



---

# DEVELOPING ADVANCED NETWORKING TECHNOLOGIES AND APPLICATIONS OVER ACTS

**Robert Bauer**

robert.bauer@grc.nasa.gov

NASA Glenn Research Center

Cleveland, OH 44135 USA

**2nd Annual International Symposium on  
Advanced Radio Technologies (ISART)**

Boulder, CO Sept. 8-10, 1999



# OUTLINE



- **Internet via Satellites**
- **ACTS Overview**
- **Internet Technology over ACTS**
- **Internet Applications over ACTS**
- **Summary**



---

# INTERNET VIA SATELLITES



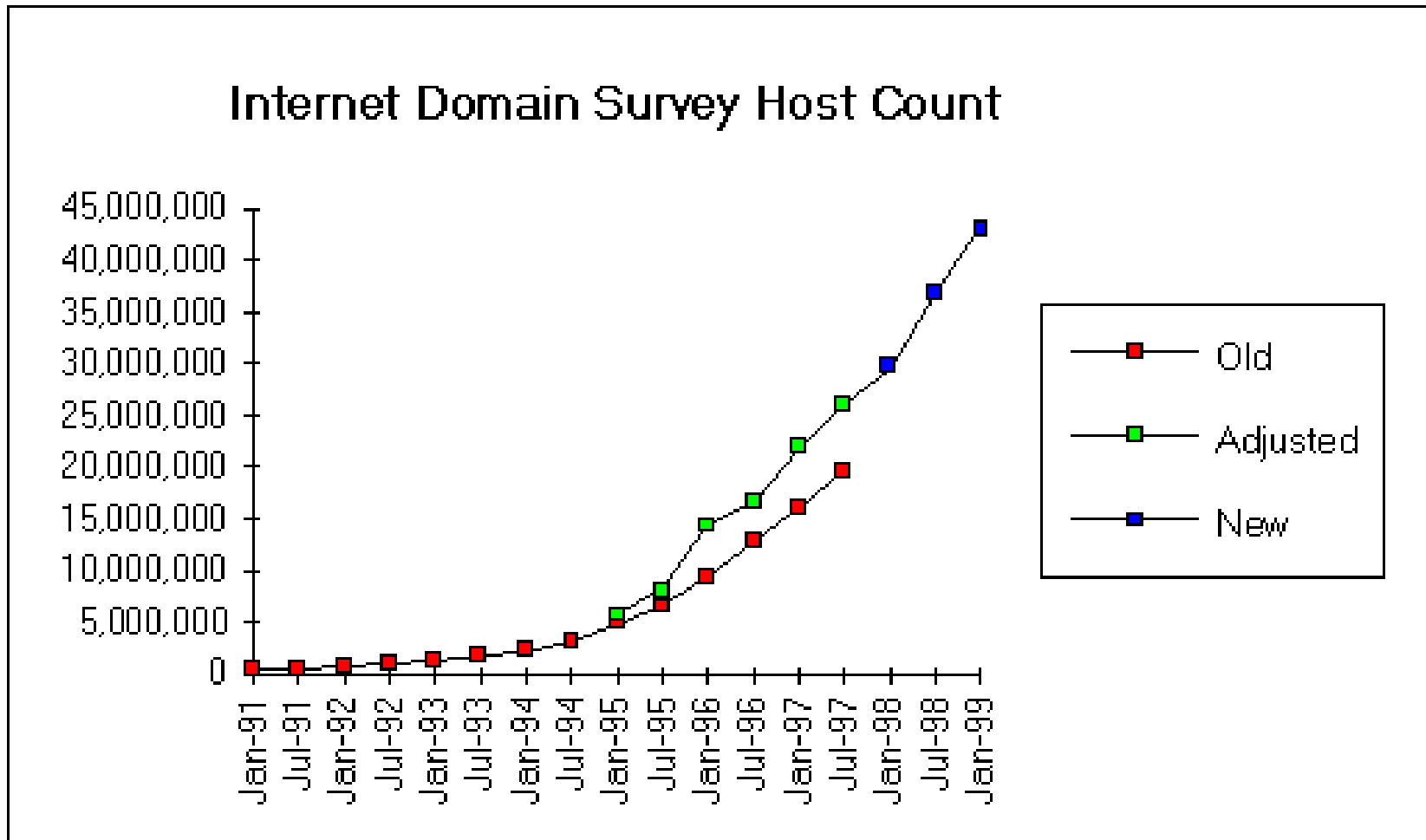
# DRIVERS



- Exponential growth of the Internet/Intranet
- Convergence of Personal Computers and TV
- Integration of satellite, wireless & wired communication networks
- Developments in satellite systems and technologies
- Global markets and corporations
- Government requirements for use of commercial assets



