Connectivity, Security, and Performance of an NGI for Medical Imaging Applications

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Objectives

1. Establish a high-speed communication network that emulates an NGI between 3 remote sites
   - Capable of bandwidths exceeding 100 Mbps

Objectives

2. Establish security of data transmissions between connected sites
   - Public network
   - Use commercial software to encrypt data and establish a VPN

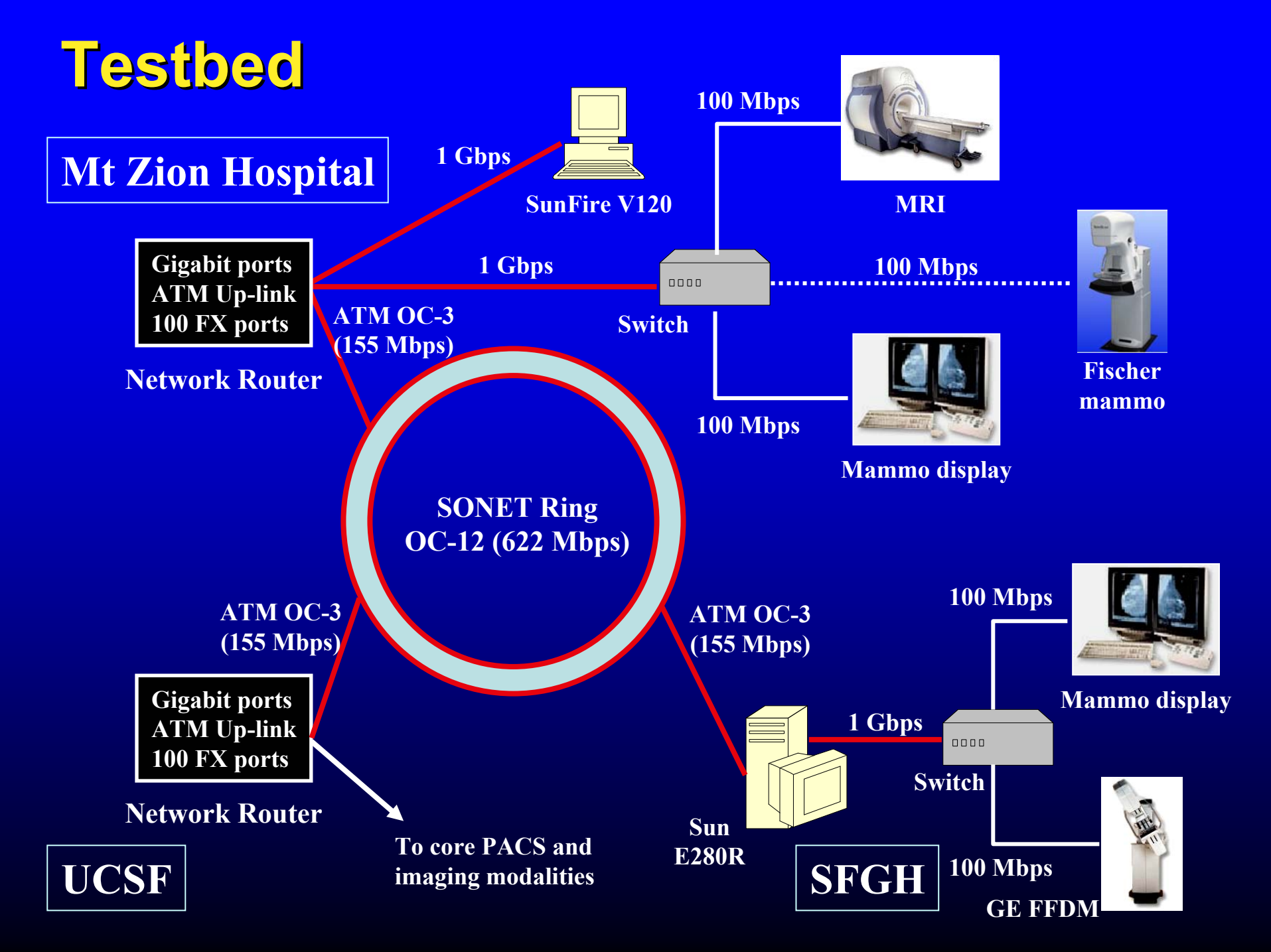
Objectives

3. Investigate the utility of data compression to speed transfer of large data sets
   - Mammographic data sets can exceed 400 MB/study

