are over 10 years old will be discarded. Figure 3.6 shows the 4-level disks storage in a data base archive.

As we have discussed before, optical are the best candidate for mass storage. The only disadvantage to using an optical disk in our current technology is its data transfer rate which makes the overall system performance very inefficient. To resolve this problem, we distribute an image into several optical disks, and let the optical disks run in parallel. This will make the data transfer rate much faster. The data transfer rate and disk access time of disk level-1, level-2 and level-3 can be any values. The reader can set these parameters in the data input file. Section 3.7.1 will show an example of such parameters.

3.4.2 Channel Serving Processor

Once an image request arrives to the DBA system, a process is employed for that particular request. The employed process provides information about the requested image. The database management then sends this information to a disk process for saving or retrieving the image(s). If the disks are busy, the disk process simply goes in a queue. If another request arrives while the first request is in progress, the system employs another process set to perform the same procedure.

There are 4 Channel Serving Processors (CSPs) at the DBA side. The system uses all 4 channels with the

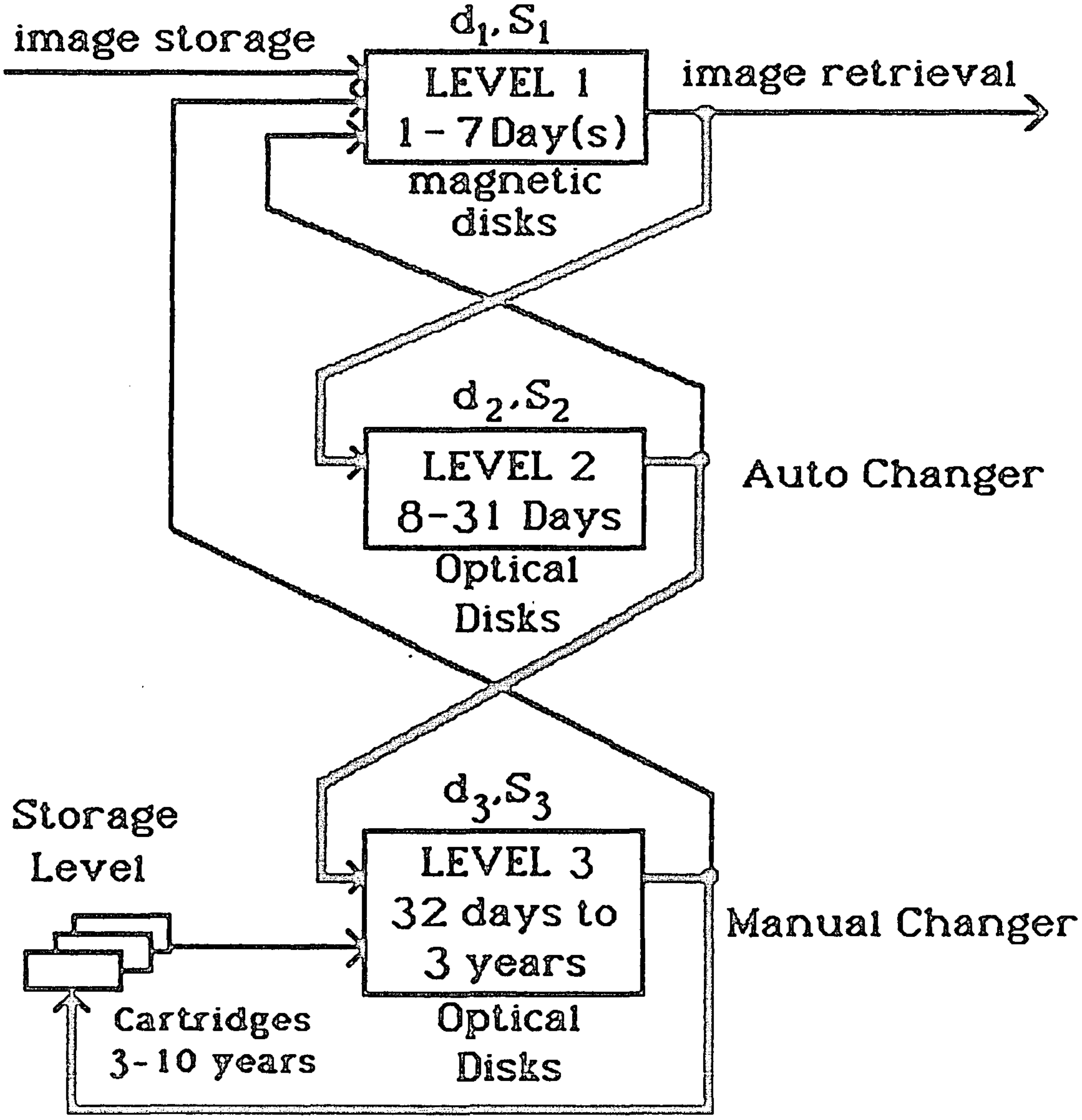


Figure 3.6 4 Levels Images Storage Architecture

wavelengths of 0.81, 0.89, 1.2 and 1.3 micron for fiber optic data linkage. The requested queue management will feed the appropriated duty to any CSP, it implies that any channel is available. Then the data transfer begins between data generation node and DBA or DBA and review console workstation. When the task has done its job, the occupied serving processor is released, freeing it for another job. These processors stay between the NIU's and ACR-NEMA standard servers as depicted in Figure 3.7.

3.5 Image Migration of Data Storage in DBA

In the 3-level hierarchical storage for medical images in the DBA, there is a need to keep the images moving among those 3 levels. In order to achieve a good throughput (less waiting time in queue, for example) of the system, the images should flow efficiently through the storage system. For example, the images flow from imaging equipment to magnetic disks level-1 or from the 3-level storage to review workstations through INET. This action is based upon the requests of physicians or radiologists.

3.5.1 Image Migration Downloading

For level-2 and level-3, optical disk cartridges are used for storing the images. One cartridge has a data capacity of approximately 3 gigabytes. After 24 hours, the system will check the 'examination date' and 'current in

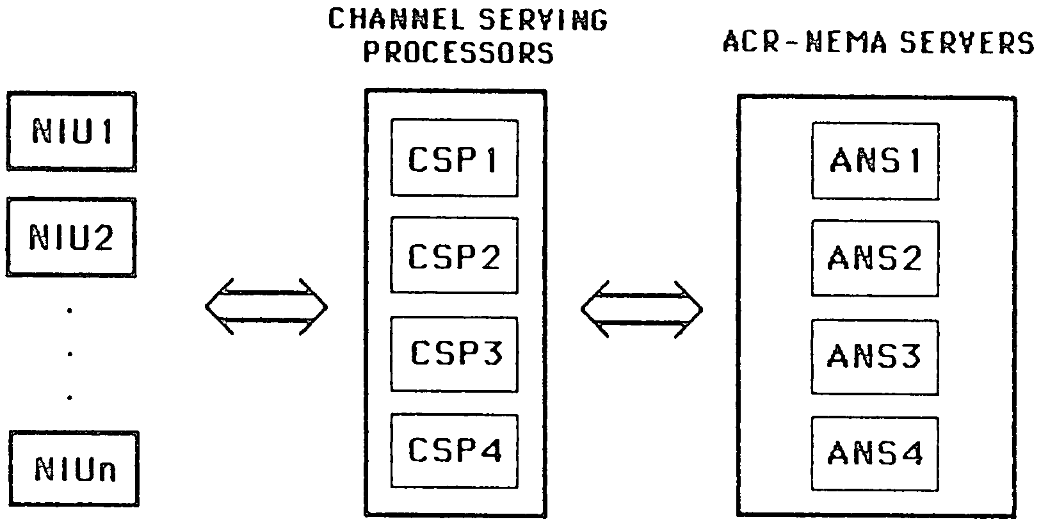


Figure 3.7 Channel Serving Processor Location in DBA

level' of images in the image directory. This is for validating the images in a particular level. If the image expired at that level, the system will move that image to next lower level. This request of moving is sent to the internal schema processor in the image database management system. The database management has the function of transferring the images in the physical disk storage in parallel (see Figure 2.11).

However, in levels 2 and 3, an examination of the space availability and any mixed date of images in the cartridge should be made. If there is more space and/or any valid image in the same cartridge, the system cannot move the expired images because we need to move the whole cartridge not just part of it. Once the optical disk is written, it cannot be erased according to present technology. However, an erasable optical disk will be available in the near future. In this case the image directory will update the 'current in level' and 'current in cartridge identification number' for that particular image. The procedure described above is the image migration downloading which will be performed after 24 hours. Figures 3.8 and 3.9 depict the image migration downloading procedure.

In order to find the size of each level, we need to run the program from the history data input of patients.

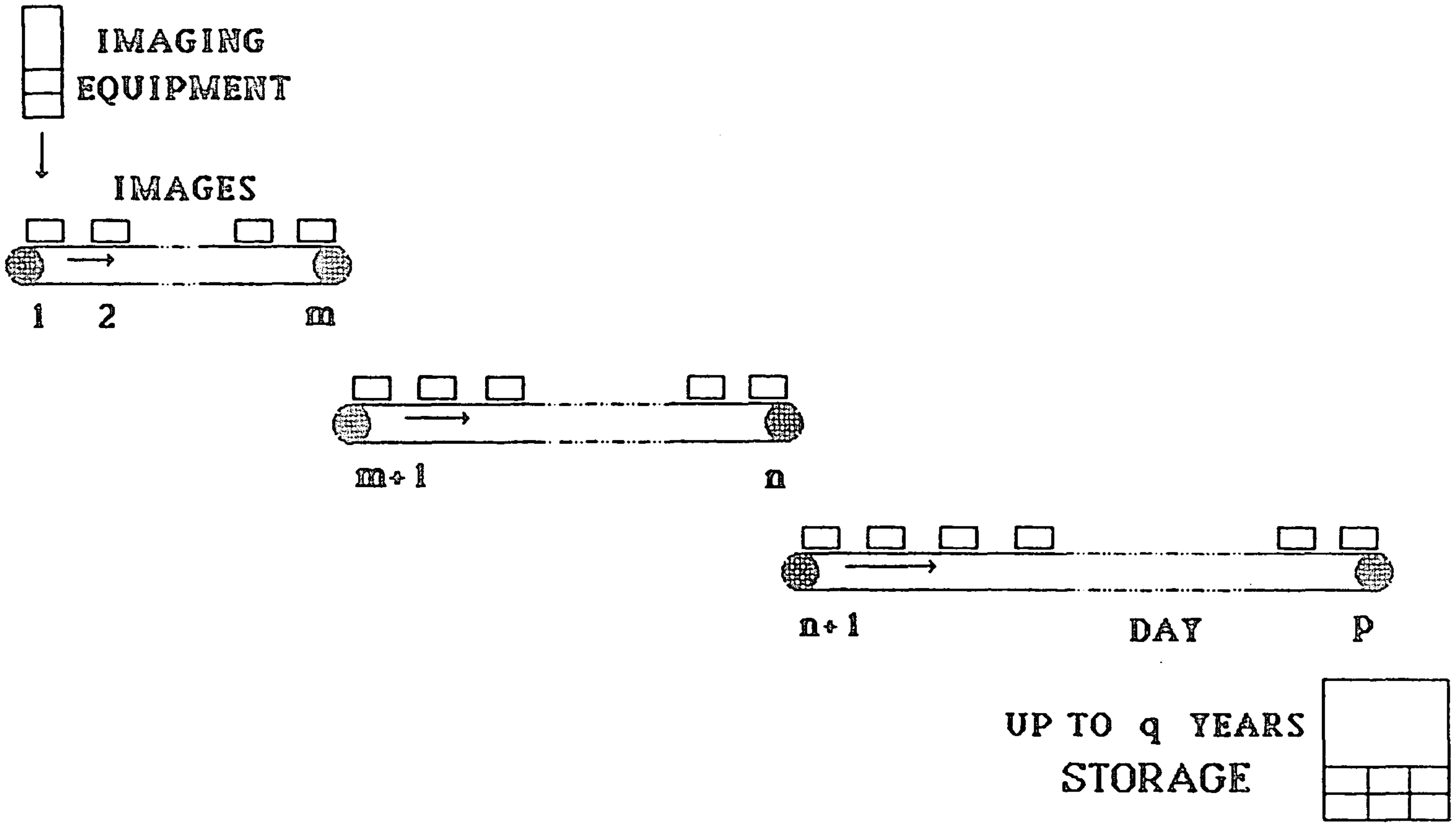


Figure 3.8 Image Migration Downloading in 4 Levels

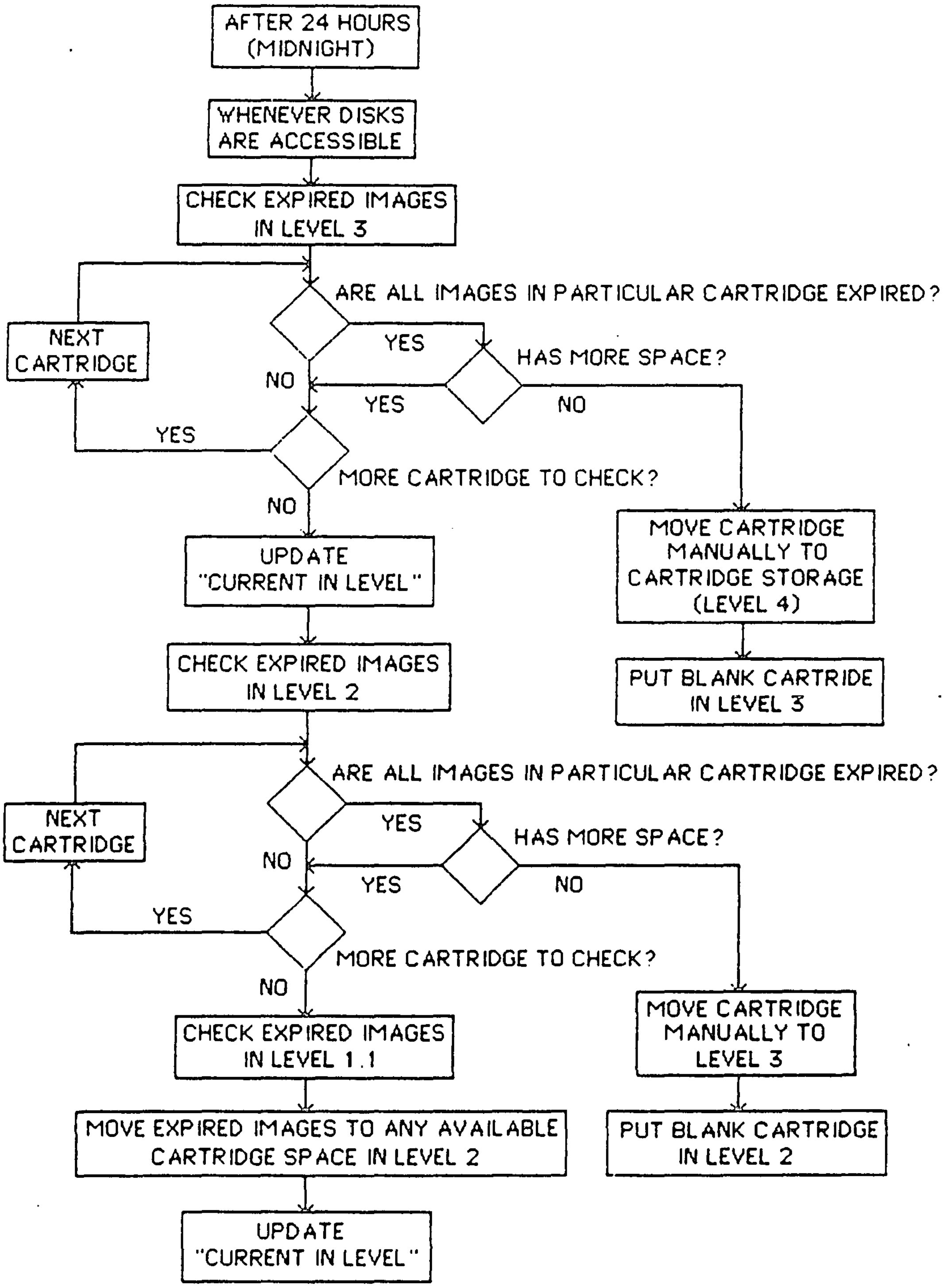


Figure 3.9 Image Migration Downloading Procedure

Figure 3.10 shows the mathematical model to find the maximum size of each level for downloading only. The following section will show the mathematical descriptions for this model.

Let $\Delta S_1 = S_1(t+1) - S_1(t)$ (1)

$\Delta S_2 = S_2(t+1) - S_2(t)$ (2)

$\Delta S_3 = S_3(t+1) - S_3(t)$ (3)

$\Delta S_4 = S_4(t+1) - S_4(t)$ (4)

$Y_1(t+1) = X_1(t) + S_1(t) - S_1(t+1) = X_1(t) - \Delta S_1$ (5)

$Y_2(t+1) = Y_1(t+1) + S_2(t) - S_2(t+1) = Y_1(t+1) - \Delta S_2$ (6)

$Y_3(t+1) = Y_2(t+1) + S_3(t) - S_3(t+1) = Y_2(t+1) - \Delta S_3$ (7)

$Y_3(t+1) = S_4(t+1) - S_4(t) = \Delta S_4$ (8)

Where S_i is the size of the storage at level i = 1,2,3,4

X_i is the # of images input to level i = 1,2,3,4

Y_i is the # of images output from level i = 1,2,3

Suppose $X_1(t) = 0$ for $0 < t < 32$ days, from (5)

Then $Y_1(t+1) = -\Delta S_1$ (9)

Substitute (9) in (6), get

$Y_2(t+1) = -(\Delta S_1 + \Delta S_2)$ (10)

Substitute (10) in (7), get

$Y_3(t+1) = -(\Delta S_1 + \Delta S_2 + \Delta S_3)$ (11)

Figure 3.11 shows the flowchart of the program to create the curves of four levels. The curves that the

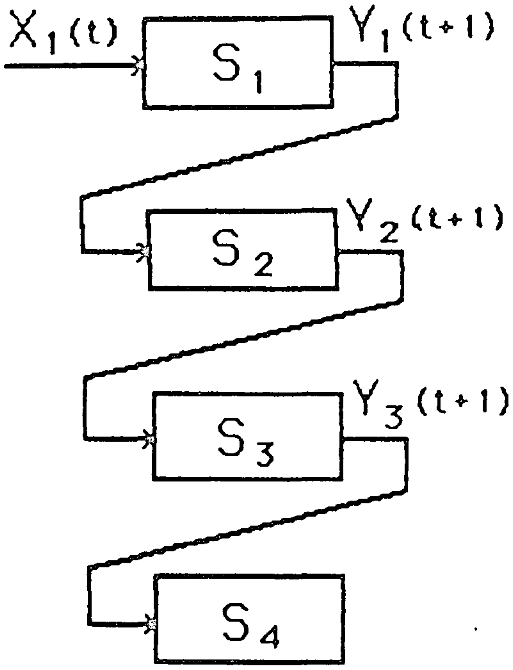


Figure 3.10 Mathematical Model for Finding the Size of Each Level (Downloading Only)

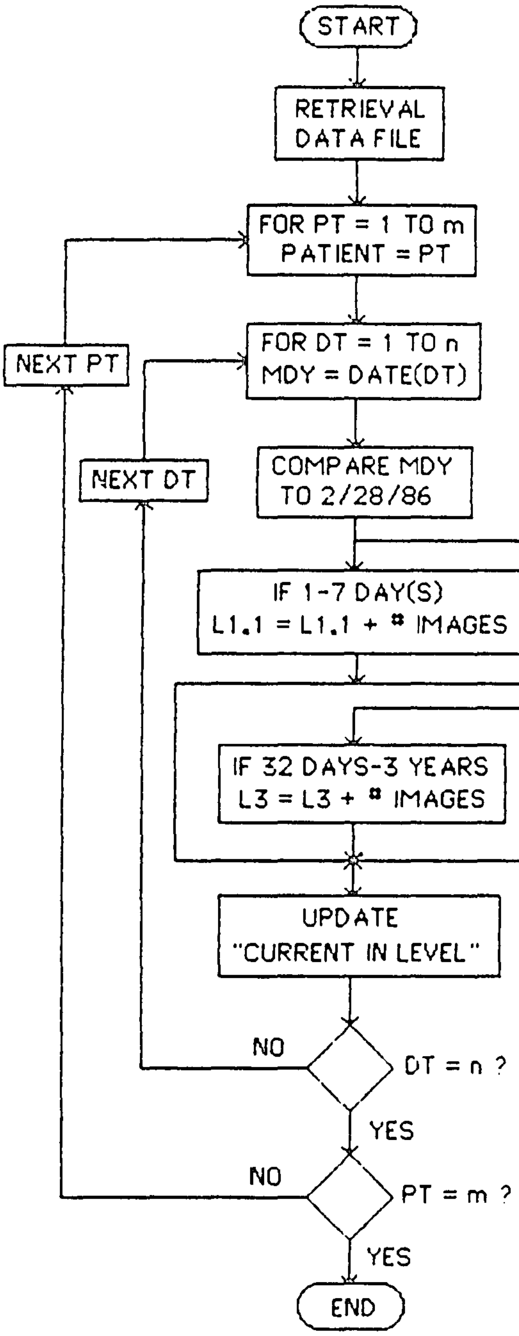


Figure 3.11 Flow Chart to Create Curves for Finding the Size of Each Level (Downloading Only)

reader can find in Chapter 4 are determined by the number of images remaining in a particular level. To achieve such a task, we use both the curves and the mathematical description as mentioned earlier. Then we can calculate the size of each level and the amount of data downloading to each level per day basis.

3.5.2 Image Migration Uploading

Figure 3.12 illustrates the mathematical model for 4-level disks storage. The following section will show the mathematical descriptions for this model.

$X_{1.1}$ = IE (amounts of data from imaging equipment)

$Y_{1.1C} + Y_{1.2C}$ = RC (amounts of data to review console)

Subscript C means copy.

$$X_{1.2} = Y_{2C} + Y_{3C}$$

$$X_2 = Y_{1.1}$$

$$X_3 = Y_2 + Y_4$$

$$X_4 = Y_3$$

$$X_{1.1} + X_{1.2} = IE + Y_{2C} + Y_{3C}$$

$$Y_{2C} = f(nR_2(Dr.ID),\ nI_2(Dr.ID,\ size,\ dL_{1.2}))$$

$$Y_{3C} = f(nR_3(Dr.ID),\ nI_3(Dr.ID,\ size,\ dL_{1.2}))$$

$$S = h(IE,\ Y_{2C},\ Y_{3C},\ nR_1(Dr.ID),\ nI_1(Dr.ID,\ size,\ dL_{1.1}),\ldots)$$

$$S = h(IE,\ f(nR_2(Dr.ID),\ nI_2(Dr.ID,\ size,\ dL_{1.2})),$$
$$f(nR_3(Dr.ID),\ nI_3(Dr.ID,\ size,\ dL_{1.2})),$$
$$nR_1(Dr.ID),\ nI_1(Dr.ID,\ size,\ dL_{1.1}),\ldots)$$

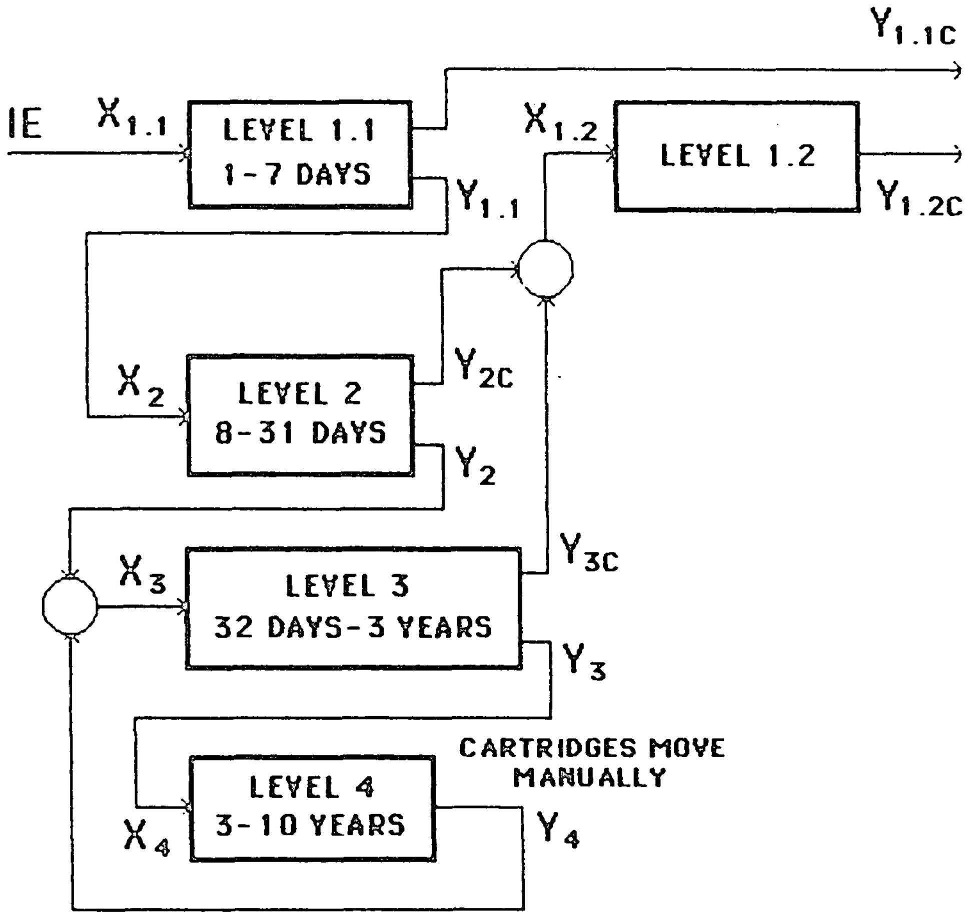


Figure 3.12 Mathematical Model for 4-Level Disk Storage

Where nR_i = no. of requests for level i = 1,2,...

nI_i = no. of images for level i = 1,2,...

dL_i = duration time that the images will reside in level i = 1,2,...

= $g(nR_i, TI, tL_i)$

TI = type of illness

tL_i = time needed to stay in level i = 1,2,..

S = size of magnetic disks needed

The disks in level-1 need to be separated into 2 sections in order to increase the throughput of the hierarchical disk storage. When the generation procedure which uses level-1.1 takes place, then the uploading process which uses level-1.2 can proceed. The uploading process performs its task by copying the images from level-2 or level-3 to level-1.2. The size of disk storage level-1.2 is critical to determine. It depends on the length of the day and size of the images (which is determined by the physicians, radiologists, and inference engine). The size can also depend on the type of illness, knowledge and rules base, and the requests of physicians.

In order to achieve the high throughput, or a lower channel utilization, implementing the simulation program is essential. One way to do this is to let the retrieval process do it in advance upon requests from physicians for needed images. Refer to Figure 3.13, from point 'a' to point 'b', the system can process the requested images during this time period. A doctor can send a request for previous exams needed in advance at point 'a'. The system then copies the images from level-2 or level-3 to level-1.2 whenever the channel is busy, and disks are accessible. However, if the INET channel is free, the system will send the images directly from the specified level.

The images are copied to level-1.2 first. when the generation process has finished, the copied images in level-1.2 can be sent to INET at a faster transfer rate than the optical disk itself. However, the system will handle the rest of the requested images in level-2 and level-3 after finishing the transfer in the level-1.2. Figure 3.14 shows the flowchart of the program to implement this idea. The knowledge header which adapted from JAMIC (Japan Medical Industries Committee) & SIDBA (Standard Image Database) from Figure 2.12 is used in the process in Figure 3.14.

3.6 Control & Management Network (CMNET)

This model will represent only the data rate transfer. It ranges from 128 Kilobits per second to 10 Mbps, depending on the network type used, broadband Sytek networks or baseband Ethernet.

