Network & Storage Design

The archive and communication system requirements depend on acquisition and presentation requirements.

- **Acquisition:**
  - Where are the modalities located and how much data is generated?

- **Retrieval:**
  - Who will retrieve images, how often, and where are they located?
For each operational region, the procedure volume done by each modality was considered in relation to the professional radiology workgroup.

### HFHS Procedure/Workgroup Model

For each operational region, the procedure volume done by each modality was considered in relation to the professional radiology workgroup.

<table>
<thead>
<tr>
<th>Region</th>
<th>General</th>
<th>Chest</th>
<th>Skeletal</th>
<th>Breast</th>
<th>Nuclear Med.</th>
<th>Body CT - MRI</th>
<th>Neuro</th>
<th>Ultrasound</th>
<th>Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT</td>
<td>2167</td>
<td>na</td>
<td>19499</td>
<td>21665</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>MR</td>
<td>5744</td>
<td>na</td>
<td>5744</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>NM</td>
<td>na</td>
<td>na</td>
<td>12678</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>US</td>
<td>3547</td>
<td>na</td>
<td>31926</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Mamm</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Radiogr.</td>
<td>na</td>
<td>12741</td>
<td>na</td>
<td>100578</td>
<td>70469</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
</tr>
</tbody>
</table>

### Data storage per modality/workgroup

The exam data size was determined in relation to modality and workgroup in order to model network traffic and storage requirements based on procedure volume.

- Determined data size/study based on average acquisition parameters.
- Average number of images acquired/study/workgroup determined by audit.

<table>
<thead>
<tr>
<th>Modality</th>
<th>Image Size</th>
<th>Mbytes*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT - Neuro</td>
<td>0.529 MB</td>
<td>35 MB</td>
</tr>
<tr>
<td>CT - Skeletal</td>
<td>0.529 MB</td>
<td>200 MB</td>
</tr>
<tr>
<td>CT - Body</td>
<td>0.529 MB</td>
<td>70 MB</td>
</tr>
<tr>
<td>MR - Neuro</td>
<td>0.135 MB</td>
<td>120 MB</td>
</tr>
<tr>
<td>MR - Skeletal</td>
<td>0.135 MB</td>
<td>150 MB</td>
</tr>
<tr>
<td>MR - Body</td>
<td>0.135 MB</td>
<td>200 MB</td>
</tr>
<tr>
<td>US</td>
<td>0.6 MB</td>
<td>35 MB</td>
</tr>
<tr>
<td>Mamm</td>
<td>na</td>
<td>na</td>
</tr>
<tr>
<td>Radiogr.</td>
<td>10 MB</td>
<td>2 MB</td>
</tr>
</tbody>
</table>

### Study Acquisition time

For each modality, the time to deliver images to the archive depends on the study size and available bandwidth.

For example:

<table>
<thead>
<tr>
<th>Study</th>
<th>sec</th>
<th>MB</th>
<th>Mb/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeletal CT</td>
<td>300</td>
<td>42.3</td>
<td>1.4</td>
</tr>
<tr>
<td>General Radiology</td>
<td>300</td>
<td>20.0</td>
<td>0.7</td>
</tr>
<tr>
<td>Body MR</td>
<td>300</td>
<td>10.8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Note: 1 MB/sec of data requires ~ 10 Mb/sec channel speed.

### Communication channel requirement

For all modalities that share a channel, the required channel speed must be available the majority of the time for all devices.

For example:

<table>
<thead>
<tr>
<th>Study</th>
<th>devices/hr</th>
<th>Mb/s Peak</th>
<th>Mb/s Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeletal CT</td>
<td>4</td>
<td>2.0</td>
<td>0.9</td>
</tr>
<tr>
<td>General Radiology</td>
<td>6</td>
<td>4.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Body MR</td>
<td>2</td>
<td>1.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Network Mb/sec = 3 * Mb/s Minimum
This is the approximate peak to mean ratio.
HFHS network specifications

HFHS PACS Network

<table>
<thead>
<tr>
<th>Facility</th>
<th>Net</th>
<th>MB/s</th>
<th>Sec/CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Campus</td>
<td>LAN</td>
<td>7 - 9</td>
<td>.5</td>
</tr>
<tr>
<td>Fairlane</td>
<td>OC3</td>
<td>7 - 9</td>
<td>.5</td>
</tr>
<tr>
<td>W. Bloomfield</td>
<td>OC3</td>
<td>7 - 9</td>
<td>.5</td>
</tr>
<tr>
<td>Lakeside</td>
<td>OC3</td>
<td>7 - 9</td>
<td>.5</td>
</tr>
<tr>
<td>Sterling Hts</td>
<td>DS3</td>
<td>2.5 - 3.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Taylor*</td>
<td>2 T1</td>
<td>.25 - .35</td>
<td>13</td>
</tr>
<tr>
<td>Livonia*</td>
<td>2 T1</td>
<td>.30 - .35</td>
<td>12</td>
</tr>
<tr>
<td>Detroit NW*</td>
<td>2 T1</td>
<td>.20 - .24</td>
<td>18</td>
</tr>
</tbody>
</table>

*acquisition only

Network performance

The PACS network at HFHS delivers a single CR image in 5 seconds to Radiology reading stations.