Objectives

4. Use the optimized testbed for breast imaging applications, allowing radiologists at different institutions to consult and confer in the interpretation of studies

Testbed


Mt Zion Hospital
1 Gbps
SunFire V120
100 Mbps
MRI
Gigabit ports
ATM Up-link
100 FX ports
Network Router
1 Gbps
ATM OC-3
(155 Mbps)
Switch
100 Mbps
Fischer
mammo
100 Mbps
Mammo display
SONET Ring
OC-12 (622 Mbps)
ATM OC-3
(155 Mbps)
ATM OC-3
(155 Mbps)
100 Mbps
Mammo display
Gigabit ports
ATM Up-link
100 FX ports
Network Router
1 Gbps
Switch
To core PACS and
imaging modalities
Sun
E280R
UCSF
SFGH
100 Mbps
GE FFDM

Testbed: Comments

- The FFDM unit at SFGH is located in a mobile van
  - Initial plan was to link to van with wireless link BUT SFGH has not established wireless standards. Rather, they choose to ban wireless altogether.
- SFGH has many layers: hospital, city

Breast Imaging: Digital Mammography

- Digital mammograms
  - 4 to 12 images per study
  - Fischer SenoScan: 46 Mbytes/image (≥ 200 Mbytes/study)
  - GE Senographe 2000D: 9 Mbytes/image (≥ 40 Mbytes/study)

Fischer SenoScan

1. Slot scanning system using fiber taper onto CCD
2. CsI phosphor
3. Coverage: 22 x 30 cm
4. 54 μm or 27 μm pixels
5. 4096 x 5624 matrix
6. 12 bit acquisition

GE Senographe 2000D

1. DR plate mounted on DMR unit
2. “Indirect” DR using CsI phosphor
3. Coverage: 19 x 23 cm
4. 100 μm pixels
5. 1914 x 2294 matrix
6. 14 bit acquisition
7. Installed base ≥ 400

Breast Imaging: MRI

- MRI
  - 256^2 to 512^2 matrix, 16 bit acquisition
  - 0.125 to 0.5 Mbytes/image
  - 4 to 20 series with 12 to 180 images/series (typically 600+ images per study)
  - 60-400 Mbytes per study

Test Data Sets

1. 10 Fischer mammographic images: 439 Mbytes
2. 17 GE mammographic images: 143 Mbytes
3. GE MRI breast study: 696 images (512^2), 354 Mbytes

Factors Effecting Transmission Time (Disk-to-Disk transfers)

1. Pixel volume
2. Individual image size
3. Transfer format
4. Bandwidth
5. Software overhead
   - file open/close operations

Benchmark Conditions

1. No contention on the network for fast ethernet
2. ATM and Gigabit ethernet used clinical network
   - Possibility for contention at peak clinical times
   - Measurements repeated 10 times - minimal difference in results (≤ 2% variation)
3. Single process (no multiple child processes)
   - Transfer times could be improved by concurrent transmissions

Benchmark Tests

Bandwidth	Transfer Mode	Disk-to-Disk					
		Fischer Mammo		GE Mammo		MRI	
		Elapsed time, s	Rate, MBps	Elapsed time, s	Rate, MBps	Elapsed time, s	Rate, MBps
Gigabit Ethernet (1000 Mbps)	TCP	19	23.13	7	20.44	41	8.62
	FTP	28	15.7	12	11.93	82	4.31
	DICOM	28	15.7	21	6.81	132	2.68
ATM (155 Mbps)	TCP	34	12.43	11	13.01	56	6.31
	FTP	43	10.22	17	8.42	83	4.26
	DICOM	54	8.14	22	6.51	144	2.45
Fast Ethernet (100 Mbps)	TCP	42	10.46	14	10.22	59	5.99
	FTP	52	8.45	24	5.96	88	4.02
	DICOM	53	8.29	25	5.72	154	2.3