# DRIVERS



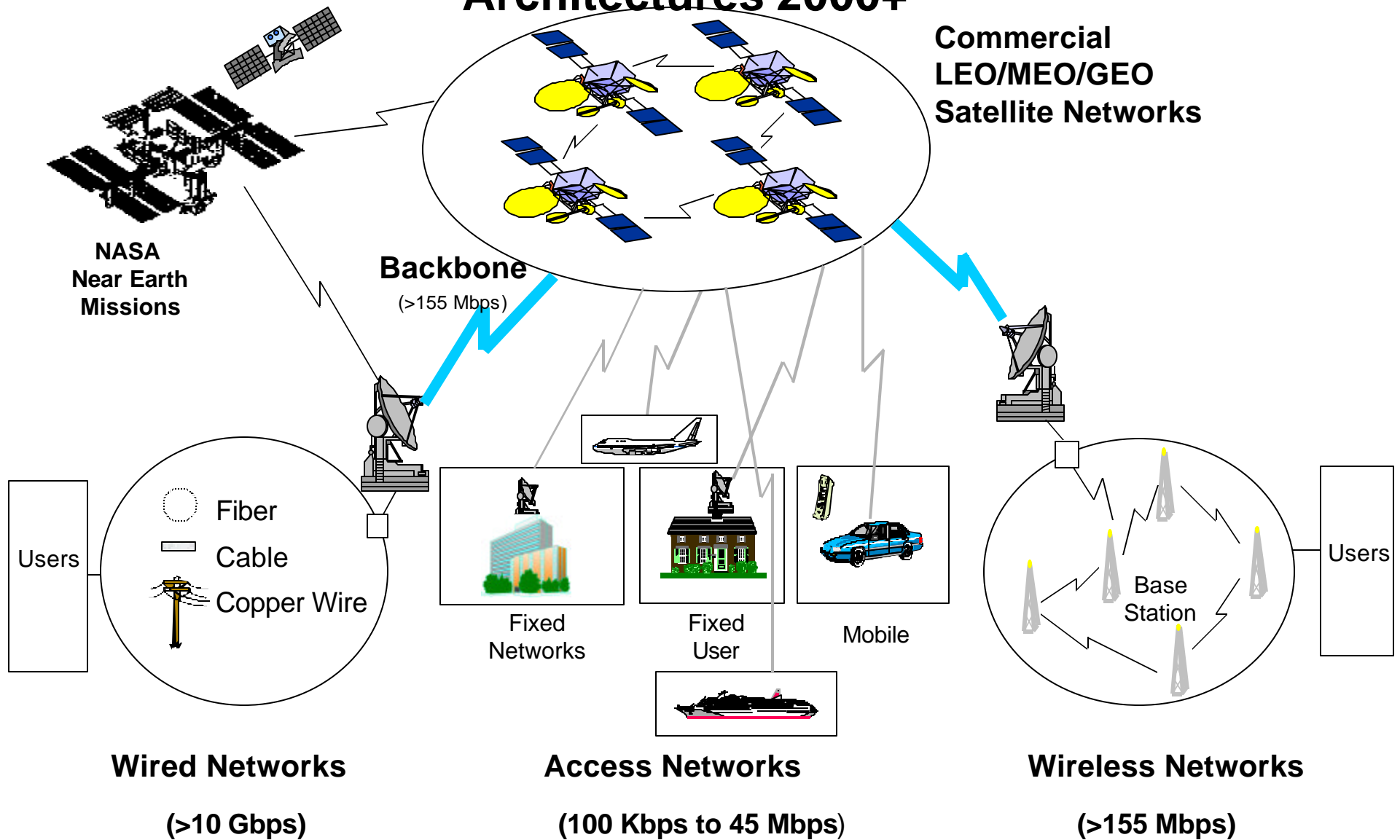
Source: Internet Software Consortium



# NEXT-GENERATION COMMUNICATION NETWORKS



## Architectures 2000+



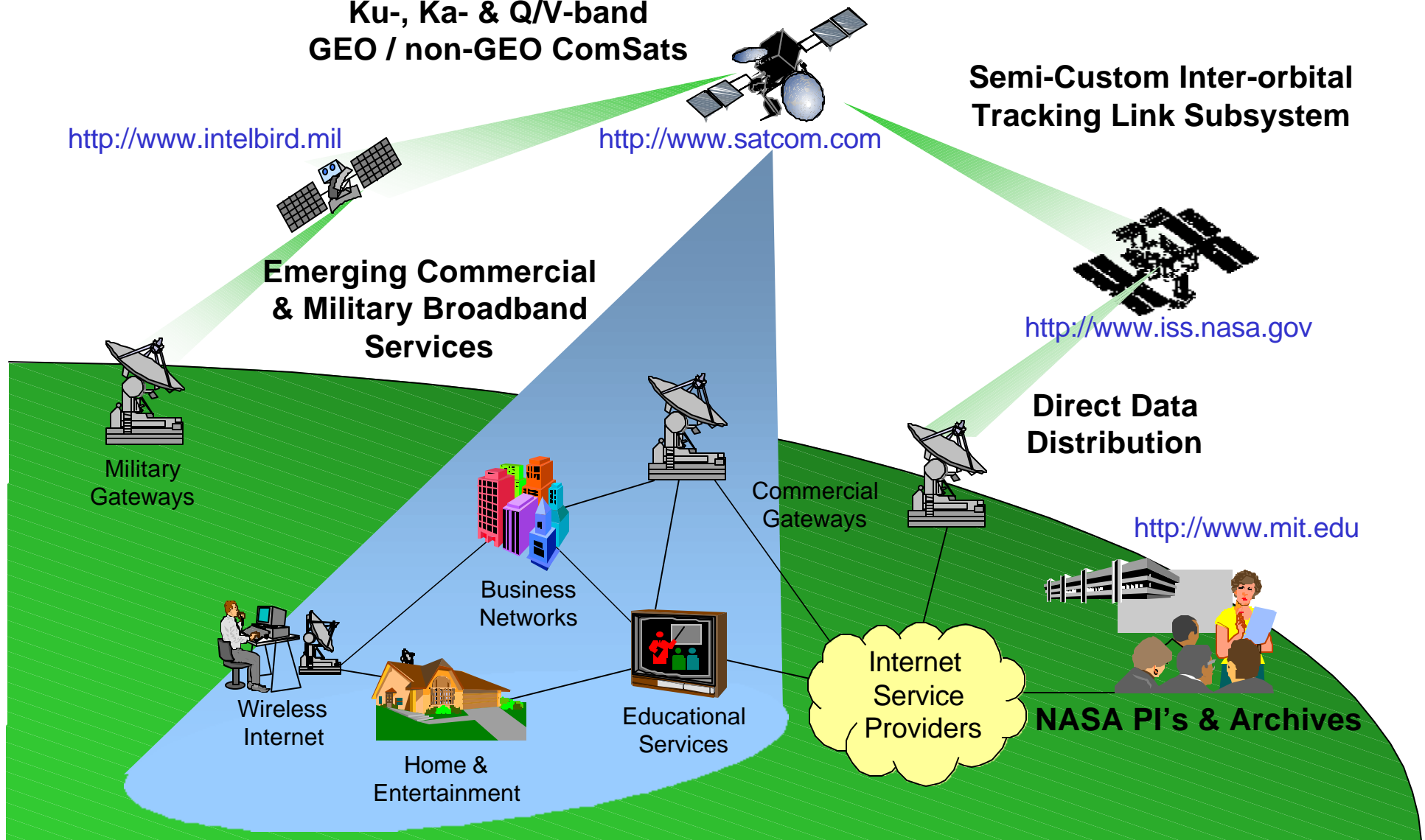


# SPACE INTERNET VISION



## SPACE ASSETS AS ELEMENTS OF THE INTERNET

Ku-, Ka- & Q/V-band  
GEO / non-GEO ComSats





# NETWORKING CHALLENGE AND ISSUES



8

- Challenge

- \*Standards and Interoperability
  - Achieving seamless interoperability between satellite and terrestrial networks

- Issues

- Interworking between networks using ATM
- Data Protocols (e.g., TCP/IP over hybrid networks)
- Mobile Satellite Issues
- GII Architectures and Reference Models





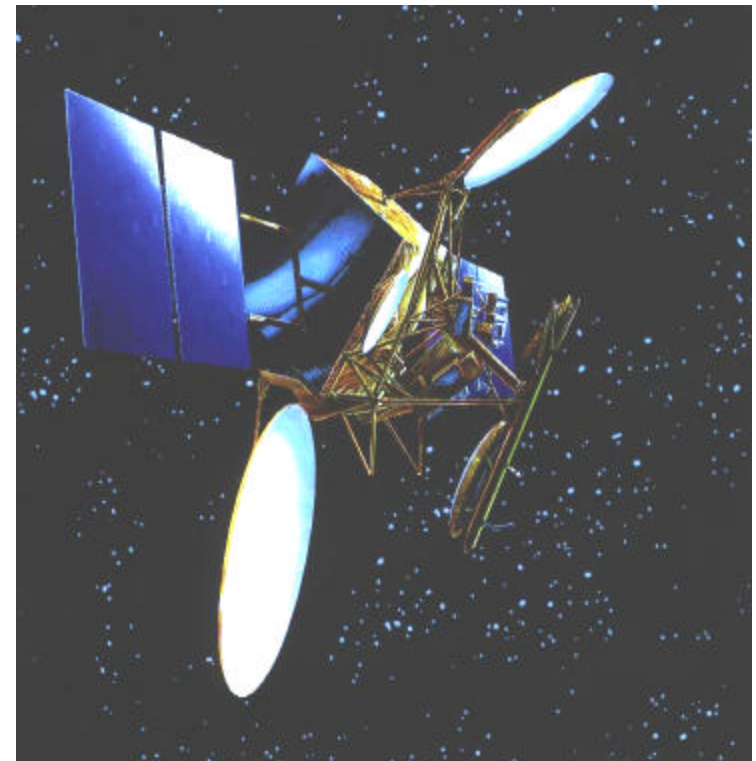
---

# ACTS OVERVIEW



# WHAT IS ACTS?

- Advanced Communications Technology Satellite (ACTS)
- Experimental system sponsored by NASA to pave the way for next generation communication satellites
- National research facility available for use by US organizations and US-sponsored organizations to test and demonstrate advanced communications satellite technologies





# KEY ACTS TECHNOLOGIES



## High Gain, Fast Hopping Spot Beams

- EIRP >64 dB
- G/T >20 dB/K
- Frequency Reuse  $\gg 4$
- 20 dB improvement over CONUS beams

## Onboard Processing & Switching

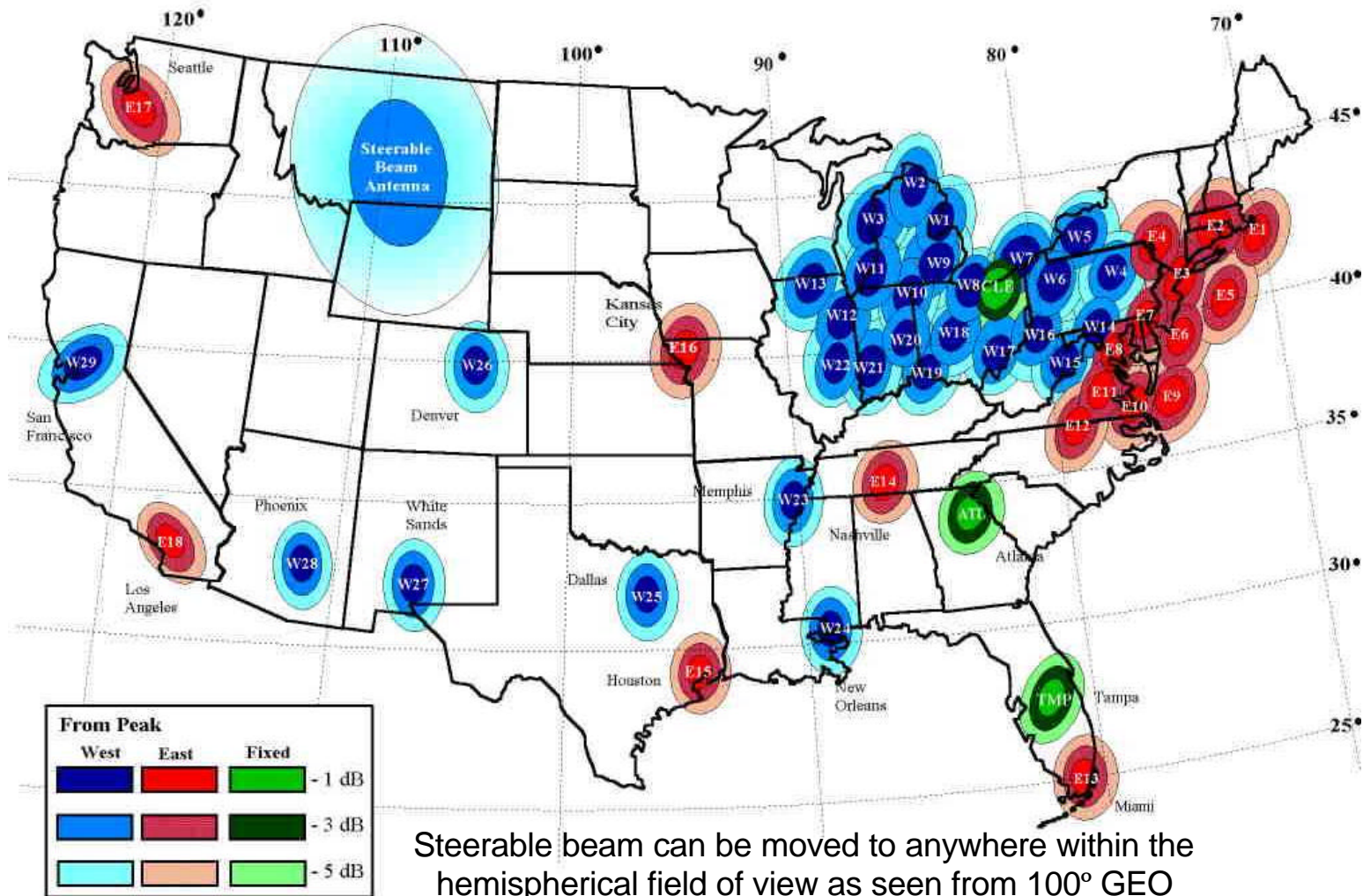
- Baseband Switching at 64 kbps circuit level
  - Max throughput of 220 Mbps
  - Full mesh, single hop connectivity
- Wideband Switch Matrix of 3 channels at 900 MHz each

## Ka-Band

- 30/20 GHz RF spacecraft & earth station components
- Adaptive rain fade compensation
- Propagation measurements to characterize band
- Only currently available 30/20 GHz satellite testbed in U.S.

