'91 KACC 1991. 10. 22~24

PICTURE ARCHIVING AND COMMUNICATIONS SYSTEMS DEVELOPMENT AND PERFORMANCE RESULTS

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ABSTRACT

Picture Archiving and Communication Systems (PACS) provide an integration of digital imaging information in a hospital, which encompasses various imaging equipment, viewing workstations, database archive systems, and a high speed fiber optic network. One of the most important requirements for integration is the standardization of communication protocols to connect devices from different vendors. Since 1985, the ACR-NEMA standard provides a hardware interface, a set of software commands, and a consistent set of data formats for point-to-point interconnection of medical equipment. However, it has been shown to be inadequate for PACS networking environments, because of its point-to-point nature and its inflexibility to allow other services and protocols in the future.

Based on previous experience of PACS developments in The University of Arizona, a new communication protocol for PACS networks has been suggested to the ACR-NEMA Working Group VI. The defined PACS protocol is intended to facilitate the development of PACS's capable of interfacing with other hospital information systems. Also, it is intended to allow the creation of diagnostic information data bases which can be interrogated by a variety of distributed devices. A particularly important goal is to support communications in a multivendor environment. The new protocol specifications are defined primarily as a combination of the International Organization for Standardization / Open Systems Interconnection (ISO/OSI) protocols and the data format portion of ACR-NEMA standard.

This paper addresses the specification and implementation of the proposed PACS protocol into network node. The protocol specification, which covers Presentation, Session, Transport, and Network layers, is summarized briefly. The implementation has natural extentions to Global PACS environments. The protocol implementation is discussed based on our implementation efforts in the UNIX Operating System Environment. At the same time, results of performance evaluation are presented to demonstrate the implementation of defined protocol. The testing of performance analysis is performed on the PACS prototype node.

1. INTRODUCTION

The concept of Picture Archiving and Communication Systems (PACS) has evolved to integrate digital imaging information in a hospital, since the early 1980's. PACS is a digital image information system which provides digital imaging storage, processing, and transfer. To provide a totally digital imaging information system, it needs to integrate various imaging equipments, various image viewing workstations, large size of image databases, and a high speed fiber optics network.

Enhancements of PACS to conventional film image system are numerous, such as fast image transfer, easy management of image, convenient application of modern technology in image processing, providing better security from image loss and a cost saving in the image handling. But, there are some obstacles, such as large amount of initial cost to set up the system, a potential rejection from radiologist to complicated new technology, a lack of well defined standard, and a proper integration of various device.

Following a progress on computer network and storage device technology, PACS became realistic and important to digital radiology and medical imaging. During last eight years, continuous research on PACS has been done in The University of Arizona and the Toshiba Corporation as joint work. PACS designs have been evaluated using performance evaluation and simulation techniques [1].

PACS requires a high speed optical network and large image databases to handle the large volume of image data, which is generated daily in a hospital. Also, the standardization of communication protocols is required to integrate imaging devices from different vendors for totally digital radiology department. The standardization includes a hardware interface, a set of software commands, a set of services provided, and a consistent set of data formats. The ACR-NEMA standards committee has developed a point-to-point standard for communications in digital radiology equipment in 1985 [2]. The ACR-NEMA standard mainly covers protocol definition for the Physical, Data Link, and Transport/Network layers. The standard does not have a network layers, and primarily defines the interface between an imaging equipment and a network interface unit, or another imaging equipment. The ACR-NEMA is inadequate to use in a networked PACS environment and would be too difficult to modify [3,4].

Based on our study, papers have been written on PACS protocols at all layers of the Open Systems Interconnection (OSI) reference model [5,6] and new PACS communication protocol standard have been proposed to ACR-NEMA standard committee [7]. The implementation effort of the proposed protocol have been done on the SUN workstation and the VAX 11/730, which are available for this research.

2. REVIEW of PROPOSED PACS PROTOCOL

The proposed PACS protocol is defined in a layered systems approach. It encompasses the protocol definition and specification for the Presentation, Session, Transport, and Network layers. It is defined based on the following two major conditions and assumptions. First, the Application layer packages will change according to radiologist needs and will emerge in the future. Second, the Physical and Data Link layer can be varied according to new fiber optic networking technologies and need to include current available networks. The proposed protocol defines only PSTN layers with these assumption as shown in Figure 1. The defined protocol in these layers can be established on networks with various topologies and transmission media. As new technologies evolve for PACS networks, then these may be interfaced to the PACS Network layer using a common set of interfaces and protocols.

