

### 3.3 - ACTS Satellite Telemammography Network Experiments

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#### Abstract

The Satellite Networks and Architectures Branch of NASA's Glenn Research Center has developed and demonstrated several advanced satellite communications technologies through the Advanced Communications Technology Satellite (ACTS) program. One of these technologies is the implementation of a Satellite Telemammography Network (STN) encompassing NASA Glenn, the Cleveland Clinic Foundation, the University of Virginia, and the Ashtabula County Medical Center.

This paper will present a look at the STN from its beginnings to the impact it may have on future telemedicine applications. Results obtained using the experimental ACTS satellite demonstrate the feasibility of Satellite Telemammography. These results have improved teleradiology processes and mammography image manipulation, and enabled advances in remote screening methodologies. Future implementation of satellite telemammography using next generation commercial satellite networks will be explored.

In addition, the technical aspects of the project will be discussed; in particular how the project has evolved from using NASA developed hardware and software to commercial off the shelf (COTS) products. Development of asymmetrical link technologies was an outcome of this work. Improvements in the display of digital mammographic images, better understanding of end-to-end system requirements, and advances in radiological image compression were achieved as a result of the research.

Finally, rigorous clinical medical studies are required for new technologies such as digital satellite telemammography to gain acceptance in the medical establishment. These experiments produced data that were useful in two key medical studies that addressed the diagnostic accuracy of compressed satellite transmitted digital mammography images. The results of these studies will also be discussed.

#### Introduction

Radiology and more specifically, mammography, require the services of trained experts or radiologists. In order to support these specialists, a reasonably large patient base is required. Therefore, most specialists are located in large medical institutions. To add to this, the Food and Drug Administration (FDA) requires that radiologists perform a minimum number of readings annually to remain certified. In fact, every site performing mammography in the United States must now be accredited by a nationally based accreditation program or by a state agency<sup>1</sup>. As a result, a large amount of diagnostic images are either shipped to a larger medical facility for review or are held for review by a roaming radiologist.

Teleradiology, the electronic transmission of digitized images, addresses the issues stated above. Radiologists would be certain to maintain their quota by reading additional images sent electronically; electronic transmission eliminates the need for the traveling radiologist. A significant benefit is the availability of improved healthcare to remote, rural and underserved areas where the population is insufficient to support medical specialists.

Breast cancer is the leading cause of death for women from 35 to 50 years of age in the United States<sup>2</sup>. Each year sees an increase in the number of women who enter the age range for which a mammography screening is

recommended. This, coupled with the millions of women who live great distances from mammography interpretation centers, makes telemammography a practical and viable option, and of great importance to study within satellite telemedicine. Also, telemammography is the most challenging subset of teleradiology due to the very high image resolution required, resulting in very large data files to be transmitted. Hence, techniques developed in this study can be easily applied to the less challenging types of teleradiology.

To achieve the needed advances in satellite telemammography, a simple project goal was established: To develop and demonstrate techniques allowing the transmission of a complete set of mammography images for a typical breast cancer screening (4 images) over a basic DS1 rate (1.544 Mbps) satellite link in one minute or less.