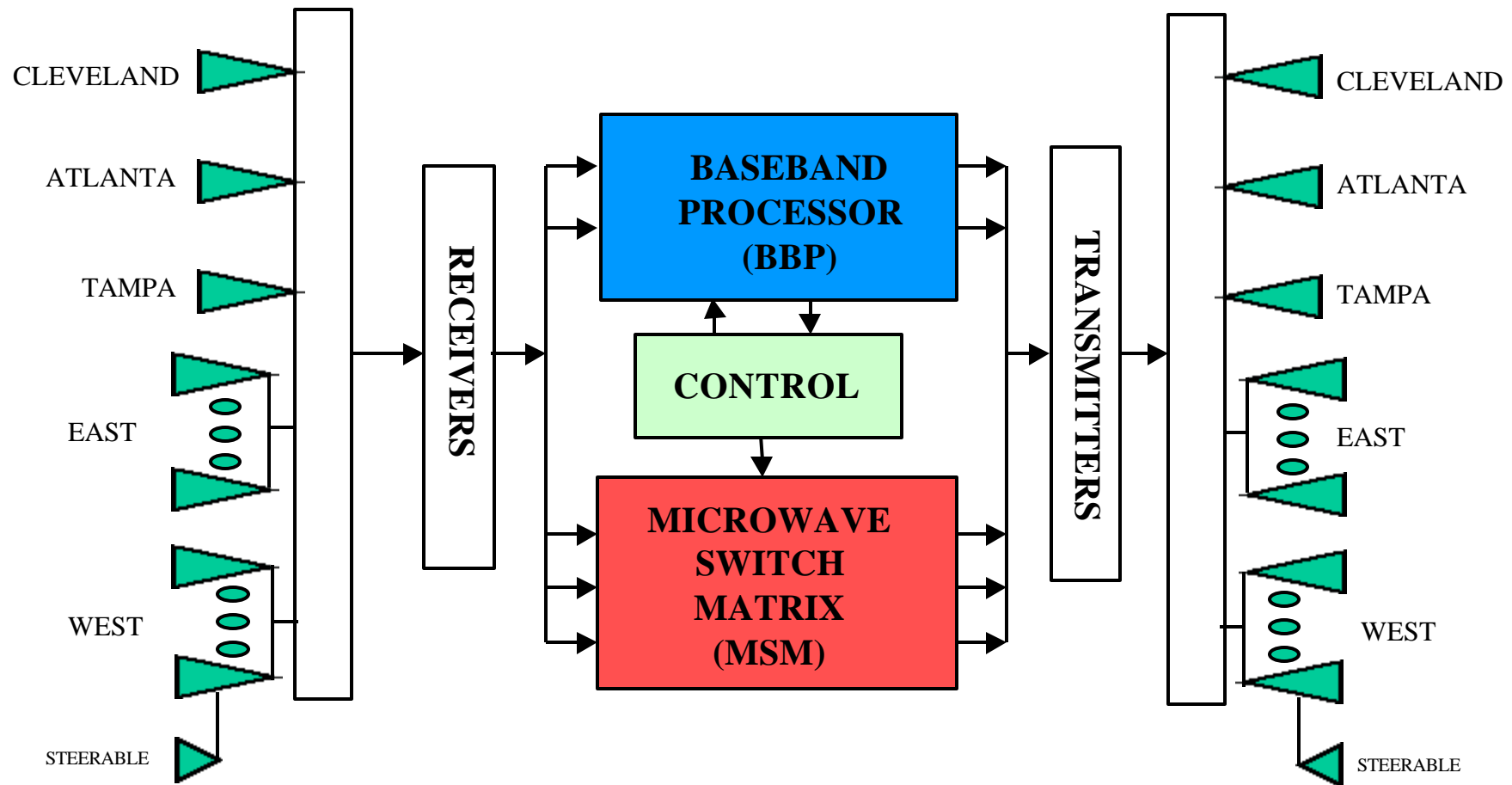


# ACTS COVERAGE





# ACTS PAYLOAD





# INCLINED ORBIT OPERATIONS

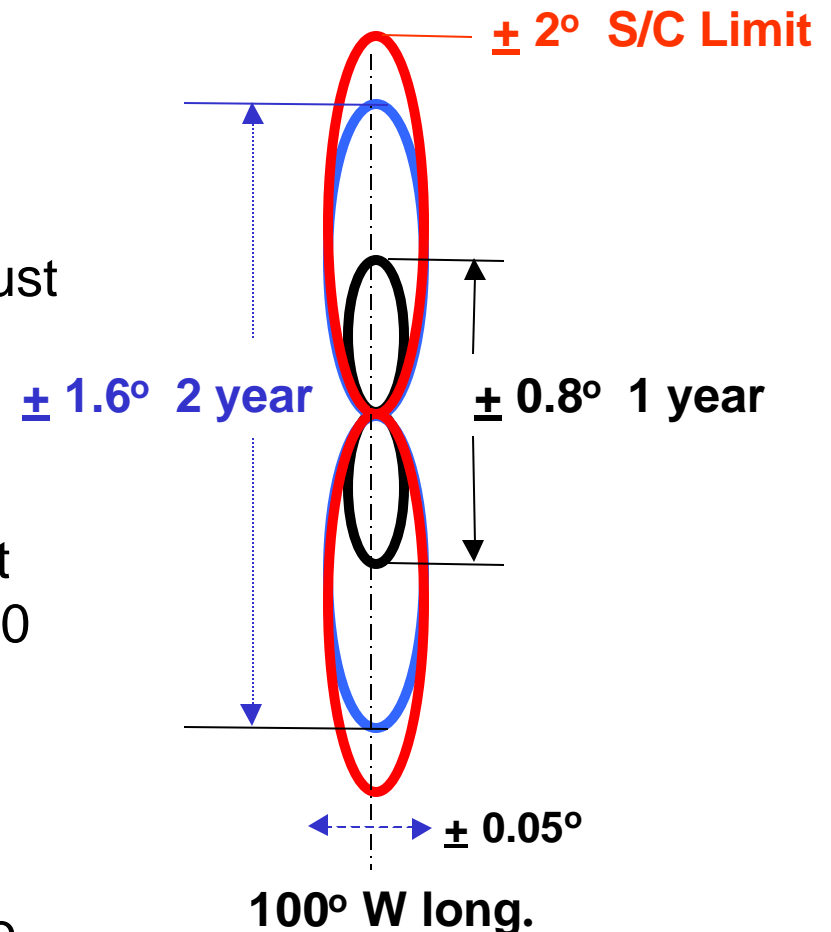


## Spacecraft

- Last North/South maneuver on July 9, 1998
- S/C exceeded  $0.05^\circ$  in latitude on August 8, 1998
- Satellite will drift in N/S direction increasing by  $\sim 0.8^\circ$  per year
- Capability to maintain ACTS East/West stationkeeping at  $\pm 0.05^\circ$  for approx. 30 months
- Beam pointing maintained

