NASA

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Research in Satellite-Fiber Network Interoperability		5. Report Date 6. Performing Organization Code
7. Author(s) Burt Edelson		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address George Washington University 2100 M Street, NW Suite 310 Washington, DC 20052		11. Contract or Grant No. NAS5-32337 USRA subcontract No. 5555-066-50
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001 NASA Goddard Space Flight Center Greenbelt, MD 20771		13. Type of Report and Period Covered Final February 1996 - September 1997 14. Sponsoring Agency Code

15. Supplementary Notes

This work was performed under a subcontract issued by
Universities Space Research Association
10227 Wincopin Circle, Suite 212
Columbia, MD 21044

Task 66

16. Abstract

This four part report evaluated the performance of high data rate transmission links using the ACTS satellite, and to provide a preparatory test framework for two of the space science applications that have been approved for tests and demonstrations as part of the overall ACTS program. The test plan will provide guidance and information necessary to find the optimal values of the transmission parameters and then apply these parameters to specific applications. The first part will focus on the satellite-to-earth link. The second part is a set of tests to study the performance of ATM on the ACTS channel. The third and fourth parts of the test plan will cover the space science applications, Global Climate Modeling and Keck Telescope Acquisition Modeling and Control.

17. Key Words (Suggested by Author(s)) acts experiment	18. Distribution Statement Unclassified--Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 1	22. Price

NASA Form 1626 Oct 86

TEST PLAN FOR

ACTS

SPACE SCIENCE EXPERIMENTS

Introduction

The Advanced Communications Technology Satellite (ACTS) represents a large investment by NASA to design, develop and demonstrate new satellite technologies to support and promote the nation's civil, commercial and military satellite communications programs.

To test and demonstrate high data rate satellite communications, NASA and ARPA developed ground terminal equipment that can operate at SONET data rates up to 622 Mb/s (OC-12). A series of high data rate experiments have been approved. These experiments will characterize the use of the ACTS satellite with new digital protocols, algorithms and architectures and will demonstrate space science applications that require the high data rate of supercomputer networks.

George Washington University has prepared the following test plan to evaluate the performance of high data rate transmission links using the ACTS satellite, and to provide a preparatory test framework for two of the space science applications that have been approved for tests and demonstatrations as part of the overall ACTS program. This test plan will provide guidance and information necessary to find the optimal values of the transmission parameters and then apply these parameters to specific applications. The test plan is comprised of four parts. The first part will focus on the satellite-to-earth link. The second part is a set of tests to study the performance of ATM on the ACTS channel. The third and fourth parts of the test plan will cover the space science applications, Global Climate Modeling and Keck Telescope Acquisition Modeling and Control.

The ACTS high bit rate terminals are scheduled to be delivered to the Jet Propulsion Laboratory, the Goddard Space Flight Center and the State of Hawaii in October, 1995. This test plan will begin by establishing the initial pointing accuracy of the antennas and continue through the demonstration of the applications. The test plan is prepared as a roadmap and introduces an evolutionary approach to thoroughly test and demonstrate the merits of high data rate rate networking via the ACTS satellite. Finally, the test plan provides an easy framework for evaluating the results of the experiments and assists in preparing technical papers and final reports that will validate the level of accomplishment of the experiments.

Part I.– Satellite–to–Earth Link Tests

1.- INTRODUCTION

The ACTS high data rate earth stations operates at 30/20 GHz (Ka–Band). It is known that Ka–Band frequencies are subject to disruptions of service due to precipitation attenuation. Further, the beamwidths of the antenna for both transmit and receive functions are quite small, with the transmit 1/2–power beamwidth being only 0.3 degrees. That means that a pointing error of 0.15 degrees from the correct direction will reduce the power transmitted by a factor of two. Thus, antenna pointing must be done quite accurately.

The ACTS satellite moves with a period of 24 hours within a small 'box' in the pointing space, azimuth and elevation. It is necessary, therefore, to optimize the pointing of the antenna when the satellite is in the center of its box.

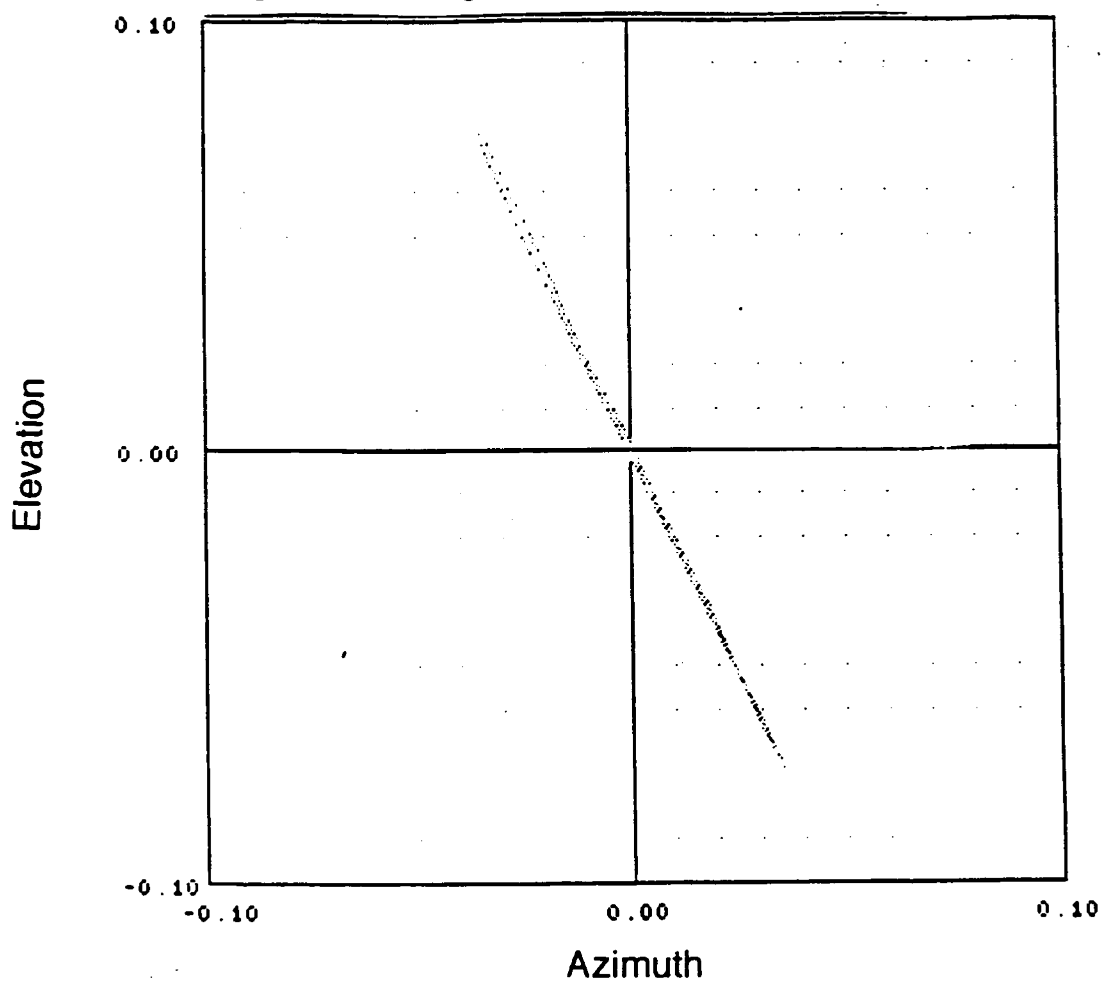
To optimize the transmission parameters it is prudent to make some measurements on the satellite link as part of the high data rate digital experiments. These measurements also will include effects of rain, so that we can obtain some operational familiarity with the service reliability of the link, rather than simply measure propagation using the beacon frequency.

2.- POINTING ACCURACY

To obtain an estimate of the pointing accuracy, it will be necessary to measure the beacon power received over several 24–hour periods. Unfortunately, the antenna does not pass the 30 GHz beacon frequency to the receive side on the communications equipment. With the ability to obtain the 20 GHz beacon frequency, we intend to plot received power vs. time. From this we can extract the pointing accuracy, both in angle and in time. If it is not possible to view the beacon, then we will ask to have a signal put up through the satellite to serve as a beacon. The latter is somewhat less desirable, since the transmitted signal includes the effects of the uplink. But, since the satellite is hard limiting on the uplink, these effects are minimized.

From the orbital elements for the satellite, it is possible to plot the daily motion of the satellite within its nominal 'box' as a function of time. Using that information and the observed beacon power, we should be able to determine the actual pointing angles of the earth station antenna, and, if necessary, make required corrections in the pointing angles.

Figure 1, shows the satellite motion for a 24-hour period as a change in azimuth and elevation for the GSFC position of the earth station. To obtain a current plot of figure 1, we require the orbital elements of the ACTS satellite. This information is available from the Lockheed Martin Astro Space satellite orbit manager, Mr. Kent Mitchell. The satellite is being kept within a very tight box, about +/- 0.05 degrees in latitude and longitude, centered on the nominal satellite position of 100 degrees west longitude.



Maximum Pointing — Maximum Signal Loss

30 GHz — Fixed Point 1.12dB

Figure 1: Satellite Position - Earth Station Pointing

3.- PROPAGATION EFFECTS

Propagation effects at 30/20 GHz can be fairly severe. Heavy rain can cause path losses of ten dB or more. Studies have been made by others, e.g. COMSAT, of the propagation effects by measuring the power received from the satellite beacons and correlating these measurements with observed rainfall, etc.

We do not intend to duplicate these measurements, but it will be instructive to determine the effects of rain on the actual performance of the link. For that purpose we need to install a simple rain guage near the antenna and make BER measurements during periods of rain. In addition to that, we must make some visual observations of the actual weather conditions. Severe rain tends to be fairly local, e.g. a thundershower, but to cause rain fading, the rainfall must be within the antenna beam, and it can often be observed visually and/or by making intelligent estimates. Since we do not have access to the link continuously, we need to keep a log of observed weather conditions and BER values during our allocation of satellite availability.

The results obtained should yield an estimate of the link in–service reliability. The link reliability obtained from the actual operational experience will then be compared to the predicted link reliability obtained from link budget calculations.

Since the link operation is affected by both the up and down links, it will be necessary to know the prevailing weather conditions at the other end of the link. Thus, a similar station log needs to be maintained at the other end. In view of the limiting conditions of the satellite transponder on the up link, mild degradations on the transmitting end should not show up on the receiving end. Therefore, we need not obtain very accurate rainfall information from the transmit station.

4.- LINK CALCULATION VERIFICATION

4.1 Theoretical Link Performance

We will make theoretical link performance calculations based on the performance data for the earth station and the satellite. We will try to include any known effects or degradations that pertain to the particular earth station.

4.2 Observed Link Performance

We will use a spectrum analyzer at the 3 GHz intermediate frequency to make Signal–to–Noise measurements. We will at the same time measure the error performance of the modem. The two measurements should show a fairly good correlation. We will make an analysis of the results to verify the operational parameters of the system.

5.- ANALYSIS OF PERFORMANCE RESULTS

The following areas will be noted in the operation log books and then analyzed in more detail. These analzses will then be described in the final report on the transmission characteristics associated with the ACTS high data rate space science experiments.

5.1 Weather

5.2 Pointing

5.3 Antenna Performance (Tx, Rx , other)

5.4 Up Link

5.5 Down Link

5.6 Performance at GSFC vs. Performance at LeRC, JPL, and Hawaii

The initial results obtained at the GSFC site will be compared with the transmission parameters obtained at LeRC during its experiment with the Boeing Corporation. This comparison will be made as soon as possible to determine that the re–installation of the earth terminal at GSFC has not changed the overall earth station performance measured when the HDR terminal was located at LeRC.

6.- CONCLUSIONS (Part 1)

In addition to a comprehensive final report on Part 1, the Satellite–to–Earth Link Tests, an initial report will be prepared on the effects of moving the terminal from LeRC, if any, as well as its performance at the GSFC site. This initial report will assist the space science team in the conduct of their experiments.

Part 2.- ATM over an ACTS Channel

1.- INTRODUCTION

The Part 2 tests will characterize the performance of the basic protocols which are used in the Global Climate Modeling applications [11] and in the Keck Acquisition Visualization and Control over ACTS [13] experiments. Previous work has been done to characterize the application level protocol, namely PVM, performance for the Global Climate Modeling application [3] on a high speed satellite link. Additional work has been done over a low speed (T1) ACTS link, that addresses the limitations of the TCP protocol. It suggests an elegant solution that can be applied to the file transfer protocol (FTP) and other applications [12].

In this part of the test plan we are proposing a set of tests which will evaluate the limitations and characterize the performance of each one of the protocols (IP, TCP and UDP) by itself, before addressing the application layer protocol performance. These tests will provide a solid background to the science teams in terms of what would be the performance ceiling of the ACTS ATM link. In addition, we are proposing to use the application layer solution to the file transfer protocol (XFTP) [12] and compare the performance results with those of the standard FTP using the TCP extended window option. In summary, we will provide the throughput, latency and packet loss rates of the above protocols as functions of the packet and window sizes, the link speed and the number of nodes.

2.- PRELIMINARY TESTS

2.1 Test Configuration and Methodology

In order to characterize the ACTS channel with regard to ATM traffic, we propose an end-to-end test. ATM cells will be fed to the GSFC ATM (Fore Systems) switch by an ATM analyzer (generator function). These will be received by the other ATM analyzer (analyzer function) connected to the ATM switch at JPL.

During the preliminary phase, loop back tests (figure 2) will be undertaken at GSFC. These tests will characterize the overall communication link and system, from the ATM switch to the satellite. This will include the fiber optic OC-3 link, the HDR terminal and the satellite up and down link. This test will require the use of only one analyzer. This analyzer will perform both traffic generation and measurement functions. The ATM switch will be configured so that the forward and backward traffic always are switched between the same ports. These ports will be identified as port1 and port2 (OC-3 155.52 Mbit/s fiber link interfaces).

In both configurations, the switch management function will be turned off to avoid the influence of band traffic on the performance. Transfer latency, cell loss ratio, cell delay variation and cell error ratio will be measured for different physical Bit Error Rates values (This will be simulated by a noise generator.)

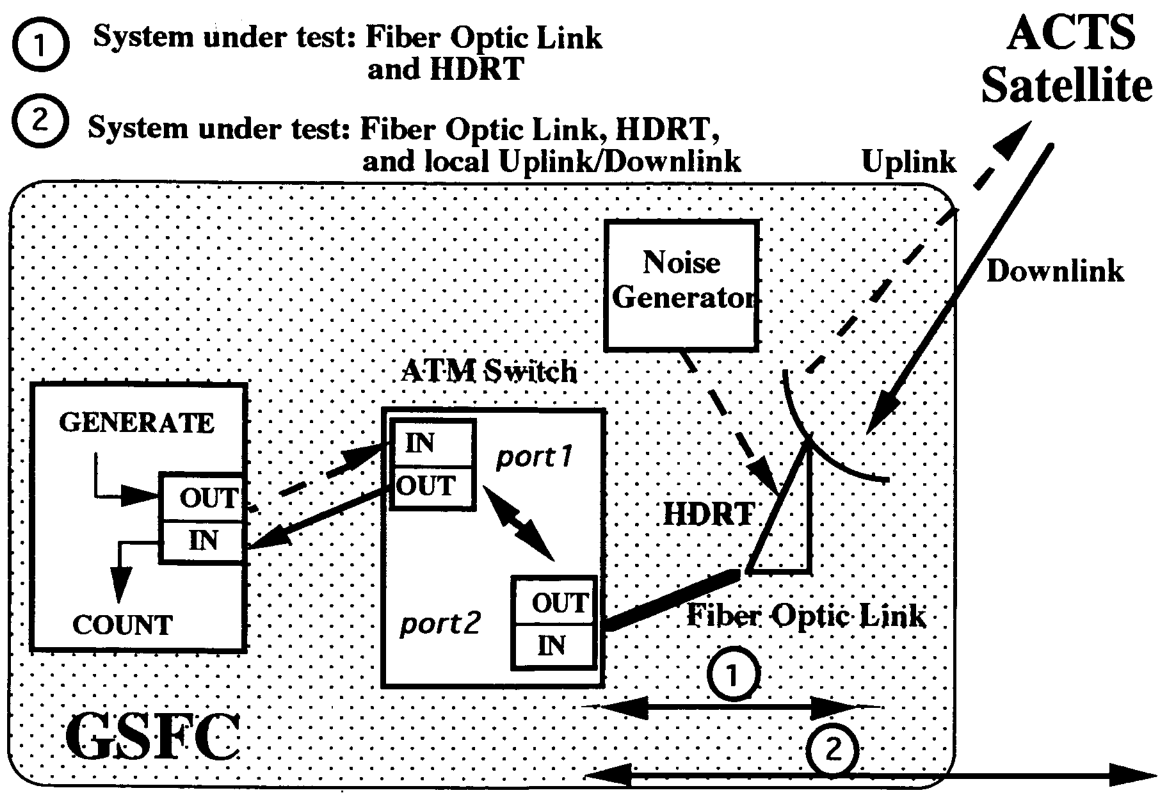


Figure 2: Loop back tests configuration

<u>2.2 Latency - Cell Transfer Delay</u>

This parameter measures the amount of time required to establish a virtual connection and to transmit cells between two end-stations. The end-to-end configuration will allow measurement of the latency between cell transmission and reception, for cells flowing within a single virtual circuit. A constant bit rate stream (for example, one cell every 20 cell times) will be used for the test.

<u>2.3 Cell Loss Ratio</u>

By comparing the cells sequence number on an end-to-end basis, we can estimate the amount of cells that eventually have been lost over the ACTS channel.

Then, cell loss ratio will be derived by dividing the number of cells lost by the number of cells transmitted.

2.4 Cell Delay Variation

This cell delay variation parameter refers to the differences in end-to-end transit times for a given series of cells. It allows the investigator to estimate the consistency of the transmission of cells on the ACTS channel. In fact, when latency varies, cell inter-arrival times fluctuate. Cell delay variation will be measured by taking the standard deviation of cell delay over a certain number of cells, transmitted via a constant bit rate stream.

2.5 Cell Error Ratio

This parameter measures the accuracy of the ATM connection between GSFC and JPL. It will indicate how the ACTS channel latency and characteristics affect end-to-end ATM cells flow. The cell error ratio is computed by dividing the number of error cells by the number of cells transmitted. ATM level Bit Error Rate is given by analyzing the integrity of data within cells payload.

PART 3.- CBR/VBR TRAFFIC

This CBR/VBR traffic test will verify the ability of the ACTS channel to protect delay-sensitive CBR (constant bit rate: simulation of a voice traffic) flow when such traffic is sent to a port already fed with bursty VBR (variable bit rate: simulation of a data traffic) cells flow. As bursty traffic, we will consider "IP-over-ATM" like traffic generated by the analyzer. The frame size will be set to 9-kbyte, which is the maximum size defined by the IETF (Internet Engineering Task Force). The data flow burst will be a certain percentage of the available bandwidth on the OC-3 ATM interface, once the CBR cells were accounted for. This test will indicate if the latency introduced by the ACTS channel will disrupt or not delay-sensitive traffic as voice and video.

PART 4.- TCP/IP TESTS

The following TCP/IP measurements should be performed on an incremental loopback, point to point, multiple hop and point to multipoint (multicasting) configurations between the available HDR terminals. All these different architectures will illustrate the peculiarities of an IP/ATM ACTS network.

4.1. IP Tests

The purpose of the IP tests in the test plan is to characterize the performance of the IP/ATM link. This set of measurements will evaluate the performance of the satellite link over a wide range of rates from OC-3 to OC-12. Prior to the space science experiments over ACTS, it is important to evaluate the throughput of the IP/ATM link parametrized by the link speed and the message size.

In addition to these parameters, IP tests will discuss the impact of the number of hops between origin and destination. This test is important because the obtained results can be compared to similar test results from the NSF terrestrial IP/ATM backbone (vBNS). Such a comparison will clarify the role of the IP as the network protocol in satellite and hybrid high speed networks.

In this experiment, we will use a diagnostic tool, namely "windowed ping" [1], which provides direct measurement of IP performance, including queue dynamics. It uses a transport style sliding window algorithm combined with either ping or traceroute to sustain packet queues in the network. It can directly measure such parameters as throughput, packet loss rates and queue size as functions of packet and window sizes. Other parameters, such as switching time per byte or per packet can also be derived.

The need to understand the performance limitations of IP equipment and technologies vis-a-vis a high rate, high delay link drives this set of experiments. As the author of windowed ping discusses[1], rate based IP performance tools, can measure performance at rates below queue formation but only at ill defined points beyond congestion. They cannot measure switch performance under conditions of sustained partial queues. Clearly, in a megabit networking environment, the behavior of IP formed queues is of great importance. Windowed ping measures throughput (delivered data) and packet loss as functions of packet size and window size. During the IP link evaluation, we will measure the above quantities and in addition we will introduce as test parameters, the amount of hops in the IP path between the source and the destination, and the line speed. The amount of hops can either be two or four, depending on whether we use loopback configuration. Figure 3 illustrates the experiment architecture.

In addition to the IP performance, IP multicast performance will be tested. IP multicast, uses a substantially smaller number of packets than the IP when it delivers data to a group of users. Therefore, it is expected that the protocol switch performance should be better due to the smaller size of the partial IP queues throughout the network.

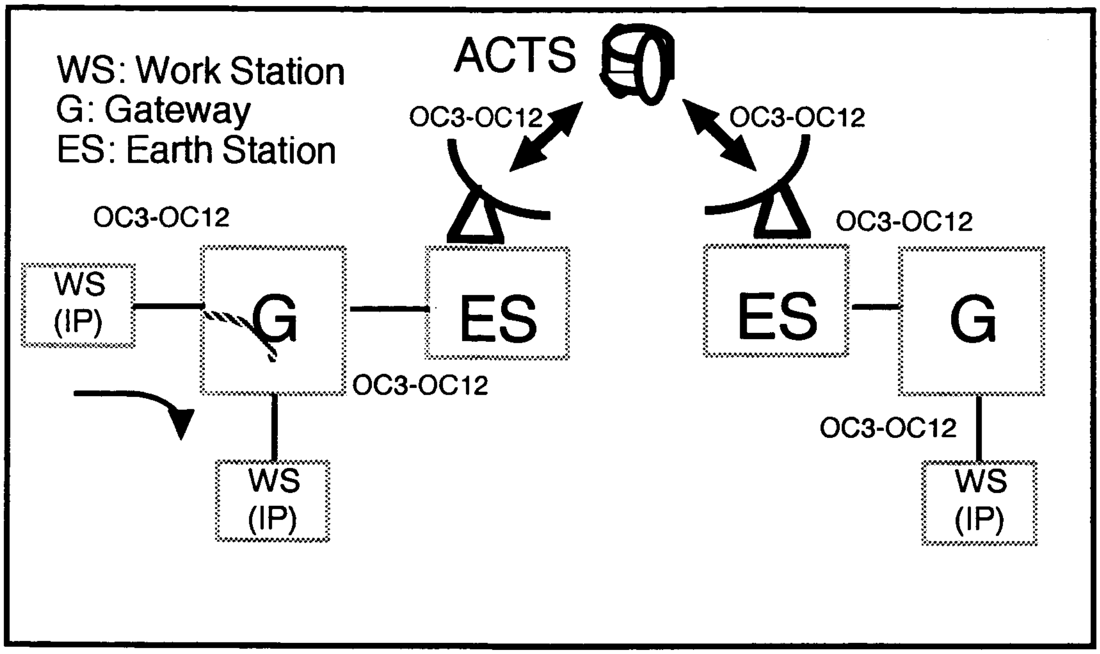


Figure 3: IP Testing

4.2 TCP-UDP Tests

The purpose of the TCP tests is to characterize the performance of the TCP protocol over the ACTS IP/ATM link. We will perform a series of measurements to evaluate the throughput and the latency of the TCP/IP suite, as a function of the link speed, the message size and the window size. Similar network architecture as in the IP tests will be used (figure[1]). This architecture will enable us to run point to point tests as well as tests between two or four nodes (hops) and measure the TCP performance in a single and a multiple link satellite network.

Previous work has been done on evaluating TCP and UDP on a local testbed [2], [4] and by using PVM both locally and over the ACTS [3], [12]. The proposed tests will take in consideration all the previous results on the TCP performance over the ACTS T1 link, and they will investigate TCP on the IP/ATM ACTS backbone. The main tool to evaluate the latency and the throughput parametrized by the window size, the message size, the number of hops and the line speed is TTCP [8]. Other analysis tools that may be used include tcpdump, netstat and/or atmstat [7].

In addition to the investigation of the performance of the TCP Extended Window option, the proposed (for T1 satellite links) solution at the application layer [12] will be investigated as well.

The application layer protocol used at the Global Climate Modeling experiment is PVM, which uses mainly UDP for remote process communication.

Since UDP is not a reliable protocol, PVM uses its own error recovery mechanism. The proposed techniques [4] to overcome the PVM error recovery protocol limitations will be used. The UDP protocol also is used in the proposed multimedia multicasting demonstration to carry IP packets to multiple groups of users.

Since UDP is the protocol used in applications over ACTS, such as PVM and MBONE, it is crucial to analyze its behavior in a high rate, high delay environment. Because UDP operates at the same level as TCP, i.e., on the top of IP, the same TCP tests will be performed to evaluate the throughput and the latency of UDP as a function of packet and speed link over the IP/ATM ACTS backbone.