### **Approach**

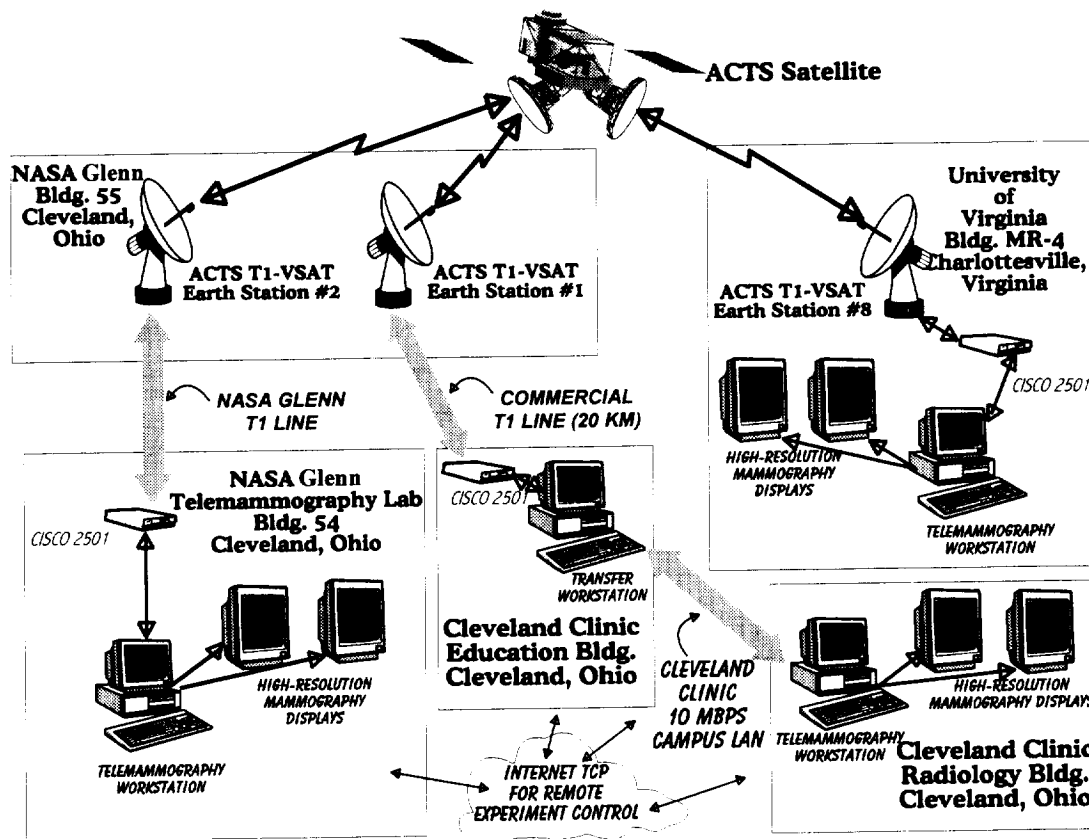
The University of Virginia was in the forefront of teleradiology in the early 1990s. At that time, however, much of the telecommunications was performed over Plain Old Telephone Service (POTS) with transmission rates limited to 9.6kbps, requiring hours for the transmission of a mammography image set.

The mid-90s brought digital communications at DS1 to a more affordable level. That decade also produced a new generation of satellites and communication technologies. The NASA Advanced Communication Technology Satellite (ACTS) was the first to incorporate this digital technology on board the spacecraft<sup>3</sup>. In particular, it demonstrated data rates up to 622Mbps by taking advantage of the 30/20GHz Ka Frequency Band. The higher frequency band also provided for savings in another area, physical space. Essentially, the Ka-band antenna can be one-half the size of a Ku-band antenna and obtain the same antenna gain, enabling the placement of small, inexpensive satellite earth stations at small remote clinics and on mobile medical vehicles.

The Internet was in its infancy in the mid-90s. Routing and switching equipment was costly and in very limited deployment. Therefore, the first phase of the Satellite Telemammography Network (STN) experiments used "routers" that were developed in-house by the Satellite Networks and Architectures Branch. These black boxes acted as a data buffer between the high-speed serial interfaces of the UNIX workstations and the T1 cards of the ACTS Earth Stations. Application specific software was developed to control these black boxes and ultimately transmit and receive the mammography images. This allowed seamless and continuous data flow, although without error detection/correction.

As the Internet evolved, routers became more readily and economically available as commercial off the shelf (COTS) products. The black boxes were replaced with Cisco 2501 routers in Phase II of the STN. The NASA-developed application specific software was replaced by a Transmission Control Protocol/Internet Protocol (TCP/IP) file transfer application, FTP (File Transfer Protocol). This allows interoperability of the satellite link with terrestrial networks, including Internet based networks and medical campus local area networks (sometimes known as Picture Archiving and Communications Systems, or PACS) which operate using TCP/IP protocols. The Phase II experimental setup is illustrated in Figure 1.

Throughout both phases of STN, major accomplishments were achieved. Phase I saw the simultaneous transmission via ACTS of over 5000 digitized mammograms to both the University of Virginia and the Cleveland Clinic Foundation, all of which were received free of data errors. Phase II was highlighted by the first ever real-time compression and transmission via ACTS of a four-view mammography case, including real-time interpretation by a Cleveland Clinic radiologist, and the subsequent diagnosis relayed back to the sending station.