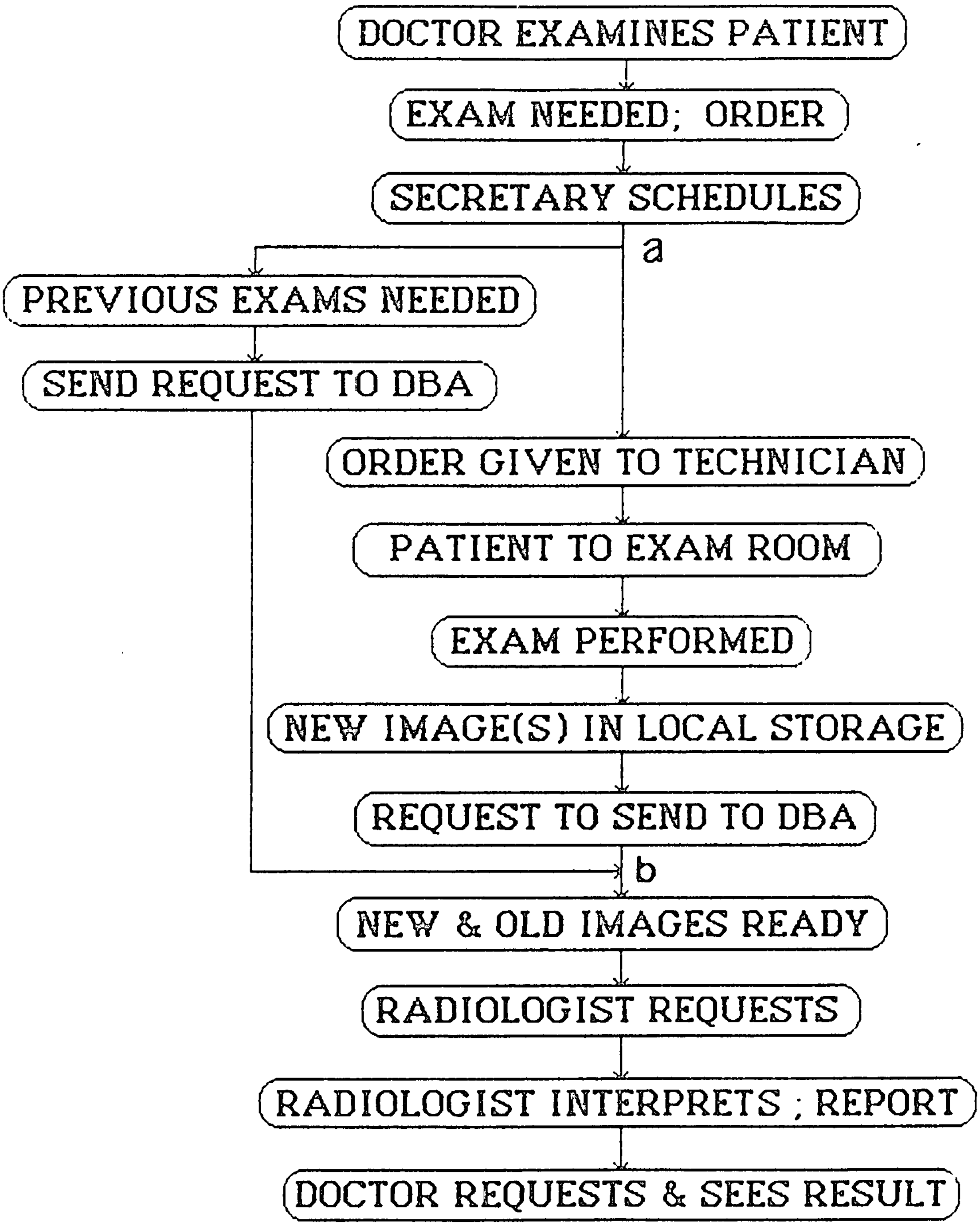


Figure 3.13 Patient Examination Routine

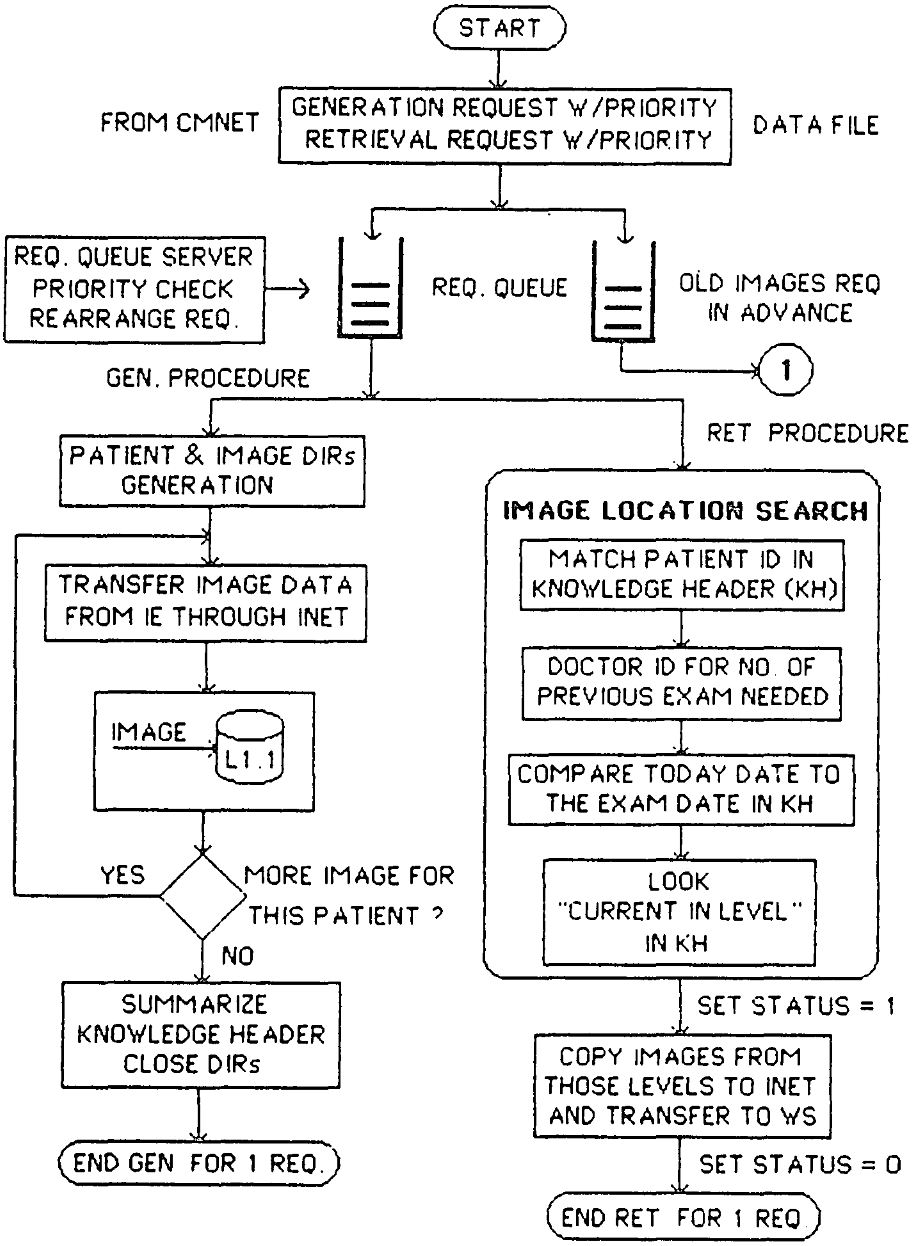


Figure 3.14 Image Generation & Retrieval Procedure with Advanced Retrieval Request

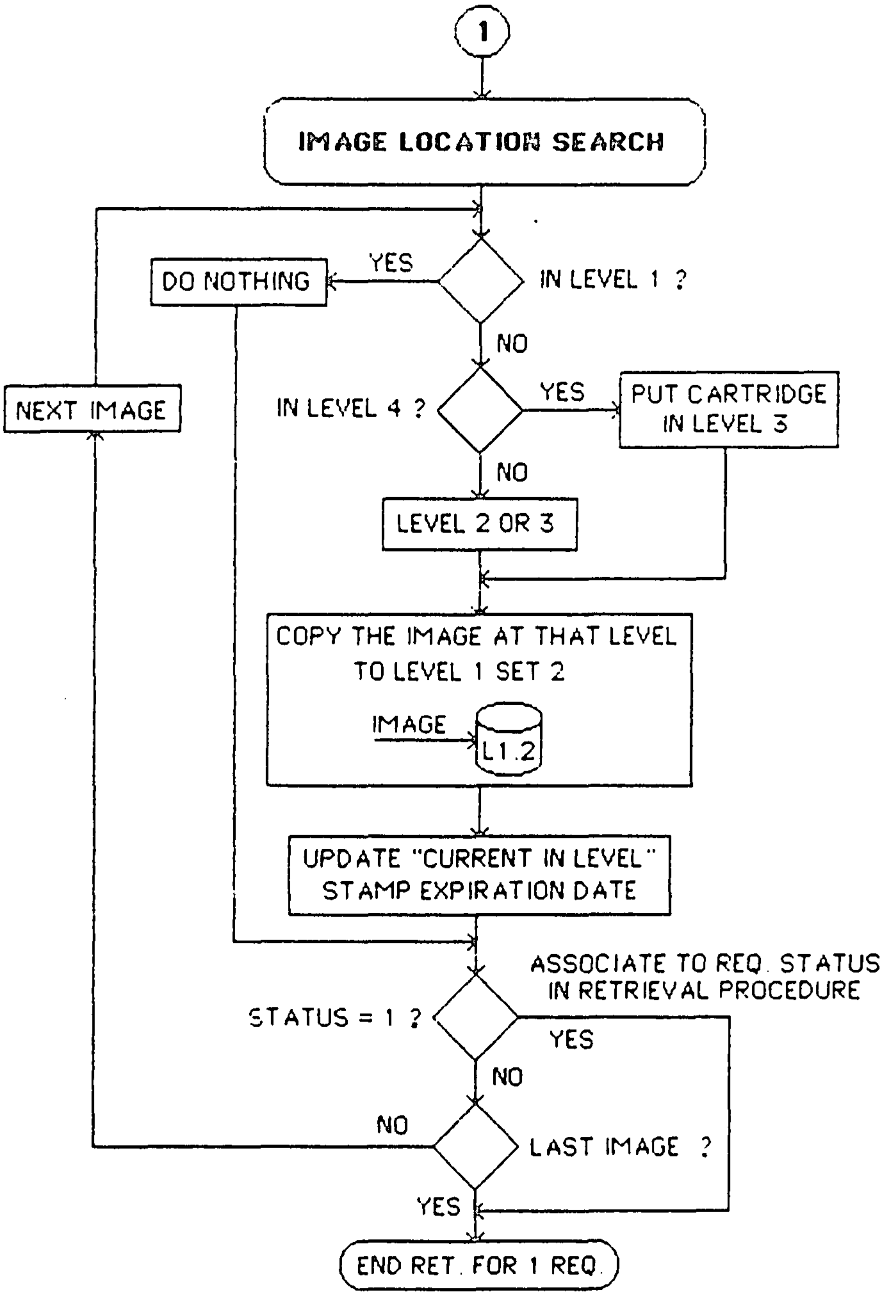


Figure 3.14 (Continued)

3.7 Simulation Data Inputs

3.7.1 Models Parameters

This represents the data input file. It consists of the reference date of raw data generation & retrieval, number of Channel Serving Processors, number of buffers in NIU. It also includes the data transfer rate of review console, ACR-NEMA module, INET, disks level-1, level-2 and level-3. It also comes with a minimum and maximum access time of disks level-1, level-2 and level-3, ACR-NEMA frame processing time. Figure 3.15 shows an example of this input file. The header of the output data file will correspond to the value of the data input file. This will identify the output data to the value of the input parameters used. Figure 3.16 represents an example of the header output data file.

3.7.2 Generation

The raw data of the week of March 17-23, 1985 and February 28, 1986 is the data generation input files. This raw data was originally generated from the Radiology Department, University of Arizona. Figure 3.17 shows an example of the raw data generation. The input file comprises process name which is the name of simulation process, room number of generation node, patient identification number. It also includes requested time (to notify DBA that the generation node is ready to send the data at that time). In

```
2       28      86
1       2
64.0    64.0    139.26
64.0    8.0     8.0
0.06    0.1     1.0     8.0
19.0    21.0
500.0
```

Figure 3.15 Example of Parameters Input Data File

```
Reference Date :  2/28/1986

Number of Channel Serving Processor(s) : 1   Number of Buffers in NIU : 2
Console, ACR-NEMA, INET Data Rate    64.00      64.00      139.26  Mb/sec
Disk Data Rate Level 1, 2 and 3      64.00       8.00        8.00  Mb/sec
Min, Max Disk Access Time Level 1, 2 : 0.06   0.10    1.00   8.00  Seconds
Min, Max Optical Disk Access Time Level 3            19.00  21.00  Seconds
ACR-NEMA Frame Processing Time                              500.00  usecs/frame
```

Figure 3.16 Header of Output Data File

Process Name	Requested Time	Room No.	Patient ID	No. of Film(s) Type 1	2	3	4

Example

ACT	0.00	0	3093200	0	0	0	0	*
ACT	0.17	98	480236	0	0	0	4	*
ACT	0.25	6	3403565	0	0	0	2	*
ACT	0.33	0	3291416	0	0	0	5	*
ACT	1.58	7	4180907	0	1	1	2	*
ACT	2.25	55	3291275	0	0	0	4	*
ACT	2.75	55	3291416	0	0	0	4	*
ACT	3.50	7	3905700	0	1	1	0	*
ACT	3.79	55	4179040	0	0	0	4	*
ACT	3.92	7	3292547	1	0	2	1	*
ACT	5.00	7	3292547	0	0	0	1	*
ACT	5.00	6	1242270	0	0	0	3	*
ACT	6.00	85	3414935	0	0	0	2	*
ACT	6.00	55	3291275	0	0	0	4	*
ACT	6.00	55	3291366	0	0	0	4	*
ACT	6.00	55	4179040	0	0	0	4	*
ACT	6.00	55	3291382	0	0	0	4	*
ACT	6.00	55	4175055	0	0	0	4	*
ACT	6.83	4	4181020	0	0	2	2	*

Figure 3.17 Example of Data Generation Requests

addition, it comes with a number of film(s) corresponding to the type of film, and the request terminator (*).

3.7.3 Retrieval

Figure 3.18 depicts an example of raw data retrieval requests on February 28, 1986. This raw data was originally generated from the University Hospital to represent a typical day. The input file consists of a patient identification number, doctor identification number, request priority (the higher the number, the higher the priority). It also includes the image examination date, examination (procedure) code, and number of film(s).

Patient ID | Doctor ID | Priority

Exam Date | Exam Code | No. of Film(s)

Example

3093200	1	0
22886	3	9
22786	22	2
22786	24	5
22786	40	4
22786	9	4
0	0	0
480236	1	0
22886	1	2
0	0	0
3403565	1	0
22886	1	2
0	0	0
3291416	1	0
22886	5	4
22786	10	2
22786	1	2
0	0	0

Figure 3.18 Example of Data Retrieval Requests

CHAPTER 4

TDIS SIMULATION RESULTS

The SIMSCRIPT II.5 software package is an important simulation tool for evaluating the system's performance. The raw data gathered in the investigation from the week of March 17-23, 1985 was for data generation only. The other data from February 28, 1986 was for both data generation and retrieval. This data was the input files to our simulation task. The simulations consisted of two major parts. One was data generation only and the other a combination of data generation and retrieval with and without an image migration policy. The results included the hourly channel utilization, queue length, and response times. In addition, this chapter describes the simulations of a single channel of the network for a combined data generation & retrieval.

There are 4 phases to the TDIS simulation works as shown in Figure 4.1. Phase I starts the simulation from the Imaging Equipment (IE) up to the Channel Serving Processor (CSP) in a Database Archive through INET and NIUs. Phase II is similar to Phase I, but the simulation takes place up to the level-1 disk storage in DBA. This phase also adds the ACR-NEMA frame processing time for both sides (DBA & work station). Phase III has the image retrieval process

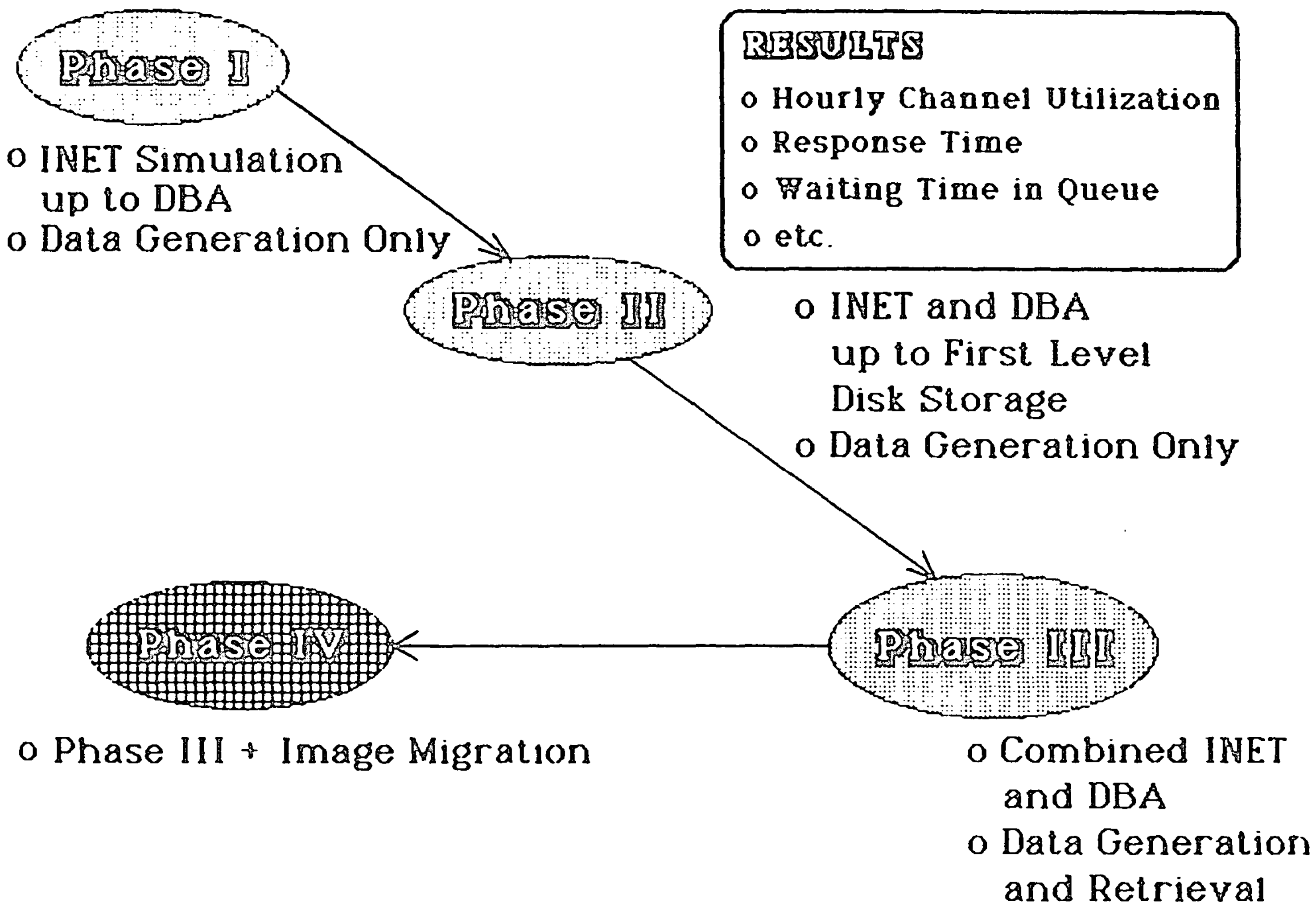


Figure 4.1 Simulation Road Map

combined to the Phase II, involving the hierarchical disk storage on all 3 levels. Finally, Phase IV combines the image migration algorithm in DBA to Phase III. Phase I and II uses both single and 4 channels. Phase III and IV uses only a single network channel to evaluate the system's performance.

Before going to the simulations from Phase I to Phase IV, a simple single buffer size evaluation was performed. Using NIU from Figure 3.5, we assume the input data transfer rate to the buffer is 100 Mbps (network side). The output data transfer rate from the buffer is 64 Mbps (ACR-NEMA interface side), one image size has 2048x2048x12 bits. As you see the input data transfer rate is faster than the output data transfer rate. The buffer will be full at one point of time if the buffer size is not large enough to handle the whole image. This assumes that the incoming data flow is in active while the outgoing data flow is taking place. This is similar to a water tank with more water flowing in a faster rate than flowing out.

Figure 4.2 represents the result of this simulation. As you can see from the results, the more sections an image has, the less the buffer size will be. In addition, if an image has more sections, it spends more time transferring an image. For example, if one image has 8 sections, the buffer size needs 0.15 MWord or 300 KB. The DBA sends 1 section (6

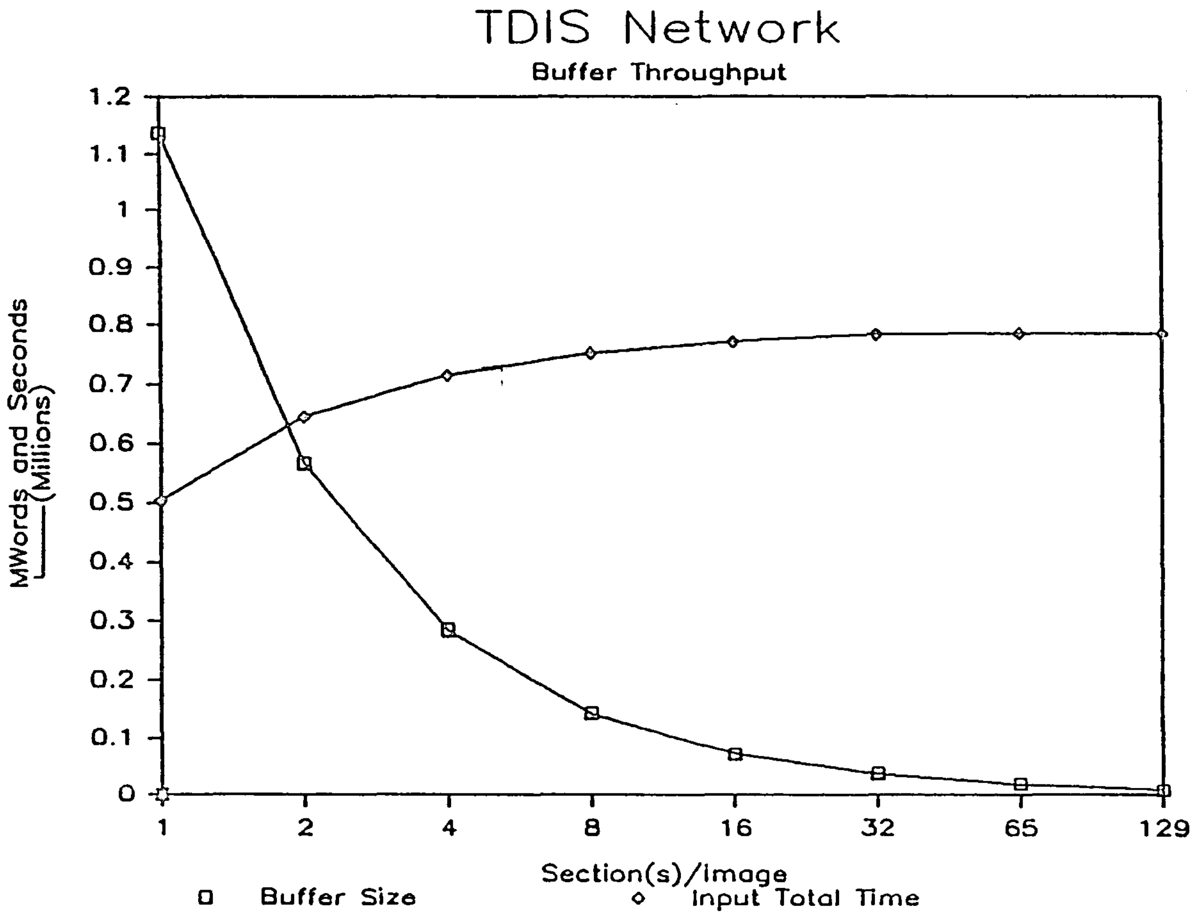


Figure 4.2 Simple Buffer Size Evaluation

Mbits) to the buffer one section at a time. It will also take a total of 0.74 seconds to fill one image in the buffer.

4.1 Data Generation Simulations

4.1.1 From IE up to Channel Serving Processor

4.1.1.1 Assumptions. Figure 4.3 gives the simulation block diagram of the TDIS Network Data Generation. Because the system has 4 channels for a fiber optic network, it uses a total of 4 Channel Serving Processors (CSP). Any CSP can occupy any channel. The system can use all 4 channels simultaneously at any time in order to process the jobs in parallel. The ACR-NEMA Imaging Equipment generates the request which has activating time, image data frame, and a number of films in different size. The equipment can be attached to any NIU and CMNET This phase assumes no delay time for data flow from INET to DBA.

4.1.1.2 Data Flow Scenario. The ACR-NEMA imaging equipment nodes produce the requests which pass to the DBA via CMNET. These requests will go the request queue in the DBA. Figure 3.17 shows an example of these requests which will be the input data generation file for our specific simulation task. The activating time is strictly in an ascending order from top to bottom in the second column.

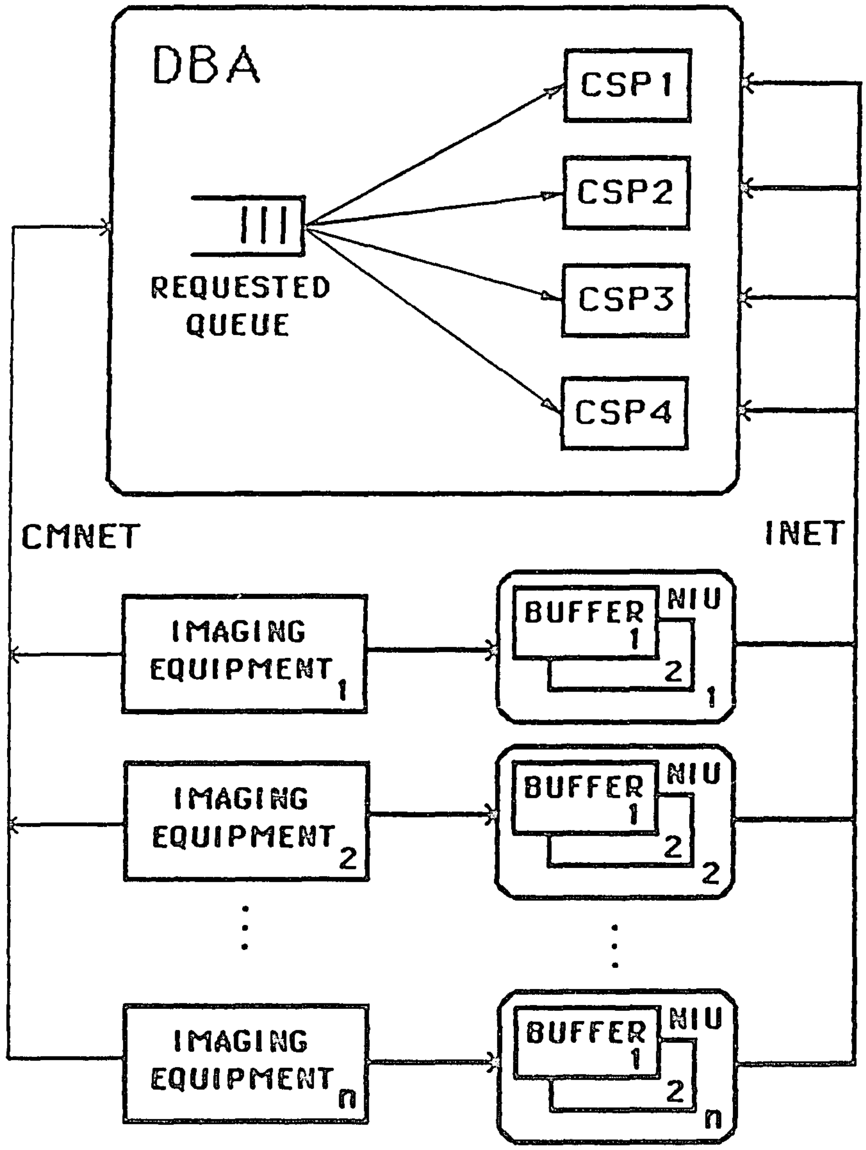


Figure 4.3 Simulation Block Diagram from IE up to CSP

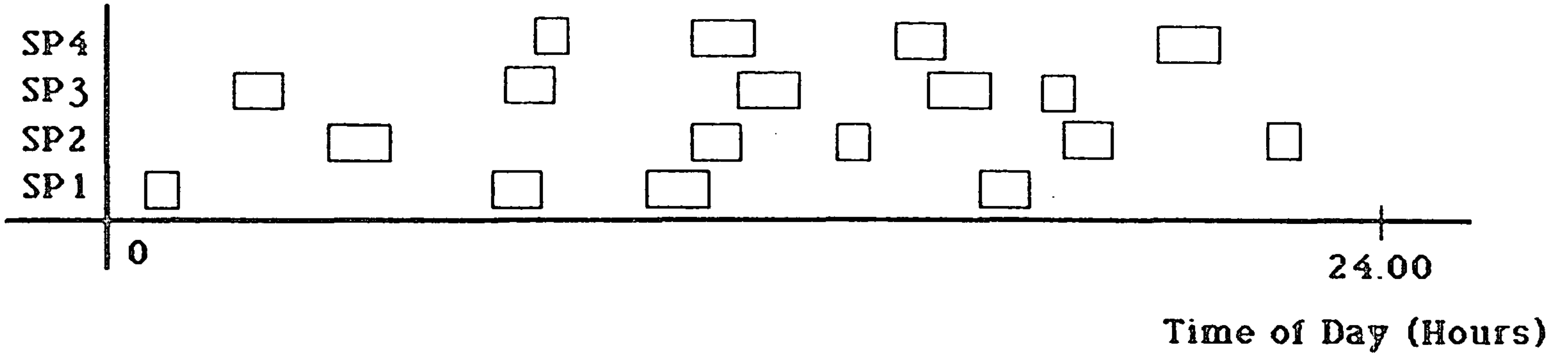
Once one of the CSPs accepts the request, that CSP will assign the channel number to that data generation node. Then the data transfer begins at a particular activating time. The size of an image at this moment will then be broken down into frames. One frame contains 4 Kbytes for image data, 6 bytes for header, and 2 bytes for checksum based on ACR-NEMA standard. The size of the last frame may be less depending on the image size. The buffer in NIU which has 2 buffers receives each frame from imaging equipment at data rate of 64 Mbps. Each buffer can contain maximum of 4 Kbytes + 6 bytes + 2 bytes of data.

When the buffer is full, the NIU sends the 'ready' signal to CSP while the another buffer receives the next frame. By checking the buffer status (full/empty), that particular CSP will then draw the data from that buffer. At this point, the effective data transfer rate is 139.26 Mbps. The buffer in the NIU (at DBA) gets the data frame and sends it to the DBA for processing. The program simulates up to this point only and no further processing is done for this phase.

After completing frame transfer, the CSP issues the 'done' signal to NIU, which in turn, changes that buffer status to empty. The process goes on until it has reached the last portion of the image. The system will test the maximum bit-error, if the bit-error exceeds the threshold value, that image is useless. In this case we assumed no error at all. Then the system gets the next image or next request if there is any. The data rate transfer as mentioned above can be any value in order to evaluate the performance of this system.