After performing the above measurements for the individual protocols of the the link and understanding the expected performance of the TCP-UDP/IP suite in correlation with the high data rate terminal characteristics and the ATM level tests, we will investigate the performance of a network application. The proposed experiment follows.

PART 5.- APPLICATIONS TESTS

The GWU test plan now merges with the test plan activities of the two space science applications. A preparatory level of tests may be conducted to obtain transmission link data. But the conduct of the majority of the applications tests will be done to further the experiment behavior of the science applications.

5.1 HIPPI/ATM/SONET Test

The HIPPI/SONET architectures provide this test plan with the potential of using the full OC-12 (622 Mb/s) bandwidth of the ACTS channel, with the lowest host or network overhead. This test will use the HIPPI/SONET Gateway device made at the Los Alamos National Laboratory. It is likely that this HIPPI/SONET transmission will provide thê highest ACTS channel throughputs and thus it will be coordinated closely with the space science applications

The SONET/ATM tests will operate in the OC-3 (155 Mb/s) speed, and a complete end-to-end ATM test using multi-node hybrid networks is proposed. For example, an ATM signal would originate at a supercomputer at one of the Advanced Technology Developement (ATD) network nodes, and route the terrestrial traffic to the earth terminal at GSFC and the via the ACTS satellite to the JPL and Hawaii earth terminals, where it would be routed through terrestrial fiber cable networks to locations such as the San Diego Supercomputer Center or the Maui Supercomputer Center.

5.2 Multicasting Multimedia Test

The main goal of this applications test is to implement and evaluate a multimedia multicasting session between the three earth stations (GFSC, JPL, Hawaii) where the number of participants changes dynamically. During the sessions we will apply all the previous results to evaluate how user level performance correlates to the network utilization for different link speeds and different sources of traffic. Specifically, we will try to evaluate user level performance in the presence of data only, voice and data, video, voice and data, etc. The multicasting architecture will be both, one to many configuration (classroom environment) and many to many (teleconference environment).

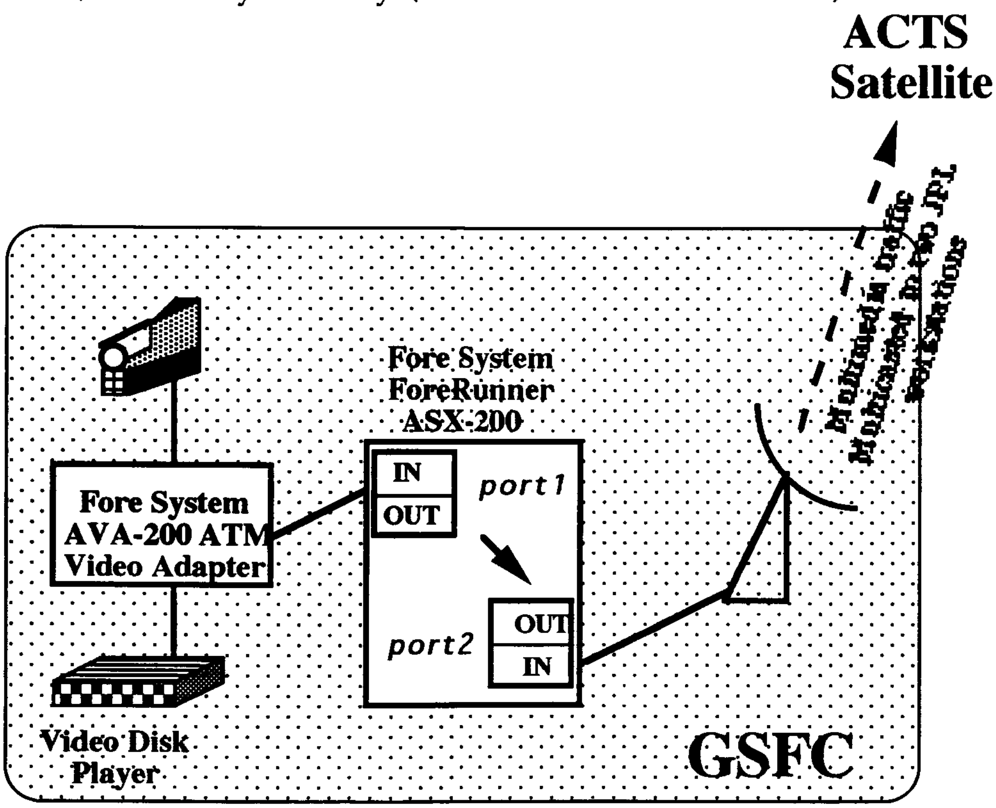


Figure 4: Multimedia communications over the ACTS channel

5.2.1 **Option 1: Fore System Platform.-** Multimedia traffic will be multicasted from GSFC via the Fore System AVA-200 ATM Video Adapter, to one or many Workstations at JPL (figure 4).

5.2.2 **Option 2: MBONE Framework.-** The main protocol that supports network multicasting is IP multicast. IP multicast provides for the delivery of IP datagrams to multiple hosts across an IP based backbone. First defined in 1988 by Steve Deering [9], IP multicast is used today across the global Internet. IP multicast is composed of three parts: extensions to the IP protocol, which is little more than group addressing standard; a group management protocol called IGMP to allow hosts to join and leave groups dynamically and a multicast protocol to enable routers to correctly forward multicast datagrams.

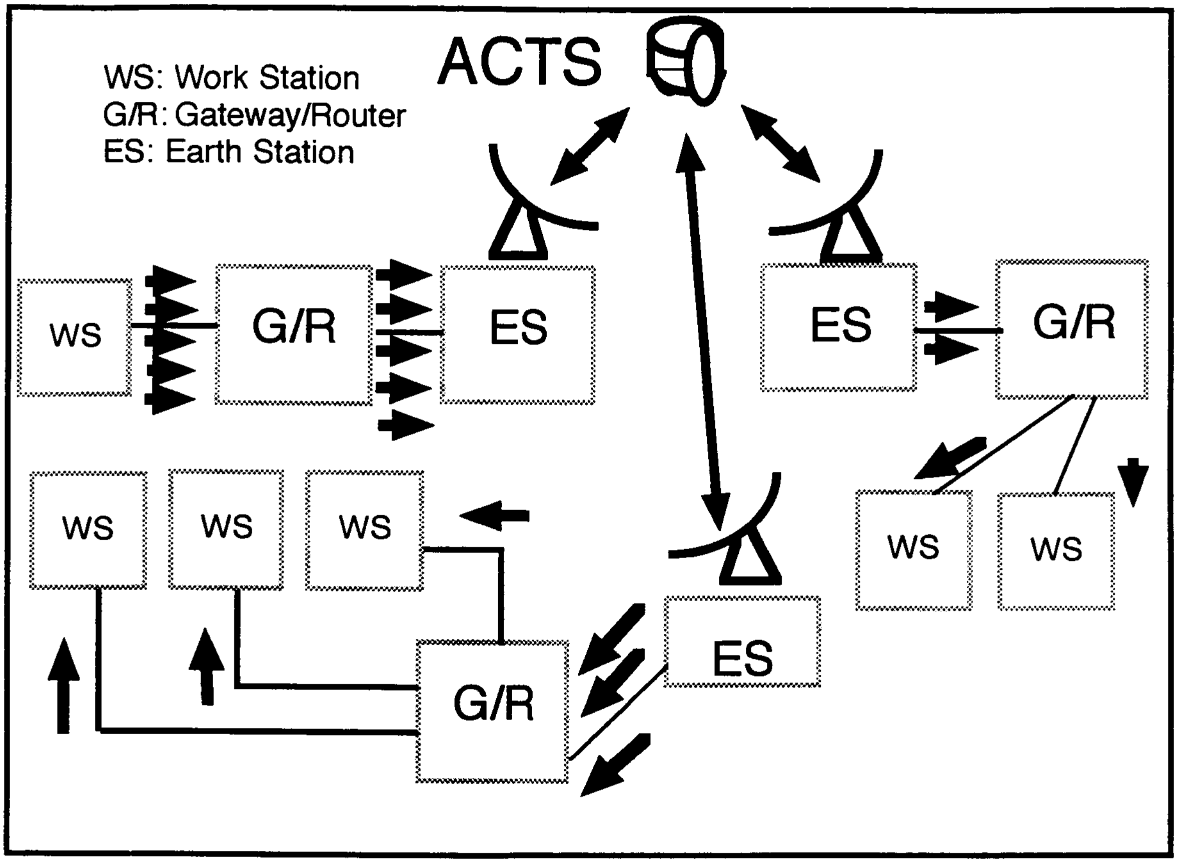


Figure 5: Unicast Transmission

IP multicast traffic is carried over a virtual network called the MBONE [10]. Traffic on the MBONE is audio, video and imagery all carried over UDP. A set of publicly available tools allows a user connected to the MBONE to sit on tele-conference, video conferences of special events and audio programs. A user can scan the list of active sessions at any time and join one or more of them. As a result of this degree of freedom and the lack of resource reservation, user level performance can degrade sharply during periods of heavy use. These are the phenomena in conjunction with the IP partial queue sizes that we would like to investigate over the ATM ACTS link parametrized by the link speed (OC3-OC12).

The advantage of multicasting versus unicast transmission is illustrated in figures 5 and 6. A single source sends the same message to five destinations. In figure 5, five data units, one for each destination are sent through the network traveling the same route for much of their journey. We would like to take advantage of the common paths and send only one copy where the route is shared. This idea is the one behind multicasting, as shown in figure [3] where one data unit is injected into the network and travels along the shared path. The benefits to be gained by multicasting in terms of reduced bandwidth and other network resources should be clear in this example scenario.

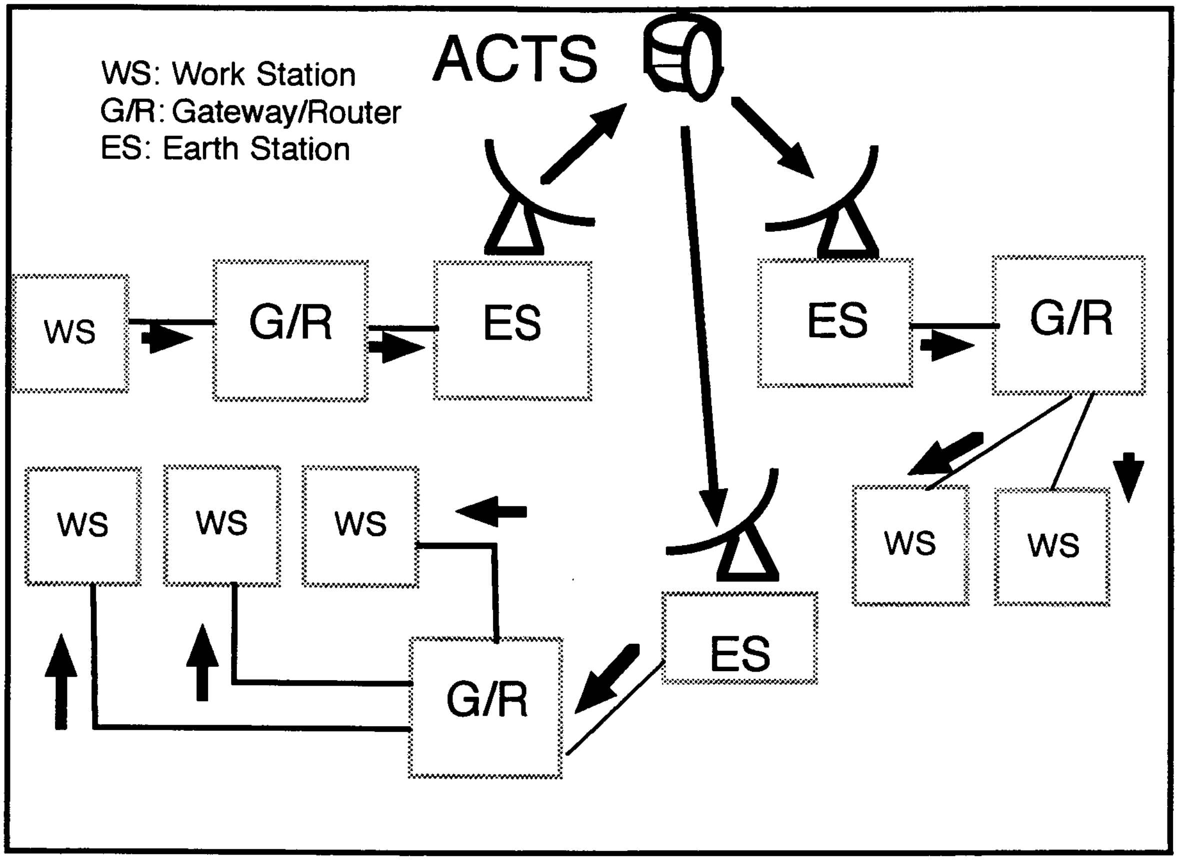


Figure 6: Multicast Transmission

The vast majority of traffic over the MBONE is audio and video streams running over UDP. Applications have been built by the Internet research community to send and receive audio and video. Additional hardware (a camera and microphone) is needed only if a user wishes to send. In our experiment, we would like to explore both cases and see how the performance of the application degrades when the traffic increases. All the previous measurements, in specific IP and UDP/IP, should be taken to account in order to understand the limitations of ACTS ATM multicasting sessions. Finally, empirical results of session performance as a function of the number of participants, the speed of the link and the nature of the traffic will be furnished.

6. - TEST EQUIPMENT

m: Mandatory
o: Optional

1.- Two ATM analyzers for the end-to-end test (Wandel & Goltermann ATM-100 analyzer or any ATM analyzer). (m)

2.- Two Fore Systems Fore Runner ASX-200 ATM switches. (m)

3.- Three workstations with a Fore Systems Network Adapter Card on each of them (for the multimedia test). (m)

4.- A Fore Systems ATM Video Adapter model AVA-200. (o)

5.- MBONE software. (o)

6.- A camera and a video disk player. (o)

7.- Noise generator. (m)

8.- Spectrum Analyzer with a frequency coverage including 3.5 GHz. (m)References

7. - REFERENCES

[1] M.Mathis. "Windowed Ping: An IP layer performance diagnostic" (DRAFT) Proc. INET '94/JENC5

[2] P.W.Dowd,S.M.Srinidhi,E.Blade,R.Claus. "Issues in ATM supportof high performance geographically distributed computing" NASA-Lewis Research Center.

[3] D.E.Brooks,T.M.Carrozi,P.W.Dowd,I.Lopez,P.A.Pellegrino,S.M.Srinidhi "ATM based geographically distributed computing over ACTS". NASA-Lewis Research Center.

[4] P.W.Dowd,S.M.Srinidhi,P.A.Pellegrino,T.M.Carrozi,R.Claus,D.Guglielmi "Impact of transport protocols and message passing libraries on cluster-based computing performance". NASA-Lewis Research Center.

[5] M.F.Wehner et all. "Toward a high performance distributed memory climate model". Proc. 2nd International symposium on high performance distributed computing. pp.102-113.

[6] C.Mechose, J.Ferrara,J.Spahn. "Achieving superlinear speedup on a heterogeneous distributed system". IEEE parallel and distributed technology, Summer 1994. pp 57-61.

[7] J.P.Gary. "Distributed global climate model experiment via ACTS", slide presentation, ACTS results conference, September 1995.

[8] J.P.Gary,S.M.Srinidhi. E-mail conversation and early performance data on the SONET/ATM satellite link.

[9] S.Deering. "Host extensions for IP multicasting". RFC 1112, SRI Network Information Center, August 1988.

[10] M.Macedonia,D.Brutzman. "MBONE provides audio and video across the Internet". Computer magazine, IEEE Computer Society, April 1994.

[11] N.R.Helm,B.I.Edelson. "ACTS Supercomputer Network of Global Science Applications", AIAA 15th International Communications Satellite Conference, San Diego, CA., February, 1994.

[12] M.Allman,H.Kruse,S.Ostermann. "Data Transfer Efficiency Over Satellite Circuits Using a Multi Socket Extension to the File Transfer Protocol (FTP)", ACTS Results Conference, August 1995.

[13] L.A.Bergman,J.G.Cohen,P.Shopbell. "KECK Acquisition, visualization, and Control over ACTS"

ACTS TSTI EXPERIMENTAL APPLICATIONS

REQUEST FOR USE OF ACTS FOR FIELD TRIAL/EXPERIMENT

July 24, 1996

Please submit the following information with your request to use ACTS for a field trial/experiment:

1. The name, address, phone and fax number of the requester and technical contact. The name(s) of the organizations associated with performing, sponsoring and/or funding the demonstration.

P.I.:
Pat Gary
NASA GSFC
MS Code 933
Greenbelt, MD 20771
tel:(301)286-8834 fax: (301)286-1777
email: pat.gary@gsfc.nasa.gov

Co-P.I.:
Larry Bergman
Jet Propulsion Laboratories
4800 Oak Grove Drive, MS 300-329
Pasadena, CA 91109
tel:(301)571-2523 fax: (301)564-4408
email: larry@jplopto.Jpl.Nasa.gov

Prakash Chitre
COMSAT Laboratories
22300 Comsat Drive
Clarksburg, MD 20875-9471
tel:(301)428-4167 fax: (301)428-7747
chitre@ntd.comsat.com

Neil Helm
IASR, George Washington University
2020 K Street, NW Room 304
Washington, DC 20052
tel:(202)994-5509 fax: (202)994-5296
email: helm@seas.gwu.edu

Richard Wolff
Bellcore
MRE 2L287
445 South Street
Morristown, NW 07960-6438
tel:(201)829-4537 fax: (201)829-5888
email: rsw@thumper.bellcore.com

The testbeds will be opened to other participants such as government agencies, professional organizations, communications carriers, universities

2. The dates requested (actual date(s) of the field trail/experiment plus any set-up and/or testing dates).

FY'97 October 1 through the end of FY'98 or through the end of ACTS experiment program, whichever comes first.

3. A schedule of the needed satellite hours (EST hours per each requested date).

Testbeds will request a minimum of 10 hours/week for testbed testings with some latitude in the actual time of the day (i.e: The testbed may be able to operate during evening hours). SIT testbed will request a number of demonstration times in the second half of FY'97 and throughout FY'98.

4. A description of the assistance and services requested from NASA (include NASA personnel resources, if applicable).

The TSTI backbone consists of HDR terminals located at GSFC and JPL. A TSTI laboratory or test center will be established at GSFC with personnel to be provided primarily by COMSAT, Bellcore, and GWU.

It is proposed to connect most of the NASA centers into the interoperable network using HDRs or the NASA NREN as appropriate. It is expected that each center will pay for its own resources.

This TSTI experiment will require no special resources from the ACTS satellite or from the ACTS Project Office at the LeRC.

5. A description of the field trial/experiment, including:

This proposed project will design, develop, integrate and manage a satellite interoperable testbed (SIT) to test and demonstrate the required interoperable communications hardware and software interface specifications, protocols, architectures and standards. The testbed will develop the tools to work on the interoperability problems that are inherent characteristics of satellite links- (a) errors, (b) delay, and (c) bandwidth limitations. The U.S. communications carriers, industry and government will benefit directly from the testbed by the transition of tools, technologies and standards to provide interoperable hybrid terrestrial cable and satellite communications networks, operating seamlessly around the globe.

a. A technical abstract which contains

(1) A system diagram (the transmit/ receive data rates, a list of all equipment requested from NASA, and a list of all experiment equipment).

The HDR terminals at GSFC and at JPL

(2) A plan for testing and checking-out the field trial/experiment.

[Include task chart to be prepared by Bellcore]

(3) A chart indicating the roles and responsibilities of those performing the field trial/experiment.

[To be included and prepared]

(4) The location(s) of all field trial/experiment sites.

GSFC and JPL

b. The objective of the field trial/experiment. In addition, please discuss

(1) The significance of using ACTS in the field trial/experiment.

The recent technology development in communications satellites, such as broadband high data rate transponders and on-board processing, especially demonstrated by NASA's ACTS satellite, combined with the reality that implementation costs of optical fiber cables with natural barriers such as oceans, mountains and international political boundaries, result in a realization that future communications networks must rely on hybrid wire and wireless facilities.

(2) A list of all requested Government equipment (Earth Stations, application equipment, etc.).

HDR terminals at GSFC and JPL

(3) The target audience the field trial/experiment is intended to reach.

US industry, communications carriers and government agencies

(4) The method of publicity and the display/handouts to be used (if any) which show the participation of ACTS in the field trial/experiment.

A series of demonstrations are scheduled to take place primarily at conferences and expositions for industries with communication carriers, and government agencies. Specifically for NASA, demonstrations will be scheduled at GSFC and JPL, where Headquarters personnel will be invited.

(5) The metric to be used to measure whether the objective was attained.

The metric will be the conduct of seamless inoperable communications networks. In addition, a specific transfer of technology task will be maintained to see that the results of the SIT tests, demonstrations and interoperable tools such as software protocols are transferred to US industries and communication carriers

6. A brief outline of the paper to be submitted to NASA upon completion of a field trial/experiment with ACTS.

Keynote Remarks*

HIGH DATA RATE SATELLITE COMMUNICATIONS

Burton I. Edelson
George Washington University
Washington, DC - USA
202-994-5509/5505 (fax)
edelson@seas.gwu.edu

--

Science and technology have progressed to such a degree that communications through the use of space satellites has become possible. — I invite all nations to participate in a communications satellite system, in the interest of world peace and closer brotherhood among peoples of the world.

[John F. Kennedy, 24 July 1961]

--

With these words, thirty-five years ago, President Kennedy set in motion a train of events which developed into the high quality, cost-effective global satellite communications network we know today. Soon after Kennedy's policy statement, the U.S. Congress passed the Communications Satellite Act of 1962 to form Comsat Corporation. The United States then joined with ten other nations to form the international body known as Intelsat. And in April 1965, less than four years after the concept was suggested, the world's first commercial satellite, Intelsat I, known as Early Bird, was launched, and operational telecommunications service inaugurated between North America and Europe. This first satellite link carried 240 telephone circuits at $32,000 per circuit-year compared with the single undersea telephone cable then existing which carried only 150 circuits at about $100,000 each. The satellite also had a unique broadband capability, frequently demonstrated, to carry television across the ocean with the phrase "live via satellite."

Unfortunately, though, Early Bird had some embarrassing limitations. It had no multiple access capability, so it could provide only a single trans-Atlantic link, from Canada *or* the U.S. to either France, Germany, Italy *or* the UK. We had to take turns! Also, that first satellite could carry only multiple telephone circuits *or* a single TV channel, not both. To transmit a World Cup football match, for example, we had to cut off all the telephone circuits!

Early Progress

Technological and operational progress was very fast in the early days of satellite communications. By the end of its first decade, Intelsat was well into the fourth generation of successively larger, more powerful satellites (see table)—providing global coverage, connecting hundreds of earth stations, carrying thousands of telephone circuits plus television and data.

	Intelsat I	Intelsat IV	Δ
First launch	1965	1971	6 years
Weight	38 kg	700 kg	18x
Power	40 w	700 w	17x
Bandwidth	50 MHz	500 MHz	10x
Capacity (circuits)	240	4000	16x
Cost/circuit-year	$32,000	$1,200	4%

* Prepared for presentation at the Second Ka-band Utilization Conference and SCGII Workshop, Florence, Italy, 24 September 1996

With more powerful satellites came the opportunity to shrink the size of earth stations which could then be customized to fit users' requirements—located on a roof top, for example, or on a moving platform. Microwave technology moved ahead rapidly in the 1970s, bringing improved TWT and solid-state power amplifiers, microwave integrated circuits, and multi-beam antennas. These technologies led to the development of domestic satellite systems in several countries—in Canada (1972), the U.S. (1974), and Indonesia (1976). Marisat, the first mobile satcom system, was established in 1976 later to be incorporated into the INMARSAT system.

Because power and bandwidth are such precious commodities in the geostationary orbit, satellite systems have led the way in one of the most important developments in telecommunications—the shift from analog to digital processing and transmission techniques. Digital techniques (e.g. PCM coding, PSK modulation, TDMA) were rapidly developed and introduced in satellite communications systems starting in the mid-1970s, installed in many systems in the 80s, to provide efficient data compression, demand assignment, and multiple access systems.

Satcom Today

Satellite communications today is big business—exceeding $20 billion per year, with various sectors growing at annual rates of 10% to 30%. As the first and still the only significant commercial pay-off from space, satellite communications continues to return $30 for every dollar invested in R&D. More than two hundred countries and territories are involved in satellite communications; ten with significant industrial capacity. There are some thirty national, regional and international satcom systems in operation employing over 200 satellites in geostationary orbit. Thousands of large earth stations ranging from three to thirty meters, some 200,000 VSAT terminals (1 to 3 meters), and millions of broadcast receivers (less than one meter) carry voice, video and data traffic to international capitals and remote villages, to ships at sea and aircraft in flight, around the globe and around the clock.

Of the three satellite communications services—fixed, mobile, and broadcast—only the first may be considered really mature—growing at rates of 5-10% per year. Within the fixed service, telephone traffic seems to be flat or decreasing, TV distribution is increasing slowly (offset somewhat by gains in transmission efficiency), and VSAT systems are increasing rapidly (but account for relatively little transponder capacity).

