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### 4.3 - NASA and Industry Benefits of ACTS High Speed Network Interoperability Experiments

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#### Abstract

This paper provides synopses of the design, implementation, and results of key high data rate communications experiments utilizing the technologies of NASA's Advanced Communications Technology Satellite (ACTS). Specifically, the network protocol and interoperability performance aspects will be highlighted. The objectives of these key experiments will be discussed in their relevant context to NASA missions, as well as, to the comprehensive communications industry. Discussion of the experiment implementation will highlight the technical aspects of hybrid network connectivity, a variety of high-speed interoperability architectures, a variety of network node platforms, protocol layers, internet-based applications, and new work focused on distinguishing between link errors and congestion.

In addition, this paper describes the impact of leveraging government-industry partnerships to achieve technical progress and forge synergistic relationships. These relationships will be the key to success as NASA seeks to combine commercially available technology with its own internal technology developments to realize more robust and cost effective communications for space operations.

#### Introduction

NASA's ACTS has been in operation since 1993. This period of successful operation far exceeds the initial two-year experimentation plan as well as the four-year design life of the system. The current state operation in an inclined orbit with the remaining fuel allows extended usage of the still totally functional payload. Although antenna-tracking systems are now needed on the earth stations, experiment operations continue with very little disruption.

The Experiments Program has validated the key ACTS technologies of Ka-band transmission, very wide bandwidth transponders, on-board switching, and high gain, hopping spot beams. The original goals of the Experiments Program were to:

- 1) Conduct technology verification experiments to evaluate and characterize the ACTS technologies and,
- 2) Conduct a balanced set of experiments and demonstrations to evaluate and promote new and innovative applications enabled by the ACTS technologies.

ACTS remains as the only operational testbed for Ka-band geosynchronous satellite communications over the Western hemisphere. The ACTS experiments program continues to support investigations by industry, government and academic organizations in preparation for the deployment of next generation commercial satellite communications systems. The last two years of operations have involved a number of experiments that integrate terrestrial computer and networking technologies with satellite networks.

By design, the ACTS experiments program seeks to gain greater relevance to NASA's mission from the results of the experiments that are performed.

Thus, the objectives of the Experiments Program during the Inclined Orbit phase of ACTS operations were redesigned to:

- 1) Demonstrate NASA and other Government use of future satellite services
- 2) Evaluate communication protocols for satellite-terrestrial network interoperability
- 3) Evaluate spot beam satellite inclined orbit operations
- 4) Verify new Ka-band technology and hardware.

Of particular interest is the evaluation of NASA's and other U.S. government agencies' transition to commercial space assets in order to meet their respective communications needs. Also, significant to both the government and commercial sectors is the investigation of issues related to interoperability with terrestrial networks of protocols such as TCP/IP and ATM over wide band satellites. NASA uses satellites extensively in near-Earth, inter-planetary, and deep space applications. NASA's goal is to extend the Internet to space to communicate with these systems based on commercial technologies and assets. Therefore, commercial entities have been involved in various activities to ensure that the hardware, software and protocols being used will include the characteristics of satellite links such as large bandwidth-delay products.

### **Acts High Data Rate (HDR) Background**

The ACTS High Data Rate Experiments program, which combined truly unique ground and space capabilities with innovative applications, has exceeded expectations. Besides proving that satellite communications can be achieved at comparable speed and performance as fiber networks, the respective interoperability issues and promising applications have been dispelling conventional the "can't be done" myths.

The NASA Advanced Communications Technology Satellite (ACTS) has the bandwidth and the routing capability to provide wideband networking. This is referred to the Gigabit Satellite Network (GSN) and is comprised of several High Data Rate (HDR) ground stations in conjunction with the spacecraft's capability. The GSN was designed to provide fiber-like service by incorporating Reed-Solomon coding and offset-QPSK modulation to achieve 622 Mbps channels with bit error rates in the range of 10<sup>-12</sup>. This is comparable to terrestrial OC-12 fiber service. The ground stations were designed with SONET interfaces and the flexibility to utilize either one 622 Mbps or a combination of 155 Mbps channels. Further, using electronically hopped spot beams and an on-board microwave switch matrix, true satellite-switched time division multiple access is achieved. The Defense Advanced Research Projects Agency (DARPA) partnered with NASA on the design, development, and operation of the GSN. In addition to the DARPA sponsorship of some trailblazing experimentation, the GSN has been interconnected with advanced research terrestrial networks such as DARPA's Advanced Technology Demonstration Network (ATDnet), Multimedia applications and Gigabit Internetwork Consortium (MAGIC), the National Transparent Optical Network (NTON), as well as the NASA Research & Education Network (NREN).

This capability enabled a unique and advanced experiments program to examine the feasibility of wideband satellite communications, respective protocol performance over wideband hybrid networks, and several interesting applications. The strategy of the HDR experiments program was to start simple and become increasingly complex in networking scenarios and technical objectives. After an intense GSN integration and test, the first such field experiment commenced in February 1995. A summary of the initial activity is provided in the following experiments and demonstrations: Engine Inlet Simulation (sponsored by NASA's High Performance Computing & communications Program (HPCCP))<sup>1</sup>, Distributed 3-D Hydrodynamic and Atmospheric Forecast Modeling (sponsored by DARPA)<sup>2</sup> and the ACTS Results Conference (Sept. '95).

Since these trailblazing experiments validated the feasibility of wideband satellite communications, many combinations of ACTS and fiber terrestrial networks have been initiated involving a variety of investigations. These included advancing applications that take advantage of the capability and agility that this type of satellite system technology offers. A summary of the follow-on HDR activities conducted using ACTS:

Experiments - Keck Telescope Remote Astronomy (sponsored by NASA's HPCC)<sup>3</sup>, Global Climate Modeling (sponsored by NASA's HPCCP)<sup>4</sup>, Application of ACTS to Group Practice as a Paradigm for Clinical Outreach (sponsored by DARPA), ACTS and Supercomputing in Remote Cooperative Medical Triage Support and

Radiation Treatment Planning (sponsored by DARPA), TransPacific High Definition Video using ACTS and INTELSAT<sup>5</sup>, Tuning TCP over High Speed Satellite Links, Evaluation of ATM Flow Control and Traffic Monitoring Techniques in a 622 Mbps Hybrid Network, Multimedia Telemedicine Applications over ACTS, Access to Biomedical Databases over High Speed Satellite Networks, ATM Gran Prix, Multi-platform Evaluation of TCP/IP over ATM Interoperability over Hybrid Satellite Environment, Distributed Parallel Storage System Performance in a Hybrid Satellite Environment, High Speed TCP Interoperability Testing<sup>6</sup>, ATM and TCP Interactions, Joint ACTS Student Satellite Testbed Experiments, and High Performance TCP/IP Investigations as the Foundation for Internet in Space Implementation.

