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13. ABSTRACT (Maximum 200 Words)
The purpose of this investigation was to develop a broker system to manage connections between PACS located at multiple institutions, allowing secure and reliable retrieval of selected image data. The project proposed to design and establish a Meta Medical Image Archive (MMIA) testbed that would connect remote PACS, allowing end user transactions between these systems, and permit storage of studies within the MMIA for future retrieval. This testbed has been implemented in our Laboratory of Radiological informatics. A software infrastructure has been developed that minimizes the likelihood of misidentification of a patient between institutions with different medical record systems. DICOM applications have been implemented that permit commands of find, move and store of study data. A database for studies stored within the MMIA has also been implemented.

The project also developed a hardware configuration utilizing state-of-the-art failover components. Since computer cluster technology has evolved rapidly, this configuration differs somewhat from what was initially proposed. Hardware has been purchased, configured and connected to simulated PACS for testing. One intra-institutional connection has been made and a second connection is imminent. Security of transactions between institutions is being implemented by data encryption using commercial software. A no-cost extension is being requested.

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Introduction

Most major medical facilities now acquire, store, distribute and display images electronically using PACS. Standardized communication protocols (DICOM) allow users with appropriate permissions to query and retrieve studies to a DICOM compliant device or system from a remote DICOM server. If a patient accesses care at multiple institutions, the PACS in those facilities need to be integrated to provide cross-system interoperability. A solution to address problems with this integration that stems from different information infrastructures at different institutions, is to use a meta-manager as a systems broker to interconnect the different databases using DICOM protocols. A primary concern of the broker implementation approach is how to identify and protect patient information across the enterprise-wide medical imaging infrastructure, since transactions are out of the security domain of an individual PACS in a local hospital setting. The purpose of this project was to develop a Meta Medical Image Archive (MMIA) test-bed that interconnects multiple PACS and permits issues such as reliability, security, and image authenticity to be addressed and explored.

Body

Design and implementation of a Meta Medical Image Archive (MMIA) test-bed

A) Hardware implementation (Task 3)

1. MMIA Cluster Design

To assure high reliability of the MMIA, a redundant CPU architecture using failover software was proposed. As discussed in last year's report, implementation of this CPU cluster using Sun cluster software requires that all computers have the same bus structure. At that time, we had an S-bus and a PCI based computer and we recognized the need to change hardware. In this past year, a new architecture was developed and the hardware components for this configuration were purchased. The new dual-server MMIA cluster will provide the high-availability services with failover capability we proposed and use computers that are fully supported by the manufacturer (Sun). Figure 1 shows the hardware configuration of the MMIA cluster.

