SESSION IX: Enterprise Architectures and Information Management

Performance and Function of a High-Speed Multiple Star Topology Image Management System at Mayo Clinic Scottsdale

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Mayo Clinic Scottsdale (MCS) is a busy outpatient facility (150,000 examinations per year) connected via asynchronous transfer mode (ATM; OC-3 155 MB/s) to a new Mayo Clinic Hospital (178 beds) located more than 12 miles distant. A primary care facility staffed by radiology lies roughly halfway between the hospital and clinic connected to both. Installed at each of the three locations is a high-speed star topology image network providing direct fiber connection (160 MB/s) from the local image storage unit (ISU) to the local radiology and clinical workstations. The clinic has 22 workstations in its star, the hospital has 13, and the primary care practice has two. In response to Mayo's request for a seamless service among the three locations, the vendor (GE Medical Systems, Milwaukee, WI) provided enhanced connectivity capability in a two-step process. First, a transfer gateway (TGW) was installed, tested, and implemented to provide the needed communication of the examinations generated at the three sites. Any examinations generated at either the hospital or the primary care facility (specified as the remote stars) automatically transfer their images to the ISU at the clinic. Permanent storage (Kodak optical jukebox, Rochester, NY) is only connected to the hub (Clinic) star. Thus, the hub ISU is provided with a copy of all examinations, while the two remote ISUs maintain local exams. Prefetching from the archive is intelligently accomplished during the off hours only to the hub star, thus providing the remote stars with network dependent access to comparison images. Image transfer is possible via remote log-on. The second step was the installation of an image transfer server (ITS) to replace the slower Digital Imaging and Communications in Medicine (DICOM)-based TGW, and a central higher performance database to replace the multiple database environment. This topology provides an enterprise view of the images at the three locations, while maintaining the high-speed performance of the local star connection to what is now called the short-term storage (STS). Performance was measured and 25 chest examinations (17 MB each) transferred in just over 4 minutes. Integration of the radiology information management system (RIMS) was modified to provide location-specific report and examination interfaces, thereby allowing local filtering of the worklist to

remote and near real-time consultation, and remote examination monitoring of modalities are addressed with this technologic approach. The installation of the single database ITS environment has occurred for testing prior to implementation.

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MAYO CLINIC SCOTTSDALE (MCS) is a busy outpatient facility (150,000 exams per year) that is connected via asynchronous transfer mode (ATM; OC-3 at 155 MB/s) to a new Mayo Clinic Hospital (178 beds). The hospital opened for patient care on October 27, 1998. It is 12 miles distant from the clinic, while the Thunderbird Primary Care practice lies roughly halfway between. All three locations are staffed by Radiology, a group of 17 providing support to the physician staff of 250. When hospital construction was announced in 1996, Radiology prepared for its opening, which was to be fully softcopy, by first converting all modalities at the clinic to digital (except for mammography), then by selecting a primary picture archiving and communications systems (PACS) vendor. The vendor, General Electric Medical Systems (GEMS), Milwaukee, WI) completed installation of their legacy product in March, 1998.

OUTPATIENT CLINIC STAR

The clinic outpatient facility installation includes the permanent archive (Kodak ODJ 2000, Rochester, NY) currently providing 2T capacity, a 256-GB central image storage unit (ISU), with seven Digital Imaging and Communications in Medicine (DICOM) gateways in use to connect 18 modality devices. Modalities include: six Fuji (Stamford, CT) AC-3s, which are DICOM via Analogic SD-100s, one Philips Thoravision, two GE magnetic resonance images (MRIs), one Philips (Best, Netherlands) MRI, one GE computed tomography (CT), one Elscint (Haifa, Israel) CT, one Siemens (Islin, NJ) CT, nine ultrasound systems connected via ALI Ultrasound Mini-PACS, two Siemens Sierskop TOP Digital fluoroscopy systems, one OEC (Salt

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Lake City, UT) C-arm, one Gastrointestinal (GI) edoscopic retrograde cholangiopancreatography (ERCP) room (InfiMed, Liverpool, NY), and three nuclear gamma systems via ADAC (Milipitas, CA) Pegasys. The nuclear and digital fluoroscopy systems are not yet routinely going to the archive, since these systems have not yet been provided with the accession number field necessary to keep the technologist from having to electronically match examinations with orders, a workflow problem in these busy areas. However, all chest, bone, and other plain film are digital, and have been routinely been transferred to the archive since the third quarter of 1997. All CT and MRI examinations have been archived since first quarter, 1998. Since color images are not supported at this time in the GEMs PACS, the ultrasound images are stored in the ALI Technologies (Richmond, CA) Mini-PACS and not redundantly archived. This is also true for those nuclear examinations for which color is needed (ie, cardiac single-photon emission computed tomography [SPECT]).