**Figure 1. PHASE II CONFIGURATION OF THE SATELLITE TELEMAMMOGRAPHY NETWORK EXPERIMENT**

### Role of Telemedicine

This highlight strengthened the commitment of the medical community to expand the use of telemedicine. With the proliferation of major hospitals building and purchasing remote medical locations, the need to centralize certain services is obvious. Without centralization, the specialized professional would always be mobile, traveling to and from several locations. Not only are the services of these specialists lost while they are in transit, the medical institution typically compensates for the travel expenses. Through telemedicine the time of these specialists can be better utilized. In fact, some larger hospitals are now selling radiology services to smaller medical establishments through teleradiology.

In sparsely populated areas of the country or world, having a roaming specialist is impractical. Satellite-based telemedicine enables the provision of specialized services with easily installed connectivity where the terrestrial infrastructure is inadequate or non-existent.

However, the benefit of telemedicine is limited by the ability to quickly move large amounts of data. If the time to transmit and receive the data is greater than the time to travel to the remote location and perform the procedure, and results in high telecommunications costs, there is no advantage. Therefore, it is imperative that transmission times for various types of diagnostic imaging over various data links be examined. Table 1 outlines this information. From the table, it can be seen that medical imagery is data intensive. Transmitting any of these types of image modalities over a 56kbps modem is impractical. Even at DS1 data rates, some of the transmission times become excessive.

## Image Compression

Image compression is an approach to overcome this obstacle. With a STN project goal to transmit a case (4 images) in less than one minute at DS1, compression ratios between 4:1 and 20:1 were necessary. Much has been written in the past decade about various forms of compression. One of the more recent publications illustrates the advantages of using a wavelet compression for digitized mammography images<sup>4</sup>. Therefore, a commercially available wavelet compression package, AccuPress for Radiology (Aware, Inc., Bedford, Massachusetts) was chosen for testing in this project to achieve faster telemammography transmission times. The impact of image compression on diagnostic accuracy is discussed below.

**Table 1. TYPICAL FILE SIZE AND TRANSMISSION TIMES FOR DIAGNOSTIC IMAGING**

Image Type	Images per case/study	Total data required (Mbytes)	Time to transmit at 56 kbps, mins.	Time to transmit at DS1, mins.	Compression ratio required for <1 min. to transmit at DS1
Plain film x-ray	2 to 6	8 to 84	19 to 200	0.7 to 7.3	8:1
CT, MR	20 to 300	5 to 150	12 to 357	0.4 to 12.9	16:1
Ultrasound	300 frames	40	95	3.5	4:1
Mammography digitized film, 100 microns	4	24	57	2.1	4:1
Mammography digitized film, 50 microns	4	96	228	8.3	12:1
Mammography direct digital	4	192	457	16.6	20:1

## Compression Studies

Before the medical community will accept compression of mammographic images, clinical evaluations comparing compressed images to standard film are needed. One of the successful medical studies performed by the Cleveland Clinic Foundation (CCF) as a part of this project is described in a paper entitled "Clinical Evaluation of Wavelet-Compressed Digitized Film Mammography<sup>5</sup>." In this study, sixty sets of mammograms were digitized at a spatial resolution of 100  $\mu$ m. The images were compressed at 8:1 using a wavelet algorithm. Several mammographers reviewed the images in comparison with the original films in a controlled study. The study revealed that the mammographers' mean diagnostic accuracy using compressed images and films was 0.832 and 0.860, respectively. In other words, the ability of a mammographer to obtain the correct clinical result using compressed images and films were similar.

The success of the CCF Study on compressed images versus film, led to a study by the Ohio State University (OSU) to investigate the optimum wavelets for application to mammography. This work is still in progress. This study is examining orthogonal wavelets from Haar, Daubechies, Coffman, and Belykin as well as several biorthogonal wavelets. The results from this work are to be completed shortly, to be followed by a clinical evaluation by the CCF.