Demonstrations - ATM Research & Industrial Enterprise Study (ARIES) for Texas Medical Center in Houston (Oct. '95), Global Legal Information Network in Washington D.C. (May '96), ICC Supercom in Dallas (June '96), ARIES for Society of Exploration Geophysicists in Denver (Nov. '96), ARIES for Radiological Society of North America in Chicago (Dec. '96), Pacific Telecommunications Conference 97 in Honolulu (Jan. '97), Satellite Communications Exposition & Conference in Washington D.C. (Sept. '97), Supercomputing 97 in San Jose (Nov. '97), Pacific Telecommunications Conference 98 in Honolulu (Jan. '98), and Next Generation Internet/DARPA at Highway One facility in Washington D.C. (March '98).

### **Supercomputing '97 Demonstration**

#### *High Speed TCP/IP Data Transfer Demonstration using off-the-shelf application and hardware*

Following a second four-month round of TCP/IP tests on ACTS at 622 Mbps called project 118j (one of a suite of experiments numerically designated as ACTS Experiment #118), it was decided to display the results publicly. The venue for this demonstration was SuperComputing '97 (SC97) in San Jose, CA during November 1997. The intent was to demonstrate the feasibility of exchanging a Terabyte of application data between the show floor in San Jose and Cleveland in under five hours using the ACTS as a primary component in a 622 Mbps ATM network. Ampex tape drives and robots were the source of the terabyte of application data and several Sun Ultra workstations were used to optimize TCP and ATM system parameters.

For the demonstration, a contiguous OC-12 link was established from Building 142 at the NASA Lewis Research Center, across the satellite to Lawrence Livermore National Laboratory in Livermore, CA. From there, the OC-12 traversed the backbone of the National Transparent Optical Network (NTON) into the San Jose Convention Center, where it connected, via a dedicated fiber, to the NASA booth on the show floor.

At the time of the demonstration, the only computational platforms that had been thoroughly tested were Sun Microsystems Ultra 2s, running Solaris 2.6. Most of the TCP/IP parameters that had recently been tested and verified in the experiment were now available in the production release of Solaris 2.6, so the implementation that was demonstrated at SC97 was using off-the-shelf TCP/IP capabilities, available to any host running Solaris 2.6.

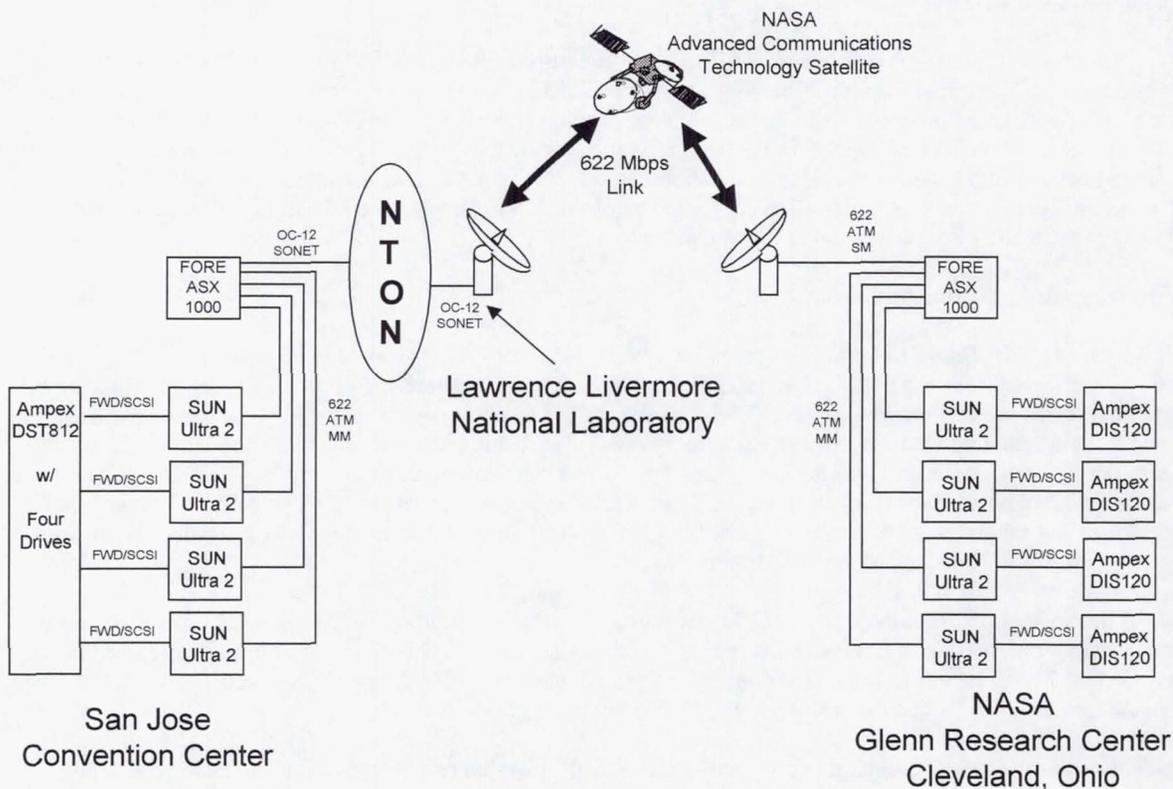
In addition to core protocol work with Sun, the 118j experiment team worked with Ampex Data Systems to gain a better understanding of the complexities of performing data transfer to and from high-performance tape peripheral devices. A data transfer program was written that resided in memory on the Ultra 2s and performed a 'shuttle' operation between the Ampex DIS-160 tape drives and the satellite network. The DIS-160 devices were capable of reading and writing tape at 20 Megabytes per second. In order to allow the tape devices to transfer data at line rate, the data transfer program moved data using optimized blocking factors to the tape devices (which were connected via Fast-Wide-Differential SCSI) and optimized TCP/IP parameters for the high-rate, long-delay satellite network. The goal of this portion of the demonstration was to make the satellite network appear to be transparent to the tape devices. Ampex provided four DIS-160 tape drives at each end of the satellite network to support the demonstration, which were also validated in the experiment.

This part of the demonstration was particularly taxing, since the only time the experiment team would ever have access to these tape assets would be at this particular venue, due to the high value of the borrowed equipment. Therefore, the team performed demonstrations during the day while the exhibits were open - and performed experiments and optimizations during the off-hours. The results were impressive:

Simultaneous tape to tape transfer using three pairs of workstations and tape drives reached an average, per stream, transfer rate of 120 Mbps and a single stream memory to memory transfer of 487 Mbps between an

Ultra workstation in San Jose and one in Cleveland. A peak transfer rate of 96% of the theoretical rate was obtained in this investigation thereby dispelling any myths using TCP/IP over geosynchronous satellites for wideband applications.