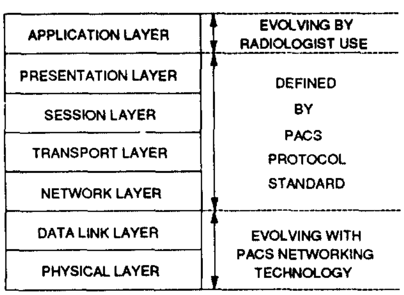

Figure 1. The PACS Seven Layer Model

These layers would reside in nodes on a PACS. The nodes would be Imaging Equipment, Viewing Workstations, and Database Archive Systems, or other specialty nodes in digital radiology. The PACS networks can be Local PACS (L-PACS) limited to a hospital community, or can be Global PACS (G-PACS) extended across a large geographical area, such as national or international boundaries. The result of an ISO-based PACS protocol is very attractive for future interoperability. The specification of PSTN layers are defined to support integrated voice, image, and text services. These layer are enhanced for PACS operation in local and global PACS environments. The specification defined the protocols functions and interfaces in each layers. It states several PACS protocol terminologies and networking designs. It examines networking topologies for PACS and the user scenarios for local and global PACS environments. The proposed PACS protocols for PSTN layers are defined based on following characteristics and requirements.

It requires a large amount of image data transfer and fast response time. It has different requirements of error rates and allowable data transfer delay for control, voice, or text data. The protocol must operate not only in the Local PACS environment but also in the Global PACS environment. User-to-user real time communication of image, text, voice, and overlay pointing image should be supported to serve the consulting nature of radiology. The encryption and the data compression for text and image data are different. Because of the large amount of image data generated in the hospital, the image files may be stored in the distributed data base.

Protocol data units of each layer are defined as data PDU, image PDU, and voice PDU. The data PDU is defined to transfer patient information, control information, and image related information. The image PDU is defined to carry pixel data of image. The voice PDU is defined to transfer voice data. These three types of data are defined to have three separate data flow, control, and processing in each layer.

The presentation layer provides a common representation of information between application entities. The representation of information includes the representation of data, image, image related information, data structure, and syntax. Using this common representation of information, the presentation entity provides common transfer data format between peer application entities. The ACR-NEMA data format is used to generate common transfer data format, because of it's popularity and little overhead for hospital imaging network.

The ISO-OSI standard has defined Abstract Syntax Notation one (ASN.1) and Basic Encoding Rules (BER) to provide the common representation of information and generate the common transfer data format. ASN.1 and BER are enhanced to generate ACR-NEMA data format for the PACS user data. The presentation layer protocol allows that the user may send encrypted text data and compressed image data at the same time. The encryption and compression scheme between application entities are negotiated while they are establishing session.

The voice service in application layer has two separate services. One is a control of voice transfer, the other is a delivery of voice data streams as shown in Figure 2. The voice data must be delivered within 150-200 msec to preserve the integrity of a conversation. A group of sampled voice data is delivered directly to transport layer to reduce the overhead from packetization. The control of voice transfer use presentation layer protocol to negotiate voice data format.

The session layer provides the cooperation of presentation entities. It organizes and synchronizes their dialog to manage their data PDU, image PDU, and voice PDU exchange. The session layer provides a service such as session connection establishment, session connection release, data PDU transfer, image PDU transfer, and control of voice transfer. When user requests to transfer data, image, and voice data, which requires distinguished data flow, session layer will establish three separate sessions in the transport layer. Also, the session layer provides three distinct dialog controls and synchronizations. This separation in the session service provides a powerful feature to develop conference applications and distributed data base applications.

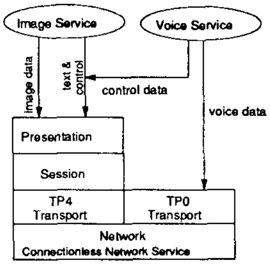

Figure 2. The Flow and Control of Three Types of Data.

The transport layer service provides a transparent transfer of data, image, and voice PDU from sender to receiver. It provides reliable data transfer to the transport layer service user over the possibly varying reliability of the network. ISO-OSI standard defines different classes of connection oriented transport layer protocols; TP0, TP1, TP2, TP3, and TP4. TP0-TP3 is normally used when the network layer service is connection oriented. TP4 provides reliable data transfer in the connection-less oriented network layer.