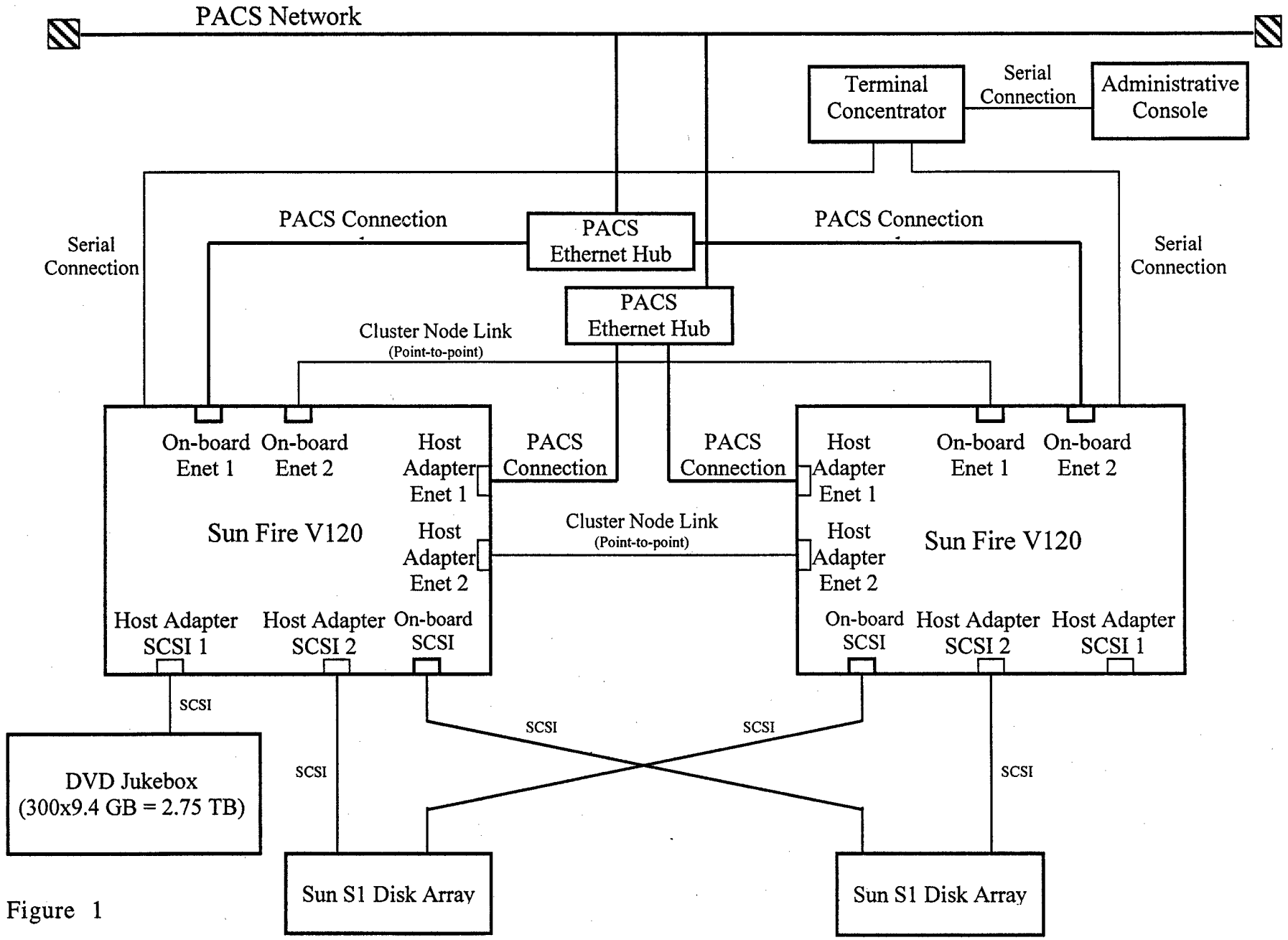
PACS Network
Terminal Concentrator
Serial Connection
Administrative Console
Serial Connection
PACS Connection
PACS Ethernet Hub
PACS Connection
Serial Connection
PACS Ethernet Hub
Cluster Node Link
(Point-to-point)
On-board Enet 1
On-board Enet 2
Host Adapter Enet 1
PACS Connection
PACS Connection
Host Adapter Enet 1
On-board Enet 1
On-board Enet 2
Sun Fire V120
Host Adapter Enet 2
Cluster Node Link
(Point-to-point)
Host Adapter Enet 2
Sun Fire V120
Host Adapter SCSI 1
Host Adapter SCSI 2
On-board SCSI
On-board SCSI
Host Adapter SCSI 2
Host Adapter SCSI 1
SCSI
SCSI
SCSI
SCSI
SCSI
DVD Jukebox
(300x9.4 GB = 2.75 TB)
Sun S1 Disk Array
Sun S1 Disk Array

Figure 1

As shown in this figure, the following hardware components are used in the MMIA cluster:

- Two Sun Fire V120 systems as the primary and secondary MMIA servers
- Two Sun SCSI-based S1 disk arrays as a mirrored storage for MMIA
- A dedicated terminal concentrator (TC) connected to the V120 systems
- Dual Ethernets for the private cluster transport (inter-server heartbeat link)
- Dual Ethernets to connect the MMIA cluster to the UCSF clinical PACS network

The high level of redundancy is apparent. Each CPU (Sun V120s) is connected to dual disk arrays (Sun S1s) with mirrored software. Each CPU has dual, 100BaseT Ethernet connections to the PACS network to which remote PACS are connected. The PACS network connection is through separate switches to eliminate a single-point of failure in this vital connection. In addition, the CPUs have dual Ethernet channels for the inter-server private cluster transport, which provides the heartbeat communication required for failure detection.