4.1.1.3 Channel Utilization Definition. The network channel utilization is defined as the time average of the channel serving processors which are busy in the specified period. Figure 4.4 shows the network channel utilization definition.

4.1.1.4 Double, Triple & Quadruple Data. 2, 3 and 4 times the amount of data generation to the original one are necessary. This can predict the work load of the network performance when the services increase in the near future. Figures 4.12 depicts the method of how to generate the double data generation. For example, by taking an average of the requesting time of the neighbor (10:00 & 11:00), a new requesting time (10:30) results. Then it duplicates the number of film(s) type from the first requested time, i.e. 0 0 0 5. This technique also applies to the triple & quadruple data generation with the same manner. However, the sum of the neighbor existing requested time will be multiplied by 1/3 and 2/3 for triple data, by 1/4 , 2/4 and 3/4 for



$$\text{Average Busy Time of Channel Serving Processors} = \left[\left[\sum_{\text{Time}} SP1 + \sum_{\text{Time}} SP2 + \cdots \sum_{\text{Time}} SPN \right] \Big/ TP \right] \times 100 \Big/ N \ \%$$

$\triangleq$ Channel Utilization

TP : TIME PERIOD e.g. 24.00 hours

N : NO. OF CHANNEL e.g. 4 channels

Figure 4.4 Network Channel Utilization Definition quadruple data. The number of films are the same as in the first requested time.

4.1.1.5 Simulation Results. The simulation model used the actual raw data generation in the week of March 17-23, 1985 as shown in Figures 4.5-4.11. Radiology Department, Arizona University, provided the raw data for this TDIS simulation purpose. The simulation also used the developed NIU and INET simulation models which is based on the TDIS specification and ARC-NEMA standard. There are 2 buffers (2 KB each) in the NIU. The Data transfer rate is 64 Mbps for ARC-NEMA, 156.672 Mbps for fiber optic INET. The NIU has a 4-channel fiber optic data path (4 channel serving processors). The simulation ran from ARC-NEMA imaging equipment nodes up to the beginning of data management in DBA through NIU and INET . However, the data generation requests from imaging equipment nodes passed to the CMNET model. Figure 4.13 shows a sample data input/output of the TDIS74 simulation program. Tables 4.1 and 4.2 summarize the results. Figures 4.14 and 4.15 show the results from Table 4.2.

In addition, the simulation ran with a number of channel serving processors and a number of buffers in NIU. The produced results showed the significant changes of these particular measurement parameters for this INET simulation. Table 4.3 with Figures 4.16 & 4.17, and Table 4.4 with

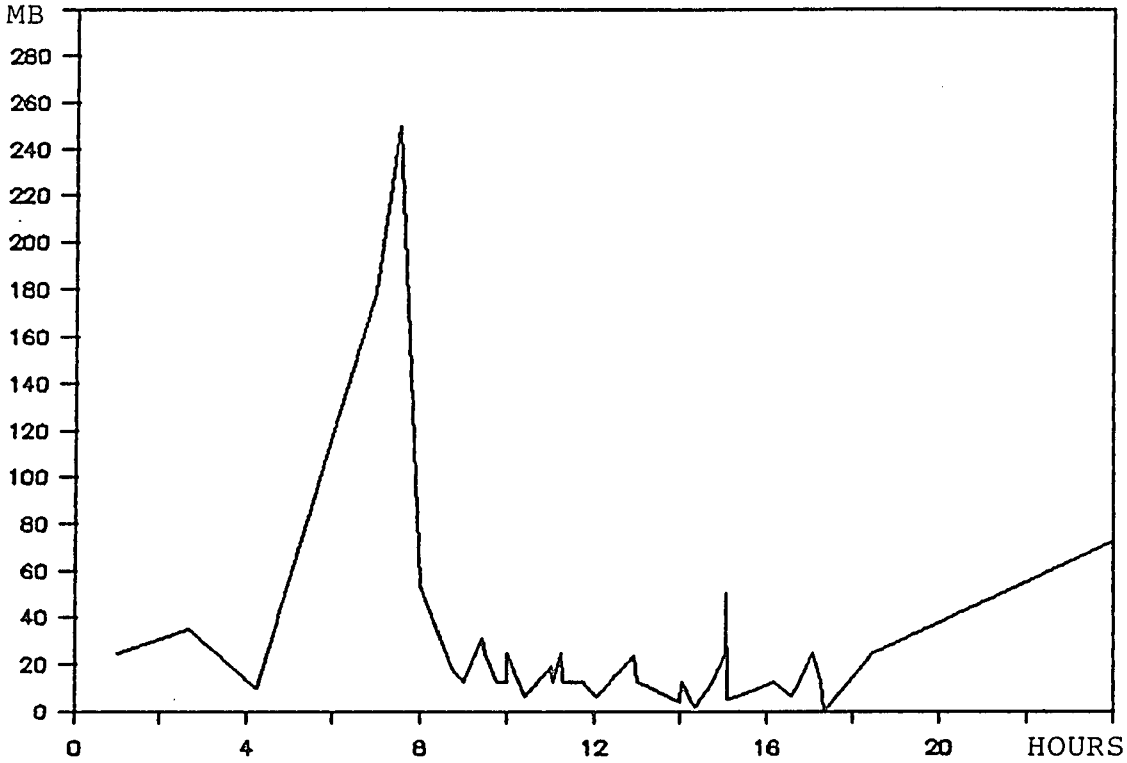


Figure 4.5 Data Generation on Sunday 3/17/85

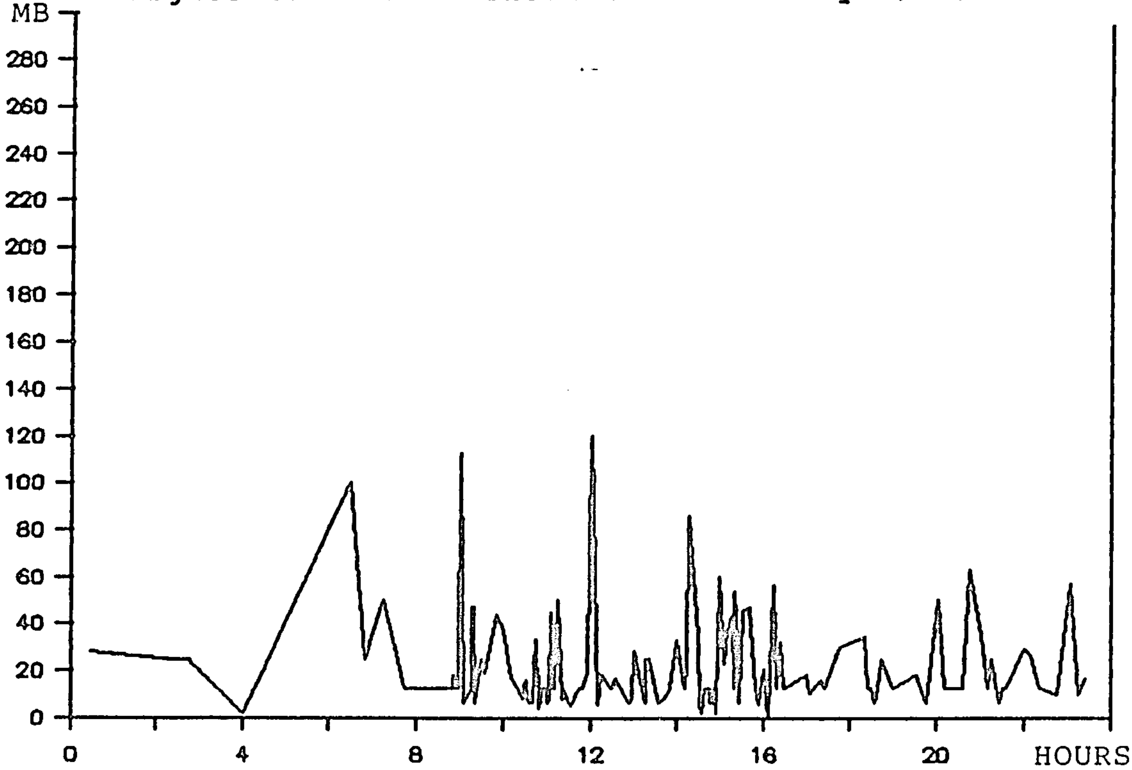


Figure 4.6 Data Generation on Monday 3/18/85

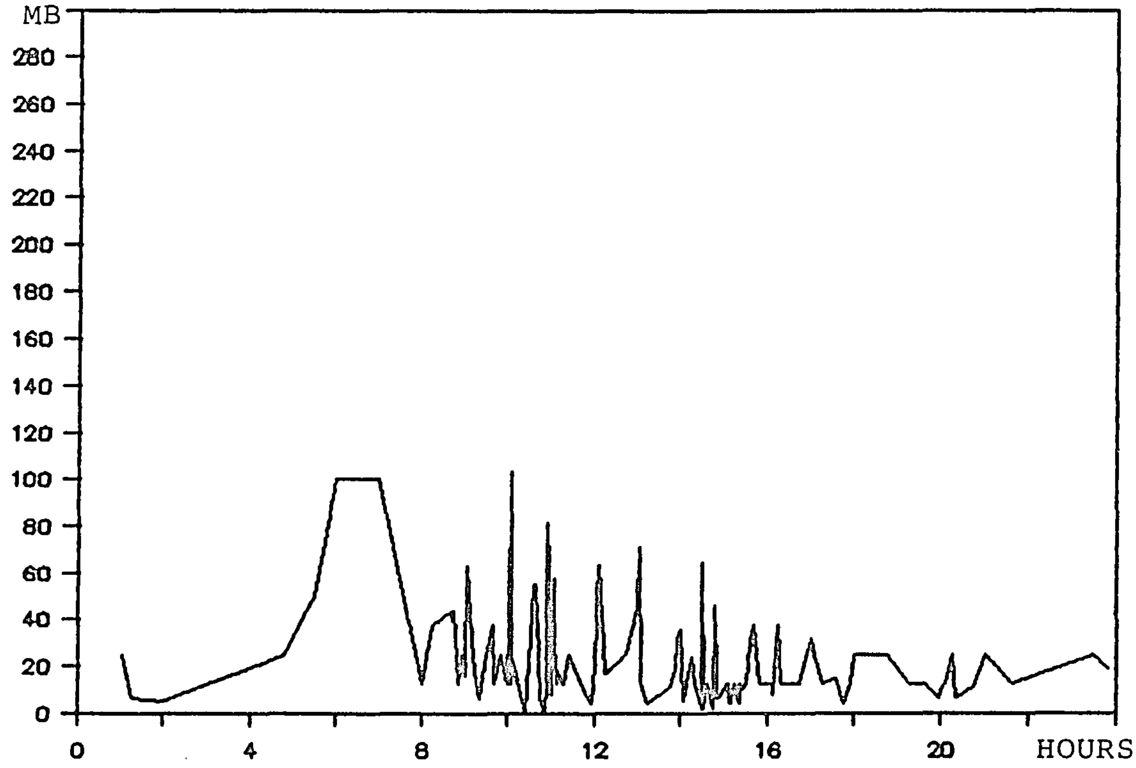


Figure 4.7 Data Generation on Tuesday 3/19/85

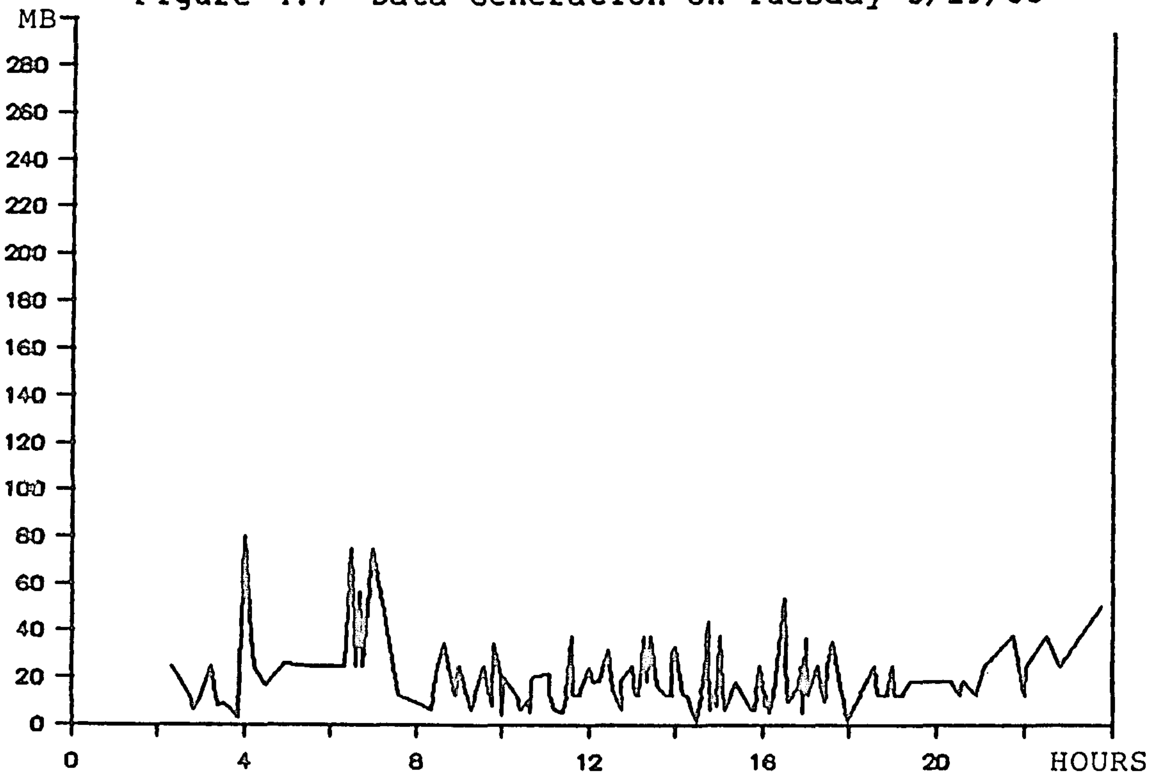


Figure 4.8 Data Generation on Wednesday 3/20/85

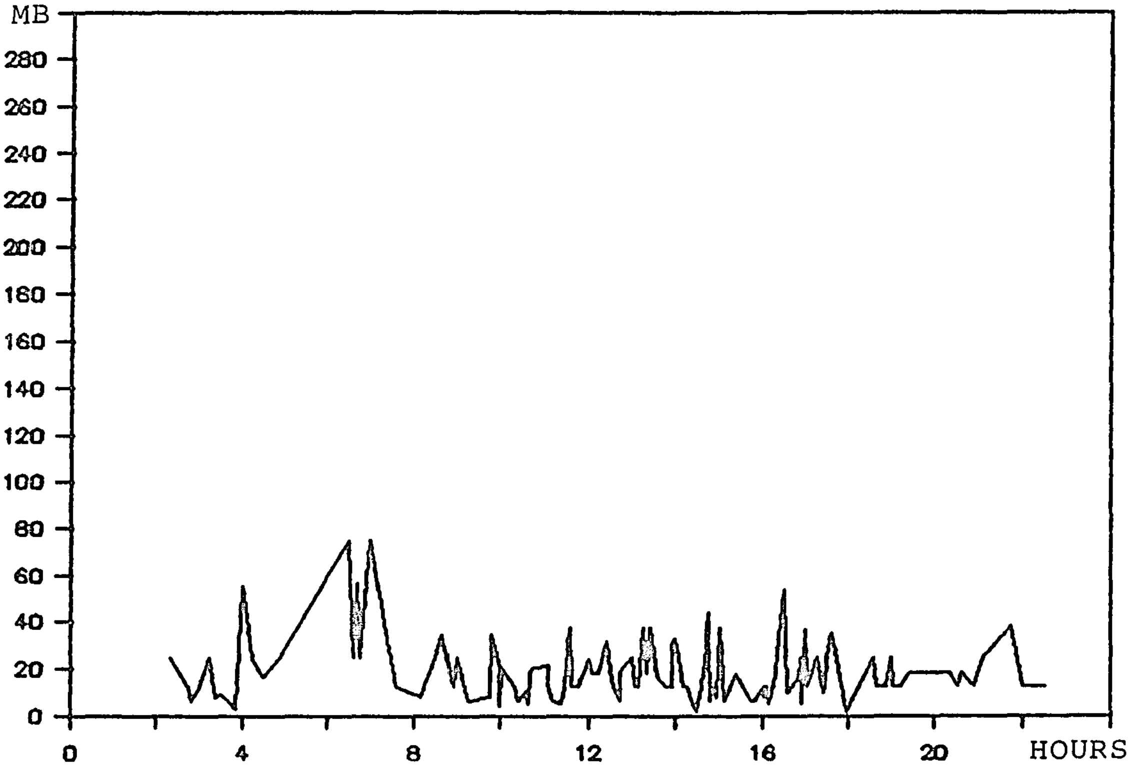


Figure 4.9 Data Generation on Thursday 3/21/85

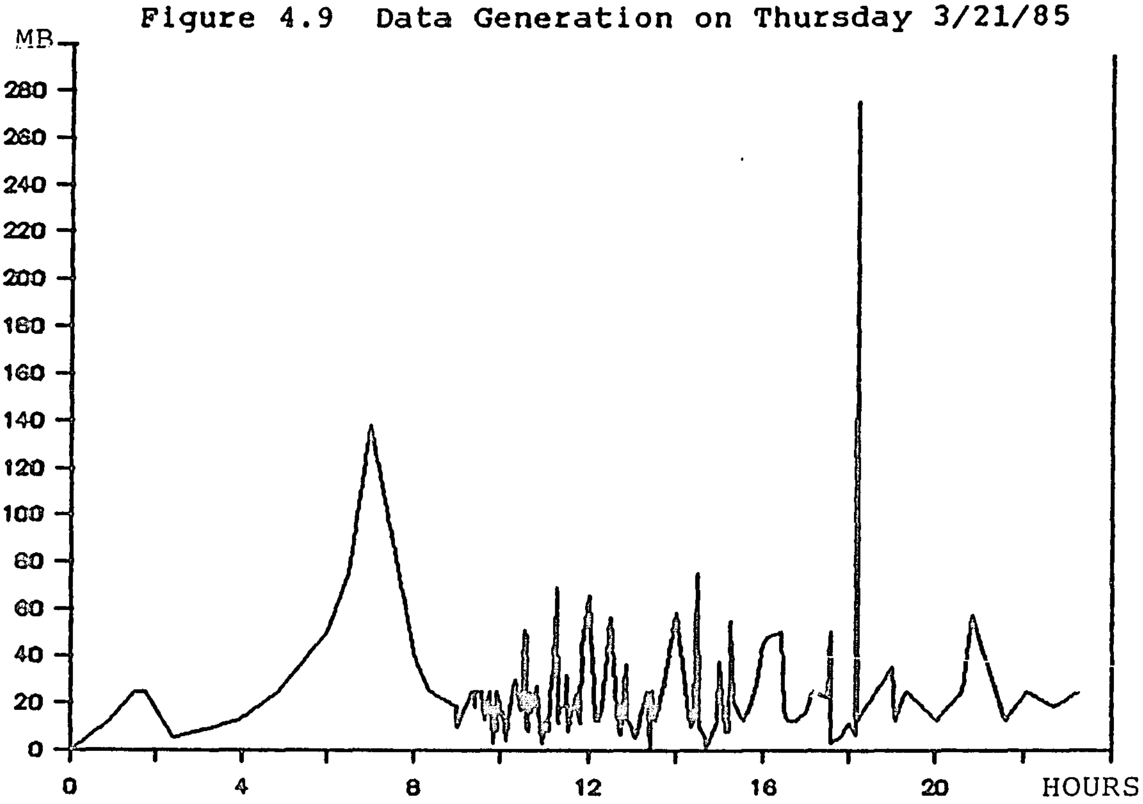


Figure 4.10 Data Generation on Friday 3/22/85

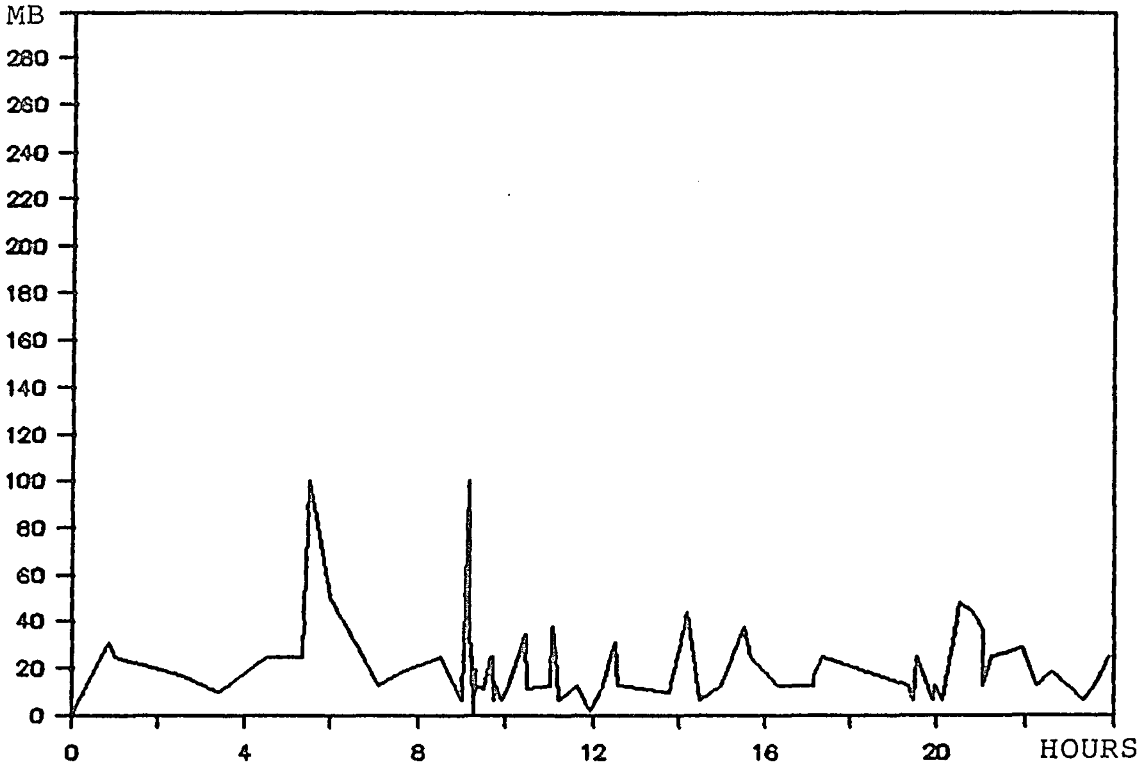


Figure 4.11 Data Generation on Saturday 3/23/85

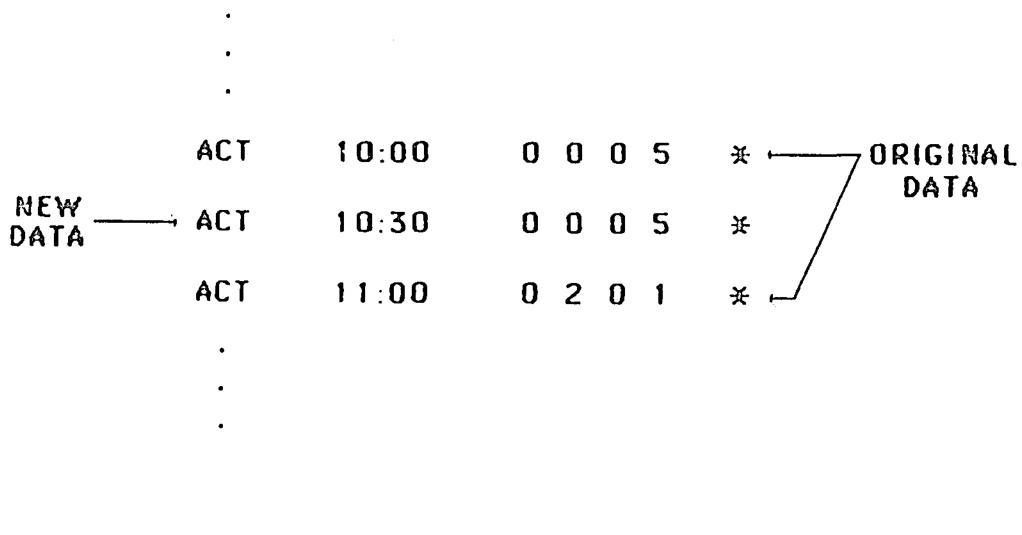


Figure 4.12 Double Data Creation Technique

```
$ def simu01 coutl.a74
$ run tdis74
Enter Number of Serving Processor(s) and Buffer(s) :
II.5> 4 2
Enter INET and NEMA Transfer Rate in Mb/sec :
II.5> 139.26 126

TDIS Network Study for    204  Images    58  Jobs in     24.0100  Hours
The Channel Utilization                                   0.0209  %
The Max, Avg Queue for SPU                      6         0.0002  Jobs
The Max, Avg Waiting Time in Queue              3.2038    0.3038  Seconds
Min, Max, Avg Image Processing Time    0.1342   0.4005    0.3543  Seconds/Image
Min, Max, Avg Processing Time (+que)   0.1342   4.8057    1.5500  Seconds/Job
Min, Max, Avg Processing Time (-que)   0.1342   3.4143    1.2461  Seconds/Job
$
$
$
```

Figure 4.13 Input/Output Example of TDIS74 Program

Table 4.1 Data Generation in the week of 3/17-23/85

Day	# of Requests	Data Amount (MB)
Sunday	59	1129.00
Monday	203	2922.00
Tuesday	177	2790.50
Wednesday	173	2583.50
Thursday	161	2302.25
Friday	194	3171.25
Saturday	86	1571.25
Total in 1 week	1053	16469.75

Table 4.2 Simulation Results from Phase I with 4-Channel & 2-Buffer

Day	# of Jobs	CSP Util %	Max Que	Avg Proc Sec/Job
SUN	59	0.0434	6	3.2306
MON	203	0.1143	1	1.9890
TUE	177	0.1035	3	2.1028
WED	173	0.0941	0	1.8880
THU	161	0.0835	0	1.7992
FRI	194	0.1315	2	2.3996
SAT	86	0.0612	0	2.4711

Table 4.3 Simulation Results on 3/17/85 with 2-Buffer

# of Buffer	SPU Util %	Max Que	Avg Proc Sec/Job
1	0.0592	6	4.3538
2	0.0434	6	3.2306
3	0.0414	6	3.0472
4	0.0414	6	3.0472
8	0.0414	6	3.0472

Table 4.4 Simulation Results on 3/17/85 with 4-Channel

# of SPU	SPU Util %	Max Que	Avg Proc Sec/Job
1	0.1656	9	6.2981
2	0.0828	8	4.0845
4	0.0434	6	3.2306
8	0.0226	2	2.7782
16	0.0115	0	2.6947