## End-to-end Demonstration Layout at SuperComputing '97



### *Geographically Distributed Terrain Database using ACTS*

Designed to showcase the high capacity, interactivity, and performance qualities of such hybrid networks, a three-dimensional Terravision<sup>7</sup>, developed by SRI International with NASA virtual reality (VR) extensions, demonstration also took place. ACTS OC-12 connectivity with the National Transparent Optical Network (NTON) and the NASA Research & Education Network (NREN) allowed users at SC97 to transverse through virtual territory by accessing data stored on servers at geographically dispersed servers. The VR equipment manipulated by the user senses the direction of movement and retrieves low resolution Bdata "tiles" adjacent to the direct path. As the direction of movement is confirmed, high resolution data replaces the low resolution "tile" - similar to your vision adjusting as your head movement dictates your ability to focus on any given area. Thus, the robustness of broadband digital satellites coupled with terrestrial fiber networks lets people test drive the technology and stimulate new and innovative applications.

### **High Speed Interoperability Testing**

Beginning May 1998, the next round of 622 Mbps experiments on ACTS was started by the 118 experiment team known as Experiment 118x. These new set of OC-12 experiments tried to optimize point-to-point data transfer over ACTS using TCP/IP across multiple computer platforms and operating systems such as Sun, Silicon Graphics, IBM,

and Microsoft. Further, satellite manufacturers were involved to address, firsthand, any lingering questions concerning the ability/validity of TCP/IP and ATM to deliver advanced services over Geostationary platforms.

While previous experiments had focused on ATM switching equipment provided by FORE Systems and computer hardware provided by Sun Microsystems, there was a strong desire to perform TCP/IP performance tests on other networking hardware, as well as other operating systems and computing platforms. For this phase of the experiment, known as 118x, Sun Microsystems, FORE Systems and Ampex Data Systems were joined by Cisco Systems, Intel, Digital Equipment / Compaq, Microsoft, WindRiver Systems and FTP Software. The Sprint Advanced Technology Laboratory in Burlingame, CA provided laboratory space to the 118x team. The terminal at Lawrence Livermore was used for the experiment, and terrestrial connectivity between Lawrence Livermore and Burlingame was again provided by the NTON.

Additionally, since the experiment was of high interest to the satellite community, the 118x team invited the satellite industry to get involved with the experiments. During the experiment, Lockheed Martin, Space Systems/LORAL, Hughes Space & Communications, and Spectrum Astro all participated in team meetings and helped to keep the experiment configurations and results reporting relevant.

Unfortunately, during the period of time that encompassed the 118x experiment, the ACTS High Data Rate network was plagued with problems that limited the team's aggressive schedule and test productivity. Many of the platforms were successfully tested, however - setting the stage for the next phase of experiments, which became known as '118neXt' or officially as ACTS Experiment #154.

### **High Performance TCP/IP Investigations As The Foundation For Internet In Space Implementation**

#### *Background*

Experiment 154 expanded on the partnerships, "lessons learned" and goals resulting from the previous 118 series of experiments. It is currently examining alternative network transports such as Gigabit Ethernet, 100-baseT, and "Packet over SONET" besides a pure ATM transport, active areas research of "Error Vs Congestion" TCP/IP work such Explicit Congestion Notification (ECN), and the newer OS and workstation platforms available.

Original research examined how bulk "TCP/IP over ATM" transfers behaved using "standards-based", "off the shelf" workstation equipment and OSs over the ACTS satellite using a subset of equipment and partners at 622Mbps with a ~530ms RTT available to Experiment 154. The goal was to convince system integrators when "standards-based" systems can support hybrid terrestrial/satellite system and where further work was needed. Experiment 154 furthers this goal by revisiting earlier immature software and hardware platforms. Also, it explores technologies and partners previously unavailable by creating two major objectives reflecting the earlier spirit of Experiment 118 and current Experiment 154 goals.

This network was built upon previous configurations, but added participation by Cabletron Systems, Hewlett-Packard, and IBM on the networking and computing hardware side. Also, several other NASA centers became more actively involved in the experiment and dialogue during Experiment 154, including the Goddard Space Flight Center and the Ames Research Center.

Also, during the break between 118x and 154 experiments, the Consolidated Space Operations Contract (CSOC) at the Johnson Space Center became active in the experiment. The Prime Contractor on CSOC is Lockheed Martin Space Operations (LMSO). An ACTS HDR Terminal was installed at the LMSO 'CSOC Central' facility in Houston, TX, about three miles from the Johnson Space Center. For all 154 experiment operations, the satellite link was connected between NASA Glenn in Cleveland and LMSO in Houston. Several LMSO engineers and Co-op students also supported the experiment configuration from the Houston location.

In an effort to stay abreast of advancements in the state-of-the-network, the 154 team endeavored to examine two relatively new networking technologies that were now available - Packet over SONET (POS) across the satellite network and Gigabit Ethernet in the Local Area Network. Cisco Systems and Cabletron Systems provided PoS technology. All new computing platforms were equipped with capability to handle ATM at 155 and

622 Mbps, 10/100 Ethernet, and Gigabit Ethernet. This mix of technologies offered a wide range of new test configurations. However, the small size of the core experiment team, coupled with the continued erratic behavior of the HDR network both limited the team's productivity.

The first objective is "Cross Vendor TCP/IP Interoperability testing over large (Bandwidth\*Delay) networks". This explores the homogenous and heterogeneous testing of current commercial TCP/IP stacks using "off the shelf" equipment in high bandwidth and delay environment. This environment is a 540ms RTT, 622Mb OC12c SONET link between Houston, TX and Cleveland, OH using various network protocol transports on the LAN and WAN side. Packet traces, various network, workstation, operating system parameters, experimental tools were used to provide feedback to vendors/researchers on how commercial TCP/IP stacks behave for bulk TCP/IP transfers in an high\*BW environment such as ACTS. As of this writing, there doesn't exist a commercial OC12 SONET delay to explore this realm of research. It is anticipated future satellite system supporting these rates or higher can rely on more commercial solutions for data interoperability into existing terrestrial networks.

The second objective examines "errors vs congestion TCP/IP behavior in an high delay and deterministically errorable satellite link". Experiment 154 provides a satellite testbed to examine how network congestion and errors influence commercial and research TCP/IP stacks across the ACTS satellite using deterministic error and congestion environment. Again, it is anticipated the information influences future satellite system to use commercial, "off the shelf" solutions to preserve interoperability between diverse workstation and networking platforms.

