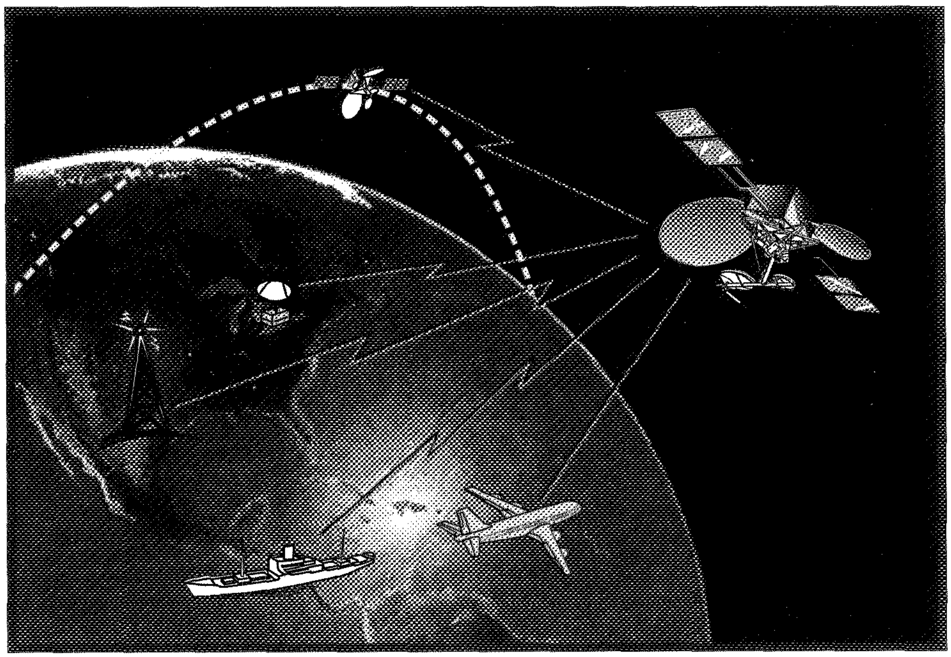
NASA/CP—1998-208524

Satellite Networks: Architectures, Applications, and Technologies



August 1998

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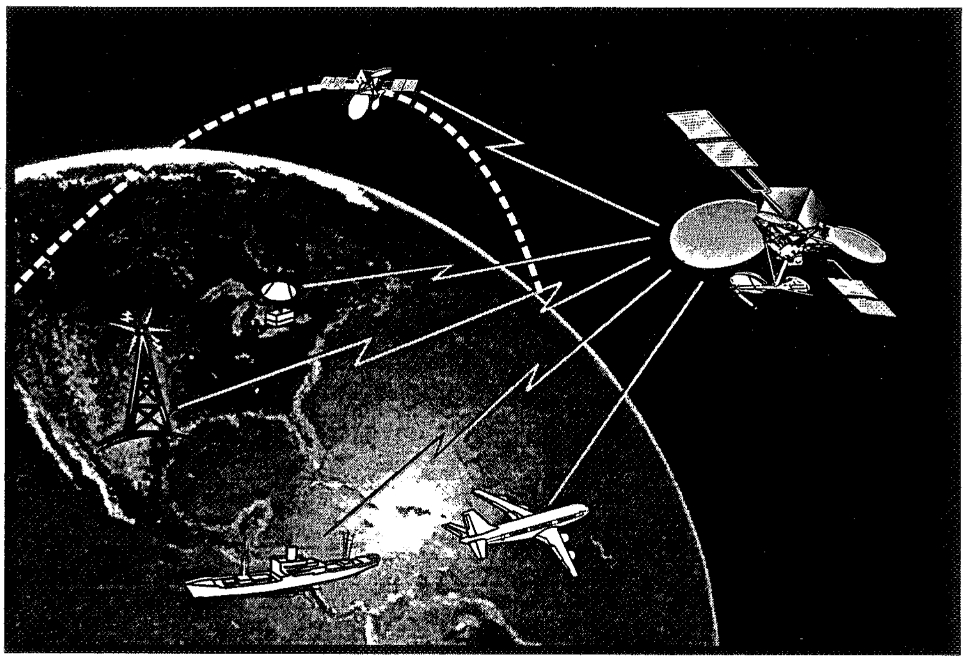

Proceedings of a conference sponsored by
NASA Lewis Research Center
Cleveland, Ohio
June 2–4, 1998

National Aeronautics and
Space Administration

Lewis Research Center

August 1998

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NA = Not Available for Publication

Preface

A workshop on the Satellite Networks: Architectures, Applications, and Technologies, hosted by the Space Communication Program at NASA Lewis Research Center in Cleveland, Ohio was held on June 2-4, 1998 at the Sheraton Airport Hotel in Cleveland, Ohio. More than 275 representatives of industry, academia and government participated in the workshop.

We decided to host this workshop because global satellite networks are moving to the forefront in enhancing national and global information infrastructures—due to the unique networking characteristics of communication satellites. Simultaneously, broadband data services are emerging as the major market driver for future satellite and terrestrial networks. Convergence of satellite and terrestrial networks is widely acknowledged as the foundation for an efficient global information infrastructure. In the past two years, various task forces and working groups around the globe have identified pivotal topics and key issues to address if we are to realize such networks in a timely fashion. In response, industry, government, and academia undertook efforts to address these topics and issues. There was a need to assess the progress made to date and chart the future. This workshop provided a forum to assess the current state-of-the-art, identify key issues, and highlight the emerging trends in the next-generation architectures, data protocol development, communication interoperability, and applications.

The response to the workshop was outstanding and the results are shown in the attached papers. In addition to several panels, workshop sessions covered a wide range of topics

- Access technology and protocols
- Architectures and network simulation
- ATM over satellite networks
- Internet over satellite networks
- Interoperability experiments and applications
- Multicasting
- NASA interoperability experiment programs
- NASA mission applications
- TCP/IP over satellite: issues, relevance, and experience

Contributions to this workshop are highly appreciated, and we hope to build on its success.

Kul Bhasin
Workshop Organizer
Chief, Satellite Networks and Architectures Branch
NASA Lewis Research Center

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AGENDA

Tuesday, June 2, 1998
The Internet: Enhancing the Internet for Space Today

8:30 Welcoming Remark: Donald J. Campbell, Director, NASA Lewis

8:40 NASA/Industry Programs: A Response to the Satellite Industry Task Force Challenges Ballrooms A & B
Chair: James Bagwell; Manager; Commercial Communications Program; NASA Lewis

Samuel Venneri; Chief Technologist; NASA Headquarters
Thomas Brackey; Executive Director of Technical Operations; Hughes Space & Communications
Prakash Chitre; Vice President Technology; COMSAT Laboratories
Ramon DePaula; Program Executive, Code S; NASA Headquarters
Charlene Gilbert; SOMO Technology Manager; NASA Johnson

Session description: This session will address the ad hoc Satellite Industry Task Force (SITF) technical challenges and NASA's response to them.

The ad hoc SITF consisting of satellite communications industry representatives, academia, and government observers came together in late 1994 to address the role of satellites in the emerging national and global information infrastructure. On July 31, 1996, the SITF presented its findings to Daniel Goldin, NASA Administrator; Kaminski, then Deputy under Secretary for Defense for acquisition; high-ranking government executives; and industry executives.

In this opening session, Samuel Venneri, NASA Chief Technologist, and other NASA executives will outline NASA's response to several of SITF's technical findings. Thomas Brackey, Executive Director of Technical with Hughes Space and Communications, and Prakash Chitre, Vice President of Technology with COMSAT Laboratories, will provide industry's perspective on these interoperability issues.

10:20 Break

10:35 Opening the Technical Program: Kul Bhasin, Chief, Satellite Networks & Architectures Branch; NASA Lewis

10:40 Invited Session: Internet over Satellite Networks
Ballrooms A & B
Chair: Frank Gargione; ACTS Project Manager; Lockheed Martin

Dennis Conti; Vice President; Hughes Networks Systems

"Satellite Networks: The Next Frontier"

Burt Liebowitz; Chief Technology Officer; Orion Network Systems
"Providing Internet Access to ISP's Using Geosynchronous Satellites – A Case History Based on Orion's Worldcast Services"

John Baras; Director; Center for Satellite and Hybrid Networks; University of Maryland
"Linking Satellites and Terrestrial Networks for Broadband Internet Services"

David Beering; Principal; Infinite Global Infrastructures
"Internet Protocols over ACTS at 622 Mbps: Implications for Future Advanced Internet Services"

Demonstration of Internet over Bi-Directional Satellite Link
Jim Griner, Paul Mallasch, Mark Allman, and David Stewart; NASA Lewis

12:10 Lunch

1:30 Plenary Session: TCP over Satellite: Issues, Relevance, and Experience
Ballrooms A & B
Moderator: Aaron Falk; Network Systems Engineer; TRW Space & Electronics

Keynote:
Craig Partridge
Principal Scientist; BBN Technologies
"Does TCP Work over Satellite Links or Not?"

Norman Butts; Manager; Systems Engineering; Telecommunications Interactive Technology Center; Lockheed Martin

Eric Travis; Systems Engineer; Jet Propulsion Laboratory

Lori Jeromin; Member of Technical Staff; MIT/Lincoln Laboratory

Victor Barajas; Member of Technical Staff; Hughes Spaceway

Session description: providing Internet service over satellite depends largely on providing good Transmission Control Protocol (TCP) performance. This panel will discuss the issues with today's TCP; solved and unsolved problems; the relevance to commercial; NASA, and military applications; and approaches to dealing with or avoiding TCP problems. Craig Partridge will provide an overview presentation on TCP performance over satellite. The remaining panel members will each provide brief presentations (about 5 minutes) on specific topics of their choosing. Following the presentations; there will be an open question-and-answer period.

3:00 Break

3:30 Session Breakout

Session 1 – Ballroom A
TCP/IP over Satellites

Chair: Dan Glover; Team Leader, Satellite Networks & Architectures Branch; NASA Lewis

Han Kruse
Ohio University
"Performance Analysis of HTTP Protocol on Geostationary Satellite Links"

J. Scott Stadler
MIT/Lincoln Laboratory
"Peformance Enhancements for TCP/IP over a Satellite Channel"

Mark Allman
NASA Lewis/Sterling
"Estimating Bottleneck Bandwidth Using TCP"

Nihal Samaraweera
University of Aberdeen
"LFN and SACK over DVB Satellite Networks"

Session 2 – Ballroom B
NASA Mission Applications

Chair: Dan Williams; Chief, Communications Technology Division; NASA Lewis

James Budinger
NASA Lewis
"NASA's Use of Commercial Satellite Systems: Concepts and Challenges"

Robert Lease
Stanford Telecomm/NASA Goddard
"Commercial Support of NASA LEO Missions"

Calvin Ramos
NASA Lewis
"OhioView: Distribution of Remote Sensing Data Across Geographically Distributed Environments

Paul Baker
Global Science & Technology
"Simple Automatic File Exchange – SAFE – to Support Low-Cost Spacecraft Operation via the Internet"

Fred Huegel
NASA Goddard
"Satellite Telemetry and Command Using Big LEO Mobile Telecommunications Systems"

Session 3 – O'Hare Room
Architectures and Network Simulation

Chair: Kent Price; System Architect; Cyberstar Loral

Gary Johanson
Nortel
"Satellite System Architectural Issues for Broadband Interactive Multimedia Communications"

Thomas Wallett
NASA Lewis
"Simulation of a NASA LEO Satellite Hybrid Network"

E. Geraniotis
University of Maryland
"Multimedia Traffic Modeling and End-to-End QoS Evaluation Tools for Satellite Networks"

Bachittar Singh Sembi
Vistar Telecommunications
"Characteristics of Internet Traffic for Planning Satellite Networks"

Michael K. Jones
Jet Propulsion Laboratory
"Interoperability for Space Mission System Monitor and Control: Applying Technologies from Manufacturing Automation and Process Control Industries"

5:00 Close

5:30 Bus leaves for Nautica

Wednesday, June 3, 1998
Seamless Interoperability:
Expanding the Information Infrastructure

8:30 Invited Session: NASA Interoperability Experiment Programs
Ballrooms A & B
Chair: Pete Vrotsos; Chief, Space Communications Office; NASA Lewis

Keynote:
Al MacRae
Senior Research Scientist, Institute for Applied Space Research; George Washington University; formerly Director, Satellite Communications; AT&T Bell Labs
"Interoperability – What Is It and Why Is It So Important?"

Robert Bauer; ACTS Project Manager; NASA Lewis
"New Opportunities with the Advanced Communications Technology Satellite (ACTS)"

Richard desJardins and Kenneth Freeman; Networking Consultants, Next Generation Internet Project; NASA Ames
"NASA/NREN Next Generation Internet (NGI) Activities"

Ramon DePaula; Program Executive, Code S; NASA Headquarters
"Overview of G8 Global Interoperability for Broadband Networks (GIBN) Project"

10:00 Break

10:30 Plenary Session: Addressing Interoperability
Ballrooms A & B
Moderator: Burt Edelson; Director, Institute for Applied Space Research; George Washington University

Keynote:
Raj Jain
Professor of Computer and Information Sciences
Ohio State University
"Addressing Interoperability: Issues and Challenges"

Charlene Gilbert; SOMO Technology Manager; NASA Johnson
Mark Plecity; New Business Development; Iridium
Sastri Kota; Technical Consultant; Astrolink
Jim Justiss; Director of Systems Engineering; Hughes Space and Communications

Session description: achieving interoperability among satellite, terrestrial, and cellular network systems is the key to providing a seamless global information infrastructure. This panel will discuss the operational, standards, market, and technical barriers that are being addressed by industry, government, and academia for the purpose of achieving interoperability.

12:00 Lunch

1:30 Session Breakout

Session 4 – Ballroom A ATM over Satellite Networks

Chair: Tom vonDeak; Team Leader, Satellite Networks & Architectures Branch; NASA Lewis

Enrique Cuevas
AT&T
"Overview of ATM Performance and QoS Requirements for Satellite Systems"

Simon Nawrot
AT&T
"ATM over Terrestrial/Satellite Network – CTD & CVD QoS Laboratory Measurements"

William Ivancic
NASA Lewis
"Satellite/Terrestrial Networks: End-to-End Communication Interoperability QoS Experiments"

Yung Ho
Yurie Systems
"Efficient and Flexible Link Enhancement Techniques for Wireless ATM"

Session 5 – Ballroom B Multicasting

Chair: Paul Mallasch; Computer Engineer, Satellite Networks & Architectures Branch; NASA Lewis

Keynote:
Kenneth Miller
Starburst Communications
"Reliable Multicasting over Satellite: Issues & Applications"

Antoine Clerget
INRIA U.R. (France)
"Organizing Data Transmission for Reliable Multicast over Satellite Links"

Doug Dillon
Hughes Network Systems
"Satellite-Multicast Enhanced Consumer Internet Services"

Yongguang Zhang
Hughes Research Labs
"Integrating Satellite Networks with Internet Multicast Backbone (Mbone)"

Daniel Friedman
University of Maryland
"Error Control for Satellite Multicasting"

Session 6 – O'Hare Room Interoperability Experiments and Applications

Chair: Richard Gedney; President, Advanced Communication Technology

Mehran Shariatmadar
SpaceBridge
"Applying Heritage Inter-Networking Solutions to ATM Satellite Systems"

Thomas Stephenson
Milstar, USAF
"ATM over Satellite for the Warfighter"

Dan Daly
Bellcore
"ATM Traffic Measurements over the ACTS OC-12c HDR Channel with a Distributed Test System"

Patrick Gary
NASA Goddard
"Testbed for Satellite and Terrestrial Interoperability (TSTI) – A FY98 Program Product of 632-50-50 Communications - Terrestrial"

Dan Shell
CISCO
"Satellite Interoperability"

3:00 Break

3:30 Session Breakout

Session 7 – Ballroom A ATM over Satellite Network Quality of Service

Chair: Will Ivancic; Team Leader, Satellite Networks & Architectures Branch; NASA Lewis

Keynote:
Louis Dellaverson
Motorola Radio Research Lab
"Mobile ATM Networking"

Rohit Goyal
Ohio State University
"Traffic Management for Satellite-ATM Networks"

Prakash Chitre
COMSAT Laboratories
"ATM via Satellite: Link and Networking Technologies"

Sastri Kota
Astrolink
"Satellite ATM Networks: Architectural Issues and Challenges"

Pong Chu
Cleveland State University
"FPGA Based Reconfigurable ATM Switch Testbed"

Session 8 – Ballroom B Access Technology and Protocols

Chair: Ben Pontano; President, COMSAT Laboratories

Gorry Fairhurst
University of Aberdeen
"Integrated Packet/Modem Processing for Transportable Terminals"

Bill Shvodian
Lockheed Martin
"Multiple Priority Distributed Round Robin – ATM Satellite MAC Protocol"

Leandros Tassiulas
University of Maryland
"Broadcast Delivery with Limited Feedback"

John Baras
University of Maryland
"Flow Control and Dynamic Bandwidth Allocation in DBS-Based Internet"

Session 9 – O'Hare Room TCP/IP over Satellites

Chair: Patrick Gary; Network Project Leader; NASA Goddard

Jeff Semke
Pittsburgh Supercomputer Center
"Automatic TCP Buffer Tuning"

Keith Scott
Jet Propulsion Laboratory
"Improving TCP Performance over Mobile Satellite Channels: The ACKPrime Approach"

Tom Henderson
University of California, Berkeley
"Transport Protocols for IP – Compatible Satellite Networks"

James Stepanek
The Aerospace Corporation
"Internet Services over a Direct Broadcast Satellite Network: Challenges and Opportunities"

DC Palter
Mentat
"Improved Satellite Networking Using the Mentat SkyXpress Protocol"

Thursday, June 4, 1998
Next-Generation Space-Based Architectures

8:30 Visionary Session – Architectures, Applications, and Technologies
Ballrooms A & B
Moderator: Kul Bhasin; Chief, Satellite Networks & Architectures Branch; NASA Lewis

Edward W. Ashford; Vice President, Broadcast Satellites; Lockheed Martin
James Bagwell; Manager, Commercial Communications Program; NASA Lewis
William Bailey; Manager, New Markets and Technology; CISCO
John Baras; Director, Center for Satellite and Hybrid Networks; University of Maryland
Joe Bravman; Senior Vice President, Corporate Development; Orbital Science
Steve Goldstein; Program Director; National Science Foundation
Marie-José Montepit; Network Design Team; Teledesic

Session description: Looking back 20 years at the satellite and telecommunication industries, it is hard to comprehend the vast changes that have occurred. Just five years ago, the Internet was unknown to the general public. What will the next 20 years bring? Who will be the users, and what will their requirements be? What are the next-generation architectures (post-2005) to meet the users' requirements? What are the technology trends to be able to implement the future architectures? This session will attempt to answer some of these questions. Panel members will provide their vision of the applications and architectures, including technical issues that must be resolved for satellites to be the integral element of the 21st century telecommunication infrastructure.

10:30 Break

11:00 Open Forum: Next Step
Ballrooms A & B
Moderator: Thomas Brackey; Chair, Telecommunications Industry Association, Satellite Communication Division

Session description: Broadband data services are emerging as the major market driver for future satellite and terrestrial networks. The convergence of satellite and terrestrial networks is widely acknowledged as the foundation for an efficient global information infrastructure. Various working groups have identified pivotal topics and key issues to be addressed for the realization of such networks in a timely fashion. In response, efforts have been undertaken by industry, government, and academia in addressing these topics and issues. This workshop has provided the forum to assess the current state-of-the-art, identify key issues, and highlight the emerging trends in the next-generation architectures, data protocol development, communication interoperabilty, and applications. Thomas Brackey will lead the session attendees in discussing and summarizing the issues that should be addressed to further realize the goal of interoperable satellite networks. The output of this discussion process will be used in the planning processes.

Opening Session

NASA/Industry Programs:
A Response to the Satellite Industry Task Force Challenges

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COMSAT LABORATORIES

Satellite Communications
and
Interoperability

Prakash Chitre
COMSAT Labs
Clarksburg, MD 20871
Tel: 301 428-4167
Fax: 301 428 7747
e mail: prakash.chitre@comsat.com

COMSAT LABORATORIES

Satellite Communications and Interoperability

- Interoperability
  - Terrestrial and Satellite Network Integration
  - Common Air Interface Specifications for Satellite Networks
- Challenges
- Current Solutions
- Future Prospects

COMSAT LABORATORIES

Seamless Integration of Satellite and Terrestrial Networks

- Satellite Link Transparent to the End User
- Service Provisioning in a Cost-Efficient Manner

COMSAT LABORATORIES

Steps for Achieving Interoperability

- Modify Existing Telecommunications Standards
- Develop New Standards
- Design and Implement Satellite Interface Products
- Develop Next Generation Satellite Networks
- Conduct Tests and Demonstrations

COMSAT LABORATORIES

Communications and Interoperability Section and TR-34.1

- Wireless ATM
- ATM Traffic Management
- ATM Speech
- ATM QOS
- Internet Over Satellite
- Common Air Interfaces for Satellite Systems
- Interoperability Reference Models

COMSAT LABORATORIES

Communications and Interoperability Section/TR-34.1

Major Accomplishments

- Established a liaison with ATM Forum Wireless ATM Group for the joint development of satellite ATM network architectures, protocols, mobility standards
- Worked closely with Internet Engineering Task Force (IETF) for internet protocols to work well over satellite
  - TCPSAT Group has been established
- ATM Traffic Management (TM 4.0)
  - Modifications to accommodate satellite delay were approved by ATM Forum
- ATM Speech
  - Worked with ATM Forum to develop ATM speech standards to be bandwidth efficient
- Common Air Interface for Satellite Systems
  - Standardize Common Air Interfaces for a range of satellite systems from satellite personal communications systems to broadband satellite systems
- Letter Ballots on ATM Networks and GMPCS

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Common Air Interfaces for Satellite Systems

- GMPCS
  - Letter Ballot: "High Level Requirements for Common Air Interface for GEO Mobile (Super-GEO) Satellite Communications Featuring Dual Mode Operation with Terrestrial GSM"
- Satellite Link Protocol
  - Requirements for the Common Air Interface for ATM Over Satellite Links

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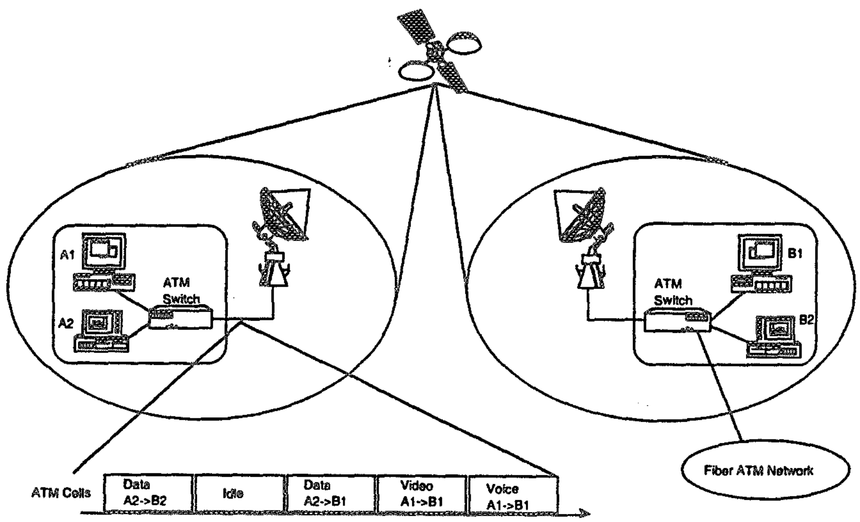
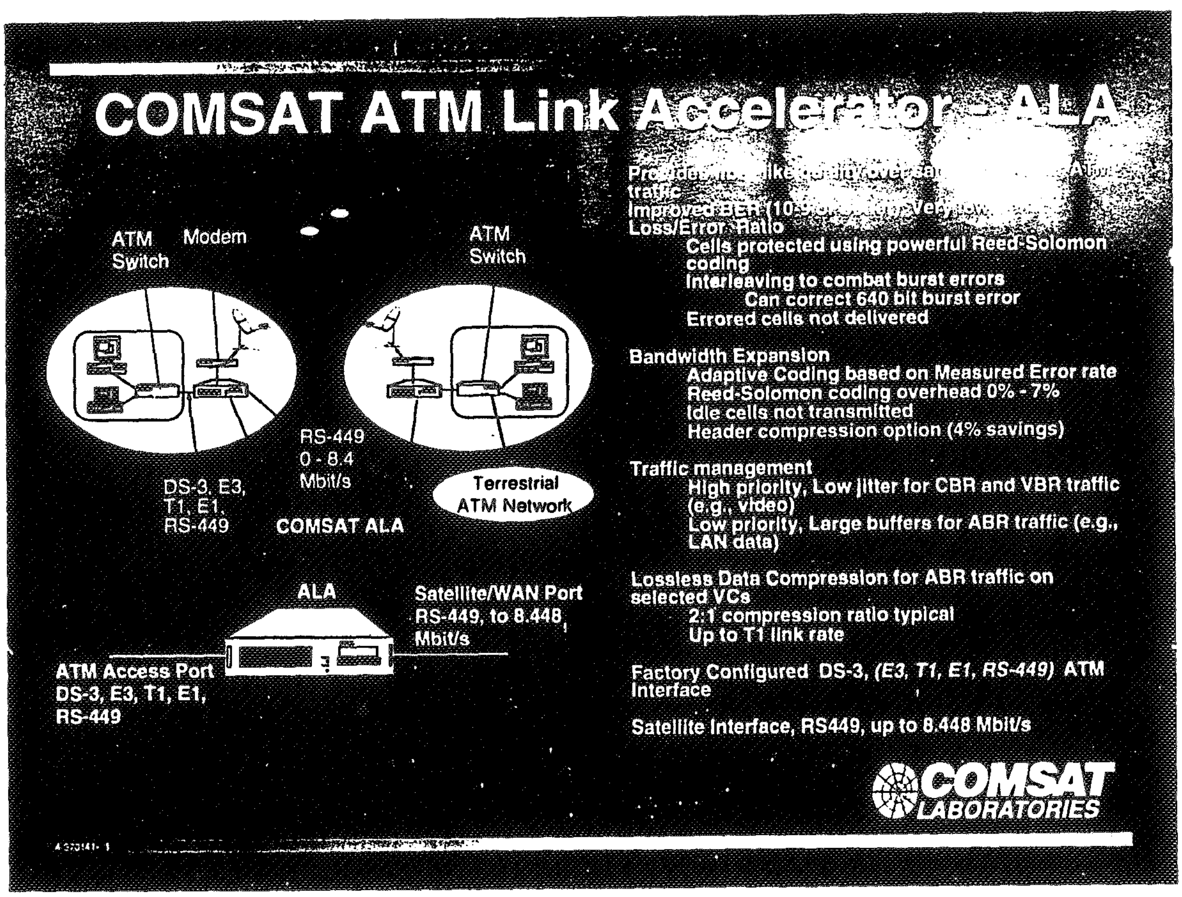
Current Solutions