TP4 is designated to transfer image PDU and data PDU including control data for voice. It provides a reliable data transfer for the connection-less network by recovering the lost packets, removing the duplicated packets, and resequencing the out of order packets. TP0 is designated to transfer voice data, since the other redundant protocols in TP4 is not required for voice PDU transfer. Voice packets are transferred without requesting acknowledgement and are not retransmitted even if it is lost. It must be transferred in sequence using a source routing.

The network layer grants the independence of higher layer from underlying local area networks and provides functions which transfer data from sender to receiver over various of sub-networks. The Connection-less mode Network Protocols in ISO are defined as a network layer protocol for PACS.

3. IMPLEMENTATION of PACS PROTOCOL

The defined protocol is implemented as a PACS prototype. The environment of implementation is derived by the available workstations, operating systems and network. SUN workstations and VAX 11/730 are used as developing nodes of prototype PACS. The network software of PACS is coded entirely with a C programming language. It is implemented on the top of SunOS in Sun Microsystem and Berkeley BSD4.3-Reno operating system in VAX. The underlying network is the Ethernet, which connects hosts in The University of Arizona.

The network programming of PACS requires the use of Interprocess Communication facilities (IPC) for the interaction of two or more processes. There are different facilities to provide the interaction between processes, such as pipes, message queues, semaphores, shared memory, sockets, and Transport Layer Interface. The main goals of these facilities are to allow multiprocess programming and to provide access to communication networks. The pipe facility is a reliable, flow-controlled, byte stream that can be established between two processes on the same machine. It is used for interprocess communication between processes which are running on the same host.

The socket is the abstract object which is created within a communication domain. It is built as an interface of several different protocols on the top of transport layer, such as UDP, TCP, XEROX NS, ISO TP4, and ISO TP0. The concept of socket is developed in Berkeley UNIX. The Transport Layer Interface in System V is the corresponding abstract object as in Berkeley UNIX. Sockets are used to send and receive messages between two processes on the different machine, only because the base of our prototype development is the Berkeley UNIX operating system and also socket interface is available in SUN OS.

The PACS protocol is implemented on the top of TP4 socket as a required protocol stack of PSTN layers and also on the top of TCP/IP socket for a station which does not provide ISO services. The TCP/IP side of implementation will be used as a transition protocol until migration to ISO occurs. It is described in figure 3.

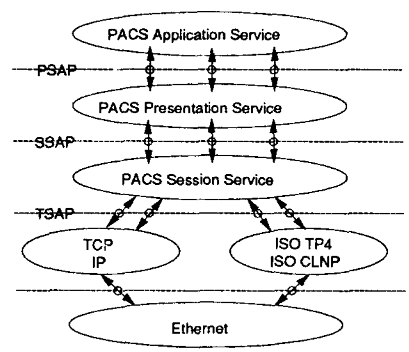

Figure 3. The Implementation of PACS Protocol

The PACS protocol is implemented with considerations of modularity, portability, transparency, efficiency, and compatibility.

a. Modularity: Services defined in Application, Presentation, and Session layers are implemented as independent procedures. Each service is available only through the service access point as defined in protocol specification. The modification of current service or addition of new service will affect only those services in the bordering layer. As an example, the service available in the transport layer will affect the interface element of session layer services.

b. Portability: The implemented PACS can be easily ported into other UNIX machine. If the operating system includes the Berkeley socket, it is expected to have no trouble porting the program by just compiling the source cord. However, the porting to the host with System V requires a little modification on the part of transport layer interface. Message queues, semaphores, and shared memory are not used because it generates problems in porting and the pipe facility can carry out required functions.

c. Transparency: Communication between nodes of PACS should not depend on the machine and the OS of the machine. The developed PACS protocol is based on the UNIX machine which is very popular operating system. Thus, it is easily ported on the machine with UNIX operating system.

d. Efficiency: The network programming of PACS is limited by its performance, because of large size of image data to transfer and expectations from impatient physicians. Particularly, following layered communication protocol specification requires more attention on the performance. The protocol of each layer can be implemented as a separate process with using IPC facilities or as independent functions without using IPC facilities. Although building each layer as a process with IPC facilities provides more modular, it would have required that more communication overhead to access more server processes of each layer.

The most sensitive factor of the performance in the layered protocol implementation is the method of message passing. The excessive copy operation is required when each layer is built as a separate process, since it requires one copy operation for writing in the sender side and another copy operation for reading in the receiver side. Figure 4 shows the technique that used to implement protocol layers.