## Ground Segment

- Tracking modifications (2 axis) made to experimenter terminals



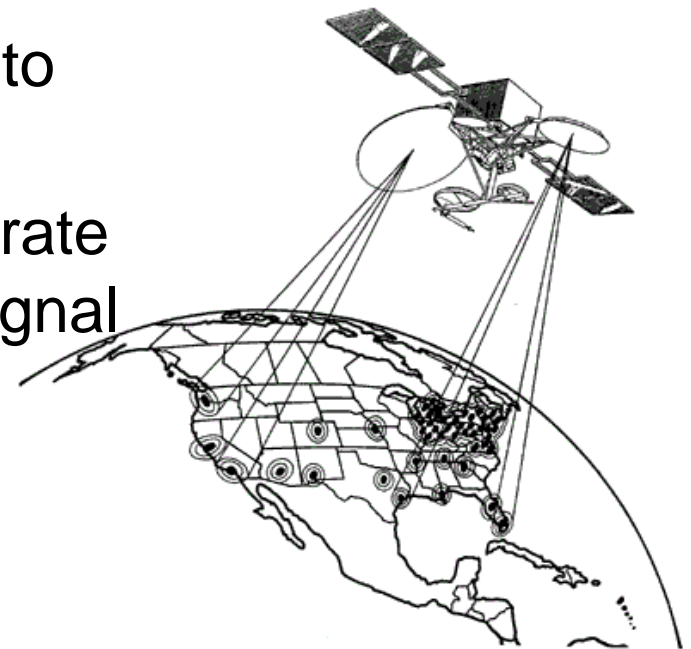
**OPERATE THROUGH**

**JUNE, 2000**



# ON-BOARD SWITCHING

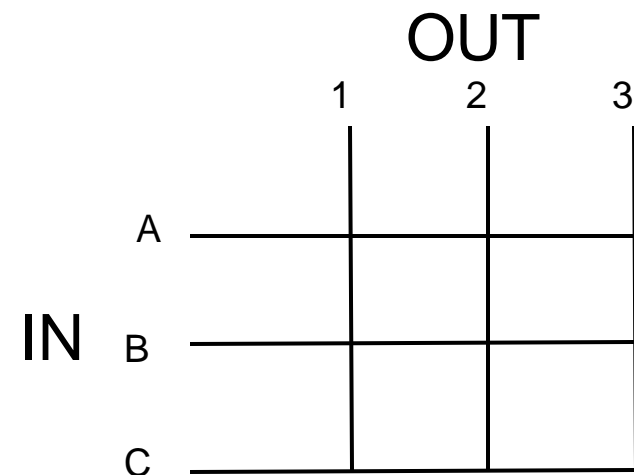
- Baseband Processing (BBP)
  - Memory mapped processor to receive, store, and forward data
  - On-board demodulation and remodulation
  - TDMA mode on both input and output
    - 1 msec frame; can visit 40 terminals per frame
  - Spot beams visited only in response to traffic demand (DAMA)
  - Convolutional coding and data burst rate reduction on demand to overcome signal fading due to rain





# ON-BOARD SWITCHING

- Microwave Switch Matrix (MSM)
  - 3 X 3 matrix connects any input to any of up to 3 outputs
  - Saturated transponder with 900 MHz bandwidth
  - Can be used in static mode for bent-pipe applications similar to today's typical transponder
  - Can be used in 1 msec or 32 msec switched mode
  - Provides no on-board storage
  - Can support high density imagery, supercomputers, large file transfer



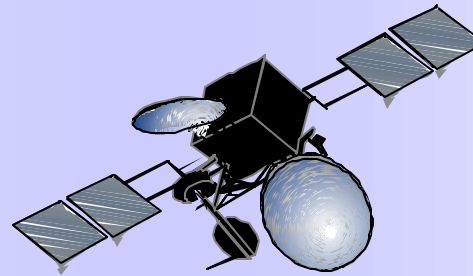




# FAMILY OF GROUND STATIONS



1.2 m T1 VSAT



0.6 m USAT



3.4 m Gigabit  
Earth Station



5.5 m NASA  
Ground Station



4.7 m Link Evaluation  
Terminal (LET)



# GROUND STATION SUMMARY



NAME	ITEM							
	MODE	ANTENNA (m)	HPA (W)	EIRP (dBW)	G/T (dB/K)	BURST RATES (Mbps)	DATA RATES (Mbps)	MODULATION
NASA GROUND STATION	BBP	5.5	200	68/74	26.5	U/L: 27.5 or 110 D/L: 110	64 kbps to multiple T1 & T2	SMSK
T1 VSAT	BBP	1.2	12	60/66	16/22	U/L: 27.5 D/L: 110	1.792 (max)at 64 kbps increments	SMSK
USAT	MSM	0.6, 1.2	.25, 1.0, 2.0	42 (0.6 m, 1 W)	13 (0.6 m)	Not a burst terminal	U/L: low kbps to T1 D/L: up to 45 Mbps	BPSK
HDR	MSM	3.4	100	76	28	upto 696	311 or 622	BPSK (OC-3) O-QPSK(OC-12)
LET	MSM	4.7	10-60	68-76	27	Up to 220		SMSK

Various other “unique” terminals have been developed for MSM operations such as, ground and aero mobile, and other non-NASA user-developed terminals.



# EXPERIMENTS PROGRAM



- 150+ organizations involved in 90+ experiments & 80+ demonstrations to various audiences.
  - Thin route customer promises services at 64 kbps increments
  - Terrestrial, shipboard, and aeronautical mobile services
  - Full motion compressed video, fractional T1 to users' premises
  - ISDN telephony and videoconferencing
  - ATM Networks
  - Transmission at OC-12 rates (622 Mbps) with full fiber connectivity
  - Asymmetrical link connections



# GOALS - INCLINED ORBIT PHASE

---

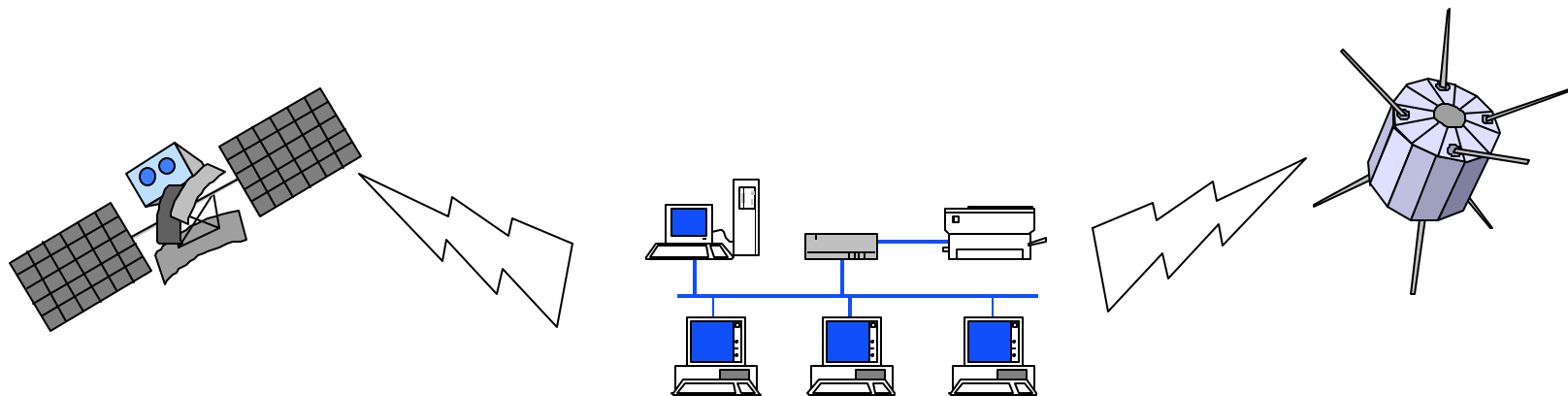


1. Demonstrate NASA & other government uses of commercial satellite services.
2. Test, verify & resolve technical issues using Asynchronous Transfer Mode (ATM), Internet Protocol (IP), or other protocols over satellite, including interoperability issues with terrestrial networks.
3. Evaluate spot beam satellite operations in an inclined orbit.
4. Verify new satellite Ka-band technology and hardware.



# ACTS FEATURES

- Fiber-like quality links: BER up to  $10E-11$
- Narrowband to wideband: 64 kbps-622 Mbps
- Small terminals similar to commercial systems
- Next-generation satellite system simulator: Ka-band, spot beams, on-board processing, available as testbed





---

# INTERNET TECHNOLOGY OVER ACTS

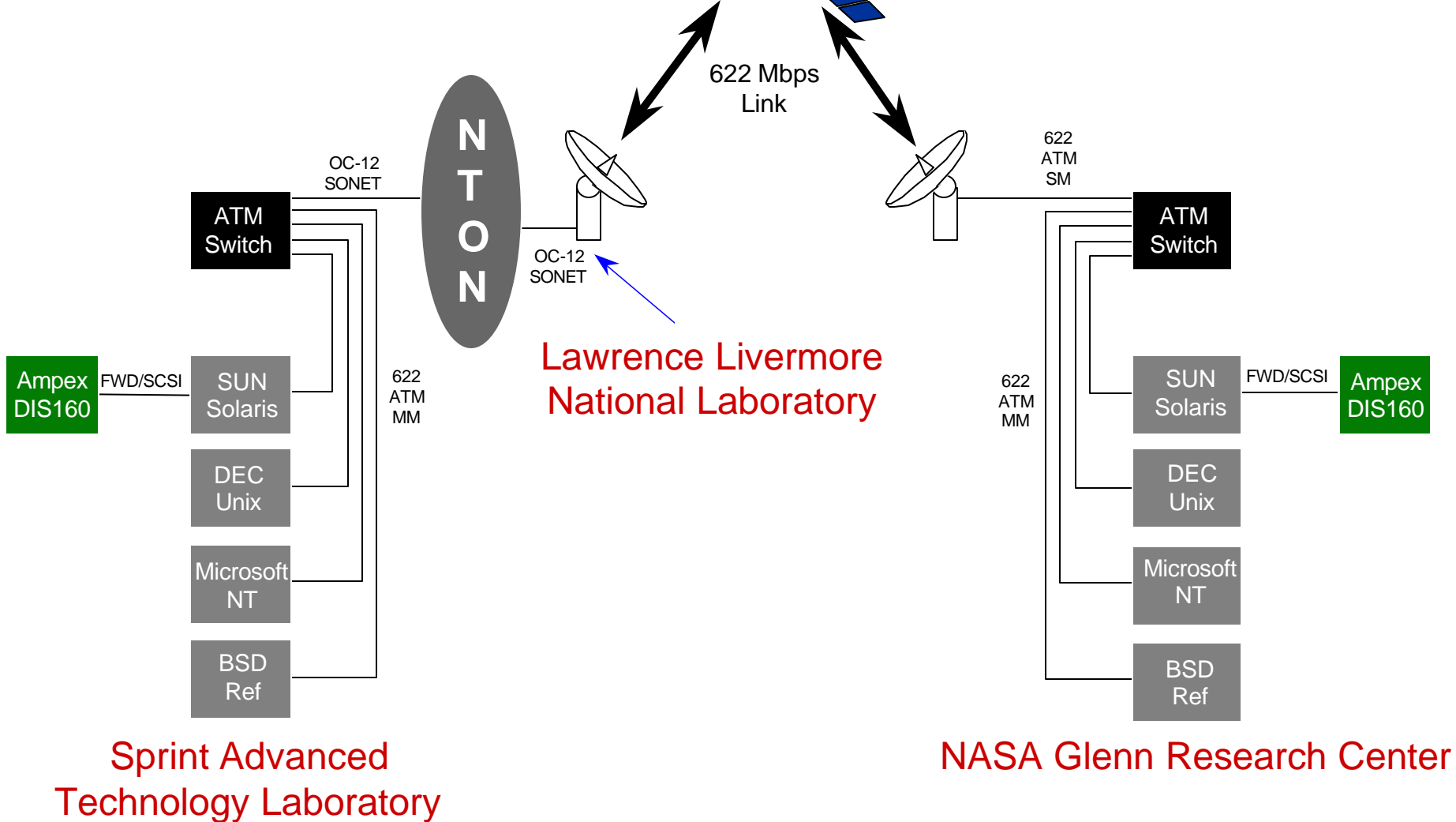
- Internet Backbone
- Internet Access - fixed
- Internet Access - mobile
- Multicasting