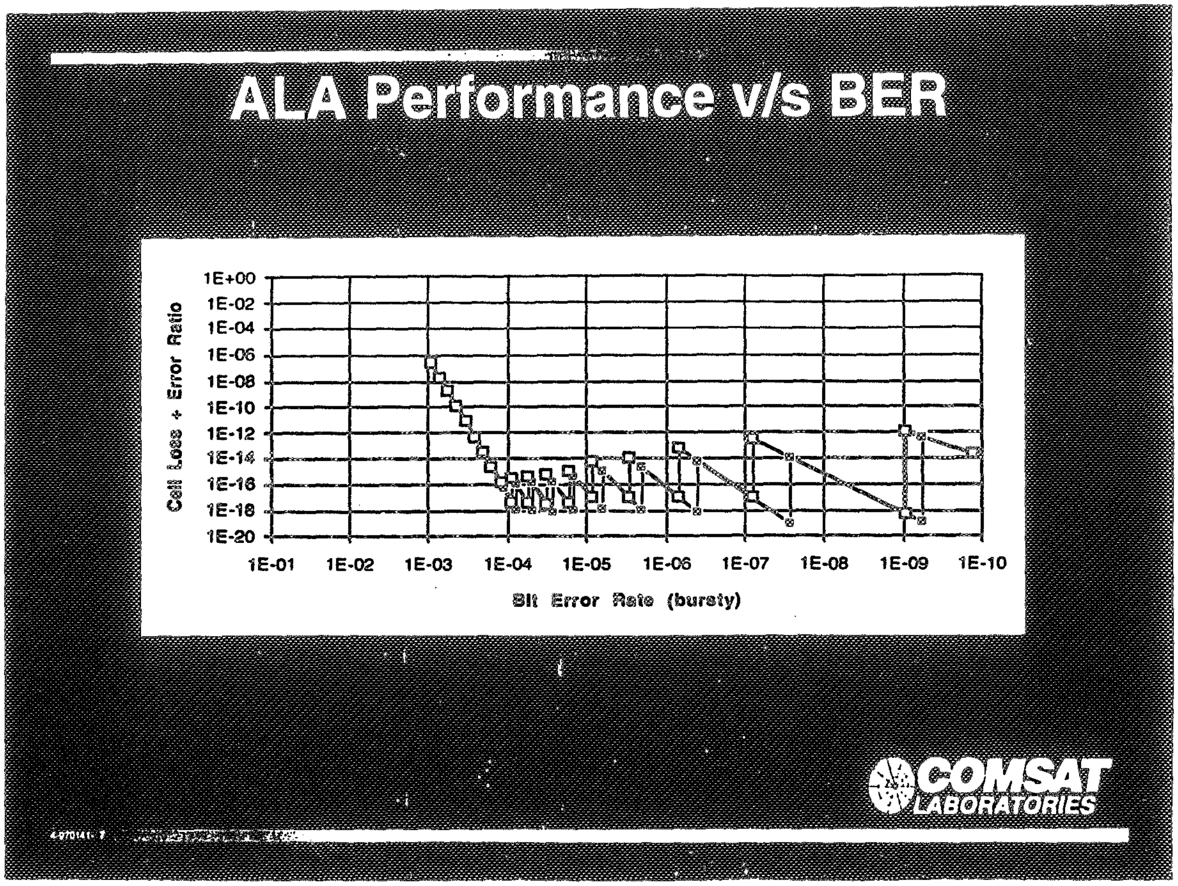
- ATM Standards
  - Some Evolving to be Satellite Compatible
- ATM Satellite Link and Networking Proprietary Products for High Quality, Cost Efficient Operation
- Internet Standards
  - A number of TCP Optional Implementation for Better Performance Over Satellite
- Satellite Internet Products with Proprietary Solutions

Asynchronous Transfer Mode (ATM) over Satellite



ATM designed for high speed multi-media traffic
ATM networks expect fiber-like quality from satellite link




ALA Performance v/s BER
1E+00
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1E-08
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1E-16
1E-18
1E-20
Cell Loss + Error Ratio
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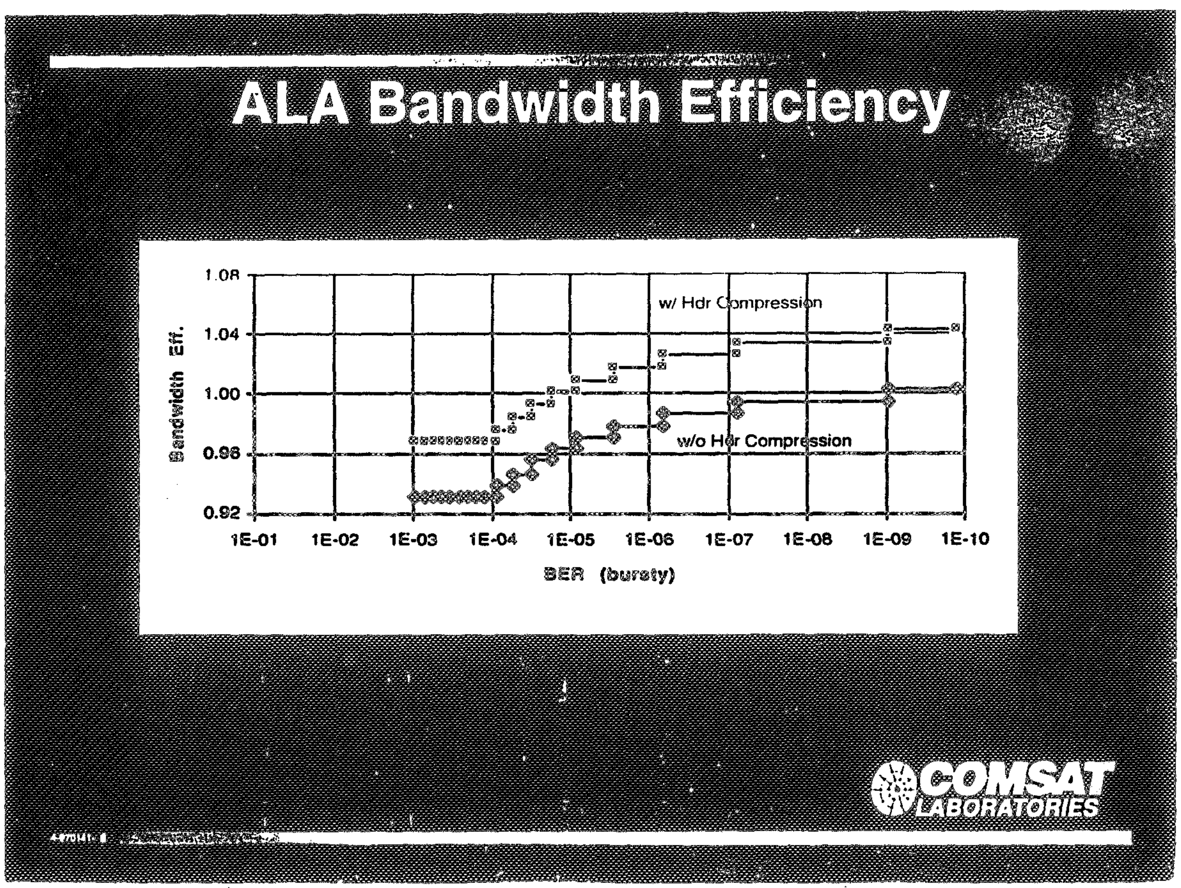
Bit Error Rate (bursty)
COMSAT LABORATORIES


ALA Bandwidth Efficiency
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1.04
1.00
0.96
0.92
Bandwidth Eff.
w/ Hdr Compression
w/o Hdr Compression
1E-01 1E-02 1E-03 1E-04 1E-05 1E-06 1E-07 1E-08 1E-09 1E-10
BER (bursty)
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Future Prospects

- Common Air Interface Specifications for
  - GEO Mobile with Dual Mode Operations with Terrestrial GSM
  - ATM Over Satellite Links
  - TCP/IP Over Satellite Links
- UMTS Compatible Satellite Common Air Interface Protocol
- Satellite Network Protocols for Ka-band Systems

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Commercialization in NASA

Space Operations

NASA/LeRC Satellite Networks Workshop

June 2, 1998

Charlene E. Gilbert
Space Operations Management Office
Technology Program Manager
NASA Johnson Space Center
charlene.e.gilbert1@jsc.nasa.gov

Agenda

- NASA's Plan
- Space Operations
- Space Operations Technology
- Space Operations Technology Strategy

Space Operations Management Office
National Aeronautics and Space Administration

NASA's Plan

Reality - NASA's budget is flat

The prospect of getting additional funds from Congress for new program starts is faint

Where will the money come from$?

The Game Plan

- Change strategy in the relationship of technology and missions
  - Technology enables the missions
    - One Galileo mission vs 12 small planetary missions - $1.9 Billion dollars
- Integrate technology across the Agency
- Consolidate the management of space operations
- Implement strategies to reduce the cost of operations
  - NASA spends more than $4 Billion/year on operations
  - **Outsource, privatize, commercialize**
- Redirect the cost savings to exploration and new program starts

Space Operations Management Office
National Aeronautics and Space Administration

Space Operations

Space Operations Management Office (SOMO) is an agency-wide provider of mission and data services. Includes the expertise and systems necessary to support the mission preparation and flight execution phases of a program or project.

Mission: Implement Agency space operations goals while successfully providing services which enable Enterprise mission execution

Goal 1: **Meet the strategic mission needs** of the NASA Enterprises while **reducing operations costs**, consolidating and integrating operations across the Agency, emphasizing the use of **technology**, and **increasing standardization** and **interoperability**

Goal 2: **Transition the civil service and** Jet Propulsion laboratory (JPL)/**Cal Tech** work force from routine, day-to-day operations to science, research, and development, except for core competencies

Goal 3: Transition all operations contracts for products and services to **performance-based contracting**

Goal 4: **Transition operations** functions that generate products and services to outsourcing, privatization, and, ultimately, commercialized services

Goal 5: **Restructure management** and operational processes using the concept of **customer/service provider**

Space Operations Technology

SOMO has overall responsibility for communications and operations technologies required to

- **Enable** and/or **reduce the cost** of future NASA missions, includes space and ground elements
- Promote sustained **U.S. Industry leadership** in commercial communications
- Maximize NASA's ability to **acquire commercial services** to meet its communications and operations needs.

The Space Operations & Communications Technology & Advanced Development Program

- **Defines NASA's program** for future communications and space operations technology development
- Supplies **new capabilities** required for SOMO to meet their mission
- Is an integral part of NASA's **strategy** to move towards using commercial services to cost-effectively meet the Enterprises' space operations needs, particularly the **Commercial Satellite Communications program**

Space Operations Technology Strategy

Partner with the Commercial Satellite Communications Industry to

- Enable NASA's use of commercial services and assets to reduce the cost of operations
- Develop pre-competitive technologies to act as a catalyst to open new markets for the U.S. SatCom Industry

Near-term areas of collaboration

- Interoperability issues
- Critical areas of pre-competitive technology
- Trade studies and system architecture assessments
- SatCom workforce enhancement

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Invited Session
Internet over Satellite Networks

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HUGHES
NETWORK SYSTEMS
A HUGHES ELECTRONICS COMPANY

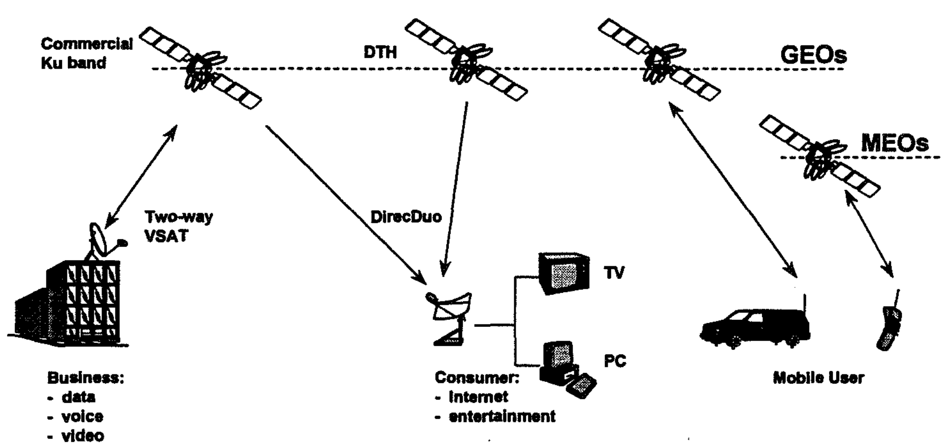
Satellite Networks: The Next Frontier

by

Dennis M. Conti, Ph.D.

HUGHES
NETWORK SYSTEMS
A HUGHES ELECTRONICS COMPANY

Today's Satellite Networks



Today's Applications

HUGHES NETWORK SYSTEMS
A HUGHES ELECTRONICS COMPANY

- Internet/Intranet characteristics:
  - TCP/IP based
  - asymmetric bandwidth requirements
- IP Multicasting gaining in popularity
- Growing popularity of:
  - third-party applications with "chatty" characteristics

Next Generation Satellite Characteristics

HUGHES NETWORK SYSTEMS
A HUGHES ELECTRONICS COMPANY

- Ka band => available spectrum
- Spot beams => frequency reuse, higher bandwidth
- On board processing => true mesh connectivity
- LEOs => lower latency, but no broadcast

Summary Comments

HUGHES
NETWORK SYSTEMS
A HUGHES ELECTRONICS COMPANY

- The LEO/MEO/GEO wars will only increase the FUD factor (fear, uncertainty, and doubt) among potential satellite network buyers
- It is in the interests of all such systems to foster standards efforts that:
  - allow TCP to operate better with higher latency and jitter
  - result in more efficient browser implementations
  - support security standards at levels above IP
  - advance quality of service (QoS) standards

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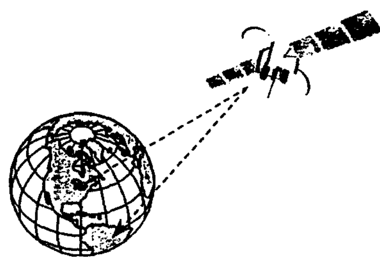
Providing Internet Access to ISPs using Geosynchronous Satellites

A Case History Based on Loral Orion's WorldCast® Service

Presented to Satellite Networks: Architectures, Applications and Technologies Workshop

June 2, 1998

Cleveland, OH



Burt H. Liebowitz
Chief Technical Officer
Loral Orion Inc.
Rockville, MD

The Internet Market

- Customers
  - End Users in the Home
  - Internet Service Providers (ISPs)
  - Corporations (Multi-user Enterprises)
- Services
  - File Transfers
  - Mail
  - Web Search
  - Multicast
  - Etc.

Role of Geosynchronous Satellites in Internet/Intranet

- Economic Provision of Services to Customer Base, especially where:
  - There is no terrestrial infrastructure
  - There is an asymmetric traffic flow
  - Terrestrial lines/services are congested
  - >64 Kbps is expensive terrestrially
  - Broadcast/multicast services are prevalent
- Satellites can be used for:
  - Backbone
  - Trunking to POP from Internet NAP
  - Direct delivery to customer premise

5/27/98 llg:Geo6298.ppt 3

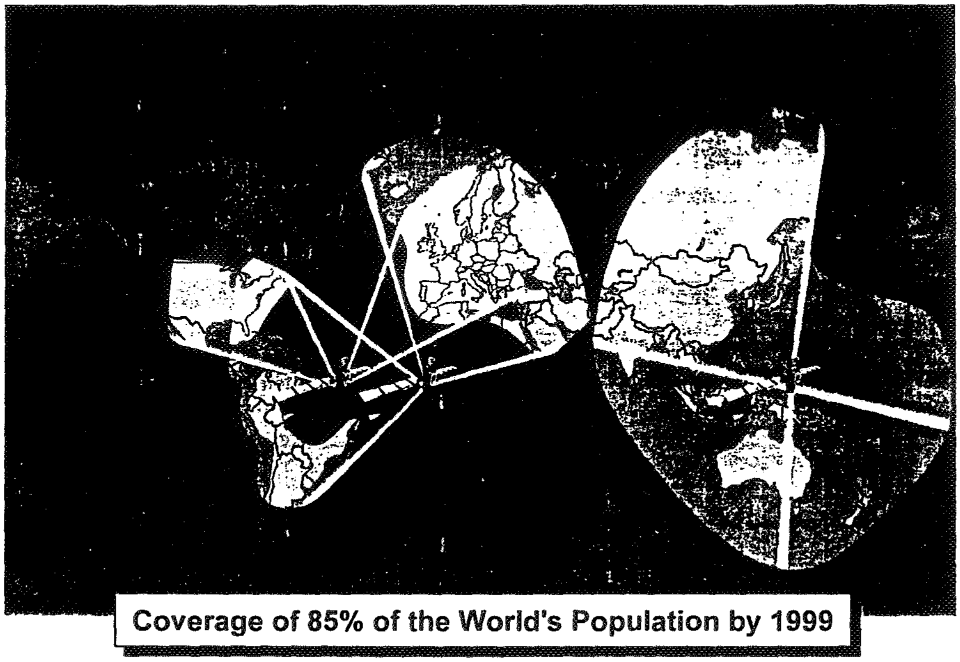
An Example: Loral Orion's WorldCast Service for ISPs

- Large Earth Station Uplink in US to Europe, then Asia and Latin America
- Low Cost Access to US Internet
- Asymmetric Data Transfer
  - High bandwidth to Europe
  - Low bandwidth for request and ACKs (via satellite or terrestrial link)
- Broadcast/Multicast Services
- Quality of Service Guarantees designed primarily for Overseas ISPs and ISP-like Enterprises
  - Uses frame relay CIR concept to insure bandwidth

5/27/98 llg:Geo6298.ppt 4

Orion's Coverage Map

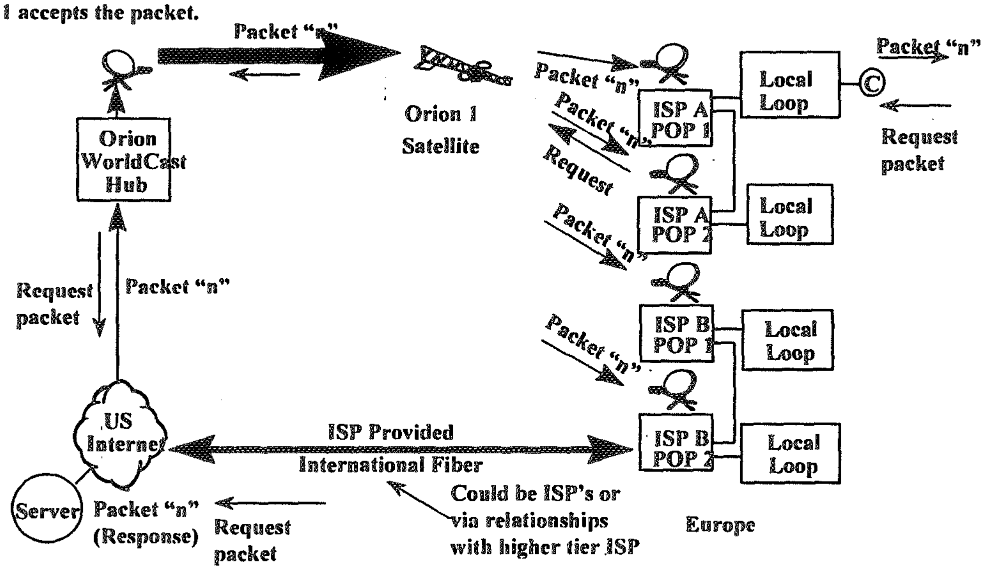
Orion 1 - Now
Orion 2 - Early 99
Orion 3 - Late 98



Coverage of 85% of the World's Population by 1999

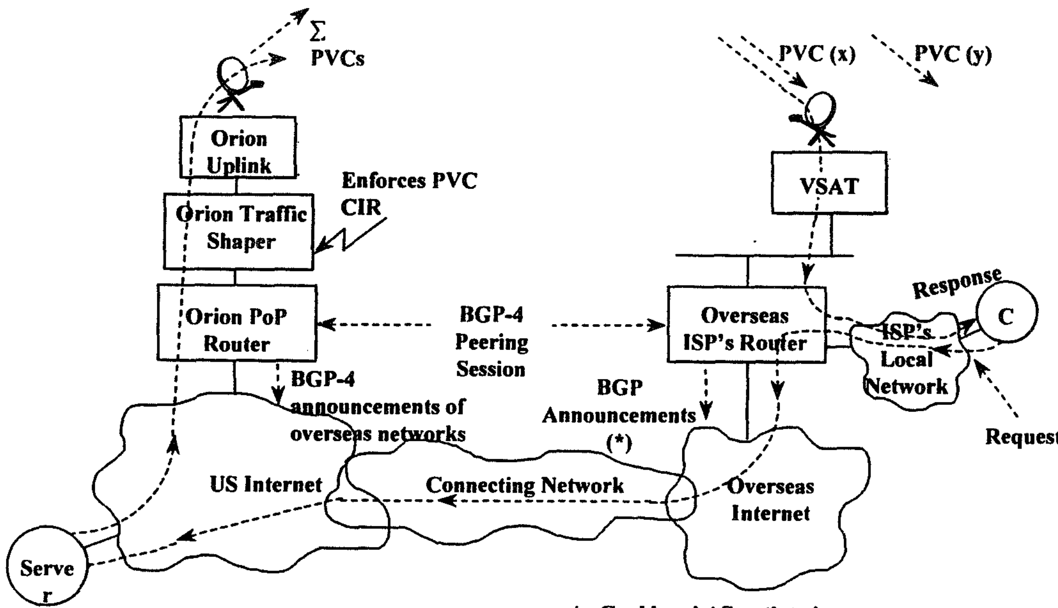
WorldCast - US to Europe

Single carrier example of Orion's WorldCast System. Packets are transmitted from the Orion hub to two European ISPs. ISP A has 2 POPs, one of which has a satellite request. ISP B has 2 POPs and uses a terrestrial request. In this example, Packet "n" is transmitted from the US Internet to all sites. Only ISP A's POP 1 accepts the packet.



5/27/98 llg:Geo6298.ppt 6

WorldCast ISP Routing/Hybrid System



* Could pad AS path to insure return over satellite

5/27/98 llg:Geo6298.ppt 7

Geosynchronous Satellite Versus Terrestrial or LEO

- **Pro-GEO Satellite**
  - Efficient for broadcast/multicast
  - Can access remote locations
  - More bandwidth in some locations
  - Statistical multiplexing for wide area aggregation
  - Amenable to asymmetric data transfer (to match traffic flow)
  - Can bypass congestion points
  - Bypass expensive national back hauls
- **Con-GEO Satellite**
  - For some applications, impact of satellite delay on TCP/IP can limit throughput of file transfers and increase response time for Web page retrievals
  - Unicast could be more expensive in highly developed countries

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Concerns When We Announced Service

- Customer
  - Throughput degradation because of satellite delay
  - Impact of bit error rate on satellite link "goodput"
  - Ability to fill a channel with multiple simultaneous file transfers
- Loral Orion
  - Surge impact for overbooked ISPs
  - Security Issues

Outcome

- Customer Concerns
  - No problem regarding throughput
    - Most ISP customers limited by local modem or ISDN line
  - Bit error rate not an issue
    - We design at BER $<1x10^{-7}$ for either 99% or 99.5% availability (use Reed-Solomon)
  - Channels can be filled
- Loral Orion Concerns
  - Surges limited because most customers do not order EIR
  - Security not an issue in ISP world

Future: Expansion to Corporations for Inter and Intranet (direct to roof-top)

- Move to DVB/MPEG technology for
  - Security
  - Controlled access to services
  - Broader range of CIRs
  - Lower cost VSAT
  - Saturated transponder operation (up to 54 mbps per carrier)
  - Video, voice and data service on same carrier
- Caching
- Performance Enhancement for higher end to end throughput because Corporation is no longer modem limited
  - Spoofing
  - Proxy server
  - IP enhancements
  - Caching

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Summary

- Geosynchronous satellites are extending the reach of Internet
- Could be a performance hit, but will not be noticed by most customers and will not affect ISP's ability to fully utilize satellite channels
- Performance enhancements are (or soon will be) available for customers who need high data rates, and low response times
- GEO satellites are uniquely capable of providing multicast applications
- GEOs can overcome "last mile" problem, especially in emerging countries

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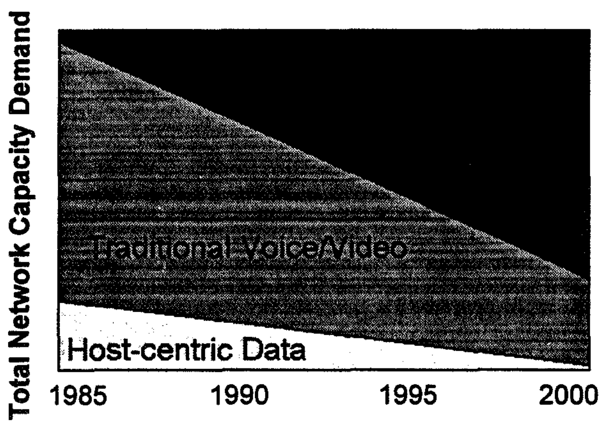
Center for Satellite and Hybrid Communication Networks

Linking Satellite and Terrestrial Networks for Broadband Internet Services

John S. Baras
Center for Satellite and Hybrid Communication Networks
University of Maryland College Park

Satellite Networks: Architectures, Applications and Technologies
NASA Lewis Research Center
June 2, 1998

New Business Paradigm



- The "New Data": Internet / Intranet / Extranet applications
  Digital, compressed voice, audio and video

- Paradigm shifts:
  - **Data applications require flexible connectivity**
  - **Applications require much larger capacities and "bandwidth-on-demand"**
  - **Subscribers require low-cost, high capacity access**
  - **Enterprise networks require in addition scalability,dependable performance, simple network management, controlled costs**

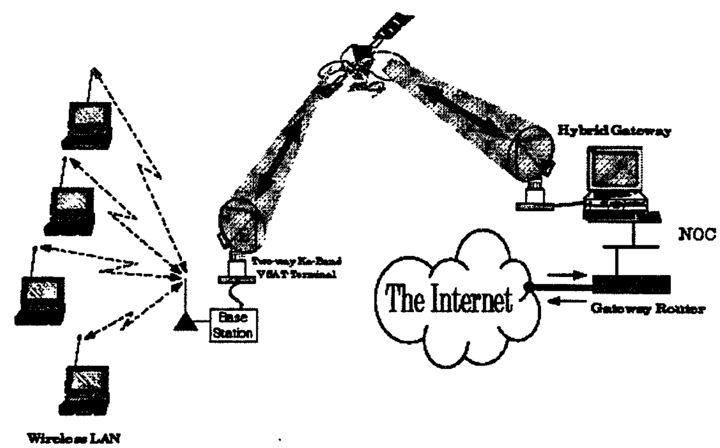
The "Last Mile" is Key

- **Local Access options :**
  - Fiber to anywhere (FTTN, FTTC, FTTH, SDV)
  - Copper twisted pair wire (ADSL, VDSL, ... HDSL)
  - Cable Television (CATV), coaxial cable (HFC)
  - Multichannel Multipoint Distribution Service (MMDS)
  - Local Multipoint Distribution Service (LMDS)
  - Broadband Satellites
- **Not a technology issue**
- **Economic and marketing issue**
- **Time of deployment & market penetration**

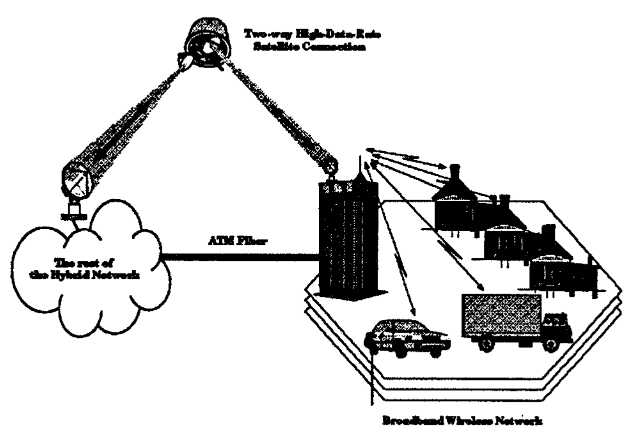
Broadband Wireless Infrastructures: Satellite Constellations

- **DBS major success**
- **New remarkable satellite constellations**
  - FSS or Mobile, LEO or MEO
  - From 8kbps to 1 Gbps and higher; ***on demand***
  - Competition to fiber ("faster than light")
  - On-board processing, spot beams, hoping beams, autonomy
  - Globalstar, Iridium, Teledesic, Spaceway, CyberStar, PanAmSat, Astrolink, ...
  - Newest EHF satellites: Celestri, OrbLink, Lockheed Martin, ...