Broadcast and mobile satellite services are growing rapidly—both over 20% per year. The future of direct broadcast television service looks very bright indeed with an untapped and untried additional market in data broadcasting. Within the mobile service, the concept of personal communications by satellite, with users employing handheld phones, has caught the imagination of many (and the pocketbooks of quite a few). Competition for the personal service market among LEO, MEO and GEO systems is furious. Although it is clear that not all can be winners, it is certain that a few will—and the market is huge!

Within the fixed service, sparkling new opportunities appear to lie in high data rate networks—the market created by the introduction of optical fiber cables into local and regional telecommunications systems. The question seems to be whether satellites will have a significant role in interconnecting these local and regional networks into national and international ones, or whether fibers will overwhelm the global information infrastructure.

It is important to note that all three services—fixed broadcast, and mobile—have competitive terrestrial systems (see table).

Service	Competitor	Satellite advantage
Fixed	Optical fibers	Multi-node networks
Broadcast	Cable networks	Wide area coverage
Mobile	Cellular	Wide area coverage

When we claim "a role of satellites in the GII" we generally emphasize the wide area coverage and the attendant distance-insensitivity to cost that satellites provide. This capability gives satcom an enormous and unchallenged advantage in the broadcast and mobile services. The networking advantages of satellites over cables are somewhat more subtle (and a principal subject of these remarks).

Satellites *vs* Cables

The rapid growth in telecommunications around the globe is causing a demand for ever higher data rates. Many businesses today are subscribing to ISDN service (64 kb/s), and corporate networks are going to T-1 (1.5 Mb/s). Research centers are requesting T-3 (45 Mb/s). National and international carriers (including the Internet backbone) are now employing OC-3 (155 Mb/s). "Gigabit testbeds" (such as those in the U.S. HPCC program) are operating at OC-12 (622 Mb/s) and OC-48 (2.4 Gb/s), and advanced technology experiments are pushing to rates as high as 100 Gb/s. There is little doubt that the first decade of the next century will see operational requirements emerge for all of these high data rates. Experience has shown that tomorrow's users "require" what today's technology provides!

Let us examine the role that satellites can, and hopefully will, play in these future HDR networks. First, we must concede that, for short point-to-point links, fiber-optic cables (like other terrestrial links) are preferable. Even for quite long links, providing direct connections exist, cables win out. Before touting satellites, we must recognize that, for the same data rate and quality of service, cable links have greater bandwidth, are more cost-effective, and have less delay time (latency), than do satellite links. Since most computer networks will involve only a few machines located in a small geographical area, it can be expected that fiber-optic cables will play the dominant role in connecting them. However, some networks in the future will connect a relatively large number of links, some of which may be quite distant from each other—across continents or oceans—and thus can be more efficiently handled via satellites.

If several widely separated sites are to be interconnected, satellites can provide significant performance and cost advantages over cables. If many sites are to be connected, satellites win handily. Because of satellites' wide area coverage, and their valuable demand assignment and multiple access capabilities, these advantages increase with:

The number of nodes in the network
The distance between the nodes
The variation in traffic loading on network paths
The existence of geographic or political boundaries between nodes in the network

These four factors all contribute to the preference for satellite-based networks in trans-continental, trans-oceanic, and international service.

In addition to multi-node networks, a traditional niche for satellites has been in "thin route" service, and they will undoubtedly be so employed in the future. Although it seems strange now to think of an OC-3 link as "thin", when the world is girdled with multi-gigabit fiber-optic networks, links to remote areas carrying "only" 155 Mb/s will be considered "thin"—and will just as surely be carried by satellites then as they are today.

Satellites, with their multiple-access demand-assignment capabilities can provide great flexibility as well economy to networks. One satellite transponder, for example, may be used as a transmission channel between Italy and Canada at one instant of time, then a millisecond later, between England and Mexico, adjusting rapidly to traffic loading.

This network advantage for satellite service is very clear in VSAT systems in which the national switched telephone system is by-passed. The General Motors Corporation in the U.S., for example, has a 9000-node VSAT network connecting all of its offices, factories, suppliers and dealers. Current VSAT systems operate at low data rates (fractional T-1), but will inevitably move up the data rate scale. This same advantage will also exist at higher data rates, i.e. what is true at T-1 today, will be equally true at thirty times the rate (T-3) tomorrow, and at one hundred times the rate (OC-3) the day after. Indeed, calculations (by AT&T) show that for satellite service to be more cost-effective than terrestrial service between two sites in the United States, they need to be separated by 5000 kilometers; for three sites, 3500 km; four sites, 1300 km; and five sites, only 800 km. Of course, for many sites, say 100 or more, the satellite's advantage is overwhelming.

Satellite-based networks, as we know, also have additional advantages in terms of mobility and transportability—factors which are important for video news coverage, emergency service, and military use. Satellite ground terminals may be installed much more quickly than cables can be laid. Incidentally, satellites can, and often have been used for cable restoral. The use of satellites in providing emergency communications after the Kobe earthquake was a striking example of this.

It is most likely, then, that satellite-based networks for high data rate digital transmissions—will have their maximum use in multi-nodal, transcontinental or international linkages, particularly when subject to dynamic loading and where cost, flexibility or mobility are important considerations.

The HDR Market

What will the future requirements for national and international high data rate service be? First, we can assume that some of the same services now being provided at medium rates, such as T-1 and T-3, will be provided at higher rates in the next decade, increasing by factors of 10 every few years. Also, we might note that since computer and communications technologies are merging and that computers are running faster and faster, data links will go to higher rates. These are likely trends, what might be termed "thermodynamic factors".

A driving force in high performance networking today is the need for distributed processing in computationally-intensive science and engineering applications such as global climate modeling, computational biology, or aircraft system design and manufacturing.

These applications may require interconnectivity among supercomputers, high performance servers, large data bases and remote I/O. Many require distribution of interactive video (tens of Mb/s). Some require multi-channel video coupled with fast access to large remote data bases and visualization — and these mean even higher rates in the hundreds of megabits per second. Once the computing and communications capabilities have been combined and the networking technologies developed to serve science and engineering applications, their use in industrial and commercial applications will surely follow—and on a worldwide basis.

The G-7 Information Society Program

In 1994, the leading economic nations adopted a vision statement asserting that:

> *Progress in information technologies and communications is changing the way we live: how we work and do business, how we educate our children, study and do research, train ourselves, and how we are entertained."*

They created the G-7 Information Society Program "to contribute to the integration of all countries into a global effort." Eleven projects were initiated:

Global Inventory
Cross-cultural Education and Training
Electronic Libraries
Electronic Museums and Galleries
Environment and Natural Resources Management
Global Emergency Management
Global Healthcare Applications
Government On-line
Global Marketplace
Maritime Information Systems
Global Interoperability for Broadband Networks

Ten of these projects require high data rate communications, much of it by satellite. The last-named project, GIBN, should be of special interest to this audience. It has as its objective "to facilitate the establishment of international links between the various high speed networks and testbeds supporting advanced applications." The GIBN project will provide the connectivity that the ten others require. It will be the testbed to demonstrate the capability of national and international satellite and terrestrial HDR networks to work seamlessly together.

HDR Satcom Imperatives

The arguments favoring high data rate satellites will not be readily accepted by the telecommunications industry. Indeed, they are not yet recognized by many of the satellite carriers. Although, many new satcom systems are planned, including a dozen at Ka-band, none have announced plans to provide HDR service. Most seem to be concentrating their efforts at providing multiple T-1 service.

What will it take to convince the world of the value of satellite HDR service? To be incorporated into national information infrastructures and the GII, satellites will have to demonstrate four capabilities, namely to:

Carry data at SONET rates (>155 Mb/s)
Provide high quality service (BER ~ 10^{-10})
Tolerate transmission delay (>250 ms)
Show performance and/or economic advantages

A word about delay (or "latency" in computer parlance). Those of us who have worked with Geo satellite communications all of these years, understand that, with good echo control, the delay in voice circuits is a psychological factor. It is certainly not desirable, but not disqualifying either. Where an economic advantage exists, satellites have served well, and the delay accepted. Delay in a data circuit is an engineering factor. There are many cases where even a one-second delay is of no consequence—examples: TV distribution, fax, e-mail.

However, there are many cases in data communications—and distributed computing is the most critical—where latency is of great concern. Where CPU's work in small fractions of a nanosecond, it is a problem for computer designers to get efficient operation of computing modules separated by even a short distance (remember that electronic pulses travel at 30 cm/ns). If two computers have to work together across an ocean, the delay might be 30 ms by cable, 250 ms by satellite. For the terrestrial circuit, the delay might then be 8 orders of magnitude greater than the processing rate, the satellite 9. This reduces the delay problem to one of engineering—it's a big problem for cables, only slightly bigger for satellites. To a computer it makes little difference if the link to its companion goes by satellite in any orbit, or by cable hugging the earth or on the ocean bottom. The engineering solution is the same—partition the problem suitably, use long block length cells, provide adequate buffering in the interface units, and use appropriate transmission and error control codes. A particular problem is the adaptation of ATM transmission protocols, originally developed for cable use, to suit satellite channels.

Once the techniques that are suitable for networking over satellite links have been developed it is necessary to get them adopted into the standards and protocols that are used in international communications. That is a very serious and time-consuming process which requires the attention of all of us who are interested in satellite communications.

The Role of ACTS

The Advanced Communications Technology Satellite (ACTS), representing a $700 million investment by U.S. taxpayers, has been in orbit for three years. It was originally intended to accomplish two objectives:

- Develop advanced technologies:

- Demonstrate new applications

ACTS has accomplished its first objective with flying colors. It has shown that its advanced technologies (Ka-band, microwave matrix switch, multiple hopping-beam antenna, baseband processor) work in orbit. ACTS is making excellent progress toward its second objective. It has already demonstrated its prowess at modest data rates, conducting experiments in many fields—in banking, distance learning, tele-medicine, and in military and mobile service. But ACTS' most significant set of demonstrations—those at high data rate—are just getting underway.

ACTS has a unique capability, the value of which we could not have appreciated when ACTS was designed more than fifteen years ago. By virtue of the bandwidth available to it at Ka-band, ACTS can transmit digital signals at rates up to one gigabit per second. With five newly developed HDR terminals, ACTS is demonstrating its ability to transmit at SONET rates (OC-3 and OC-12).

One of ACTS' most demanding experiments is in supercomputer networking, in which a Cray supercomputer at the NASA Goddard Space Flight Center in Maryland is being connected with a another Cray at the Jet Propulsion Laboratory in California through the satellite at OC-3 (155 Mb/s). This experiment Global Climate modeling will analyze and characterize the global ocean-atmosphere interface. Because the atmospheric scientists, their computer programs, and their huge data base are at Goddard, while the oceanographers with their programs and data base are at JPL, both data bases and a HDR link are needed to work the problem. It has been necessary to design and configure the satellite link and the computers to match each other. This means partitioning the computer programs appropriately for distributed processing over a long delay link. It requires the design of interface boxes and protocol converters with adequate buffering to accommodate the satellite/terrestrial communications and computer interfaces. In particular, it requires the adaptation of the ATM protocol to match the bursty error characteristics of satellite transmissions. And it requires the use of appropriate transmission modulation and coding techniques to deliver the required error rate.

In another experiment, now in progress, the Keck telescope in Hawaii is being connected to the astronomical data processing facility at CalTech to perform a set of experiments in remote facility control and data visualization and analysis.

Soon ACTS will assume an international role by serving as a link in a set of trans-Pacific experiments originally planned as part of the Japan-US Space Cooperative program, now a part of the GIBN. ACTS will connect the U.S. mainland and Hawaii and Intelsat will link Hawaii and Japan. The double-hop link will provide a very high definition video transmission test between Tokyo and Los Angeles for the Sony Corporation.

Thus, through this series of experiments and demonstrations, ACTS is demonstrating that satellites can provide reliable, high quality, cost effective HDR service—that satellites can contribute significantly to the GII. For the satcom community, ACTS is demonstrating a new and continuing role for the fixed satellite service in a world strung with fiber optic cables. For national and military systems, ACTS is demonstrating that HDR interoperability and mobility are also attainable through satellite service.

Gigabit Network in the Sky

During the first SCGII workshop held in Hawaii last November, thanks to the foresight of the Japanese Ministry of Posts and Telecommunications, an important meeting was held by representatives of the G-7 nations to consider actions aimed at introducing satcom into the GIBN project. It was called the "Quadrilateral Group" since four parties were represented—Canada, Japan, Europe and the United States. That meeting turned out to be a very productive one. Unanimous agreement was reached that satellite communications should be introduced into the GIBN as quickly as possible. Ten new experiments were proposed, involving a wide variety of innovative applications. Several of these reached beyond the G-7 nations to involve other countries. Most important, plans were announced to provide HDR satcom links across the Atlantic and across the Euro-Asian continents to provide, together with the existing trans-Pacific link, a complete round-the-world capability. The satellite links will be interconnected with fiber-optic networks on each continent to provide seamless interoperability.

The recommendations of the Quadrilateral Group were accepted by the GIBN coordination group and it may now be stated that satellite communications is an integral part of the GIBN. With that position secured, we can now look forward, hopefully within a year, to the operation of a "Global Gigabit Testbed"—with both satellite and terrestrial components.

The Quadrilateral Group will meet again during the present SCGII workshop to review progress on the trans-Pacific experiment and to plan for additional links and new experiments. Enthusiasm runs high as we view satellite communications playing an increasingly stronger and more vital role in the Global Information Infrastructure.

Conclusions

In these remarks, I have tried to stress several points:

1. Satellites have significant cost and performance advantages over terrestrial systems in multi-node networks

2. Ka-band is an enabling technology that gives satellites a high data rate capability

3. There is a large future market for HDR satellite communications in the GII

4. The international satcom community must cooperate to demonstrate the interoperability of satellite and terrestrial systems

This last conclusion requires the attention and dedicated effort of us all. To insure that satellite communications is prepared and allowed to play a maximum role in the GII, we must work together, across international boundaries, to develop and demonstrate the performance and cost-effectiveness of high data rate satellite services.

TESTBED FOR SATELLITE AND TERRESTRIAL INTEROPERABILITY (TSTI) EXECUTIVE SUMMARY 7-24-96

The Testbed for Satellite and Terrestrial Interoperability (TSTI) will be used to test and demonstrate interoperable satellite and fiber optic communications for industry, government and academia. As described in the attached Development Plan, the Team Members will design, develop, integrate and manage the basic testbed and the measurement tools required to test and validate interoperable communications hardware and software interface specifications, protocols, architectures and standards. Then, within the first year of the project, the testbed will be opened to the U.S. satellite and terrestrial communications carriers, vendors and other user communities to test and demonstrate hardware, software protocols, applications and complete end-to-end systems. Special outreach efforts will be made to the Satellite Industry Task Force members and the fourteen new Ka-band system operators that have filed applications with the FCC. These communications providers and users will be invited to participate in a TSTI Carrier/Industry Advisory Committee that will assist the user in gaining easy access to the NASA testbed. Access to the testbed will be administered under a recently approved NASA Joint Sponsored Research Program that is dedicated to promoting R&D partnerships between NASA and the private sector.

The TSTI concept, resources and networks are shown on the figure attached to this Executive Summary. The communications backbone will use the NASA ACTS satellite, and other government and commercial satellites as available. The TSTI Center will be located at the Goddard Space Flight Center and will be connected, via its ACTS high data rate terminal, to a similar terminal at the Jet Propulsion Laboratories. These backbone locations were specifically chosen as each NASA Center is interoperable with a number of high data rate terrestrial networks, such as the NREN, ATDNet and the CALREN network. Further, the NASA Centers have an excellent set of resources in the form of network interfaces, ATM switches, performance measurement tools, high performance computers and a qualified technical staff. Extensions to other interoperability testbeds will be actively pursued. The team will coordinate its ACTS satellite experiments activities with the NASA ACTS project office at LeRC, and will coordinate other satellite and terrestrial activities with the appropriate government, industry and communications carrier representatives.

The NASA Team Members, GSFC and JPL, will be complemented by a strong industrial/carrier research team consisting of Bellcore and Comsat Laboratories. These organizations are currently leaders respectfully in terrestrial and satellite communications interoperability research, development and standards. The George Washington University, a pioneer in high data rate satellite communications research, will be the academic member of the team.

The TSTI technical tasks include the design, development, integration, and management of the interoperability testbed. The testbed will be used to develop and evaluate tools to work on satellite and terrestrial interoperability problems, including the inherent characteristics of satellite links-errors, delay and bandwidth limitations. Specific measurement and analytic tools such as a SONET/ ATM network analysis system will be integrated into the testbed to measure and observe the interoperability of satellite and terrestrial communications in test sequences as well as real-time applications operating over the end-to-end network. Measurements of both data traffic and signaling messages will be used to analyze the interoperability of ATM systems exchanging traffic over satellite and terrestrial communications links. Performance measures such as burst length, traffic load and spectrum load will be examined as well as quality of service measures such as cell loss and cell delay.

Application testing on the TSTI will build initially on the existing hybrid terrestrial/ACTS infrastructure at GSFC and JPL used with the Distributed Global Climate Modeling task. This computationally intensive task, developed by GSFC and JPL, could potentially use the full high data rate channel capacity of the ACTS satellite. Other applications will be solicited from industry, government and academia. These solicitations will provide an opportunity to test a wide range of applications over a hybrid satellite/terrestrial network.

Testbed users will be solicited as part of the outreach activities of this project. The user community will include Federal Agencies, other NASA Centers, communications companies, equipment vendors, carriers, universities, experimenters and standards developers. This open cooperation with the user community will be administered under a new NASA Joint Sponsored Research Program (JSRP) that was approved in April, 1996. The JSRP permits NASA to provide resources, including funds, services, equipment, information, intellectual property or facilities on a shared or pooled basis to non-government users. Intellectual property rights will be negotiated, but basically intellectual property created or introduced by a user will be owned solely by that user. Testbed users may have to provide for their access to the testbed and may need to fund the actual costs of special equipment to be used as part of their tests or demonstrations. However, the team does not intend to charge fees from the users for testbed use. The user community will be encouraged to share resources with the testbed, including the use of commercial communications satellites to interoperate with the testbed.

It is anticipated that ATDNet participants such as the NRL, DISA and the National Institutes of Health will request access to the testbed. DARPA, with its MAGIC testbed, has indicated a desire to be interconnected with the east and west coasts via the ACTS satellite. Other NASA Centers, such as LeRC (which is funding a number of interoperability studies) will be especially encouraged to participate and use the testbed to test and demonstrate the results of its studies. NASA ARC will also be connected via the NASA NREN network, and may also be connected via the all-optical NTON network that is proposed to connect ARC and JPL. The two NASA CCDS's for satellite communications will be invited to conduct experiments over the testbed An ACTS Experiments Application has been sent to the project office at LeRC for coordination and approval prior to the start of the actual testbed.

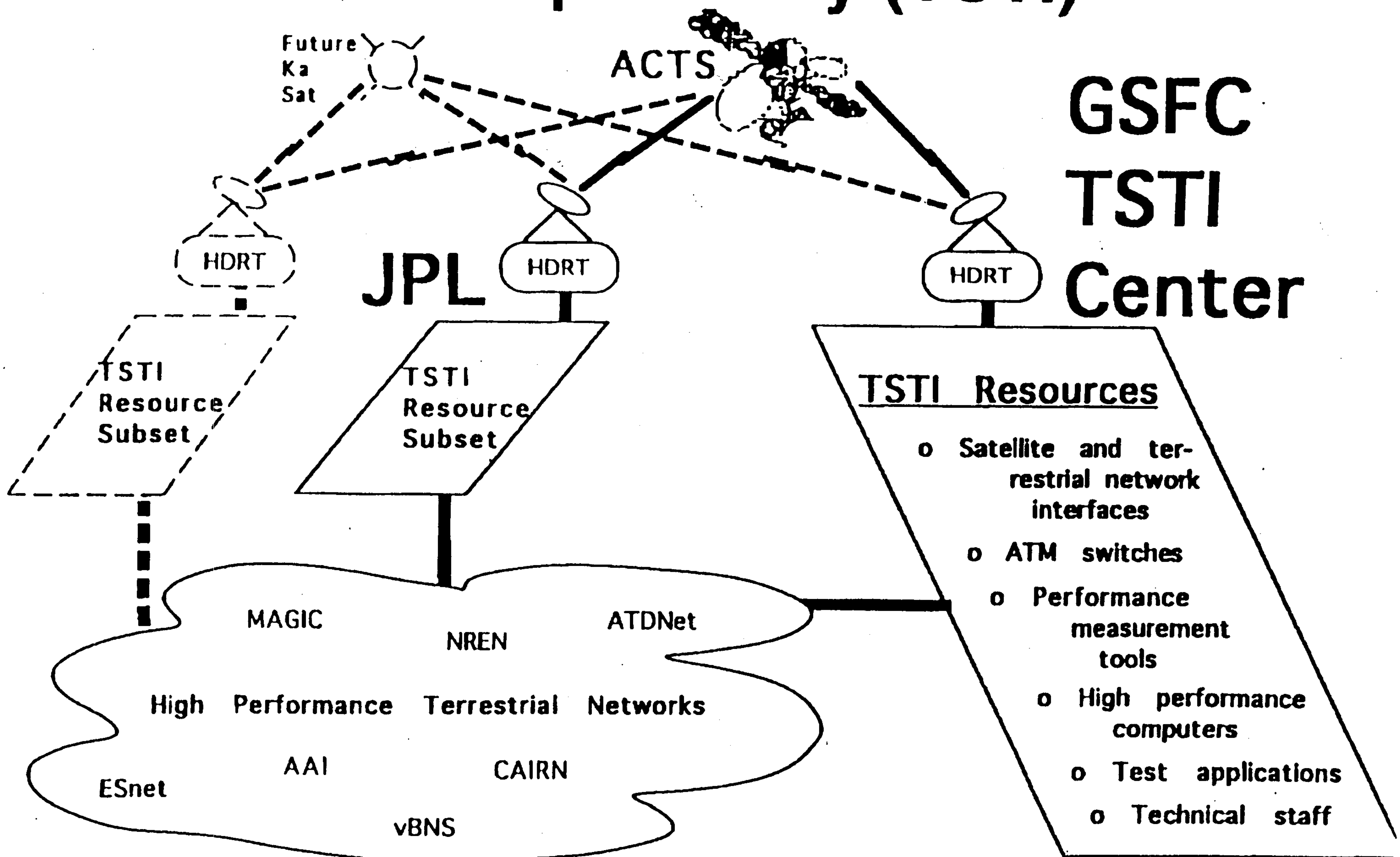
Who will benefit? The TSTI will develop the hybrid satellite terrestrial communications technologies, systems and networks that will expand the nation's overall growth of the national and global information infrastructures, for economic competitiveness, scientific research and defense communications.

The ACTS satellite program will benefit from a high visibility testbed that will provide state-of-the-art high data rate tests and demonstrations with commercial providers, that will validate the success of the NASA experiment.

The TSTI will enable the communications industry, in cooperation with government agencies, to address and resolve generic issues in high data rate hybrid satellite terrestrial networks and to accelerate the development and deployment of the next generation of commercial satellites by the private sector. The fourteen U.S. companies that have made Ka-band satellite filings with the FCC will especially benefit from the availability of the ACTS Ka-band equipment and tools in this testbed, to conduct pre-competitive tests and demonstrations.

The recent telecommunications restructuring will make direct access satellites more competitive in the international telecommunications market. US industry must compete for the $70 billion international access market. This TSTI will make the US providers more competitive and cost effective.