# INTERNET BACKBONE



## Expt. 118x - Multi-Platform High Speed GEO Protocol Performance





# INTERNET BACKBONE



- **Description**

- Model TCP in a high speed satellite network (622 Mbps SONET OC 12) using the NetBSD TCP stack over ATM
- Three scenarios: symmetrical balanced links; highly asymmetric links; direct broadcast satellite
- Experimentation with various TCP enhancements at high speeds

- **Impact**

- Results will assist in IETF standardization process
- Illustrates TCP performance in a high speed satellite network in a multi-vendor environment
- Industry using results to improve commercial products

- **Participants**

- Satellite Communications Industry
- Information Technology Industry
- Government Research Labs

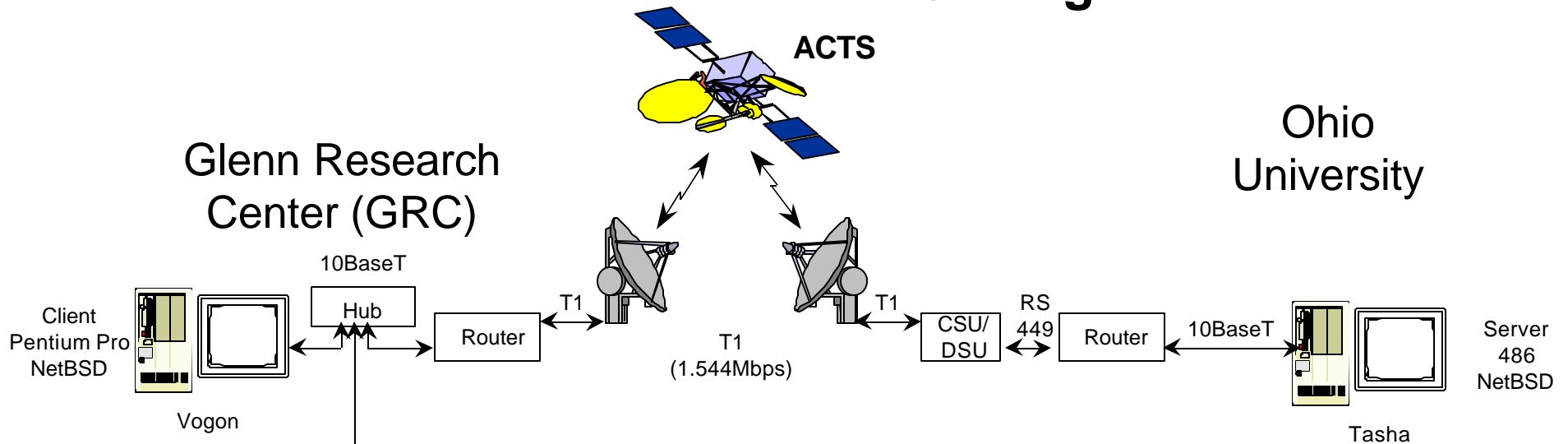




# INTERNET ACCESS - FIXED



## Internet Protocol Performance and Coding Effects





# INTERNET ACCESS - FIXED



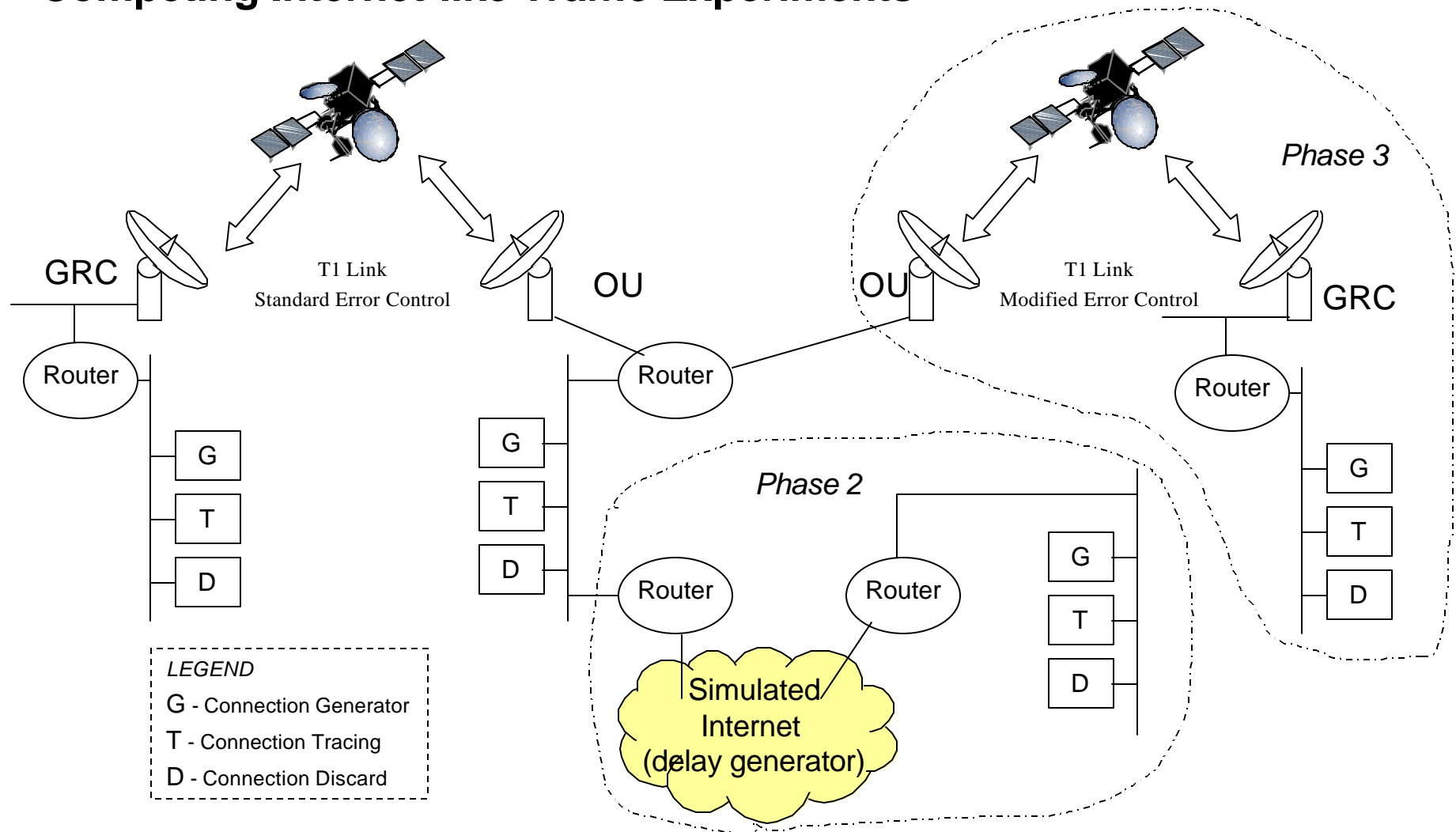
- **Description**
  - HTTP/1.1 with pipelining makes the transfer time of WWW pages over ACTS at least as fast as transfers over current dialup modems
  - Experimentation with TCP with larger initial windows showed performance improvements. These findings aided the IETF in the standardization of larger initial window
- **Impact**
  - Results assisted in IETF standardization process (RFC 2414)
  - Illustrated that satellite networks are feasible for a major Internet application
- **Participants**
  - Ohio University
  - Glenn Research Center (GRC)