Hybrid Networks Architectures:
High-Data-Rate Ka-band SatCom and Wireless or Wire-line Terrestrial



Hybrid Networks Architectures:
High-Data-Rate SatCom, Fiber and LMDS



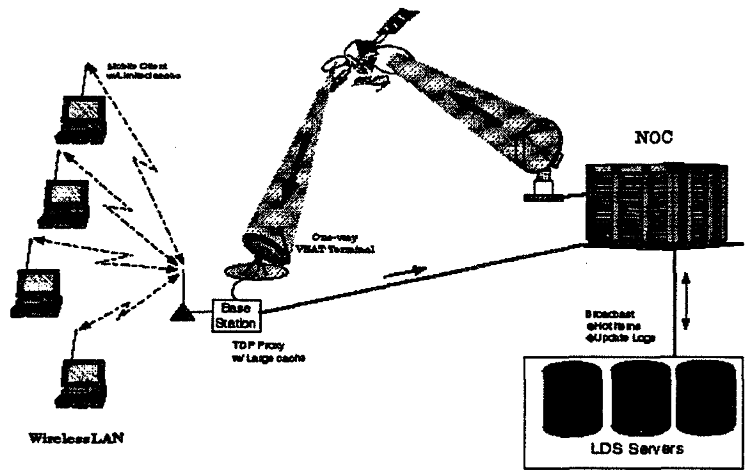
Efficient Broadband Sevices not just a Bandwidth Issue

- <u>Challenge:</u> **Exponential growth in demand workloads cannot be met by traditional data services with scalability groth linear in network bandwidth and server capacity**
- **Traditional unicast (poin-to-point) connection-oriented data services uneconomical and wasteful**
- **Utilize distributed caching, smart prefetching, dynamic bandwidth allocation, reliable multicast, adaptive hybrid data delivery**
- **Need to broadacst the right set of data: highly in demand**
  - Balance data delivery modes to match user's request
  - Broadcast the right amount of the hottest data and provide the rest on demand

"Push" Information Distribution

- **Why important?**
  - **Audio/video streaming, software distribution, message distribution**
  - **Give listeners up-to-date -ness guarantee**
  - **Get network economies of scale and efficiency**
  - **Event driven enterprises**
  - **Individualized content need not require per-user data streams: filtering at the desktop, integration at the desktop**
- **"Push" spending: 1996 $ 8 B, 2002 $ 19 B**
- **"Push" needs multicast : Intranet and Internet multicast**

Distributed Multi-Tier Database Architecture



Network Operations Center (NOC) for Hybrid Internet Service

- **HGW : first NOC object that receives data (Router)**
  - HGW prioritizes Hybrid Internet traffic
- **SGW jobs : mixture of Internet and exogenous traffic**
  - Exogenous traffic: package delivery and data feed traffic
  - SGW maintains four queues : two for package delivery and data feed
    two for the two priority levels of Internet
- **Exogenous traffic high priority : fluctuations in bandwidth allocated to Hybrid Internet**
- **Self-similar traffic: Interactive users as ON-OFF processes**

NOC: Bandwidth Allocation Strategies

- **Comparison of Bandwidth allocation strategies**

Buffer per Connection	500 packets
Total Bandwidth	15 packets/unit time
Number of Connections	5 connections
Constant Arrival Rate	10 packets/unit time
Mean of the Uniform Arrival Rate	5 packets/unit time
Delay Imposed to Queued Packets	0.1 unit time

Common Input Data

Conn1:	1.4469	1.4468	0.0
Conn2:	2.0720	2.0720	0.5298
Conn3:	1.6941	1.6689	0.204
Conn4:	2.0541	2.0524	0.0741
Conn5:	1.7182	1.7088	0.8847
	EB	FB	MDQSF

Average Delays

- **All strategies: controller knows (per connection) queue status**
- **Three strategies investigated:**
  - **Equal Bandwidth allocation (EB)**
  - **Fair Bandwidth allocation (FB)**
  - **Most Delayed Queue Served First Bandwidth allocation (MDQSF**
- **MDQSF is best**

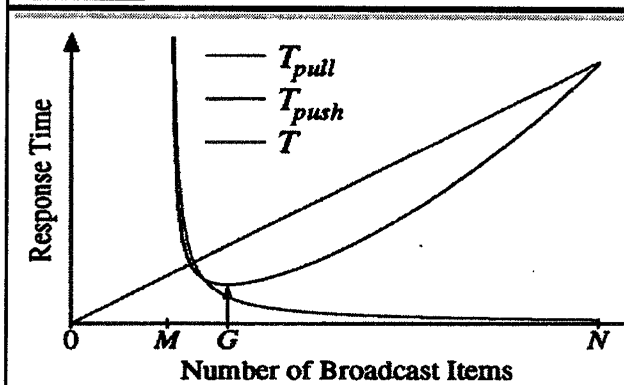
DBS-based Internet Access: IP Multicast and Enhancements

- **Two IETF WGs: TCP over Satellite and Unidirectional Internet routing**
- **Intelligent asymmetric data transmission**
  - **Two types of traffic (depending on threshold T bps):**
    - Low data-rate (or "short length") via terrestrial
    - High data-rate (or "bulky") via satellite
- **Terrestrial LAN extension of DBS-based Internet**
  - Distribute DBS services from a single receiver out to multiple users, thus reducing cost
  - Satellite hybrid hosts can redistribute data to mobile users
  - "Local loop" anything: Ethernet, ATM, cable TV, wireless

Hybrid Data Delivery

- **Objective: deliver needed data with minimum delay to very large numbers of users**
- **Pure data broadcast ("push"):**
  - Passive users; Accessed concurrently by any number of users
  - Limitation: users wait for data of interest to appear
  - Access latency depends on volume of broadcast data
- **Pure unicast ("pull"):**
  - Active users; Cannot scale beyond capacity of server and network
  - Access latency depends on aggregate workload and network load
- Ammar and Wong (1985), Wong (1988); teletext, videotex
  Gifford (1985, 1990); community information services (Boston)
  Imielinski and Badrinath (1994), Franklin and Zdonik (1996); wireless communications and mobile computing

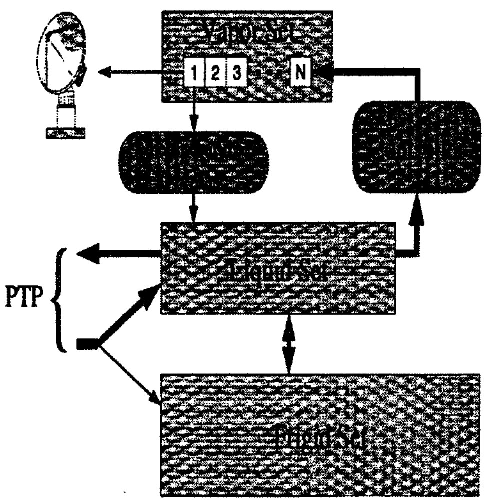
Hybrid Data Delivery Model



- DB contains N items of equal size S
- Demand for i^{th} item : Poisson ; rate λ_i
  $\lambda_1 > \lambda_2 > \ldots > \lambda_N$
- Server M/M/1; mean service time = $1/\mu$
- Server can broadcast at rate B

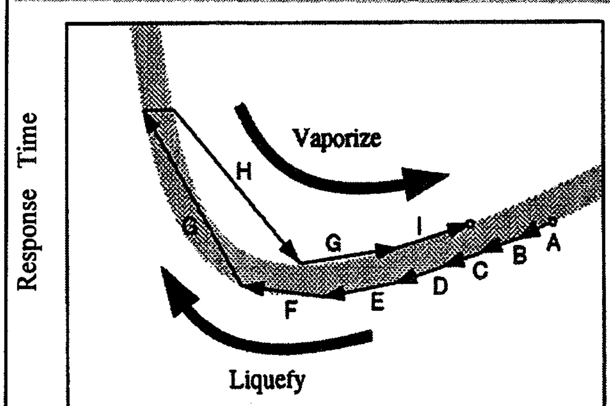
- Broadcast n first items ; On-demand N-n items; $\Lambda_k = \Sigma_1^k \lambda_i$
- Expected response time for requests : $T_{pull} = 1/(\mu-(\Lambda_N - \Lambda_n))$; $T_{push} = nS/2B$
- Expected response time for hybrid : weighted average of T_{pull} and T_{push}

Adaptive Repetitive Data Broadcast



- Size and content of broadcast continuously updated; Not fixed schedule
- Queue storing vapor data: V
- Item broadcast appended to tail of V and its temperature reduced by <u>*Cooling Factor*</u>
- Contents of V modified every cycle defined by a placeholder
- Notification on to-be broadcast items by broadcasting index: <u>*the signature of V*</u>

Two-Phase Algorithm to Update Broadcast Queue Contents



Λ_V

$\lambda_A \leq \lambda_B \leq \lambda_C \leq \lambda_D \leq \lambda_E \leq \lambda_F \leq \lambda_I \leq \lambda_G \leq \lambda_H$

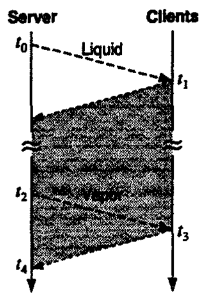
Vapor : A, B, C, D, E, F, G ; Liquid: H, I

- Sort items by their temperature
- Demote to liquid all vapor data with temperature < hottest liquid item
- Marginal gains :

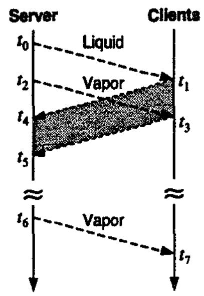
(2a) Demote vapor items in increasing order of temperat. while $\theta > \theta_0$

(2b) Promote liquid items in decreasing order of temperat. while $\theta < \theta_0$

Temperature Probing



Without probing



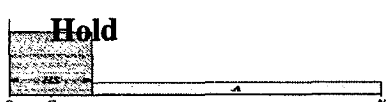
With probing

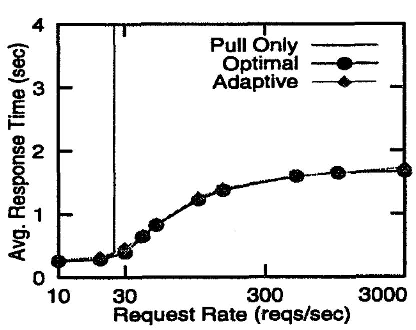
- Critical factor: probing interval $[t_0, t_2]$
- Probing time = <u>*Probing Factor*</u> *x* (N_V / Λ_V)

- **Avoid premature demotion of a very hot item**
- **Temperature probing :**
  - **After demotion at t_0**
  - **Re-promote at time t_2**
  - **Creates small window for re-evaluation: probe the temperature of the item**

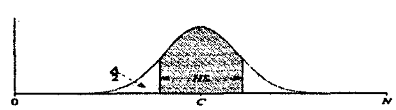
Performance Evaluation: Static Workloads

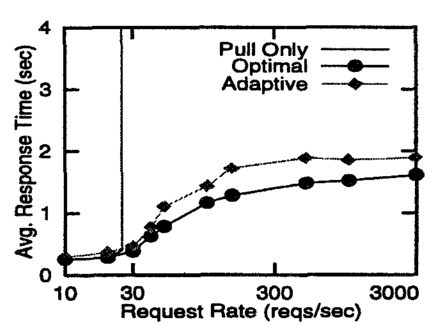
Hold-Cold Uniform





Gaussian





Performance Evaluation: Simulation Experiments

- **Parameters:**
  - **Broadcast and down link rates: 12 Mbps**
  - **Uplink rate: 28.8 kbps**
  - **DB has 10,000 items, each 50 kB in size**
  - **System's pull capacity μ : 30 items/sec**
  - **Vary workload from light ($RR < \mu$) to heavy ($RR = 100\,\mu$)**
- **Response time depends only on hot-spot size (100 items) (not on workload intensity**
- **Scalability increased by two orders of magnitude**

Acknowledgements

- **The work on Hybrid IP Multicast is joint with my student I. Secka.**
- **The work on Flow Control and Bandwidth allocation for Hybrid Internet is joint with my student G. Olariu.**
- **The work on Adaptive Hybrid Data delivery is joint with my colleague Professor N. Roussopoulos and our student K. Stathatos.**
- **For additional related papers/reports see: http://www.isr.umd.edu/CSHCN**

Advanced Communications Technology Satellite

NASA Lewis Research Center

Cleveland, Ohio

ACTS

Experiment 118x

Where WDM, SONET, ATM, and TCP/IP come together

David R. Beering
Infinite Global Infrastructures, LLC
On contract to Sterling Software
630-665-1396
drbeering@sprynet.com

What is 118x?

- 118x is the latest in a series of "118" experiments, designed to study the optimization of TCP/IP and ATM protocols over geostationary distances across multiple operating environments using NASA's Advanced Communications Technology Satellite (ACTS)
- Experiment 118j ran from August to November, 1997 using and focused on Sun's Solaris 2.6 TCP/IP implementation
- Experiment 118x operates during May-September, 1998
- The satellite link operates at 622 Mbps (OC-12c) between Livermore, CA and Cleveland, OH

118x Experiment Goal

- To develop a recognized, interoperable, high-performance TCP/IP implementation across multiple operating platforms working in partnership with the computer industry
- To work with the satellite industry to answer outstanding questions regarding the use of standards (TCP/IP and ATM) for the delivery of advanced data services, and for use in spacecraft architectures

118x Experiment Participants

Government Laboratories

- NASA Lewis Research Center
- NASA Johnson Space Center (SOMO)
- NASA Jet Propulsion Laboratory
- Lawrence Livermore National Laboratory NTONC Lead
- Naval Research Laboratory

118x Experiment Participants
Communications Industry

- Ampex Data Systems (DIS-160 Tape Systems)
- Cisco Systems (LS-1010 ATM Switches)
- FORE Systems (ASX-1000 ATM Switches)
- Sprint (Laboratory space, terrestrial network)

118x Experiment Participants
Computer Industry

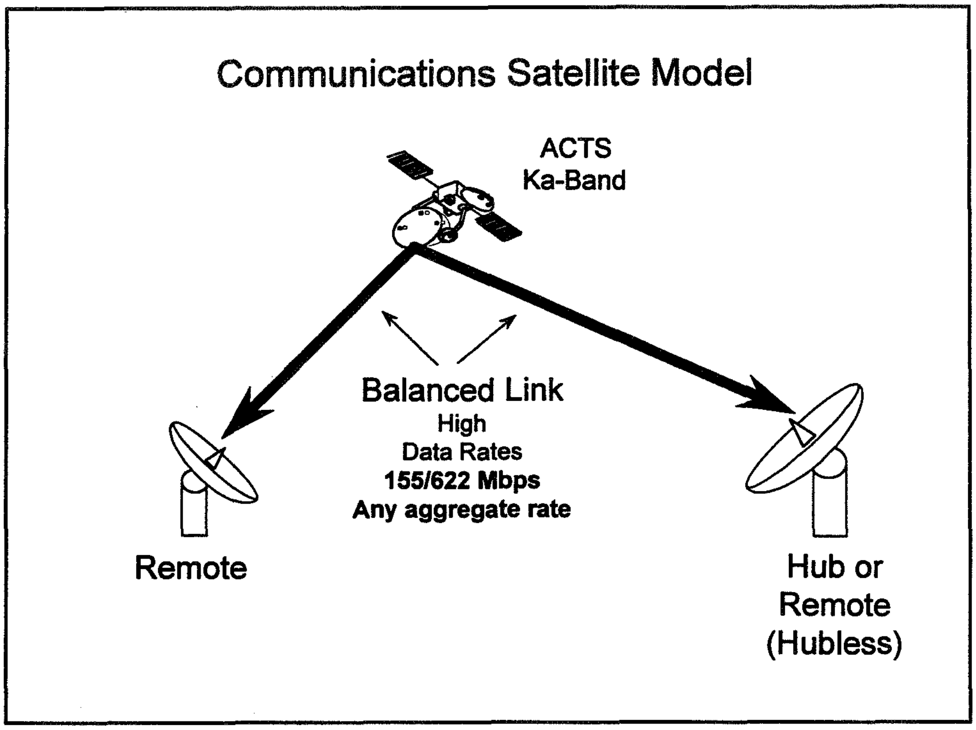
- Sun Microsystems (Solaris 2.7, Ultra workstations)
- Microsoft (NT 4.0, NT 5.0)
- Digital Equipment (DEC Unix 4.3, DEC Alphas)
- Pittsburgh Supercomputing Center (Integration)
- Intel (Pentium II Development Systems)

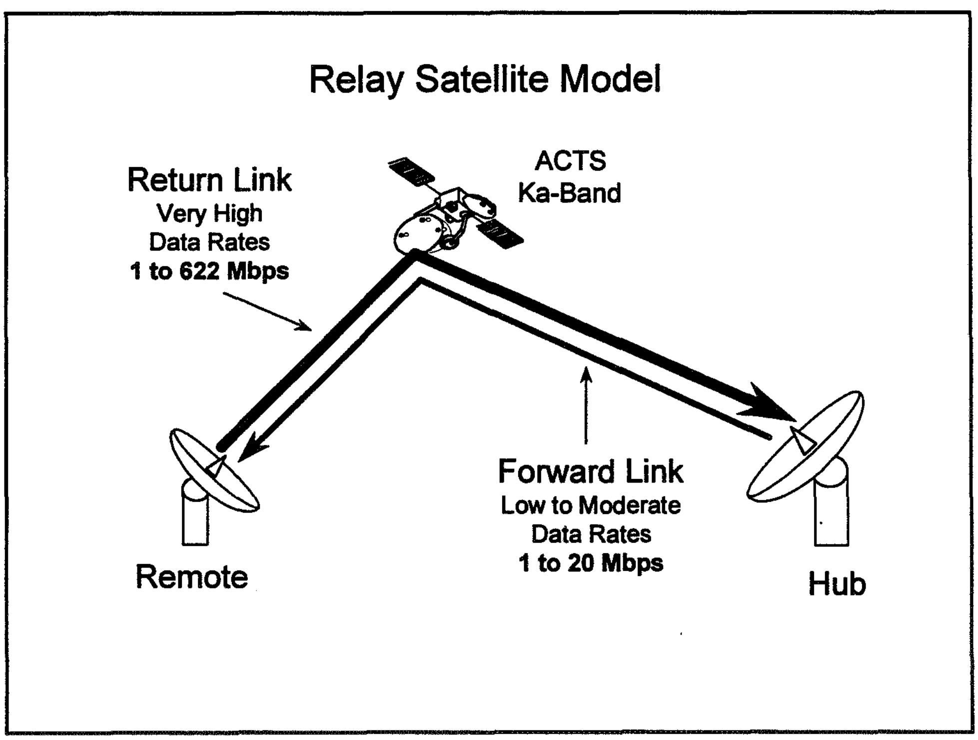
118x Experiment Participants
Satellite Industry

- Hughes Space & Communications
- Lockheed Martin Corporation
- Space Systems / LORAL
- Spectrum Astro

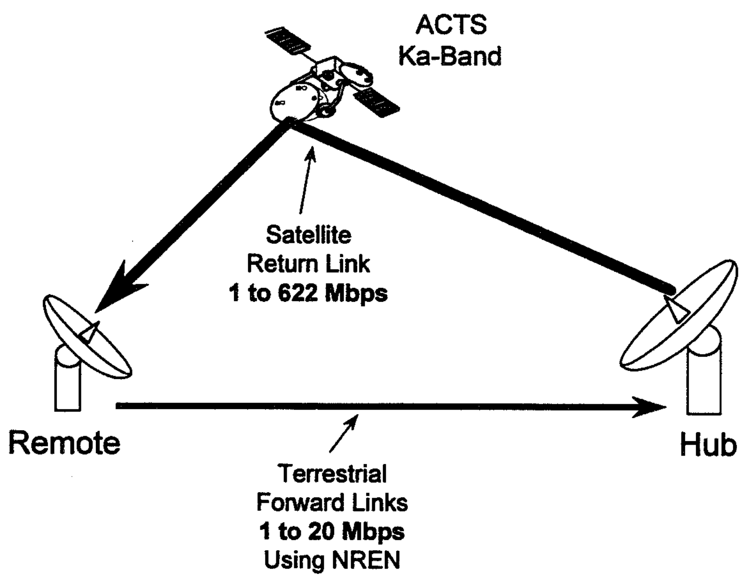
Introducing NASA's Advanced Communications Technology Satellite

The world's best satellite system simulator!


Communications Satellite Model
ACTS
Ka-Band
Balanced Link
High
Data Rates
155/622 Mbps
Any aggregate rate
Remote
Hub or
Remote
(Hubless)


Relay Satellite Model
Return Link
Very High
Data Rates
1 to 622 Mbps
ACTS
Ka-Band
Forward Link
Low to Moderate
Data Rates
1 to 20 Mbps
Remote
Hub

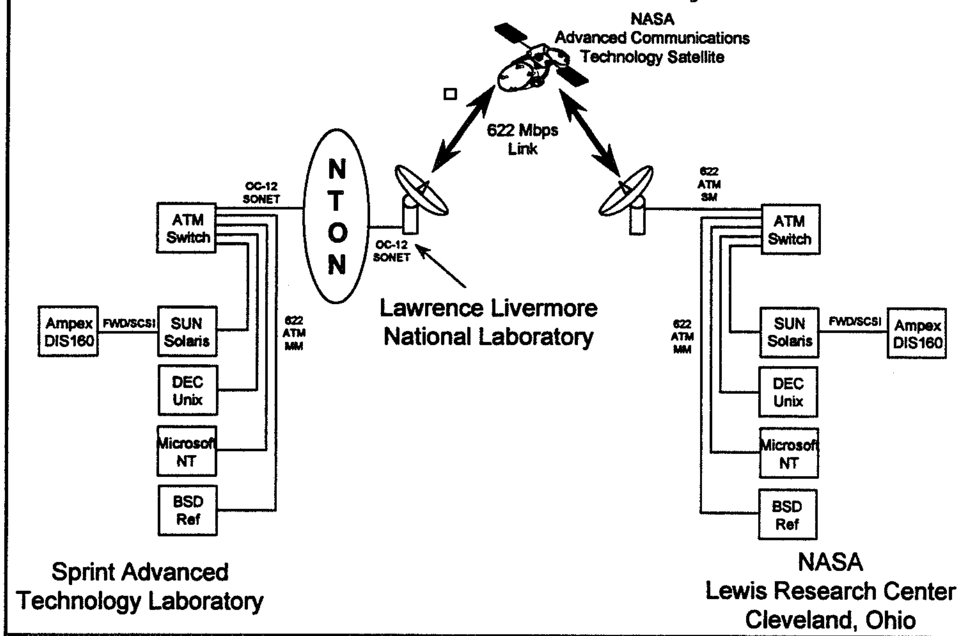
Digital Broadcast Satellite (DBS) Model



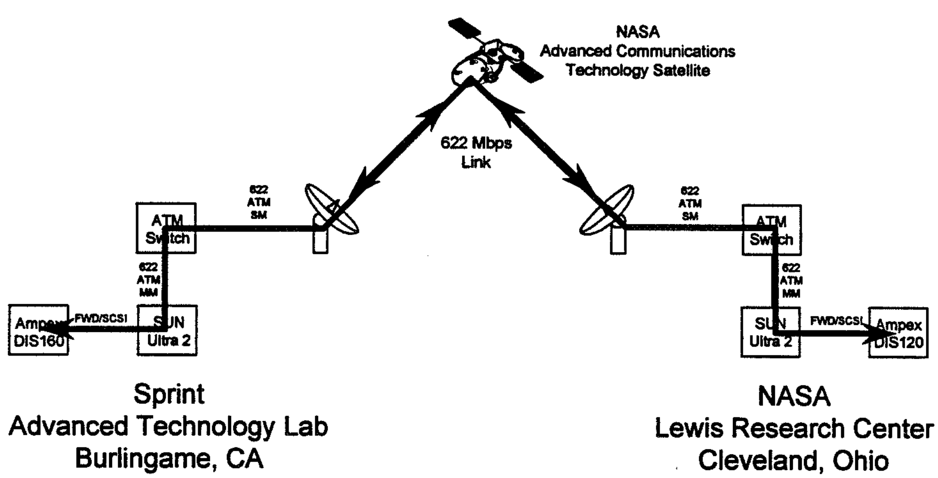
118x Participating Sites

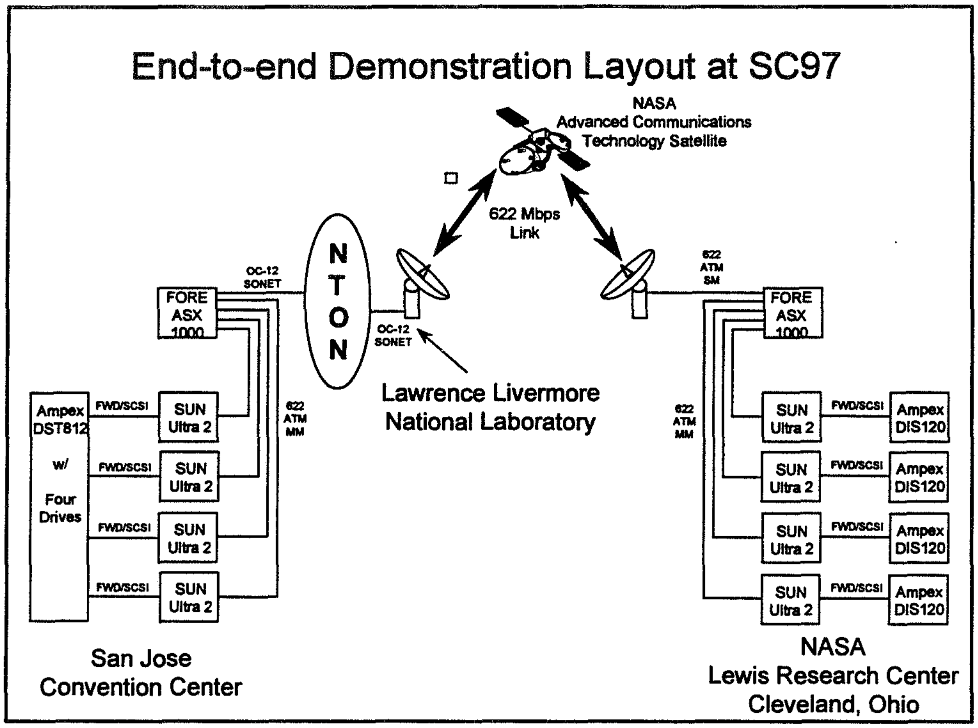
- NASA Lewis Research Center (LeRC) - Cleveland, OH
- Lawrence Livermore National Laboratory (LLNL) - Livermore, CA
- Sprint Advanced Technology Laboratory (ATL) - Burlingame, CA