As of April 8, 2000, we are preceding to complete the objectives before the end of life of ACTS scheduled for May 31, 2000. The subsets completed will depend on the health and operational status of the satellite network of a system well past its original design life for high data rate experiments. Please see <http://acts.grc.nasa.gov> for any updates not reflected in this paper. These types of high bandwidth delay product investigations need to continue as other hybrid network opportunities become available.

Our present list of partners with no preferential order: NASA Glenn Research Center at Lewis Field's Space Communications Office, Lockheed Martin Space Operations Company (LMSOC) under the Consolidated Space Operations Contract (CSOC), NASA Johnson Space Center, Sun Microsystems, Compaq, IBM, Microsoft, HP, Intel, Marconi(Fore Systems), Cisco Systems, Cabletron, 3Com, Yuri System, Hughes, Boeing, Spectrum Astro, Ampex Data and Jet Propulsion Laboratory.

Our list of equipment with no preferential order: Marconi ASX2400 switch, Marconi ASX1200 ATM switch, Cisco 7507, Cabletron SSR8000, Compaq Alphas(Au600+AXP1000), Compaq Proliant 6400R dual processor PentiumIII, IBM RS6000, SUN Ultra60, Sun Netra, SUN atmcard, Marconi HE622 + PCA200, gigabit cards, and HP J5600 workstation.

### **Cross Vendor TCP/IP Interoperability Testing Over Large (Bandwidth\*Delay) Networks**

#### *Background*

The primary objective is to document the progressive steps required to reach {near} optimal bulk TCP/IP data transfers between homogenous and heterogeneous platforms across a high bandwidth\*delay path. Partner supplied equipment and workstations OS used tcp, tcptrace, netstat, tcpdump, vendor feedback, custom test scripts, network and workstations statistics and netperf to show these incremental data rate improvements. These tests became an iterative process of running simulated TCP/IP bulk transfers using tcp, examining the results at various network and workstation data points, working with vendors to optimize the next test by tuning or documenting kernel or workstation limitations, repeat until we reach the limits of the platform based on results reached by LAN test. These tests will be graphically plotted to see the effects of this tuning and feedback. The goal is to maximize the utilization of the link for TCP/IP.

Actual performance numbers are not intended for performance comparison between various vendors but to show how heterogeneous and homogenous workstations and networks behave in this extreme networking environment. Also, Experiment 154 examines if further work is necessary to get these platforms to interoperate while maximize the utilization of the data path.

*Network, platform interconnectivity and equipment list*

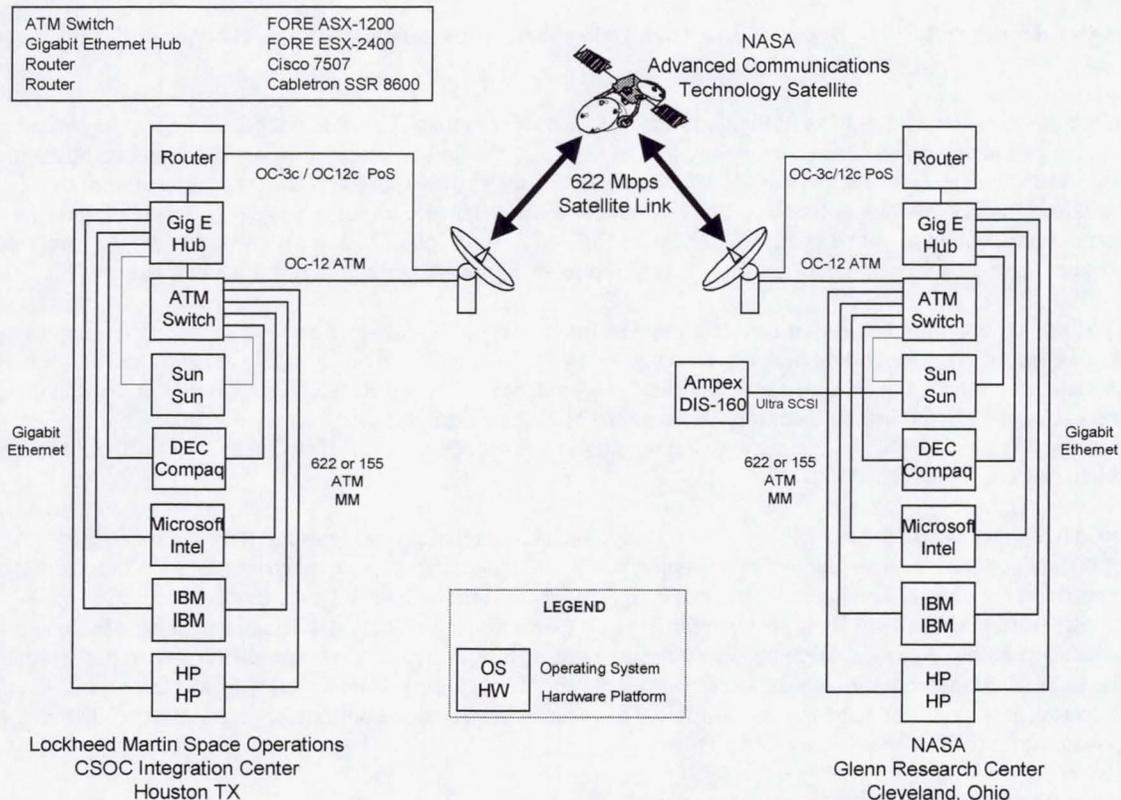
We are presently using these platforms and operating systems from:

- Compaq - Alpha processor-based 600au and AXP1000 platforms running TU64-4.0F and an Intel-based Proliant 6400R server running Windows2000 and Linux2.3.45. INTEL provided an earlier beta platform but was replaced when a COTS platform became available.
- IBM - RS60000 running AIX 4.3.4
- HP - J5600 running HP-UX.
- SUN - Ultra60 and Netra platforms running Solaris7/8

We are using network hardware from:

- Cisco Systems - 7507 series with "Packet over SONET"(POS) interfaces for 100BaseT and Gigabit across ACTS.
- Marconi Systems - ASX1200 ATM switches with FORERunner OC3 and OC12 workstations network cards and ESX2400 edge products for GigaBit and 100 BaseT connectivity using ATM over SONET across ACTS.
- Cabletron - SSR8000 for Gigabit over OC12 PoS between the two sites across ACTS.
- SUN and IBM network cards for Gigabit and "IP over ATM" OC12c support.

A C T S E x p e r i m e n t 1 5 4 e n d - t o - e n d N e t w o r k L a y o u t



*Where are we now, as of April 3, 2000?*

We have recorded network and platform statistics of Alpha to Alpha, IBM to IBM, Windows2000 to Windows2000, Sun to Sun, and some combinations of cross platform tests using a pure ATM transport at OC3/OC12, Gigabit and 100BaseT ethernet using ATM as the base transport across the satellite. Some of these tests have only verified

connectivity between platforms, while others have recorded TCP packet traces, network level statistics, and ATM cell rate traces during a bulk TCP/IP run.