Transfer Times

Bandwidth	Transfer Mode	Disk-to-Disk			
		Fischer mammo		MRI	
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Transfer Rates

Bandwidth	Transfer Mode	Fischer Mammo Rate, MBps	GE Mammo Rate, MBps	MRI Rate, MBps
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Effective Transfer Rate: TCP

	TCP Transfers, Mbytes/sec		
	Fast ethernet	ATM	Gigabit ethernet
Fischer Mammo	23.13	12.43	10.46
GE Mammo	20.44	13.01	10.22
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Effective Transfer Rate: DICOM

	DICOM Transfers, Mbytes/sec		
	Fast ethernet	ATM	Gigabit ethernet
Fischer Mammo	8.29	8.14	15.7
GE Mammo	5.72	6.51	6.81
MRI	2.3	2.45	2.68

Bandwidth Utilization: TCP

Type	Bandwidt Mbytes/s		Fischer Mammo	GE Mammo	MRI
Gigabit Ether	125	Rate, MBps	23.13	20.44	8.62
		% of max	18.5%	16.4%	6.9%
ATM	19.4	Rate, MBps	12.43	13.01	6.31
		% of max	10.4%	10.9%	5.3%
Fast Etherne	12.5	Rate, MBps	8.62	6.31	5.99
		% of max	68.96%	50.48%	47.92%