As shown in Figure 1, the long-term archive, a 300 platter DVD jukebox, has not been mirrored. Management of the DVD prevents dual-hosting as currently configured. We are considering if a mirrored long-term archive is necessary. Note that this archive is redundant storage as the studies are also archived on the PACS from which the data was initially obtained. In the event of failure of the CPU controlling the DVD, the alternate CPUs broker functions will still be functional. Thus a user seeking to retrieve a study that is stored on the DVD archive can still obtain that study by a query and retrieve from the PACS where the study originated. The consequence would be some time penalty as it would be faster to satisfy queries from remote PACS from the broker's archive but we have we have not yet determined how much. This is an area we intend to investigate and believe to be dependent on the local PACS. PACS frequently have a priority setting for processing transactions with remote entities and, if the priority is low, at peak times of the day, response times may be slowed due to

slow response of the local PACS. Note that for all transactions, network bandwidth and traffic may influence response times.

2. MMIA Network Connection (Task 4)

The MMIA has been connected to a commercial PACS (Agfa IMPAX) and a DICOM compliant archive and display system (Merge Technologies eFilm) via the UCSF clinical network. Figure 2 shows the network connections between the MMIA cluster, the IMPAX, and the eFilm systems. The clinical network can communicate with 2 remote institutions, the San Francisco VA and the San Francisco General Hospital. The network infrastructure is designed and maintained by UCSF personnel, both in radiology and in Hospital IT, and the MMIA connection to this network has been coordinated with these people. Although the current MMIA hardware interfaces do not support Gigabit, the PACS backbone could. While we do not plan to implement Gigabit on the testbed, as the amount of study transfers is small, there is no technical reason why the higher bandwidth could not be implemented.

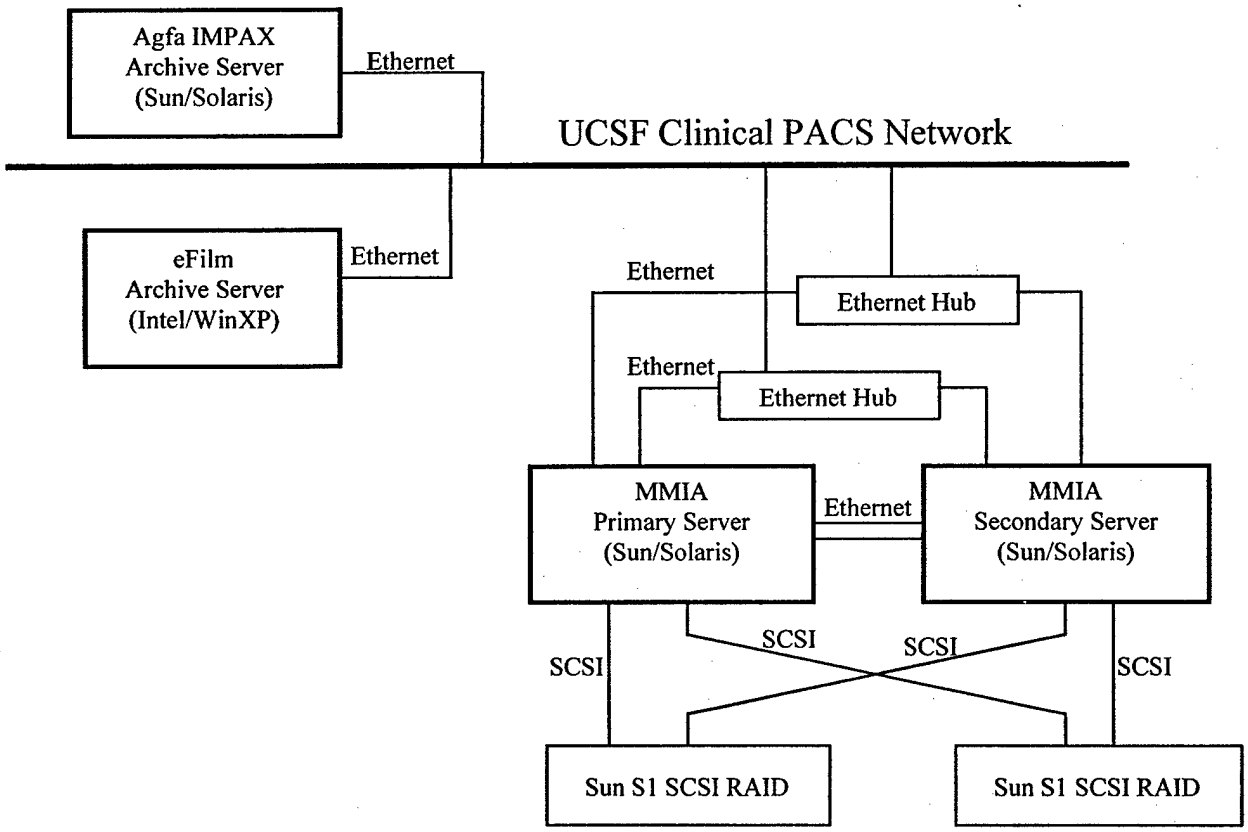

Figure 2 Network connections between the MMIA servers, the Agfa IMPAX and Merge Technologies eFilm systems.