We are seeing runs as low as 1 Mbps in some configurations to near line rate in other platform across the satellite. Currently, we don't feel comfortable associating vendor names to actual numbers until the end of the 154 experiments, set for May 2000. We are trying to document the steps necessary to bring the network utilizations of these systems up to the expected limits based on network and workstation architecture. If we can't, we need to get this information to the community to address those problems in a follow work. Please see: <http://acts.grc.nasa.gov> for updates during the summer of 2000.

#### *Current test plan and goals until ACTS "end of life" on May 31, 2000*

We are trying to finish recording TCP/IP bulk transfer behavior across ACTS with a combination of homogenous and heterogeneous platform using their respective ATM and ethernet interfaces for the three possible network configurations between the Cleveland, OH and Houston, TX.

1. Platform's ATM interface for IP transport using "ATM over SONET" across the ACTS satellite.
2. Platform's 100BaseT and GigaBit ethernet for IP transport using "ATM over SONET" across the ACTS satellite.
3. Platform's 100BaseT and GigaBit ethernet for IP transport using "Packet over SONET" across the ACTS satellite.

We are planning to record as much data as possible, based on the platform selected, for any future follow on work and completion of missed configurations. Please see <http://acts.grc.nasa.gov> for any updates not reflected in this paper. It is hope any missed configuration can be picked up when commercially available OC12c and higher SONET delay simulators and/or satellite links become available.

### **Errors vs Congestion TCP/IP Behavior in a High Delay and Deterministically Errorable Satellite Link**

#### *Background*

One of the more challenging aspects of the high-performance work is that TCP/IP is not presently able to distinguish between errors and congestion. As a result, any loss of traffic on the end-to-end connection between two hosts is assumed to be caused by congestion. For satellite data transfer scenarios - especially those at high data rates - this effect can lead to very low link utilization. The experiment team endeavored to gain a better understanding of the various mechanisms that might be available to help TCP/IP do a better job of distinguishing between link errors and congestion. This part of the 154 experiment was referred to as 'Explicit Corruption Notification Testing'.

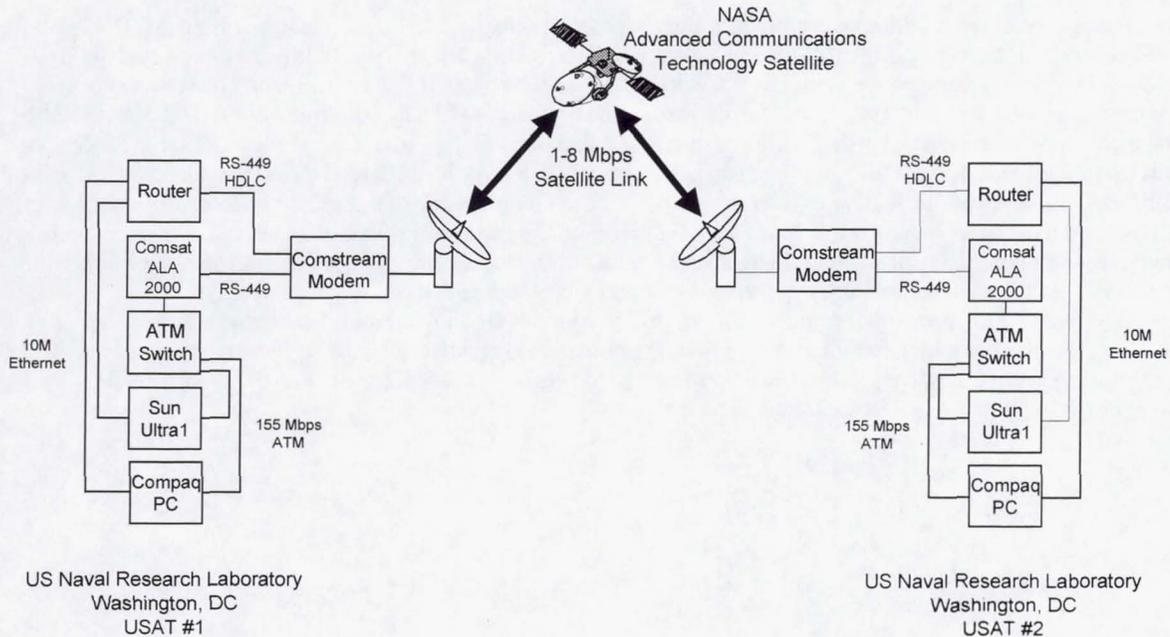
During March of 2000, the 154 experiment team started the process of building a new testbed facility to support links across the ACTS spacecraft at data rates ranging up to 8 Mbps, with any bit error rate. The testbed will utilize laboratories at the NASA Glenn Research Center in Cleveland, the US Naval Research Laboratory in Washington, DC, and Lockheed Martin Space Operations in Houston. The experimenters may leverage the unique ability of ACTS to support satellite links operating at extremely high rates (155Mbps, 622Mbps) for this work, should that be desirable in the context of these tests.

The focus of the new laboratory capability was to study mechanisms that provide explicit notification of link corruption and congestion, with the goal of gaining a better understanding of these mechanisms in order to promote further work on the most promising mechanisms. Insights gained from the Explicit Corruption Notification experiments would hopefully make it possible for Explicit Corruption Notification mechanisms to be safe for implementation in the Internet at-large at some point in the near future. The experiment team solicited participation from the Internet community through personal invitations, and through an announcement that was distributed via the IETF's 'tcpsat', 'pila', and 'end2end' interest groups. This work is expected to continue beyond the end of life of the ACTS spacecraft utilizing another satellite platform.

#### *Network, platform interconnectivity and equipment list*

The workstations and networking hardware to support the experiment were assembled initially at the Naval Research Laboratory in Washington, DC. This configuration initially included two Sun workstations supporting Solaris 7, and two PC platforms supporting Linux, FreeBSD and Win2000. Other platforms and operating system environments could be added at a later date depending on requirements.

## 1 5 4 E C N E x p e r i m e n t L a y o u t



### *Where are we now, as of April 3, 2000?*

A number of experiment proposals were received and evaluated by the team for their ability to be integrated for testing in the new environment. For those mechanisms selected, access to the hardware platforms (in-person and/or remote) was provided, along with satellite time on the ACTS spacecraft for testing and evaluation of the mechanisms. Currently, the initial test configuration has been setup at the Naval Research Laboratory (NRL) and satellite checkouts have commenced.