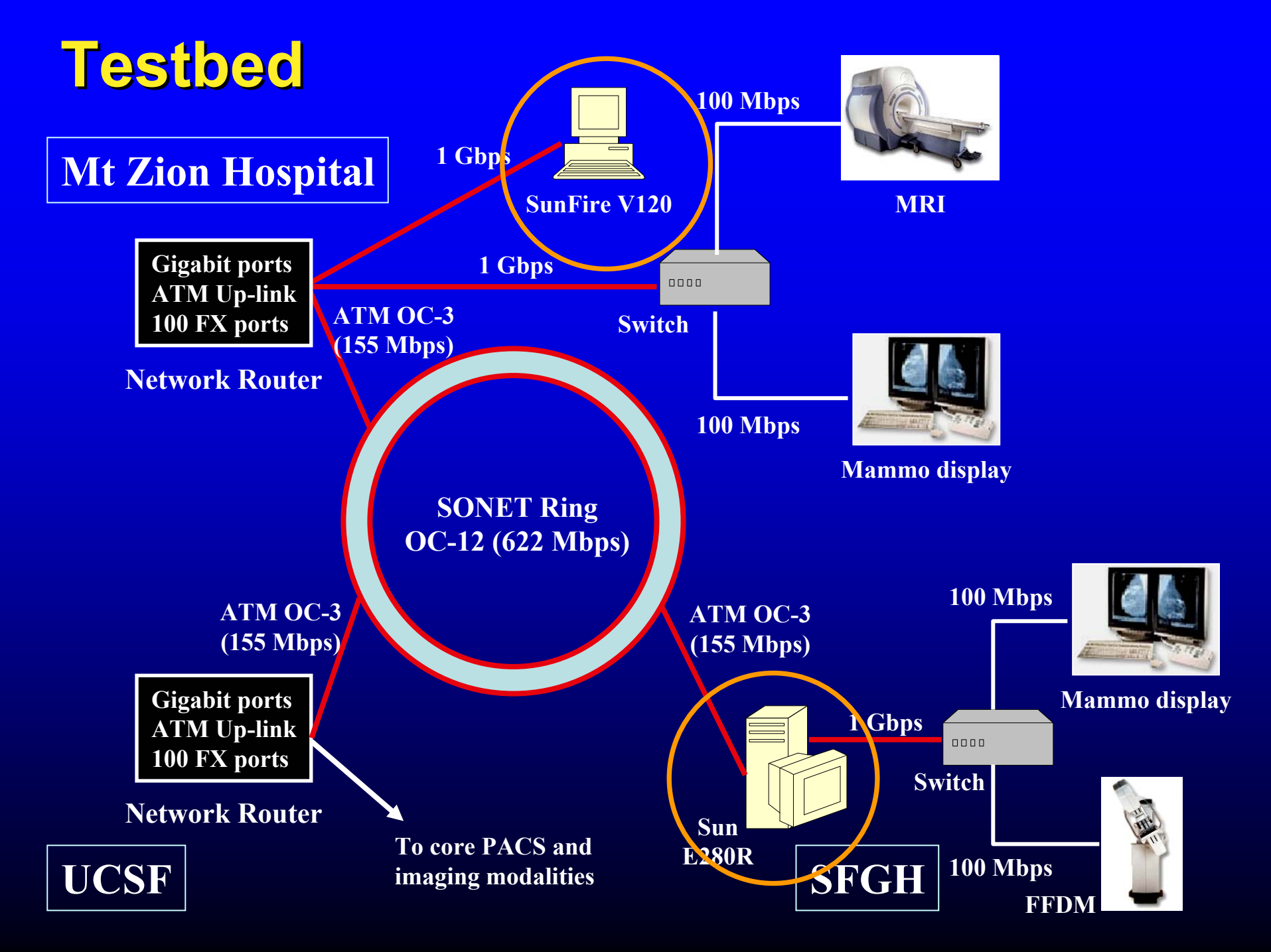
Bandwidth Utilization: DICOM

Type	Bandwidth Mbytes/s		Fischer Mammo	GE Mammo	MRI
Gigabit Ethern	125	Rate, MBps	15.7	6.81	2.68
		% of max	12.6%	5.4%	2.1%
ATM	19.4	Rate, MBps	8.14	6.51	2.45
		% of max	6.8%	5.5%	2.1%
Fast Ethernet	12.5	Rate, MBps	8.29	5.72	2.3
		% of max	66.32%	45.76%	18.40%

Security

- Establish encrypted tunnel between sites
  - Use off-the-shelf, industry standard software solution: Checkpoint
- Currently having difficulties implementing over the ATM connection

Testbed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Compression

- Widely used in current PACS both for storage and transmission of images
  - Lossless in primary reading applications
  - Often lossy for remote viewing applications (teleradiology, web access)

Compression Algorithms

- Need to run on Unix platform
- Pegasus Imaging Corporation
  - JPEG lossless
  - Wavelet lossy
- Compress only pixel data, not the header information

JPEG Lossless

			Time to		
	Ave comp ratio	Stan Dev	Comp	De-comp	Total
Fischer	4.6:1	0.98	4:26	1:52	6:23
GE	4.5:1	1.15	1:01	0:39	1:40
MR	10.2:1	0.51	3:22	2:15	5:37

Wavelet Compression

	Ave compression ratio	Stan Dev	Total added time, sec
MR (512^2)	30.15	3.0	4:52

Average compression/de-compression time per image

Image Type	Time, sec	Compression type
Fischer	38.3	JPEG
GE FFDM	5.9	JPEG
MR (512^2)	0.48	JPEG
MR (512^2)	0.42	Wavelet

Image Transfer Times

	Average transfer time/image (s			
	Gigabit Etherne		Fast Ethernet	
	TCP	DICOM	TCP	DICOM
Fischer	1.90	2.80	4.20	5.30
GE FFDM	0.41	1.24	0.82	1.47
MR	0.06	0.19	0.08	0.22

Conclusions to Date

1. DICOM protocol adds significant overhead
   - Complying with industry standard reduces efficiency
2. No benefit from compression currently demonstrated
   - Bandwidth not the limiting factor in transmission rate
   - Use of multiple child processes could effect results

Conclusions

3. Packing the images into a single file and use of TCP implementation would provide most effective use of bandwidth
   - Not industry standard transmission