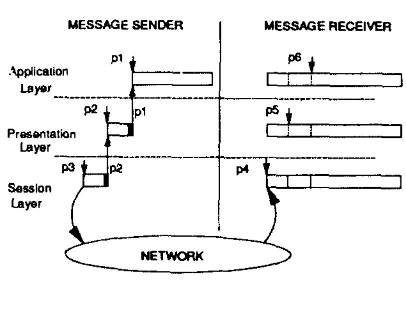

Figure 4. The Message Passing Architecture

The right side of the figure depict simple example of the message sending service such as request and response. The left side depict the message receiving service such as indication and conform. The different execution structures of two sides are derived from its inherent characteristics and for memory management.

In the sender side, the application layer service provider of the sender allocates memory for there service data unit, writes data in the allocated memory, puts null pointer in the tail, and passes the pointer 1 of the application service data unit to presentation layer. The presentation layer service provider receives this pointer, allocates memory for header, generates presentation header with pointer 2, puts received pointer 1 in the tail, and passes pointer 2 to session layer. The session layer service provider receives pointer 2, generates session header with pointer 3, serialize it, and sends to transport layer service provider until it reaches null pointer.

In the receiver side, the session layer receives data, reads session header, moves pointer, and transfers the new pointer to the session layer service user. The presentation layer service provider do the same process and sends new pointer to the presentation layer service user. The application layer receives pointer and reads data following pointer.

4. PERFORMANCE TEST

The environment of PACS is somewhat differ from the other computer network environment. Basically the purpose of PACS is to provide better care to the patients and to provide better handling of image by interconnecting the image archive, image storage, and image retrieve. The performance of PACS has great affect on the feature of the PACS. Not only the quantity of data for image transfer is very large, but also the quality of data for image transfer is extremely sensitive in the PACS environment. The issues of performance on PACS are availability, response time, throughput, reliability, and security. As a first step, we test the response time of image file transfer in the protocol development station.

The sparc SUN workstation with SEGATE 1.2 Gbyte disk is used for the protocol development on the top of TCP/IP. The VAX 11/730 with DEC R80 120 Mbyte disk is used for the protocol development on the top of TP4/CLNP. Actually, the PACS protocols are developed on the SUN station and ported into VAX for the development of full stack of protocol. The porting is not fully completed yet, even though the full stack of protocol works partially. We planed to present the test result including this full stack of protocol, but only the test result from SUN workstation will be given due to delay on project. The response time in figure 5 is the time delay of file transfer. It is tested that the time delay of disk-to-disk file transfer and the time delay of memory-to-memory file transfer.

The disk-to-disk response time is tested as follows:

Client :

1. Get time (t1).
2. Send test request to server.
3. Read file from disk and send to Server.
4. Receive file from Server and Write to disk.
5. Get time (t2).
6. Get response time (t3 = t2 - t1).

Server :

1. Wait for request.
2. Receive test request from client.
3. Receive file from client and store to disk.
4. Read file from disk and send to client.
5. Go to step 1.

The response time of memory-to-memory file transfer is tested in the same way without reading file from disk and writing file to disk.

File Size (Byte)	D-to-D Avg	D-to-D Min	M-to-M Avg	M-to-M Min
8192	0.199	0.149	0.146	0.119
32768	0.369	0.199	0.180	0.130
65536	0.789	0.719	0.330	0.260
131072	1.468	1.339	0.540	0.470
262144	4.739	2.789	1.370	1.120

Figure 5. The response time of file transfer(seconds).

The test is done by 100 times iteration each at midnight to reduce the number of users on the network and the testing host. The Average response time and the minimum response time are derived from the test. The result does not shows the best of the protocol performance, because the network was connected to numerous hosts in the University and several demons were running in the testing host. But, it shows the reasonable performance of the system in more realistic situation. The response time of the Disk-to-Disk file transfer shows the excessive time delay comparing to the memory-to-memory file transfer.

5. RESULTS AND DISCUSSION

The implementation of PACS protocol is intended to facilitate the development of PACS, which is capable of interfacing with a variety of distributed imaging devices. Also, it intended to provide a test base for performance evaluation and to prototype the creation of diagnostic information data bases.

In this paper, we present the implementation effort on defined PACS protocol and the results of performance test to demonstrate the performance of the system. The aim of PACS network is to support the image and data transmission in the hospital environment. The test result shows that the PACS network needs high transmission rate to handle large amount of data. Also, the disk access speed in each node will extremely affect the performance of PACS.

The implementation of defined protocol on the top of TP4/CLNP is our current research. It will be completed in near future. The test in the full stack of ISO implementation will be compared with the current result and other available data by survey of paper.

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