Testbed for Satellite and Terrestrial Interoperability (TSTI)



DRAFT

Development Plan for NASA Communications Program Code XS

Testbed for Satellite and Terrestrial Interoperability (TSTI)

Team Members:

Goddard Space Flight Center
Jet Propulsion Laboratory
Bellcore
Comsat Laboratories
George Washington University

July 24, 1996

Table of Contents

Executive Summary i

VOLUME 1 - TECHNICAL SECTION

1. Introduction 1

2. Challenge 1

3. Mission 2

3.1 Team Members 2

3.2 Users 3

3.3 Carrier/Industry Advisory committee 3

3.4 Mission Benefits 4

4. Statement of Work 4

4.1 Testbed Design, Development, Integration and Management 4
4.1.1 Testbed Design 4
4.1.2 Testbed Development 5
4.1.3 Measurement Systems and Objective 5
4.1.4 Testbed Integration 9
4.1.5 Testbed Management 10

4.2 Outreach to Industry, Government and Academia 10
4.2.1 Research and Development Outreach 10
4.2.2 Technology Transfer 10
4.2.3 Technical Support 10

4.3 Application Testing on the TSTI 11
4.3.1 Distributed Global Climate Modeling 11
4.3.2 ATM Speech 11
4.3.3 Internet and Visualization Data 12

4.4 Improving Performance of Application 12
4.4.1 TCP Booster 13
4.4.1.1 ARQ Booster 13
4.4.1.2 FEC Booster 14
4.4.2 TSP/SSCOP 15
4.4.3 ATM Link Enhancer 16
4.4.4 ATM Link Accelerator 17
4.4.5 ATM Traffic Management 17
4.4.5.1 Introduction 17

4.4.5.2 Network Configuration 18
4.4.5.3 Specific Study Points 20

4.5 Contribution to Standards 21

4.6 Intellectual Property. 21

REFERENCES. 22

<u>VOLUME 2 - MANAGEMENT SECTION</u>

5. Scope of Work. 23

5.1 Task 1 - Testbed Design, Development, Integration, and Management. 23

5.2 Task 2 - Outreach, Industry, Government and Academia. 23

5.3 Task 3 - Application Testing on the TSIT 23

5.4 Task 4 - Improving Performance of Applications 24

5.5 Task 5- Contribution to Standards 24

6. Milestone Schedule 25

7. Curriculum Vitae. 27

<u>VOLUME 3 - COST SECTION</u>

8. Resources & Budget

8.1 GSFC. 32

8.2 JPL 33

8.3 COMSAT 33

8.4 Bellcore. 34

8.5 GWU. 34

8.6 TOTAL PROPOSAL BUDGET. 35

ANNEX 1: Experiment Plan for 622 Mbps Network. 36

ANNEX 2: ATM Speech. 40

APPENDIX A: ATM Service Categories Defined in the ATM Forum TM 4.0 Specification. 43

APPENDIX B: ATM Traffics and Congestion Control Defined in the ATM Forum TM 4.0 Specification. 44

APPENDIX C: ABR Parameters 46

APPENDIX D: List of Acronyms. 48

ATTACHMENT 1:ACTS TSTI Experimental Application. 49

Testbed for Satellite and Terrestrial Interoperability (TSTI)
7-24-96

VOLUME 1
TECHNICAL SECTION

1. INTRODUCTION

The Testbed for Satellite and Terrestrial Interoperability (TSTI) will test and demonstrate interoperable communications hardware and software interface specifications, protocols, architectures and standards. As described in this Developemnt Plan, the testbed will develop the tools to work on the interoperability problems that are inherent characteristics of satellite links--errors, delay, and bandwidth limitations. The U.S. communications carriers, industry and government will benefit directly from the testbed by the transition of tools, technologies and standards to provide interoperable hybrid terrestrial cable and satellite communications networks, operating seamlessly around the globe. The fourteen U.S. companies that have filed for Ka-band satellite systems with the FCC will especially benefit from the availability of the ACTS Ka-band equipment and tools in this testbed, to conduct pre-operational tests and demonstrations.

Satellite communications is the largest economic return from our investment in space. Global networks with more than 200 active satellites are providing revenues of over $20 billion a year. Satellite communications is an important part of our national and global information infrastructures that are enabling critical communications and information to reach the outermost edges of our world to promote global prosperity and peace.

In the development of the nation's high performance computing and communications initiatives, the testbed activities concentrated on computing efficiencies and low latency networks using protocols that do not perform well over satellites. However, satellite communications systems are going to be essential components of the NII/GII and thus must be integrated more closely with the development of our nation's computing, communications and information technologies. The synergy and interoperability of these technologies, systems and networks are important to our country's economic competitiveness, national defense and scientific advances.

2. CHALLENGE

One of the conclusions of the Satellite Industry Task Force (SITF) Working Group is that currently there are no commercial hybrid satellite/terrestrial communications networks operating at data rates above 155Mb/s. In the rapid development of computing and communications networks, data communications protocols were designed for high efficiency and low latency. Further, these development activities often used new optical fiber cables over comparable short distances, so overall communications traffic and network efficiency were never a factor.

The recent technology development in communications satellites, such as broadband high data rate transponders demonstrated by NASA's ACTS satellite, will challenge and complement the excellent development of optical fibers that will be used interoperably in future communications wire and wireless networks.

There are some excellent existing and proposed ACTS experiments that show the technology benefits of high data rate satellites. But these small scale experiments and demonstrations are not developing the hardware and software interface equipment or procedures needed by the satellite and terrestrial communications carriers. Thus, the SITF is asking for a sustained industry, government testbed activity to develop and demonstrate the required interoperable communications hardware and software interface specifications, protocols, architectures and standards. Also, the testbed users will be responsible for the transfer of the technologies and techniques to the commercial high data rate communications providers and to national and international standards developers.

Satellite communication systems are going to be essential components of the Information Infrastructure. Currently there are a number of major challenges in its ability to provide broadband services based on synchronous optical network (SONET) and Asynchronous Transfer Mode (ATM) protocols. These challenges stem from the fundamental differences in the satellite and fiber environments and that most network architectures and protocols are designed for a fiber optic cable infrastructure.

The interoperability problems arise due to three inherent characteristics of satellite links- (a) errors, (b) delay, and (c) bandwidth limitations. The satellite RF links, especially for Ka band operation, will have a much more degraded error performance than the fiber links and typical forward error corrected satellite links will have bursty errors with variable error rate as opposed to random errors on the fiber links. ATM operation is intolerant to burst errors and the ATM Quality of Service (QoS) requirements for multimedia applications are much more stringent than what a typical satellite link will currently provide. The single hop propagation delay of around 250 msec, which is intrinsic to geosynchronous satellite communications, has an adverse impact on data communications protocols like TCP at high speed (fractional T1 or more) and conventional ATM traffic and congestion control procedures. Finally, satellite communications bandwidth is a precious asset and cannot afford the bandwidth inefficient operation of some ATM protocols. As a result, the onus is on the operator of a bandwidth limited network to either live with the bandwidth excesses of these technologies or design special signal processing functionality that reduces the overhead across a bandwidth constrained network path.

3. MISSION

In response to these challenges, we plan to design, develop, integrate and manage a Testbed for Satellite and Terrestrial Interoperability (TSTI) that will serve as a sustained resource for the communications and satellite industries. The testbed will provide an open environment, available to all in industry, government and academia, to develop the necessary test tools and procedures and to conduct quantitative, reproducible experiments to demonstrate and validate interoperability between satellite and terrestrial communications networks. The TSTI architecture will follow emerging standards and protocols and enable users in industry forums and standards bodies to develop, test and refine their contributions to the standards process. This standard-based testbed architecture will also enable communications equipment suppliers, service providers and carriers to address interoperability and end-to-end service assurance issues. The TSTI will serve as a resource to the industry, avoiding costly duplication of facilities and effort in software and tool development. Subsystem developers, application builders, and a wide range of service providers will also benefit from the TSTI, as it will provide them access to a diverse, unique hybrid communications infrastructure that cannot be reproduced in small scale experiments. We plan to encourage broad participation in the testbed through an intensive industry out reach program and through technical support to its users. The TSTI will contribute to a robust, competitive satellite communications industry, well integrated with the terrestrial infrastructure.

3.1 Team Members

The TSTI will be developed by a team consisting of NASA's GSFC and JPL, representing the government, Bellcore and Comsat Laboratories representing industry/communications carriers and George Washington University as the academic representative. The team members were chosen for their current capabilities and expertise in the development of the next generation of hybrid seamless interoperable communications systems and networks. GSFC will direct the TSTI project, with GWU acting as the TSTI prime contractor. All members of the team will participate in and be responsible for the overall engineering development, integration, maintenance, test and demonstration of the testbed.

The NASA team members, GSFC and JPL, have high performance computing and communications infrastructure, including backbone connections to the ATDNet, MAGIC, NREN, AAI, CAIRN, CASA, and NTON networks. Bellcore and Comsat Laboratories, as research leaders for the communications industry, are currently involved in the development of high data rate protocols and software components that are directly applicable to the testbed. The Institute of Applied Space Research of GWU has played an evolutionary role in the development of high data rate satellite equipment and experiments for the ACTS program. All the partners are currently providing leadership roles in the development of satellite and terrestrial communications standards.

3.2 Users

The team members are planning to be users of the TSTI and several of their applications and performance experiments are described below in section 4.4. Additional testbed users will be solicited as part of the outreach activities of this project. The user community will include Federal Agencies, other NASA Centers, communications companies, equipment vendors, carriers, universities, experimenters and standards developers. This open cooperation with the user community will be administered under a new NASA Joint Sponsored Research Program (JSRP) that was approved in April, 1996. The JSRP permits NASA to provide resources, including funds, services, equipment, information, intellectual property or facilities on a shared or pooled basis to non-government users. Intellectual property rights will be negotiated, but basically intellectual property created or introduced by a user will be owned solely by that user. Testbed users may have to provide for their access to the testbed and may need to fund the actual costs of special equipment to be used as part of their tests or demonstrations. However, the team does not intend to charge fees from the users for testbed use. The user community will be encouraged to share resources with the testbed, including the use of commercial communications satellites to interoperate with the testbed.

It is anticipated that ATDNet participants such as the NRL, DISA and the National Institutes of Health will request access to the testbed. DARPA, with its MAGIC testbed, also has indicated a desire to be interconnected with the east and west coasts via the ACTS satellite and, jointly with NASA GSFC, has proposed a number of 622 Mb/s network tests between ATDNet and MAGIC users via ACTS as described in Annex 1. Other NASA Centers, such as LeRC (which is funding a number of interoperable studies) will be especially encouraged to participate and use the testbed to test and demonstrate the results of its studies. NASA ARC will also be connected via the NASA NREN network, and may also be connected via the all-optical NTON network that is proposed to connect ARC and JPL. The two NASA CCDS's for satellite communications will be invited to conduct experiments over the testbed. In addition, a number of equipment vendors will be invited, such as GTE, FORE and CISCO, who are developing ATM equipment that will operate up to OC-12 (622Mb/s). An ACTS experiments application has been sent to the project office at LeRC for coordination and approval prior to the start of the actual testbed.

3.3 Carrier/Industry Advisory Committee

To reinforce the technical and research capabilities of the TSTI, and to assure that the effort is well focused on developing timely and effective interfaces with emerging terrestrial high data rate services, it is planned to establish a Carrier/Industry Advisory Committee (CIAC) consisting of current and future providers of satellite and terrestrial high-bandwidth telecommunications services. The CIAC will function collectively, or in subcommittees, as advisors to the TSTI, providing guidance in setting priorities for experiments, identifying interface requirements, assisting in the integration of industry guidelines and standards, and in disseminating the results of the TSTI work among other industry forums. The CIAC will be encouraged to participate actively in the TSTI work program, by providing access to terrestrial services and supporting demonstrations of satellite/terrestrial network interoperability. The CIAC will assist users in establishing a legal relationship to the testbed as part of the NASA Joint Sponsored Research Program.

This CIAC is in direct response to the recommendations of the SITF for joint partnership research projects and recommended roles for technology transfer, proprietary data and intellectual property. Therefore, all the members of the SITF along with the fourteen companies that have filed for Ka-band satellite systems will be invited to join the CIAC and this planned joint research project.

3.4 Mission Benefits

Via the development and evaluation of hybrid satellite terrestrial communications technologies, systems and network interfaces, the TSTI will contribute to an expansion of the nation's overall growth of the national and global information infrastructures, for economic competitiveness, scientific research and defense communications.

The ACTS satellite program will benefit from a high visibility testbed that will provide state-of-the-art high data rate tests and demonstration with commercial providers, that will validate the success of the NASA experiment.

The TSTI will enable the communications industry, in cooperation with government agencies, to address and resolve generic issues in high data rate hybrid satellite terrestrial networks and to accelerate the development and deployment of the next generation of commercial satellites by the private sector. The testbed provides government and industry with the unique opportunity to work cooperatively in a pre-competitive environment. The TSTI will facilitate technology transfer and enhance American competitiveness in the global satellite communications systems and services market.

4. STATEMENT OF WORK -- TECHNICAL APPROACH

This technical approach is to design, develop, integrate and manage a Testbed for Satellite and Terrestrial Interoperability (TSTI) with high data rate satellite and terrestrial communications hardware and software components. These components will be assembled and integrated with new communications protocols and architectures into an open testbed configuration that will test and demonstrate the next generation of hybrid seamless interoperable communications systems and networks.

4.1 [TASK 1] Testbed Design, Development, Integration and Management

4.1.1 Testbed Design

The TSTI team will design an end-to-end testbed with specific technical goals and objectives, such as necessary interface requirements, and yet have the flexibility for the Carrier/Industry Advisory Committee and other users to test and demonstrate satellite/terrestrial interoperability. The design will begin with an ACTS satellite high data rate backbone that will be employed from GSFC to JPL. The backbone will be able to support application data rates from sub-OC-3 (155 Mb/s) to OC-12 (622 Mb/s). Both primarily nodes, GSFC and JPL, will be designed to provide easy access to other high performance terrestrial networks and users such as the ATDNet in the Washington, DC area and the CASA network on the west coast, enabling experiments with a diverse range of applications.

4.1.2 Testbed Development

The TSTI development will build on a backbone foundation of hardware and software made up of the ACTS satellite high data rate equipment along with the computing and communications infrastructure located at GSFC and JPL. Figure 1 illustrates some of the existing computing and communications infrastructure located at GSFC, a similar infrastructure exists at JPL, and the illustration of their wide area interconnection is provided in Figure 2. The development activities will include an improved set of satellite/terrestrial interface tools, including protocols and algorithms that are developed within an improved architecture that allows for latency and other transmission characteristics that are normal to hybrid communications networks, and are also discussed further in section 4.4.

4.1.3 Measurement System and Objectives

The TSTI will consist of one or more satellite links integrated with one or more terrestrial networks. The terrestrial networks of interest are broadband, high throughput networks carrying a diverse set of services. SONET/ATM networks are the most common and the most versatile example of such public broadband networks, so the measurement system used to analyze the performance of the TSTI will be a SONET/ATM network analysis system. This also means that the smallest unit of data traffic to be measured in the TSTI will be the ATM cell. Since OC-3c (155 Mb/s) and OC-12c (622 Mb/s) are likely to be among the most widely deployed SONET/ATM backbone networks in the next decade, the TSTI test hardware will be chosen to work at both these speeds.

The TSTI can be viewed as islands of broadband terrestrial networks connected by satellite links. The measurement system proposed for the TSTI consists of Local Test Units (LTUs) that monitor the flow of traffic and signaling messages in and out of these islands. These LTUs are independent processors located throughout the network. The measurement programs in these LTUs are set up on a centralized Network Test Controller (NTC) that sets up, manages and tears down the tests. As shown in figure 3, measurements can be made on both the traffic flow or on the content of signaling cells that pass back and forth managing the network. Measurements can be taken simultaneously on each of the islands by the LTUs and each measurement is time-stamped by a Global Positioning System (GPS) clock with an accuracy of 1 microsecond. Traffic and signaling data can be processed at the LTU and the results of the measurements can be stored in the LTU and transmitted on demand back to the NTC for global analysis.

GSFC Local Network Interface Configuration for ACTS

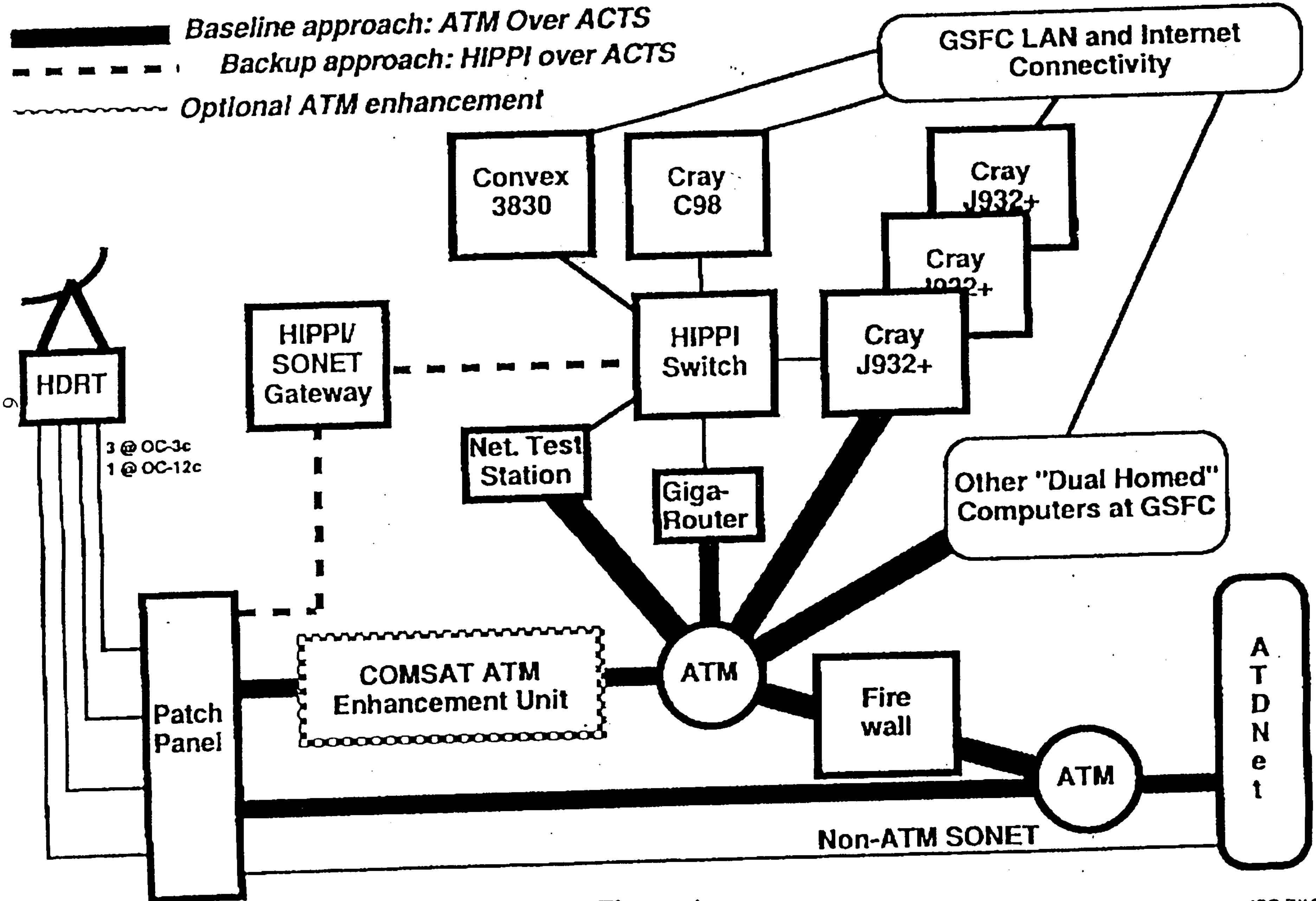
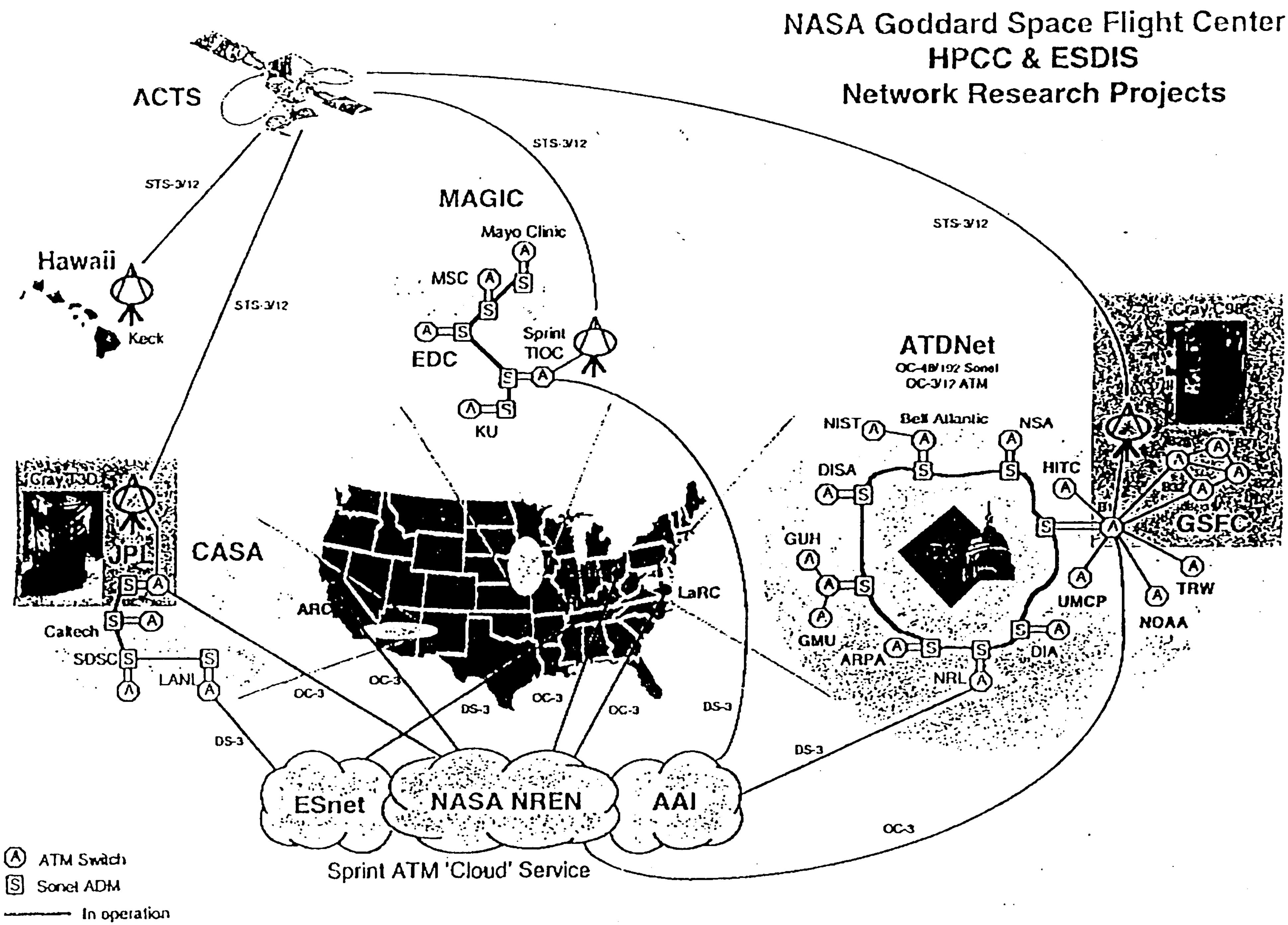


Figure 1

JPG 7/19/96



NASA Goddard Space Flight Center
HPCC & ESDIS
Network Research Projects
ACTS
STS-3/12
STS-3/12
STS-3/12
STS-3/12
Hawaii
Keck
MAGIC
Mayo Clinic
MSC
EDC
Sprint TIOC
KU
ATDNet
OC-48/192 Sonet
OC-3/12 ATM
NIST
Bell Atlantic
NSA
DISA
HITC
GUH
GMU
ARPA
NRL
DIA
UMCP
NOAA
TRW
Cray C98
GSFC
Cray T3D
JPL
CASA
Caltech
SDSC
LANL
ARC
LaRC
OC-3
OC-3
DS-3
OC-3
OC-3
DS-3
DS-3
DS-3
OC-3
ESnet
NASA NREN
AAI
Sprint ATM 'Cloud' Service
ATM Switch
Sonet ADM
In operation
In planning
JB 27Oct95

Figure 2

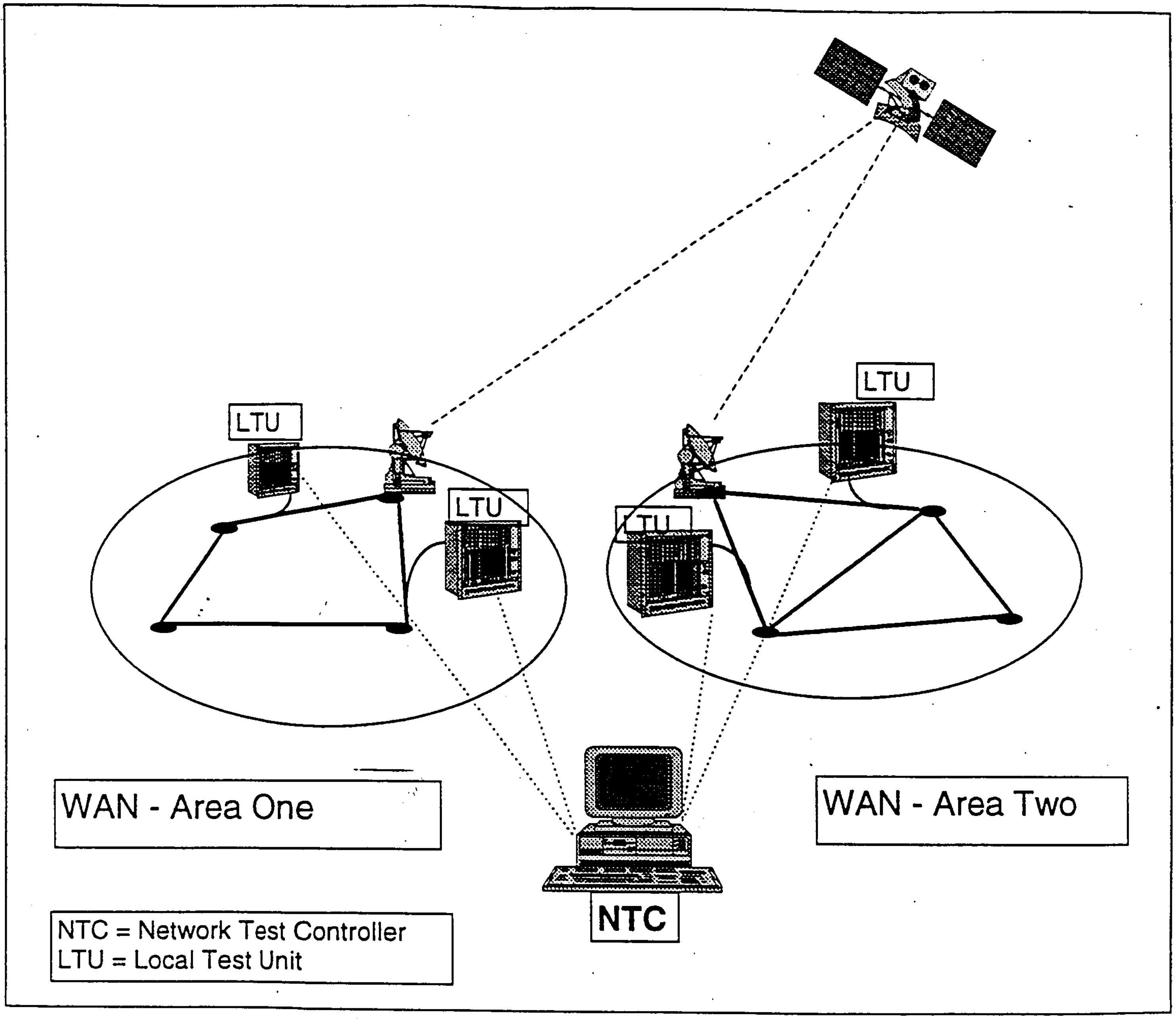


Figure 3. Interoperability Test System

The Interoperability Test System is being developed by a consortium led by Bellcore as part of an Interoperability TRP contract supported by DARPA and NSF. The test set equipment (LTUs and NTC) specifications will be made available to the TSTI, thereby saving duplicate development costs. The specific tests performed on this system are controlled by user scripts created on the NTC and down loaded into each of the LTUs on the network. The data collected in these tests are gathered at the NTC for global analysis. This project will support the development of user scripts for satellite-terrestrial network interoperability testing and the global analysis routines for interpreting the results of these tests, extending the application domain of the test system.