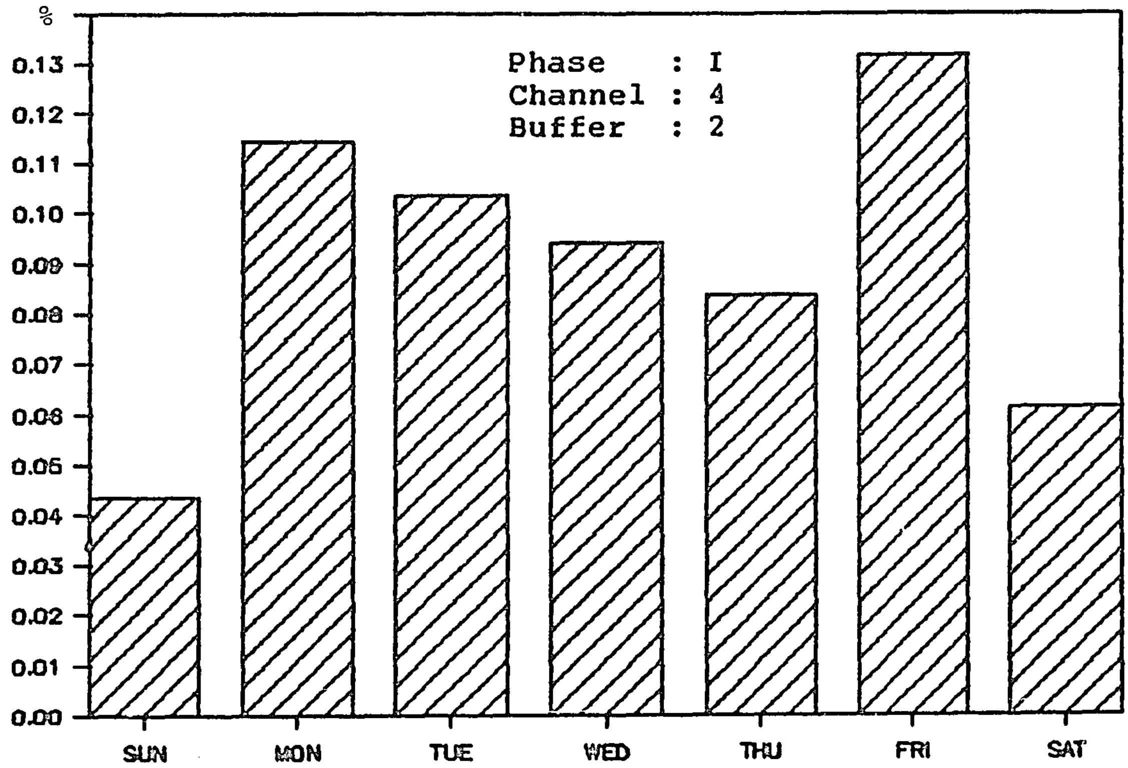


Figure 4.14 Average Channel Utilization Phase 1.1

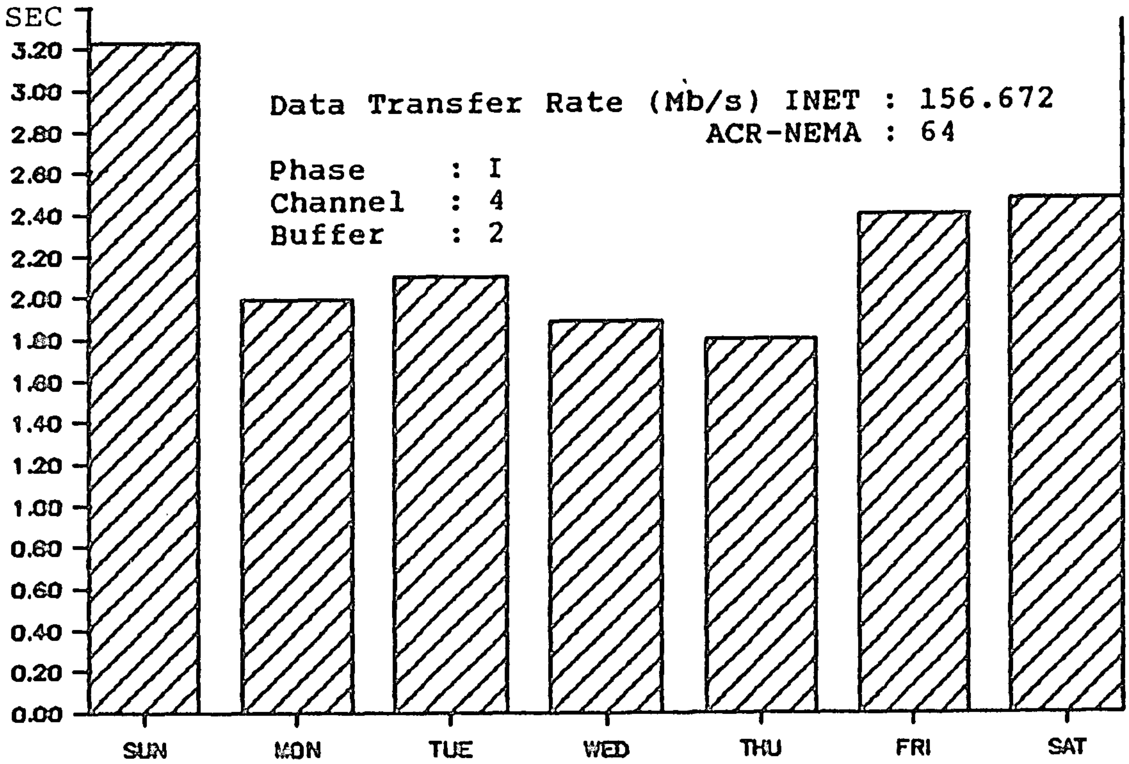


Figure 4.15 Average Response Time per Job Phase 1.1

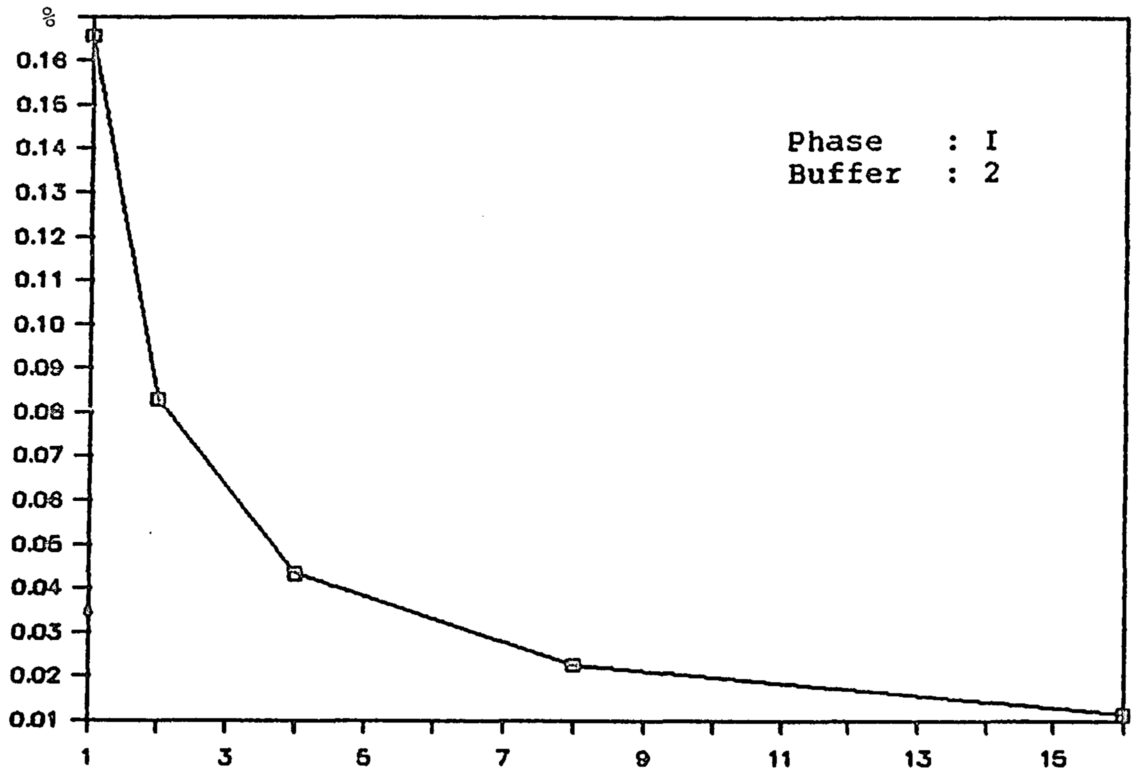


Figure 4.16 Average Channel Utilization vs. # of CSPs

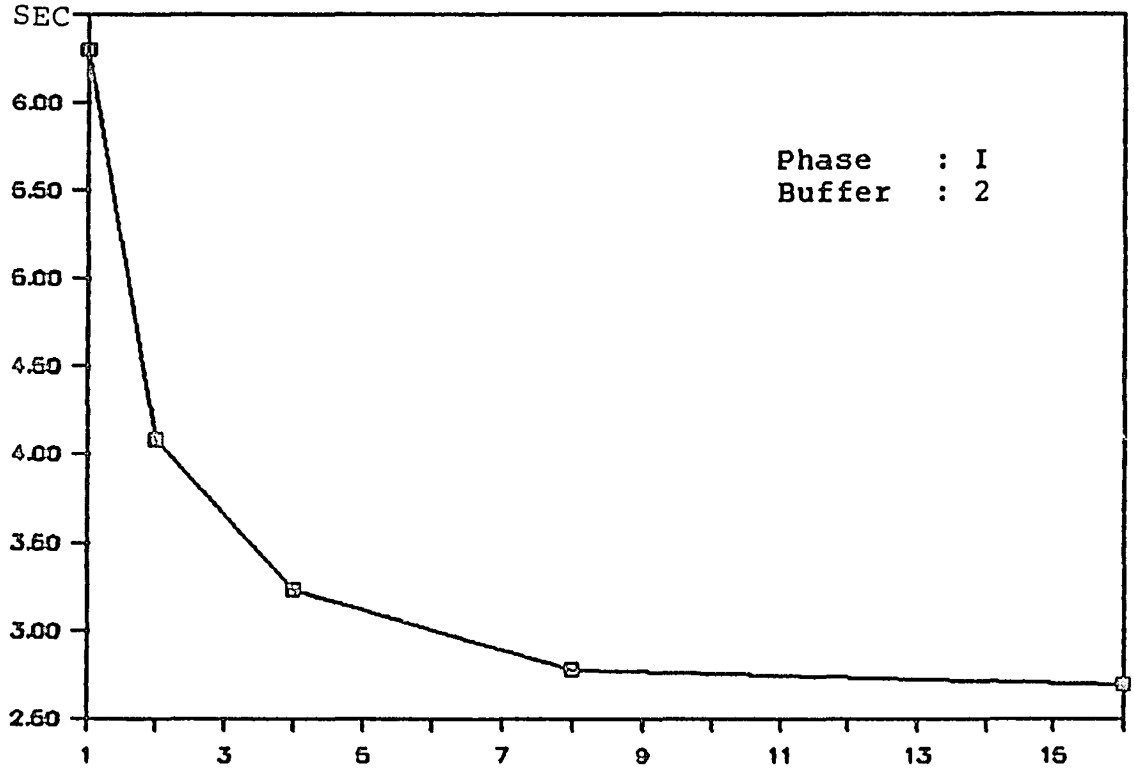


Figure 4.17 Average Response Time per Job vs. # of CSPs

Figures 4.18 & 4.19 depict the results. Table 4.5 summarizes the results of the original & double data with single channel and 4 channels. The simulation used the INET & ACR-NEMA data rate of 139.26 and 126 Mbps respectively. Figures 4.20-4.22 illustrate the results from Table 4.5. Furthermore, the interactive I/O of the TDIS74 simulation program accepted several values of various parameters. Such parameters were data transfer rates for both in INET and ACR-NEMA, number of CSPs. Figure 4.23 shows the channel utilization result for 4 channels with both original & double data. Figures 4.24-4.26 illustrate the results for original data only with both single channel & 4 channels. The results will give channel utilization, response times and maximum waiting time in queue.

4.1.2 From IE up to Level-1 Data Storage

We have modified and refined the previous simulation models for this phase. This simulation program (TDIS75) included the ACR-NEMA packet processing time and disk storage (first level) in DBA. The NIU has a double buffer and handshakes for controlling the data flow. Figure 4.27 depicts the simulation block diagram for this phase.

4.1.2.1 NIU Model & Assumption.

a. NIU has double buffer. Each buffer has 4 KB for image data plus 6 bytes for header and 2 bytes for checksum.

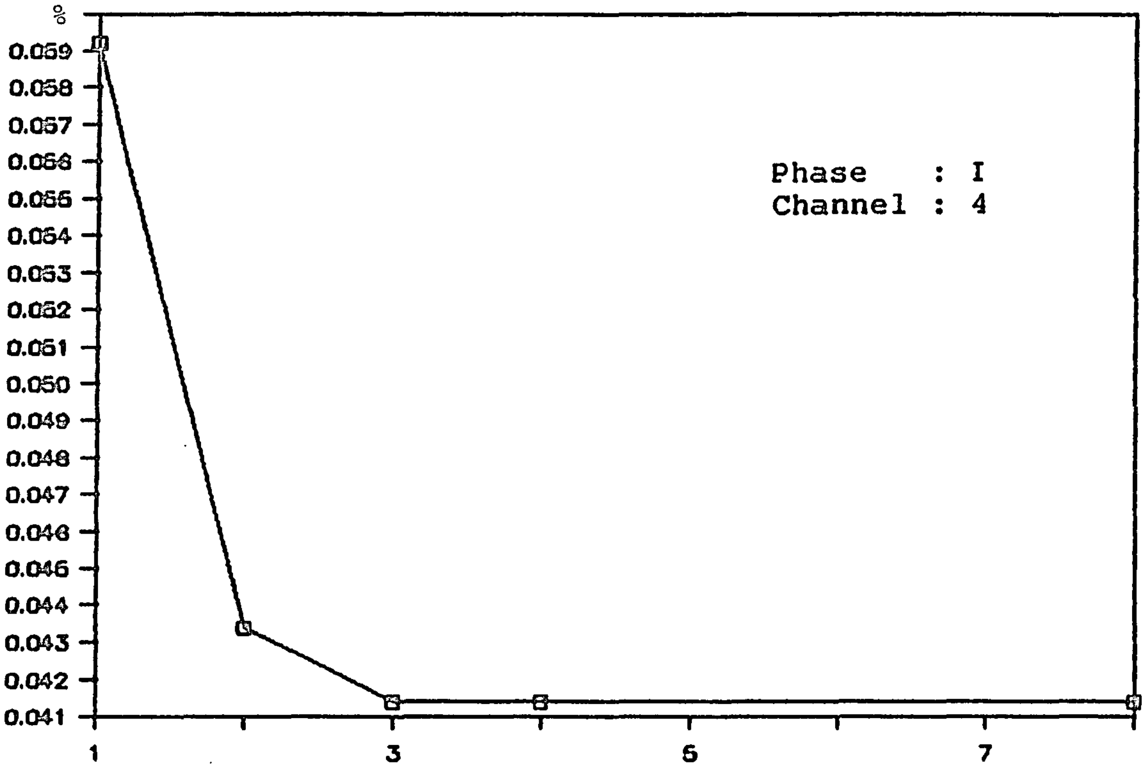


Figure 4.18 Average Channel Utilization vs. # of Buffers

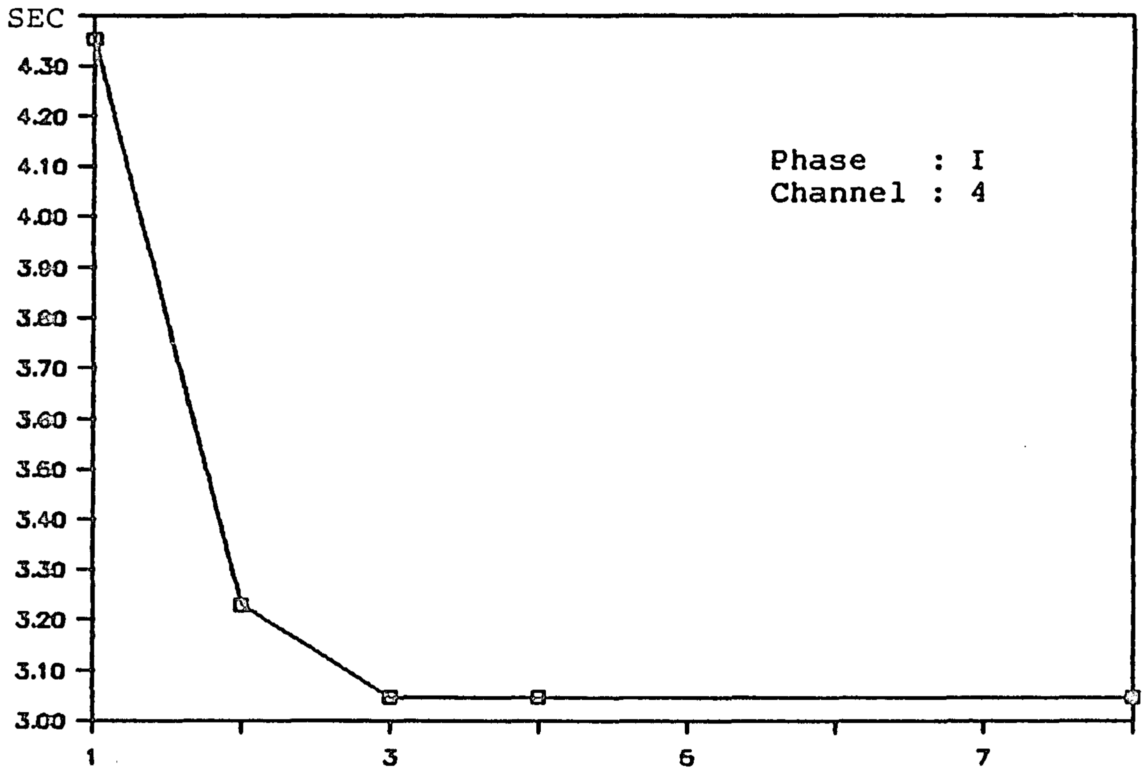


Figure 4.19 Average Response Time per Job vs. # of Buffers

Table 4.5 Summary of Simulation Results on 3/17-23/85 with
1/4 Channel(s) & Original/Double Data

Original Data

	1 Channel			4 Channels		
	Ch Util %	Max Wait(Que) Sec	Avg Proc Sec/Job	Ch Util %	Max Wait(Que) Sec	Avg Proc Sec/Job
Sun	0.0836	14.4172	3.2420	0.0209	3.2038	1.5499
Mon	0.2168	6.4077	1.4790	0.0542	1.6019	0.9425
Tue	0.2065	4.8057	1.6672	0.0516	0.8010	1.0406
Wed	0.1915	3.2038	1.2818	0.0479	0.0000	0.9680
Thu	0.1707	3.2038	1.2249	0.0427	0.0000	0.9277
Fri	0.2352	7.2086	1.6642	0.0588	1.6019	1.0906
Sat	0.1164	4.8057	1.5722	0.0291	0.0000	1.1977

Double Data

	1 Channel			4 Channels		
	Ch Util %	Max Wait(Que) Sec	Avg Proc Sec/Job	Ch Util %	Max Wait(Que) Sec	Avg Proc Sec/Job
Sun	0.1672	28.8345	5.0579	0.0418	6.4077	1.9874
Mon	0.4335	12.8153	1.8791	0.1084	3.2038	1.0258
Tue	0.4130	9.6115	2.2013	0.1032	2.0024	1.1565
Wed	0.3830	6.4077	1.4895	0.0958	1.6019	1.0009
Thu	0.3413	6.4077	1.4231	0.0853	1.6019	0.9582
Fri	0.4704	16.0191	2.1737	0.1176	3.2038	1.1864
Sat	0.2328	9.6115	1.8405	0.0582	1.6019	1.2645