# INTERNET ACCESS - FIXED

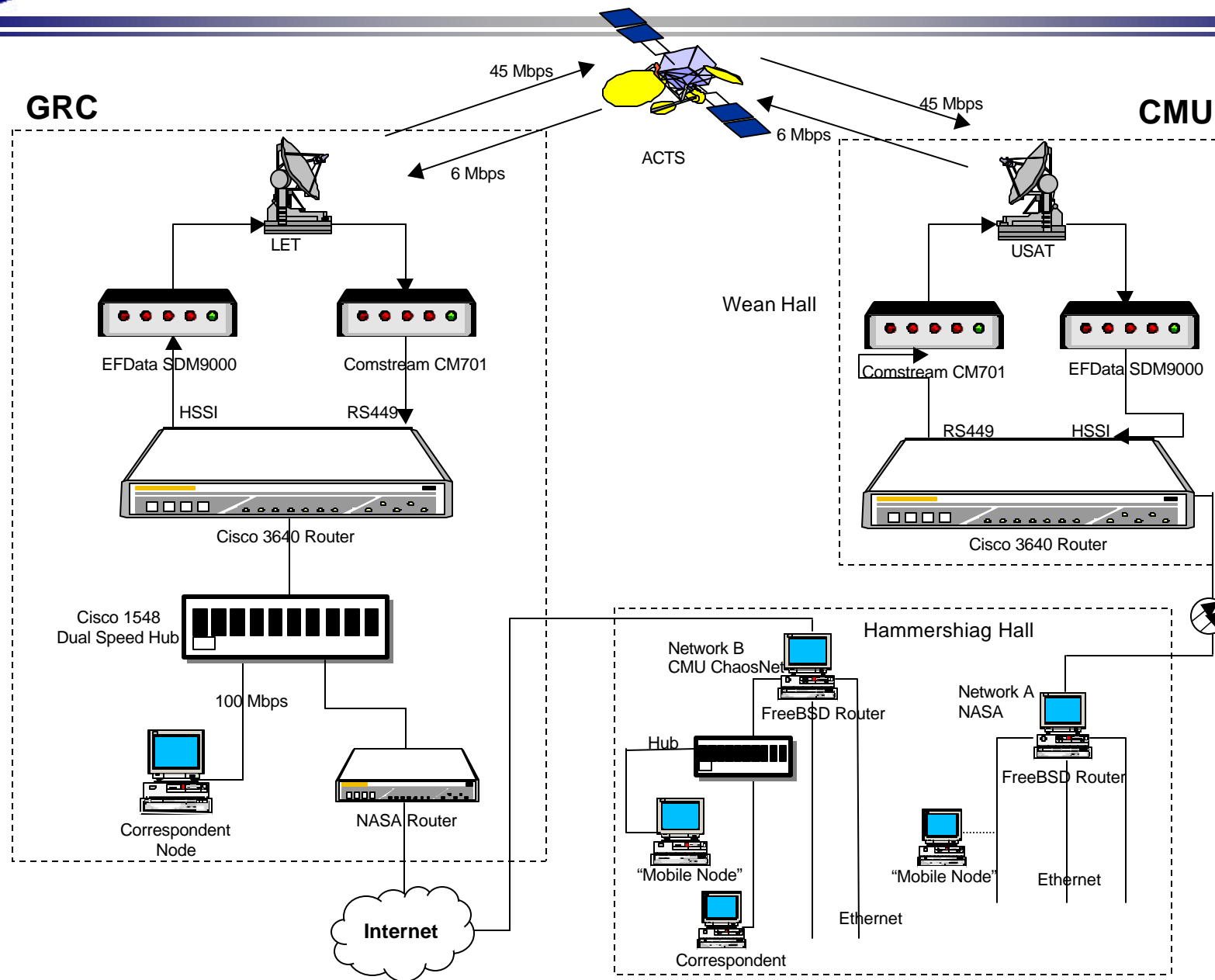
## Follow-on Work

### Competing Internet-like Traffic Experiments





# INTERNET ACCESS -MOBILE





# INTERNET ACCESS -MOBILE



- **Description**

- Performance analysis and improvement of TCP behavior over ACTS
- Mobile IP performance over ACTS
- Error modeling for the ACTS link and fade effects on TCP

- **Impact**

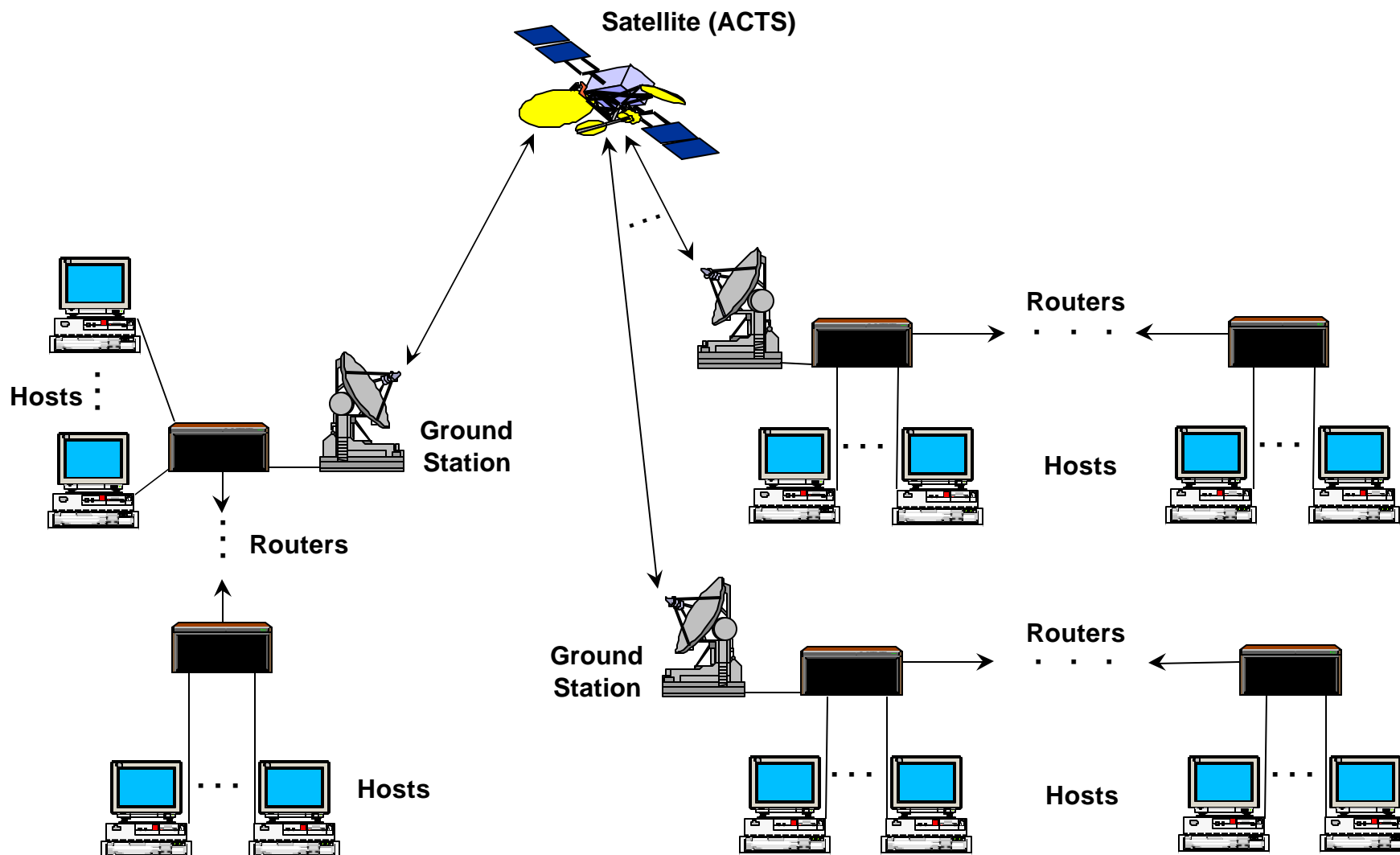
- Model verified and is usable for research of current and future protocols over similar links
- Illustrated that satellite networks are feasible for a major Internet application

- **Participants**

- Carnegie Mellon University (CMU)
- Glenn Research Center



# MULTICAST CHARACTERIZATION





- **Description**

- Investigate the interoperability of multicasting between satellite links and terrestrial networks
- Working with commercial equipment providers, develop improvements to protocols, hardware and/or software that lead to open standards for supporting multicasting in hybrid networks

- **Impact**

- Bidirectional asymmetric satellite links can increase network efficiency in implementing multicasting by reducing the network branches.