An additional study<sup>6</sup> performed at the NASA Glenn Research Center showed that if the wavelet is tuned specifically for mammography, greater compression ratios are possible. In this effort it was found that by using a biorthogonal wavelet as opposed to the Daubechies order 3 wavelet used in the AccuPress software, a compression ratio of 34:1 was possible. This has not yet been clinically evaluated.

## Asymmetric Links

In addition to compression, another area of interest to telemedicine is in asymmetric links. While data flow through the satellite link transmitting images may be quite high, the return data link may consist of only requests for images, data acknowledgements, and return of diagnoses, resulting in a highly asymmetric link. This problem can be addressed by a technique known as Unidirectional Link Routing (UDLR). The NASA Glenn

Research Center in cooperation with Cisco Systems has been experimenting with this type of network architecture. Cisco Systems has modified some of the layer 2 and layer 3 code in its router Internetworking Operating System (IOS) software. UDLR provides a method for receiving data over a simplex high bandwidth satellite link and returning the data over a terrestrial (and possibly a lower bandwidth) network. This technology has been used successfully in the STN to distribute mammograms to several locations simultaneously.

### **Impact of Project**

The STN project has produced results that have significantly improved satellite teleradiology processes. The demonstration of most of the end-to-end satellite telemammography process (including image compression, satellite transmission and reception, decompression, image display and evaluation, and return of diagnostic result) performed within five minutes validates the utility of satellite-based teleradiology. Adding the step of image digitization at the front end of this process will be attempted before the completion of the ACTS Experiments Program. The first step of the process, the initial image capture, will not be attempted due to the logistic difficulties in having real patients participate. However, it is a physically disconnected step that can be added to the process without difficulty.

The teleradiology process developed and demonstrated by STN can also be adapted to the new direct digital imaging equipment which is being introduced. The direct digital image capture will eliminate the steps of film developing and digitizing and make the satellite teleradiology process faster and simpler.

The Cleveland Clinic Foundation (CCF) has begun shifting its radiology processes from film-based to all digital image-based. CCF is also actively marketing radiology services to other medical establishments, emphasizing the availability of its world class diagnostic radiologists in an easy and cost-effective way through teleradiology. These initiatives result in part from the successful technology developments and demonstrations of the STN.

The development and demonstration of asymmetrical link technology over satellite links was a significant outcome of the STN experiments. Use of asymmetrical links will lower the overall cost of operating satellite-based telemedicine links by allowing the minimal use of satellite resources, resulting in minimum access charges. STN has shown that asymmetrical satellite links can be integrated into common Internet and PACS networks using TCP/IP through standard commercial routing equipment. This integration demonstrates the seamless interoperability potential of satellite links within digital telemedicine networks.

### **Next Generation Satellite Systems**

In the next few years, several regional and global satellite networks plan to be in operation (see Table 2). Conservative estimates suggest that nearly 500 broadband satellites will be operational in the next 10 years<sup>7</sup>. Many of these proposed systems encompass the technologies of ACTS. Some of the technologies that are obvious spin-offs from ACTS are the use of multiple spot beams, on board processing, and the use of the Ka frequency band. Most of the proposed systems plan to offer services at DS1 or fractional DS1 rates. The STN experiment has shown that these types of systems will be adequate for effective satellite telemammography and teleradiology.

As the number of satellites in service increase in the coming years, costs for satellite services will be driven down. Although it is probably too early to predict actual costs, various publications have projected costs of earth stations to be under \$2000 and DS1 service to be under \$2 per minute. This compares favorably with a dedicated terrestrial T1 line and can actually be more cost effective when considering that satellite services only charge for time used. The STN experiment shows that costs of electronic transmission of radiology images over satellite will be lower than courier-based transportation of radiology films, which is in widespread use today.