The measurement system will be able to use 32 bit filters applied to headers of ATM cells (all the independent bits of the header) to select the cells that are members of the one of the measured sets. ATM traffic that is observed on the islands of the terrestrial network will exhibit any effects on the traffic flow caused by the long latency and lower reliability of the satellite link. By making simultaneous observations at each end of the link and using the universal GPS time-stamp to determine the sequence of events, it is often possible to infer what caused the observed traffic behavior.

Measurements of both data traffic and signaling messages will be used to analyze the interoperability of the ATM systems exchanging traffic over the satellite link. The measurements will determine the performance and the Quality of Service of the link.

Performance measures are:

- cell interarrival time
- burst length
- silent length
- traffic load
- load correlation
- load spectrum.

The QOS measures are:

- cell loss
- cell delay
- cell delay jitter.

These measures make it possible to determine quantitatively how successfully the ATM systems on the terrestrial network islands are interoperating over the long latency satellite link. If the measurements show poor interoperability, then they can also provide detailed information to diagnose the specific cause of the problem. Interoperability problems are often caused by different nodes in the network having conflicting information about the state of the network at certain periods of time. One of the unique advantages of the interoperability test system described above is the ability to simultaneously gather information (with universal times stamps) at several sites in the network and then correlate the results at the NTC.

4.1.4 Testbed Integration and Tools

The TSTI integration activities include combining the hardware and software that currently exists with the new development tools. Further, as new users desire to access the TSTI, they will be requested to define their equipment, configuration, experiment, and proposed results in a written guideline that will be coordinated with the team members and reviewed by the Carrier/ Industry Advisory Committee. With proper notifications and guideline instructions, experiments proposed by new users will be integrated into the overall TSTI. Other integration activities will be discussed below in the rest of the statement of work (SOW) tasks.

4.1.5 Testbed Management

The TSTI team will manage the testbed activities. The team will establish a "testbed activity center" at GSFC building 28, where most of the TSTI technical tasks, tests and demonstrations will be conducted. GSFC will have ultimate responsibility for the testbed, with the TSTI Director and Principal Investigator being supplied by GSFC. The GSFC P.I. will be the interface with NASA Headquarters and the ACTS satellite Project Office at LeRC. The JPL co.-P.I. will be responsible for the west coast node of the TSTI and will direct all tasks, tests and demonstrations that use the JPL node. The GWU co.-P.I. will be the TSTI administrator and be responsible to the Director for administrating and coordinating all TSTI activities. The GWU administrator will be the interface to all outside users, and will chair the Carrier/Industry Advisory Committee. The Bellcore and Comsat co.-P.I.s will be responsible for specific technical tasks as set forth in the SOW, be members of the CIAC, and will be especially active contributors to the technology transfer activities of the tests and demonstrations. GSFC will be the NASA TSTI project leader and will establish a prime contract with GWU, the TSTI administrator. GWU will then establish subcontracts with Bellcore and Comsat as well as act the TSTI administrator with all other users.

4.2 [TASK 2] Outreach to Industry, Government, and Academia

This task will be conducted throughout the entire life span of the project. It will facilitate the transfer of technology to industry for commercialization, and for encouraging as many government, industry, and academic institutions to use the testbed for testing new applicable systems and applications. This task will be composed of the following activities:

4.2.1 Research and Development Outreach

This subtask will be to develop and implement an ongoing dialogue with government, industry and academia to stimulate their interest in using the testbed to support systems and networks of interoperability. This dialogue may include inviting key organizations to join the Carrier Industry Task Force or other advisory panels. Progress reports on the preparation of measurement tools and test practices will be sent to key organizations and professionals to encourage their participation. Coordination of users with NASA's Joint Sponsored Research Program will be an active part of this task.

4.2.2 Technology Transfer

Using the same outreach mechanisms described above, this task will identify and establish a focused dialogue with commercial vendors that have the potential for adopting the findings of our research activities and incorporating them into existing or new interoperability satellite/terrestrial products, systems and services.

4.2.3 Technical Support

While new users from government, industry, and academia will be encouraged to participate in the testbed to verify their newly developed systems and applications, we realize that the use of the testbed will not be straightforward. Substantial technical information will be furnished to new users on routing addresses, specific equipment and systems interfaces, and on how to utilize the performance measurements tools. In addition, as new users get their work underway, new questions and needs for technical assistance will arise. This technical support effort will assemble the crucial information to get experiments started, and provide support through the completion of the experiment.

4.3 [TASK 3] Applications Testing on the TSTI

4.3.1 Distributed Global Climate Modeling

This computationally intensive task, directed by GSFC, could potentially make full use of the ACTS communications channels between JPL and GSFC in a coupled atmosphere/oceans climate model. GSFC will provide the lead for the atmospheric part of the model while JPL researchers would lead the development of the oceans segment, essentially paralleling the assignments for two of the Distributed Active Archive Centers (DAACs) of the EOSDIS. Time scales of the two models differ and conveniently support dissection of the problem into two coupled parallel processes. Close association with the data sets of the related DAAC would facilitate calibration to reality.

A major objective in the experiment investigation is to explore methodology and performance issues for decomposing a coupled atmosphere/ocean global climate model (GCM). This model will run concurrently on heterogeneous computers, presently the Cray J932 at GSFC and the Cray YMP-232/T3D at JPL interconnected via the ACTS. Additional objectives are to: (1) determine the communications bandwidth requirements for different decomposition strategies, (2) determine the effects of latency and communications cost for different decomposition strategies, (3) find methods to mask latency with computation, and (4) achieve a super linear speedup of the coupled GCM code in distributed, heterogeneous environment. This model is described in more detail in reference [1].

4.3.2 ATM Speech, (also see Annex 2)

Voice is inherently variable bit rate (VBR) traffic. To date, constant bit rate (CBR) solutions for transport of voice and voiceband data have been considered, however, no compression gains for the voice traffic are realized by using CBR techniques. Despite this, potential compression gains are significant and, given the amount of voice traffic in today's networks, these gains should not be ignored.

CBR solutions are being proposed from the standpoint of expediency and ease of interworking. They are a legacy of the organization of the public switched telephone network (PSTN) into a hierarchy based on 64 kb/s. While ATM will always need to interwork with PSTN/narrowband integrated services networks (NISDNs), the efficient carriage of voice traffic should not be discouraged by the way in which older networks were organized.

An approach needs to be developed in which the CBR solution is a short-term or fall-back one, but in which an easy migration path to one (or more) VBR solutions is provided. In this scenario, ATM signaling, of which the major information elements (e.g., broadband LLC) are already in place, can be used during call establishment to select an appropriate speech coding algorithm.

The use of AAL1 for the transport of single voice call per VC over ATM, with optional silence removal and/or voice compression is described below. The proposed technique is applicable to the transport of voice between narrowband interworking functions (trunking) to native ATM terminals, and to interoperation between native terminals and narrowband interworking function (IWF). The intention is to develop a solution for the bandwidth-efficient transport of voice over ATM networks that does not impose any added complexity on networks and terminals that do not use it. This solution allows terminals and networks which use silence elimination and/or voice compression techniques to achieve bandwidth-efficiency gains with little added complexity. Interoperation with terminals that do not choose to implement silence elimination and/or voice compression is through a default 64-kb/s pulse code modulation (PCM) CBR mode.

4.3.3 Internet and Visualization Data

One of the key uses of satellite-terrestrial networks will be the transport of high speed computer generated images and other forms of supercomputer data. Much of this data today is generated by equipment using the HIPPI format. Bellcore has an experimental system, called the HAS (HIPPI-ATM-SONET), that converts the HIPPI data (nominally 800Mb/s) used on local computer buses into the ATM data at the OC-12c data rate (622 Mb/s) typically used in high-speed public backbone networks. This system can'take the high resolution images used in visualization programs for supercomputers and convert them to ATM to pass across the public networks and the satellite link of the TSTI network. Other sources of such data for testing the TSTI could be the new graphics workstations that are currently being furnished with ATM I/O ports. Also, high speed ATM switches with OC-12c ports are expected to be common in the market before the end of 1996. Such switches can be used to multiplex several signals onto a single fiber line (at OC-12c rate) for transport across the satellite link. Bellcore will make the HAS available for use on the TSTI to enable interoperability experiments involving Supercomputer applications.

One of the challenges for this work on interoperability of satellite terrestrial networks will be getting a sufficient sample of real user traffic.

4.4 [TASK 4] Improving Performance of Applications

The focus of activities for the use of the testbed is the opportunity to implement and measure the effectiveness of protocols designed to enable a wide range of applications to perform efficiently over heterogeneous satellite/terrestrial networks. The scope of work is defined to address interoperability problems posed by the use of satellite links in conjunction with high-speed terrestrial networks, which are migrating toward ATM and the use of evolving the Internet protocol suite for end-to-end networking.

Within this domain, there are numerous approaches to addressing the effects of latency, errors and bandwidth limitations imposed by satellite links being investigated by researchers and developers in the private and public sectors. This testbed will enable these investigations to be tested, refined, validated and compared in an environment that offers a rich set of realistic networking conditions, and an extensively instrumented data acquisition and measurement capabilities. It is our intention to make the testbed available to the research community, as a neutral playing field, facilitating quantitative and repeatable examination of hardware and software-based protocol enhancements.

The scope of work described below suggests investigation of several specific techniques that are under development for improving performance by making changes or additions to protocols at the ATM, TCP/IP and application layers. These particular techniques are being explored in research programs underway at the facilities of the testbed partners and will be implemented and evaluated on the testbed.

The testbed will also be used to evaluate other techniques, under development elsewhere, as they become available. The testbed will be made available to researchers carrying out related work funded under other programs such as the Lewis Research Center (Internet Communications Over High-Latency Links, NRA-96-LeRC-3) and others funded by DARPA, OSD, NSF and other agencies. The overall goal is to enable the research community to more efficiently address the issues of using satellite links and to establish the application domains where various techniques for improving application performance are applicable. The value of using the testbed as a common, shared resource will be measurable financially, in costs saved by the elimination of duplicative facilities, technically, as the use of a common test environment will enable more quantitative comparisons of test results, and in convergence, as the testbed will encourage industry dialog and more rapid dissemination of interface requirements and accelerate the adoption of standards.

4.4.1 TCP Boosters

TCP is an embedded, highly used system that is likely to be around in its current form for a long time. However, TCP is inefficient over networks with high delays, such as those including a satellite link. How, then, should networks with inherently high delays provide efficient Internet services?

One option is to modify TCP to allow for high latency. As TCP is already an embedded system, however, changing the protocol will be a difficult and time consuming process. We could wait for the solution proposed by the IETF [2], but this will take years to get into existing implementations and may not fully address the problems specific to geostationary satellites [4] [5].

One solution, that Bellcore has already started working on [3], is the development of protocol "boosters" to ride with TCP. The booster would be placed transparently around the satellite network, without any change to the end-to-end protocols (e.g., TCP and UDP). The boosters will use existing software implementations applied selectively to specific streams.

In effect, these TCP boosters make it appear as if we are using an advanced version of TCP over the parts of the link between the boosters. TCP remains intact at the end systems, while the TCP boosters mitigate the high latency and high noise channel conditions. It is expected that most of the booster's features will be moved into enhanced TCP implementations (which we will propose at the IETF). However, as it takes many years to propagate changes through the Internet community, TCP boosters are needed in the interim to allow immediate performance improvements and give much needed experience in designing and tuning these protocols.

Two different types of boosters are being proposed here: ARQ Boosters and FEC Boosters.

4.4.1.1 ARQ Boosters

We propose implementing an ARQ Booster that allows existing TCP implementations to work efficiently over a large bandwidth delay product network. The ARQ Booster removes link ARQ inefficiency using its knowledge of the end-to-end protocol. Figure 4 shows a pair of ARQ Boosters at the edges of an integrated satellite- terrestrial network, with the satellite used as an access network.

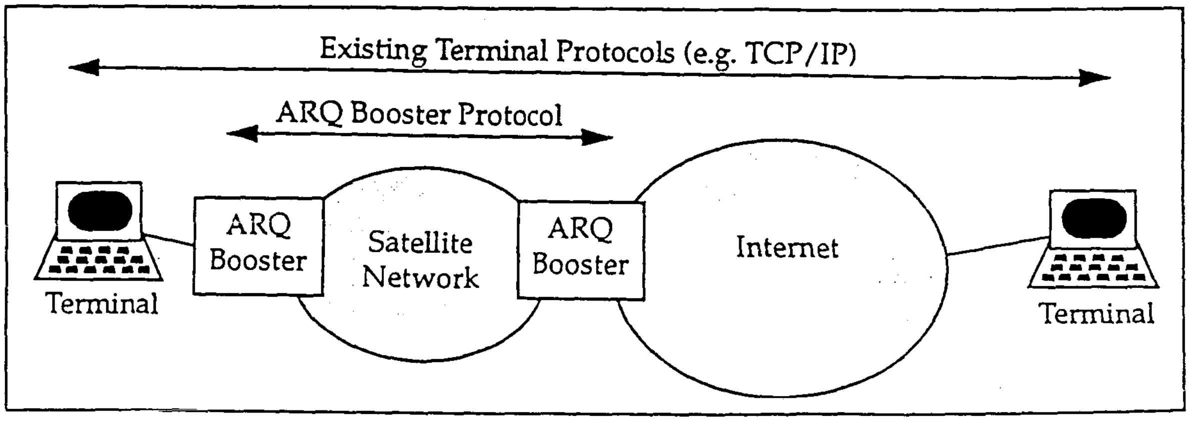


Figure 4. Communications Over a Satellite Access Network with an ARQ Booster

TCP uses Automatic Repeat request (ARQ) to re transmit data unacknowledged by the receiver. The receiver uses cumulative acknowledgments, sending the highest sequence number such that all data with lower sequence numbers have been received. When a packet loss is detected (after a time-out interval or receipt of three or more duplicate acknowledgments), the transmitter typically retransmits all unacknowledged data (go-back-N retransmission).

Efficient use of networks with high latency (and/or high loss) requires more sophisticated ARQ protocols that use selective acknowledgment and selective retransmission. With selective acknowledgment, the receiver acknowledges all received data instead of providing only a single sequence number, as does cumulative acknowledgment. Selective retransmission means that all data is retransmitted independently - the loss of some data does not automatically cause the retransmission of all unacknowledged data. Selective acknowledgment adds more bandwidth overhead, but is typically more efficient due to reduced retransmissions.

The ARQ Booster could combine several mechanisms, such as:

1. Add selective acknowledgment information over the satellite link.
2. Add selective retransmission by blocking packets that have recently been acknowledged by the ARQ Booster nearer the Receiver.
3. Give up attempts to retransmit data when it sees duplicate data sent by TCP sender.

Bellcore is currently developing the basic ARQ Booster as part of an DARPA/CSTO funded research project to develop new protocol design methodologies for heterogeneous distributed computing systems [3] The focus of the DARPA funded project is on terrestrial networks and the research program does not specifically include satellite links. As we expect most mechanisms will be useful for any high latency or high error subnetwork, we will use the techniques developed there as the basis for an ARQ Booster adapted to satellite networks. Some changes will be necessary, however, because satellite links can exhibit different characteristics (compared to large bandwidth delay product networks with lesser delays or to terrestrial wireless networks without FEC).

After gaining experience with the ARQ Booster, some of the features of the ARQ Booster would be proposed to be integrated with future versions of TCP. However, by not requiring TCP to change, the benefits of high bandwidth satellite links can be realized immediately. We plan to implement these boosters and evaluate their performance over high-latency, high-bandwidth satellite links.

4.4.1.2 FEC Boosters

Another example of a TCP booster is Bellcore's FEC Booster. The FEC Booster was developed to boost both TCP and UDP on terrestrial wireless networks. It is designed primarily to reduce end-to-end latency for real-time applications; but, paradoxically, the redundant packets can also be used to improve efficiency by reducing the need for end-to-end TCP retransmissions.

The FEC Booster takes advantage of its knowledge of TCP to improve overall performance compared to an independent FEC link protocol. The FEC booster selectively adds redundant packets without changing existing end-to-end packet flow. If the sending FEC Booster adds h additional packets to a group of k end-to-end packets, the receiving FEC Booster can add any missing end-to-end packets provided at least k of the k+h packets were received.

The Bellcore FEC booster software implements a powerful packet FEC that runs in software at multi-megabits per second. This proposal would use the multi-megabits software prototype FEC booster over the satellite link.

4.4.2 TSP/SSCOP

A new retransmission strategy can be implemented at the host or between two routers on either side of the satellite link. Comsat has devised a protocol called The Time Sequence Protocol (TSP) which can provide a high throughput over high latency links, even when the link quality degrades considerably. TSP has several new key features such as a new retransmission strategy, high throughput performance, optimum delay performance, insensitivity to network delay variance and is very simple to implement. TSP has a new generalized retransmission strategy, of which the more traditional selective retransmissions and Go-Back-N are special cases. There are no duplicate retransmissions in TSP resulting in an optimal number of retransmissions. One way to solve TCP's retransmission problem is to introduce TSP on either side of the satellite link. Also, TSP has a built in data compression algorithm which would help alleviate the limited bandwidth problem over satellites. Figure 5 shows this approach.

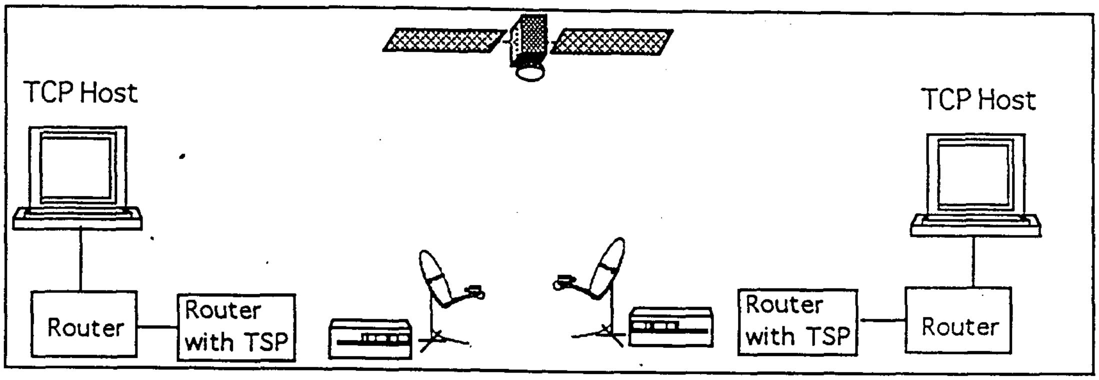


Figure 5. Combined TCP/TSP Approach

The advantage of this solution is that it requires minimal changes to TCP software at the host, which is important since any proposed changes to TCP must be implemented by several vendors who support it on various platforms. Another advantage is that it could identically be applied to TCP over ATM over satellites. Comsat currently has a number of products such as the Data Communications Link Accelerator (DCLA) and the ATM Link Accelerator (ALA) which are based on this approach. Figure 6, shows the performance of TCP in the presence and absence of TSP over a satellite link.

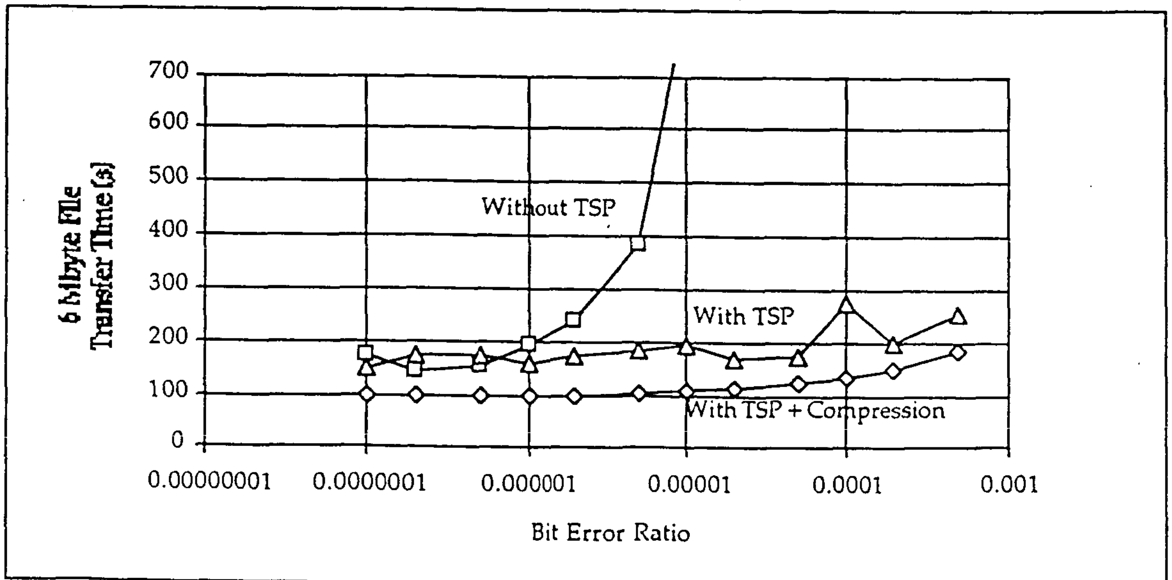


Figure 6. TCP Vs TSP Performance

Alternately, one could devise a new retransmission strategy that could be implemented in the hosts themselves. TCP essentially uses a "Go-Back-N" retransmission scheme where a loss of a packet causes retransmission of all packets numbered beyond the lost packet, even though many of these packets may have been successfully delivered to the destination. The fast retransmit amendment [Jacobson 88] allows retransmission of a single packet within a window. Retransmissions trigger window reduction, thereby affecting throughput. The new "SACK" proposal [TCPLW-SACK] addresses this concern, but does not go far enough.

Comsat has been a pioneer in the development of selective retransmission protocols. Both the Time Sequence Protocol (TSP) and the ATM Service Specific Connection Oriented Protocol (SSCOP) --which is based on TSP-- include very effective, optimal retransmission schemes. Comsat will test TCP performance over the ACTS HDR testbed based on techniques from TSP and SSCOP.

4.4.3 ATM Link Enhancer

To make ATM service feasible over satellites at the same quality level as fiber, Comsat has developed ATM link enhancer and ATM link accelerator techniques that are capable of providing significant improvements in ATM QOS.

To test the effectiveness of ALE/ALA techniques for applications running over the ACTS satellite, it is proposed to evaluate the performance of DS-3 ATM and ATM at 6 - 8 Mbps (for MPEG-2 video). The tests will be conducted via the ALE and ALA and the ATM switches (e.g. FORE ASX-200) which will have the appropriate interfaces to the applications and the OC-3 interface to the ACTS HDR terminal.

The Comsat ATM link enhancer (ALE) is a hardware device that can significantly improve the performance of ATM links routed over satellite channels that use convolutional forward error correction (FEC). The basic problem that the ALE corrects is the poor performance of some AAL, ATM, and physical layer protocols in a burst error environment. The ALE implements selective interleaving to distribute FEC residual burst errors so that they appear as random bit errors in the data stream. The ALE essentially makes it possible for such satellite links to provide an acceptable "cell discard probability" without requiring an unreasonably high link margin. In addition to improving the performance of the HEC on ATM cells, the ALE has options that can also improve the performance of AAL type 1 and 3/4 protocols. For DS-3 interfaces, the ALE also significantly improves the performance of Physical Layer Convergence Protocol (PLCP) framing by performing preprocessing on the PLCP overhead.