HFHS PACS Network

- OC3 - 150 Mbps IP
- DS3 - 45 Mbps Voice, IPX
- DS3 - 45 Mbps PACS
- 2 T1 - 3 Mbps PACS

Gartner #1

Bandwidth will be more cost effective than computing:

- The number 1 technology prediction by Gartner is that network capacity will increase faster than computing, memory and storage capacity to produce a major shift in the relative cost of remote versus local computing.
- This is catalyzing a move toward more centralized network services, using grid computing models and thin clients.
Estimation of Storage Requirements

- Knowledge of procedure volume by modality and study type along with the corresponding study data size allows the storage requirements of an archive to be accurately estimated.

Because of the low cost of storage devices, redundant storage is practical for cache and for disaster recovery purposes.

Stentor iSyntax

Dicom processors convert modality data to compressed coefficients that are stored in cache units while migrating to the central archive.

Stentor iSyntax

Softcopy Image Presentation

- Display Type:
  What type of display should each user group be using?
  Pixel size and Field of View

- Calibration:
  How can similar grayscale be configured for all devices?
  Enterprise grayscale calibration
The retina of the human eye contains a network of rods and cones interconnected by neural cells. Particularly thin cones (2 µm) are densely packed in the central 50 microns of the fovea centralis. They provide high detail color response.

At 60 cm, 1 degree corresponds to a 1 cm field of view. This area is focused on a 288 micron region of the retina, the fovea centralis.

A variety of test patterns are used to assess visual acuity. Clinical measures are done typically with a Snellen eye chart. Much psychovisual research has been done using sinusoidally modulated test targets.

Contrast sensitivity is the inverse of contrast threshold. A. Contrast Sensitivity & spatial acuity
A. Pixel Size at Maximum Spatial Acuity

- The pixel size of a display system that matches the resolving power of the human eye depends on the observation distance.
- The visual spatial frequency limit and associated pixel size can be defined as that for which $C_s = 10\%$ of maximum.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Frequency (cycles/mm)</th>
<th>Pixel Size (mm/pixel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close inspection</td>
<td>5</td>
<td>0.100</td>
</tr>
<tr>
<td>(0.33 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal viewing</td>
<td>2.5</td>
<td>0.200</td>
</tr>
<tr>
<td>(0.66 m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consultation view</td>
<td>1.7</td>
<td>0.300</td>
</tr>
<tr>
<td>(1.00 m)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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B. Field of View

- 21 inch (diagonal) monitors with a field of 32 x 42 cm have provide an effective viewing field for digital radiographs at a normal distance (2/3 m).

C. Pixel array and Megapixels

- The pixel size needed for visualizing full detail and the field of view dictate the pixel array size and the total number of pixels.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Pixel Size (mm)</th>
<th>32 x 42 cm Array Size</th>
<th>MegaPixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Close (0.33 m)</td>
<td>0.100</td>
<td>3200 x 4200</td>
<td>13.4</td>
</tr>
<tr>
<td>Normal (0.66 m)</td>
<td>0.200</td>
<td>1600 x 2100</td>
<td>3.4</td>
</tr>
</tbody>
</table>

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D. Field of View

- Use of image zoom features is ergonomically better than leaning forward for close inspection.
- Split deck tables with a broad front deck usefully prohibit close inspection with 3 MP monitors.
During interpretation, all regions of the recorded radiograph should be viewed with a 1 -> 1 alignment of image pixel values to display pixels.

- Zoom levels of 1 -> 2 and 1-> 4 are needed to map detail at the detector pixel level to the region where visual contrast sensitivity is maximized.
- High zoom levels are of particular importance for direct DR detectors with extended MTF performance.

Minification of 2 -> 1 can also have value by increasing the frequency of diffuse structures and improving their contrast sensitivity. Such minification is commonly used for mammography and chest radiography.
HFHS Clinic stations

Clinical workstations
- Enterprise desktop replacement
- One month deployment
- 1550 single 1mp color lcd stations

HFHS Clinic stations

Clinical workstations
- 25 dual 1mp color lcd stations
- Surgery and selected Clinics
- 8 dual 1mp mono in ERs

Grayscale calibration for enterprise systems

- Calibration look-up tables were generated for a set of Dell 1905FP monitors and found to be similar.
- A single generic LUT was identified for installation in 1000 workstations deployed for ePACS use.