**Table 2. PROPOSED SATELLITE CONSTELLATIONS**

System	Proposer	Orbit	No. of Satellites, Coverage	No. of Antenna Beams	On-board switching/processing	Service Data Rates
Astrolink	Lockheed-Martin	GEO	9, Global	96	Yes	.25DS1
Ka-Star	Ka-Star Communications	GEO	1, Regional	52	Yes	.25DS1 to DS1
OrbLink	Orbital Sciences Corp.	MEO	7, Global	100	Yes	DS1 to DS3
SkyBridge	Alcatel	LEO	64, Global	45	N/a	E1
Spaceway	Hughes Communications	GEO	20, Global	24	Yes	DS1 to DS3
Teledesic	Teledesic Corp.	LEO	288, Global	64	Yes	DS1 to E1
V-Stream	PanAmSat	GEO	2, Regional	12	Yes	56 Kbps to DS3
WEST	Matra Marconi	GEO/MEO	11, Global	N/a	N/a	STS-3

Notes: DS1 is 1.544 Mbps; DS3 is 44.736Mbps; E1 is 2.048 Mbps; STS-3 is 155.520 Mbps; N/a is not presently publicly available.

### Satellites and Telemedicine

In the early 90's there was concern about the performance of TCP/IP over satellite links. There was much discussion about the latency of the satellite link and the effect this would have on TCP/IP. As it turned out, there were many reasons for this misconception – out of date implementations, improperly configured TCPs, and poor testing techniques<sup>8</sup>. A simple upgrade to a newer implementation can improve the data rate significantly. However, the STN has demonstrated that even with current technology the performance of TCP/IP over satellite is adequate for teleradiology.

The integration of satellite-based teleradiology with currently available PACS and other telemedicine and medical information networks is beyond the scope of the STN project. But based on the technical demonstration of TCP/IP based interconnectivity of satellite links, this integration should be relatively easy to accomplish. The end-to-end teleradiology process, the majority of which has been demonstrated during the STN project, will be an easy to use process once fully commercially developed. Assuming small, inexpensive and easily installed earth stations providing DS1 service through the new generation of communications satellites, connecting remote medical facilities to large urban medical centers for teleradiology services will be easily realizable.

However, of particular interest to the medical community is the addition of the Digital Imaging and Communications in Medicine (DICOM 3.0) standard to satellite communication links. Since data transmission using DICOM depends upon the TCP/IP protocol, problems encountered by TCP/IP and satellite links will affect DICOM performance. This is of particular concern in cases where DICOM database queries require multiple question and answer transmissions between the database and the requester. Hence, the performance of DICOM over satellite must be examined before complete integration of a hybrid network with a medical LAN is considered complete.

### Growth of Telemedicine

There is little doubt that telemedicine is a growing field and that satellite-based telemedicine is in its infancy. The STN has brought to the forefront many of these technologies to the medical community. This was achieved through studies published in medical journals and through general articles written in medical oriented magazines<sup>9</sup>. It was probably never more evident than in the many conversations that were a part of the STN exhibit at the Radiological Society of North America's (RSNA) annual conferences in 1997 and 1998. It was there that the project presented an awareness of satellite technology to thousands from across the globe; it was there that numerous parties expressed a genuine interest in satellite-based telemedicine.

The awareness of the role satellites must play in telemedicine is apparent by the inquiries the STN project has received from outside sources. The STN project has interfaced with personnel from abroad, in particular,

Telespazio in their efforts to provide telemedicine in Italy. STN personnel have also participated in radio interviews and television broadcasts have aired on the subject<sup>10</sup>.

### **Importance of ACTS**

The ACTS satellite represents the first of a new generation of commercial communications satellites and satellite services. As such, it was the ideal and necessary platform for the STN experiments, which have brought satellite teleradiology technologies and methodologies in line with the next satellite generation. In particular, ACTS provided a demonstration platform for high-gain spot beams enabling high-quality DS1 rate satellite links through very small earth stations. These qualities, enhanced through the use of Ka-band frequencies and on-board processing for improved link error performance, were essential to the development and demonstration of satellite-based teleradiology.

### **Summary**

The Satellite Telemammography Network Experiment has proved the feasibility of satellite-based teleradiology and telemammography through experiments performed with NASA's Advanced Communications Technology Satellite. The availability of high quality specialized medical expertise to nearly every remote location, nationally and globally, and the potential to reduce costs for radiological services, can be achieved with the deployment of the next generation of commercial communications satellites and the commercial offering of integrated telemedicine systems.

The STN has achieved significant advances in satellite-based teleradiology and telemammography, including: improved teleradiology processes; application of image compression to medical imaging resulting in faster transmission and lower costs; use of TCP/IP protocols in satellite-based teleradiology, enabling integration of satellite-based telemedicine with TCP/IP-based Internet and medical campus LANs; and demonstration of asymmetrical satellite teleradiology links using commercial network routers, allowing more efficient and lower cost connectivity.