Because it operates on standard interfaces defined by International Telecommunication Union (ITU) recommendations, the Comsat ALE can be used to interconnect different ATM networks at the network-to-network interface (NNI) or user network interface (UNI). The ALE supports the DS-3 interface specified in ITU-Telecommunications Sector (ITU-T) Recommendation G.804.

Full bit interleaving of ATM cell headers performed by the ALE tends to "distribute" or "spread" the bit errors between ATM cell headers after deinterleaving on the receive side. The probability of an ATM cell header being in error by two or more bits is reduced. Further, error cell headers having single-bit errors are more likely, and these can be corrected by the cyclic code in the cell header, improving the QOS by many orders of magnitude.

Comsat has designed a second-generation ATM link enhancer (ALE-2) to improve ATM performance for ATM cell error ratio and ATM misinsertion ratio in addition to ATM cell loss ratio over transmission facilities which exhibit burst errors.

The ALE-2 implements cell-based adaptive Reed-Solomon (RS) coding in order to correct residual burst errors that are due to inner Viterbi decoding of the coded satellite channel. Furthermore, it improves performance by many orders of magnitude without adding any overhead. The Reed-Solomon decoder checks each received signal block for errors. If the RS decoder detects an uncorrectable error on a block that includes headers, the ALE-2 discards the affected cells and inserts unassigned cells. The ALE transparently transfers the necessary physical layer overhead.

The two primary interfaces for which the ALE-2 is intended are the DS-3 direct mapped interface and the E3 interface specified in Rec. G.804. The industry is moving away from PLCP-based DS-3, especially on international interfaces.

4.4.4 ATM Link Accelerator

The Comsat ATM link accelerator (ALA) significantly improves network performance and improves the bandwidth efficiency of wide area network (WAN) links used to carry ATM traffic. The ALA is ideally suited for use over satellite or terrestrial wireless links, operating at fractional T1 to 6-Mbit/s data rates. The ALA provides cell-based Reed-Solomon-based FEC and interleaving, thereby providing fiber-like link quality over noisy satellite or wireless point-to-point links. Bursty bit errors, produced by typical satellite and wireless modems, are corrected by the ALA to provide cell loss ratio and cell error ratio of 10^{-10} and better. With its adaptive coding mechanism, it can dynamically change the RS coding rate as well as the modem Viterbi coding rate depending on the quality of the link, thereby providing high link quality as well as improved data rates depending on link conditions. For example, on "clear" days, it uses very little overhead for coding, thereby providing additional throughput to ATM applications. During inclement weather, it increases the coding rate at the expense of throughput, providing high link availability and maintaining high link quality.

The ALA can perform lossless data compression for selected ATM virtual circuits and thus double or triple the effective link rate for ATM available bit rate (ABR) traffic, reducing the need for upgrading expensive leased or dial-up data lines. The ALA includes the Comsat Time Sequence Protocol (TSP), which provides data integrity and very high throughput performance over terrestrial, single-hop, and double-hop satellite links.

The ALA supports a variety of interfaces to the ATM switch—DS-3, E3, T1, E1, and RS-449—and connects to WAN equipment using a programmable-rate RS-449 interface. This allows the connection of ATM equipment over nonstandard-rate WAN links.

4.4.5 ATM Traffic Management

4.4.5.1 Introduction

The ATM Forum TM Specification 4.0 is currently in the final review process before general release. The document will be released as a formal ATM Forum specification if it passes the final vote in the April, 1996 meeting.

The TM Specification 4.0 defines five service categories along with a set of parameters to describe the traffic presented to the network, the Quality of Service (QoS) required of the networks, and a set of traffic and congestion control mechanisms that the networks may utilize to meet these QoS requirements. Although much effort has gone into the preparation of this document, the effectiveness of the traffic and congestion control mechanisms defined are not well understood. This specification defines a number of traffic management functions and procedures whose implementation are network specific. In addition, these functions and procedures require a large number of parameters to be fine tuned based on the traffic and network characteristics.

The objective of the effort proposed here is to investigate the effectiveness of the traffic and congestion control mechanisms defined in the ATM Forum Traffic Management (TM) Specification 4.0 over a high speed satellite link by using analytical and simulation modeling and experimentation. The initial phase of this study will include a detailed simulation of the traffic and congestion control mechanisms. Analytical modeling will be used where possible for performance evaluation. All issues related to the operation of these mechanisms over a high speed satellite link will be identified. Network specific functions, traffic and congestion control related parameters, and policies for congestion detection will be optimized for operation over high speed satellite links. In the second phase of the work, the optimized mechanisms and parameters will be implemented and tested over the ACTS TSTI testbed.

4.4.5.2 Network Configuration

Figure 7, depict the network configuration that will be used in this study. The performance of the ABR traffic control mechanism over a high speed long delay path is of particular interest in this study. The ABR sources and destinations and the ATM switches follow the reference behaviors specified in TM 4.0. In order to vary the bandwidth available to the ABR sources, we also use VBR and UBR sources as well. The ATM switch at the transmit side multiplexes cell streams coming from these sources onto an OC-3 link for transmission over the ACTS satellite. All connections are established after a call admission control. The ATM switches have knowledge of the traffic descriptors and QoS requirements of each connection. Table 1 below summarizes the traffic and congestion control functions that must be implemented in this network.

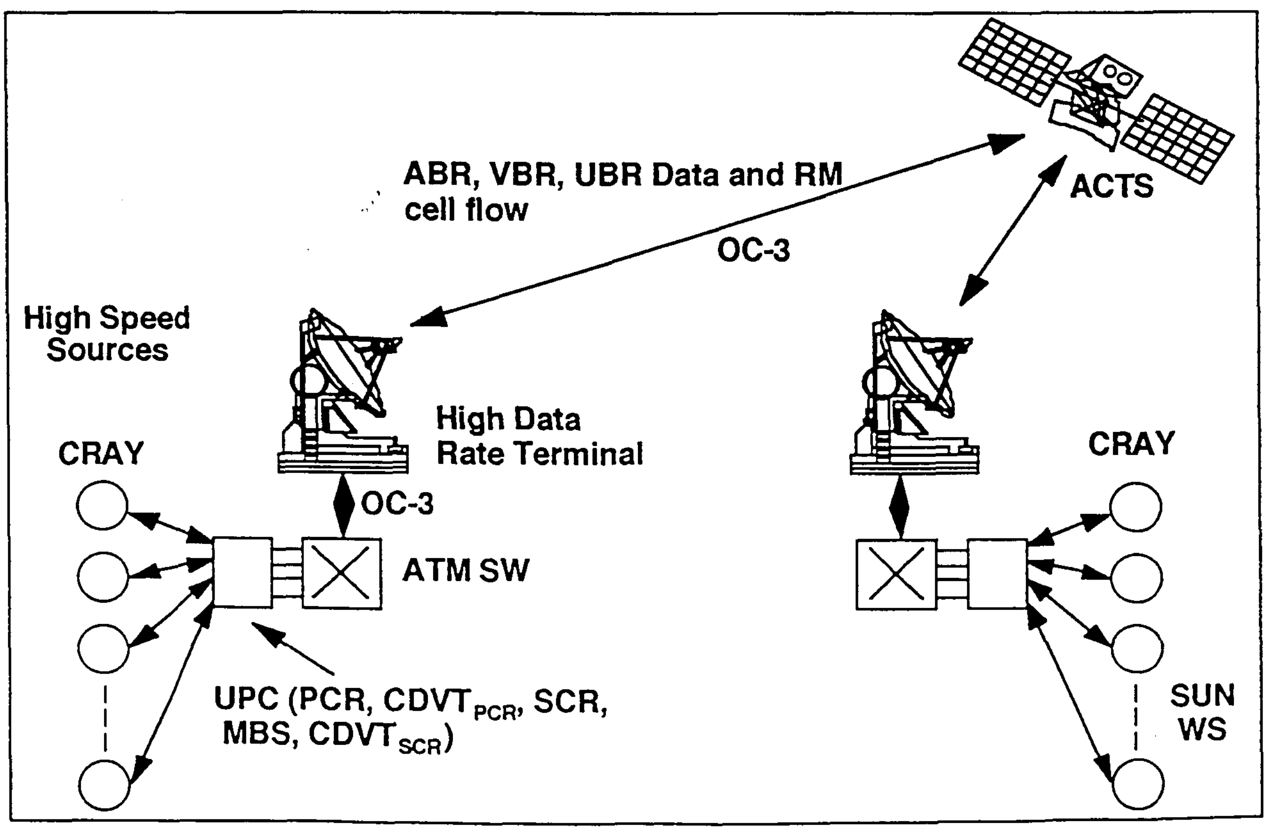


Figure 7: Network Configuration, ATM-Satellite Testbed

Traffic and Congestion Control Functions	ATM SOURCE	ATM SWITCH
Cell Level Functions:		
Cell discarding		√ (note 1)
Cell marking	√ (note 2)	
Cell tagging		√ (note 3)
Buffer management/Service Policy		√ (note 4)
Traffic Shaping		√ (note 5)
UPC		√ (note 6)
Feedback Controls:		
RM Cells (for ABR)	√ (note 7)	√ (note 8)
VS/VD		√ (note 9)
EFCI Notification		√ (note 10)

Table 1: Traffic and Congestion Control Functions to be implemented at the ATM-Satellite Testbed

Notes on Table 1:

note 1: Any cell incoming from the sources will be discarded at the transmit ATM switch if it is found to be non-conforming to the connection's traffic contract by the UPC and if the cell tagging option is not selected.

note 2: Optionally, a VBR source may generated cells with the CLP bit set to 1 to protect its high priority cells during congestion. In this case, the congested ATM switch first discards marked cell.

note 3: According to the current ATM Forum 4.0 Traffic Management Specification, networks are not required to support cell tagging. Furthermore, cell tagging only applies to VBR service category, and the user must explicitly select the tagging option. IF the network supports tagging, cells that are found not conforming to the connections traffic descriptions are tagged instead of being discarded. Tagged cells are discarded first during congestion.

note 4: The ATM switch must implement certain buffer management and priority queue service policies to share the OC-3 link capacity among the connections according to their traffic descriptors. In addition, the ATM switch must implement certain policies in order to share the available bandwidth fairly among ABR and UBR connections.

note 5: Traffic shaping must be performed at the receive ATM switch to eliminate perturbation caused on cell delay and cell delay variation (CDV) due to queuing at the transmit ATM switch and satellite access.

note 6: UPC must be performed at the transmit ATM switch on traffic streams incoming from the sources to test the conformance of the streams to the traffic contract. Cells that are not conforming to the traffic contract may be discarded or tagged. The algorithms to be used for conformance testing requires further study. However, the Generic Cell Rate Algorithm (GCRA) specified in TM 4.0 Specification can be a basis.

note 7: The ABR sources must generate forward and backward RM cells, modify their rate according to the information carried in the received RM cell, and write onto the RM cell according to the source and destination behavior described in TM 4.0

note 8: The ATM switch will modify certain fields of the RM cells that it receives and it may also generate backward RM cells according to the reference switch behavior described in TM 4.0.

note 9: An ABR connection, as shown on figure 8, may be divided into two separately controlled ABR segments at the ATM switches as shown below. The concept of virtual source and virtual destination is especially attractive for long delay paths. The coupling between the two adjacent ABR control segments associated with the ABR connection is currently not well defined.

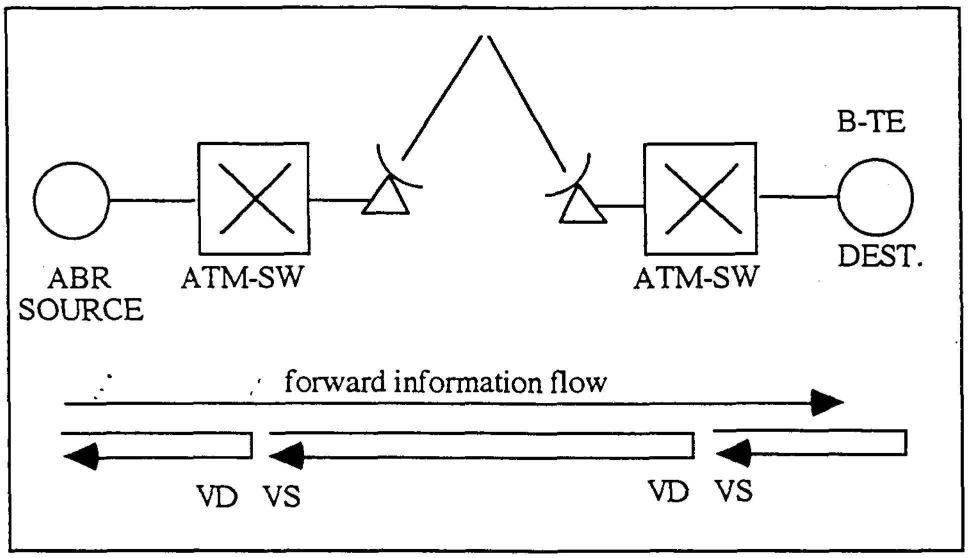


Figure 8. ABR Connection.

note 10: The ATM switch may also mark cells incoming from the ATM node as "congestion experienced" by Explicit Forward Congestion Indication (EFCI) during congestion.

4.4.5.3 Specific study points:

The proposed study will specifically investigate the following:

- The TM 4.0 specification defines a number of parameters that must be negotiated between the ABR source and the network during call establishment (Appendix C). How must these parameters be fine tuned for operation over the ACTS satellite at the OC-3 rate ?
- What are the buffer requirements at the sources and the switches ?
- What policies must the ATM switch on the transmit side use to detect the beginning and ending of congestion ? The ATM switch has the traffic descriptors (e.g, PCR, SCR, MBS, $CDVT_{PCR}$, CDV_{SCR}) of all connections that are agreed upon during call establishment. How can this prior information on the traffic descriptors can be combined with the actual traffic statistics for detection of congestion ?

- Can the OC-3 link be operated at an acceptable efficiency by an appropriate choice of the ABR parameters or what improvements can be made to the reference source, switch, and destination behaviors specified in TM 4.0 ?

- How can the ABR performance over a satellite link be improved by segmenting the connection using the VS/VD concept ? What is the coupling between the VS and VD portions, as shown in Figure 8.

- What are the buffer management and queue service plovies that must be implemented at the ATM switches to meet the QoS requirements of all connections when VBR, ABR, and UBR sources share a common OC-3 link.

- What is the performance of the higher layer protocols such as TCP/IP over various ATM service categories for high delay and high speed links ?

4.5 [TASK 5] Contribution to Standards

All of the Team Members are currently active in standards development. Bellcore is a strong participant in the IETF and the ATM forum, and will provide its results in this testbed to the IETF at the ATM forum, to assure that these standards activities include satellite characteristics. Comsat is one of the strongest standards proponents for the satellite communications industry. Dr. Chitre directs and participates in the international and national standards activities in ATM, ISDN, B-ISDN, and Data Communication as they apply to satellite communication. He was Chairman of the Working Group on Protocols and Network Timing Function of the CCIR/CCITT Joint Ad Hoc Group on ISDN/Satellite Matters during 1990-1992. Currently, he is the Chairman of the Working Group on New Technologies in the ITU Intersector Coordinating Group (ICG) on Satellite Matters. Mr. Helm of GWU is active with the IEEE standards committee, especially for the development of new standards for the NII/GII. Also, he chairs the AIAA Standards Committee on Satellite Communications. All of the partners will look for opportunities to promote the TSTI results in U.S. and international standards bodies.

4.6 Intellectual Property

Intellectual Property will be negotiated with NASA under its Joint Sponsored Research Program. However, it is understood that Team members will retain all rights and title in technical data and software developed under the contract, but will grant NASA government-purpose rights to use such data and software in further NASA-funded research. Team members will retain all rights and title to inventions and resulting patents, made under the contract, but will grant NASA government-purpose rights under such patents. Intellectual property created jointly by team members under this contract will be jointly owned; intellectual property created by a single team member under this contract will be owned solely by that team member. Team members retain all rights to previously existing intellectual property which may be used in the performance of this project, and will grant NASA government-purpose rights to its use.

Bellcore is subject to the terms of the Telecommunications Act of 1996 (the "Act") and is prohibited thereunder from engaging in the manufacture of telecommunication equipment or CPE. Bellcore will not undertake any activity with regard to this project that does not comply in all respects with the Act. Specifically, under this project, Bellcore will not engage in the design or manufacture of telecommunications equipment or CPE. Any experimental prototype components created with the participation of Bellcore will be used solely for limited-duration experiments to prove the technical feasibility of the novel architecture and technology proposed herein.

****

References:

[1] J. Gary, "Distributed Global Climate Model Experiment Via ACTS", Proceedings of ACTS results conference, NASA LeRC, Cleveland, OH, September 11-13, 1995

[2] M. Mathis, J. Mahdavi, S. Floyd, A. Romanow, "TCP Selective Acknowledgment Options," INTERNET-DRAFT (Draft-ietf-tcplw-sack-00.txt), April 1996. (ftp://ftp.ietf.cnri.reston.va.us/internet-drafts/draft-ietf-tcplw-sack-01.txt)

[3] DARPA/CSTO Booster Project. (http://gump.bellcore.com/~dcf/boosters/homepage.html)

[4] A. J. McAuley, D. S. Pinck, T. Kanai, M. Kramer, G. Ramirez, H. Tohme, and L. Tong, "Experimental Results From Internetworking Data Applications Over Various Wireless Networks Using a Single Flexible Error Control Protocol," Fifth WINLAB Workshop: Third Generation Wireless Information Networks, East Brunswick, New Jersey, April 26-27, 1995.

[5] S. Bajaj, C. Brazdziunas, D. Brooks, D. Daly, I. Lopez, S, Srinidhi, T. Robe, & F. Vakil, "Performance of TCP over ATM on an ATM/SONET ACTS Channel," Proceedings of the 16'th AIAA International Communications Satellite Conference, Washington D.C., pp.1008-1019, February 1996.

Testbed for Satellite and Terrestrial Interoperability (TSTI)

VOLUME 2
MANAGEMENT SECTION

Member Responsible for Tasks - (GSFC, JPL, Comsat, Bellcore, GWU, all)

5. Division of Responsibilities

1. TASK 1-Testbed Design, Development, Integration and Management

1.1. Testbed Design - GSFC
Design an end-to-end testbed, interface requirement, to support tests and demonstrations.

1.2. Testbed Development - GSFC, JPL
Develop a backbone foundation of ACTS HDR equipment and communications infrastructure located at GSFC and JPL.

1.3. Measurement Systems and Objectives - Bellcore
Develop analysis tools for satellite terrestrial network interoperability testing, and the global analysis routines for interpreting the results of these tests.

1.4. Testbed Integration and tools - GWU
Integrate new users and tools into the overall TSTI, establish Carrier/ Industry Advisory Committee.

1.5. Testbed Management - GSFC
Manage the TSTI testbed activities, establish testbed laboratory at GSFC

2. TASK 2- Outreach, Industry, Government and Academia

2.1. Outreach, External Relations - GWU
Solicit new users for the testbed from government, industry, and academia to test new equipment, systems and networks.

2.2. Technology Transfer - GWU
Transfer team and user research to commercial venders, carriers via demonstrations, technical papers etc.

2.3. Technical Support - All
Help new users in accessing the testbed and act to alleviate technical problems in user tests and demonstrations.

3. TASK 3- Application Testing on the TSTI

3.1. Distributed Global Climate Modeling. - GSFC, JPL

3.2. ATM speech - Comsat
Develop and test silence removal, lost cell detection, low-rate encoding, call setup procedure and bandwidth allocation, and channel associated signaling.

3.3. Internet and Visualization Data - Bellcore
Convert high resolution images used in visualization program to ATM, to pass across the satellite link of the TSTI network.

4. TASK 4- Improving Performance of Applications

4.1. TCP Booster - Bellcore
Modify TCP to allow high latency, with and without a optional booster.

4.1.1. ARQ Booster - Bellcore
Implement an ARQ Booster that allows existing TCP implementations to work efficiently over a large bandwidth of delay.

4.1.2. FEC Booster - Bellcore
Develop Booster for both TCP and UDP on terrestrial wireless networks.

4.2. TSP/SSCOP - Comsat
Develop and test TSP on either side of the satellite link, and devise a new retransmission strategy that could be implemented in the hosts.

4.3. ATM Link Enhancer - Comsat
Implement cell-based adaptive Reed-Solomon (RS) coding in order to correct residual burst errors that are due to inner Viterbi decoding of the coded satellite channel.

4.4. ATM Link Accelerator - Comsat
Perform lossless data compression tests for selected ATM Virtual circuits.

4.5. ATM Traffic Management - Comsat

4.5.1. Investigate effectiveness of traffic and congestion control mechanisms. - Comsat

4.5.2. Network Configuration - Comsat
Configured ATM satellite testbed, as seen in figure 7.

4.5.3. Specific Study Points - Comsat
Study TM 4.0 Specification, buffer requirements, ATM switching policies, OC-3 link, ABR performance, buffer management, and performance of TCP/IP over various ATM configurations.

5. TASK 5 - Contribution to Standards - all

Contribute technical papers and results of testbed activities to national and international standards bodies.

6. Schedule and Milestones

The TSTI Team is prepared to begin the design and development of the testbed in August 1996. The tests, demonstrations and transfer of the testbed technologies to commercial systems and networks will extend for a minimum of two years, through FY 1998. Figure 9 shows the TSTI schedule and milestones for a two year duration. If the ACTS satellite lifetime were to be extended with the use of tracking ground terminals, or if the testbed had test and demonstration commitments to other developmental testbeds and networks such as the NREN or the G7/GIBN, it is proposed to extend the testbed life for additional years. The availability of commercial satellites and networks to be interoperable with the TSTI will also be considered in proposals to expand the scope and the longevity of the testbed.

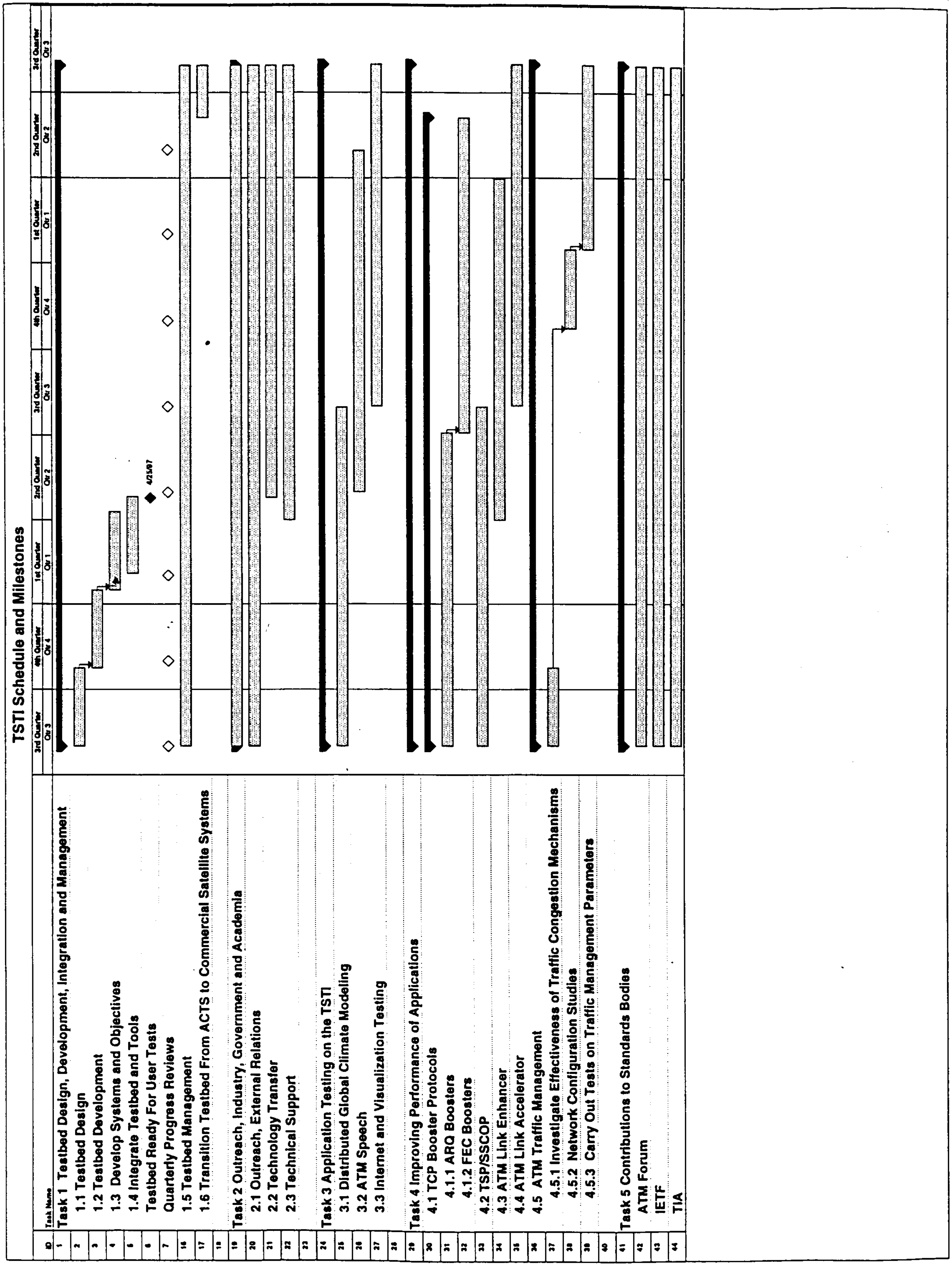


Figure. 9 TSTI Schedule and Milestone

7. Curriculum Vitae - Research Team

J. Patrick Gary, GSFC: Head of Computer Network and Communications Branch

Mr. Gary is Head of the Computer Networks and communications Branch at the NASA Goddard Space Flight Center. In this position, he is responsible for management, design, development, and implementation of advanced computer networking systems for high speed access to GSFC computing facilities by university and NASA in-house scientists and for planning, integration, and operational management of network servers and advanced computer systems enabling domain name services, USENET News access, online Network Information Center, and applications gateway servers among computer networks using different protocols (e.g., TCP/IP, DECnet, RSCS) in support of GSFC local area network which presently supports over 16,000 directly attached computers.