- **Participants**

- Glenn Research Center
- Ohio University
- Cisco Systems



---

# **INTERNET APPLICATIONS OVER ACTS**

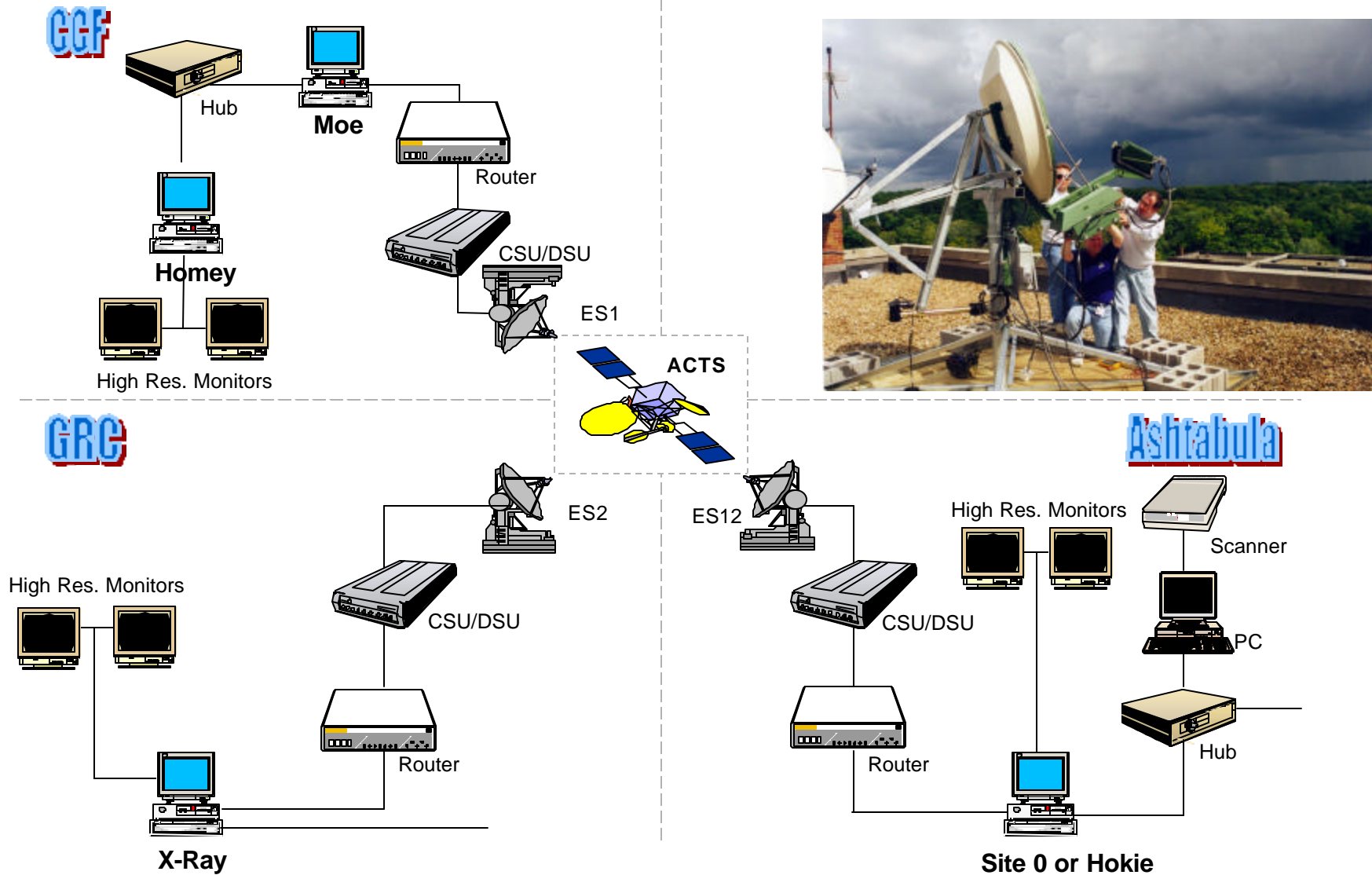




# TELEMEDICINE INTERNET EXPERIMENT



## Satellite Telemammography Network: *Open (TCP/IP) Standards Network*





# TELEMEDICINE INTERNET EXPERIMENT



- **Description**

- Multicast transmission of digital mammography images over ACTS
- Three-node hybrid satellite/terrestrial network
- Lossy image compression (DICOM) used with detail intensive application (telemammography)

- **Impact**

- Improves BW utilization for high-resolution digital mammography images
- Over 5,000 digital mammography images transmitted without error
- Common transmission protocols with large files and large BW-delay-product links provide very acceptable service

- **Participants**

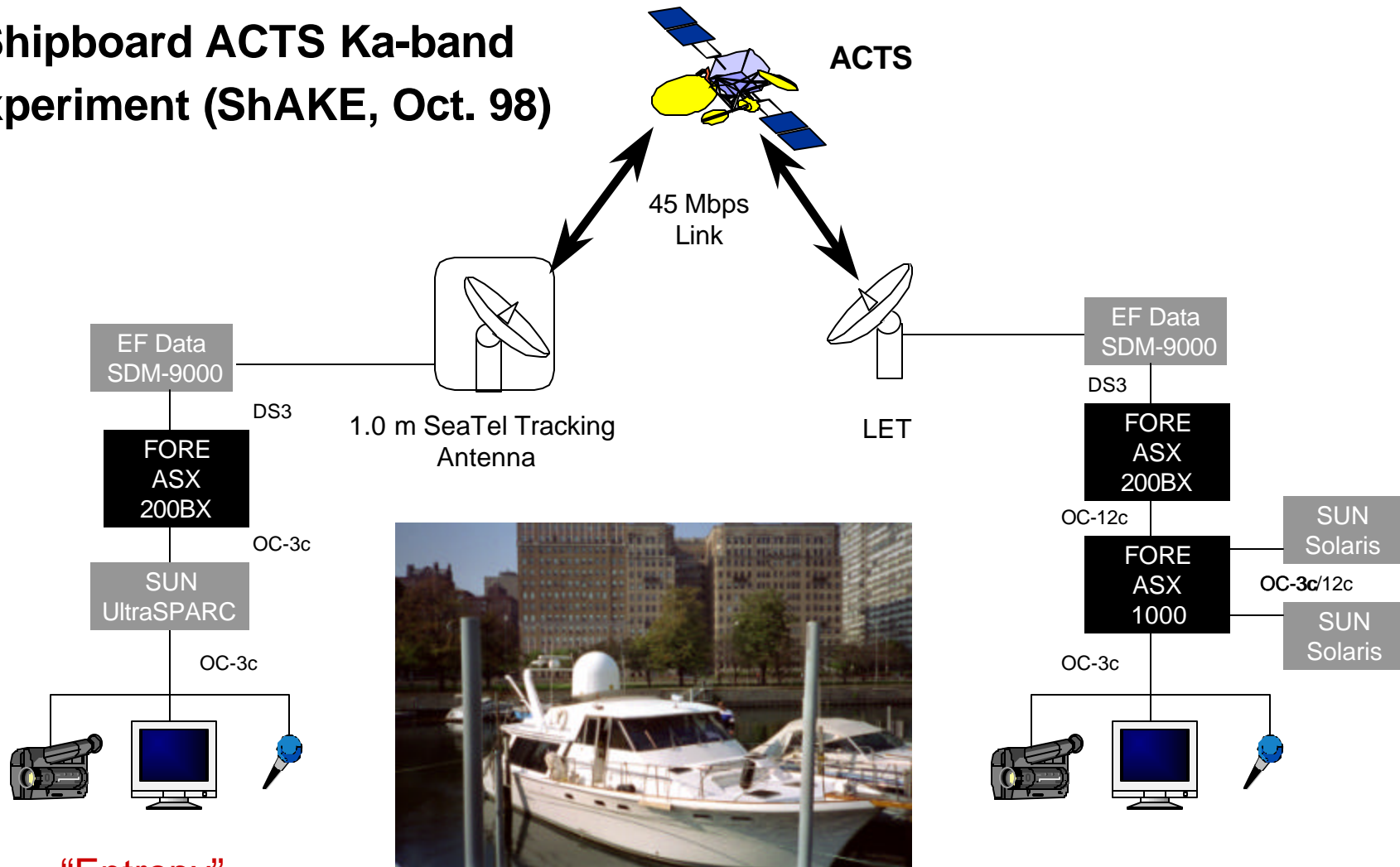
- Glenn Research Center
- Cleveland Clinic Foundation
- University of Virginia
- Ashtabula County Medical Center



# SHIPBOARD INTERNET EXPERIMENT



## Shipboard ACTS Ka-band Experiment (ShAKE, Oct. 98)



“Entropy”  
Lake Michigan

NASA Glenn Research Center



# SHIPBOARD INTERNET EXPERIMENT



---

- **Description**

- High speed TCP/IP file transfers to/from a ship at 45 Mbps Tx/Rx
- Multimedia network connectivity at constant and variable data rates
- High data rate WAN to link ship LAN to terrestrial networks
- Evaluate networking, protocol, terminal, and BOD issues with variable bit rate service

- **Impact**

- Illustrates mobile high speed TCP performance in a seamless satellite/terrestrial network environment
- Demonstrate 20x greater rate than current standard ship rates
- Extrapolate tracking scenarios for use in low/medium earth orbit satellite communications systems