### **Acknowledgements**

The authors gratefully acknowledge participation, support, and valuable expertise provided by the ACTS staff, and in particular Mr. Terry Bell of COMSAT; Dr. Kimerly Powell, Dr. Bill Chilcote, and Mr. Stefan Ganobcik of the Cleveland Clinic Foundation; and Dr. Samuel J. Dwyer III of the University of Virginia.

In addition, over the years several others have contributed their knowledge and time to the STN Project. They are Paul G. Mallasch, Quang Tran, Diepchi T. Tran, Gerald J. Chomos, and Duc H. Ngo of the NASA Glenn Research Center, Communications Technology Division. The authors gratefully acknowledge their dedicated efforts.

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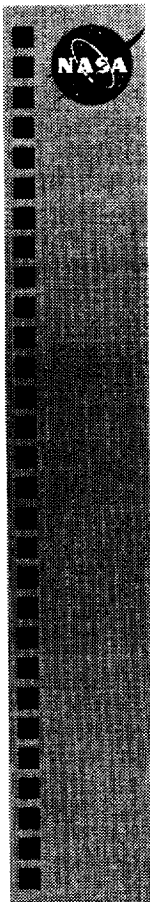
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Sixth Ka-Band Utilization Conference/ACTS Conference 2000, May 31 - June 2, 2000, Cleveland, Ohio



### Outline

- Introduction
- Satellite Telemammography Network (STN)
- Main Accomplishments
- Other Highlights of STN Project
- Impact on Telemedicine
- Importance of ACTS
- Future of Satellite Telemedicine
- Summary

# Introduction

- Breast cancer
  - ◆ leading cause of death in women age 35 - 50
  - ◆ second leading cause of death in all women
- Mammography screening
  - ◆ increases survival rates
  - ◆ need for certified experts for interpretation
  - ◆ needed for more than 60 million Americans
- X-ray film
  - ◆ shipping is costly in time and money
  - ◆ digitization is advancing rapidly
  - ◆ will be replaced by totally digital solutions soon

# Introduction (cont.)

- Teleradiology
  - ◆ can address problems with film
  - ◆ using satellite communications, can reach remote and mobile sites
- Telemammography
  - ◆ most difficult and data extensive modality
  - ◆ can serve millions living in remote locations
  - ◆ subject of this research