Note that the clinic star is the only one for which long-term archiving is possible (Fig 1). This decision was reasonable since the majority of images are produced at the clinic, and thus network trafficking is reduced with this design. Since all images produced, either at the hospital or at the primary care sites must necessarily be moved to the clinic for archiving, this star is designated as the "hub."

MCS, as is the case with Mayo Clinic Rochester and Mayo Clinic Jacksonville, shares a common radiology information management system (RIMS),¹ which had been in use at MCS since November 1995. The implementation of the PACS to RIMS interface at MCS leveraged the work that was accomplished at Mayo Clinic Rochester in their PACS implementation program,² which used the same product offering chosen at MCS. This RIMS implementation is noteworthy in that the communication between RIMS and PACS is directly between the database-stored procedures, providing a tight coupling of the functionality of PACS and RIMS. Messaging is both ways from RIMS to PACS and vice versa. A consequence of this approach is that the performance in image transfer and display necessarily includes transactions with RIMS, which as will be discussed, does not isolate completely the functionality or performance speed of the PACS product. Installed at MCS were a total of 22 workstations, using the proprietary direct fiber connections to the ISU. This system gives high performance image transfer (160 MB/s) enhanced further with 2:1 lossless compression. Soft-copy interpretations have been routinely performed since early 1998, with 13 workstations in radiology forming this star. Workstations are also provided in key clinical areas of the outpatient practice, including orthopedic surgery, urology, and pulmonology.

The term "star" is used here to describe the central dependency by each of the workstations

Fig 1. Multistar topology image management and communication at MCS. Fiber = 160 MB/s.

upon the ISU to which they are attached for the transfer of images. No local disk storage occurs, and the images are rapidly accessed and displayed as requested by the radiologists. While the image display time is specified by the manufacturer to be 3 seconds, we see sub-second performance for the majority of first image availability.

THUNDERBIRD PRIMARY CARE

Two rooms of x-ray and one ultrasound unit are located at Thunderbird Primary Care, which is staffed by radiology. The facility has a 64-GB ISU, with two direct fiber connected workstations. The workload at the facility is small (≈ 40 examinations per day) and the opportunity for workshare with the outpatient clinic was evident. Connecting the Thunderbird Primary Care to the main clinic is a T1-line dedicated for image transfer. The GEMs product offering includes a transfer gateway (TGW), a non-DICOM connectivity box that provided the solution for this need. No images are currently digitally produced at Thunderbird (except for ultrasound, which is not archived at the moment), so the transfer need exists in only one direction. In addition to the image transfer limitations imposed by 128 KB/s, workshare capability also implies the presence of a solution for workflow. Our short-term solution has been to remote print the RIMS worksheets at Thunderbird, keeping the paper RIMS worksheets from entering the clinic reading rooms, whenever examinations are electronically transferred to Thunderbird. Until the soft-copy worklist can control the routing and ownership of the examination to be interpreted, an administrative solution such as this has been necessary. It is possible for either the technologist to select a number of examinations to push to Thunderbird, or for the radiologists to pull images from the clinic to facilitate interpretation workflow. The first arrivals can be opened and read while the remainder of the examinations complete their transfer.

FOUNTAIN HILLS AND ARROWHEAD PRIMARY CARE FACILITIES

Two newly built facilities were each equipped with a Fuji AC-3 for their one room of x-ray. Images produced automatically are transferred to the Clinic for interpretation once the technologist enters the imaging plate into the reader. Connectivity is provided by the Fuji HI-C 654 over the US West Advanced Technologies (Boulder, CO)-

provided transparent local area network (LAN) service. Soft-copy review by the primary care physicians occurs and no film print capability exists. Fountain Hills has been online since 4Q1995, and Arrowhead has been active since 3Q1997. Note that the connectivity to the clinic places these remote sites on the clinic star.