### *Current test plan and goals until ACTS "end of life" on May 31, 2000*

The current plan is to investigate the relation between congestion and link error detection/correction using various protocols such as TCP/IP, Satellite Communication Protocol Standard (SCPS) and protocol implementation and link characteristics.

### *Lesson learned to date for these objectives*

Commercial equipment and networking hardware can support bulk transfer of TCP/IP using high bandwidth\*delay satellite link such as ACTS. It is necessary to test these platforms to address any glitches discovered when running vendor's TCP/IP implementation in this extreme environment. Tuning and locating kernel/driver bugs may be required from the application down to the network card level but with proper tools and partner participation, we can show remarkable improvement of bulk TCP/IP data rates, without resorting to custom hacks to the TCP/IP protocol.

## Conclusion

The convergence of the satellite, telecommunications, and computing industries has benefited from ACTS High Speed networking interoperability experiments. Data rates over hybrid terrestrial/satellite links have evolved from 70 Mbps TCP/IP requiring an high end ONYX workstation with beta quality OC3c workstation, networking equipment, and operating systems, in 1995, to achieving near theoretical TCP/IP performance at 622 Mbps/OC12 data rates, in 1999, using off-the-shelf network, hardware, and networking protocols. Thus, a GSN system designed to transport OC3c/OC12c SONET between two points in CONUS back in 1993 for Telcos, has adapted to support emerging COTS network technologies over the years. This evolution is one of our greatest accomplishments with the GSN and its success is greatly due to the government-industry partnerships that have formed to address such complex system issues. By using ACTS High Speed Network Interoperability Experiments to stay the course with commercial off-the-shelf technologies and demonstrate how the work is directly applicable to hybrid terrestrial/satellite systems, without resorting to propriety solutions for moving user data across a network. Therefore, this work has long term impacts upon how future hybrid architectures are implemented for space missions, data services, or even aeronautical applications to achieve a space internet or airborne internet by leveraging the terrestrial internet technologies.

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<sup>2</sup> Carlson, Wayne E., Bedford, Keith W., The Viento Project: Distributed Coupling of Mesoscale Atmospheric and Lake Models Using NASA's ACTS, 16th AIAA International Communications Satellite Systems Conference, February 25-29, 1996

<sup>3</sup> Cohen, J., Shopbell, P., Bergman, L. Remote Observing with the Keck Telescope Using the ACTS Satellite, Final Report for NASA Grant #BK-509-20-42-00-00, March 1, 1998

<sup>4</sup> Bergman, L.A., Gary, J.P., Edelson, B.I. and Helm, N., High Data Rate ACTS Experiments for Performing Global Climate Model, 16th AIAA International Communications Satellite Systems Conference, February 25-29, 1996

<sup>5</sup> Gargione, F., Bergman, L. A., U.S.-Japan Transpacific High /Data Rate Intersatellite Link , 16th AIAA International Communications Satellite Systems Conference, February 25-29, 1996

<sup>6</sup> Brooks, D., Buffinton, C., Beering, D., Welch, A., Ivancic W., Zernic, M., and Hoder, D., "ACTS 118x Final Report High Speed TCP Interoperability Testing", NASA/TM-1999-209272, July, 1999

<sup>7</sup> Y. G. Leclerc and S. Q. Lau (1994). "TerraVision: A Terrain Visualization System", AIC Technical Note 540, SRI International, Menlo Park, CA, March 1994.

## 4.3 - NASA and Industry Benefits of Acts High-Speed Network Interoperability Experiments

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

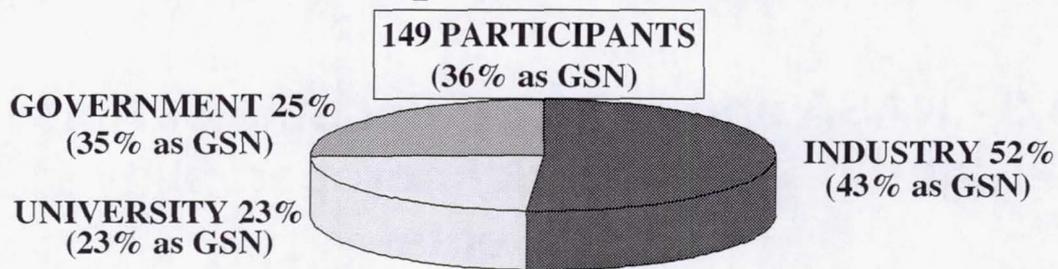
### ACTS Experiments Program Objectives

- Characterize ACTS Technologies
- Promote New and Innovative Applications
- Demonstrate Use of Future Satellite Services
- Evaluate Satellite-Terrestrial Interoperability
- Evaluate ACTS in inclined orbit operations
- Verify new Ka-band Advancements

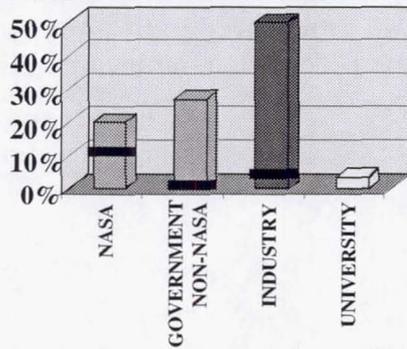
**Inclined Orbit Operations has enabled  
18 networking experiments (27 total) and over  
50 government and industry partners**