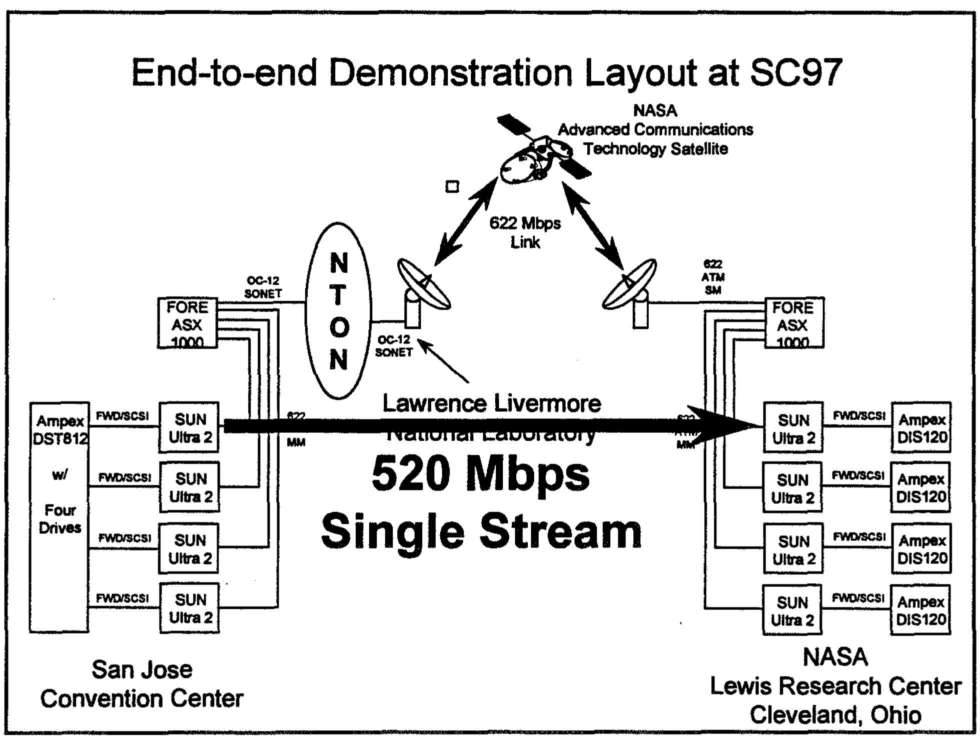
118x End-to-end Network Layout



High-Speed Magnetic Tape Test




End-to-end Demonstration Layout at SC97
NASA
Advanced Communications
Technology Satellite
622 Mbps
Link
NTON
OC-12
SONET
FORE
ASX
1000
OC-12
SONET
622
ATM
SM
Lawrence Livermore
National Laboratory
622
ATM
MM
Ampex
DST812
w/
Four
Drives
FWD/SCSI
SUN
Ultra 2
Ampex
DIS120
San Jose
Convention Center
NASA
Lewis Research Center
Cleveland, Ohio


End-to-end Demonstration Layout at SC97
NASA
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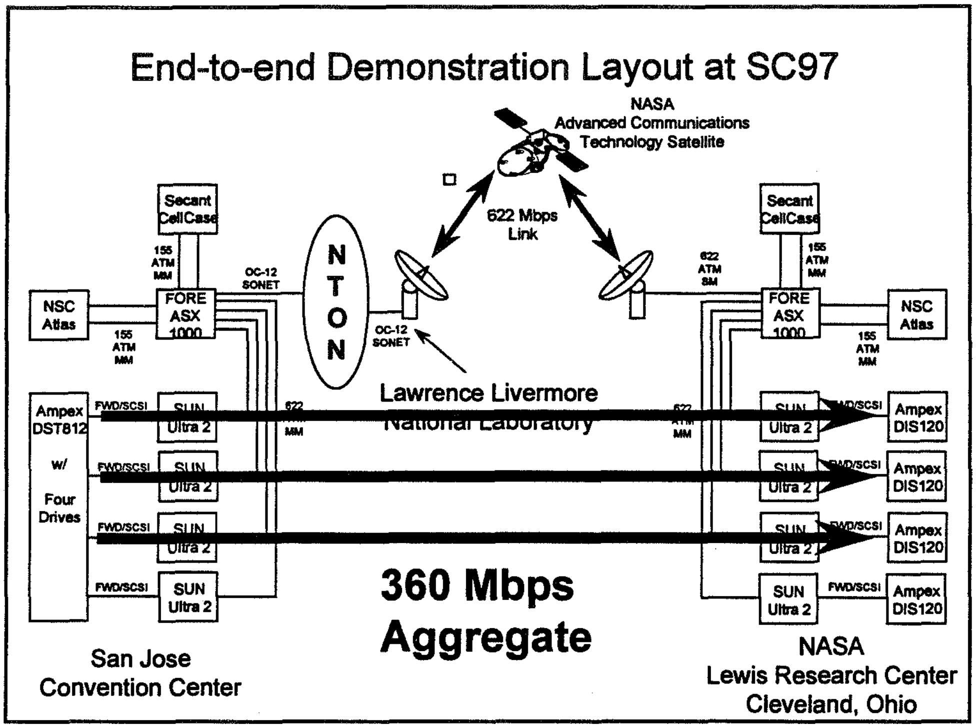
SM
Lawrence Livermore
Ampex
DST812
w/
Four
Drives
FWD/SCSI
SUN
Ultra 2
Ampex
DIS120
520 Mbps
Single Stream
San Jose
Convention Center
NASA
Lewis Research Center
Cleveland, Ohio


End-to-end Demonstration Layout at SC97
NASA
Advanced Communications
Technology Satellite
622 Mbps
Link
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Drives
FWD/SCSI
SUN
Ultra 2
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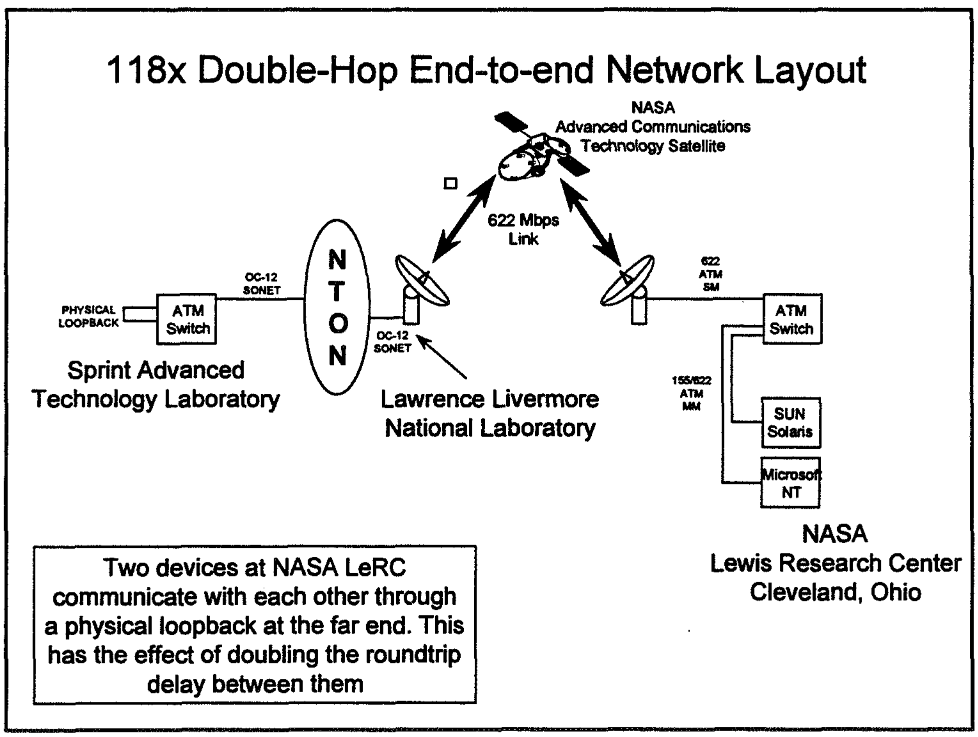
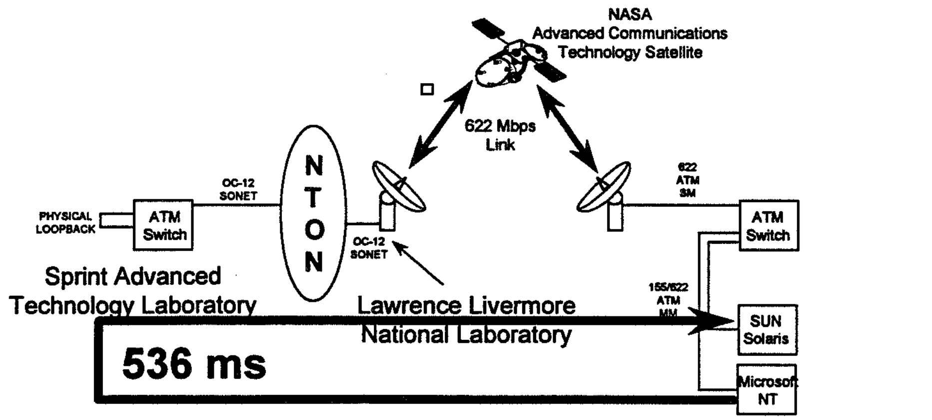
Lawrence Livermore
National Laboratory
622
ATM
SM
360 Mbps
Aggregate
San Jose
Convention Center
Ampex
DIS120
NASA
Lewis Research Center
Cleveland, Ohio


118x Double-Hop End-to-end Network Layout
NASA
Advanced Communications
Technology Satellite
622 Mbps
Link
OC-12
SONET
PHYSICAL
LOOPBACK
ATM
Switch
Sprint Advanced
Technology Laboratory
N
T
O
N
Lawrence Livermore
National Laboratory
622
ATM
SM
155/622
ATM
MM
SUN
Solaris
Microsoft
NT
NASA
Lewis Research Center
Cleveland, Ohio
Two devices at NASA LeRC communicate with each other through a physical loopback at the far end. This has the effect of doubling the roundtrip delay between them

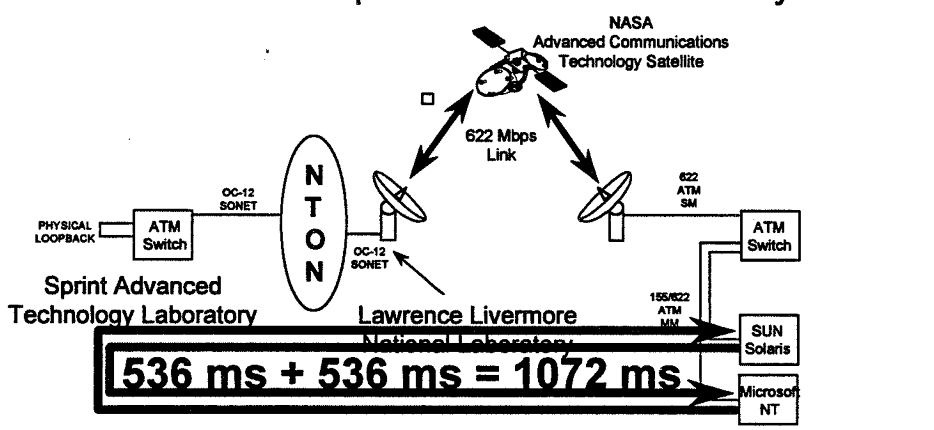
118x Double-Hop End-to-end Network Layout



NASA
Lewis Research Center
Cleveland, Ohio

Two devices at NASA LeRC communicate with each other through the physical loopback at Sprint. This has the effect of doubling the roundtrip delay between them

118x Double-Hop End-to-end Network Layout



NASA
Lewis Research Center
Cleveland, Ohio

Two devices at NASA LeRC communicate with each other through the physical loopback at Sprint. This has the effect of doubling the roundtrip delay between them

118x Plans

- Complete first phase workplan by end of September, 1998
- Demonstrate - demonstrate - demonstrate
- Leverage relationships and technology base to further the state-of-the-art in high-speed satellite applications using standard protocols
- Apply the technology to NASA's unique data handling problems using TDRSS
- Leverage the architecture for space commercialization

Industry Challenges

- Incorporate error-recovery techniques (like those found in SCPS) into TCP/IP
- Demonstrate these capabilities to broader audiences
- Implement the technology to lower the cost of building and delivering advanced applications

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Internet over a Bi-Directional Satellite Link

Jim Griner
Mark Allman
Paul Mallasch
David Stewart

Satellite Networks: Architectures, Applications, and Technologies Workshop
June 2-4, 1998

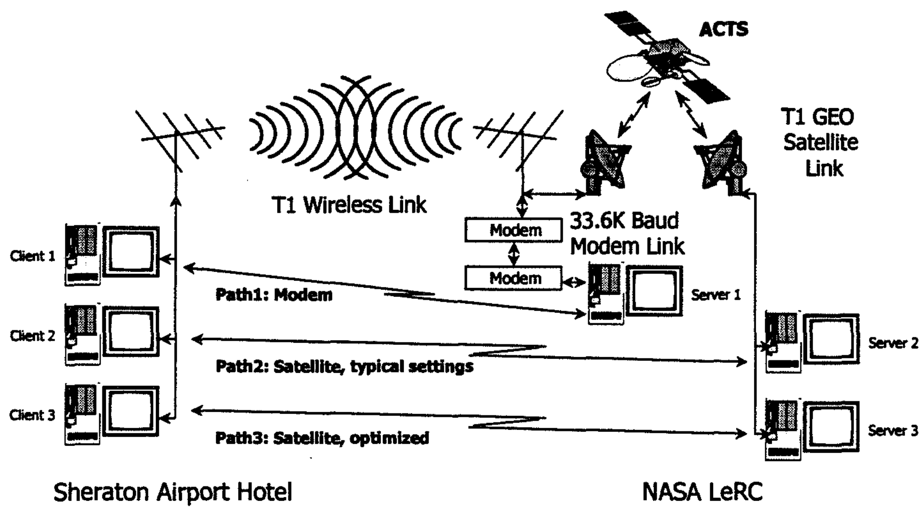
Internet over a Bi-Directional Satellite Link

- Comparison of HTTP over several network channels
  - 33.6k modem connection
  - Satellite connection, standard TCP stack and typical application settings
  - Satellite connection, optimized for satellite networks
    - larger window sizes
    - larger initial congestion window
    - TCP bug fixes
    - new versions of the HTTP protocol
- By using appropriately tuned applications and TCP settings, we demonstrate improved performance of HTTP when compared to today's off-the-shelf software

Optimizations are based upon findings from experiments conducted between satellite research networks at NASA Lewis Research Center and Ohio University.

Internet over a Bi-Directional Satellite Link

Demonstration Setup



Internet over a Bi-Directional Satellite Link

- HTTP Comparison Pages
  - 20 pages gathered from several Ohio related sites
  - Pages with varying attributes
    - Number of images from 1 to 27
    - Image sizes from 177 bytes to 360 kilobytes
- Demonstration setup in Dulles
  - Three computers, one for each of the network channels
  - Pages are synchronized to start at the same time
  - The computers will pause for one minute, before moving on to the next page
  - The 20 pages will repeat continuously, for the duration of the workshop

Plenary Session

TCP over Satellite: Issues, Relevance, and Experience

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Does TCP Work over Satellite Links or Not?

Dr. Craig Partridge
BBN Technologies

The Puzzle

- TCP was designed to work over satellites
  - the goal of the research project that created TCP was to link SATNET and ARPANET
- TCP's theoretical maximum data rate is 15 Gb/s
  - faster than any satellite link
- So why do people feel TCP doesn't work over satellites?

The Reasons

- Bad reasons
  - out of date implementations
  - misconfigured TCPs
  - poor testing technique
- Good reasons
  - high bandwidth
  - TCP startup delays

Out of Date Implementations

- TCP, as specified in 1981, had limitations
  - max data rate of 1 Mb/s over GEO link
  - 286 Mb/s overall max
- Limitations repaired in early 1990s
  - PAWS and big windows
  - max data rate now 15 Gb/s over GEO
  - 8 Tb/s overall max
  - make sure you're up to date!

Misconfigured TCPs

- An up-to-date implementation doesn't help if you don't configure it
- Many TCPs shipped with 64KB maximum window size
  - 64KB/250ms is 2 Mb/s
- Must turn on PAWS and large windows and set default window to be large!

Bad Testing

- Lots of people test performance by taking TCP, out of the box, and FTPing a megabyte of data
- That's stupid
  - TCP may be misconfigured
  - 1 MB is far too small for anything but a LAN
- Configure the TCP, then transfer a gigabyte

High Bandwidth

- Moving from 56 Kb/s links to megabit links has implications
  - more data in flight (more sender effort to fill the pipe)
  - error rates must go down proportionately
  - big transfers get most of the benefit

Big Transfers Get Most of the Benefit

- Faster isn't really faster
  - speed of light says a 1 bit pulse takes the same time it always did
  - faster really means bits are thinner on the wire
- Big transfers win; small transfers don't
  - big transfers get all their bits on the line sooner
- Web transfers are small...
  - transfer time dominated by transmission delay

TCP Startup Delays

- On startup, TCP probes a link to learn how much capacity is available
  - goal is to avoid overloading network; and
  - fairly sharing with existing connections
- Startup time depends on delay and bandwidth
  - on a GEO at 155 Mb/s, it takes 11+ seconds
  - first 20 GB are sent during this probe stage

How Do We Go Forward?

- Recognize that terrestrial guys have the same problem with startup
- So look for general solutions
  - Hoes' algorithm
  - pacing
- Avoid link-specific algorithms
  - spoofing

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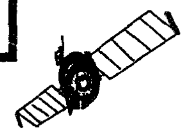

TCP OVER SATELLITES
ISSUES, RELEVANCE, & EXPERIENCE

Norm Butts
Manager, ITC Systems Engineering
Lockheed Martin Telecommunications

Interactive Technology Center
Norm Butts (408) 543-3021

06/02/98

Lockheed Martin Telecommunications

TCP Relevance

(Why is Lockheed Martin Interested in TCP over Satellite)

TCP over Satellite Applications:

- *GEO Fixed Satellite Services*
  - *Internet Service Providers (wholesale)*
  - *Satellite Internet (retail)*
  - *Private Networks (VSAT)*
- *GEO Mobile Telecom Satellites*
  - *email/internet add-on services*
- *GEO Direct Broadcast Satellites*
  - *DVB based Internet add-on Services*
- *GEO Broadband Satellites*
  - *Astrolink*
  - *Other Ka Band Systems*

Many customers are looking for pre-integrated applications

Bottom line: applications drive satellite sales

Interactive Technology Center
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06/02/98

Lockheed Martin Telecommunications

Astrolink Environment

Characteristics:

- *Nine GEO satellite constellation at five locations*
- *Frequency: Ka Band, 20GHz (downlink) 30Ghz (uplink)*
- *Terminal Bandwidth: SOHO - 384 Kb/S, Med. Enterprise - 2.3 Mb/S, Large Enterprise - 9.2 Mb/S*
- *Format: ATM, Multi-Frequency TDMA, DAMA*
- *Latency (Round Trip) ≈ 500 ms (one hop) to ≈1.6s (worst case three hop)*

Performance of Today's TCP implementations

- *Win 95 40 Kb/S (3 hop) to 128 Kb/S (1 hop)*
- *UNIX - Many are "tunable" for better satellite performance but default to similar performance levels*

Conclusion: Today's TCP implementations fall short of needed performance

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TCP Satellite Performance Improvement Issues

Improved End to End TCP Implementations

- *Many improved alogrithms are available or on the way*
- *Implementation by major O/S suppliers is the big question*
- *Fairness issue cannot be resolved without major changes*

Transparent Gateways/Proxies (AKA Spoofing)

- *Works with existing TCP implementations*
- *Can overcome fairness problem*
- *Has been used with success in unidirectional satellite w/ dial-up return channel*
- *Implementation is difficult and risks possible side-effects*
- *Lockheed Martin is working on a proof-of-concept bi-directional gateway*

ATM Issues

- *Further research on TCP/ATM interaction is required*

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Norm Butts (408) 543-3021

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Mixing TCP And Satellites: A View From Above

(Irreverent Confessions From The Standards Trenches)

NASA LeRC Workshop on Satellite Networks
Cleveland, Ohio
June 2, 1998

Eric Travis /NASA Jet Propulsion Labs (e.j.travis@ieee.org)

SCPS

Why Are Open Protocol Standards Important?

- **The Vision:**
  - **Cheaper, better, faster**
  - **Risk reduction & stability**
  - **Interoperability**
  - **Efficiency**
- **Potential Problems In Realizing The Vision:**
  - **Broad applicability not recognized**
  - **Flexibility contends with simplicity**
  - **Deployment into an installed base**
- **Do You Get A "Big Tent" Solution Or Just A "Big Top" Oddity?**
  - **Candor, industry participation and feedback will make the difference**
- **A Parable For Our Times: Should The Tail Be Wagging The Dog?**

SCPS

Space Mission Operations Standardization Program
National Aeronautics and Space Administration

Protocols Are Like Galoshes: One Size Does *Not* Fit All

- **The Dynamic Range Of Network Environments Is Larger Than Ever**
  - **Satellite networks mirror the full spectrum: wireless to fiber, mobile to static**
  - **Environments are Opaque: "On the Internet, nobody knows you're In orbit"**
- **You Probably Own Only Part Of The Railroad**
  - **Actions at a distance can affect your bottom line performance**
    - **TCP Loss recovery is expensive and retransmissions are not always free**
    - **Loss recovery is inherently unfair to long(er) paths**
  - **Localized performance tuning keeps the trains running on-time**
    - **Spoofing and proxies: The benefits of impedance matching**
    - **Balancing security, transparency and the end-to-end argument**
- **Seamless Integration Is A Matter Of Perspective (Theory and Practice)**
- **Bottom line For Performance And Efficiency In The Near Term:**

Tailor Your Solutions, Do So With *Standardized* Mechanisms Appropriate To The Environment

SCPS

Session 1
TCP/IP over Satellites

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Performance Analysis of the HTTP Protocol on Geostationary Satellite Links

Hans Kruse
Ohio University
Mark Allman
NASA LeRC/Sterling Software
Jim Griner, Diepchi Tran
NASA LeRC

NASA Workshop June 2-4, 1998:
Satellite Networks: Architectures, Applications, and Technology

Overview

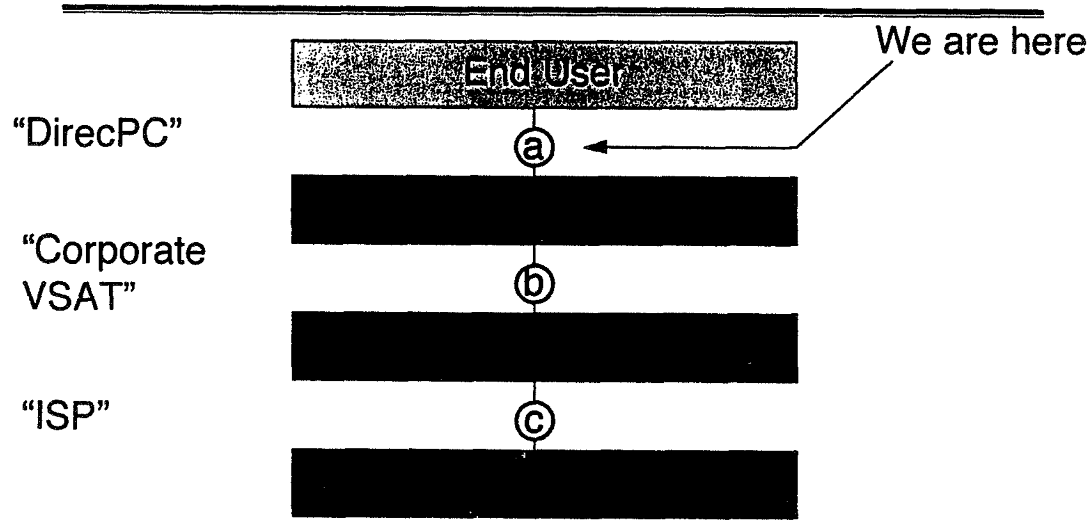
- Network Reference Points
- The HTTP 1.0 and 1.1 Mechanisms
- Experimental Setup
- TCP and HTTP Configuration
- Results and Future Work

Why HTTP

- The Obvious Answer:
  "Millions of Web Browsers..."
- The not-so-obvious Answer:
  - HTTP is a very generic multi-file transfer protocol with content/encoding awareness
  - Very well optimized HTTP servers are available
  - HTTP contains intrinsic proxy support mechanisms that allow regional caching of data

3

Network Reference Points



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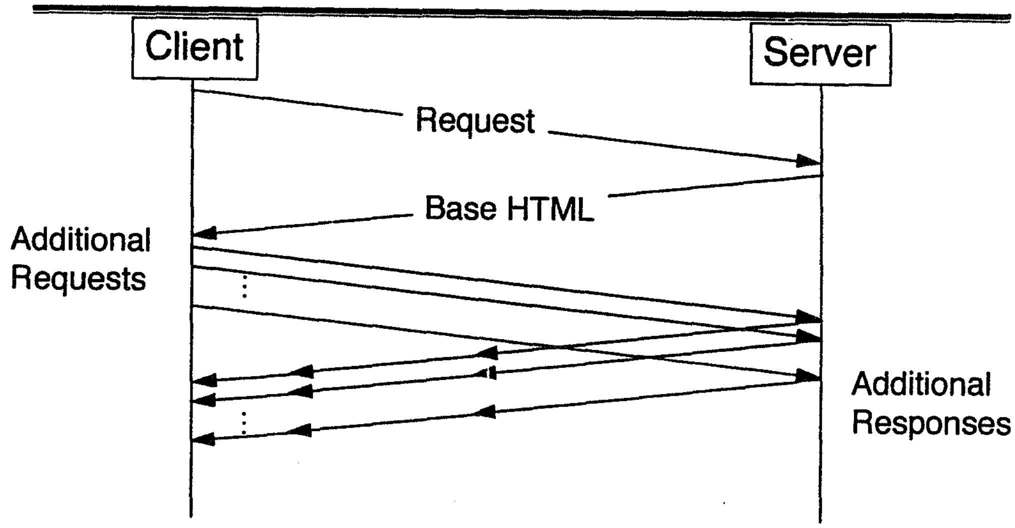
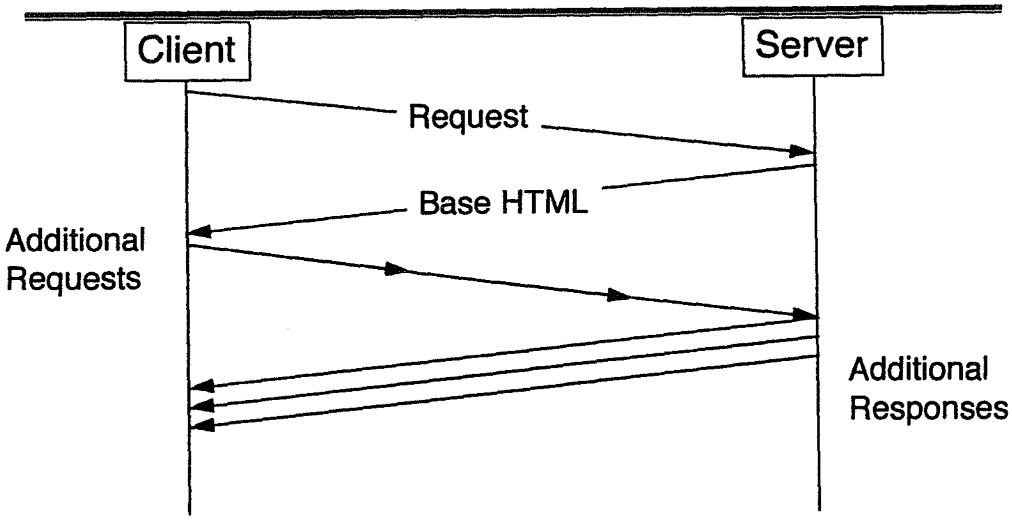
Reference Points cont...