- **Participants**

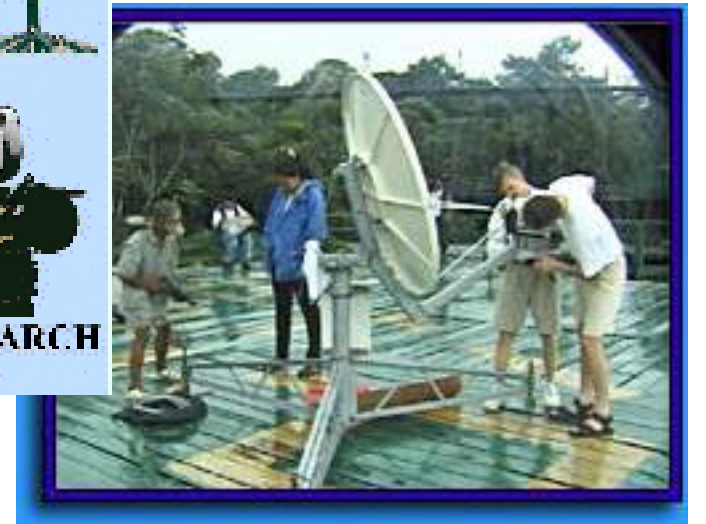
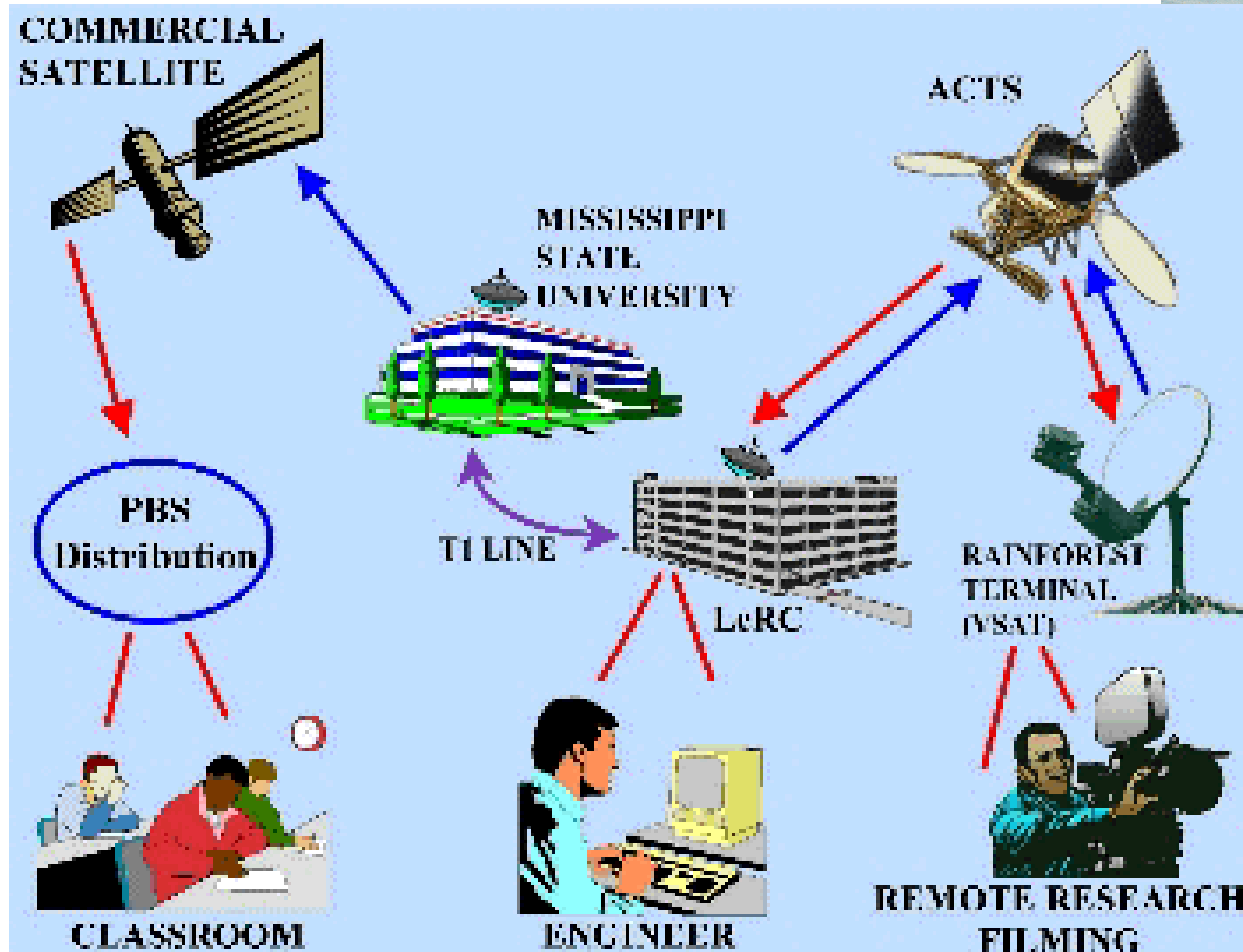
- Naval Research Lab
- Infinite Global Infrastructures
- Fore Systems, SeaTel, Xicom, Raytheon, Comsat Labs
- Hill Mechanical Group
- Glenn Research Center
- Sterling Software



# TELE-EDUCATION INTERNET EXPERIMENT



“Live from the Rain Forest” (Jan.-Apr. 1998)





# TELE-EDUCATION INTERNET EXPERIMENT



---

- **Description**

- ACTS link from Brazilian rainforest to US at T1 rate
- Terrestrial interconnect to television production and integration facility
- Internet access by several elementary/middle schools for Q&A with researchers on-site
- Re-broadcast of final production via commercial satellite

- **Impact**

- Illustrates small terminal technology with IP in a seamless satellite/terrestrial network to a remote environment
- Remote access enhanced by common access protocol in a wide area network
- Cited by participants as one of most impactful uses of the Internet

- **Participants**

- Passport to Knowledge, Public Broadcast Service
- Mississippi State University
- Smithsonian Institute
- Brazilian Institution for Research in Amazonia (INPA)
- Glenn Research Center



# REMOTE SCIENCE EXPERIMENT

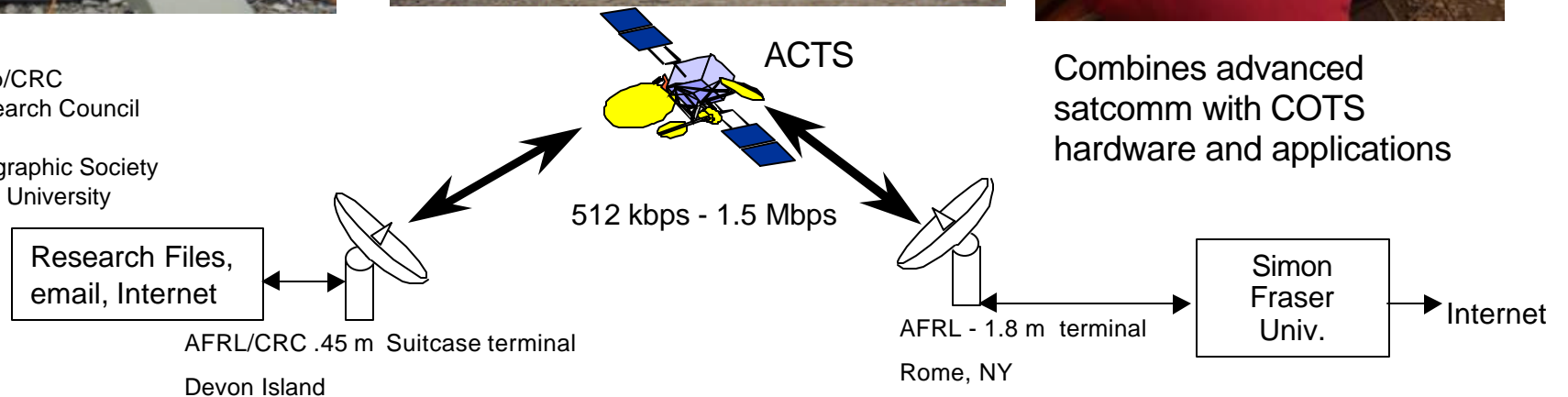


## The Haughton-Mars Project (June-July 1999)

**Devon Island**  
Canadian Arctic  
75°22'N, 89°41'W



Sponsors:  
AF Rome Lab/CRC  
National Research Council  
NASA Ames  
National Geographic Society  
Simon Fraser University





# REMOTE SCIENCE EXPERIMENT



---

- **Description**

- ACTS link from Arctic field site exploring Mars-like environment to US/Canada at 1/2 T1 rate
- Terrestrial interconnect to Internet allows data distribution, email access

- **Impact**

- 10x increase in data rate transfer compared to highest offering from other commercial options
- Illustrates very small terminal technology in an extremely low elevation angle and extremely remote location
- Seamless satellite/terrestrial network with IP enhanced by common access protocol in a wide area network can enhance remote science

- **Participants**

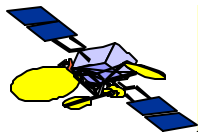
- Mars/Haughton Project
- Canadian Research Centre/AF Rome Labs
- Simon Fraser University
- NASA GRC, ARC





# SUMMARY

- ACTS remains globally the only satellite testbed to:
  - Study, evaluate, enhance, and develop standards for Internet protocols for hybrid networks
  - Demonstrate seamless interoperability based on ATM and non-ATM based networks
  - Develop advanced applications



**Offers fiber like links at variable rates for Internet access and backbone hybrid network development**

- With the exponential growth of the Internet and emerging need for space Internet

*Experimenting over ACTS is vital for Government, Industry, and Academia in producing end-end results*