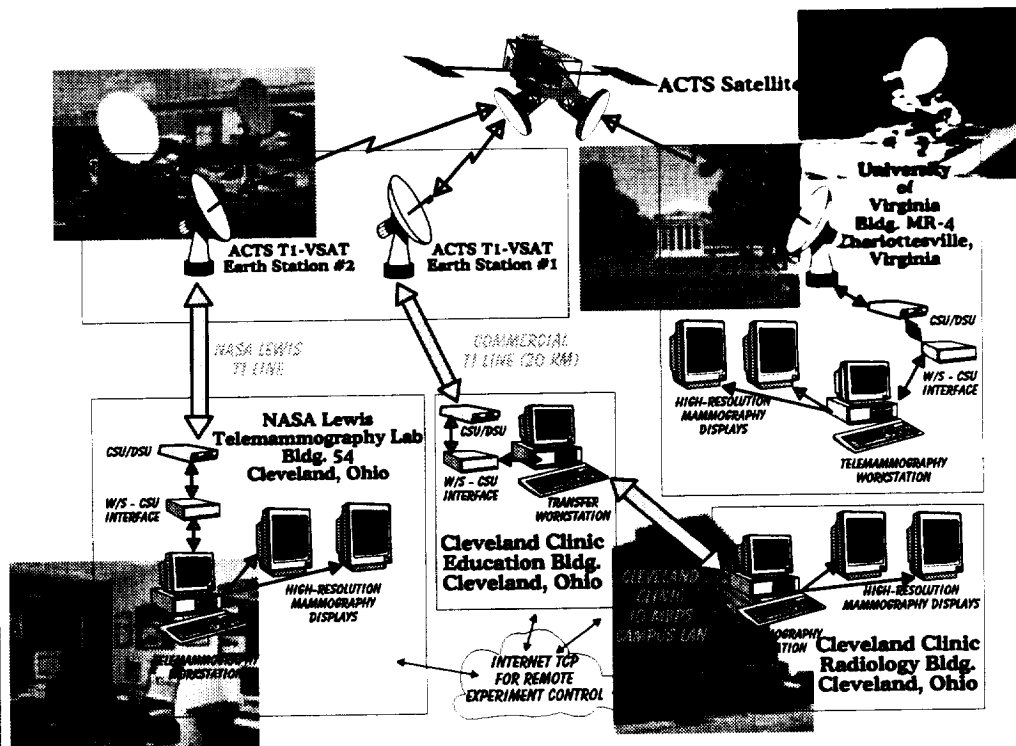


# STN Experiment Origin

- Dr. Samuel Dwyer, University of Virginia
  - ◆ first recognized need for telemammography
  - ◆ approached NASA Glenn for networking and communications help
- NASA Glenn, the University of Virginia, the Cleveland Clinic Foundation, and the Ashtabula County Medical Center
  - ◆ joint research project to investigate key aspects of satellite-based telemammography
- Backbone was the STN, based on ACTS



# Satellite Telemammography Network



# STN Experiment: Accomplishments

- Application of standard transmission protocols
- Transmission of over 5000 digitized mammography images through ACTS - all error-free
- First ever real-time telemammography session - compression, transmission, interpretation, and diagnosis
- Complete evaluation of end to end process - image capture, scanning, (de)compression, transmission/reception, viewing, and diagnosis

## Highlights: Image Compression

- *Lossless* compression can achieve about 3:1 ratio
- To meet project goal to transmit a case in under one minute, *lossy* compression was required

Image Type	Images per case	Total data required (Mbytes)	Time to transmit at 56 kbps, mins.	Time to transmit at DS1, mins.	Compression ratio required for <1 min. to transmit at DS1
Mammography digitized film, 100 microns	4	24	57	2.1	4:1
Mammography digitized film, 50 microns	4	96	228	8.3	12:1
Mammography direct digital	4	192	457	16.6	20:1



**ORIGINAL**



**COMPRESSED  
80:1**



## Highlights: Clinical Studies

- Evaluation of Wavelet-Compressed Digitized Film Mammography
  - ◆ Sixty sets compressed at 8:1 using Daubechies wavelet
  - ◆ Mammographers reviewed in controlled study
  - ◆ Clinical accuracy comparable to original film
- Investigation of Optimum Wavelet for Mammography
  - ◆ On-going OSU grant
  - ◆ Early results promising



## Highlights: Asymmetrical Links over Satellite

- Evaluated Cisco Internetworking Operating System (IOS) modified to perform over asymmetrical links
- Permits uplink through satellite on high-bandwidth channel with return link on a slower path
- Cisco router modification now available as COTS option



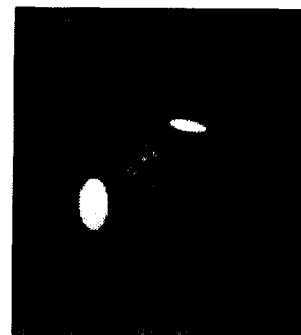
## Impact of Satellite Telemammography Work

- Improved teleradiology processes
- Demonstrated feasibility of a totally digital mammography solution
  - ◆ University of Virginia and CCF progressing towards digital mammography systems
- Asymmetrical links can be integrated into medical networks with COTS products



## Importance of ACTS

- Demonstrated to medical community the use of satellite links
  - ◆ high-quality DS1 links
  - ◆ very small earth stations
  - ◆ availability to remote locations





# Future of Satellite Telemedicine

- Telemedicine is in its infancy
- Future will see growth of remote locations served by a specialized central hub with satellite links
- STN team currently participating in other telemedicine activities



# Summary

- Proved feasibility of satellite-based teleradiology and telemammography
- Demonstrated new paradigm in medical care
  - ◆ experts centrally located with remote centers providing personalized care
- Fostered acceptance in medical community of compression to medical imagery
- Promoted use of TCP/IP over satellite links