B) Software developments

1. MMIA component software

The MMIA CPUs have been configured within a Sun Solaris 8 operating system that is compatible with the Sun cluster software. The S1 disk arrays are supported with Veritas Volume Manager 3.5 software. The local database management system is Oracle 8i. The DICOM application software to support MMIA's image communication and storage applications uses the Mallinckrodt Institute of Radiology's CTN 3.0 utility libraries and is installed on both CPUs. Standard DICOM C-STORE, C-FIND, and C-MOVE SOP Class services have been implemented. This software uses C programming and an appropriate compiler has been purchased and installed.

To provide a clustered-server operating environment, Sun cluster software is being installed. Failures can occur because of hardware or software problems. The cluster software should detect any hardware problems and seamlessly switch operation to the secondary CPU. The cluster software should also be able to detect many some types of application failures and, with the software mirrored on the disk drives, allow continued operation. The cluster server software has not yet been successfully implemented but is the major thrust of our current activities (Task 6).

2. We have successfully implemented a broker function in the MMIA server that allows a query initiated by a user at a workstation connected to the PACS network to be relayed to a third-party image archive via the MMIA. The MMIA receives the response from the remote archive, creates a study list and returns this list to the user. The user can then request retrieval of selected images to the workstation. This retrieval request initiates a DICOM C-move request from the remote archive and the selected images are moved to the user's workstation. These activities are illustrated in Figure 3.

The brokering of Query and Retrieve requests via the MMIA was the most significant software accomplishment during this past year. As noted in previous reports, services within the MMIA were developed, for example DICOM C-FIND and C-MOVE services. Thus a DICOM device could perform functions directly with the MMIA such as sending a study for storage within the MMIA or retrieving a study from the MMIA's archive, but query and retrieve requests could not be relayed to remote PACS.