Mr. Gary has received a M.E.A. in Engineering Administration in 1981 from George Washington University, a M.S. in Computer Science in 1974 from University of Maryland, and a B.A. in Mathematics in 1968 from The Catholic University of America.

Larry A. Bergman, JPL: Supercomputer Project Engineer

Dr. Bergman joined the Jet Propulsion Laboratory in 1975, where he has been developing spacecraft data buses and computer networks. Since 1981, he has lead the development of multi-gigabit fiber optic networks, fiber optic sensors, and VLSI optical interconnects. He has authored many papers, received several patents, and lectured in the fields of fiber optics and high - speed communications. He presently supervises the High Speed Optical Systems group, and is also the Project Engineer for the JPL Supercomputer.

Over the last ten years, Dr. Bergman has served as a consultant to the optics, motion picture, and data processing industries as well as nearby universities in the areas of electro - optic system design, telecommunications, and computer science. In 1984, he was awarded the first place prize at the European Conference on Optical Communication (ECOC), Stuttgart, West Germany, for a new system approach that achieves multi- gigabit/s data rates for ring LANs.

Dr. Bergman received the B.S.E.E. degree from California Polytechnic State University, San Luis Obispo, in 1973, the M.S.E.E. degree from California Institute of Technology, Pasadena, in 1974, and the Ph.D. EE degree from Chalmers University of Technology, Gothenburg, Sweden, in 1983. Dr. Bergman is a member of IEEE, OSA, ASA, AES, SMPTE, Tau Beta Pi, Eta Kappa Nu, Phi Kappa Phi, Sigma Xi, and has authored more than 40 papers in the optics field.

Dattakumar M. Chitre, Comsat Laboratories: Director of Network.

Dr. Chitre is currently Director of Operations in the Network Technology Division at COMSAT Laboratories. He has been involved in research and development activities in ATM, ISDN, VSAT networks, data communications and network systems and architectures. Prior to his current positions, Dr. Chitre was Associate Executive Director in the Network Technology Division at COMSAT Laboratories.

Dr. Chitre joined COMSAT Laboratories in 1980. He has made major contributions to the analysis and architecture of ATM, data communication, ISDN, and B-ISDN via satellite. Dr. Chitre directs and participates in the international and national standards activities in ATM, ISDN, B-ISDN, and Data Communication as they apply to satellite communication. He was Chairman of the Working Group on Protocols and Network Timing Function of the CCIR/CCITT Joint Ad Hoc Group on ISDN/Satellite Matters during 1990-1992. Currently, he is the Chairman of the Working Group on New Technologies in the ITU Intersector Coordinating Group (ICG) on Satellite Matters. Dr. Chitre is a member of the U.S. Satellite Industry Task Force and Chairman of the Standards and Interoperability Committee. Dr. Chitre was a program manager during 1990 and 1991 on a contract from INTELSAT on Systems Studies on Satellite Communications Systems Architectures for ISDN and Broadband ISDN Systems. Currently, he was the technical manager of the DoD Contract on ATM via Satellite Demonstration. Dr. Chitre is the Program Manager of an INTELSAT Contract on the "Analysis and Top-Level Specification of INTELSAT ISDN Subnetworks and SDH Compatible Transport Network," which started in 1993 and will run through 1995. Dr. Chitre is also the Program Manager of a recently (15 August 1994) awarded contract from INTELSAT on "Transport of ATM Based Traffic via the INTELSAT System - Test-bed and Simulation."

Dr. Chitre is the Chairman of the Communications and Interoperability Section of the Satellite Communications Division of the Telecommunications Industry Association (TIA). He is also on the Industry Advisory Board of the Center for Commercial Development of Satellite of the University of Maryland.

Dattakumar M. Chitre received his B.Sc. from the University of Bombay, India; an M.A. in mathematics from the University of Cambridge, U.K.; and a Ph.D. in physics from the University of Maryland.

Faris R. Faris, Comsat Laboratories: Associate Manager in the Network Systems Dept.

Mr. Faris is currently the Associate Manager in the Network Systems Department of the Network Technology Division at COMSAT Laboratories. His present responsibilities include research in the areas of ISDN, B-ISDN, and ATM networks, on-board switching architectures, intelligent network applications in mobile satellite systems, and advanced modulation and transmission techniques for future satellite systems. His contributions in these areas include system architecture design and definition, as well as system modeling, analysis, and simulation.

Since joining COMSAT in 1985, Mr. Faris has made several contributions in the areas of network system studies and simulations. His work in the area of computer modeling and analysis includes software development and computer simulations of satellite transmission methods and modulation/coding techniques, packet transmission protocols for satellite applications, software emulation of low-level digital modem hardware, congestion control in ATM networks, DAMA scheduling algorithms for LR-TDMA networks, transmission link analysis, interference analysis, intermodulation analysis, and frequency planning, His work in the area of overall system architecture design and definition includes studies of satellite networks utilizing small earth stations, cost-effective system architectures for future satellite applications, on-board processing system architectures for INTELSAT future generation satellites, ISDN and B-ISDN compatible satellite systems, bit synchronous LR-TDMA VSAT system, and on-board fast packet switch architecture design and development.

Mr. Faris received his B.S.E.E. from the American University of Beirut in 1983; and his M.S.E.E.at University of Virginia, 1988. Mr. Faris represents COMSAT in the ATM Forum he is a also a member of IEEE.

Anil K. Agarwal, Comsat Laboratories: Scientist

Mr. Agarwal is currently the Principal Scientist in the Network Technology Division. He is responsible for directing and managing the development of software for data communications and real-time applications. He has more than 10 years experience in the design and development of terrestrial and satellite-based data networks, network management systems, real-time operating systems, data communication protocols, expert systems and software engineering.

He is presently directing the development of an integrated network management system that manages a multi-vendor, multi-media, and multi-protocol data communications network. He is also directing a number of projects that use expert systems technology for network management. His department is involved in the standardization process, performance evaluation, and implementation of OSI and ISDN protocols.

For the past 5 years, he has managed and designed software for several data communications projects. He managed the development of the advanced COMSAT research data network, which involved development of X.25, X.75, X.28, TCP/IP, SNA and BISYNC protocols, an adaptive distributed routing protocol, congestion control algorithms, network simulation, network management, graphics and windowing software and expert systems to perform network fault management. He has also managed a joint project with NIST which involves implementation of OSI protocols (all seven layers) for performance evaluation over satellite links.

Mr. Agarwal received his B.S.E.E. at the University of Florida in 1967; M.S.E. (E.E.), in 1968 at the University of Pennsylvania, and a Ph.D. Candidate at the University of Pennsylvania, in 1969.

Burton I. Edelson, GWU: Director of The Institute for Applied Space Research

Dr. Edelson is the Director of The Institute for Applied Space Research of the George Washington University. He is also a Research Professor of Electrical Engineering and Computer Science at the George Washington University.

From 1982 to 1987, Dr. Edelson was Associate Administrator for Space Science and Applications of the National Aeronautics and Space Administration. In that position, he was responsible for the direction of all NASA space science programs; space applications, including the development of communications satellites; and for institutional management of the Goddard Space Flight Center and the Jet Propulsion Laboratory. At NASA, he initiated and directed the ACTS program and the mobile satellite program.

From 1968 to 1982, Dr. Edelson held executive positions at the Communications Satellite Corporation including Director of Comsat Laboratories, Vice President for Systems and Engineering, and Senior Vice President.

Neil R. Helm, GWU: Deputy Director of the Institute for Applied Space Research

Mr. Helm is the Deputy Director of the Institute for Applied Space Research and a Senior Research Scientist in the EECS department of The George Washington University.

From 1984 to 1991 he was the President of a Washington, D.C. consulting firm which provided technical systems and services, primarily in the satellite communications field. One project included being the Principal Investigator for the final integration, testing, launch, and in orbit demonstration of a DOD satellite.

From 1967 to 1984 Mr. Helm held technical and senior management positions at Comsat, including Director Marketing of the Technical Services Division and Manager of Technical Development at Comsat Laboratories. He is a Corresponding Member of the International Academy of Astronautics, a Senior Member of IEEE and an Associate Fellow of AIAA. He has published more than 25 technical articles.

Tarek A. El-Ghazawi, GWU: Associate Research Professor

Dr. El-Ghazawi, is currently an Associate Professor (research) in the Department of Electrical Engineering and Computer Science of the George Washington University. Prior to joining GWU, he held academic positions at the University of Helwan, Frostburg State University and the Johns Hopkins University. His research interests include high performance computing, experimental computer architecture, high-performance I/O systems, and performance evaluations. Dr. El-Ghazawi has published extensively in these areas and his research has been supported by NASA HPCC, CESDIS, NASA GSFC, Hughes Applied Information Systems, and Computer Science Corporation. He has served as the workshop chair for Frontiers' 95 ; the program co-chair for the International Conference on Parallel and Distributed Computing and Systems, 1991; and was a key contributor to the Joint NSF/NASA Initiative on Evaluations (JNNIE).

Dr. El-Ghazawi received his Ph.D. degree in 1988 from New Mexico State. He is a Senior Member of the IEEE, a member of the ACM, and the Phi Kappa Phi national honor society.

Daniel Daly, Bellcore Applied Research: Director of the Network Control and Interoperability Research

Dr. Daly is currently the Director of the Network Control and Interoperability Research Group at Bellcore in Morristown, NJ. He has research and engineering experience in solid state physics, semiconductor circuit processing technology, semiconductor circuit design, and high speed network technology. He has been a Director of various research groups in Bellcore's Applied Research Area since 1986. In recent years he has lead research programs in broadband network performance analysis, the measurement and analysis of ATM traffic over satellite systems, the implementation of experimental research prototype systems for broadband networks and ATM interoperability testing.

Dr. Daly received the B.S. in physics from St. Bonaventure University in 1961 and the M.A. and Ph.D. in solid state physics from Columbia University, New York City, in 1963 and 1966 respectively. He worked at Purdue University and Bell Telephone Labs before joining Bellcore in 1984.

Anthony J. McAuley, Bellcore Applied Research: Researcher

Dr. McAuley has been a researcher at Bellcore since 1987, . He is currently working on an Software Forward Erasure Correction Booster for wireless networks using new efficient codes. He is also leading a Mobile-IP Internetworking project. He was part of the team that designed the TP++ transport protocol for the AURORA Gigabit testbed, designing general purpose protocol processing elements and efficient codes to detect and correct errors. His software implementation of TP++ has been used widely in wireless network experiments over PCS, Cellular, RAM, and satellite radio networks.

Prior to Bellcore, Dr. McAuley was a research assistant at Caltech working on a high level language processor. He received his BS & Ph.D in Electrical Engineering, from the University of Hull.

Deborah Bakin (nee Pinck), Bellcore Applied Research: Researcher

Ms. Bakin has just returned to Bellcore after 5 years working for NASA's JPL on the ACTS Mobile Terminal (AMT). While at JPL, Ms. Bakins responsibilities included designing and conducting satellite communications experiments with the AMT including: an integrated satellite-terrestrial personal communications network (with Bellcore), Satcom-on-the-Move for the US Army, Telemedicine and Teleradiology experiments (with the University of Washington School of Medicine), and propagation tests at K/Ka-bands for mobile satellite communications. In addition, she was responsible for managing software development for a data analysis tool as well as analyzing results from numerous satellite communications experiments. Prior to working at JPL, Ms. Bakin worked for Bellcore on the design of the Advanced Intelligent Network with an emphasis on knowledge-based solutions for network management.

Ms Bakin received her BS from Caltech, & MS from Cornell in Electrical Engineering.

ANNEX 1: Experiment Plan for 622 Mbps Network

From: DFTNIC:PGARY "J Patrick Gary 301-286-9539 GSFC" 14-MAY-1996 12:45:48.38
To: ZERNIC,HODER,IN%"apsch@wpogws.lerc.nasa.gov"
CC: IN%"atdn-exec@cmf.nrl.navy.mil",IN%"atdn-exp@cmf.nrl.navy.mil",
IN%"mankin@isi.edu",IN%"kempner@helix.nih.gov",FEUQUAY,
IN%"frost@eecs.ukans.edu",IN%"rdv@fore.com",PGARY
Subj: Exp Plan for 622 Mbps Net Tests Betw ATDNet & MAGIC via ACTS

Dear Colleagues,

I am pleased to formally submit the "Experiment Plan for 622 Mbps Network Tests Between ATDNet and MAGIC Via ACTS" provided below as the basis for requesting ACTS time.

This plan is based on the original discussions at both the 3/14/96 ATDNet Experimenters Meeting and the 3/28/96 ATDNet Steering Committee Meeting, and followup discussions at both the 5/2/96 ATDNet Steering Committee Meeting and the 4/11/96 and 5/9/96 ATDNet Experimenters Meetings.

As noted in the plan, GSFC's Pat Gary will be the primary interface to the ACTS HDR Experiments office for coordinating details of the ACTS time requests for this experiment.

Please contact Pat directly to start arranging specific ACTS time schedules for this experiment.

Pat

5/14/96
Experiment Plan for 622 Mbps Network Tests
Between ATDNet and MAGIC Via ACTS

PI's: J. Patrick Gary/NASA GSFC
Gary Minden/DARPA

1.0 Introduction

The key purpose of this experiment plan is to document the basis for scheduling time on the Advanced Communications Technology Satellite (ACTS) to enable network tests at 622 Mbps rates between the Advanced Technology Demonstration Network (ATDNet) and the Multidimensional Applications and Gigabit Internetwork Consortium (MAGIC) network via the ACTS.

1.1 Background

DARPA has funded several terrestrial-based gigabit network testbeds. Of particular importance to this experiment plan are the ATDNet (see http://www.atd.net/ATDNET/) and MAGIC (see http://www.magic.net/) networks which, with a few notable exceptions, have involved ATM at only 155 Mbps rates. However, parts of both ATDNet and MAGIC have been or are planned to be upgraded to handle ATM routinely at 622 Mbps rates. NASA successfully launched the ACTS on September 12, 1993. For various information regarding ACTS, see http://kronos.lerc.nasa.gov/acts/acts.html. A particular capability of ACTS is its Gigabit Satellite Network (GSN) capability (see http://www.cgrg.ohio-state.edu/other/actsgsn/gsnhome.html) which among other features allows ACTS to concurrently support up to three separate 622 Mbps digital data streams.

To utilize ACTS' GSN capability, NASA partnered with DARPA in the development of five High Data Rate (HDR) Terminals (HDRT's). Each of the HDRT's can support either one OC-12c (622 Mbps) full duplex connection or up to four concurrent OC-3c (155 Mbps) full duplex connection.

Of particular importance to this experiment plan, one HDRT recently has been located at NASA's Goddard Space Flight Center (GSFC) which is a core site in the ATDNet, and another HDRT recently has been located at US Sprint's Technical Integration and Operations Center (TIOC) which is a key site in the MAGIC network.

To interconnect between the GSFC and TIOC sites via ACTS at 622 Mbps, a change will need to be made in the ACTS-related default beams used in data transmissions with the HDRT at GSFC. Without such a change, the interconnection via ACTS would be limited to a maximum of 311 Mbps. Such a change is presently thought to be technically feasible. If, however, it should not be, then this experiment plan will apply for 311 Mbps network tests between the ATDNet and MAGIC networks via ACTS.

1.2 Goals

This experiment plan identifies a number of special ATM-based network tests planned to be conducted at 622 Mbps rates over ACTS between sites on the ATDNet and sites on the MAGIC network. The network tests range from assessment of ATM signaling at ISO layers 1-2, "tuning" of IP/TCP protocols at network/transport layers 3-4, evaluation of new network management/monitoring techniques involving several layers, through "everyday" and special purpose presentation/applications at layers 6-7. Each of these tests is planned to be conducted so as to evaluate and maximize performance in the unique 622 Mbps high bandwidth*delay network created by the hybrid satellite/terrestrial ATDNet-ACTS-MAGIC network.

ATM-based network tests at 622 Mbps are rare today even in terrestrial-based networks. The inclusion of the ACTS-based 622 Mbps interconnection between such terrestrial-based networks creates an additional challenge, but may be indicative of many future high performance networks. The ACTS-based interconnection creates the opportunity to conduct and evaluate many experiments which were not previously possible.

1.3 Co-I's and other Participants

The Co-I's and other participants identified below largely are already either DARPA-funded (or other DoD-funded) investigators working in/for the ATDNet and/or MAGIC projects (or the ACTS ATM Internetwork (AAI); see http://info.arl.army.mil/HPCMP/DREN/testbed/aai.html) or NASA-funded investigators working in/for the ACTS project; and the network tests to be conducted under this experiment plan are relatively straightforward extensions to on-going research being conducted within those projects.

In each of the Network Test Suites below, a single Co-I has been identified who will serve as either the lead researcher for a relatively integrated group of researchers working closely together for that type of network test or as a facilitator for a number of researchers/research groups who are working relatively independently of one another.

2.0 Network Test Suites

2.1 Assessment of Satellite Links on ATM Signaling

Co-I: Rich Verjinski/Fore

Objective: Identify and measure effects of satellite-link-induced high latency transmissions on new ATM signaling options.

Approach: Exploit special hardware monitoring tools in joint collaboration involving FORE, NRL, and US Sprint in KC.

2.2 Tuning TCP over High Speed Satellite Links

Co-I: Pat Gary/GSFC

Objective: Assess effects of new TCP protocols with selective retransmissions/acknowledgments over high speed satellite links

Approach: Utilize "drop-in" UNIX codes for selective retransmissions/acknowledgements now being beta-tested at the Pittsburgh Supercomputer Center

2.3 Evaluation of ATM Flow Control and Traffic Monitoring Techniques in a 622 Mbps Hybrid Satellite/Terrestrial Network

Co-I: Victor Frost/KU

Objective: Produce new network measurement tools applicable to high speed hybrid satellite/terrestrial networks.

Approach: Extend the ATM network monitoring techniques developed in MAGIC and apply over the ATDNet-ACTS-MAGIC network.

2.4 Demonstration and Evaluation of Everyday Internet Applications across the ATDNet-ACTS MAGIC Network at 622 Mbps

Co-I: Pat Gary/GSFC

Objective: Demonstrate that high speed hybrid satellite/terrestrial networks can be applicable to typical Internet use.

Approach: Install and assess performance of client/server daemon implementations for everyday-use protocols such as ftp, http, nfs, mpi, pvm, etc., but which have been modified to utilize the extended windows needed for effective use in very high bandwidth*delay networks.

2.5 Demonstration and Evaluation of TerraVision/ISS Operating over the ATDNet-ACTS-MAGIC Network

Co-I: Jay Feuquay/EDC

Objective: Use TerraVision/ISS as an application that can stress the 622 Mbps the ATDNet-ACTS-MAGIC network.

Approach: Create and utilize ISS servers running concurrently of the ATDNet and MAGIC networks.

2.6 Multimedia Telemedicine Applications Operating over the ATDNet-ACTS-MAGIC Network

Co-I: Kenneth Kempner/NIH

Objective: Evaluate 155/622 Mbps networks for multimedia telemedicine consultation applications.

Approach: Conduct multimedia telemedicine consultation sessions, in support of medical imaging applications, between the NIH and GUMC on ATDNet, and between the NIH and Washington University in St. Louis on ATDnet and MAGIC, via ACTS.

2.7 Telemedicine-enabling R&D Testbed Experiments Operating over the ATDNet-ACTS-MAGIC/NTON Network

Co-I: Mike Gill/NLM

Objective: Evaluate 155/622 Mbps networks for telemedicine enabling technologies.

Approach: Conduct telemedicine-enabling R&D testbed experiments, typically involving large databases, between NLM on ATDnet and the Laboratory for Radiological Informatics at the University of California San Francisco on the National Transparent Optical Network (NTON) via the HDRT at JPL.

2.8 Testbedding of New Applications at 622 Mbps

Co-I: Pat Gary/GSFC

Objective: Provide opportunity for demonstrations of new applications that can effectively utilize 622 Mbps, including applications running directly over ATM. Approach: Allocate and coordinate satellite time and host computer time for developers of new applications that require high speed networks.

3.0 Coordination of Network Test Times with ACTS Operations

PI J. Patrick Gary will serve as overall coordinator and primary point-of-contact of this experiment's network test time with ACTS Operations. Mr. Gary will provide this coordination based on network test time needs provided by the above Network Test Suite Co-I's who will be responsible for identifying and organizing requests for ACTS time to support their suite of network tests.

Until further refined based on Co-I inputs, an initial request for ACTS time consisting of four hours contiguous duration in the afternoon's of Monday, Wednesday, and Friday will be submitted to the ACTS Project.

4.0 Overall Schedule

Overall this experiment plans to operate from the beginning of ACTS HDRT functional readiness at GSFC and TIOC, which is essentially May 1996, until at least September 1997.

However, at present not all of the terrestrial-based 622 Mbps network infrastructure is in place. In particular, DARPA and the rest of the ATDNet's Steering Committee only recently approved that the ATDNet's SONET service provider Bell Atlantic is to provide GSFC with a pair of 622 Mbps SONET drops off the 2.4 Gbps ATDNet backbone. This will allow the ACTS HDRT at GSFC to be accessed at 622 Mbps rates by NSA, NRL, and/or DIA which already have such speed drops in ATDNet. Furthermore, GSFC must acquire and install a new ATM core switch with three new 622 Mbps netmods - two to sustain the 622 Mbps ATM ring with NSA, NRL, and DIA, and one to interface with the ACTS HDRT.

These upgrades at GSFC are expected to be completed by mid-summer 1996.

Nevertheless, this experiment will start requesting ACTS time at 155 Mbps right away to facilitate ramping up of the various network test suites.

ANNEX 2: ATM Speech

General Architecture

Figure 10 shows a general transmitter and receiver architecture for the transport of single-channel voice with optional silence removal and voice compression.

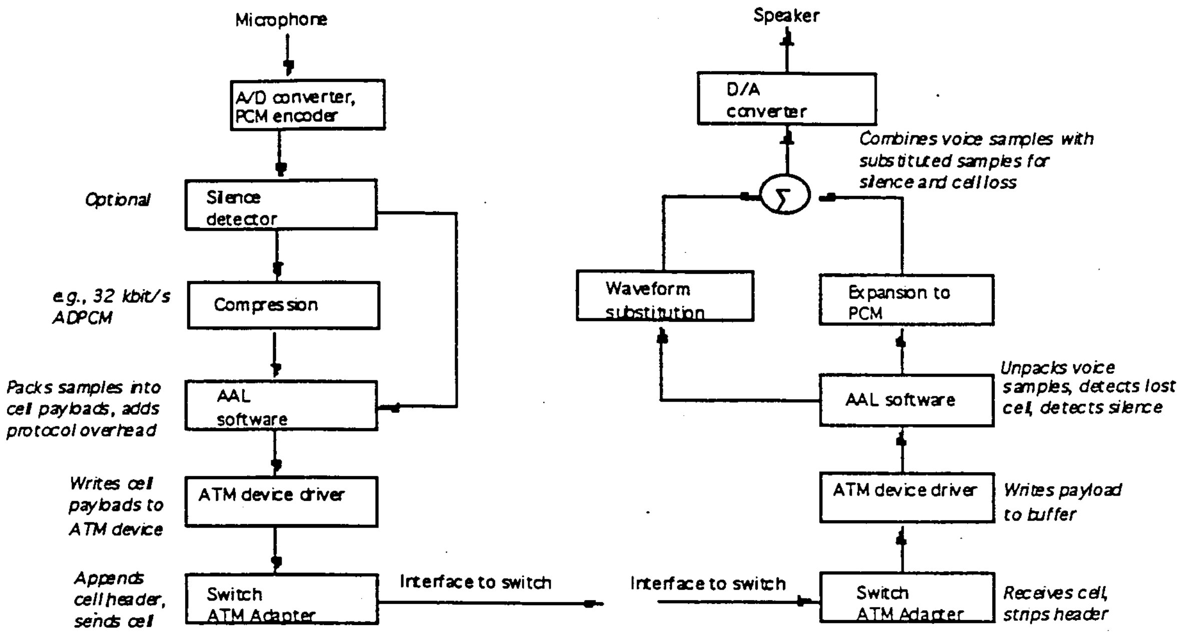


Figure 10: Transmitter and Receiver Architecture

In order to utilize either capability during a voice call, the calling terminal or IWF negotiates, during call setup, with the called entity to determine whether a corresponding capability is supported. This call negotiation defaults to the standard 64-kbit/s PCM CBR mode if the requested capability is not supported at the called terminal/IWF. If silence removal and/or voice compression are supported, samples from a single voice call are sent over an ATM VC using AAL1. Voice samples are packed into the 47-byte AAL1 payload. If silence removal is implemented, samples are sent only during periods of voice activity and the resulting traffic stream exhibits VBR characteristics.