- Interface "a"
  - Very small number of users
  - Traffic is bursty, user wants good response time, protocols dominate performance
- Interfaces "b" and "c"
  - Large and varying number of users
  - Traffic is more random, performance depends on protocols and congestion control; fairness is desirable

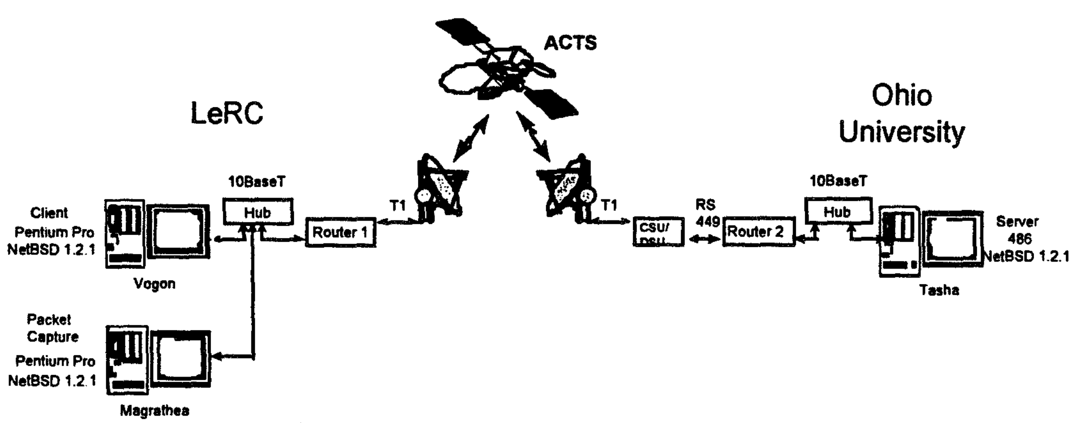
The HTTP 1.0 Mechanism



The HTTP 1.1 Mechanism



The Experimental Setup



TCP Configuration

- Standard BSD "reno" stack
- Large window support (RFC 1323)
  - experiment uses 8, 16, 64, and 96Kbytes
- Bug fixes in the NetBSD stack
  - Initial window starts with one segment
  - Acknowledgments are generated according to the standard

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HTTP Configuration

- Apache Server (HTTP 1.0 and 1.1)
  - Persistent connections in HTTP 1.0
- Netscape browser
- Netscape allows multiple connections
  - experiment uses 1, 4, 8, and 16
- Experimental HTTP 1.1 client
- Increased initial TCP window support

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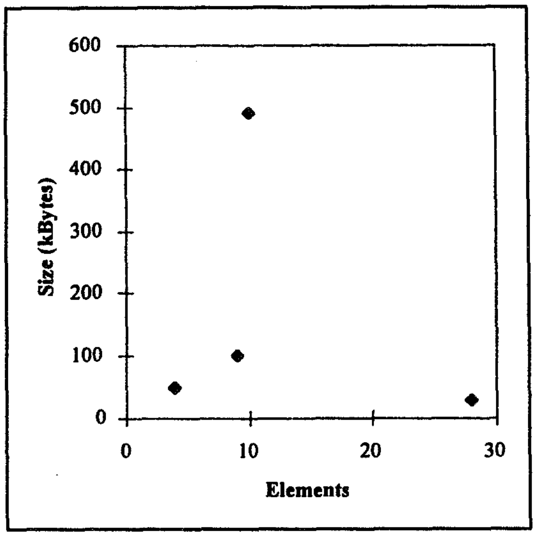
Web Pages



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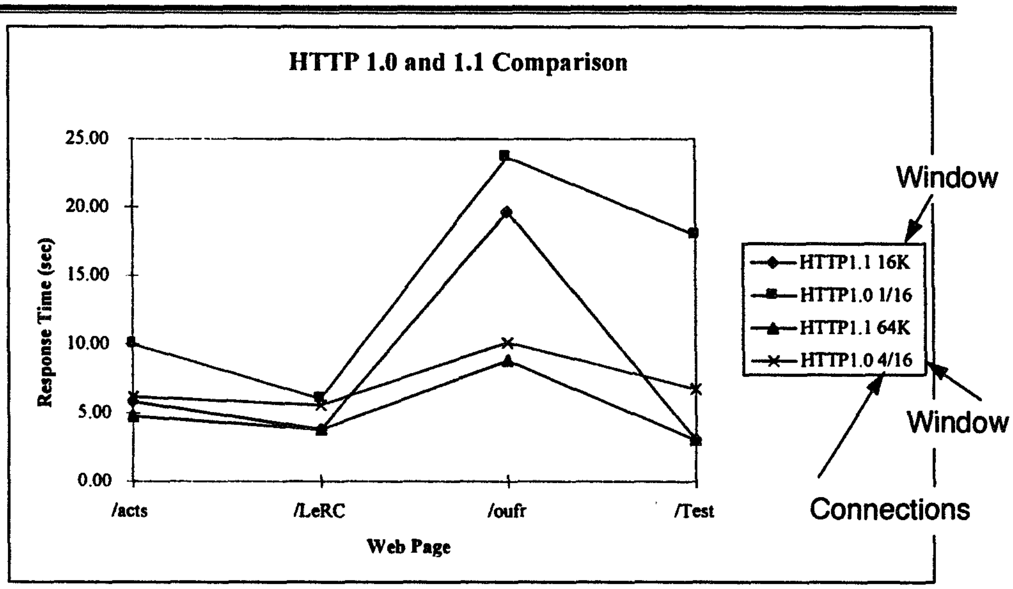
Comparing HTTP 1.0 and 1.1



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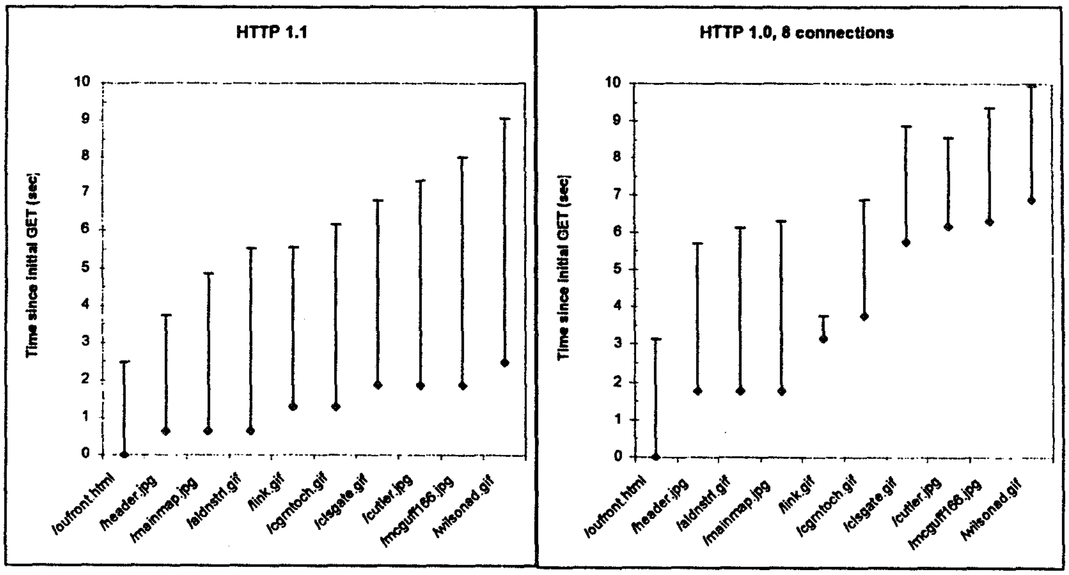
Data Flow Comparison



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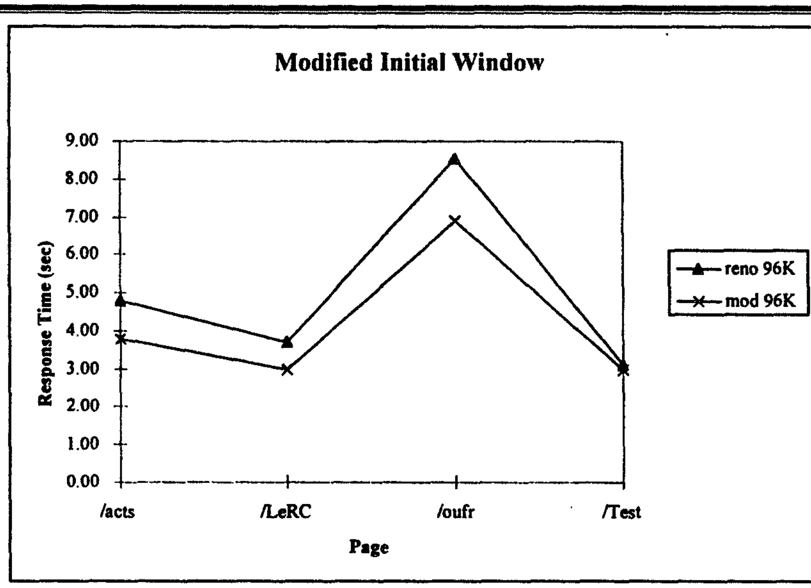
The Larger TCP Initial Window



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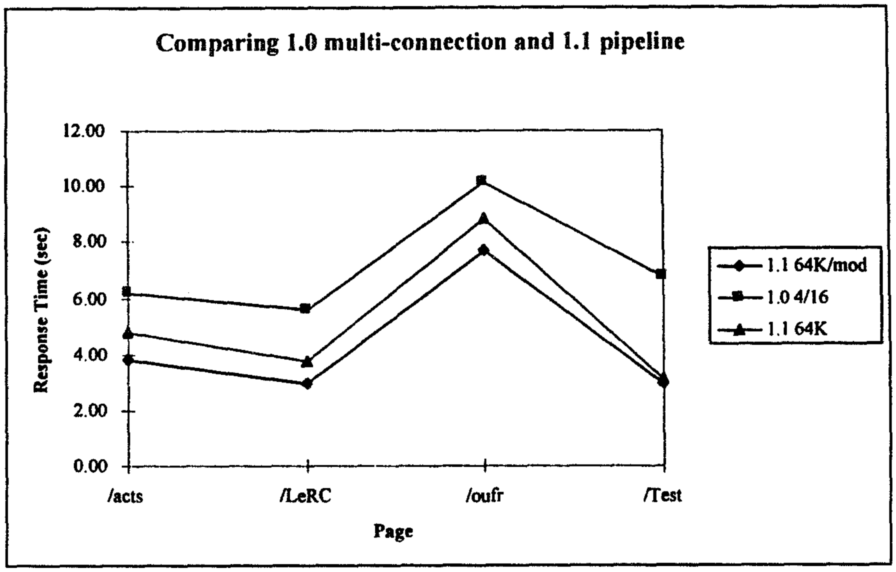
What settings are important?



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Modeling Slowstart

- Based on Heideman, et al. (IEEE Transactions on Networking Vol. 5, No. 5, Oct 1997.
- Slowstart creates an exponential increase in the data flow, up to the channel bandwidth
- Delayed acknowledgements change the rate of increase
- HTTP 1.0 requires a little extra work, results for HTTP 1.1 are shown here.

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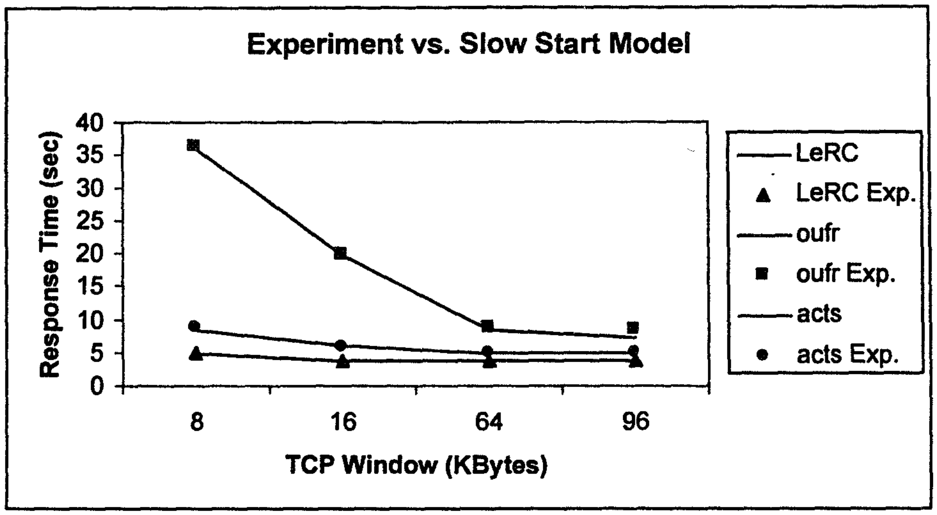
Are there unknown effects?



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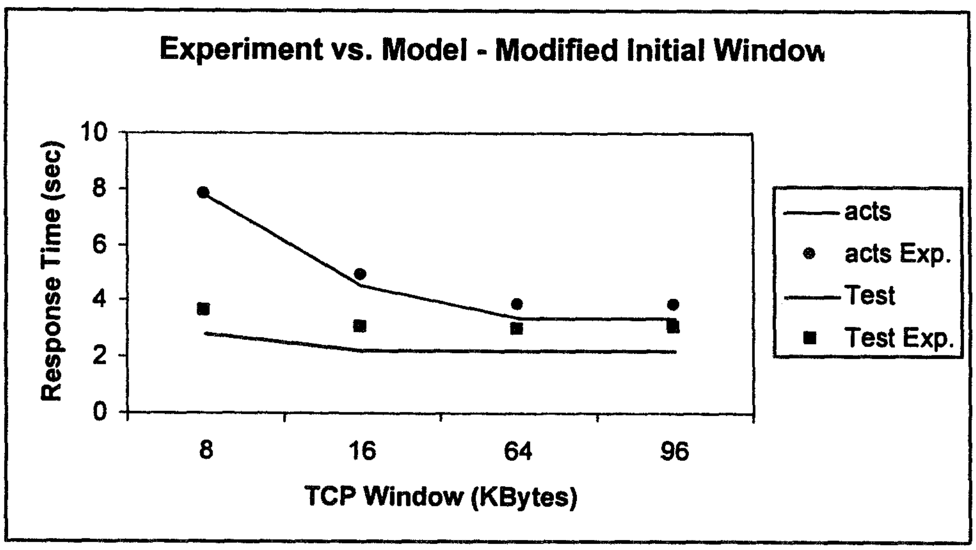
Maybe a few ...



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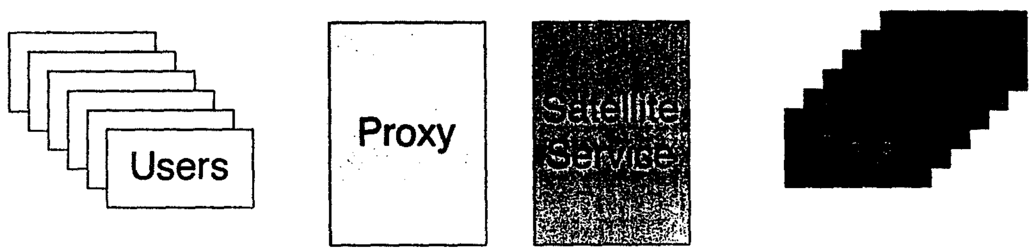
Implication for the Service Provider

Page	Best Time (sec)	Size (Kbytes)	Rate KB/Sec	Utilization	No. of Users
/acts	3.79	100	26.41	14%	7.1
/LeRC	3.00	49	16.36	9%	11.5
/oufr	6.89	491	71.23	38%	2.6
/Test	2.99	29	9.70	5%	19.3

Based on T1 (1.536Mbps) Service

Desirable Configuration:



Conclusions and Future Work

- HTTP 1.1 pipelining outperforms HTTP 1.0.
- Performance of HTTP 1.1 can be readily modeled.
- Pipelining will create new application level problems.
- Examine the reference points "b" and "c" by introducing competing background traffic with the TCP flow under study.

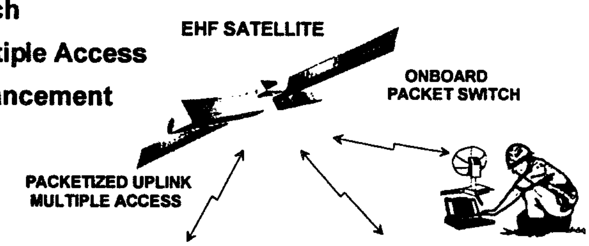
Performance Enhancement for TCP/IP over a Satellite Channel

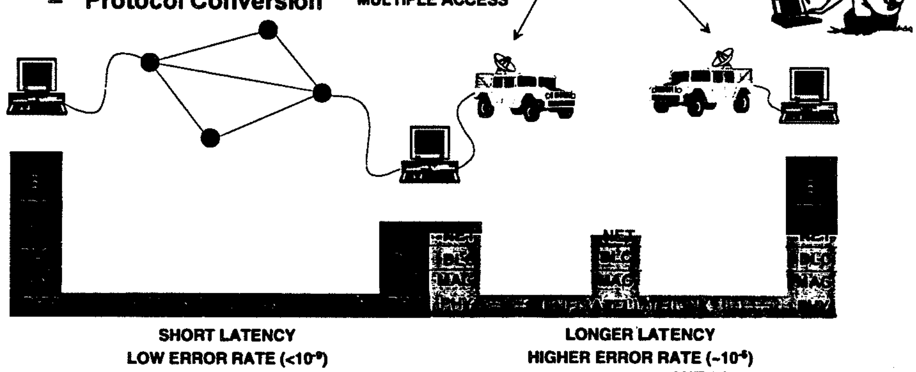
J. S. Stadler, J. R. Gelman, L. L. Jeromin

MIT Lincoln Laboratory

Satellite Data Communications Architecture

- On-board Packet Switch
- Packetized Uplink Multiple Access
- Satellite Protocol Enhancement
  - Standards
  - Link Layer
  - Protocol Conversion





Outline

- → Background - TCP via Satellite
- Lincoln Laboratory Link Layer Protocol
- Wireless IP Suite Enhancer
- Performance Results
- Summary

TCP via Satellite

- TCP operates over a large range of environments - sometimes at degraded levels of performance
  - Communication links may not be used efficiently
  - Reduced QoS as perceived by an interactive user
- In a satellite environment inefficiencies can be attributed to:
  - Latency
    GEO satellites have a minimum 0.52 second RTT
  - Bit Errors
    Satellite links can be made "error free" but a data rate penalty is incurred
  - Link Asymmetry
    Mobile/Portable terminals can typically receive much more data than they can transmit

Goals

- Transparency
  - User should not need to know that a satellite link is used
  - User should not have to follow special procedures
  - Perceived QoS should be acceptable
- Backward Compatibility
  - Approach should work with the existing network infrastructure
- Efficiency
  - Approach should make efficient use of the satellite link
- Scalability
  - Approach should scale to large systems/data rates
- Flexibility
  - Approach should be applicable with bent-pipe or processing satellites

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Existing Solutions

- Internet Engineering Task Force (IETF) Standards Track
  - TCP Extensions for High Performance (RFC 1323)
  - TCP Selective Acknowledgement Options (RFC 2018)
  - TCP Fast Retransmit/Fast Recovery (RFC 2001)
- Alternate Transport Protocols Designed for Satellite Environments
  - Satellite Transport Protocol
  - SCPS
  - XTP
- Special Purpose Link Layer Protocols
  - Lincoln Laboratory Link Layer
  - TCP Aware Link Layer

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Existing Solutions
(Cont)

- TCP 'Spoofing'
  - TCP ACKS are manipulated to reduce flow control effects
- TCP Splitting
  - TCP connection is terminated at the periphery of the satellite network
    - TCP/TCP
    - TCP/Other

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Outline

- Background - TCP via Satellite
- → Lincoln Laboratory Link Layer Protocol
- Wireless IP Suite Enhancer
- Performance Results
- Summary

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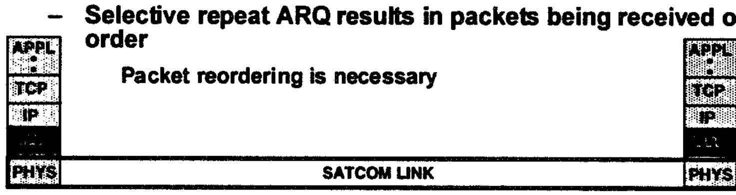
Lincoln Laboratory Link Layer Protocol

- **Link Layer protocol transparently conditions the satellite channel according to the TCP needs**
- **Approach**
  - **Get data flowing as quickly as possible**
    - Enable the TCP flow control algorithm to ramp up as quickly as possible
  - **Make sure data continues to flow**
    - Prevent the TCP flow control algorithm from reducing the transmission rate due to errors on the satellite link
    - Congestion on the terrestrial portion of the network will still result in a reduction in the transmission rate
  - **Correct errors in as efficient a manner as possible**
    - Efficient retransmission mechanism
    - Forward Error Correction

Lincoln Laboratory Link Layer Protocol: Implementation

- **Fragmentation**
  - **Decouples link layer packet size from the TCP segment size**
  - **Larger TCP segments allow data flow to ramp up more quickly without making the packets more susceptible to link errors**
- **Link Layer Selective Repeat ARQ**
  - **Hides link errors from TCP and prevents errors from being confused with congestion**
  - **Selective Acknowledgements are sent on a periodic basis**
    - Acknowledgements convey the entire receive buffer state
  - **Packets received in error are retransmitted K times**
  - **Selective repeat ARQ results in packets being received out of order**
    - Packet reordering is necessary



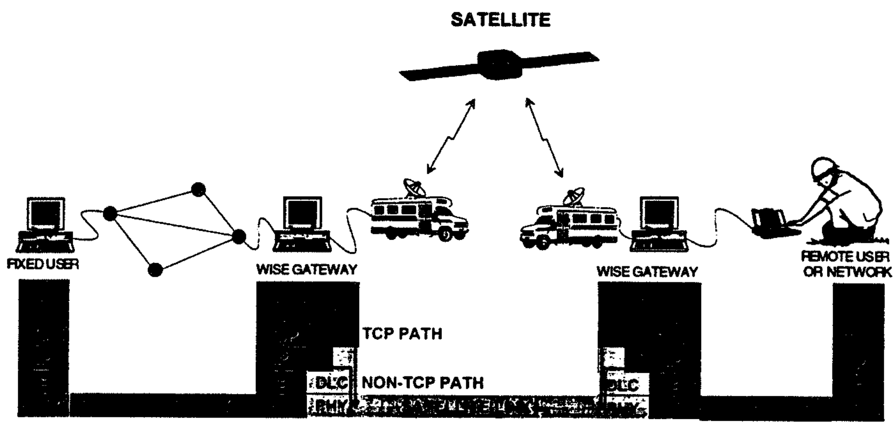
Outline

- TCP via Satellite
- Lincoln Laboratory Link Layer Protocol
- → Wireless IP Suite Enhancer
- Performance Results
- Summary

Wireless IP Suite Enhancer

- Users connect through a TCP translator at the boundary of the satellite portion of the network
  - Operates with no modifications to end user systems
  - Applications are unmodified
- Translator converts incoming TCP connections to Lincoln Laboratory Link Layer protocol
  - Error correction is performed locally on the satellite segment of the link
  - Peer translator will convert satellite protocol back to TCP
- IP packets not containing TCP packets are encapsulated in a link layer protocol (error correcting optional)

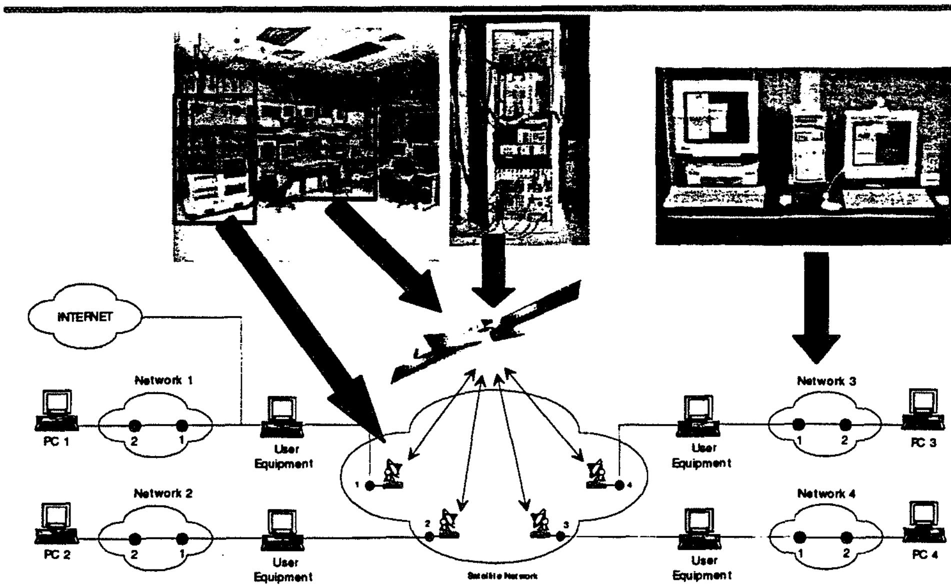
Wireless IP Suite Enhancer (WISE)



Outline

- Background - TCP via Satellite
- Lincoln Laboratory Link Layer Protocol
- Wireless IP Suite Enhancer
- → Performance Results
- Summary

EHF Networking Test-bed



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Test Results

- **Test scenario**
  - 100 Kbps link
  - 10^{-5} error rate
  - ~2048 bit packets (nominal) over satellite link
  - 1 Sec RTT delay
  - WWW applications
  - Configurations

    TCP - optimized TCP parameters

    TCP/LLLL - default TCP parameters

    TCP/WISE - default TCP parameters

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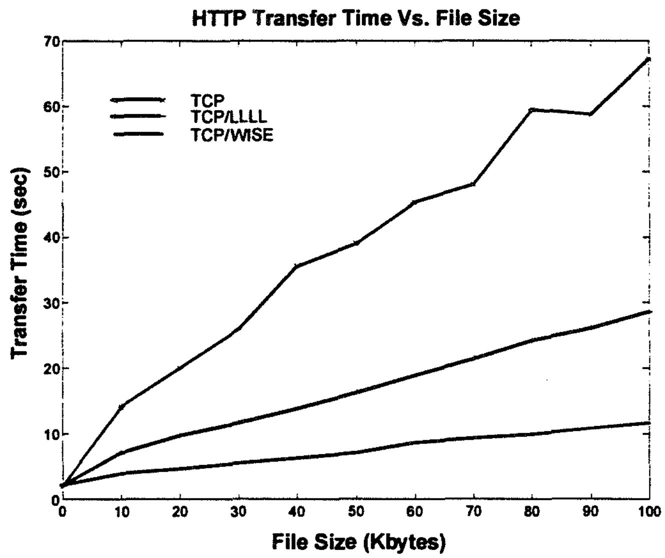
Transfer Time