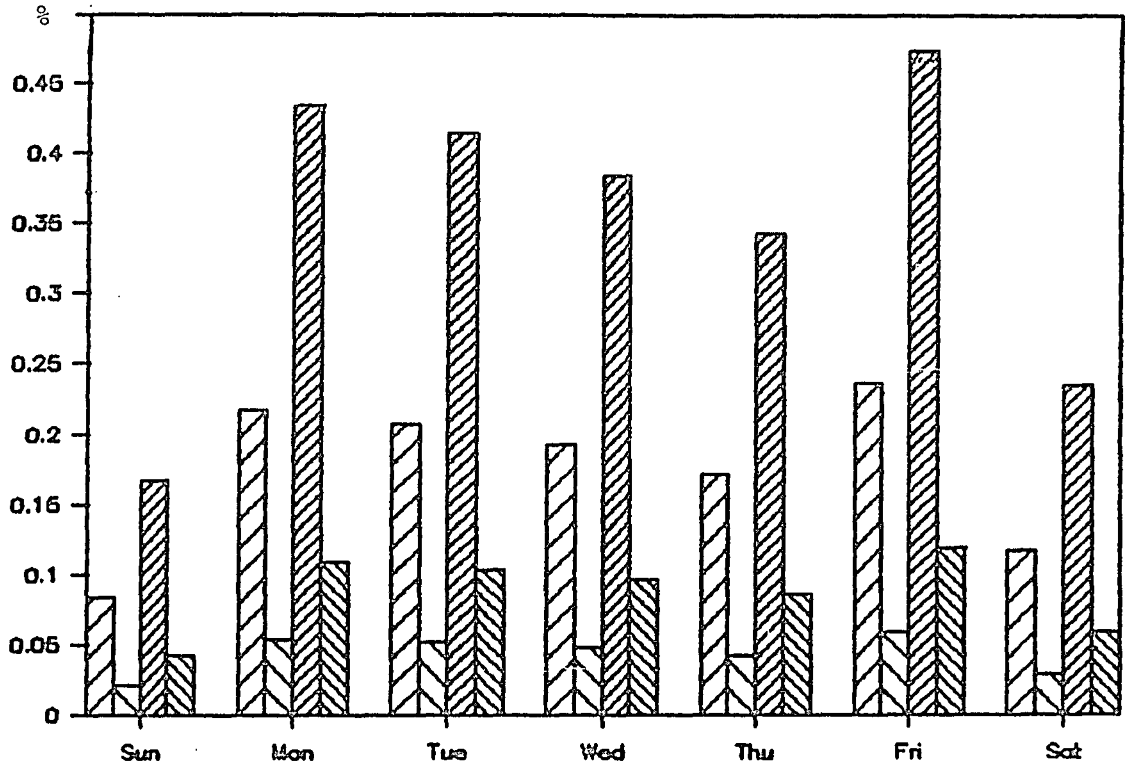


Figure 4.20 Average Channel Utilization Phase 1.2

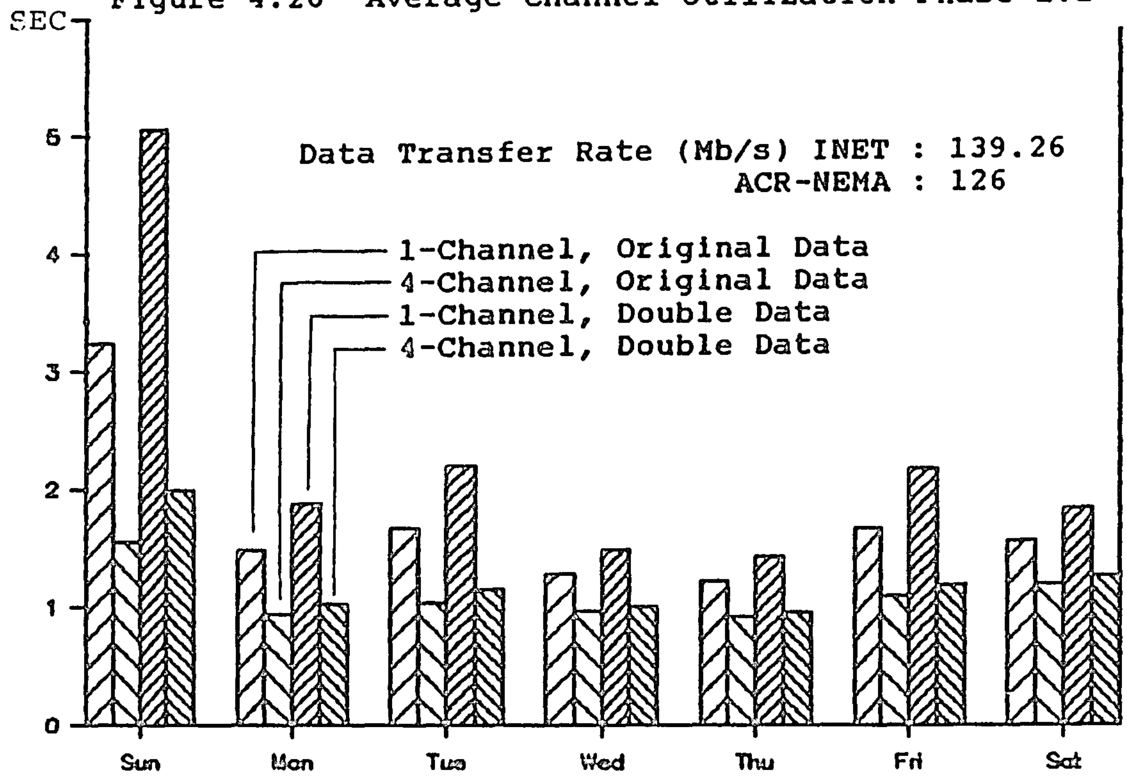


Figure 4.21 Average Response Time per Job Phase 1.2

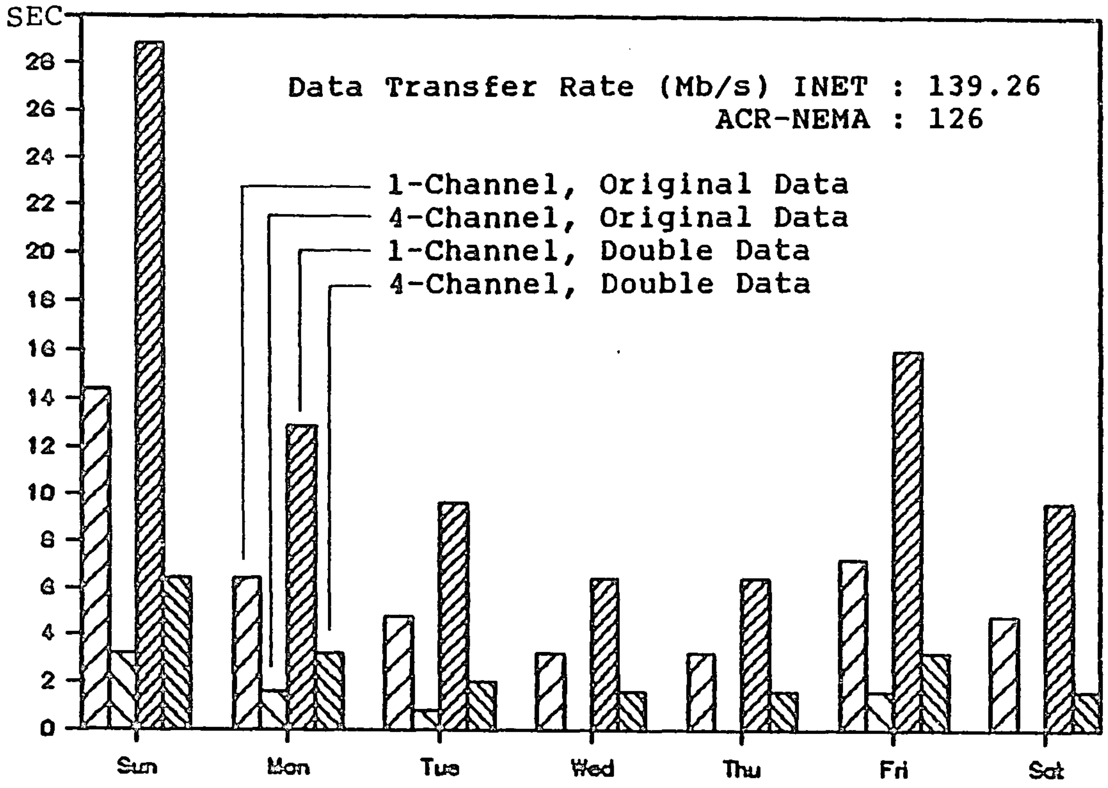


Figure 4.22 Maximum Waiting Time in Queue Phase 1.2

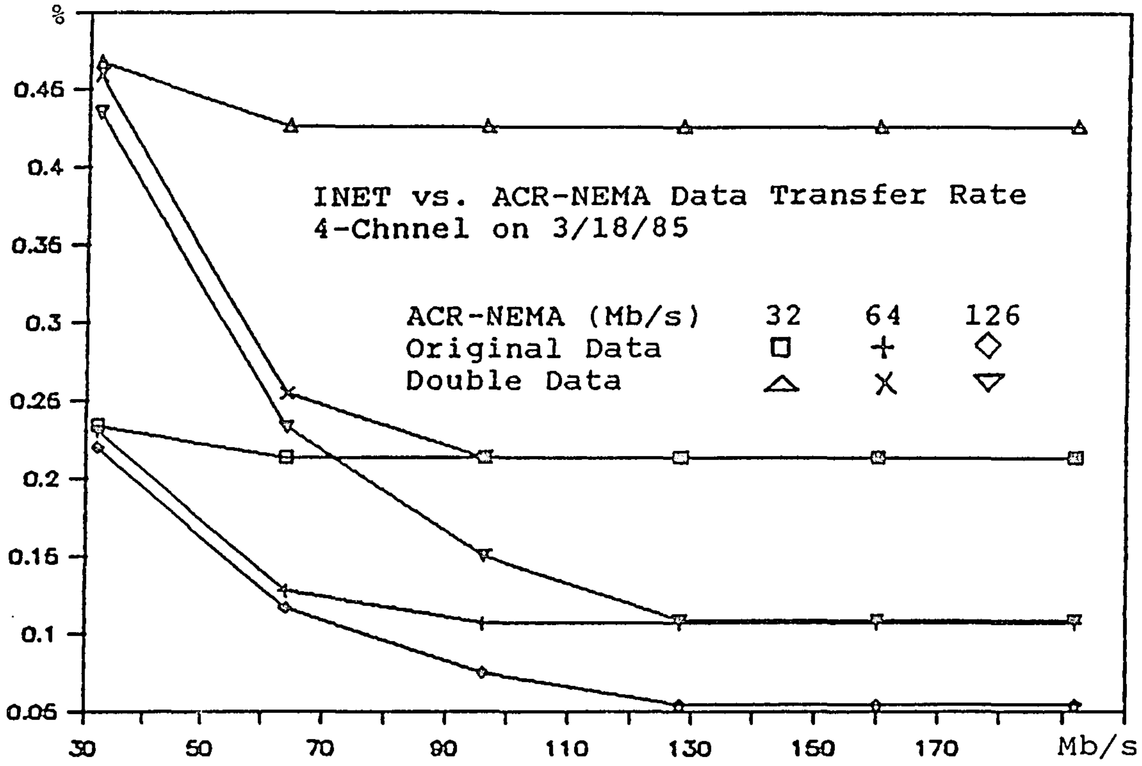


Figure 4.23 Average Channel Utilization Phase 1.3

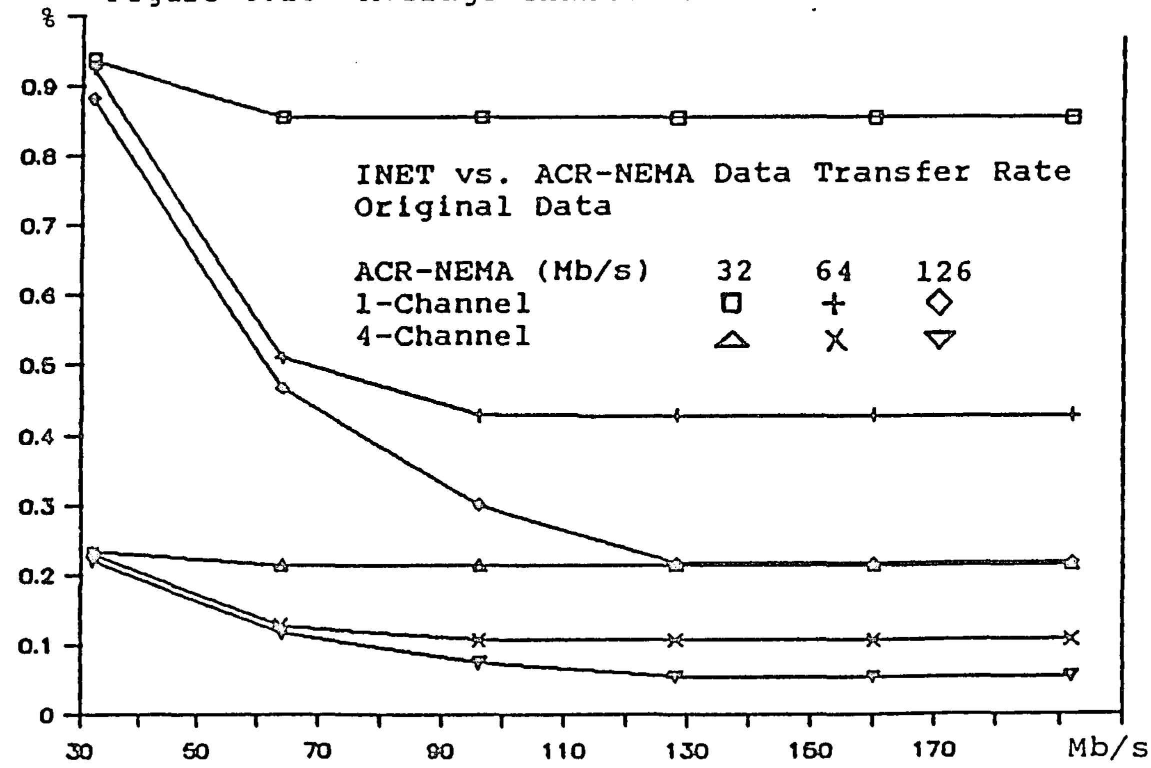


Figure 4.24 Average Channel Utilization on 3/18/85

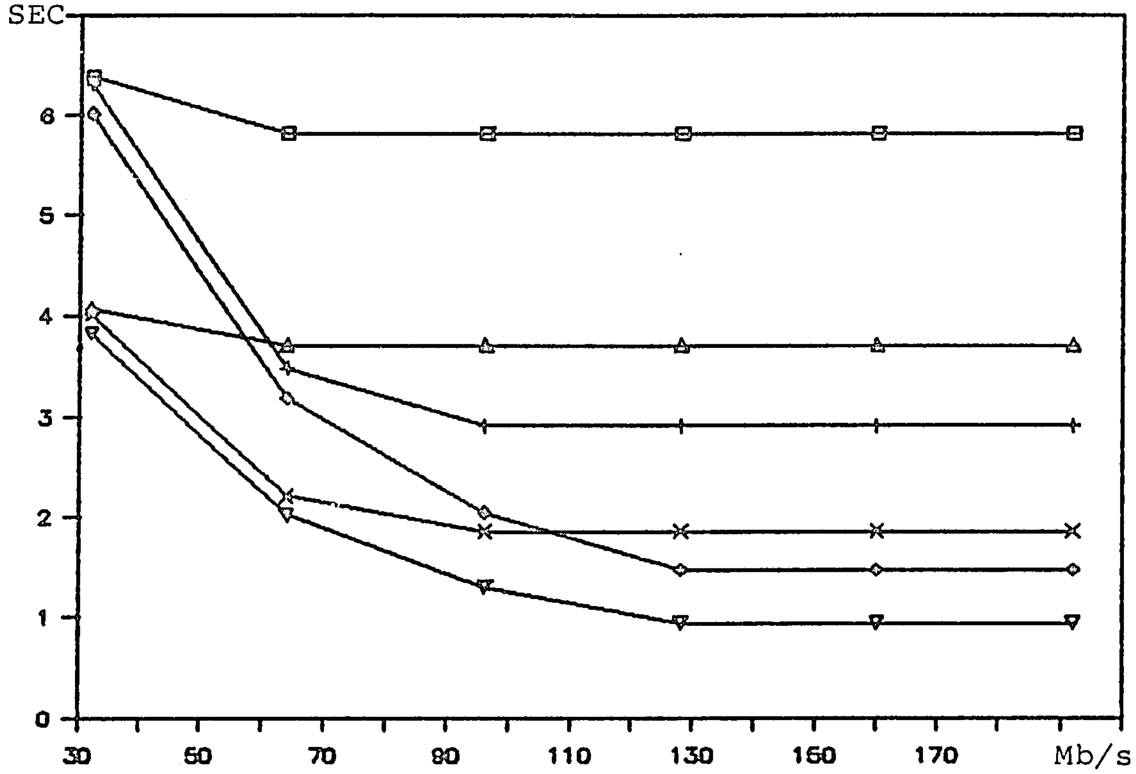


Figure 4.25 Average Response Time per Job on 3/18/85

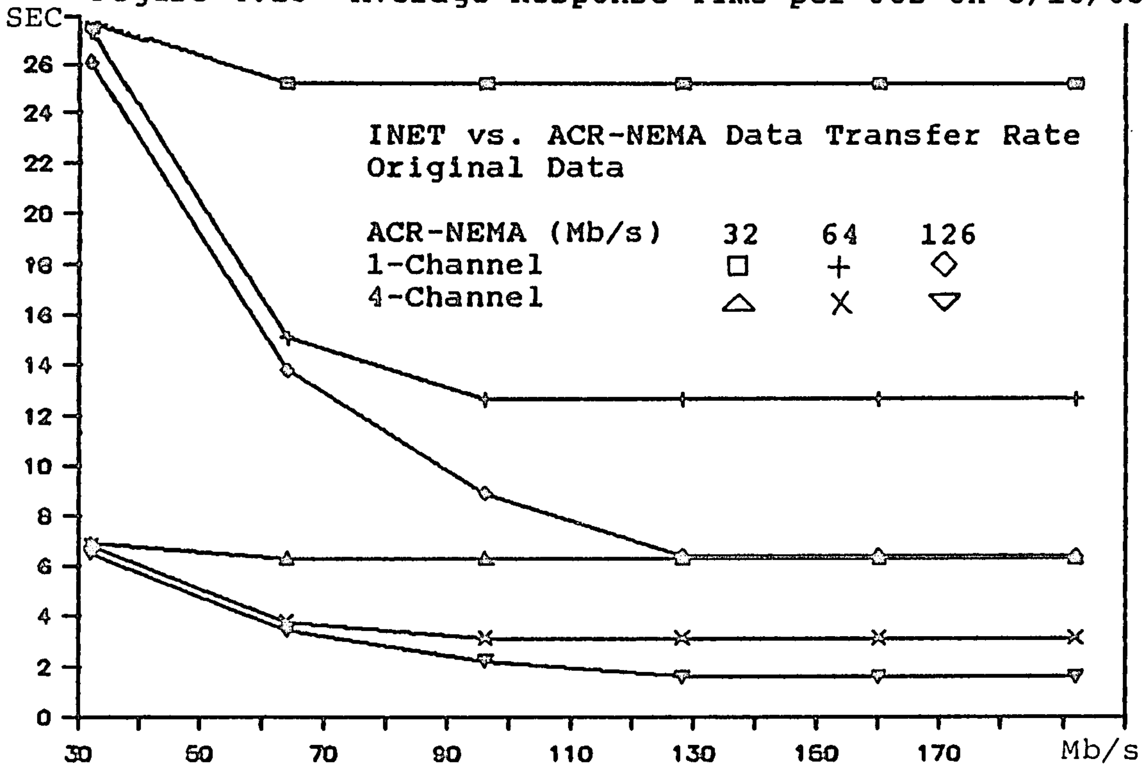


Figure 4.26 Maximum Waiting Time in Queue on 3/18/85

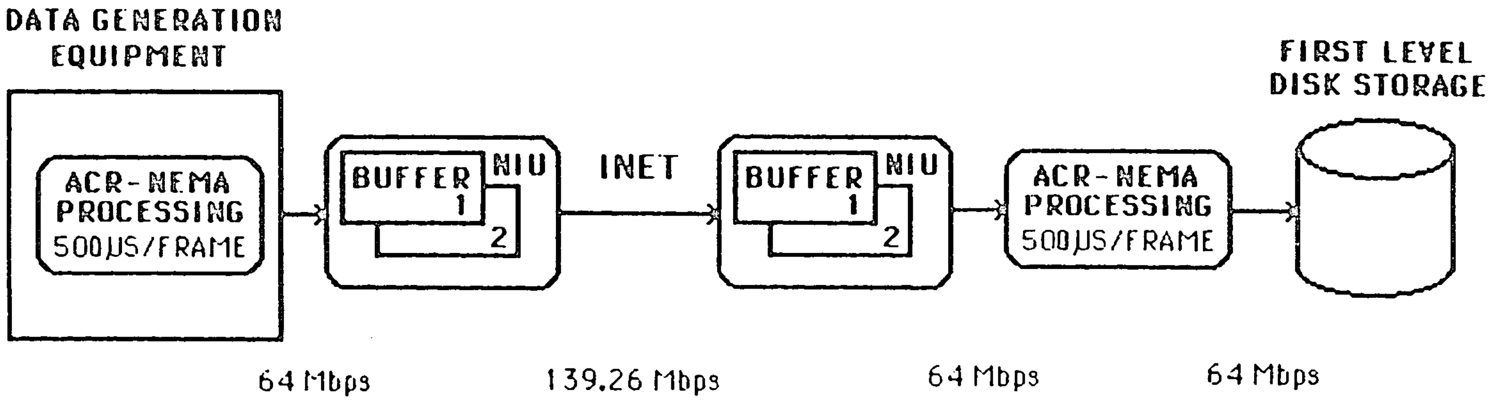


Figure 4.27 Simulation Block Diagram from IE up to Level-1

b. NIU has its own CPU either to process 3 lower layers of ACR-NEMA standard or to send the frame directly to INET.

c. NIU has status lines to indicate buffer empty, full and ready.

d. NIU has 2 connection ports, one for ACR-NEMA interface, and the other toward the INET.

e. NIU has control handshake lines for data flow controlling purpose.

4.1.2.2 ACR-NEMA Time Delay Model. The ACR-NEMA models stay both between NIU and imaging equipment, and NIU and Database Archive. The simulation assumed 500 microseconds processing time for all layers of ACR-NEMA standard throughout this TDIS simulation. This processing time can be any value in the input data file depending on the current technology.

4.1.2.3 Flowchart. Figure 4.28 represents the flowchart of this simulation phase. The details are self-explained and not intended to be describe here. The reader, however, can see Sections 3.1.2 and 4.1.1.2 for explanation.

4.1.2.4 Hourly Channel Utilization & Other Results. Figure 4.29 shows an output example of the TDIS75 simulation program. The simulation results included hourly channel utilization from data generations in the week of 3/17-23/85

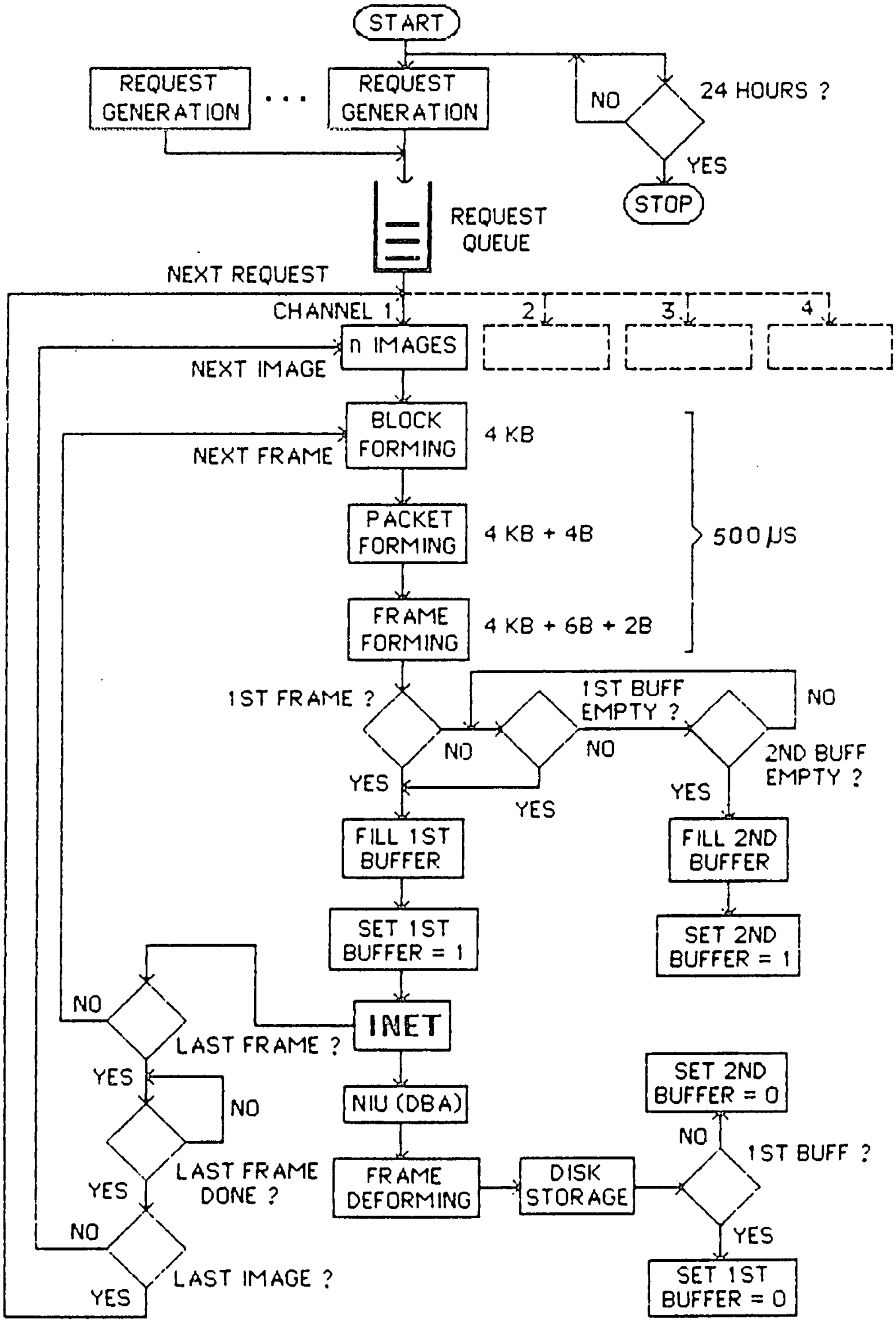


Figure 4.28 Flow Chart of Simulation Phase II

```
$ type xout128m.a75
       Hours   Hourly Utilization (%)   Accumulated Data (MB)
         1            0.82763                  66.0000
         2            0.21367                  83.0368
         3            0.60191                 131.0368
         4            0.55300                 175.1304
         5            0.                      175.1304
         6            0.30096                 199.1304
         7            1.88172                 349.1872
         8            3.26457                 609.5049
         9            1.17937                 703.5471
        10            2.82483                 928.7934
        11            2.62767                1138.2975
        12            1.77258                1279.6290
        13            3.21676                1536.1193
        14            3.15439                1787.6050
        15            4.60498                2154.8144
        16            2.73721                2373.0661
        17            2.40456                2564.7628
        18            1.71996                2701.9101
        19            0.92808                2775.9186
        20            0.95402                2851.9922
        21            0.49017                2891.0712
        22            0.                     2891.0712
        23            0.                     2891.0712
        24            0.                     2891.0712

TDIS Network Study for    194  Jobs    636  Images      2891.0712  Total MBytes
The Channel Utilization            1.51075  %   in        24.0000  Hours
The Max, Avg Queue for SPU                      5          0.0059  Jobs
The Max, Avg Waiting Time in Queue              48.7551    2.6087  Seconds
Min, Max, Avg Image Processing Time     0.9074  2.7086     2.0523  Seconds/Image
Min, Max, Avg Processing Time (+que)    0.9074  59.5895    9.3370  Seconds/Job
Min, Max, Avg Processing Time (-que)    0.9074  23.0645    6.7283  Seconds/Job
```

Figure 4.29 Output Example of TDIS75 Program with the original amount of data. Figure 4.30 shows the results from the data generation in the week of March 17-23, 1985. The simulation ran with the original amount of data for single channel. Figures 4.31-4.33 illustrate the related results in bar graph for both single channel & 4 channels.

Furthermore, the simulation outcomes of the single channel with original, double, triple and quadruple generation data were the additional results. The input amount of data (double, triple and quadruple) creation method used the same method as in Section 4.1.1.4. The outcomes included hourly channel utilization, average response time and waiting time in queue, and average queue. Figures 4.34-4.36 depict these results with the generation data on Friday 2/28/86.

4.2 Data Generation & Retrieval

4.2.1 Merging INET & DBA Models

The reader can find the Figure 3.2 that represents a combined data generation and retrieval simulation model block diagram. At this phase, we have designed and combined the data retrieval models to the existing previous data generation model. The DBA now includes a hierarchical disk storage with all levels. The simulation used the assigned INET channel for sharing data path in both directions. This phase also used the assumptions of 3 levels of disk storage with various accessing time and data transfer rates. In