MAYO CLINIC HOSPITAL STAR

Mayo Clinic Hospital has a central 256-GB ISU with four DICOM gateways providing interfacing to 12 modality devices, including a Philips Gyroscan, four Fuji AC-3s via 2 Analogic SD-100s, a Siemens angiography lab (Multistar TOP), a Siemens Sireskop TOP, a Philips Multidiagnost 4 angiographic laboratory, Siemens Somatom Plus 4, 1 ADAC gamma camera via Pegasys, two Liebel-Flarshiem Cystoscopic units, three OEC C-arms, and one Philips Thoravision, as well as several off-line review and processing stations. Examination volume is not clearly established due to the newness of the facility, but it is on the order of 10% of the outpatient volume. While every modality was specified during the purchasing process to be fully DICOM-compliant, in fact all modalities actually were proven to transfer to PACS. However, nuclear, CT, and radiographic/Auoroscopic (R/F) await incorporation of the accession number at the modality operators console. With this exception, all DICOM-required fields were present and all modalities are available for soft-copy interpretation.

Direct fiber connection exists from the 13 workstations to the ISU. Of the 13 workstations, four are located in Radiology, with the Emergency Department, Surgery, Intensive Care Unit, and the patient floors having the remainder. All radiology interpretations are soft copy; however, film continues to be printed. The new hospital introduced a large number of information systems for the medical staff to incorporate into their practice, and it was felt that the continuance of film availability would be helpful during the first months of operation. Film printing is scheduled to cease in the hospital, except for surgery needs by fourth quarter, 1999.

DESIGN OBJECTIVES IN THE MULTISTAR ENVIRONMENT

The high-speed star topology for the clinic, Thunderbird Primary Care facility, and hospital provides exceptional performance in the display of

images at the workstation at their respective locations. Since radiology staff are roughly located in number at locations in proportion to the number of examinations produced locally, this star environment serves the majority of the practice exceptionally well. Also of note is that this approach increases the on-line storage capability from the conventional implementation of this architecture. A total of 576 GB with 2:1 compression provides in excess of a full TB of online storage with high speed image data access. Three ISUs also give a degree of reliability, since failure of one does not result in a loss of enterprise service. This added reliability has in fact proven itself in actual clinical experience. The significant limitation of this design is the complex management of the three databases, a nontrivial task. A centralized database having a full view of all images, but with the ability to provide a degree of fault tolerance, as well as improved performance that occurs with the high-speed "star," is a compelling topology.

It was recognized that the design must provide an integrated and fully seamless environment for the interpretation of examinations and provision of radiology service. Staffing imbalances do occur and the areas of radiology specialty must be available throughout the care enterprise. Basically, the need is to eliminate distance as a consideration in the interpretation of examinations. A seamless environment was defined as the ability to work from a common worklist when so desired, to provide workshare among the staff. It includes the ability, as is the current practice, to monitor in real time as needed examinations such as CT and MRI, which may be from remote locations. And, of course, the transfer time of an examination or the performance of the workstation must be such that it is indistinguishable that examinations are being fetched or performed at the remote location.

This environment also presupposes that all the requisite functionality of the local star is reliably incorporated into the multistar environment. Proven functionality such as RIMS interface, worklist generation, examination archive, prefetch, examination modifications (ie, image deletion), and auto display protocols, to mention just a few, would have to work across multiple locations as well as they do in the local environment. Due to the complexity of addressing these functional provisions of a multiple star environment, the implementation process gave priority to functionality, with

the expectation that improvements in image transfer speed and workstation performance would progressively improve.

SOLUTION PATHWAY

One of the important technologies providing the connectivity among the star locations is the image transfer server (ITS), which replaced the somewhat slower DICOM-based TGW. The ITS provides the interface between the proprietary fiber connection at the STS (the ISU is now called the short-term storage or STS), for the three locations to the wide area network (Fig 1). The ITS serves the single database environment by processing transfer requests from STS to STS, thereby causing the local worklist to be updated with the new examination location. Each of the ITS units are connected to the STS using fast ethernet (100 MB/s). Transfers between ITS are performed at the commercial off-the-shelf (COTS) standard for the protocol, with 3:1 lossless compression applied for further performance. Regardless, an image in this environment that is not physically present does not have the speed to the end user if it does not reside locally. However, as discussed earlier, functional quality and reliability were of priority as compared with speed of display. To address functionality in the multistar environment, an implementation program involving two phases evolved.