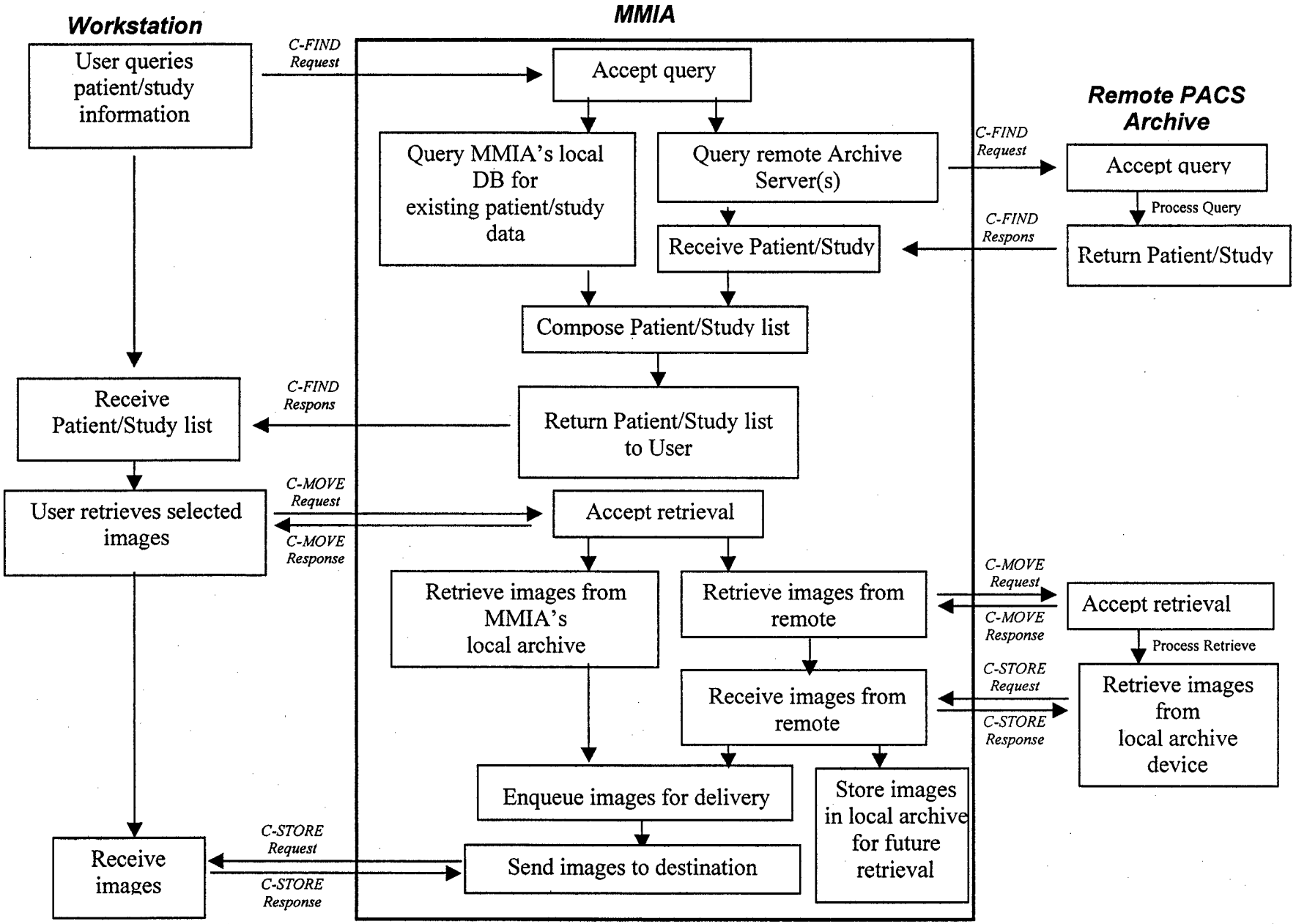

Figure 3 Broker functions: Query and Retrive

3. Image data transfers between PACS must be secure and reliable. The MMIA must itself be safe from attacks and security breaches. The MMIA has been deployed behind the Departments' firewall, but must connect to PACS outside of our institution. We have been working with our IT people to implement a software encryption program, Checkpoint, that will permit only encrypted transactions across public networks that will be used to connect to remote PACS.

C) Testing

The function of the MMIA has been tested by querying from and retrieving patient examination information and medical images to a workstation running a commercial DICOM display application, eFilm. The MMIA server relayed these service requests to a clinical PACS that is used by our institution (Agfa IMPAX). Tests were conducted that to retrieve MR studies both on a series basis and CR images on both an image and series basis. Mammographic images originating from a GE digital mammographic unit were also successfully retrieved via broker function.

Research Accomplishments

- A high availability MMIA testbed has been designed and implemented that features state-of-the-art failover architecture including dual CPUs, mirrored disk arrays and redundant connections to a PACS network.
- A broker function has been implemented on the MMIA testbed that allows query and retrieval requests from a user workstation (e.g., eFilm) be relayed to a third-party image archive (e.g., IMPAX). The response data from the requested archive server is passed back to the requesting workstation via the MMIA. These data (medical images and relevant examination information) can optionally be stored in MMIA's local archive device and database for future retrieval.
- Function of the broker activities of the MMIA has been tested using both MR and CR images, representing studies having a large data volume both per study and per image, respectively.

Reportable Outcomes

Presentations of the status, concepts and findings of this investigation have been made at several intra-institutional research seminars.

Conclusions

The growth and expansion of Picture Archiving and Communication Systems in radiology has not significantly improved access to image studies taken at multiple institutions. To replace film transport, some institutions may burn studies onto CDs along with a display program and the patient may hand carry these between institutions. But the ability to remotely query and retrieve studies from multiple PACS has not yet been implemented. Thus a functional broker that could identify image data of a given individual and manage its transfer to a user at a remote workstation remains of significant value.

Our efforts to develop a prototype Meta-Medical Image Archive have progressed and have demonstrated that brokering of interactions is possible. However, we have not completed the task and are requesting a no cost extension. The following activities remain:

- Fully implement and test the failover technology of the MMIA
- Fully implement and test the ability of the master patient table (MASTER.TBL) to identify an individual who has been assigned different medical record numbers by different medical institutions. The master patient table was discussed in previous reports and includes necessary information, obtained from DICOM header information, for mapping a patient's identification within the broker.
- Implement secure data transmission using off-the-shelf software encryption technology and test this between SFGH and UCSF, the two remote institutions identified with different PACS that will be used in testing the MMIA.
- Clinically evaluate the performance of the MMIA using digital mammographic data.