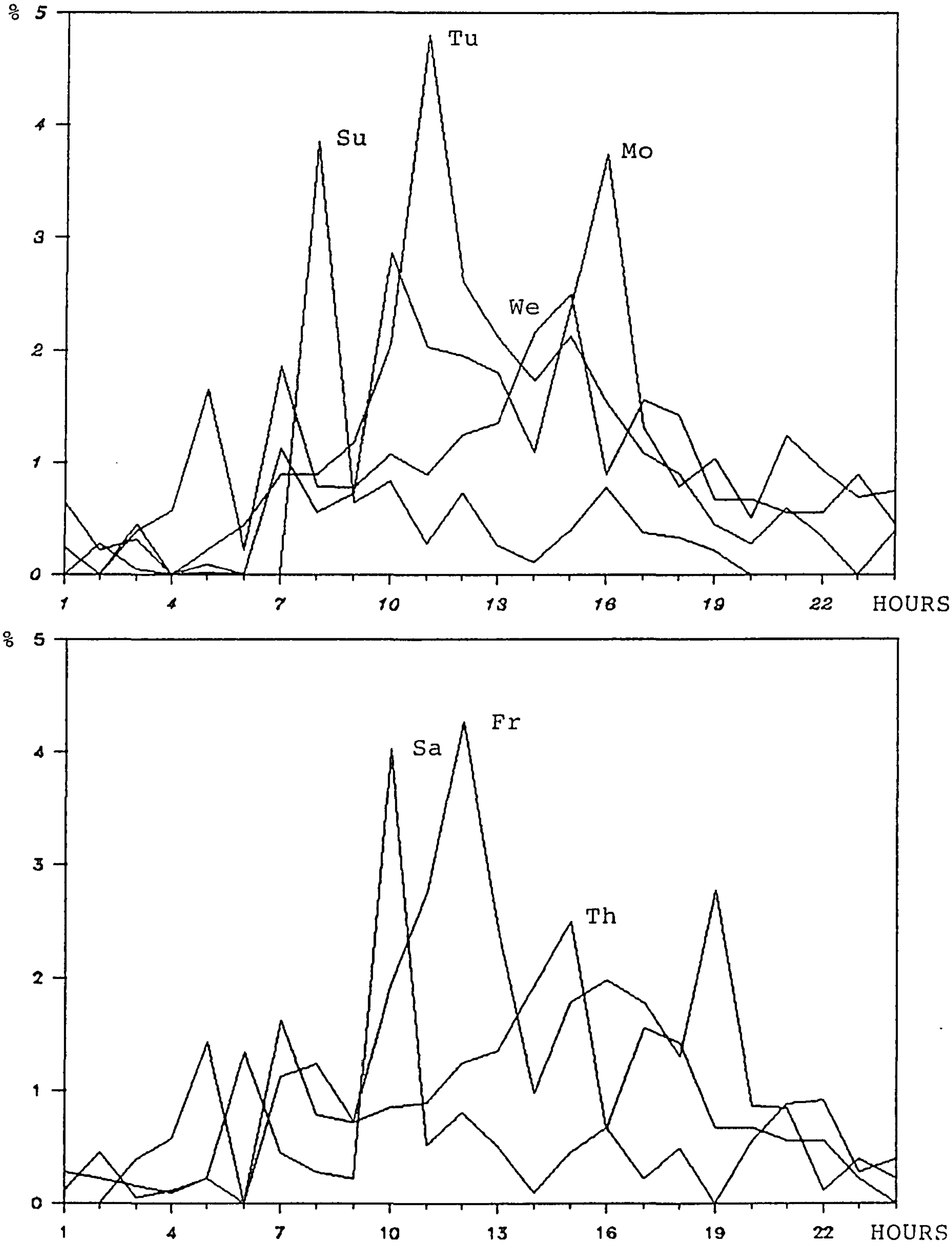


Figure 4.30 Hourly Channel Utilization for Data Generation

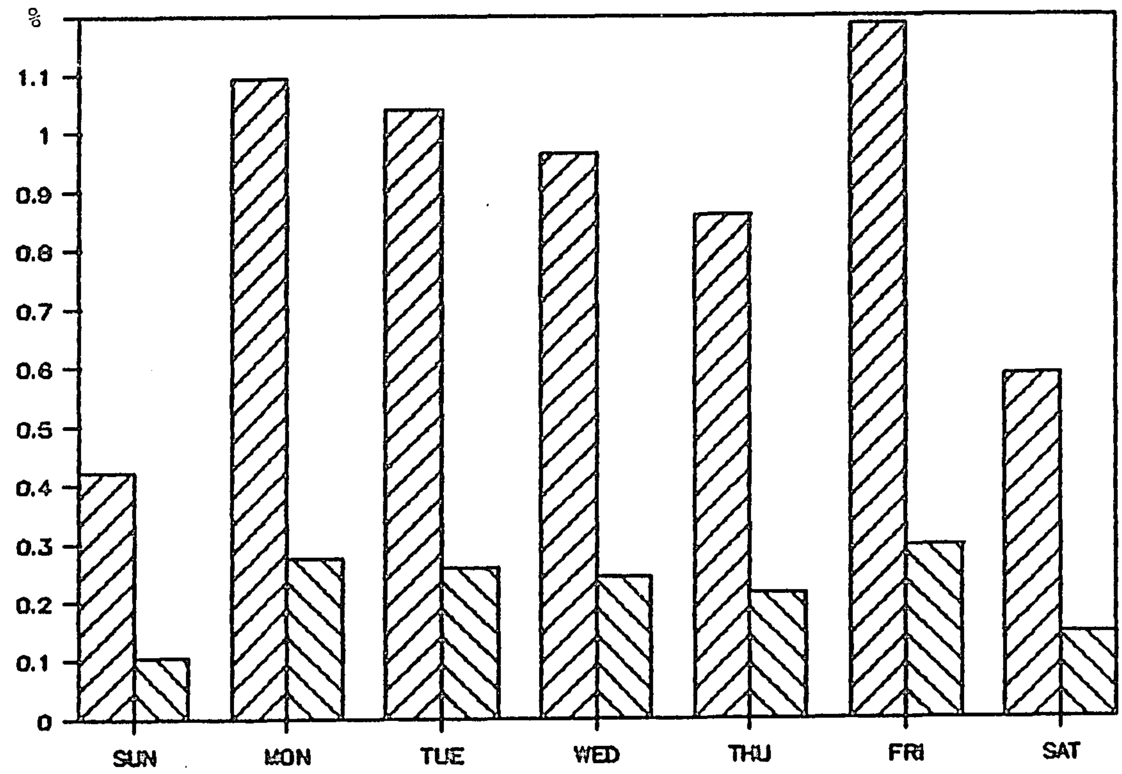


Figure 4.31 Average Channel Utilization on 3/17-23/85

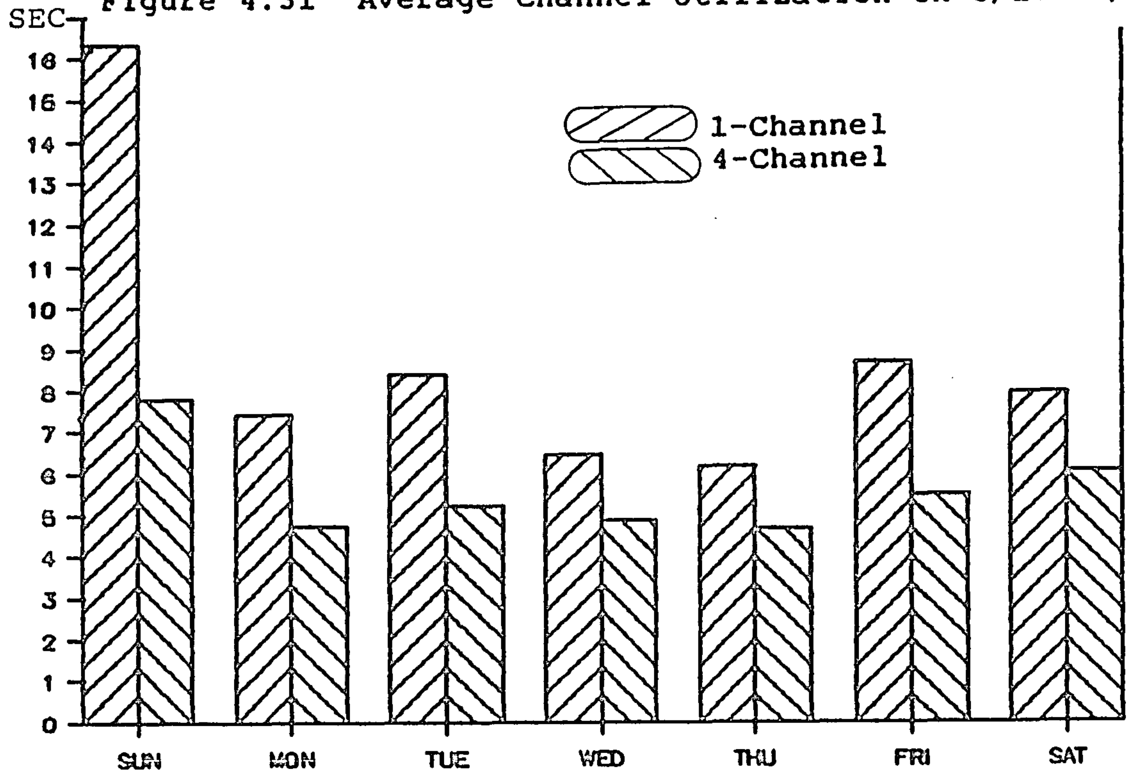


Figure 4.32 Average Response Time with Queue on 3/17-23/85

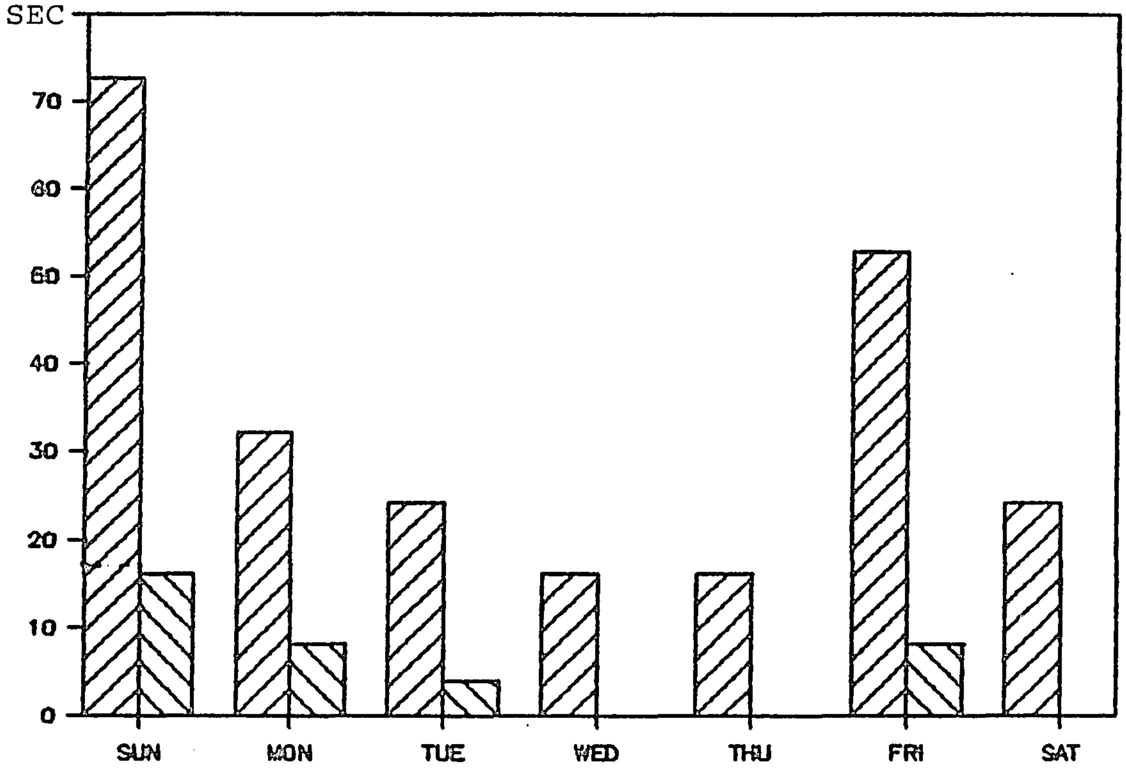


Figure 4.33 Maximum Waiting Time in Queue on 3/17-23/85

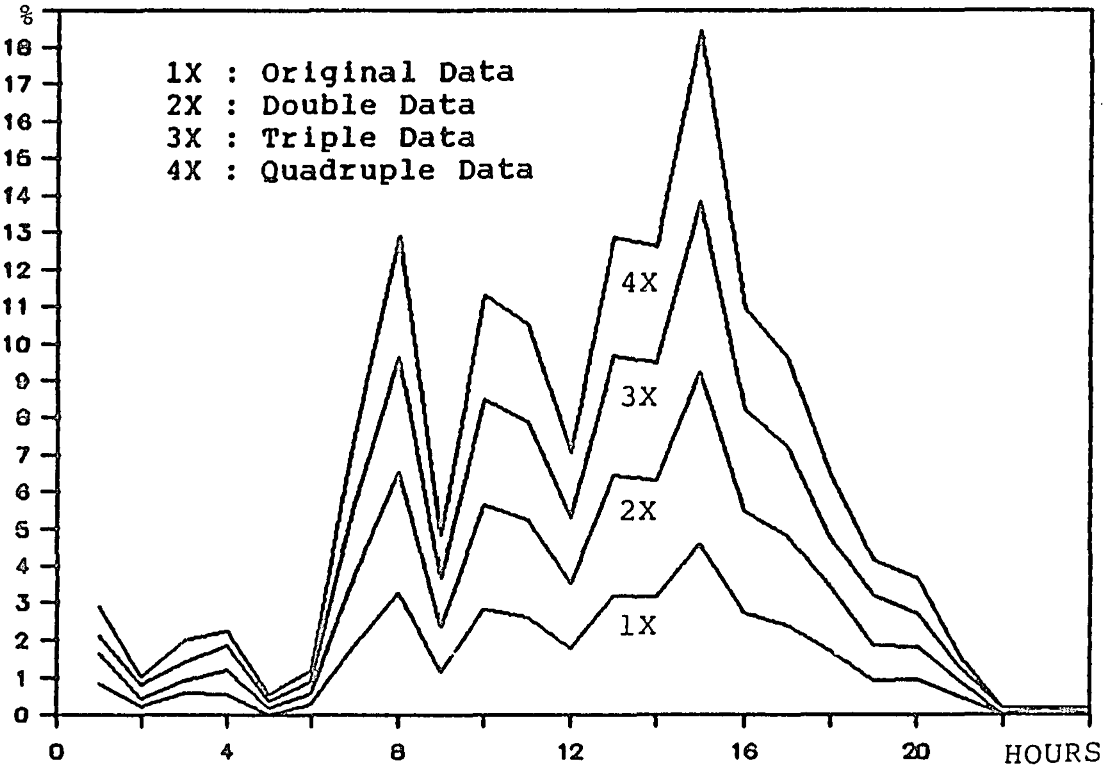


Figure 4.34 Hourly Channel Utilization on 2/28/86

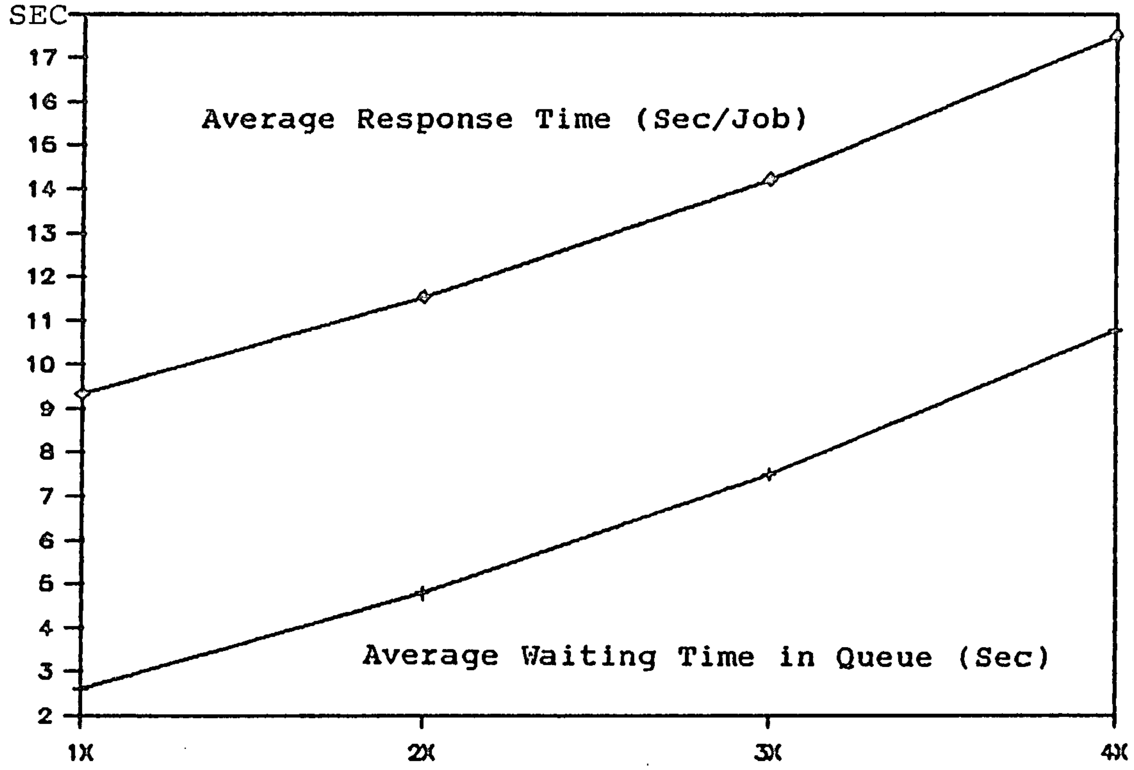


Figure 4.35 Simulation Results on 2/28/86

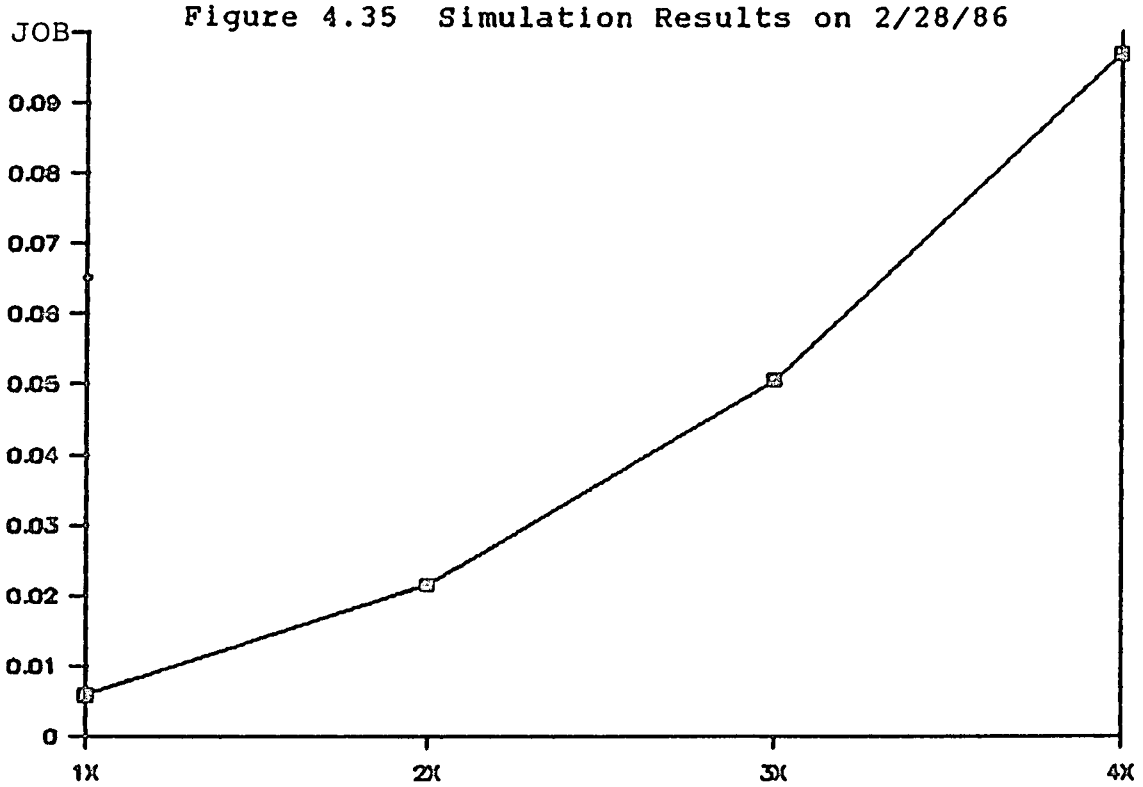


Figure 4.36 Average Queue (Job) on 2/28/86

addition, the patients retrieval data from the hospital on 2/28/86 was the added to the input file.

The scenario of the retrieval process is similar to the generation process, but the data flow now is in reverse direction. Moreover, the simulation included the viewing workstations and all 3 levels of disk storage. The number of previously needed examinations depends on the individual doctor and each examination may have several images. These images can be found at a specified level in the hierarchical disk storage depending on the age of the examinations. Figure 4.37 shows the images retrieval process. This simulation model has 3 input files and 1 output file which has been described in Sections 3.1.2 and 3.7.

4.2.2 Hourly Channel Utilization Result

Figures 4.38 and 4.39 show the results of 2 different parameter sets for a combination of data generation and retrieval. Figure 4.40 depicts the hourly channel utilization results of 2 different parameter sets. The queue length, response time, etc. are also summarized in Figures 4.38 and 4.39.

4.2.3 Hourly Created Data for Generation & Retrieval

Figure 4.41 illustrates the hourly generated data for generation and hourly required data retrieval. This

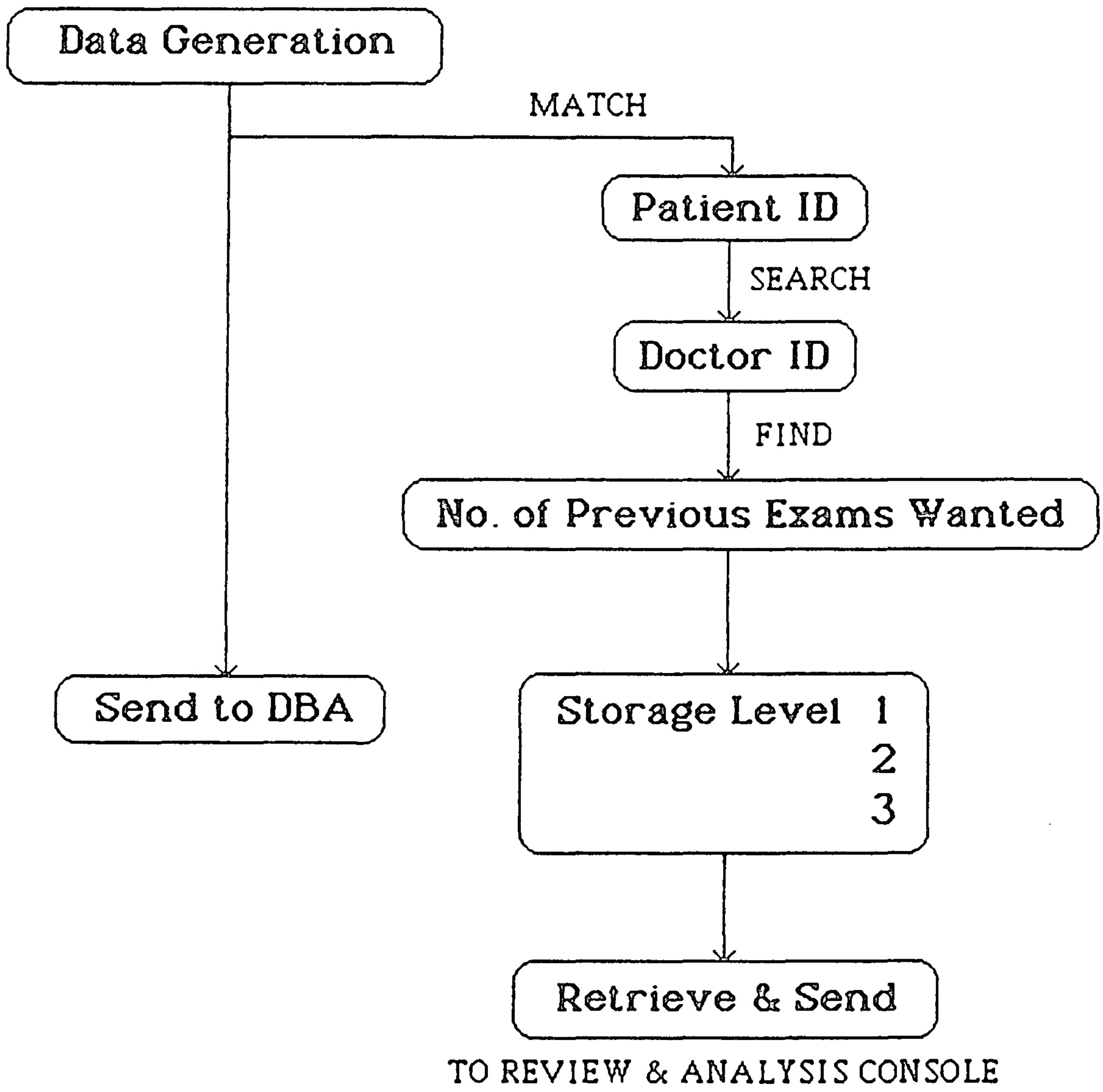


Figure 4.37 Image Data Retrieval Process

Reference Date : 2/28/1986

Number of Channel Serving Processor(s) : 1		Number of Buffers in NIU : 2			
Console, ACR-NEMA, INET Data Rate	64.00	64.00		139.26	Mb/sec
Disk Data Rate Level 1, 2 and 3	64.00	1.60		1.60	Mb/sec
Min, Max Disk Access Time Level 1, 2 :	0.06	0.10	1.00	8.00	Seconds
Min, Max Optical Disk Access Time Level 3			19.00	21.00	Seconds
ACR-NEMA Frame Processing Time				500.00	usecs/frame

Hours	Hourly Utilization (%)	Accumulated Data (MB) Generation	Retrieval
1	1.87131	66.0000	72.0000
2	0.47584	83.0368	90.0000
3	5.96786	131.0368	216.0000
4	1.94374	175.1304	312.0000
5	0.	175.1304	312.0000
6	11.10550	199.1304	432.0000
7	16.56392	349.1872	918.0000
8	25.24649	609.5049	1488.0000
9	41.44608	703.5471	1908.0000
10	74.66462	928.7934	2676.0000
11	76.08817	1105.1617	3420.0000
12	100.00000	1243.5722	4344.0000
13	100.00000	1445.8415	5400.0000
14	100.00000	1636.2183	6396.0000
15	100.00000	1851.6786	7650.0000
16	100.00000	2264.9334	8514.0000
17	100.00000	2274.9756	9498.0000
18	100.00000	2361.0093	10590.0000
19	100.00000	2703.9186	12000.0000
20	45.98929	2851.9922	12570.0000
21	1.35965	2891.0712	12630.0000
22	0.	2891.0712	12630.0000
23	0.	2891.0712	12630.0000
24	0.	2891.0712	12630.0000

TDIS Network Study in 24.0000 Hours, the Channel Utilization 45.94677 %
The Max, Avg Queue for SPU 40 6.4926 Jobs

GENERATION: For 194 Jobs	636 Images		2891.0712	Total MBytes
The Max, Avg Waiting Time in Queue		8620.4656	1471.8527	Seconds
Min, Max, Avg Image Processing Time	0.9074	2.7086	2.0523	Seconds/Image
Min, Max, Avg Processing Time (+que)	2.2750	8625.8828	1478.5810	Seconds/Job
Min, Max, Avg Processing Time (-que)	0.9074	23.0645	6.7283	Seconds/Job

RETRIEVAL: For 194 Jobs	2105 Images		12630.0000	Total MBytes
The Max, Avg Waiting Time in Queue		8174.9404	1419.6804	Seconds
Min, Max, Avg Image Processing Time	3.1137	33.8445	17.3915	Seconds/Image
Min, Max, Avg Processing Time (+que)	3.2036	8828.0109	1617.5810	Seconds/Job
Min, Max, Avg Processing Time (-que)	3.1754	1130.5943	197.9006	Seconds/Job

Figure 4.38 Simulation Results Set 1

Reference Date : 2/28/1986

Room No.	Min, Max, Avg & Total Amount of Retrieval (MB)				No. of Request(s)
0	12	186	66.2727	1458	22
1	108	156	132.0000	264	2
2	42	84	63.0000	126	2
3	12	120	47.4000	474	10
4	12	186	68.5263	1302	19
5	12	210	105.4286	738	7
6	6	228	63.7500	2040	32
7	6	144	49.7143	1392	28
10	6	132	79.7143	558	7
11	36	36	36.0000	36	1
12	12	102	48.5455	534	11
13	48	48	48.0000	48	1
30	12	144	84.0000	672	8
31	24	120	77.0000	462	6
35	78	228	153.0000	306	2
36	84	84	84.0000	84	1
55	12	120	65.1429	912	14
65	6	90	57.0000	684	12
85	36	48	44.0000	132	3
97	84	90	87.0000	174	2
98	12	132	58.5000	234	4

Level	Retrieved Images	Amount of Data Retrieved (MB)
1	1127	6762.0000
2	324	1944.0000
3	583	3498.0000
4	71	426.0000

Figure 4.38 (Continued)

Reference Date : 2/28/1986

Number of Channel Serving Processor(s) : 1	Number of Buffers in NIU : 2				
Console, ACR-NEMA, INET Data Rate	64.00	64.00		139.26	Mb/sec
Disk Data Rate Level 1, 2 and 3	64.00	8.00		8.00	Mb/sec
Min, Max Disk Access Time Level 1, 2 :	0.06	0.10	1.00	8.00	Seconds
Min, Max Optical Disk Access Time Level 3			19.00	21.00	Seconds
ACR-NEMA Frame Processing Time				500.00	usecs/frame

Hours	Hourly Utilization (%)	Accumulated Data (MB) Generation	Retrieval
1	1.87131	66.0000	72.0000
2	0.47584	83.0368	90.0000
3	3.16619	131.0368	216.0000
4	1.94374	175.1304	312.0000
5	0.	175.1304	312.0000
6	4.10134	199.1304	432.0000
7	10.96059	349.1872	918.0000
8	14.74025	609.5049	1488.0000
9	15.53068	703.5471	1908.0000
10	28.43716	928.7934	2676.0000
11	42.42128	1138.2975	3786.0000
12	28.10252	1279.6290	4524.0000
13	46.70429	1536.1193	5904.0000
14	47.33543	1752.4669	7362.0000
15	72.86469	2154.8144	9462.0000
16	50.78088	2373.0661	10992.0000
17	23.45898	2564.7628	11868.0000
18	8.96249	2701.9101	12138.0000
19	6.02826	2775.9186	12318.0000
20	8.49546	2851.9922	12570.0000
21	1.35965	2891.0712	12630.0000
22	0.	2891.0712	12630.0000
23	0.	2891.0712	12630.0000
24	0.	2891.0712	12630.0000

TDIS Network Study in 24.0000 Hours, the Channel Utilization 17.40588 %
The Max, Avg Queue for SPU 11 0.2321 Jobs

GENERATION: For 194 Jobs	636 Images		2891.0712	Total MBytes
The Max, Avg Waiting Time in Queue		806.5724	51.6465	Seconds
Min, Max, Avg Image Processing Time	0.9074	2.7086	2.0523	Seconds/Image
Min, Max, Avg Processing Time (+que)	0.9074	811.9897	58.3748	Seconds/Job
Min, Max, Avg Processing Time (-que)	0.9074	23.0645	6.7283	Seconds/Job

RETRIEVAL: For 194 Jobs	2105 Images		12630.0000	Total MBytes
The Max, Avg Waiting Time in Queue		705.4940	51.7407	Seconds
Min, Max, Avg Image Processing Time	3.1137	8.6295	5.6764	Seconds/Image
Min, Max, Avg Processing Time (+que)	3.1854	800.6319	122.5314	Seconds/Job
Min, Max, Avg Processing Time (-que)	3.1854	293.6337	70.7907	Seconds/Job

Figure 4.39 Simulation Results Set 2

Reference Date : 2/28/1986

Room No.	Min, Max, Avg & Total Amount of Retrieval (MB)				No. of Request(s)
0	12	186	66.2727	1458	22
1	108	156	132.0000	264	2
2	42	84	63.0000	126	2
3	12	120	47.4000	474	10
4	12	186	68.5263	1302	19
5	12	210	105.4286	738	7
6	6	228	63.7500	2040	32
7	6	144	49.7143	1392	28
10	6	132	79.7143	558	7
11	36	36	36.0000	36	1
12	12	102	48.5455	534	11
13	48	48	48.0000	48	1
30	12	144	84.0000	672	8
31	24	120	77.0000	462	6
35	78	228	153.0000	306	2
36	84	84	84.0000	84	1
55	12	120	65.1429	912	14
65	6	90	57.0000	684	12
85	36	48	44.0000	132	3
97	84	90	87.0000	174	2
98	12	132	58.5000	234	4

Level	Retrieved Images	Amount of Data Retrieved (MB)
1	1127	6762.0000
2	324	1944.0000
3	583	3498.0000
4	71	426.0000

Figure 4.39 (Continued)

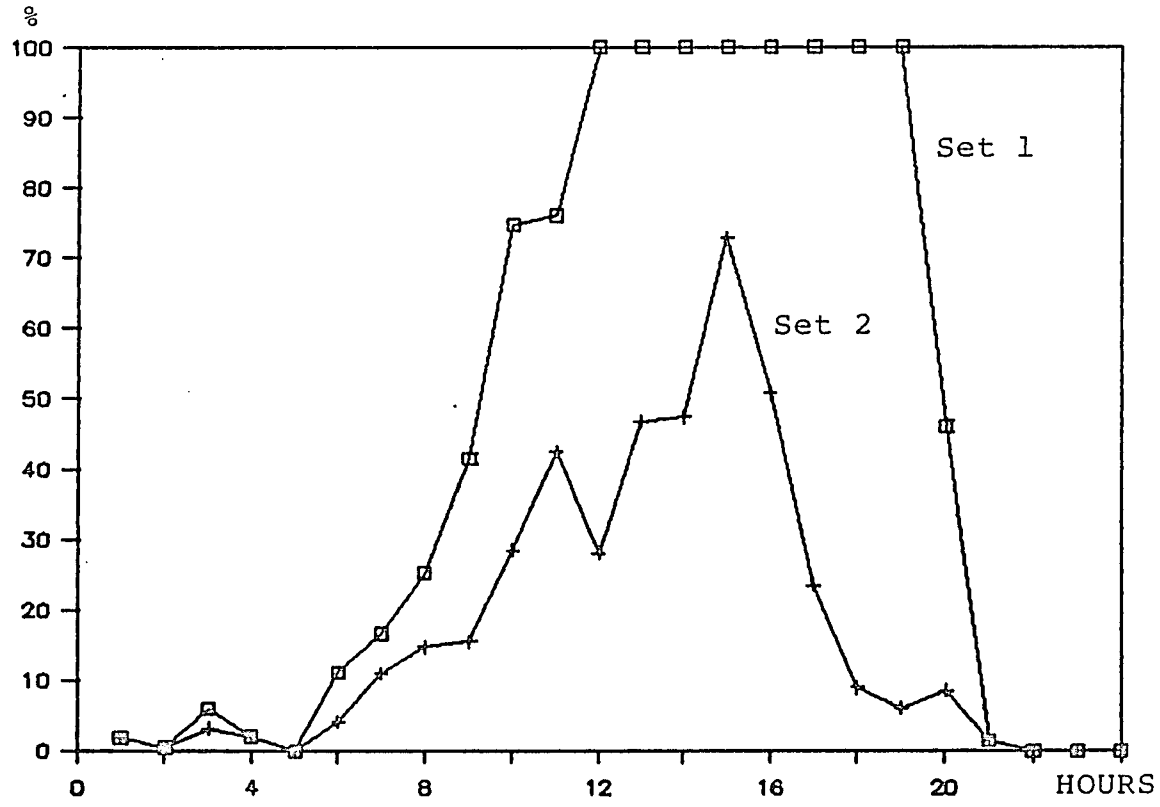
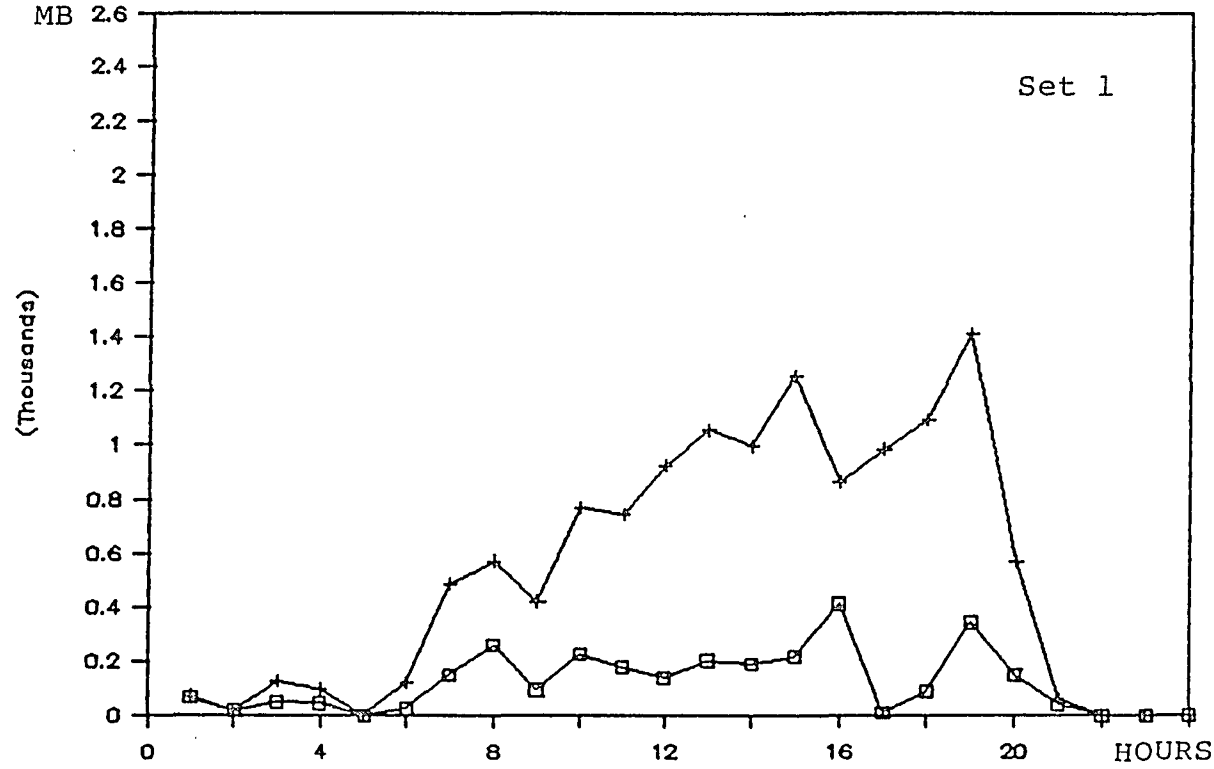


Figure 4.40 Hourly Channel Utilization Set 1 & Set 2



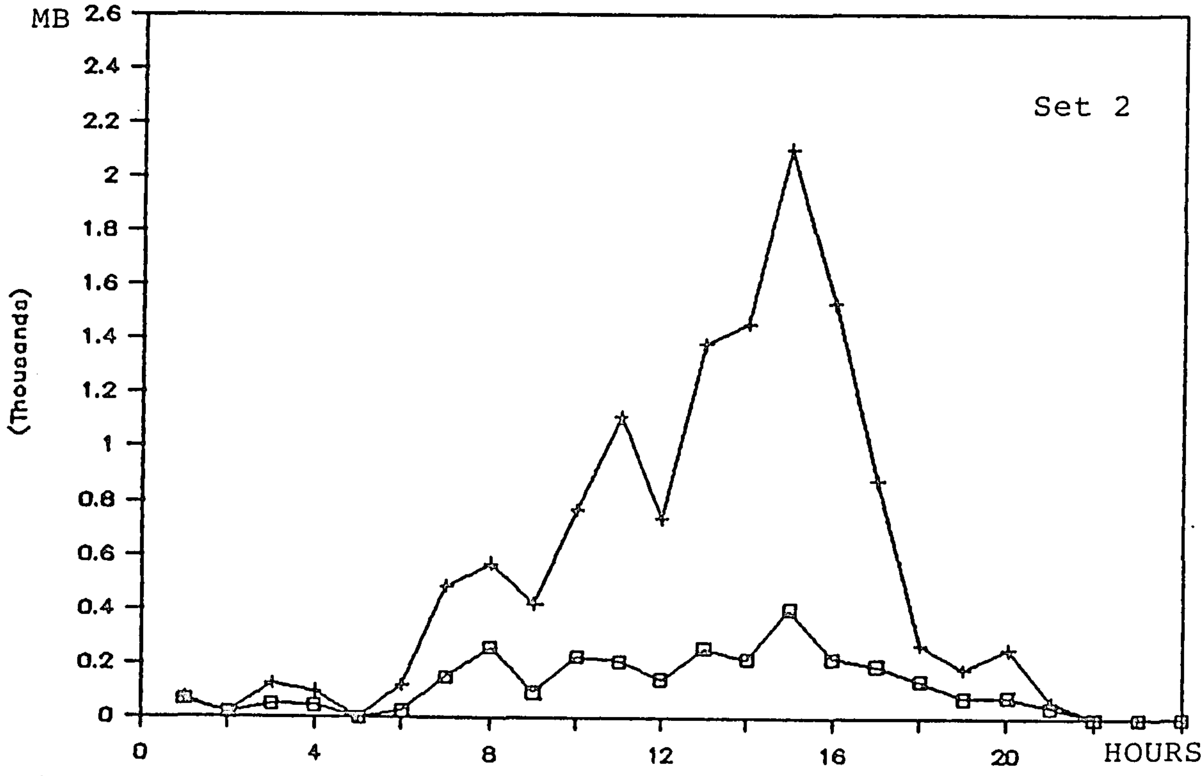


Figure 4.41 Hourly Generated Data (□) of Generation and Required Data (+) of Retrieval Through Network

result will be useful for a prediction of the work load in the network channel.