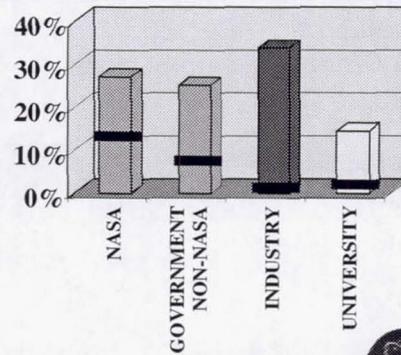
# ACTS Experiment Utilization



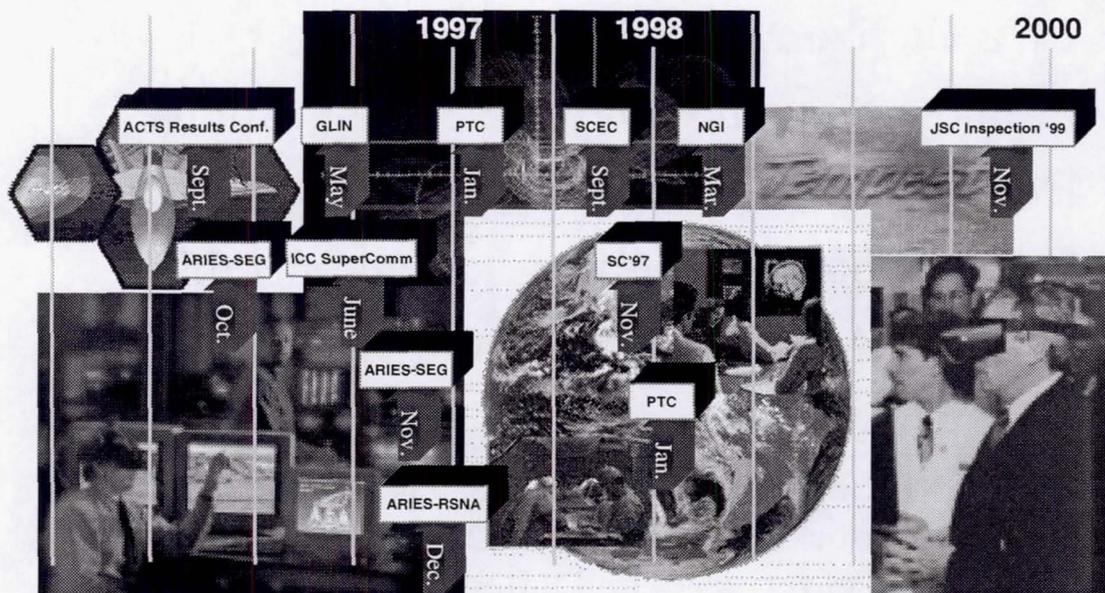
**86 DEMONSTRATIONS (14% as GSN)**



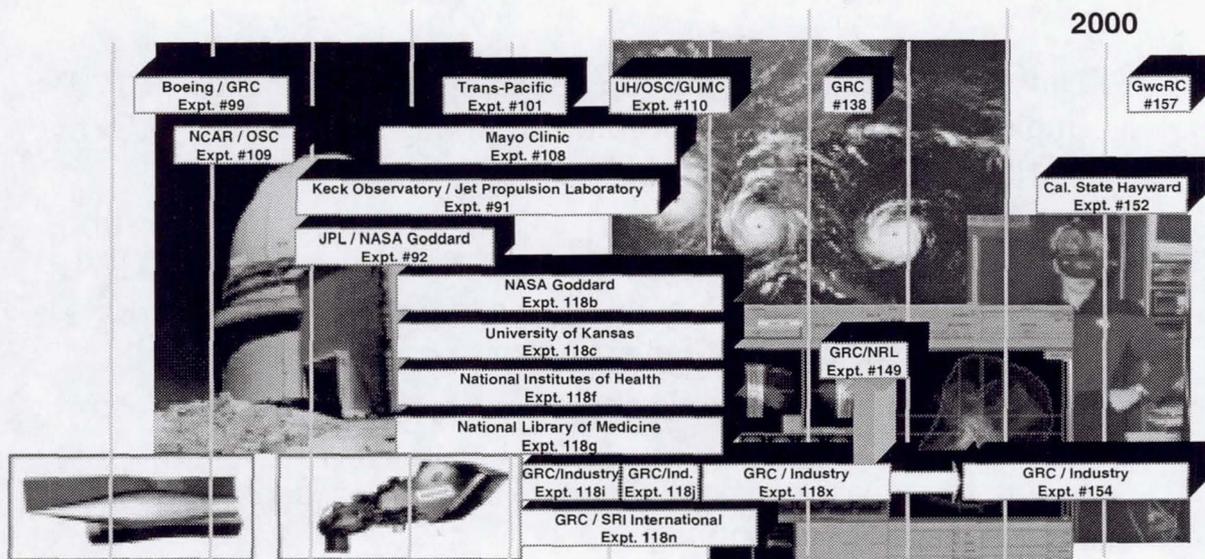
**104 EXPERIMENTS (18% as GSN)**



# ACTS GSN Demonstration Timeline



# ACTS GSN Experiment Timeline



## NASA and Industry Strategy

- Public-Private Partnerships
- Simple Evolves to Increasingly Complex
- Basic Performance
- Homogeneous/Heterogeneous Interoperability
- Hybrid Network/System Attributes
- Influence Commercial-Off-The-Shelf Products
- Operational Assessments



# ACTS Experiment 154 Objectives

- Develop a recognized, interoperable, high-performance TCP/IP implementation across multiple computing / operating platforms, working in partnership with the computer industry
- Work with the satellite industry to answer outstanding questions regarding the use of standard network mechanisms (e.g. TCP/IP and ATM) for the delivery of advanced data services, and for use onboard as a part of emerging spacecraft architectures
- Test and evaluate available and emerging network mechanisms that distinguish between losses due to link errors vs. congestion in order to advocate and develop a standard version of TCP/IP that supports this capability



# ACTS Experiment 154 Consortium

## Computing

- ❖ Sun Microsystems
- ❖ Compaq
- ❖ Microsoft
- ❖ Intel
- ❖ IBM
- ❖ Hewlett-Packard

## Spacecraft Manufacturers

- ❖ Hughes Space & Communications
- ❖ Lockheed Martin
- ❖ Space Systems/Loral
- ❖ Spectrum Astro

## Communications

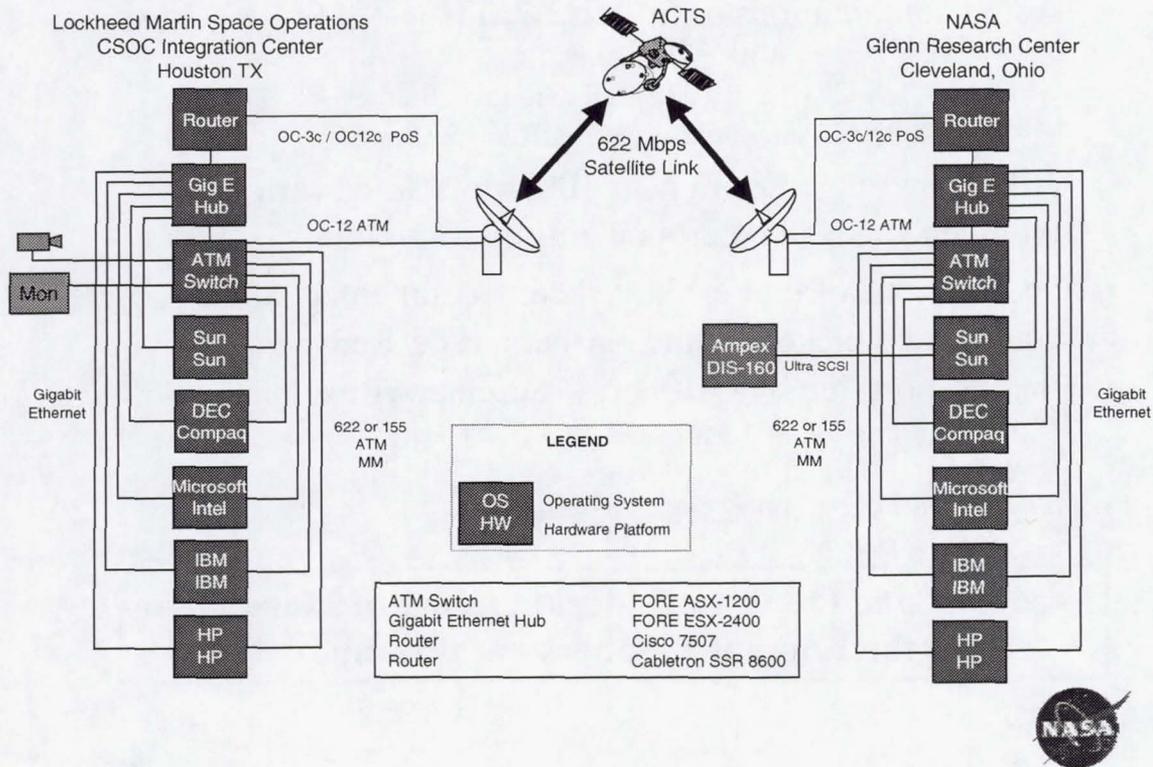
- ❖ Ampex Data Systems
- ❖ Comsat Laboratories
- ❖ Cisco Systems
- ❖ FORE / Marconi
- ❖ Raytheon Telecom
- ❖ Cabletron Systems