1786 Grayscale Palette

Each ePACS software has application for QC pattern display and DICOM/LINEAR LUT changing.
Performance/QA Monitoring

- **Image Quality:**
  - Are all images being acquired properly?
  - Are all images being displayed properly?
- **Network:**
  - Are all devices connected?
  - Are all images transmitted quickly?
- **RIS:**
  - Are HIS data packets being received?
  - Are all new studies reconciled?
  - Are all studies interpreted quickly?

Incorrect Processing

- The image processing parameters configured on CR/DR devices should be periodically audited to insure that they conform with departmental standard values.

**Grayscale Rendition:** Convert signal values to display values

**Exposure Recognition:** Adjust for high/low average exposure.

**Edge Restoration:** Sharpen edges while limiting noise.

**Noise Reduction:** Reduce noise and maintain sharpness.

**Contrast Enhancement:** Increase contrast for local detail.
1. Document all RIS-PACS Devices:
   - Effective operations require that key network and device information be known for all systems. (i.e. you can't monitor what you don't know).
   - Use of a simple device database allows easy access to parameters of interest.
   - The HFHS pacStats web site illustrates how devices can be listed by location, modality type, or manufacturer.

2. Check that all devices can be reached:
   - It is important to know that communication packets can be sent and received from all devices.
   - Network management terminology refers to a device as being 'reachable'
   - The pacStats application polls each device at timed intervals and posts the status (see the button icon on the left of the final device lists)
For debugging, a trace route can identify the switches used when communicating with a device.

The pacStats application supports a network discovery process that documents topology. Using this as a basis, abnormal network routing, which indicates problems in the network mesh, can be identified and an alert message sent.

For sending images to the archive, or for delivering images to workstations, the point to point transfer speed is important. Standard utility programs (ping) can measure the round trip speed with optional specification for a large packet. One way speed (modality -> archive or archive -> workstation) is more accurate. This requires specialized send/receive applications. DICOM services to support transfer speed monitoring would be of value.
Network management using SNMP

- SNMP is the Internet standard protocol developed to manage nodes on an IP network.
- SNMP enables network administrators to manage network performance, find and solve network problems, and plan for network growth.

However, SNMP does NOT provide point to point data transfer speed information.

http://www.snmp.org/

Network Management Software

- Numerous commercial and open source software packages are available for network monitoring. A Web site at Stanford (SLAC) contains an extensive list of tools with links to resource material.
  www.slac.stanford.edu/xorg/nmtf/nmtf-tools.html#public
- The available tools provide excellent methods for generic network monitoring, but do not address the specific needs involved with the monitoring and management of an enterprise system. This requires a more intimate knowledge of the system devices (actors) and the roles they play (transactions).

Basic #5 - Reading Stations

5. Monitor Display Workstation performance:
- Workstations should be monitored to insure proper operation of the computer, the display devices, and the RIS-PACS applications for viewing and reporting.
- SNMP provides a tool to periodically check memory utilization, cpu utilization, motherboard temperature, and medical LCD display parameters.
- Application specific data is often written to a log by the PACS display program. Extraction of data from logs can provide information regarding utilization.
- Migration of PACS utilization data directly to IHE defined SNMP agents is suggested.

Commercial PACS tools

Two commercial PACS monitoring tools are now being used at some medical centers:
- MagicWatch: A PACS/radionics information system (RIS) monitoring station from Siemens that uses HP Openview tools. Its use at the Cleveland Clinic was reported by Lannum (J. Digit Imaging. 2001 Jun;14(2 Suppl 1):17-21)
- PACSwatch: A PACS performance monitor developed originally at Mass General Hospital and previously sold by Agfa Medical Co. Agfa now considers this an end of life product and has introduced SMART for both monitoring and software maintenance.

These products function only with PACS components provided by the same manufacturer and do not provide the ability to monitor other core components and modalities of an electronic imaging operation.
Open Source PACS tools

Nagy previously reported on the use of open source tools for PACS monitoring (Radiographics 2003; 23:795-801). The studies retrieved per hour from a central archive is illustrated below along with the transmission speed.

Service contract tools

- Tools available to service providers often provide extensive information regarding the devices for which service support has been contracted.
- However, this information is generally not made available for use with PACS monitoring applications used by operations and management staff of the medical center.
- For new installations, access to performance monitoring tools should be negotiated with the service or purchase contract.