4.2.4 Data Storage Based on Room Number

Figure 4.38 also represents the total amount of retrieval data based on room number. This result shows how frequently the workstations send the requests and from which location. It is useful for adding more channels to high traffic nodes when needed.

4.2.5 Other Results

In Figure 4.38, the simulation uses 500 microseconds ACR-NEMA packet processing time. The optical disks level-2 and level-3 uses a 1.6 Mbps data transfer rate. It also has 1 to 8 seconds of uniformly distributed accessing time for level-2, and 19 to 21 seconds for level-3. The result showed that the hourly utilization was 100 % (fully busy network channel) for the period of 12:00 noon to 19:00. The maximum and average retrieval response time was 2.45 hours and 26.96 minutes per job (1 job may have several images), respectively. The maximum queue length is 40 jobs.

4.3 Data Generation & Retrieval with Image Migration

Figure 4.42 shows the result of image migration downloading for 31 days. This result is useful in obtaining the size of each storage level (see Section 3.5.1 for more details). Section 3.5 describes the full details of this

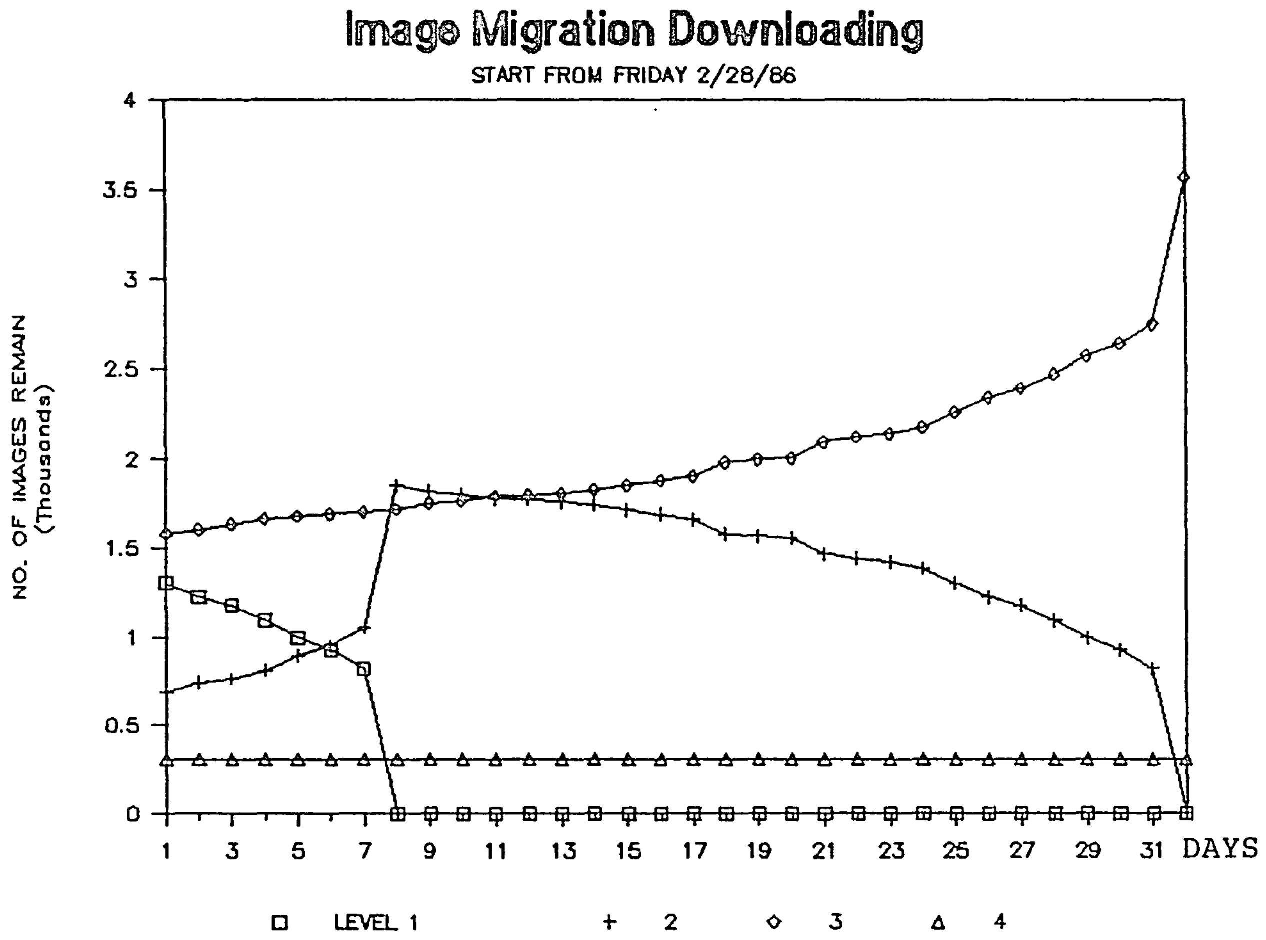


Figure 4.42 Image Migration Downloading for 31 Days

phase. The simulation assumed 4-8 minutes of a uniformly distributed function for the image retrieval process in advance. The system copies the images from level-2 and level-3 to level-1.2 within the given time. Figures 4.43 and 4.44 represent the simulation results for 2 different parameter sets. Figure 4.45 depicts the hourly channel utilization results. As you see, the channel utilization is improved when DBA adds the image migration policy. Figure 4.46 shows the hourly generated data for generation and the hourly required data for retrieval.

```
$ type otest41.tst
Reference Date :  2/28/1986

Number of Channel Serving Processor(s) : 1   Number of Buffers in NIU : 2
Console, ACR-NEMA, INET Data Rate     64.00      64.00      139.26  Mb/sec
Disk Data Rate Level 1, 2 and 3       64.00       1.60        1.60  Mb/sec
Min, Max Disk Access Time Level 1, 2 : 0.06   0.10    1.00    8.00  Seconds
Min, Max Optical Disk Access Time Level 3           19.00   21.00  Seconds
ACR-NEMA Frame Processing Time                              500.00  usecs/frame

        Hours   Hourly Utilization (%)       Accumulated Data (MB)
                                          Generation           Retrieval
          1           1.87265               66.0000              72.0000
          2           0.47551               83.0368              90.0000
          3           2.42285              131.0368             216.0000
          4           1.94438              175.1304             312.0000
          5           0.                   175.1304             312.0000
          6           2.03496              199.1304             432.0000
          7           8.90410              349.1872             918.0000
          8          11.50390              609.5049            1488.0000
          9           7.24682              703.5471            1908.0000
         10          15.36460              928.7934            2676.0000
         11          33.32058             1138.2975            3786.0000
         12          13.39530             1279.6290            4524.0000
         13          45.43759             1536.1193            5904.0000
         14          36.24311             1748.4500            7302.0000
         15          74.55777             2154.8144            9756.0000
         16          39.81607             2373.0661           10992.0000
         17          30.48552             2558.7060           11742.0000
         18           7.54546             2701.9101           12138.0000
         19           3.53278             2775.9186           12318.0000
         20           4.59481             2851.9922           12570.0000
         21           1.36055             2891.0712           12630.0000
         22           0.                  2891.0712           12630.0000
         23           0.                  2891.0712           12630.0000
         24           0.                  2891.0712           12630.0000

TDIS Network Study in  24.0000  Hours, the Channel Utilization   14.25247  %
The Max, Avg Queue for SPU                         12        0.2223  Jobs

GENERATION:   For      194  Jobs      636  Images      2891.0712  Total MBytes
The Max, Avg Waiting Time in Queue              768.8151    59.9373  Seconds
Min, Max, Avg Image Processing Time   0.9074     2.7086     2.0523  Seconds/Image
Min, Max, Avg Processing Time (+que)  0.9074   779.6495    66.6656  Seconds/Job
Min, Max, Avg Processing Time (-que)  0.9074    23.0645     6.7283  Seconds/Job

RETRIEVAL:    For      194  Jobs     2105  Images     12630.0000  Total MBytes
The Max, Avg Waiting Time in Queue              590.6017    39.0596  Seconds
Min, Max, Avg Image Processing Time   3.1137    33.8445     5.0700  Seconds/Image
Min, Max, Avg Processing Time (+que)  3.1813   965.4685    95.8063  Seconds/Job
Min, Max, Avg Processing Time (-que)  3.1813   740.7815    56.7466  Seconds/Job
```

Figure 4.43 Simulation Results Set 1 with Image Migration

Reference Date : 2/28/1986

Room No.	Min, Max, Avg & Total Amount of Retrieval (MB)				No. of Request(s)
0	12	186	66.2727	1458	22
1	108	156	132.0000	264	2
2	42	84	63.0000	126	2
3	12	120	47.4000	474	10
4	12	186	68.5263	1302	19
5	12	210	105.4286	738	7
6	6	228	63.7500	2040	32
7	6	144	49.7143	1392	28
10	6	132	79.7143	558	7
11	36	36	36.0000	36	1
12	12	102	48.5455	534	11
13	48	48	48.0000	48	1
30	12	144	84.0000	672	8
31	24	120	77.0000	462	6
35	78	228	153.0000	306	2
36	84	84	84.0000	84	1
55	12	120	65.1429	912	14
65	6	90	57.0000	684	12
85	36	48	44.0000	132	3
97	84	90	87.0000	174	2
98	12	132	58.5000	234	4

Level	Required Images	Amount of Data Required (MB)
1	1127	6762.0000
2	324	1944.0000
3	583	3498.0000
4	71	426.0000

Retrieved Images in Level 1.1 : 1127
Retrieved Images in Level 1.2 : 844
Retrieved Images in Level 2 : 57
Retrieved Images in Level 3 : 77

Figure 4.43 (Continued)

```
$ type otest42.tst
Reference Date :  2/28/1986

Number of Channel Serving Processor(s) : 1   Number of Buffers in NIU : 2
Console, ACR-NEMA, INET Data Rate     64.00      64.00       139.26  Mb/sec
Disk Data Rate Level 1, 2 and 3       64.00       8.00         8.00  Mb/sec
Min, Max Disk Access Time Level 1, 2 : 0.06   0.10    1.00     8.00  Seconds
Min, Max Optical Disk Access Time Level 3           19.00     21.00  Seconds
ACR-NEMA Frame Processing Time                               500.00  usecs/frame

        Hours   Hourly Utilization (%)        Accumulated Data (MB)
                                             Generation          Retrieval
          1           1.87265                  66.0000            72.0000
          2           0.47551                  83.0368            90.0000
          3           2.42285                 131.0368           216.0000
          4           1.94438                 175.1304           312.0000
          5           0.                      175.1304           312.0000
          6           2.03496                 199.1304           432.0000
          7           8.90410                 349.1872           918.0000
          8          11.50390                 609.5049          1488.0000
          9           7.24682                 703.5471          1908.0000
         10          14.66418                 928.7934          2676.0000
         11          22.81434                1138.2975          3786.0000
         12          12.69489                1279.6290          4524.0000
         13          28.00825                1536.1193          5904.0000
         14          32.41155                1787.6050          7680.0000
         15          40.28530                2154.8144          9774.0000
         16          25.84304                2373.0661         10992.0000
         17          19.09856                2564.7628         11868.0000
         18           5.62426                2701.9101         12138.0000
         19           3.53278                2775.9186         12318.0000
         20           4.59481                2851.9922         12570.0000
         21           1.36055                2891.0712         12630.0000
         22           0.                     2891.0712         12630.0000
         23           0.                     2891.0712         12630.0000
         24           0.                     2891.0712         12630.0000

TDIS Network Study in  24.0000  Hours, the Channel Utilization   10.30574  %
The Max, Avg Queue for SPU                            7        0.0719  Jobs

GENERATION:  For      194  Jobs      636  Images      2891.0712  Total MBytes
The Max, Avg Waiting Time in Queue              328.1946   10.5721  Seconds
Min, Max, Avg Image Processing Time   0.9074      2.7086    2.0523  Seconds/Image
Min, Max, Avg Processing Time (+que)  0.9074    333.6118   17.3004  Seconds/Job
Min, Max, Avg Processing Time (-que)  0.9074     23.0645    6.7283  Seconds/Job

RETRIEVAL:   For      194  Jobs     2105  Images     12630.0000  Total MBytes
The Max, Avg Waiting Time in Queue              308.5351   21.4383  Seconds
Min, Max, Avg Image Processing Time   3.1137      8.6295    3.4491  Seconds/Image
Min, Max, Avg Processing Time (+que)  3.1813    345.9704   60.6077  Seconds/Job
Min, Max, Avg Processing Time (-que)  3.1813    233.3269   39.1694  Seconds/Job
```

Figure 4.44 Simulation Results Set 2 with Image Migration

Reference Date : 2/28/1986

Room No.	Min, Max, Avg & Total Amount of Retrieval (MB)				No. of Request(s)
0	12	186	66.2727	1458	22
1	108	156	132.0000	264	2
2	42	84	63.0000	126	2
3	12	120	47.4000	474	10
4	12	186	68.5263	1302	19
5	12	210	105.4286	738	7
6	6	228	63.7500	2040	32
7	6	144	49.7143	1392	28
10	6	132	79.7143	558	7
11	36	36	36.0000	36	1
12	12	102	48.5455	534	11
13	48	48	48.0000	48	1
30	12	144	84.0000	672	8
31	24	120	77.0000	462	6
35	78	228	153.0000	306	2
36	84	84	84.0000	84	1
55	12	120	65.1429	912	14
65	6	90	57.0000	684	12
85	36	48	44.0000	132	3
97	84	90	87.0000	174	2
98	12	132	58.5000	234	4

Level	Required Images	Amount of Data Required (MB)
1	1127	6762.0000
2	324	1944.0000
3	583	3498.0000
4	71	426.0000

Retrieved Images in Level 1.1 : 1127
Retrieved Images in Level 1.2 : 850
Retrieved Images in Level 2 : 54
Retrieved Images in Level 3 : 74

Figure 4.44 (Continued)

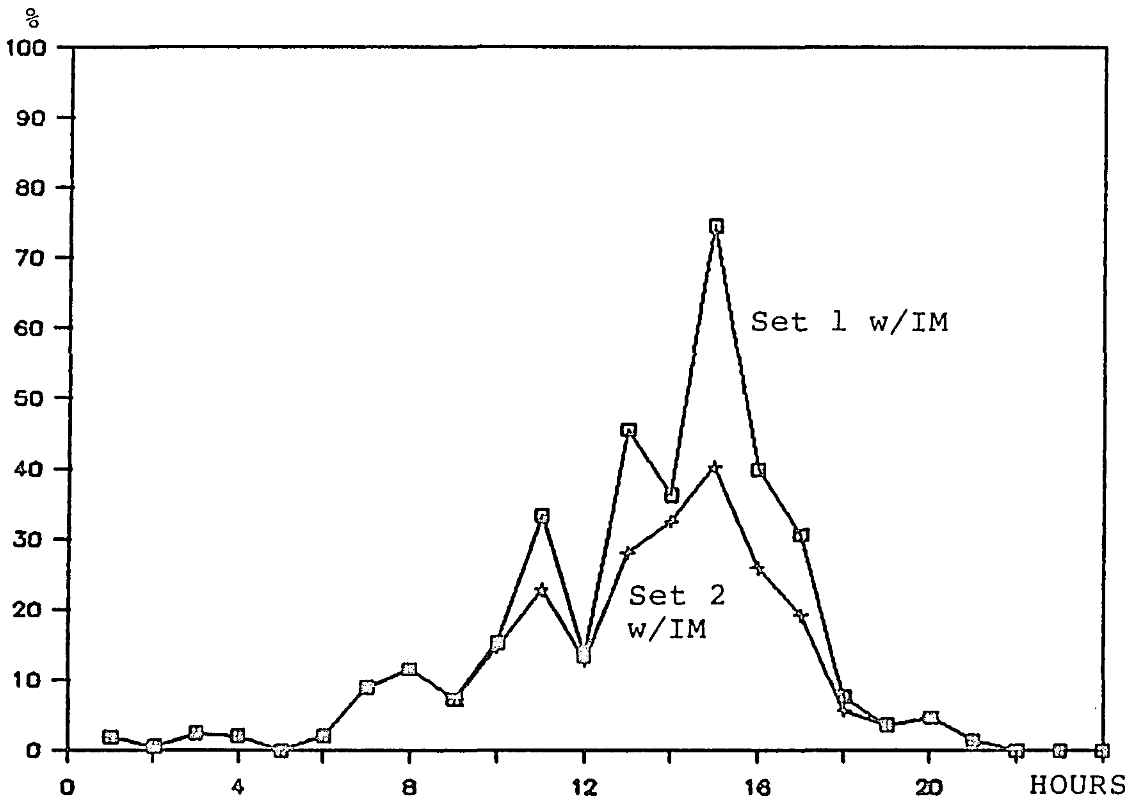


Figure 4.45 Hourly Channel Utilization Set 1 & Set 2 with Image Migration Policy

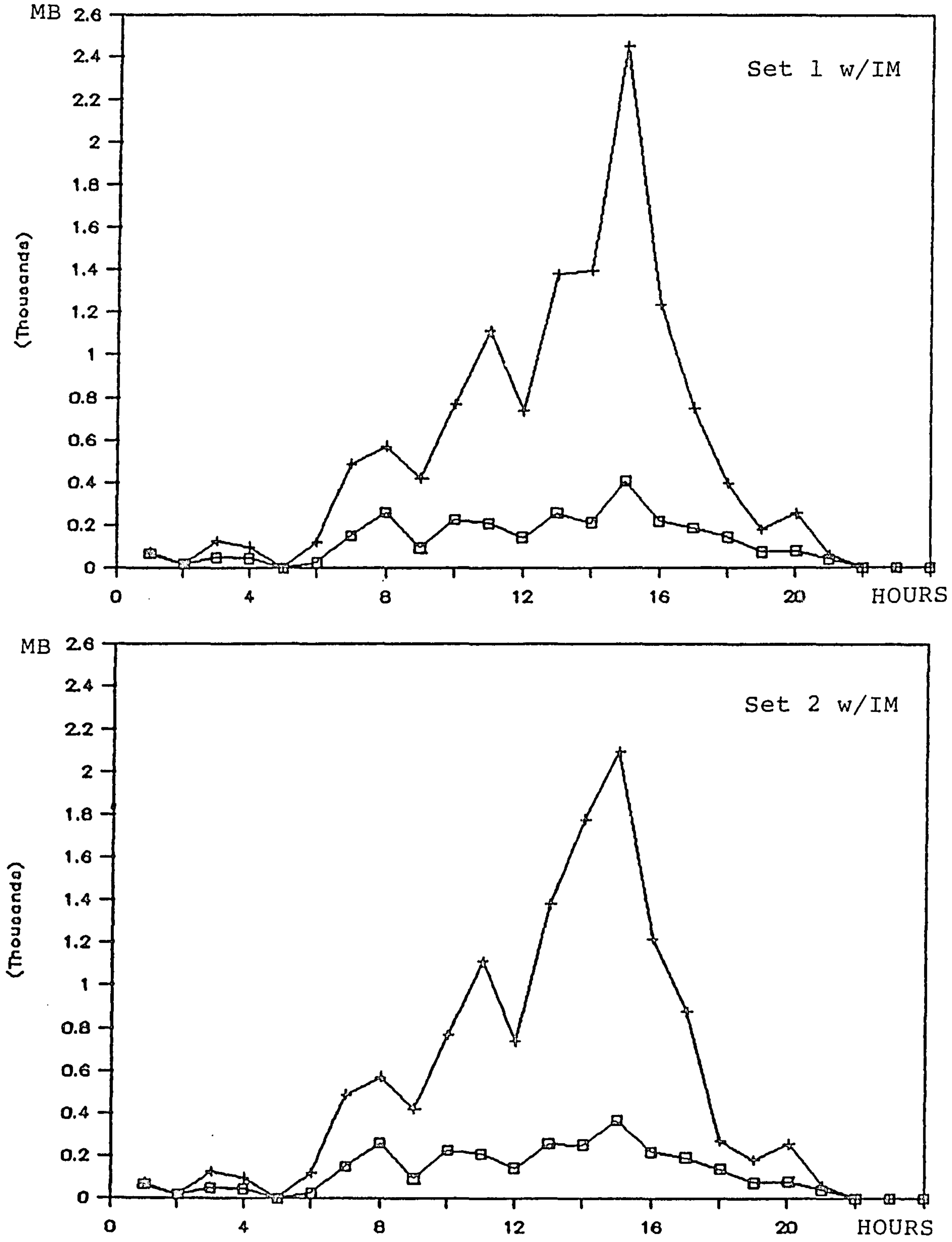


Figure 4.46 Hourly Generated Data (□) and Retrieved Data (+) Through INET with Image Migration

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 System Performance Evaluation

At the 300-bed hospital such as Arizona University Health Science Center, data generation from modalities is ranging from 1.1-3.1 Gigabytes per day. Thus, keeping the images for a 10 years period would take about 3650-10950 Gigabytes. With this huge amount of data, manipulating these images electronically in the hospital environment really challenges engineers and scientists. The following four sections discuss the performance evaluation of the TDIS system. Section a is on simulation that was performed from IE up to the CSPs in DBA. Section b is on the simulation that ran from IE up to images storage level-1 in DBA. Section c discusses the simulation results from a combined data generation & retrieval. Finally, the last section, d, discusses the simulation results from data generation & retrieval with an image migration policy.

a. IE up to DBA. As you can see from the results in Section 4.1.1, the channel utilization is very low (0.14 %). The average response time per request is about 3.2 seconds with a maximum of 6 requests in the queue on Sunday. On Thursday, the response time with no queue is 1.8 seconds.

This is because the simulation performed from IE up to the beginning of the DBA had no acknowledgment or storage delay time to keep the network channel busy. However, the reader can see the increased channel utilization and response time in Sections 4.1.2, 4.2 and 4.3 when a database archive is involved.

In addition, with the increasing of number of channels in a double buffer, the channel utilization and average response time will decrease. Eight channels provide an excellent performance, but 4 channels are adequate for most applications. Furthermore, with the increasing number of buffers for 4 channels, the channel utilization and average response time will, again, decrease. Three buffers provide an excellent performance, but two buffers are suitable for most applications.

If the system uses all 4 channels, it can reduce the channel utilization by a factor of 4 to the single channel. This is obvious according to the channel utilization definition. Also the average job processing time decreases to some value (not factor of 4). This is because the CSP's can draw the requests which are in the queue to process in parallel or concurrently. So the reduction factor of processing time can not be determined in the same manner of the channel utilization point of view. We really do not know the exact time that the CSP will start working on a particular request in queue. It also depends on the number of requests in the queue. For the double data as described in Section 4.1.1.4 the channel utilization increases twice as much as the original.

If INET data rate is slower than the ACR-NEMA, the channel utilization will increase exponentially only before the saturated point. In other words, we can say the slower the INET data rate, the higher the channel utilization. This is because of the bottle neck of buffers in the NIU. It has to wait for the outgoing data transfer processing (ACR-NEMA interface side) which is slow compared to the incoming process. In order to reduce the job response time, the INET data rate has to be faster than the ACR-NEMA data rate. However, the INET data transfer rate of 100 Mbps or more and 64 Mbps for ACR-NEMA is quite sufficient.

b. IE up to storage level-1. As shown in the result from Section 4.1.2, the channel utilization peaks to 5% at 11:00 a.m. This is only on Tuesday with the original data, single channel. The average response time, on Tuesday, is 8.2 seconds per request, the maximum waiting time in queue is 25 seconds. The network channel is usually busy from 8:00 a.m. till 7:00 p.m. In Figure 4.34, the channel utilization increases 2, 3 and 4 times as the generation data increases double, triple and quadruple respectively. In Figure 4.35, an average response time per job is proportional to the increasing data amounts almost linearly. This is the same for the average waiting time in queue of requests. From Figure 4.36, the average queue of requests varies in the manner of exponential to the amount of data. These results are useful when considering the image date increases in the near future.

c. Whole system without migration. The simulation results from Figure 4.38 show that, the hourly channel utilization is 100 % from the period of 12:00 noon to 7:00 p.m. The 100 % utilization means that the network channel is fully busy. This is based on 500 microseconds of ACR-NEMA packet processing time, 1.6 Mbps transfer rate at levels-2 and level-3. This also includes uniformly distributed accessing time of 1 to 8 seconds for level-2, and 19 to 21 seconds for level-3. The maximum and average retrieval response time are 2.45 hours and 26.96 minutes, respectively. The maximum queue length is 40 jobs.

We set up the assumption in a critical situation such as using only one channel. Also the transmission of the previous examination images from DBA begins after the data generation has done per request. This is because we need to look at the critical work load on an image network channel. A few seconds response time per image for both in data generation and retrieval is possible. If no queue has to wait, the retrieved image is from level-1 directly.

With an increasing data transfer rate of 5 times for optical disks in level-2 and level-3, the average channel utilization will decrease 62.09 %. The average waiting time in queue both for generation & retrieval will improve about 96.49 %. The average response time improves 96.05 % for generation, and 92.43 % for retrieval in 24 hours period. Retrieval images are drawn 53.54 % from level-1, 15.39 % from level-2, 27.7 % from level-3, and only 3.37 % from level-4. This shows that the most frequently retrieved images are during a 7 days period. During the period of 1 month to 3 years, the images are used infrequently. The images after 3 years old are rarely needed.

d. Whole system with migration. As the Image Migration Policy is applied to the data generation & retrieval, the average channel utilization decreases 68.99 %. When the increasing data transfer rate is 5 times greater in level-2 and level-3 the utilization decreases to 77.58 %. However, the increasing data transfer rate of level-2 and level-3 only improves the channel utilization when the network channel is heavily loaded (see also Figure 4.45). Figure 5.1 represents the hourly channel utilization with and without increasing the data transfer rate and with & without Image Migration Policy.

The average response time with queue decreases 95.49 % for generation, 94.08 % for retrieval. When the increasing

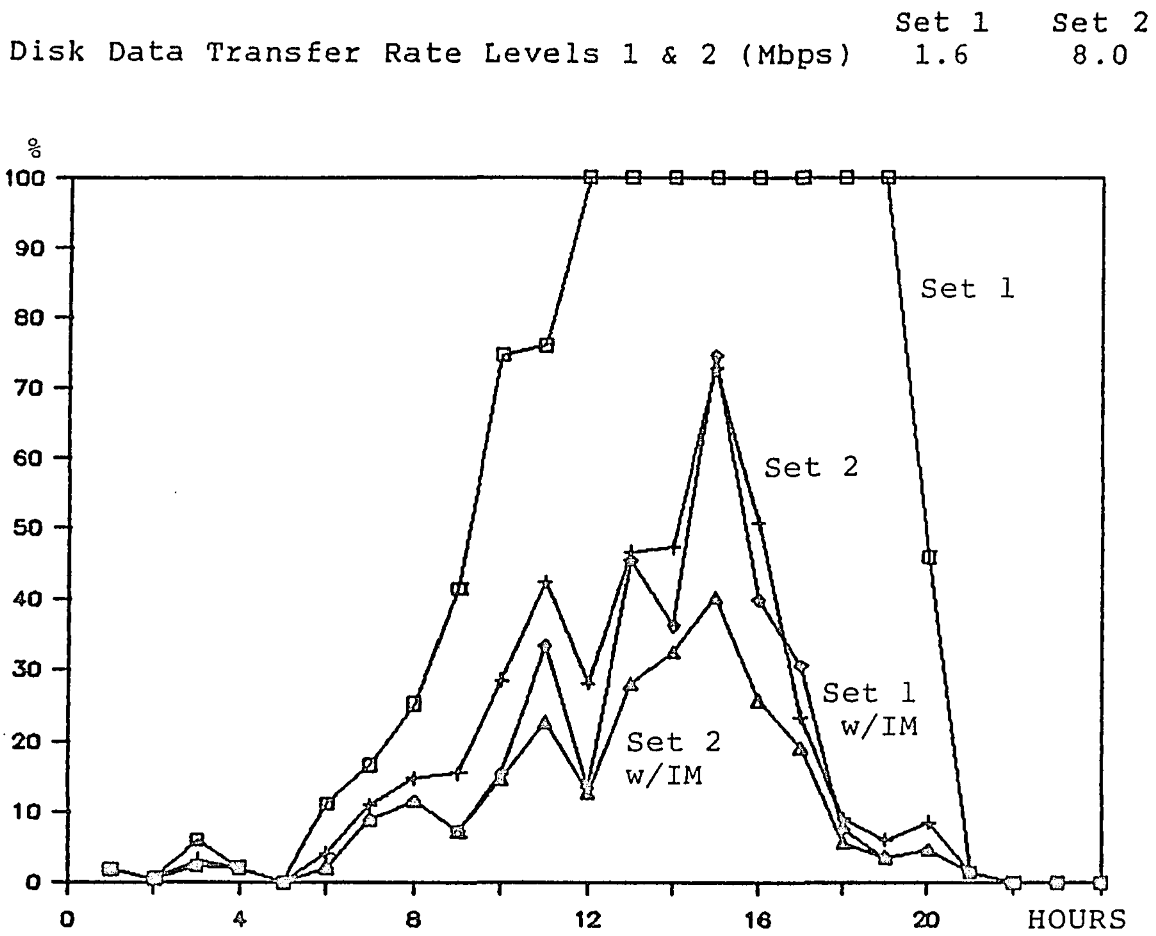


Figure 5.1 Hourly Channel Utilization Comparison for Data Set 1 & Set 2 with & without Image Migration

data transfer rate is 5 times greater, it decreases 98.83 % for generation, 96.25 % for retrieval. The amount of data from the retrieval process actually dominates the generation process. This is why the network work load is so heavy when adding the data retrieval process to the data generation process. The author has some suggestions in the next two sections to the perspective researchers who would like to continue this related work.