## U.S. Government Laboratories

- ❖ NASA Glenn Research Center
- ❖ NASA Ames Research Center
- ❖ NASA Johnson Space Center
- ❖ NASA Goddard Space Flight Center
- ❖ NASA Jet Propulsion Laboratory
- ❖ U.S. Naval Research Laboratory



# ACTS Experiment 154 Diagram



## Test Tools and Methods

- Examine the performance and behavior of bulk TCP/IP data transfers across a high bandwidth\*delay path
- Document the progressive steps necessary to reach {near} optimal TCP/IP data rates using:
  - tcp, tcptrace, netstat, tcpdump, vendor feedback, grabportstats, and other tools
  - Show the improvements of data rates using tcptrace and grabportstats
- Testing was an iterative process:
  - Bulk TCP/IP data transfer, examining the results of various network and workstation data points, work with vendors to optimize the next test, repeat until we reach the limits of the platform{or reach "LAN rates"}
  - GRC's "tcp\_script" used to automatically document receiver and transmitter workstation states for homogenous-heterogeneous runs



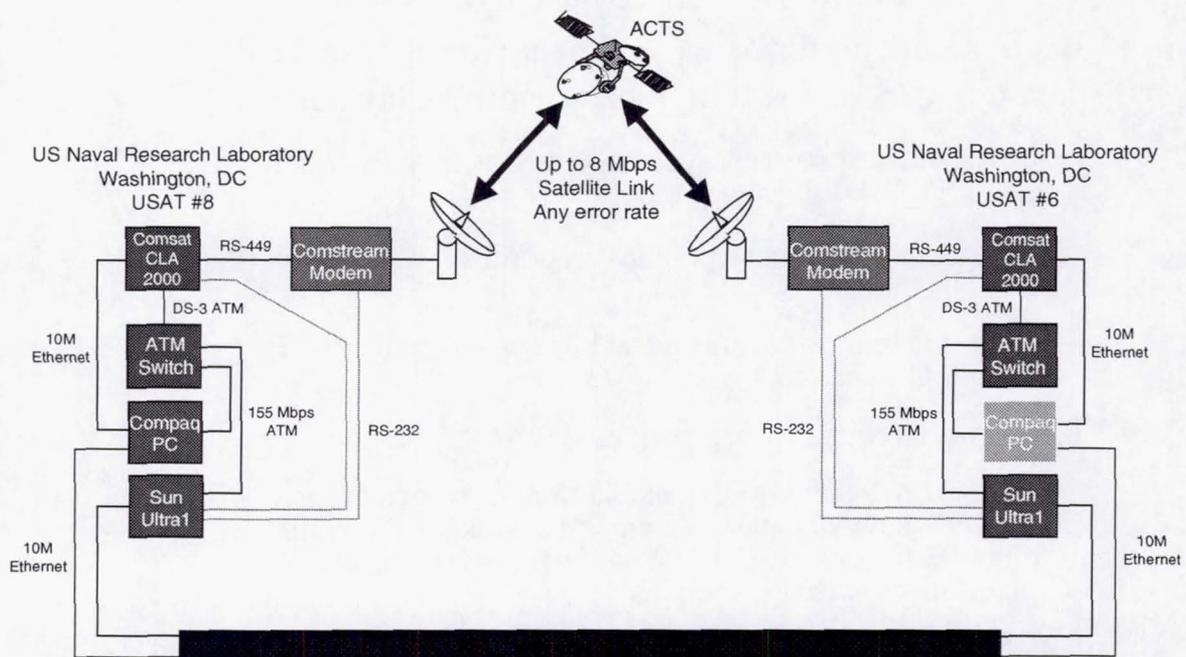
# General Preliminary Results

- Tested combinations of Solaris2.7, TU64-V4.0f, Windows 2000, HPUX 11, and AIX4.3.4
  - Used ATM CLIP and 100BaseT/Gigabit Ethernet ATM
  - OC12 SONET satellite link with a Rtt= $\sim$ 532ms
- Utilization ranged from near 100% to 2% for various homogeneous and heterogeneous configurations
- Observations of interest have been documented so the work can be picked by the partners, if desired
- Final Report due by October; Preliminary Results:
  - Win2k - Gigabit 431 Mbps(SAT)
  - Solaris - ATM CLIP  $\sim$ 510 Mbps(SAT)
  - AIX - ATM CLIP(OC3c)  $\sim$ 130 Mbps
  - TU64 to HPUX - ATM CLIP  $\sim$  330Mbps(SAT)

**Feedback and Other Considerations are of More Value than Actual Numbers - at this time**



## 154 Errors-vs.-Congestion Configuration



## NASA / SOMO / Industry Benefits

- Develop strong relationships with commercial and U.S. Government organizations in a number of critical areas with live experiment as a backdrop
- Rapid evolution of new capabilities readily incorporated into commercial platforms – ready to be used to solve NASA's problems
- Strong potential for lower lifecycle cost and lower implementation risk
- Unique technical environment able to test hardware and software /operating platforms at the leading edge of the performance envelope



## What's Next ... ?

- Continued TCP/IP Errors-vs.-Congestion testing on Telstar 11 (Ku-Band) from Loral/SkyNet at Naval Research Laboratory
- Transition of high-performance test environment to work with NASA's Tracking & Data Relay Satellite System (TDRSS)
- Ground network extensions to space links in order to more realistically emulate NASA's operational environment (via NREN, Internet2, Abilene, etc.)