The first phase leveraged the current star performance for each of the locations, but with image transfer for workshare to be under administrative direction. This phase, operational in the fourth quarter of 1998 essentially allowed the continuance of the multiple databases to exist at each of the three locations. RIMS, since it was already in place at all locations provided the connectivity to control the examination process at each of the five sites. The image database software (image management system [IMS]) was modified to transfer images automatically upon verification by the technologists to the hub star (clinic), while prefetching of historical exams that had been "washed" from the STS is to the clinic STS. This allowed radiology staff at the clinic to rapidly review images that had actually been performed at the hospital. Routine image review at the hospital or at Thunderbird Primary Care practice of examinations performed at the clinic is not automated, and requires establishing a session with the clinic database, followed by a "get exam" request; alternatively, a "push" can

effect image transfer. Given the volume, staffing, and patient mix at the hospital, this limitation was accommodated. The STS at the hospital provides a substantial online repository of hospital patients, which, to a large extent, eliminates the need for exams to be "pushed" or "pulled" ad hoc from the clinic or archive. With this installed configuration, no changes occur with the Thunderbird star function.

The second phase created an enterprise view of all the exams at MCS since it utilizes a single database to manage the data at the three STSs. The central database software (GEMS version 8.0) was delivered in November 1998 for testing prior to implementation into clinical use. This software runs independently of the STS on its own platform. Mayo installed the high-performance version, which adds speed and capacity. The central database environment requires collapsing the two databases that had been installed at the hospital and at the Thunderbird facility. By providing an enterprise view to the users, worklists are created that can see all of the examinations, regardless of location. However, the location of an examination, especially one which has comparison examinations, is currently affected with this implementation. A new function termed "patient get" must query the database to fetch all examinations called for by the auto display protocols set up during configuration. Since the database keeps track of the location of all examinations at each of the STS, and since the examination can theoretically be located at any STS, the "patient get" command is necessary to reliably utilize the auto display protocols. The retention algorithms for the STS remain independent of the central database with this implementation so that the local needs of the star can be the determinant in keeping exams online. Testing of the central database implementation continues at the time of this writing, while the Test Procedures and Results given below report on functionality and performance in the multiple star environment.

TEST PROCEDURES

Testing of the individual locations had been previously performed as part of the acceptance testing for the legacy system. Additional functional testing in the multiple star, multiple data base environment involved numerous measurements of the pass-fail variety using test scripts, which included: (1) that each modality transferred exams to

their local STS, and to the long-term archive; (2) that each modality was able to have their examination type dearchived to the hub (clinic); (3) that each location was able to uniquely configure loading of the STS; (4) that from each location, each modality could be remotely retrieved from the other STS; and (5) that from each location, the auto display protocols performed consistently.

Separate testing was performed on the messaging which is needed between RIMS and PACS, since two-way communication affects the status of an exam during ordering, arrival, completion, etc. Presented in Table 1 is an example of the testing performed using dummy patient records created for this testing. Three different patients (identified as A, B, and C in the table) each of whom have had three different examination types (identified as 1, 2, and 3) of CR, CT, and MRI where ordered, arrived, replaced, etc, from all locations (recall that the messaging for Fountain Hills and Arrowhead Primary Care sites are spokes to the clinic star). Verification of the examination by the technologist changes the examination status to allow the examination to appear on the "unread worklist," while Finalization by the radiologist allows the examination to be removed from the "unread worklist." Each of these examination status indicators must reliably function in the multiple database environment at each location.