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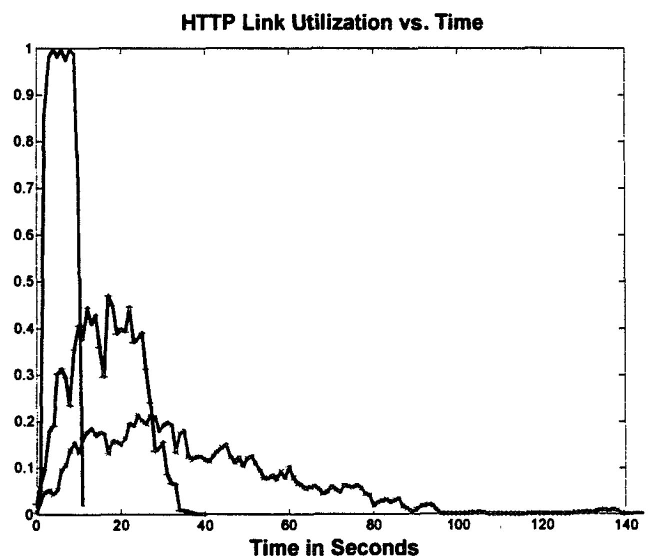
Instantaneous Utilization (1 Session)



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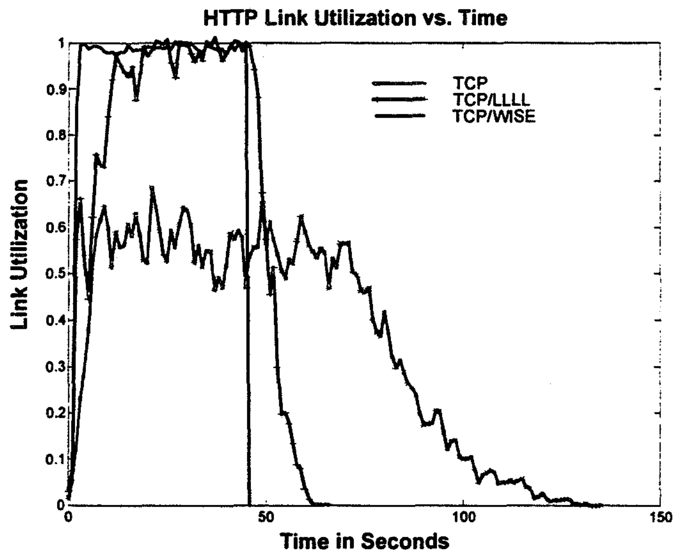
Instantaneous Utilization
(5 Session)



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Summary

- TCP/IP often operates at reduced levels of performance in a satellite environment
- The Wireless IP Suite Enhancer was designed to substantially reduce the impact of wireless links on the Internet protocol suite
  - TCP connections are converted to LLLL for transmission over the satellite segment
  - IP packets not containing TCP packets are encapsulated in the LLLL
- Performance
  - Test results show nearly optimal link utilization and significant reductions in transfer times using commercial applications
- Planned / Ongoing enhancements
  - Compression
  - IPSEC

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NASA_98_LLJ-20

Estimating Bottleneck Bandwidth using TCP

June, 1998

Mark Allman

NASA Lewis Research Center

mallman@lerc.nasa.gov

http://gigahertz.lerc.nasa.gov/~mallman

Hit our satellite with feeling
Give the people what they paid for
–The Flaming Lips

Introduction

- Why do we want TCP to estimate the bottleneck bandwidth?
  - Startup more rapidly
  - Avoid loss
- We will concentrate on estimating the bottleneck bandwidth in order to set *ssthresh* to an appropriate value and thus avoid loss.
  - "Satellite friendly" TCP often includes large windows
  - Large windows can allow a TCP to overwhelm a gateway with a larger number of segments than a small window connection
  - Therefore, estimating the bottleneck bandwidth can help TCP limit loss by slowing down before overwhelming the gateway

Background

- Making an estimate of the bottleneck bandwidth has been proposed and tested via simulation (Janey Hoe at MIT)
  - used packet-pair algorithm on the first few returning ACKs
  - the time between successive ACKs is caused by the data segments "spreading out" based on the bandwidth
  - the bandwidth estimate combined with the measured RTT can be combined to give the appropriate delay-bandwidth product of the link and therefore, the correct window size

Theory vs. Practice

- However, real networks make predicting the bottleneck bandwidth more difficult
  - delayed ACKs
    - getting successive ACKs requires more segments
  - network jitter
    - traffic from other connections getting between two successive packets
  - asymmetric networks

Possible Packet-Pair Solutions

- So, how do we get around these problems caused by real networks?
  - watch the incoming ACKs for a longer period of time
- The larger the window grows, the more important it is to avoid loss (due to the possible magnitude of the loss event)
  - As the window increases and we get more segments into the network the problem of delayed ACKs naturally fades
  - Network jitter can be averaged out if we are able to watch the ACKs for "a while"
  - Asymmetric networks?
    - Hmmm...

Preliminary Results

- We collected packet-level traces from various networks and analyzed attempted to determine the bandwidth of the bottleneck link based on the ACK stream
- ACKS were observed in the order in which they arrived only, as to attempt to simulate a TCP stack

Preliminary Results: ACTS

- We ran several FTPs over the ACTS satellite and were able to successfully estimate the bottleneck bandwidth (and therefore, the appropriate window size) within the first 40 segments (data and ACK) observed.
- This environment was free from competing traffic so it is mostly uninteresting
  - But, it shows that delayed ACKs do not make the task impossible

Preliminary Results: Internet

- We ran several FTPs between LeRC and OU to obtain traces from a dynamic environment with competing traffic
- We were able to determine a "good" window size within the first 50 segments observed
  - Our estimate is 60% higher than the window size needed to obtain the throughput we observed, on average
    - window / RTT = bandwidth
  - Our estimate is 66% lower than the window size at which loss occurred, on average
- Therefore, we hypothesize that a TCP using this algorithm would perform just as well, if not better than a TCP without bandwidth estimation (on average)

Preliminary Results: Internet (cont.)

- But, sometimes the estimate is not all that "good"
  - If the estimate is too low, we terminate slow start too soon and then depend on congestion avoidance to provide window growth
    - Slow!
  - Estimating too high is not as big a deal as we can do no worse than current implementations and possibly avoid *some* loss, even when we overestimate

Future Work

- Refine algorithms used to average the inter-ACK space
- Test in a hybrid terrestrial/satellite network
- Other mechanisms can be investigated once we have a good estimate of the bandwidth

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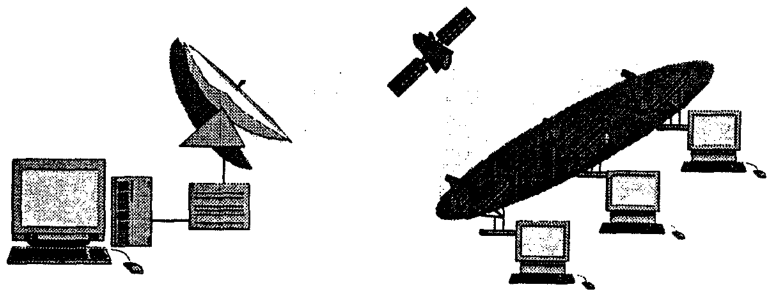
LFN and SACK over DVB Satellite links



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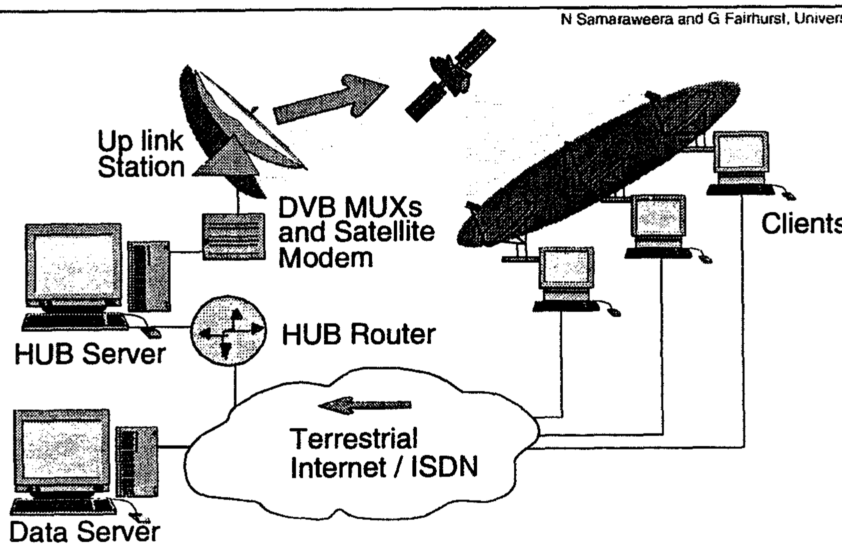
http: //www.erg.abdn.ac.uk/

DVB Networking

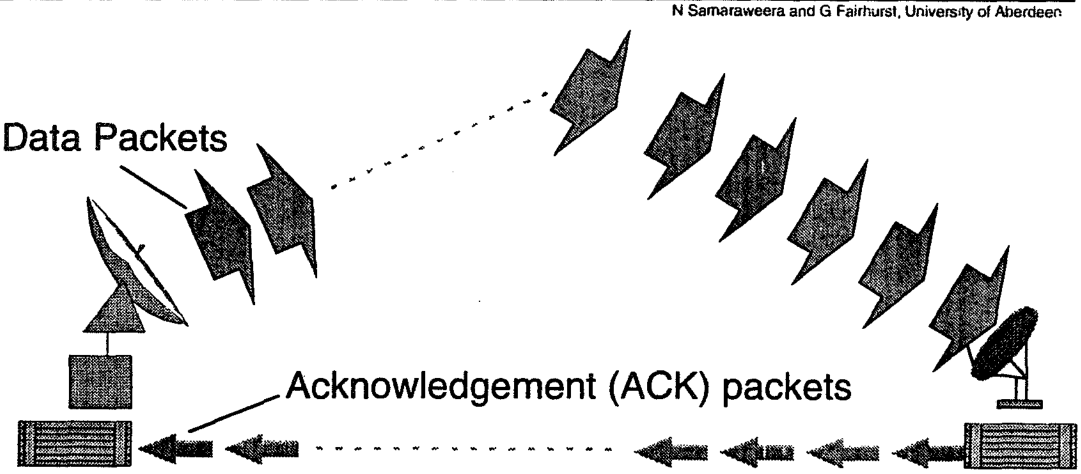


Same satellite dish receives TV and Internet traffic

High speed Internet access to home and office

What is a Long Fat Network?

N Samaraweera and G Fairhurst, University of Aberdeen

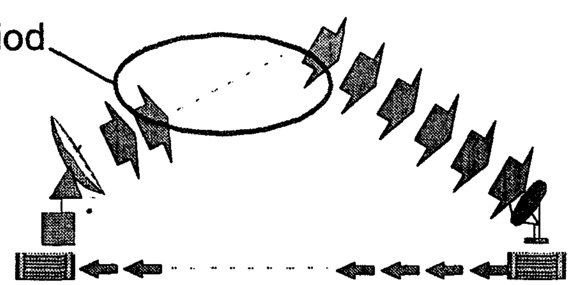


High bandwidth delay product (e.g., Satellite link)

Many terrestrial networks are more "fat" than "long"

TCP Window Limitation

N Samaraweera and G Fairhurst, University of Aberdeen

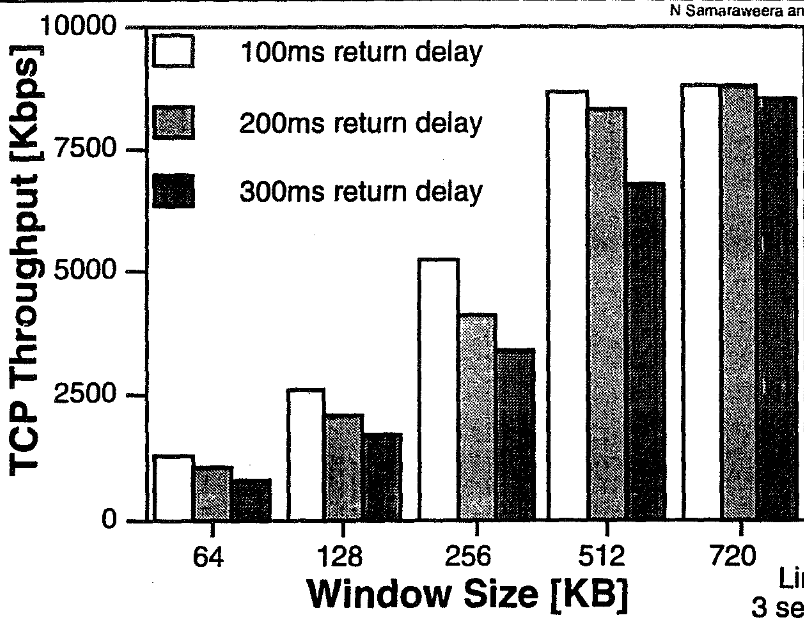


TCP unable to keep the fat pipe full
Throughput limited by maximum window size
(e.g. performance over a satellite link limited to < 1 Mbps)

Window scale option
(RFC 1072, RFC 1185, RFC 1323, IETF draft-tcp-lw)
Expands the 16 bit TCP window to 32 bits (i.e. < 1 Gbps)

Window Scaling Improves Performance

N Samaraweera and G Fairhurst, University of Aberdeen

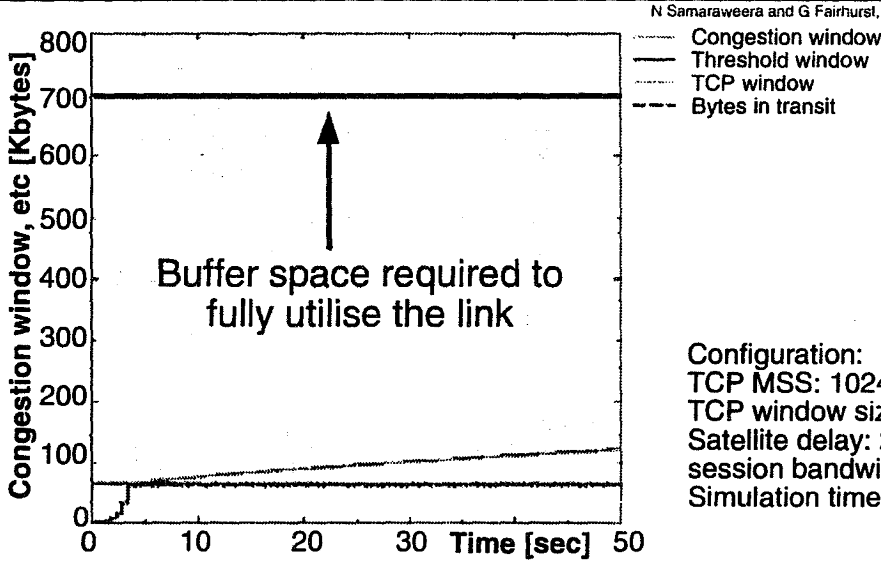


Configuration:
TCP MSS: 1024
Satellite delay: 280ms
Link bandwidth: 34Mbps
3 sessions sharing the link
Simulation time: 60 seconds

Window scaling is useful for > 1Mbps over a satellite link

Standard TCP Window

N Samaraweera and G Fairhurst, University of Aberdeen



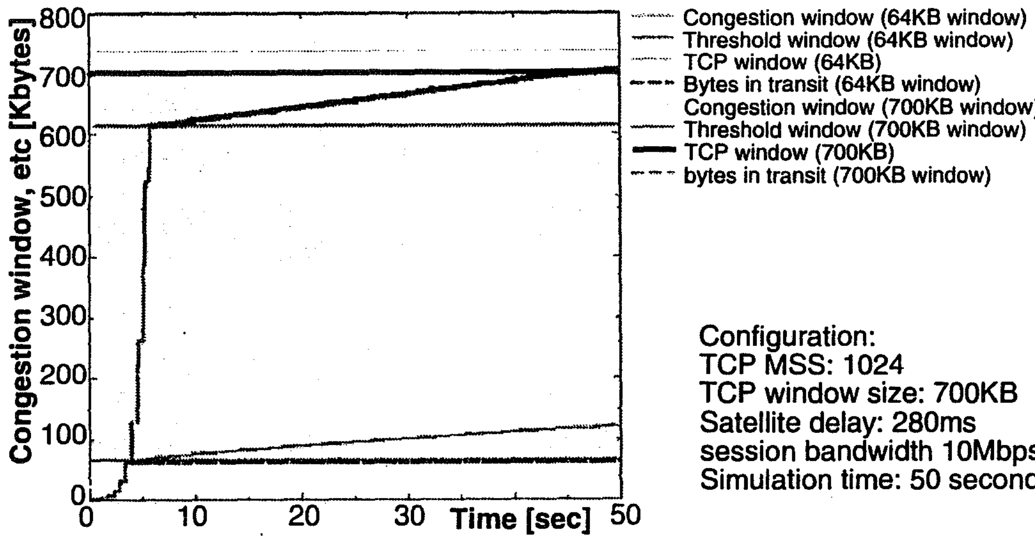
Configuration:
TCP MSS: 1024
TCP window size: 64KB
Satellite delay: 280ms
session bandwidth: 10Mbps
Simulation time: 50 seconds

Transmission rate is restricted by:

The TCP window size (for small windows)
The congestion window (for small file and large window)

Window Scaling

N Samaraweera and G Fairhurst, University of Aberdeen

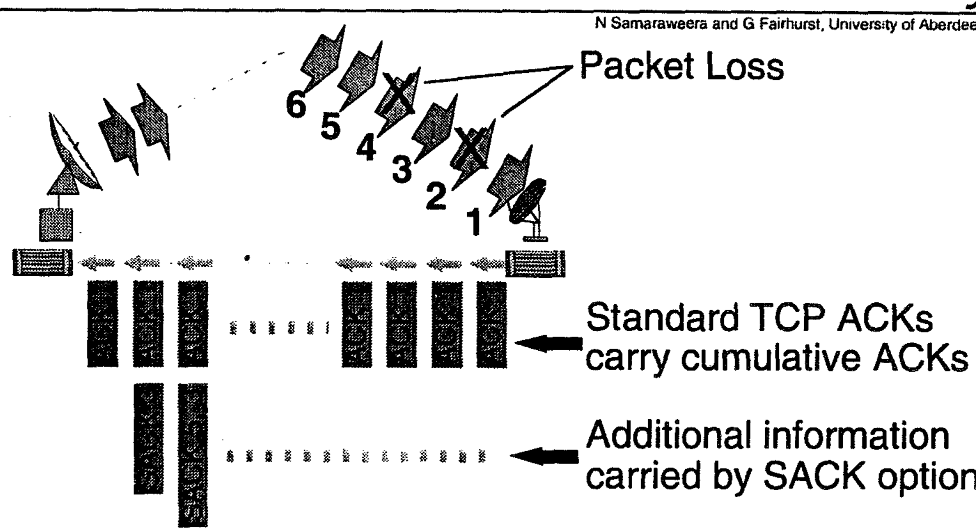


Configuration:
TCP MSS: 1024
TCP window size: 700KB
Satellite delay: 280ms
session bandwidth 10Mbps
Simulation time: 50 seconds

Only useful when file size > 126KB (over a satellite link)
Example Applications:
WWW based distance learning (CAL), News distribution

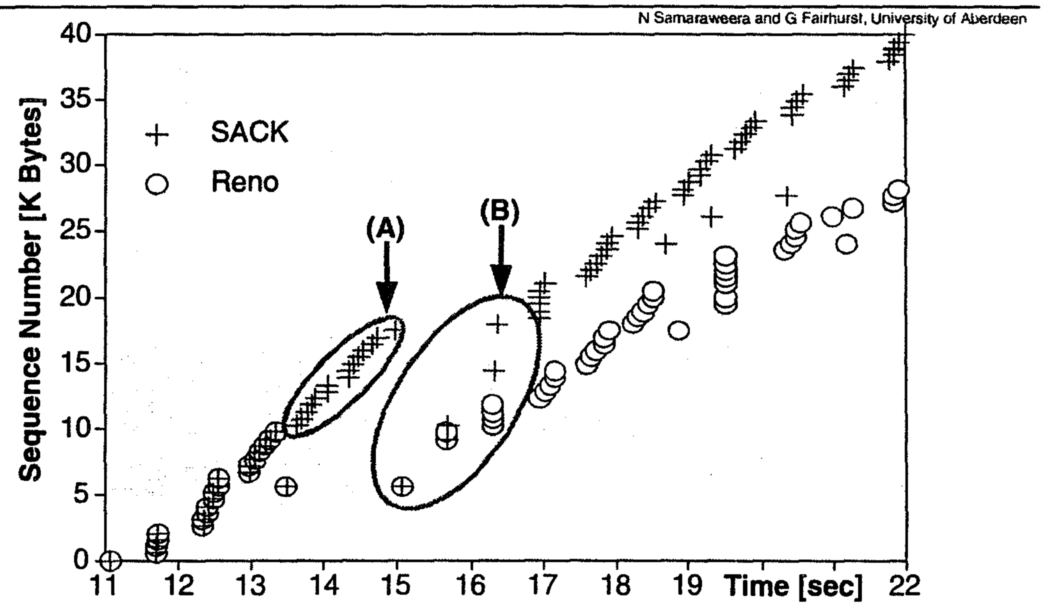
TCP Packet Loss Recovery

N Samaraweera and G Fairhurst, University of Aberdeen



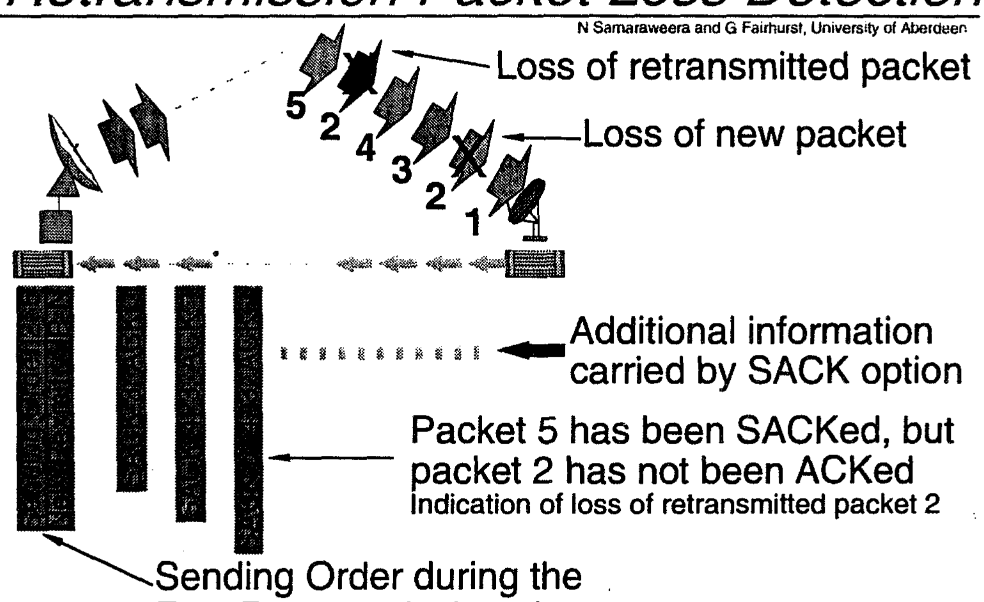
TCP may only efficiently recover one packet per window
A long fat network may loose more packets
Selective ACK Option (SACK)
Efficiently handles multiple packet loss

Performance of SACK



(A) SACK resumes the transmission after retransmission
(B) SACK selectively retransmits only packets lost

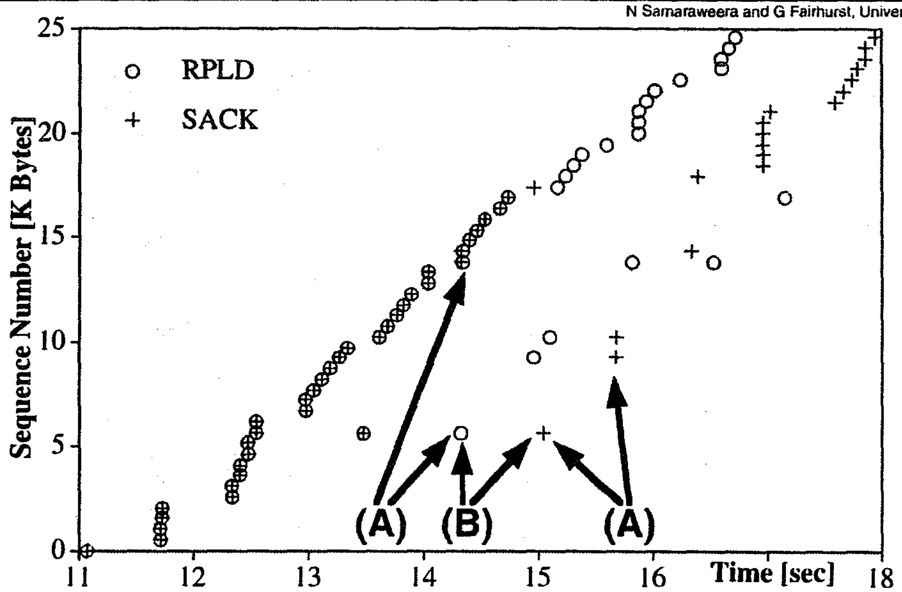
Retransmission Packet Loss Detection



Uses transmission order and additional SACK information
Uses 3 SACKs to avoid confusion due to mis-ordering

Performance of RPLD

N Samaraweera and G Fairhurst, University of Aberdeen



(A) Avoids Slow Start (does not wait to drain the pipe)
(B) Recovery delay is low (indicated by SACKs)

Asymmetric links

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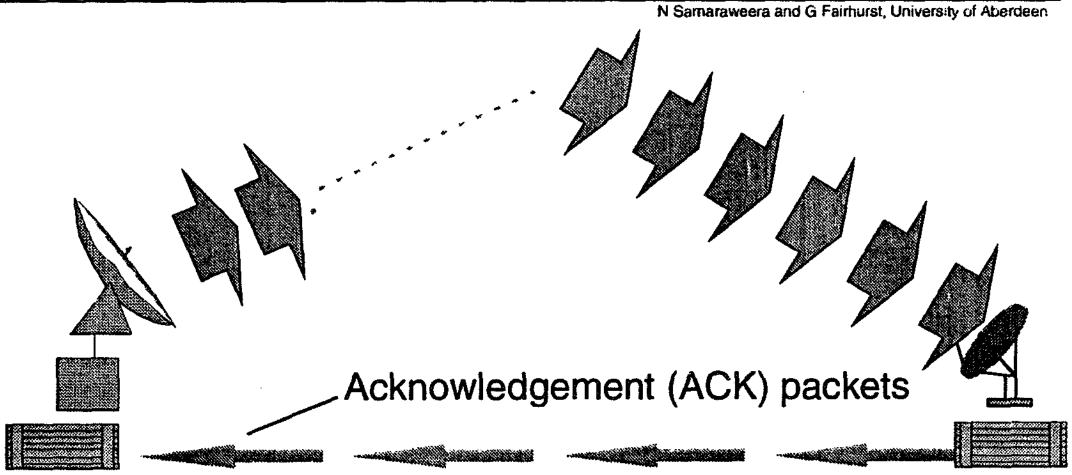

Inexpensive low speed return links are often used

Most TCP/IP connections receive much more than send

ACK Congestion

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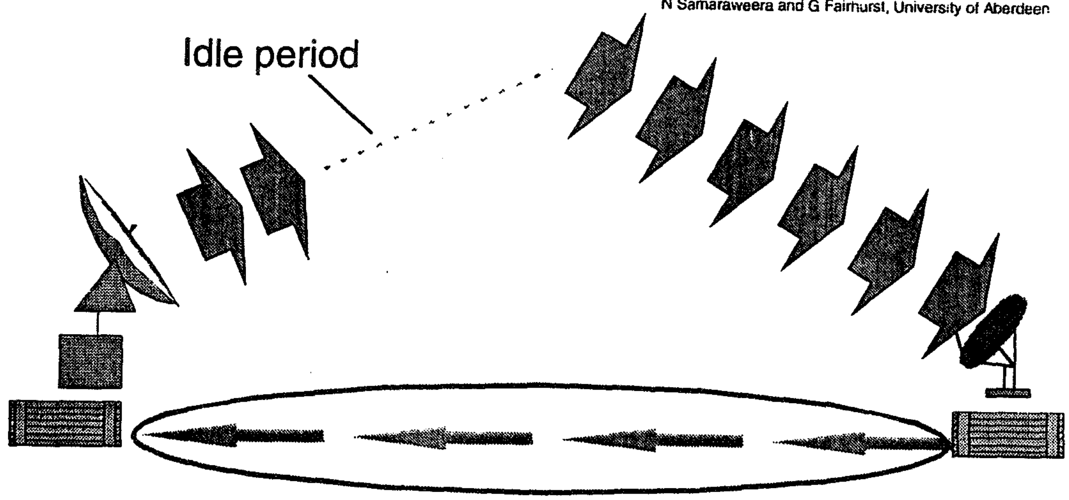

Return "pipe" fills with ACKs

Transmission rate controlled by received ACK rate

Therefore need to reduce volume of ACK data !!!