5.2 System Constraints

From the results, there is a need for a faster data transfer at the disk storage levels-2 and level-3. The data transfer rate should be more than 200 KBps in order to lower the channel utilization. If the system uses only a single channel, the serving priority should be on the data generation side or in emergency cases. As an alternative, if the system uses several channels, one channel should be used for data generation processing only. This would reduce its maximum job processing time (response time). A larger buffer size (more than 4 KB) in the NIU would reduce the number of acknowledgments, then a faster processing time would be attained. In addition, it would also reduce simulation time. This has been shown through simulation studies [Martinez 1987a].

5.3 Future Trends & Implementations

a. Various references have pointed out that the same image is accessed several times during the first few days after its initial acquisition. Therefore storing these images at the respective workstations should speed up access time. See also Anderson, W.H., et al, 1983.

b. Recently a fast overlay ring [Keller 1985] has been proposed. In the future, this could be an answer to the fast transmission of large blocks of medical imaging data.

c. The centralized image processor provided processing power to all workstations eliminating expensive duplication of a large processing capability at the workstations.

d. For the data retrieval process, an image network should have several channels to handle a heavy work load.

e. If increasing the data transfer rate of an optical disk is not possible, the Image Migration Policy should apply to the Database Archive.

f. The additional help of expert system can determine the size of the storage disk level-1.2, and decide which image should stay at that level and for how long. This depends on many factors such as kind of illness, related illness, and previous examination requests by the doctor.

g. A distributed database archive system which is based on modality would also be interesting to implement and evaluate in the next phase.

APPENDIX A

DATA GENERATION & RETRIEVAL WITH IMAGE MIGRATION PROGRAM

This simulation program represents all simulation models and is used for evaluating the performance of the TDIS system in Phase IV.

```
PREAMBLE

'' Image Migration TDIS Network Simulation
'' C. Archwamety   June 1987
'' Data input files PARAM*.A92, GEN*.A92 and RET*.A91
'' No user interactive input (need to run in background)
'' With Migration Algorithm, No reduced simulation time

     RESOURCES include SPU       '' Channel Serving Processor Unit

     PROCESSES include generator, Job.Server, INETG, hourly.util, stop.sim,
        patient.id, Retrieval, INETR
     EVERY INETG has a buff.ptrr, a buff.ptrc, an inet.packet
     EVERY INETR has a buff.ptrr, a buff.ptrc, an inet.packet
     EVERY Job.Server has a Jft1, a Jft2, a Jft3, a Jft4
        AND may belong to the status.queue
     EVERY patient.id has a pat.id, a rm.no
        AND may belong to the status.pid
     EVERY Retrieval has a LVL1, a LVL2, a LVL3, a LVL4
        AND may belong to the status.rtv
     The System owns the status.queue, the status.rtv and the status.pid

     EXTERNAL PROCESS is ACT
     EXTERNAL PROCESS UNIT is 2

     DEFINE no.buff, no.sp, curr.proc, gen.done, rn, mmr, ddr, yyr, LV1.2,
        LV2.1, LV3.1
        AS INTEGER VARIABLES
     DEFINE rate.inet, rate.nema, job.delay.time, wait.time, sec.cont,
        job.delay.time.que, image.delay.time, stop.time, rate.proc, nema.proc,
        total.amount.data, rate.cons, total.amount.dataR, job.delay.timeR,
        wait.timeR, job.delay.time.queR, image.delay.timeR
        AS DOUBLE VARIABLES
     DEFINE const.type, const.disk, const.tmin, const.tmax, AmtRMB
        as DOUBLE, 1-DIM Array
     DEFINE buffr as INTEGER, 2-DIM Array
     DEFINE date, exam.code, nfilm, totday,
        no.times, AmtB, Amtmin, Amtmax, AmtRIM
        as integer, 1-dim array

     ACCUMULATE spu.utilization AS THE AVG OF N.X.SPU
     ACCUMULATE avg.spu.queue AS THE AVG AND
        max.spu.queue AS THE MAXIMUM OF N.Q.SPU

     TALLY avg.job.time AS THE AVERAGE, no.jobs.processed AS
        THE NUMBER, min.job.time AS THE MINIMUM
        AND max.job.time AS THE MAXIMUM OF JOB.DELAY.TIME
     TALLY max.wait.time AS THE MAX, avg.wait.time AS THE MEAN OF wait.time
     TALLy avg.job.time.que AS THE AVERAGE, max.job.time.que AS THE MAX,
        min.job.time.que AS THE MIN
        OF job.delay.time.que
```

```
     TALLY avg.image.time AS THE MEAN, no.image AS THE NUMBER,
        min.image.time AS THE MIN, max.image.time AS THE MAX
        OF image.delay.time

     TALLY avg.job.timeR AS THE AVERAGE, no.jobs.processedR AS
        THE NUMBER, min.job.timeR AS THE MINIMUM
        AND max.job.timeR AS THE MAXIMUM OF JOB.DELAY.TIMER
     TALLY max.wait.timeR AS THE MAX, avg.wait.timeR AS THE MEAN OF wait.timeR
     TALLy avg.job.time.queR AS THE AVERAGE, max.job.time.queR AS THE MAX,
        min.job.time.queR AS THE MIN
        OF job.delay.time.queR
     TALLY avg.image.timeR AS THE MEAN, no.imageR AS THE NUMBER,
        min.image.timeR AS THE MIN, max.image.timeR AS THE MAX
        OF image.delay.timeR

     ACCUMULATE hour.util AS THE hourly average of N.X.SPU

     DEFINE hours TO MEAN UNITS
     DEFINE seconds TO MEAN /60.0 minutes
     DEFINE usecs TO MEAN /1000000.0 seconds

END  '' PREAMBLE


MAIN

     Call ORIGIN.R(1,1,76)        '' setup reference date back to 10 years
                                  '' for no. of day(s) calculation
                                  '' so we can group to which storage level

     Let HOURS.V = 1       '' so we don't need to time hours.v with other time
                           '' variable, see stop.sim routine

        Reserve const.type(*) as 4      '' size of film type in MB
        Reserve const.disk(*) as 3

        Reserve const.tmin(*) as 3
        Reserve const.tmax(*) as 3

        Reserve AmtRIM(*) as 4          '' retrieval from levels
        Reserve AmtRMB(*) as 4

        Reserve no.times(*) as 100      '' no. of requests
        Reserve AmtB(*) as 100
        Reserve Amtmin(*) as 100
        Reserve Amtmax(*) as 100

        Let const.type(1) = 1024.0*2048.0*12.0/1024.0/1024.0/8.0 '' MBytes
        Let const.type(2) = 1170.0*1200.0*12.0/1024.0/1024.0/8.0
        Let const.type(3) = 1460.0*1450.0*12.0/1024.0/1024.0/8.0
        Let const.type(4) = 2048.0*2048.0*12.0/1024.0/1024.0/8.0
```

```
Use 1 for input

Read mmr, ddr, yyr
'' reference date to the raw data generation & retrieval date

Read NO.SP, no.buff
'' Number of channel serving processor(s), number of buffer(s) in NIU
Read rate.cons, rate.nema, rate.inet
'' Mb/sec : Console, ACR-NEMA, INET

Read const.disk(1), const.disk(2), const.disk(3)
'' Mb/sec : magnetic disks (level 1), optical disks (level 2 and 3(juke-box))

Read const.tmin(1), const.tmax(1), const.tmin(2), const.tmax(2)
'' disk level 1 and 2 access time (seconds)
Read const.tmin(3), const.tmax(3)
'' disk level 3 access time

Read nema.proc
'' usecs/nema.frame : acr-nema frame processing time

Close unit 1

        Let rate.proc = (4.0*1024.0*8.0+4.0*16.0)/nema.proc
        '' Mb/sec based on proceesing time in usec/nema.frame

        For rn = 1 to 100,       '' initialize Amount of storage at WS's
        Do
                no.times(rn) = 0
                AmtB(rn) = 0
                Amtmin(rn) = 1000000
                Amtmax(rn) = -1000000
        Loop

        Open Unit 2 for input

     CREATE EVERY SPU(1)

     Let U.SPU(1) = NO.SP        '' number of serving processor(s)
     Let stop.time = 24.0        '' in hours


     ACTIVATE a generator NOW
     Activate a hourly.util NOW
     Activate a stop.sim in stop.time hours

     START SIMULATION

END  '' MAIN
```

```
PROCESS generator

        Activate an ACT now     '' external process

END


PROCESS ACT

     DEFINE room.no, pa.id, ft1, ft2, ft3, ft4 AS INTEGER VARIABLES

        IF PROCESS IS EXTERNAL

        READ room.no, pa.id, ft1, ft2, ft3, ft4
'' Proc.name, Activate.time, Room.number, Patient.id, Number of Film(s) Types, *

        ELSE
                ''DO NOTHING
        ALWAYS

     If ft1+ft2+ft3+ft4 <> 0

        room.no = room.no + 1    '' avoid room number 0 in reserved arrays
                                 '' however, need to subtract 1 in final results

     Activate a Job.Server giving ft1, ft2, ft3, ft4 now
     Activate a patient.id giving pa.id, room.no now

     Always      '' no operation if no film types

END


PROCESS Job.Server given Jft1, Jft2, Jft3, Jft4

        DEFINE packet.siz, l.packet.siz, r.packet.siz, rmdr, job.start.time,
                image.start.time, t1, t2, packet.start, packet.delay
                AS DOUBLE VARIABLES
        DEFINE I, L, mptr, mptc, n, film.type, intgr, no.packet, prev.pack,
                Jft1, Jft2, Jft3, Jft4
                AS INTEGER VARIABLES
        DEFINE no.film as INTEGER, 1-DIM Array
        DEFINE arrival.time and amount.data AS DOUBLE VARIABLES

        Reserve buffr(*,*) as no.sp by no.buff  '' buffer pointer status
        Reserve no.film(*) as 4

        Let no.film(1) = Jft1
        Let no.film(2) = Jft2
        Let no.film(3) = Jft3
```

```
        Let no.film(4) = Jft4

        Let arrival.time = TIME.V

        Request 1 SPU(1)

        Add 1 to curr.proc        '' assign current processor

        If curr.proc > no.sp
        Let curr.proc = 1
        Always

        Let mptr = curr.proc      '' memory pointer

        Let wait.time = TIME.V - arrival.time

        Let job.start.time = TIME.V

        For film.type = 1 to 4,
        DO

        If no.film(film.type) <> 0

                For n = 1 to no.film(film.type),
                DO

                Let image.start.time = TIME.V
                amount.data = const.type(film.type)

                total.amount.data = total.amount.data + amount.data

packet.siz = 2.0*16.0   '' in Kbits ( 2 KWords, 1 word = 16 bits )

intgr = TRUNC.F(amount.data*8.0*1024.0/(2.0*16.0))
rmdr = MOD.F(amount.data*8.0*1024.0,2.0*16.0)

If rmdr = 0.0
no.packet = intgr
Else
no.packet = intgr+1
Always

If amount.data = 0.0
l.packet.siz = 0.0
Else
l.packet.siz = amount.data*8.0*1024.0-(no.packet-1)*packet.siz   '' last packet
Always

        Wait Uniform.F(0.8,1.0,1) usecs         '' ready hand-shake
```

```
For I = 1 to no.packet,
Do

   Add 1 to mptc             '' memory pointer in column (buff no.)
   If mptc > no.buff         '' wrap around the buffer
   Let mptc = 1
   Always

   If I = no.packet          '' last packet
   r.packet.siz = l.packet.siz*1024.0+(4.0*16.0)    '' plus header and crc
   Else
   r.packet.siz = packet.siz*1024.0+(4.0*16.0)      '' plus header and crc
   Always

   t1 = r.packet.siz/rate.proc
   t2 = r.packet.siz/rate.nema

   Work t1 usecs   '' NEMA processing time
   Work t2 usecs   '' NEMA ---> NIU

   buffr(mptr,mptc) = 1      '' set status to be full at that buffer pointer

           If I <> 1         '' if not first packet

             If mptc - 1 = 0        '' get previous packet no.
             Let prev.pack = no.buff
             Else
             Let prev.pack = mptc - 1
             Always

             If buffr(mptr,prev.pack) = 1
             File job.server in status.queue

'not.mine'
             Suspend

                   If buffr(mptr,prev.pack) = 1
                   Go to 'not.mine'
                   Always

             Always

           Always

   Activate an INETG giving mptr, mptc and r.packet.siz in 1 usecs


Loop       '' each packet

   If buffr(mptr,mptc) = 1          '' check last packet done of INET
```

```
        File job.server in status.queue

'last.not.mine'
        Suspend

                If buffr(mptr,mptc) = 1
                Go to 'last.not.mine'
                Always

        Always

                Let image.delay.time =  TIME.V - image.start.time

                Loop    '' each image

        Always

        Loop    '' each film type

        Relinquish 1 SPU(1)

        LET job.delay.time = TIME.V - job.start.time

        Let job.delay.time.que = TIME.V - arrival.time

        Let gen.done = 1

           If status.pid is not empty
           Remove the first patient.id from status.pid
           Reactivate the patient.id now
           Always

END


PROCESS INETG given buff.ptrr, buff.ptrc and inet.packet

        Define inet.packet as DOUBLE VARIABLES
        Define job.server, buff.ptrr, buff.ptrc as INTEGER VARIABLES

        Reserve buffr(*,*) as no.sp by no.buff

        Work inet.packet/rate.inet usecs        '' NIU.WRK -> NIU.DBA
        Work inet.packet/rate.nema usecs        '' NIU.DBA -> NEMA.DBA
        Work inet.packet/rate.proc usecs        '' NEMA.DBA processing time
        Work inet.packet/const.disk(1) usecs    '' NEMA.DBA -> DISK

        Let buffr(buff.ptrr,buff.ptrc) = 0

        If status.queue is not empty
        Remove the first job.server from status.queue
```

```
        Reactivate the job.server now
        Always

END     '' data transfer of INET for 1 packet


PROCESS patient.id GIVEN pat.id, rm.no

        Reserve date(*) as 7
        Reserve exam.code(*) as 7
        Reserve nfilm(*) as 7
        Reserve totday(*) as 7

        Reserve no.times(*) as 100
        Reserve AmtB(*) as 100
        Reserve Amtmin(*) as 100
        Reserve Amtmax(*) as 100

        Define p.id, doc.id, pat.id, nexam, pexam, day.length, LV1, LV2, LV3,
          LV4, mm, dd, yy, cl, prio, rm.no, Amt
          As integer variables

        Define temp1, temp2
          As real variables

        Let gen.done = 0          '' initiate gen.done flag

                For cl = 1 to 7,          '' reset all arrays
                Do

                date(cl) = 0
                exam.code(cl) = 0
                nfilm(cl) = 0
                totday(cl) = 0

                Loop

        Use 3 for input

'readagain'
        Read p.id, doc.id, prio          '' p.id for patient ID

                If random.f(1) > 0.5,
                prio = 1                 '' emergency case
                Else
                prio = 0
                Always

        If p.id = pat.id

           If doc.id<7 or doc.id=9 or doc.id=10 or doc.id=12 or doc.id=16
```

```
          pexam = 3
          Always

             If doc.id = 8 or doc.id = 7 or doc.id = 15
             pexam = 6
             Always

               If doc.id = 11 or doc.id = 14
               pexam = 2
               Always

                  If doc.id = 13
                  pexam = 5
                  Always

       For nexam = 1 to pexam+1,       ''n for number, p for previous
       Do

       Read date(nexam), exam.code(nexam), nfilm(nexam)

          If date(nexam) = 0
          Go to 'end.patient'
          Always

       Let temp1 = real.f(date(nexam))
       yy = int.f(frac.f(temp1/100.0)*100.0)
       temp2 = real.f(trunc.f(temp1/100.0))
       dd = int.f(frac.f(temp2/100.0)*100.0)
       mm = trunc.f(temp2/100.0)

       totday(nexam) = date.f(mm,dd,yy)

       Loop

'end.patient'

       LV1 = 0
       LV2 = 0
       LV3 = 0
       LV4 = 0

date.ref = date.f(mmr,ddr,yyr)

       For nexam = 1 to pexam+1,       '' get no.film(s) for each storage level
       Do

          day.length = date.ref + 1 - totday(nexam)

               If 1<=day.length<=7
                  LV1 = LV1 + nfilm(nexam)
                  AmtRIM(1) = AmtRIM(1) + nfilm(nexam)
```

```
            AmtRMB(1) = AmtRMB(1) + nfilm(nexam)*6
         always

         If 8<=day.length<=31
            LV2 = LV2 + nfilm(nexam)
            AmtRIM(2) = AmtRIM(2) + nfilm(nexam)
            AmtRMB(2) = AmtRMB(2) + nfilm(nexam)*6
         always

         If 32<=day.length<=1095
            LV3 = LV3 + nfilm(nexam)       '' > 31 days up to 3 years
            AmtRIM(3) = AmtRIM(3) + nfilm(nexam)
            AmtRMB(3) = AmtRMB(3) + nfilm(nexam)*6
         always

         If 1096<=day.length<=3650
            LV4 = LV4 + nfilm(nexam)       '' 3 years to 10 years
            AmtRIM(4) = AmtRIM(4) + nfilm(nexam)
            AmtRMB(4) = AmtRMB(4) + nfilm(nexam)*6
         Always
                                           '' discarded for over 10 years
      Loop

      Work uniform.f(100.0,200.0,2) usecs  '' time for searching
                                           '' patient id & getting nfilms

      no.times(rm.no) = no.times(rm.no) + 1
      Amt = (LV1+LV2+LV3+LV4)*6            '' assume 1 image = 6 MB
      AmtB(rm.no) = AmtB(rm.no) + Amt
      If Amtmin(rm.no) > Amt
      Amtmin(rm.no) = Amt
      Always
      If Amtmax(rm.no) < Amt
      Amtmax(rm.no) = Amt
      Always

   If gen.done = 0      '' check to see if generation is done
   File patient.id in status.pid

'not.done'
   Suspend

      If gen.done = 0
      Go to 'not.done'
      Always

   Always

      Activate a Retrieval giving LV1, LV2, LV3, LV4 now

      Else
```

```
                If p.id <> 999999
                Go to 'readagain'
                Always

        Always

END


PROCESS Retrieval given LVL1, LVL2, LVL3, LVL4

        Define LVL1, LVL2, LVL3, LVL4, LVL2.1, LVL3.1, LVL1.2
        as integer variables
        Define lv2.time, lv3.time, adv.time, time.left
        as real variables

        DEFINE packet.siz, l.packet.siz, r.packet.siz, rmdr, job.start.timeR,
                image.start.timeR, t1, t2, t3, t4, rate.dsklv, tmin, tmax,
                packet.start, packet.delay
                AS DOUBLE VARIABLES
        DEFINE I, L, mptr, mptc, n, level, intgr, no.packet, prev.pack
                AS INTEGER VARIABLES
        DEFINE no.film as INTEGER, 1-DIM Array
        DEFINE arrival.timeR and amount.data AS DOUBLE VARIABLES

        Reserve buffr(*,*) as no.sp by no.buff  '' buffer pointer status
        Reserve no.film(*) as 3

        LVL3 = LVL3 + LVL4

          Adv.time = Uniform.f(4.0,8.0,2)
          lv2.time = real.f(LVL2)*6.0/(0.2*60.0)        '' in minutes
          lv3.time = real.f(LVL3)*6.0/(0.2*60.0)

                If Adv.time < lv2.time

                  time.left = lv2.time - Adv.time
                  LVL2.1 = int.f(time.left*60.0*0.2/6.0)       '' rounded

                  LVL1.2 = LVL1.2 + LVL2 - LVL2.1
                  LVL2 = LVL2.1

                Else
                  LVL1.2 = LVL1.2 + LVL2
                  LVL2 = 0
                Always

        LV2.1 = LV2.1 + LVL2
```

```
        If adv.time < lv3.time
          time.left = lv3.time - adv.time
          LVL3.1 = int.f(time.left*60.0*0.2/6.0)

          LVL1.2 = LVL1.2 + LVL3 - LVL3.1
          LVL3 = LVL3.1

        Else
          LVL1.2 = LVL1.2 + LVL3
          LVL3 = 0
        Always

LV3.1 = LV3.1 + LVL3
LVL1 = LVL1 + LVL1.2
LV1.2 = LV1.2 + LVL1.2

Let no.film(1) = LVL1
Let no.film(2) = LVL2
Let no.film(3) = LVL3

Let arrival.timeR = TIME.V

Request 1 SPU(1)

Add 1 to curr.proc        '' assign current processor

If curr.proc > no.sp
Let curr.proc = 1
Always

Let mptr = curr.proc      '' memory pointer

Let wait.timeR = TIME.V - arrival.timeR

Let job.start.timeR = TIME.V

For level = 1 to 3,
DO

If no.film(level) <> 0

   rate.dsklv = const.disk(level)
   tmin = const.tmin(level)
   tmax = const.tmax(level)

   Work Uniform.F(tmin,tmax,2) seconds

        For n = 1 to no.film(level),
        DO

        Let image.start.timeR = TIME.V
```

```
                amount.data = const.type(4)

                total.amount.dataR = total.amount.dataR + amount.data

packet.siz = 2.0*16.0   '' in Kbits ( 2 KWords, 1 word = 16 bits )

intgr = TRUNC.F(amount.data*8.0*1024.0/(2.0*16.0))
rmdr = MOD.F(amount.data*8.0*1024.0,2.0*16.0)

If rmdr = 0.0
no.packet = intgr
Else
no.packet = intgr+1
Always

If amount.data = 0.0
l.packet.siz = 0.0
Else
l.packet.siz = amount.data*8.0*1024.0-(no.packet-1)*packet.siz   '' last packet
Always


        Wait Uniform.F(0.8,1.0,1) usecs         '' ready hand-shake

     For I = 1 to no.packet,
     Do


        Add 1 to mptc              '' memory pointer in column (buff no.)
        If mptc > no.buff          '' wrap around the buffer
        Let mptc = 1
        Always

        If I = no.packet          '' last packet
        r.packet.siz = l.packet.siz*1024.0+(4.0*16.0)    '' plus header and crc
        Else
        r.packet.siz = packet.siz*1024.0+(4.0*16.0)      '' plus header and crc
        Always

        t1 = r.packet.siz/rate.proc
        t2 = r.packet.siz/rate.dsklv
        t3 = r.packet.siz/rate.proc
        t4 = r.packet.siz/rate.nema

        Work t1 usecs   '' disk processing time
        Work t2 usecs   '' DISK ---> NEMA.DBA
        Work t3 usecs   '' NEMA processing time
        Work t4 usecs   '' NEMA.DBA -> NIU.DBA

        buffr(mptr,mptc) = 1    '' set status to be full at that buffer pointer
```

```
            If I <> 1       '' if not first packet

              If mptc - 1 = 0        '' get previous packet no.
              Let prev.pack = no.buff
              Else
              Let prev.pack = mptc - 1
              Always

              If buffr(mptr,prev.pack) = 1
              File Retrieval in status.rtv

'not.mineR'
              Suspend

                    If buffr(mptr,prev.pack) = 1
                    Go to 'not.mineR'
                    Always

              Always

            Always

        Activate an INETR giving mptr, mptc and r.packet.siz in 1 usecs


     Loop       '' each packet

        If buffr(mptr,mptc) = 1         '' check last packet done of INET
        File Retrieval in status.rtv

'last.not.mineR'
        Suspend

                If buffr(mptr,mptc) = 1
                Go to 'last.not.mineR'
                Always

        Always

                Let image.delay.timeR = TIME.V - image.start.timeR

                Loop    '' each image

        Always

        Loop    '' each film type

        Relinquish 1 SPU(1)

        LET job.delay.timeR = TIME.V - job.start.timeR
```

```
        Let job.delay.time.queR = TIME.V - arrival.timeR

END


PROCESS INETR given buff.ptrr, buff.ptrc and inet.packet

        Define inet.packet as DOUBLE VARIABLES
        Define Retrieval, buff.ptrr, buff.ptrc as INTEGER VARIABLES

        Reserve buffr(*,*) as no.sp by no.buff

        Work inet.packet/rate.inet usecs        '' NIU.DBA -> NIU.WS
        Work inet.packet/rate.nema usecs        '' NIU.WS -> NEMA.WS
        Work inet.packet/rate.proc usecs        '' NEMA.WS processing time
        Work inet.packet/rate.cons usecs        '' NEMA.WS -> Console

        Let buffr(buff.ptrr,buff.ptrc) = 0

        If status.rtv is not empty
        Remove the first Retrieval from status.rtv
        Reactivate the Retrieval now
        Always

END     '' data transfer of INET for 1 packet


PROCESS hourly.util

        Define strip as integer variables
        Define hr.util as double variables

        Let strip = 0

        Use 4 for output

        Print 9 line with mmr, ddr, yyr, no.sp, no.buff, rate.cons, rate.nema,
        rate.inet, const.disk(1), const.disk(2), const.disk(3),
        const.tmin(1), const.tmax(1), const.tmin(2), const.tmax(2),
        const.tmin(3), const.tmax(3), nema.proc
        thus
Reference Date : **/**/19**

Number of Channel Serving Processor(s) : *   Number of Buffers in NIU : *
Console, ACR-NEMA, INET Data Rate   ***.**     ***.**     ***.**  Mb/sec
Disk Data Rate Level 1, 2 and 3     ***.**     ***.**     ***.**  Mb/sec
Min, Max Disk Access Time Level 1, 2 : *.**   *.**   *.**   *.**  Seconds
Min, Max Optical Disk Access Time Level 3          **.**   **.**  Seconds
ACR-NEMA Frame Processing Time                            ***.**  usecs/frame
```

```
        Print 2 line thus
        Hours   Hourly Utilization (%)        Accumulated Data (MB)
                                            Generation          Retrieval

        Until time.v = 24.0,
        Do

        Wait 1 hours

        Let strip = strip + 1
        Let hr.util = hour.util*100.0/no.sp


        Print 1 line with strip, hr.util, total.amount.data, total.amount.dataR
        thus
         **          ***.*****              ******.****          ******.****

        Reset hourly totals of n.x.spu(1)

        Loop

END


PROCESS STOP.SIM

        Define nlevel as integer variables

        Let sec.cont = minutes.v*60.0

      SKIP 1 LINES
      PRINT 15 LINES WITH
         time.v, spu.utilization(1)*100/no.sp,
         max.spu.queue(1), avg.spu.queue(1),
         no.jobs.processed, no.image, total.amount.data,
         max.wait.time*sec.cont, avg.wait.time*sec.cont,
         min.image.time*sec.cont, max.image.time*sec.cont,
         avg.image.time*sec.cont,
         min.job.time.que*sec.cont, max.job.time.que*sec.cont,
         avg.job.time.que*sec.cont,
         min.job.time*sec.cont, max.job.time*sec.cont,
         avg.job.time*sec.cont,
         no.jobs.processedR, no.imageR, total.amount.dataR,
         max.wait.timeR*sec.cont, avg.wait.timeR*sec.cont,
         min.image.timeR*sec.cont, max.image.timeR*sec.cont,
         avg.image.timeR*sec.cont,
         min.job.time.queR*sec.cont, max.job.time.queR*sec.cont,
         avg.job.time.queR*sec.cont,
         min.job.timeR*sec.cont, max.job.timeR*sec.cont,
         avg.job.timeR*sec.cont
         THUS
```

```
TDIS Network Study in  **.****  Hours, the Channel Utilization  ***.*****  %
The Max, Avg Queue for SPU                          ***          *.****  Jobs

GENERATION:    For     ****  Jobs     *****  Images     ******.****  Total MBytes
The Max, Avg Waiting Time in Queue                 *.****      *.****  Seconds
Min, Max, Avg Image Processing Time   *.****     *.****      *.****  Seconds/Image
Min, Max, Avg Processing Time (+que)  *.****     *.****      *.****  Seconds/Job
Min, Max, Avg Processing Time (-que)  *.****     *.****      *.****  Seconds/Job

RETRIEVAL:     For     ****  Jobs     *****  Images     ******.****  Total MBytes
The Max, Avg Waiting Time in Queue                 *.****      *.****  Seconds
Min, Max, Avg Image Processing Time   *.****     *.****      *.****  Seconds/Image
Min, Max, Avg Processing Time (+que)  *.****     *.****      *.****  Seconds/Job
Min, Max, Avg Processing Time (-que)  *.****     *.****      *.****  Seconds/Job

Begin Report on a new page

Print 1 line with mmr, ddr, yyr
thus
Reference Date : **/**/19**

Skip 1 line
Print 1 line thus
Room No.   Min, Max, Avg & Total Amount of Retrieval (MB)   No. of Request(s)

        For rn = 1 to 100
        Do
                If AmtB(rn) > 0
Print 1 line with rn-1, Amtmin(rn), Amtmax(rn),
real.f(AmtB(rn))/real.f(no.times(rn)), AmtB(rn), no.times(rn)
thus
  **        ******    ******    ******.****    ******           ***
                Always
        Loop

Skip 1 line
Print 1 line thus
Level   Required Images          Amount of Data Required (MB)

        For nlevel = 1 to 4,
        Do

Print 1 line with nlevel, AmtRIM(nlevel), AmtRMB(nlevel)
thus
  *         ******                    ******.****

        Loop

Skip 1 line
Print 4 line with AmtRIM(1), LV1.2, LV2.1, LV3.1
Thus
```

```
Retrieved Images in Level 1.1 : ******
Retrieved Images in Level 1.2 : ******
Retrieved Images in Level 2   : ******
Retrieved Images in Level 3   : ******

END      '' end report 2nd page

END      '' end stop sim process
```

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