The test procedures for performance were directed to those performance issues related to the multiple star environment. This basically consisted

Table 1. Performance of Image Transfer Over ATM OC-3 Between the Clinic and the Hospital

	CR	CT	MR
No. of exams	1	1	1
No. of images per exam	2	50	144
Image size	8.5 MB	529 KB	132 KB
Total exam size	17 MB	26.45 MB	19 MB
No. of associations	1	1	1
Points of measurement	STS to STS	STS to STS	STS to STS
Specification (TGW)	13 s/exam 6.5 s/image	35 s/exam 0.7 s/image	58 s/exam 0.4 s/image
Specification (ITS)	4 s/exam 2.0 s/exam	17 s/exam 0.34 s/image	41 s/exam 0.28 s/image

NOTE. Time to actually display images depends upon worklist update, disc transfer and loading.

of selecting multiple (up to 20) examinations for each modality and fetching these over the wide area network to the hospital and Thunderbird, since the images automatically are transferred upon verification to the clinic, for examinations taken at the hospital. Measurements were made at the ITS that had requested the examination. Measurements were also made of the availability of examination at the workstation, but this involved additional timing considerations due to disk transfer, queuing, and updates to the database for worklist generation. For all measurements, an unloaded system was established consistent with the specifications agreed upon with the vendor for the performance of the PACS.

TEST RESULTS

Functional testing revealed several issues in the multiple database environment: (1) It was possible to have at the clinic an image that actually had been deleted from an examination that was taken at the hospital. Since the examination already had been transmitted to the clinic for archiving, the images were present in the examination folder at the clinic. Messaging between the databases at the hospital and the clinic did not communicate the deletion at the hospital. (2) It was also found that an examination that had been merged following completion also suffered the same limitation if transfer had occurred. (3) Thoravision examinations performed

at the hospital reliably were transferred to the clinic and were long-term archived. However, the prefetch algorithm for dearchiving the Thoravision examinations did not work. Functional testing results are given in Table 2 for CR, CT, and MRI examinations. Performance of the display capabilities from local STS to the workstation are not reported upon, since these have been previously published and are well documented.³

DISCUSSION OF RESULTS AND CONCLUSIONS

Items 1, 2, and 3 were quickly addressed and have not represented a limitation, since the corrections were applied. Retesting of these items were subsequently performed and revealed no continuing or known problems. Thoravision examinations performed at the hospital had a considerable "shelf life" on the hospital STS due to the smaller volumes at that location, and the software fix occurred far in advance of the likelihood of STS unloading a chest examination. Currently, all examinations are known to dearchive as needed.

All of the functional testing with RIMS messaging as listed in Table 2, with PACS passed, with no problems identified. The performance of image movement between the STS at the hospital and the clinic indicates that a very reasonable level of workshare can occur. Examinations can now be selected and transferred with little impact on the

Table 2. Functional Testing Criteria

Action	Modality	Hospital Test (3 locations)	Clinic Test	T-Bird Test	Arrowhead Test	Fountain Hills
Order exam	X	A ¹⁻³ B ¹⁻³ C ¹⁻³	X	X	X	X
Cancel exam	X		X	X	X	X
Arrive patient	X	A ¹	X	X		
Cancel/post arrive	X	B ¹	X	X		
Replace	X	C ¹ A ²	X	X		
Cancel replaced exam	X	C ¹	X	X		
Add images in PACS	X	A ¹⁻³ B ^{2&3} C ^{2&3}				
Add images to replaced exam in PACS	X	A ²				
Reject 1 image in PACS	X	A ¹⁻³ B ^{2&3} C ^{2&3}				
Complete all exams with images in PACS	X	A ¹				
Transcribe-preliminary	X	A ¹⁻³ B ^{2&3} C ^{2&3}				
Transcribe-finalize in PACS	X	C ^{2&3}				

overall speed of the interpretation environment. Speed of image transfer is important, since the ability to remotely review exams in progress is not realistic unless near real time reviewing can take place. Improvements in image transfer speed are needed to accomplish this.

Importantly, the central worklist implementation allows for improved workflow when examination interpretation workshare is desired. The key point is that any ad hoc examination selection by the radiologist from the centralized worklist must have

the messaging associated to indicate their interpretation is in progress. Radiologists wishing to "own" certain examinations, which are yet unread, need the ability to secure their worklist from remote staff wishing to workshare. The centralized worklist currently requires a "get patient" command for the auto display functions to work as configured. This step can be eliminated once the movement of examinations is improved. Dearchiving should occur to the STS most likely to have need of the examination.

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