Configuration

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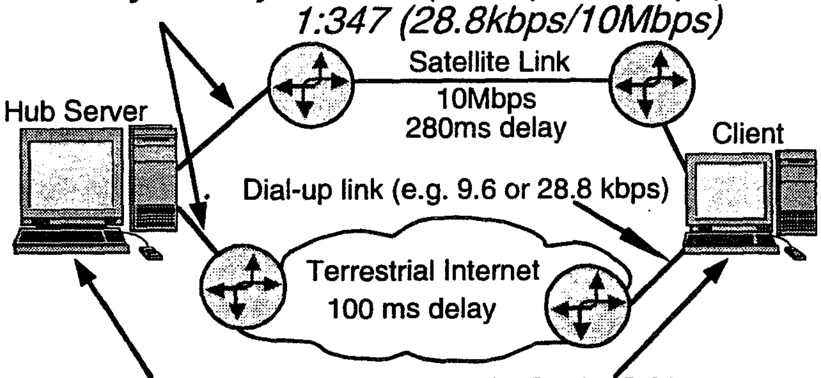
Bandwidth Asymmetry 1: 1041 (9.6kbps/10Mbps)
1:347 (28.8kbps/10Mbps)



Data asymmetry 1: 22 (ACK/MSS)

Causes ACK congestion

when bandwidth asymmetry > data asymmetry
with ACK delay, bandwidth asymmetry > N * data asymmetry
avoids congestion over 9.6 kbps link when N > 47
over 28.8 kbps link when N > 16

Note : TCP MSS = 1024B, TCP ACK = 40B, and Link overhead = 6B

ACK Suppression

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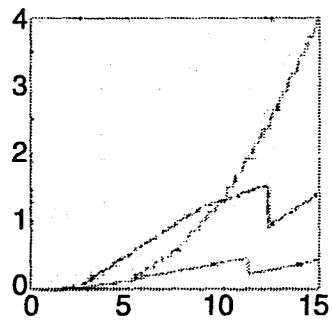
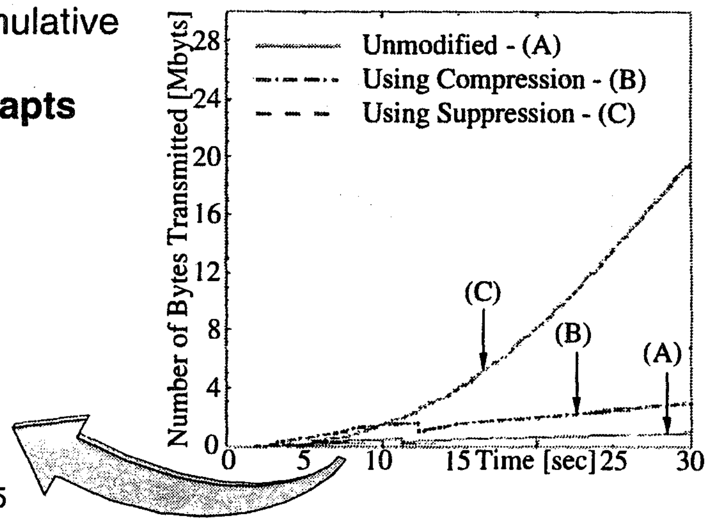
Old ACKs may be deleted from the return interface queue

TCP ACKs are cumulative

Suppression ratio adapts

Avoids congestion





Low performance for small files

Transfer < 1.2 MB (with 9.6 kbps return link)

Low Throughput with Suppression

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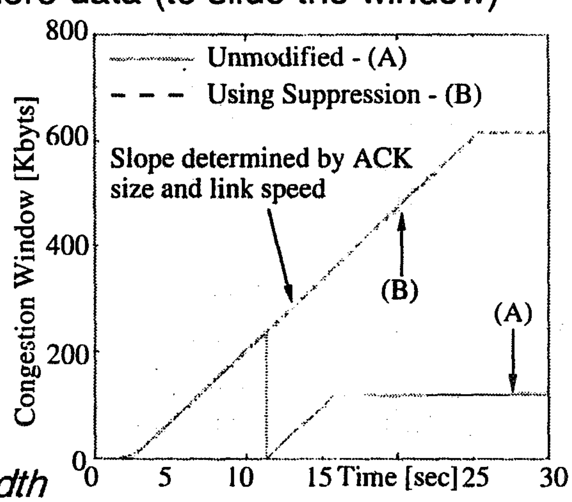
Suppression looses important information

An ACK indicates:

(a) A packet has left the network (to increase cwnd)

(b) Receiver may accept more data (to slide the window)



Need to increase ACK rate without increasing the bandwidth

ACK Compaction

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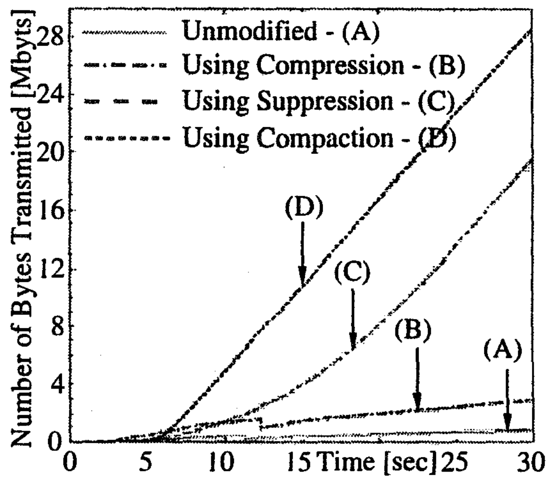
Reduces ACK size but not rate



Issues to be resolved:

ACKs may need be spaced

Interaction with SACK option

Interaction with timestamps option

Interaction with security

Conclusions

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Issues Discussed

Window scaling important for >1Mbps and transfer >126 KB

SACK is important (very difficult to eliminate congestion)

RPLD useful over long delay networks

Volume of ACK data should be reduced

Some hard questions still need to be answered!!

Impact of SACK on the asymmetric modifications

Pacing of transmission is important

Impact of satellite delay on short transfers

Acknowledgements

The Authors wish to thank the European Space Agency (ESA), and R Donadio (ESA), P. Glover (ESA), K. Hodson, R Heron (Delta Communication), R. Eley and C. Yildez (Globecast Northern Europe) for their contribution to this project.

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Session 2
NASA Mission Applications

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Lewis Research Center

NASA's Use of Commercial Satellite Systems: Concepts & Challenges

Presented at Satellite Networks: Architectures, Applications and Technologies Workshop

June 2, 1998
Cleveland Ohio

James M. Budinger
Phone: 216.433.3496 E-mail j.budinger@lerc.nasa.gov

Lewis Research Center

Abstract

- Lewis Research Center's Space Communications Program has a responsibility to investigate, plan for, and demonstrate how NASA Enterprises can use advanced commercial communications services and technologies to satisfy their missions' space communications needs. This presentation looks at the features and challenges of alternative hardware system architecture concepts for providing specific categories of communications services.

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Presentation Agenda

- Background Regarding "Commercial Utilization"
- Potential Service Categories
- System Architecture Concepts
- Features and Challenges
- Conclusions

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Commercial Utilization

- *"In the conduct of these research and development programs, NASA will seek to* ***privatize or commercialize its space communications operations."***

- *"U.S. Government agencies shall* ***purchase commercially available goods and services to the fullest extent feasible*** *and shall not conduct activities with commercial applications that preclude or deter commercial space activities except for reasons of national security or public safety."*

  – White House National Space Policy
  Civil Space Guidelines
  Commercial Space Guidelines
  September 19, 1996

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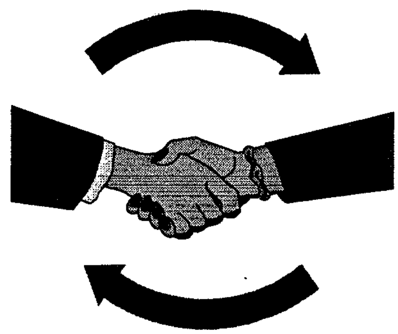
Commercialization & Utilization

Commercialization **of NASA Technology & Services**

NASA



Industry

NASA *Utilization* of Commercial Technology & Services

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LeRC Role

- Lewis Research Center's Space Communications Program has a responsibility to investigate, plan for, and demonstrate how NASA Enterprises can use advanced commercial communications services and technologies to satisfy missions' space communications needs.
- Identify candidate commercial SatCom systems to be leveraged
  - Develop an implementation plan for aligning NASA's needs with commercial capabilities
  - Select, develop and demonstrate enabling technologies and services to mitigate risk
  - Enhance U.S. industry capabilities and competitiveness

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Physical Architectures

- NASA's use of commercial communications systems requires both:
  - physical links and interfaces compatible with commercial space and terrestrial network infrastructures
  - compatible data communication network protocols
- This presentation focuses on alternative architectures for the physical communications system:
  - to establish the necessary framework for interoperability with commercial space and terrestrial networks
  - to effectively enable the suite of desired communications services

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Potential Service Categories

Service Category	Characteristics & Applications
Narrowband communications	Low-rate data, TT&C, personal communications for humans in space
Wideband tele-science	Asymetrical, experiment configuration, command, and scientific data return
Broadband tele-presence	Nearly continuous, real-time interaction with space segment
High-capacity storage and distribution	Latency-tolerant, content-rich data, file transfers to PI's and archives
On-demand integrated services	Real-time video, data, and voice, "Spacecraft on the Internet"

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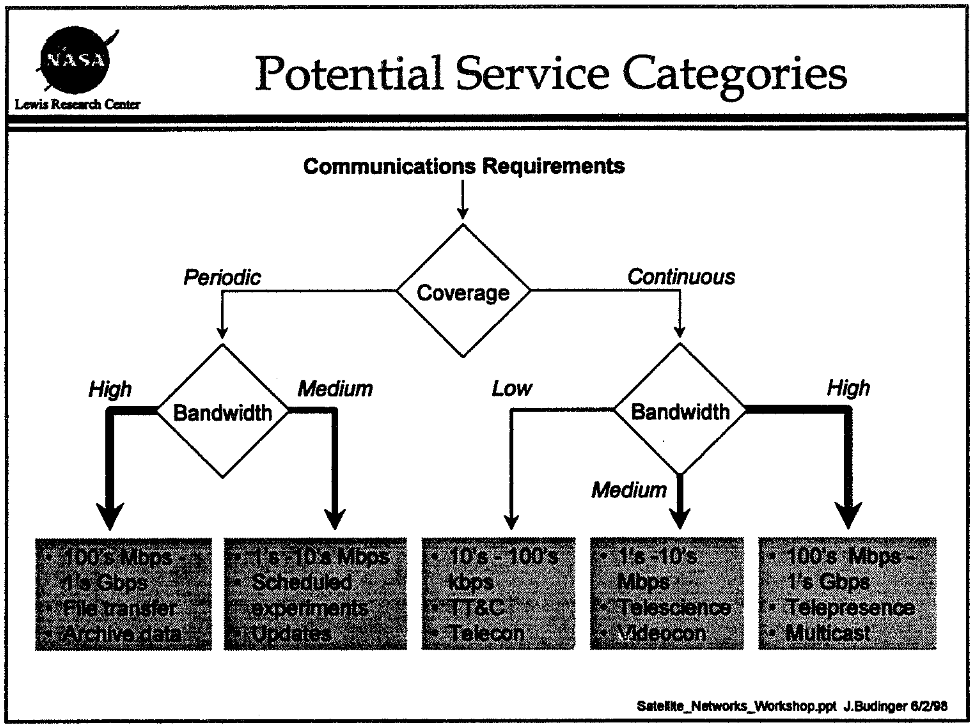
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Potential Service Categories
Communications Requirements
Coverage
Periodic
Continuous
Bandwidth
High
Medium
Bandwidth
Low
Medium
High
• 100's Mbps - 1's Gbps
• File transfer
• Archive data
• 1's - 10's Mbps
• Scheduled experiments
• Updates
• 10's - 100's kbps
• TT&C
• Telecon
• 1's -10's Mbps
• Telescience
• Videocon
• 100's Mbps - 1's Gbps
• Telepresence
• Multicast
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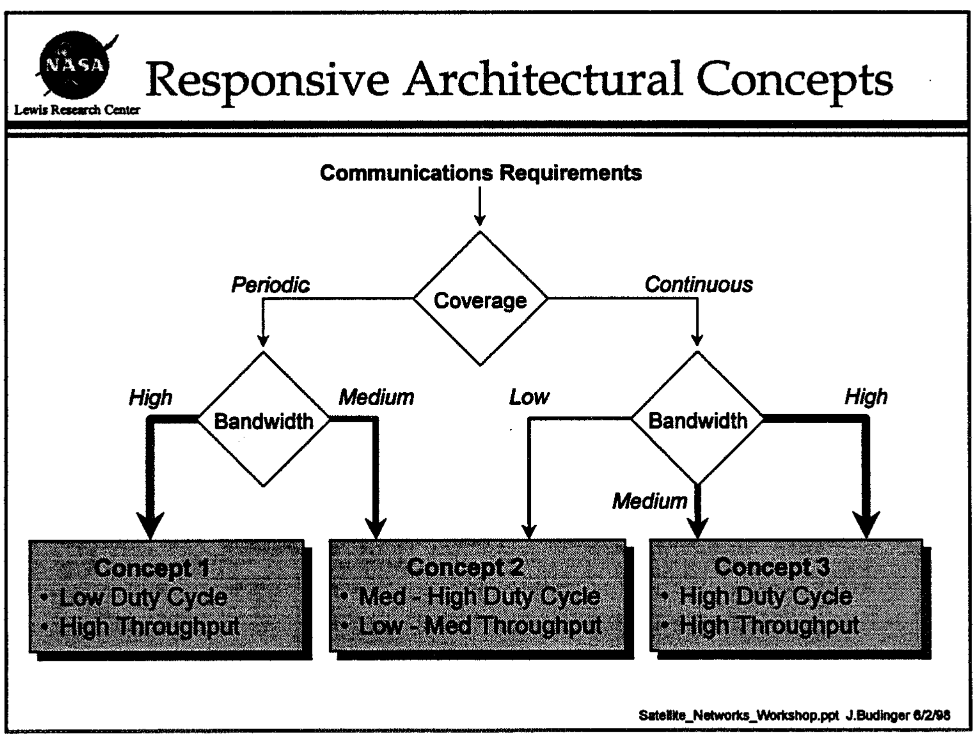
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Responsive Architectural Concepts
Communications Requirements
Coverage
Periodic
Continuous
Bandwidth
High
Medium
Bandwidth
Low
Medium
High
Concept 1
• Low Duty Cycle
• High Throughput
Concept 2
• Med - High Duty Cycle
• Low - Med Throughput
Concept 3
• High Duty Cycle
• High Throughput
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Architecture Concepts

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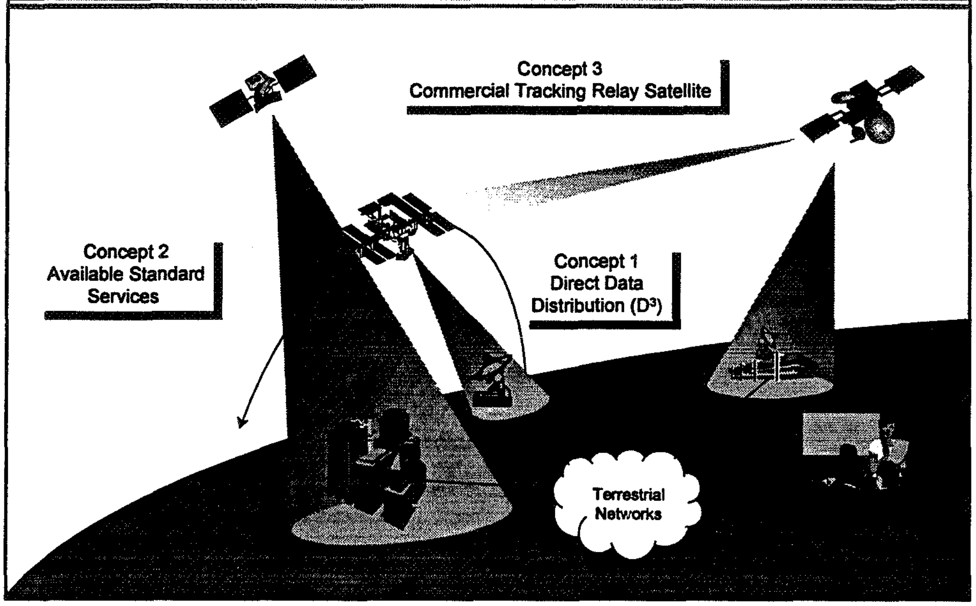

Direct Data Distribution (D^3)

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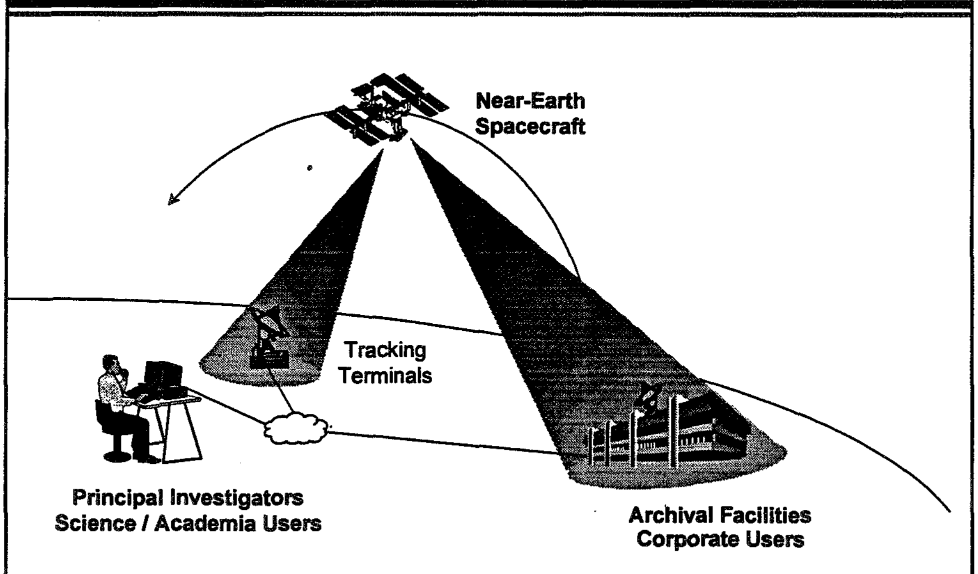
Architectural Concept 1



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Direct Data Distribution (D^3)

Features

- Onboard data storage and burst data delivery
- 1.2 Gbps downlink in commercial K-band
- ~10 Mbps uplink if needed
- Multi-beam phased array
- Efficient digital modem / codec
- 1.8-m tracking terminals
- Located to maximize contact
- Terrestrial interoperability for wide area distribution
- ~ 72 Gigabits / 1 minute contact
- No reliance on relay satellites
- Experimental capability in 2002

Challenges

- Latency tolerant applications only
- Onboard storage sufficient for multiple orbits
- Fast acquisition and tracking
- Limited contact:
  - once per orbit at poles
  - 1 or 2 per day elsewhere
- Commercially owned, licensed, & operated on NASA spacecraft & ground segment
- Close coordination with commercial gateways

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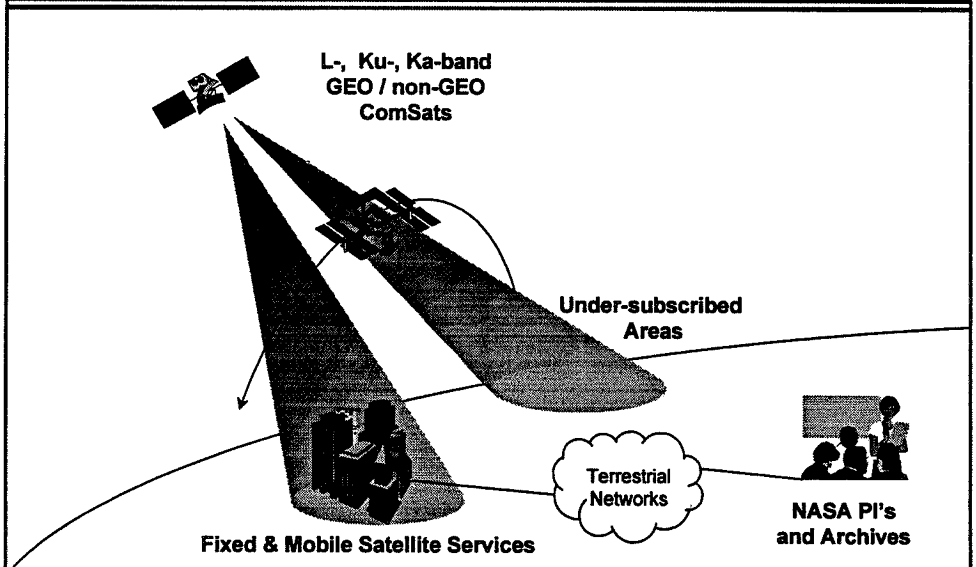
Available Standard Services

Architectural Concept 2



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Available Standard Services

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Features

- Capture available or unused, unmodified commercial L-, Ku-, and Ka-band capacity
- Global narrowband coverage
  - Multiple 64-kbps circuits
  - TT&C, Low-rate data, voice,
- Periodic wideband coverage
  - 1 to 25 Mbps Forward Link
  - 10 to 155 Mbps Return Link
  - Interactive telescience, video
- 33 to nearly 100% Coverage
- Narrowband demo in 1998 (STS-91 Spacehab - Inmarsat)
- Wideband demos in 2003

Challenges

- Current global coverage limited to voice rate applications
- Wideband transponders cover populated areas only
- Close coordination to avoid wideband interference
- Handoffs for non-GEO coverage
- Sufficient business case to provide capacity over unpopulated areas
- Regulatory issue regarding S-S use of S-E and E-S allocations

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Commercial Tracking Relay

Architectural Concept 3

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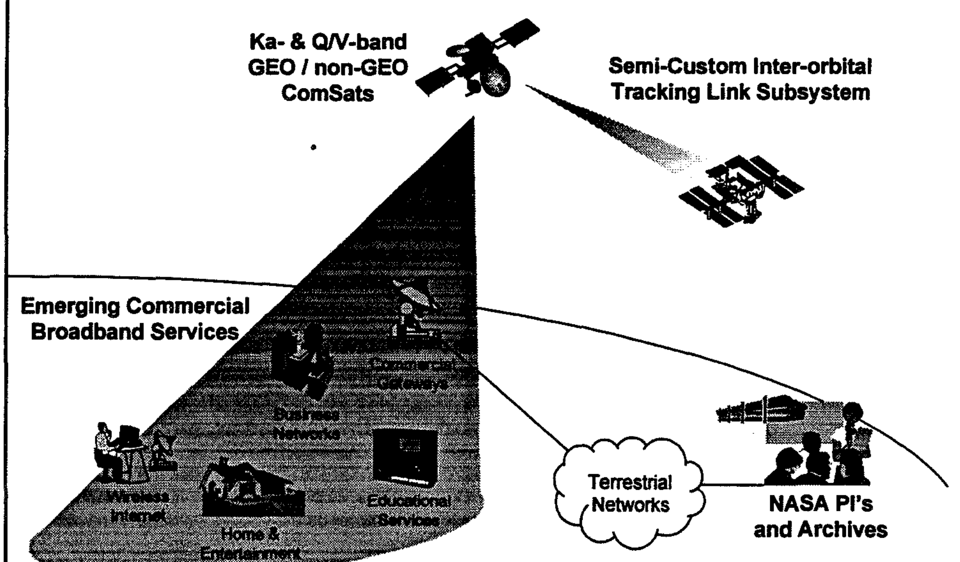

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Commercial Tracking Relay

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Features

- Semi-custom rf or optical inter-orbital tracking links
- Periodic to continuous broadband coverage
  - -- 10 to 55 Mbps forward link
  - -- 155 to 622 Mbps return link
  - -- Interactive telepresence
- Video, Data, Voice, Multicast
- 33 to 100% Coverage
- Commercial Ka- and V-band
- **"First generation commercial transceiver"** for NASA
- Service demos in 2004
- Available commercially in 2005 to 2010

Challenges

- Semi-custom modification to planned systems
- Handoffs for non-GEO system coverage
- Sufficient business case to provide global coverage
- NASA / Industry development of a **common space interface**
- Commercially owned, licensed, & operated on NASA spacecraft

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Conclusions

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- **Opportunities are present and increasing** for NASA missions in near-Earth orbit to use commercial satellite services in the future.
- **No single commercial system** is likely to provide the entire range of services desired by NASA missions.
- Proposed concepts present technical, regulatory and economic **challenges, but none appear to be insurmountable.**
- Commercial systems have limited **windows of opportunity** for modification.
- Government/Industry collaboration is required on interoperability standards for a **common space interface** to commercial satellite networks.
- Communications services first provided for NASA may have potential to open **new markets for the U.S. satellite industry.**

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Satellite Networks Workshop
June 1998

ASSESSMENT OF EMERGING NETWORKS TO SUPPORT FUTURE NASA SPACE OPERATIONS

June 1998

Badri Younes
CLASS Project Manager
Code 450/NASA GSFC
Susan Chang,
Ted Berman,
Mark Burns,
Richard LaFontaine,
Robert Lease
Stanford Telecom

Introduction

- New types of global commercial satellite systems are currently under development and expected to start providing service in 1998
  - Global communication coverage
  - Mobile communication capability
  - High speed networking
- NASA GSFC is investigating the feasibility of using emerging commercial satellite systems to support NASA LEO missions
  - Reduce mission cost
  - Enhance or maintain level of service provided by TDRSS and GN

NASA Study

- Examines technical and operational issues related to supporting a NASA LEO satellite with commercial satellite systems
- Four commercial satellite systems are addressed in this presentation
  - Mobile Satellite Service (MSS): IRIDIUM, ICO (1st gen)
  - Fixed Satellite Service (FSS): Spaceway, Teledesic

Evaluation Approach

- Communications Coverage: Geometric coverage time minus system acquisition and service acquisition time.
  - Accounts for time required for handoff
  - Accounts for dropped calls due to handoff failure
- NASA user terminal assessment including spacecraft G/T, EIRP and operational constraints relating to system acquisition, service acquisition and handoff
- Regulatory assessment

Assumptions

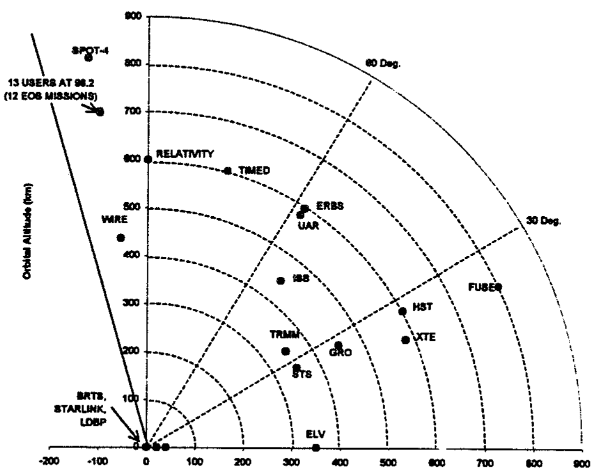
- **No modifications will be made to commercial satellite systems to support NASA missions.**
  - NASA LEO satellite will emulate a ground-based user
- **User spacecraft tracking will not be performed by the commercial satellite systems.**
  - Future NASA missions will incorporate on-board GPS equipment
- **All evaluations of the commercial satellite systems are based on public information obtained from FCC filings**

NASA LEO Missions Overview

- **NASA missions operate in a number of different orbits that depend on the mission type**
  - Launch vehicles at approximate altitudes of up to 350 km
  - Suborbital missions at altitudes less than 40 km
  - Manned space flight at altitudes of 300 - 600 km altitude and inclinations of 28°- 57°
  - Astrophysics missions at altitudes of 400 - 600 km altitude and inclinations of 23°- 35°
  - Earth science missions at altitudes of 350 - 1,350 km and inclinations of 35°- 99°
- **Considered missions scheduled through 2014**
- **Data requirements range from 1 kbps to 600 Mbps**
  - Telemetry and Command: 1 kbps to 2 Mbps
  - Payload data: 1 kbps to 600 Mbps

NASA LEO Missions Overview

Orbital Characteristics



Commercial Satellite Systems

Summary

System	Orbit Type/ Service type	BER	Service Frequency (MHz)		Service Data Rate (kbps)		ISL Frequency (GHz)	Orbit Parameters		
			Forward •	Return	Forward	Return		Satellites	Altitude (km)	Inclination
Iridium[1]	LEO MSS	10^{-3}	1616-1626.5	1616-1626.5	2.4	2.4	23.18-23.38	66	780	86.4°
ICO	MEO MSS	10^{-5}	2,170-2,200	1,985-2,015	38.4	38.4	N/A	10-12	10,355	45°
Teledesic[1]	LEO FSS	10^{-9}	17.8-18.6 and 18.8-19.3	28.6-29.1 and 27.6-28.4	n*16 (n= 1,...,128)	n*16 (n= 1,...,128)	65-71	288	1350	84.7°
Spaceway[1]	GEO FSS	10^{-10}	17.7-20.2	27.5-30.0	92,000	384-6,000	22.55-23.55 32-33 54.25-58.20 59-64	20	35,786	0°

Notes:
1. Systems use intersatellite links and onboard data processing.