At the receiver, if voice compression is used, the receiver expands the received samples to PCM. If silence removal is used, the receiver identifies silence intervals and substitutes appropriate levels of background noise for the silence.

Silence Removal and Lost Cell Detection

Voice over ATM with silence removal can be supported by the deterministic bearer rate (DBR) bearer capability, as defined in (draft) ITU-T Recommendation I.371. If voice samples are directly encoded into ATM cells with no voice activity detection, then a CBR connection is used. If voice activity detection is possible, then an on-demand-bandwidth connection is used.

Silence removal is accomplished through voice activity detection at the transmitter. ATM cells containing voice samples are sent only during voice activity. The transmit side runs a voice activity detection (VAD) algorithm to detect voice and silence. When VAD detects voice, it sends voice samples. When VAD detects silence, it sends a few cells of silence and then stops transmission. It then periodically sends one voice cell every T seconds during the silence interval. These "silence" cells contain samples of the background noise at the transmitter, which are used to determine the background noise level to be played out by the receiver. An alternative to sending "silence" cells is to encode the background noise level at the transmitter using a few bits in the cell payload.

The receive side performs cell arrival detection and determines when to substitute background noise for silence periods and when to perform waveform substitution to compensate for lost cells during speech periods.

Low-Rate Encoding

In theory, a number of low-rate encoding techniques can be supported. However, in practice, the choice of voice compression algorithms will be limited by the cell packing delays and the achievable voice quality. Thirty-two kbit/s adaptive differential pulse-code modulation (ADPCM) is a particularly attractive encoding technique which is well standardized and widely available. It is highly robust to bit errors and quite tolerant of tandem encoding. Compared to 64-kbit/s PCM, 32-kbit/s ADPCM provides the same toll quality voice with only 6 ms of additional cell packing delay. When combined with ATM statistical multiplexing gains achievable with silence removal, bandwidth gains of up to 5:1 can be realized.

Call Setup Procedure and Bandwidth Allocation

With the addition of a few codepoints in UNI (Rec. Q.2931) signaling information elements, a robust signaling mechanism can be supported. This will allow the terminals and the signaling entities to select the optimal voice protocol for the call. If compression and/or silence removal are not desired or cannot be supported, the signaling will allow the rate to fall back to 64-kbit/s CBR with no additional messages.

For example, consider an ATM terminal which implements 32-kbit/s ADPCM encoding. If a user of this terminal wishes to make a voice call, a parameter indicating 32-kbit/s ADPCM (either with or without voice activity detection) can be set in the SETUP message. This parameter traverses the ATM network to the edge of the ATM network (either an interworking unit or an ATM terminal if ATM is end-to-end). If the destination ATM terminal (or interworking unit) can handle this coding rate, it returns the same parameter to the source terminal. If not, it codes the fallback (64-kbit/s CBR) codepoint, and the source, upon receiving the revised information, sets up its connection appropriately.

This signaling information can be added to the "AAL parameters" information element (IE). This parameter is (optionally) interpreted by the network, and can be used for negotiation purposes between terminals (i.e., it is present in the CONNECT message). The network does not have to interpret this IE, it simply allocates CBR bandwidth to the connection regardless of whether silence removal is being used. In fact, the IWF/TE during call setup specifies CBR traffic. However, the bandwidth which is not used during silence intervals is available for nonreserved traffic.

Channel Associated Signaling

The requirement for transport of cost-accounting standards (CAS) is only pertinent for connections between two narrowband interworking functions. One method to transport CAS is to use SDU-type = 1 (PRI = 001 or 011). Since AAL 1 only has SDU-type = 0 (PTI = 000 or 010), SDU Type = 1 is available to transport user signaling. An alternative method is to indicate the payload type (voice cell, signaling cell, and so on) within the cell payload.

Voiceband Data

When low-rate encoding is used on connections between narrowband IWFs, for some users it may be desirable to implement a data discriminator. In this case, if data are detected, the protocol should switch to a higher data rate (such as 64-kbit/s). In order to provide this capability, user-to-user signaling (SDU type = 1) can be used in conjunction with a MODIFY message to fall back to the higher data rate.

Conclusion

It is important to develop such techniques now, or at least to define a clear migration path forward, during the early stages of ATM deployment so that less efficient CBR techniques do not become entrenched and difficult to evolve in the future. VBR voice should benefit both the network service provider, who can more efficiently carry PSTN/NISDN traffic, and the end user, whose applications can capitalize on a standard efficient coding for voice.

APPENDIX A: ATM Service Categories Defined in the ATM Forum TM 4.0 Specification

Constant Bit Rate (CBR): This service category is used by connections that request a constant amount of bandwidth that is continuously available during the connection time. Connection traffic descriptors are the Peak Cell Rate (PCR and the Cell Delay Variation Tolerance (CDVT) for PCR. QoS guarantee is based on the Cell Delay Variation (CDV), maximum Cell Transfer Delay (CTD), and Cell Loss Ratio (CLR) for the aggregate CLP=0+1 stream.

Variable Bit Rate: The ATM Forum Traffic Management specification further divides this category to VBR real-time (rt) and VBR non-real-time (nrt). Furthermore, it also distinguishes whether the Sustainable Bit Rate (SBR) is specified over the CLP=0+1 stream or the CLP=0 stream, and whether tagging is allowed or not. All sub-categories use the PCR and CDVT on PCR for CLP=0+1 streams as a traffic descriptor. All sub-categories require CLR as a QoS parameter, only VBR-rt uses the CDV and CTD as QoS parameters.

Unspecified Bit Rate: The UBR service category is intended for non-real-time applications that do not require tightly constrained delay and delay variation. PCR and CDVT on PCR for the CLP=0+1 stream are used as traffic descriptors. No numerical commitments are made by the network on the CDV, CTD, and CLR.

Available Bit Rate (ABR): This service category is intended for non-real time applications. The bandwidth available to the connection changes subsequent to connection establishment. CAC includes the specification of the PCR and Minimum Cell Rate ( ). The network only guarantees the MCR. No numerical commitments are made by the network on the CDV, CTD, or, CLR.

APPENDIX B: ATM Traffic and Congestion Control Functions Defined in the ATM Forum TM 4.0 Specification

Cell discarding: Cell discarding can be performed by the network either when there is congestion or when traffic on a connection does not conform to the traffic contract agreed upon during call establishment.

Cell marking: For some service categories, the end system may generate traffic flows where the Cell Loss Priority (CLP) bit at the header to is set to 1 (low priority). If the network treats the CLP marking significant, it can selectively discard cells with CLP=1 during congestion, to protect, as far as possible the QoS objectives of traffic flows with CLP=0 (high priority).

Cell tagging: For some service categories, the end-system may request the network to tag cells that are not conforming to the traffic contract by setting their CLP bit to 1, instead of discarding them. If the network supports tagging, the non-conforming cells are discarded only during congestion.

Usage Parameter Control (UPC): UPC is the set of actions taken by the network at the user access or the network access to check the validity of the ATM connection, and to examine if the traffic flow conforms to the traffic contract. The main purpose is to protect network resources and maintain the QoS of other already established connections by detecting violation s of negotiated parameters and taking appropriate actions. If a cell is found to be not conforming to the negotiated parameters, it can either be discarded, or tagged.

Traffic Shaping: Traffic shaping is a mechanism that alters the traffic characteristics such as peak cell rate (PCR, burst length, and cell delay variation (CDV) of a stream of cells on a connection. It can be performed by i) the source or at the UNI to ensure that the traffic is conforming to the negotiated traffic contract, or ii) by the network (at the ingress or the egress) to achieve better network utilization and meet conformance tests at the egress.

Buffer Management/Service Policy: Refers to the mechanism by which a network element schedules the transmission of cells belonging to different connections over a common transmission link. This mechanism has to ensure that each connection uses the transmission link in a manner consistent with the traffic description and the QoS agreed upon.

ABR Flow Control: Refers to the feedback control mechanism specific to ABR service category. Each end system periodically generates Resource Management (RM) cells and injects into the connection; each intermediate network element can have access to the RM cell and modify traffic parameters for the connection; each end system returns the received RM cell to the originator end system; upon receiving an RM cell an end system must follow a reference behavior for sending its subsequent cells.

Virtual Source Virtual Destination: An ABR connection may be divided into two or more separately controlled ABR segments by the concepts of Virtual Source (VS) and Virtual Destination (VD). The coupling between two adjacent ABR control segments associated with an ABR connection is currently implementation specific.

Explicit Forward Congestion Indication: A feedback control mechanism where a network element that detects congestion on one of its outgoing links marks all cells transmitted over that link as "congestion experienced" until the congestion period ends. The destination end-system that receives this notification may inform the source end-system of congestion

Routing: Routing is performed by setting up VPI/VCI translation tables at each intermediate network node during call establishment. The use of VP switching eliminates the need to enter/delete entries in the routing translation tables every time a call is established or disconnected. Each VP selected along the path must have enough bandwidth to meet the traffic and QoS requirements of the requested connection.

Call Admission Control (CAC): CAC is defined as the set of actions taken by the network during the call set-up phase in order to determine whether a connection request can be accepted or should be rejected. This involves the specification of the connection's traffic descriptor and the required QoS by the end-system, and examining by the network if a connection that can meet these requirements can be established.

Resource Allocation: Resource allocation refers to assigning capacity to VP connections and VC connections in a network. The network capacity assigned to VP and VC connections depend on the characteristics of traffic flowing through these connections and the QoS required. The bandwidth assigned to a VC is determined during connection establishment. The VP bandwidth may be changed semi-dynamically by network management.

APPENDIX C: ABR Parameters:

During Call Admission Control, the ABR source signals the following parameters:

Name	Description	Negotiation	Default
PCR	The peak cell rate which the source may never exceed.	down	mandatory
MCR	The minimum cell rate at which the source is always allowed to send.	down	0
ICR	The initial cell rate at which a source should send initially and after an idle period.	down	PCR
TBE	Transient Buffer Exposure, TBE, is the negotiated number of cells that the network would like to limit the source to sending during startup periods, before the first RM-cell returns.	down,	2^{24}
FRTT	The fixed Round-Trip Time, FRTT is the sum of the fixed and propagation delays from the source to the furthest destination and back.	accumulated	
RDF	The Rate Decrease Factor, RDF, controls the decrease in the cell transmission rate.	down	
RIF	Rate Increase Factor, RIF, controls the amount by which the cell transmission rate may increase upon receipt of an RM-cell. The additive increase AIR=PCR*RIF.	down	1/16
Nrm (O)	Nrm is the maximum number of cells a source may send for each forward RM-cell.	no	32
Trm (O)	Trm provides an upper bound on the time between forward RM-cells for an active source.	down	100 msec
CDF (O)	The Cutoff Decrease Factor, CDF, controls the decrease in ACR associated with CRM.	up	0.5
ADTF(O)	The ACR Decrease Time Factor is the time permitted between sending RM-cells before the rate is decreased to ICR.	down	0.5

Other:

CRM: Missing RM-cell count, CRM limits the number of forward RM-cells which may be sent in the absence of received backward RM-cells. It is computed as:

$$CRM = \frac{TBE}{Nrm}$$

e.g. if TBE = 3200, Nrm = 32, then the source can send 3200 cells before the first RM cell is received. Also, the source can send 100 RM cells (including the first RM cell) before the first RM cell is received.

ICR: ICR is updated after call setup to insure TBE compliance:

$$ICR = \min\left(ICR, \frac{TBE}{FRTT}\right)$$

e.g. if TBE is 3200 cells, and FRTT = 100 msec, it takes at least 100 msec for the first RM cell to come back. Therefore, ICR cannot be larger than 32,000 cells/sec.

Mrm: Controls the allocation of bandwidth between forward RM-cells, backward RM-cells, and data cells, constant fixed at 2. There must be at least two cells (backward RM or data) between two forward RM cells.

Trm: An-upper bound on the time between forward RM cells for an active source, e.g. if Trm = 10 msec, the time between sending two RM cells must be less than 10 msec.

APPENDIX D: List of Acronyms:

AAI:	ACTS ATM Internetwork
ABR:	Available Bit Rate
ATDNet:	Advanced Technology Demonstration Network
CBR:	Constant Bit Rate
CCDS:	Commercial Center for Development of Space
CDVT:	Cell Delay Variation Tolerance
CLR:	Cell Loss Ratio
EFCI:	Explicit Forward Congestion Indication
GII:	Global Information Infrastructure
IETF:	Internet Engineering Task Force
MBS:	Maximum Burst Size
MCR:	Minimum Cell Rate
NII:	National Information Infrastructure
NSF:	National Science Foundation
NREN:	National Research Education Network
NTON:	National Transparent Optical Network
PCR:	Peak Cell Rate
RM Cell:	Resource Management Cell
SCR:	Sustainable Cell Rate
UBR:	Unspecified Bit Rate
UPC:	Usage Parameter Control

ATTACHMENT 1: Acts TSTI Experiment Application

Request For Use of Acts For Field Trial/Experiment

Please submit the following information with your request to use ACTS for a field trial/experiment:

1. The name, address, phone and fax number of the requester and technical contact. The name(s) of the organizations associated with performing, sponsoring and/or funding the demonstration.

P.I.:
Pat Gary
NASA GSFC
MS Code 933
Greenbelt, MD 20771
tel:(301)286-9539 fax: (301)286-1777
email: pat.gary@gsfc.nasa.gov

Co-P.I.s:
Larry Bergman
Jet Propulsion Laboratories
4800 Oak Grove Drive, MS 300-329
Pasadena, CA 91109
tel:(818)354-4689 fax: (818)393-3302
email: larry@jplopto.jpl.nasa.gov

Prakash Chitre
Comsat Laboratories
22300 Comsat Drive
Clarksburg, MD 20875-9471
tel:(301)428-4167 fax: (301)428-7747
chitre@ntd.comsat.com

Neil Helm
IASR, George Washington University
2020 K Street, NW Room 304
Washington, DC 20052
tel:(202)994-5509 fax: (202)994-5296
email: helm@seas.gwu.edu

Daniel Daly
Bellcore
MCC-1A11B
445 South Street
Morristown, NJ 07960-6438
tel:(201)829-4339 fax: (201)829-5886
email: ddaly@notes.cc.bellcore.com

The testbeds will be opened to other users such as government agencies, professional organizations, communications carriers, universities

2. The dates requested (actual date(s) of the field trail/experiment plus any set-up and/or testing dates).

FY'97 (October 1) through the end (September) of FY'98 or through the end of ACTS experiment program, whichever comes first.

3. A schedule of the needed satellite hours (EST hours per each requested date).

Testbeds will request a minimum of 10 hours/week for testbed testings with some latitude in the actual time of the day (i.e: The testbed may be able to operate during evening hours). TSTI testbed will request a number of demonstration times in the second half of FY'97 and throughout FY'98.

4. A description of the assistance and services requested from NASA (include NASA personnel resources, if applicable).

The TSTI backbone consists of HDR terminals located at GSFC and JPL. A TSTI laboratory or test center will be established at GSFC with personnel to be provided primarily by Comsat, Bellcore, and GWU.

It is proposed to connect most of the NASA centers into the interoperable network using HDRs or the NASA NREN as appropriate. It is expected that each Center will pay for its own resources.

This TSTI experiment will require no special resources from the ACTS satellite or from the ACTS Project Office at the LeRC.

5. A description of the field trial/experiment, including:

This planned project will design, develop, integrate and manage a Testbed for Satellite and Terrestrial interoperability (TSTI) to test and demonstrate the required interoperable communications hardware and software interface specifications, protocols, architectures and standards. The testbed will develop the tools to work on the interoperability problems that are inherent characteristics of satellite links- (a) errors, (b) delay, and (c) bandwidth limitations. The U.S. communications carriers, industry and government will benefit directly from the testbed by the transition of tools, technologies and standards to provide interoperable hybrid terrestrial cable and satellite communications networks, operating seamlessly around the globe.

a. A technical abstract which contains

(1) A system diagram (the transmit/ receive data rates, a list of all equipment requested from NASA, and a list of all experiment equipment).

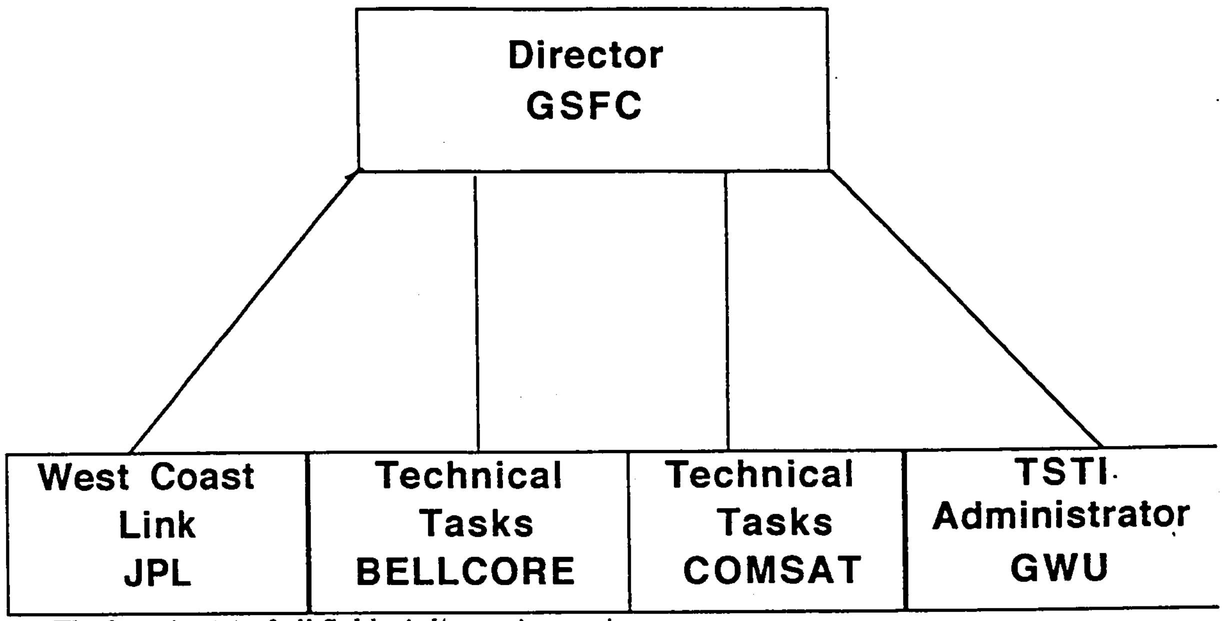
The HDR terminals at GSFC and at JPL. Figure 1 shows the TSTI concept and the GSFC TSTI resources.

(2) A plan for testing and checking-out the field trial/experiment.

Figure 2 shows the TSTI Interoperability Test System.

(3) A chart indicating the roles and responsibilities of those performing the field trial/experiment.

TSTI Responsibility



(4) The location(s) of all field trial/experiment sites.

GSFC and JPL backbone, with tests and demonstrations to include other satellite and terrestrial network location.

b. The objective of the field trial/experiment. In addition, please discuss

(1) The significance of using ACTS in the field trial/experiment.

The recent technology development in communications satellites, such as broadband high data rate transponders and on-board processing, especially demonstrated by NASA's ACTS satellite, result in a realization that future communications networks must rely on hybrid wire and wireless facilities.

(2) A list of all requested Government equipment (Earth Stations, application equipment, etc.).

HDR terminals at GSFC and JPL will be the backbone of the experiment, with other HDR terminals, such as DARPA MAGIC and Hawaii, invited to participate.

(3) The target audience the field trial/experiment is intended to reach.

US industry, communications carriers and government agencies

(4) The method of publicity and the display/handouts to be used (if any) which show the participation of ACTS in the field trial/experiment.

A series of demonstrations are scheduled to take place primarily at conferences and expositions for industries with communication carriers, and government agencies. Specifically for NASA, demonstrations will be scheduled at GSFC and JPL, where Headquarters personnel will be invited.

(5) The metric to be used to measure whether the objective was attained.

The metric will be the conduct of seamless inoperable communications networks. In addition, a specific transfer of technology task will be maintained to see that the results of the TSTI tests, demonstrations and interoperable tools such as software protocols are transferred to US industries and communication carriers

6. A brief outline of the paper to be submitted to NASA upon completion of a field trial/experiment with ACTS.

The paper will describe how we have designed, developed, integrated and managed a Testbed for Satellite and Terrestrial Interoperability (TSTI) that served as a sustained resource for the communications and satellite industries. The testbed provided an open environment, available to all in industry, government and academia, and developed the necessary test tools and procedures and to conduct quantitative, reproducible experiments to demonstrate and validate interoperability between satellite and terrestrial communications networks. The TSTI software architecture followed emerging standards and protocols and enabled users in industry forums and standards bodies to develop, test and refine their contributions to the standards process. This standard-based testbed architecture also enabled communications equipments suppliers, service providers and carriers to address interoperability and end-to-end service assurance issues. The TSTI served as a resource to the industry, avoiding costly duplication of facilities and effort in software and tool development. Subsystem developers, application builders, and a wide range of service providers also benefited from the TSTI, as it provided them access to a diverse, unique hybrid communications infrastructure that cannot be reproduced in small scale experiments. We encouraged broad participation in the testbed through an intensive industry out reach program and through technical support to its users. The TSTI contributed to a robust, competitive satellite communications industry.

Team Members

The TSTI will be developed by a team consisting of NASA's GSFC and JPL, representing the government, Bellcore and Comsat representing industry/communications carriers and George Washington University as the academic representative. GSFC will direct he TSTI project, with GWU acting as the TSTI administrator. The team will be responsible for the overall development, integration, maintenance, test and demonstration of the engineering testbed. The team members were chosen for their current capabilities and expertise in the development of the next generation of hybrid seamless interoperable communications systems and networks.

The NASA team members, GSFC and JPL, have high performance computing and communications infrastructure, including backbone network connections to the ATDNet, MAGIC, NREN, AAI, CAIRN, CASA, and NTON. Bellcore and Comsat Labs, as research leaders for the communications industry, are currently involved in the development of high data rate protocols and software components, that are directly applicable to the testbed. The Institute of Applied Space Research of GWU has played an evolutionary role in the development of high data rate satellite equipment and experiments for the ACTS program. All of the partners are currently playing leadership roles in the development of satellite and terrestrial communications standards.

Users

As the main part of the outreach activities of this project, the team members will openly solicit other communications users that will include federal agencies, other NASA Centers, communications companies, equipment vendors, carriers, universities, experimenters and standards developers in the test and demonstration of equipment, software protocols, applications, etc. This open cooperation with the user community furthers the interoperability of high performance national and global computing and communications systems and networks. The users will be administered under the recently approved NASA Joint Sponsored Research Program. The use of commercial communications satellite to interoperate with the testbed will be encouraged.

Carrier/Industry Advisory Committee

To reinforce the technical and research capabilities of the TSTI, and to assure that the effort is well-focused on developing timely and effective interfaces with emerging terrestrial high data rate services, it is proposed to establish a "Carrier/Industry Advisory Committee (CIAC)" consisting of current and future providers of terrestrial high-bandwidth telecommunications services. The CIAC will function collectively, or in subcommittees, as advisors to the TSTI, providing guidance in setting priorities for experiments, identifying interface requirements, assisting in the integration of industry guidelines and standards, and in disseminating the results of the TSTI work among other industry forums. The CIAC will be encouraged to participate actively in the TSTI work program, by providing access to terrestrial services and supporting demonstrations of satellite/terrestrial network interoperability.

This CIAC is in direct response to the recommendations of the Satellite Industry Task Force for joint partnership research projects and recommended roles for technology transfer, proprietary data and intellectual property. Therefore, all of the users of the Satellite Industry/Government Task Force along with the fourteen companies that have filed for Ka-band satellite systems will be invited to join the CIAC and this proposed joint research project.

The testbed will be kept as simple and flexible as possible. Participant/users may have to provide for their access to the testbed and may need to fund the actual costs of some special equipment to be used as part of their tests or demonstration. However, it is not intended to charge fees from the users for testbed use, or to show a monetary profit from the testbed activities.

Mission Benefits

The Testbed for Satellite and Terrestrial Interoperability will develop the hybrid satellite terrestrial communications technologies, systems and networks that will expand the nation's overall growth of the national and global information infrastructures, for economic competitiveness, scientific research and defense communications.

The ACTS satellite program will benefit from a high visibility testbed that will provide state-of-the-art high data rate tests and demonstration with commercial providers, that will likely validate the success of the NASA experiment.

The TSTI will enable the communications industry, in cooperation with government agencies, to address and resolve generic issues in high data rate hybrid satellite terrestrial networks and to accelerate the development and deployment of the next generation of commercial satellites by the private sector. The testbed provides government and industry with the unique opportunity to work cooperatively in a pre-competitive environment. The TSTI will facilitate technology transfer and enhance American competitiveness in the global satellite communications systems and services market.