Simulation Assumptions

- **Geometrical coverage determined through Communications Analysis Graphical Environment (CAGE) simulation**
  - Ten day orbit simulation
  - Commercial satellite user antenna beam modeled as a single conic
- **Communications coverage determined through CAGE simulation**
  - 30 random user satellite orbit periods
  - User satellite is positioned at a randomly selected accession angle prior to each simulation pass
  - User antenna beam modeled at sub-beam level
  - System acquisition time based on IS95 specification (16.3 sec)
  - Service acquisition time based on IS95 specification (20.0 sec)
  - Handoff time based on existing ground based cellular system performance (12 s)

Simulation Results

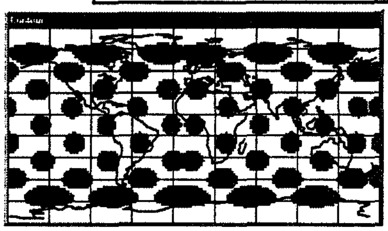
- Emerging commercial satellite systems are designed for users at or near ground level. Communications coverage at LEO altitudes is constrained.
  - Reduced communications coverage exist at LEO altitude due to the conic shape of the radiating antenna
  - Beam-to-beam handoff for a LEO spacecraft will experience a higher call drop probability than a terrestrial user due to user spacecraft velocity (12 km/sec)
- None of the evaluated systems is capable of supporting the real time communications coverage requirements of manned space flight missions and launch vehicles
- IRIDIUM and Teledesic provide the least communications coverage
  - Orbits similar to NASA LEO spacecraft
  - Less than 1% communications coverage for user altitudes > 500 km
- ICO provides higher communications service duration and data throughput
  - Service availability 20% - 40% for user altitudes > 500 km
- Spaceway (GEO) provides highest communications service duration and data throughput
  - Service availability is greater then 35% for user altitudes > 500 km
  - NASA LEO satellite must support beam-to-beam handoff (not available on FSS)

Communications Coverage - IRIDIUM

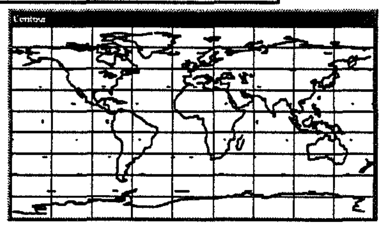
IRIDIUM Service Availability Analysis Results [1,2]

Parameter	CASE 1 300 km, 28.5 deg	CASE 2 500 km, 28.5 deg	CASE 3 700 km, 28.5 deg	CASE 4 500 km, 57.0 deg	CASE 5 700 km, 98.2 deg
FOV Coverage (%)	30.4	6.5	0.3	9.3	0.7
Service Availability (%)	6.0	0.5	-	-	-
Service Availability/orbit (minutes)	5.4	0.5	-	-	-
Average Service Duration (minutes)	0.9	0.4	-	-	-
Average Null Duration (minutes)	14.5	83.6	-	-	-
Maximum Null Duration	90.5	94.6	-	-	-
Contacts per User Period (avg)	5.9	1.1	-	-	-
Call Dropping Probability (%)	63.2	66.7	-	-	-

NOTES:
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 as follows: 1) 21.9 seconds, 2) 11.4 seconds, 3) 3.0 seconds, 4) 11.4 seconds, 5) 3.0 seconds.
2. The estimated mean sub-beam overlap time (sec) for Cases 1 through 5 as follows: 1) 5.9 seconds, 2) 3.1 seconds, 3) 0.8 seconds, 4) 3.1 seconds, 5) 0.8 seconds.
3. 48 spot beams per IRIDIUM satellite



IRIDIUM FOV COVERAGE AT 300 Km ALTITUDE



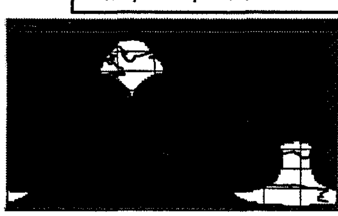
IRIDIUM FOV COVERAGE AT 700 Km ALTITUDE

Communications Coverage - ICO

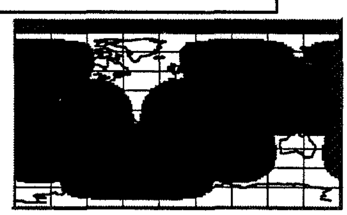
ICO Service Availability Analysis Results [1,2]

Parameter	CASE 1 300 km, 28.5 deg	CASE 2 500 km, 28.5 deg	CASE 3 700 km, 28.5 deg	CASE 4 500 km, 57.0 deg	CASE 5 700 km, 98.2 deg
FOV coverage (%)	99.0	96.1	93.2	88.6	76.9
Service availability (%)	53.8	49.3	44.9	67.5	22.0
Service availability/orbit (minutes)	46.7	46.6	44.3	63.8	21.7
Average service duration (minutes)	3.4	3.2	3.0	4.6	1.0
Average null duration (minutes)	2.9	3.3	3.7	2.2	3.7
Maximum null duration	20.5	20.6	20.7	20.8	38.1
Contacts per user period (avg)	14.4	14.6	14.7	14.0	21.0
Call dropping probability (%)	49.6	48.5	47.5	56.7	67.7

NOTES:
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 as follows: 1) 63.7 seconds, 2) 57.8 seconds, 3) 53.0 seconds, 4) 57.8 seconds, 5) 53.2 seconds.
2. The estimated mean sub-beam overlap time (sec) for Cases 1 through 5 as follows: 1) 17.2 seconds, 2) 15.6 seconds, 3) 14.4 seconds, 4) 15.6 seconds, 5) 14.4 seconds.
3. 163 spot beams per ICO satellite



ICO FOV COVERAGE AT 300 km



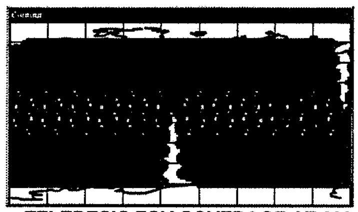
ICO FOV COVERAGE AT 700 km

Communications Coverage - Teledesic

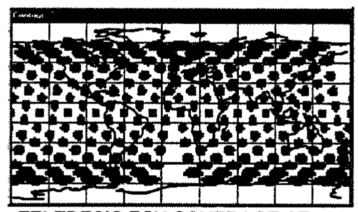
Teledesic Service Availability Analysis Results[1,2]

Parameter	CASE 1 300 km, 28.5 deg	CASE 2 500 km, 28.5 deg	CASE 3 700 km, 28.5 deg	CASE 4 500 km, 57.0 deg	CASE 5 700 km, 98.2 deg
FOV coverage (%)	97.8	66.4	34.6	75.5	50.5
Service Availability (%)	3.3	1.3	0.4	1.2	0.1
Service Availability/orbit (minutes)	3.0	1.2	0.4	1.1	0.1
Average Service Duration (minutes)	0.7	0.5	0.3	0.4	0.3
Average Null Duration (minutes)	48.0	72.3	96.5	50.9	98.8
Maximum Null Duration	90.5	94.6	98.8	94.6	98.8
Contacts per User Period (avg)	1.9	1.3	1.0	1.8	1.0
Call Dropping Probability (%)	64.9	66.2	74.1	70.3	74.6

NOTES:
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 as follows: 1) 6.7 seconds, 2) 5.2 seconds, 3) 3.8 seconds, 4) 5.2 seconds, 5) 3.8 seconds.
2. The estimated mean sub-beam overlap time (sec) for Cases 1 through 5 as follows: 1) 1.8 seconds, 2) 1.4 seconds, 3) 1.0 seconds, 4) 1.4 seconds, 5) 1.0 seconds.
3. 64 spot beams per Teledesic satellite



TELEDESIC FOV COVERAGE AT 300 KM ALTITUDE



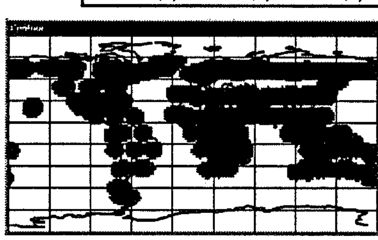
TELEDESIC FOV COVERAGE AT 700 KM ALTITUDE

Communications Coverage - Spaceway

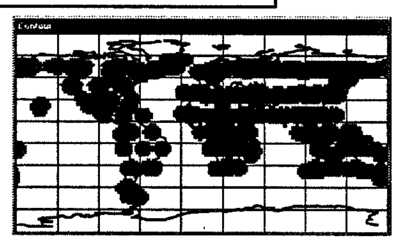
Spaceway Service Availability Analysis Results[1,2]

Parameter	CASE 1 300 km, 28.5 deg	CASE 2 500 km, 28.5 deg	CASE 3 700 km, 28.5 deg	CASE 4 500 km, 57.0 deg	CASE 5 700 km, 98.2 deg
FOV coverage (%)	53.4	51.6	50.1	47.8	35.7
Service availability (%)	53.0	51.4	47.2	46.9	35.9
Service availability/orbit (minutes)	48.0	48.6	46.6	44.4	35.5
Average service duration (minutes)	6.3	6.2	5.6	5.5	4.2
Average null duration (minutes)	5.6	5.9	6.3	6.1	7.5
Maximum null duration	41.5	43.7	47.7	47.1	55.9
Contacts per user period (avg.)	7.6	7.8	8.3	8.2	8.4
Call dropping probability (%)	21.9	23.2	26.3	29.6	44.1

NOTES:
1. The estimated mean sub-beam FOV time (sec) for Cases 1 through 5 as follows: 1) 154.0 seconds, 2) 149.0 seconds, 3) 144.0 seconds, 4) 149.0 seconds, 5) 144.0 seconds.
2. The estimated mean sub-beam overlap time (sec) for Cases 1 through 5 as follows: 1) 41.6 seconds, 2) 40.1 seconds, 3) 38.7 seconds, 4) 40.1 seconds, 5) 38.7 seconds.



Spaceway FOV Coverage at 300 km altitude



Spaceway FOV Coverage at 700 km altitude

User Terminal Assessment

- NASA LEO spacecraft will require a smaller terminal than TDRSS, for MSS, systems due to MSS LEO and MEO constellations
- FSS systems do not provide NASA LEO spacecraft any substantial terminal size advantage over TDRSS
  - GEO systems are designed to support ground users and require a high G/T and EIRP to support high burst rate TDMA
- Large number of satellites in commercial constellations will increase NASA spacecraft memory and processing burden
  - Need to determine when and where data can be transmitted
- Additional processing burden for NASA satellites
  - Doppler correction, power management, burst transmission management (TDMA), and beam-to-beam handoff

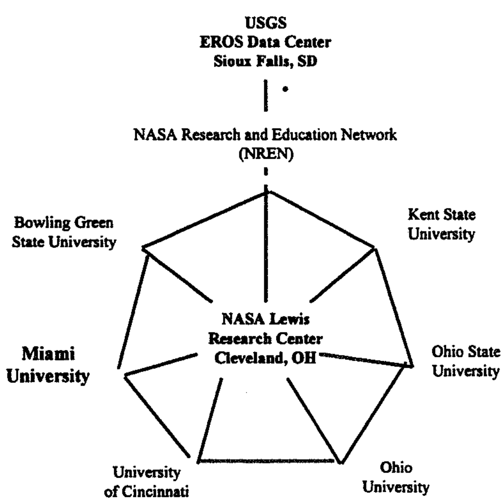
Regulatory Considerations

- Services provided by commercial satellite systems are governed by International Radio Regulations and U.S. statutes
- Definitions of MSS and FSS do not provide for space-to-space links required for NASA support
- NASA service support scenarios would require regulatory amendments
  - Feasibility studies
  - Marketing efforts
  - 4 to 14 year estimated implementation time

OhioView: Distribution of Remote Sensing Data Across Geographically Distributed Environments

June 2, 1998
Calvin T. Ramos
LeRC Project Lead
calvin.ramos@lerc.nasa.gov

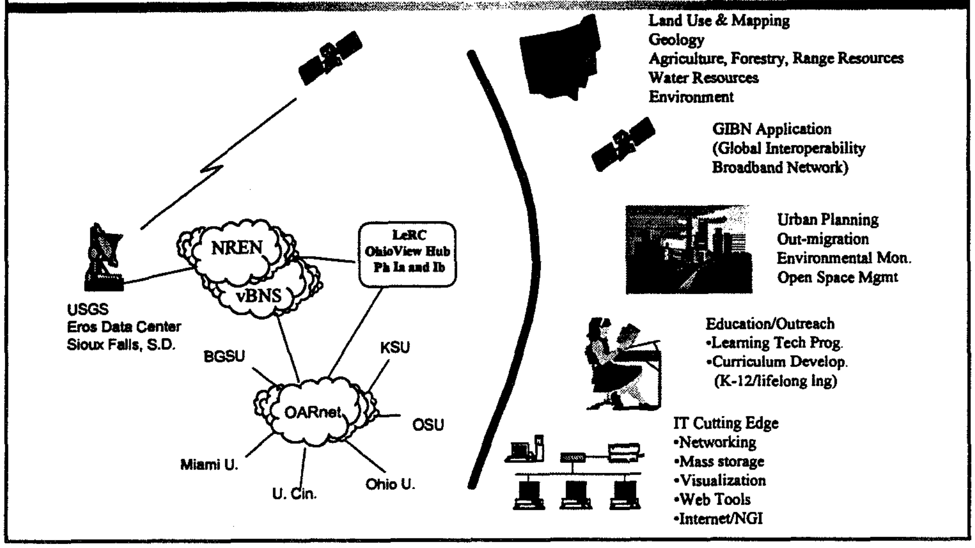
Background



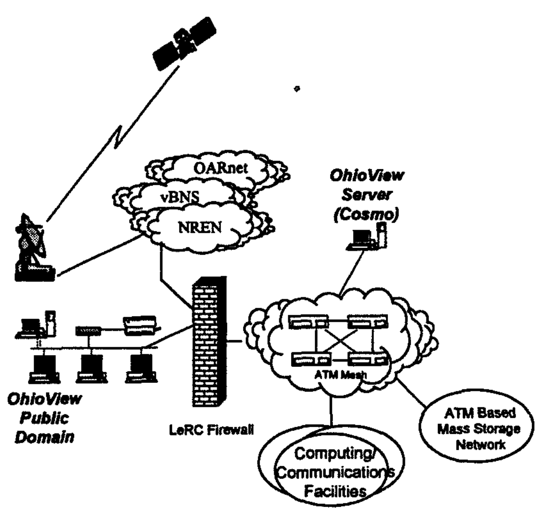
Drivers

- Access to earth science products and information
- Application of the next generation of satellite data
  - EOS Am-1 and LandSat 7
- Unique partnership between the science and library communities in the State of Ohio

High Level Architecture, Technologies & Applications



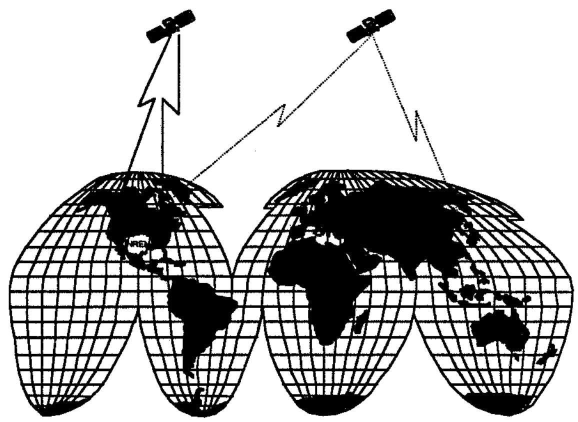
LeRC Internal Architecture & Role



LeRC Role

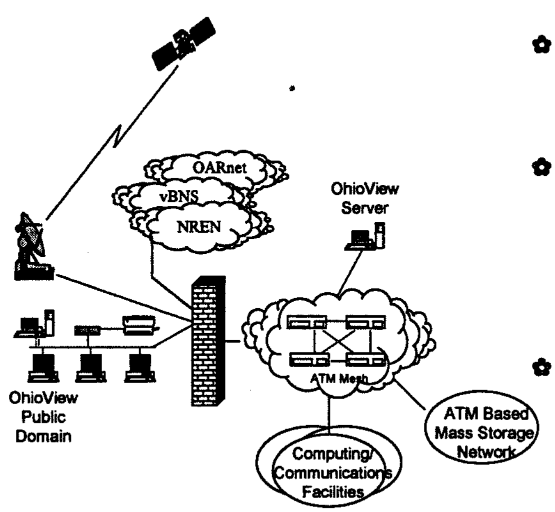
- Network Integration And Investigation
- Data Archiving and Storage
- Image Processing and Visualization
  - http://gvis.lerc.nasa.gov/ohioview
- Satellite-Network Connectivity & Interoperability

Potential GIBN Interconnect



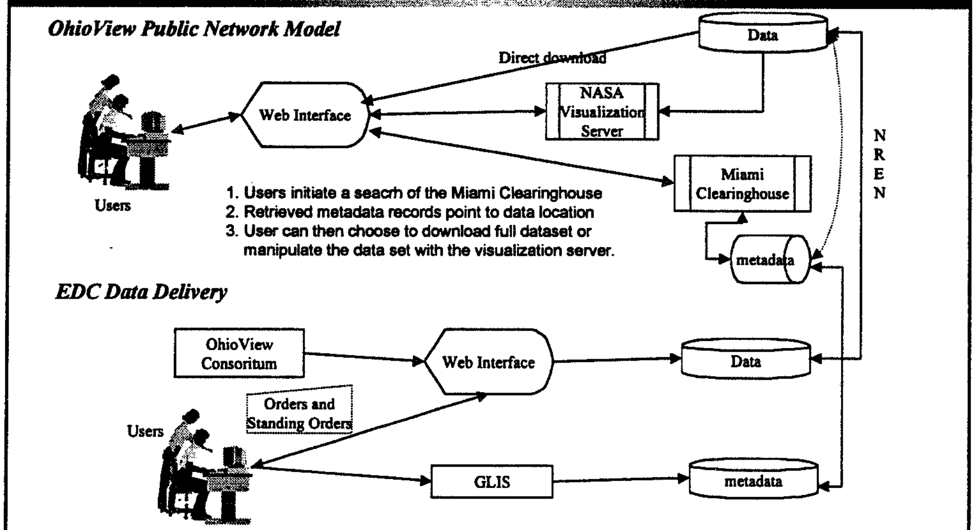
- GIBN Experiment Augmentation
- Processing of ASTER Data
- Address hybrid interoperability issues

Potential Areas of Network Investigation & Research

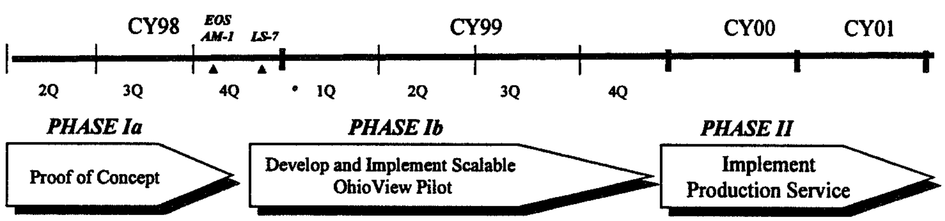


- Wide Area Multicasting
  - Terrestrial
  - Satellite
- Security
  - Mitigate LeRC Risks
  - Data Owner Protection
  - Emerging Products/Schema
  - Security Policies
- Quality of Service
  - Background experiment
  - Potential Vendor Collaboration

Draft of OhioView Data Model



LeRC Strategy/Roadmap



NREN Testing
Storage Integration
Visualization/ Web Server
Proj Mgmt/Sys Integ
Phase Ib prep

Network Perf. Integ/Anal.
Storage Prototype
Graphics/Visualization
Web Access/Development
Proj Mgmt/Sys Integ
Prep for Phase II
Consulting/Outreach

LeRC Role - TBD

Summary

- LeRC playing a key role
- OhioView - a potential national model
- Complex - both technically and politically
- Great value to broad community
- Wide application of the next generation of satellite data
- Unique partnership between the science, library, and state/federal communities in the State of Ohio

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Simple Automatic File Exchange
- SAFE -
to Support Low-Cost Spacecraft Operation via the Internet

Presentation to the Workshop:

Satellite Networks Architectures, Applications, and Technologies, June 2-4, 1998, Cleveland, Ohio, USA

Authors:

Paul Baker (GST) (pbaker@gst.com)

Max Repaci (GST) (repaci@gst.com)

David Sames (NASA/GSFC - Code 588)

Outline

Brief Introduction

Operations Concept

Implementation and Tests

Conclusions •

Additional Details

Contact Information

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Advanced Architectures and Autonomy Branch
Code 588
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The Context of the Project

Packet telemetry is acceptable for spacecraft.

End users rely heavily on Internet IP networks for scientific data exchange and collaborative research.

Emphasis on cost reduction characterizes all phases of future space missions.

Distinctive Features of the Project

Simple - SAFE provides only a few basic functions.

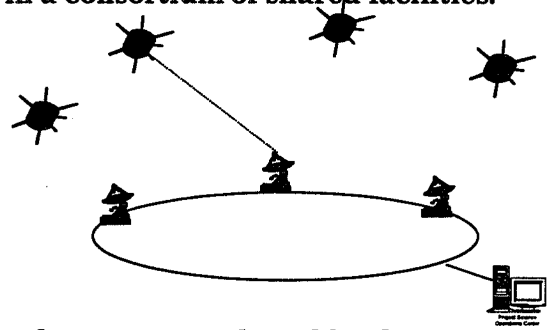
- **Simple Automatic File Exchange is <u>only</u> that! Nevertheless, it is sufficient for commands and data.**
- **Provides a major benefit for space scientists with only a minor investment in development.**
- **Aims to use commercial equipment and practices.**
- **Solves well known problems affecting IP in space by <u>avoiding</u> features that expose the problem.**

Technical Features

- **Pulls data files across the Internet with a read operation (like file read operation in NFS).**
- **Prearranged file names - no file discovery mechanism.**
- **UDP packets**
- **Congestion control at application level**
- **Simple solution to the Mobile IP problem**

Final Goal

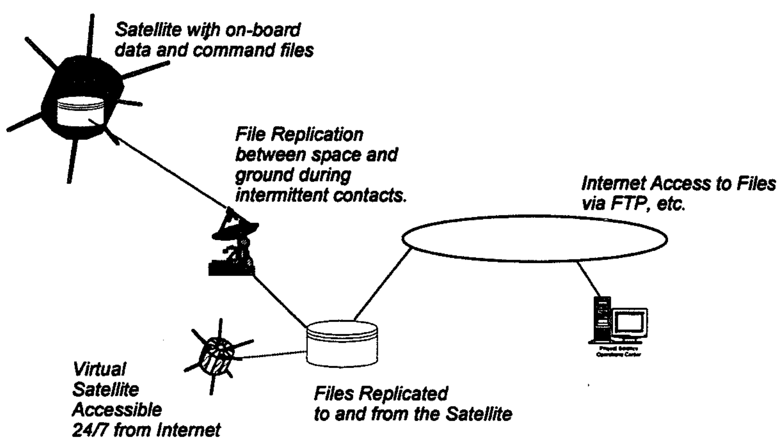
Fleets of Small Satellites will report back to data centers operated directly by the project by means of occasional communication contact with ground stations in a consortium of shared facilities.



The ground systems are shared by the project data centers and all are connected via an Internet. There are no operational costs for routine command uploads or instrument data downloads.

Operations with a Replicated File Protocol

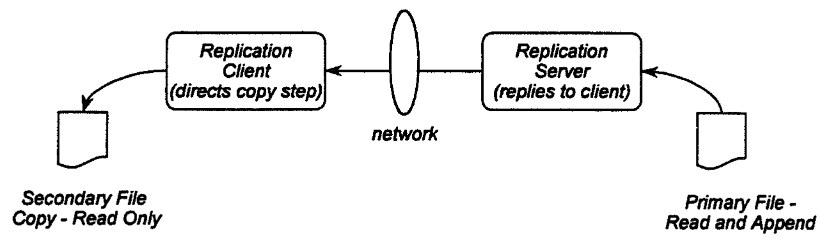
Space-ground data operations require no manual scheduling and supervision. Projects manage data processing over the Internet.



Fundamental File Exchange Operation

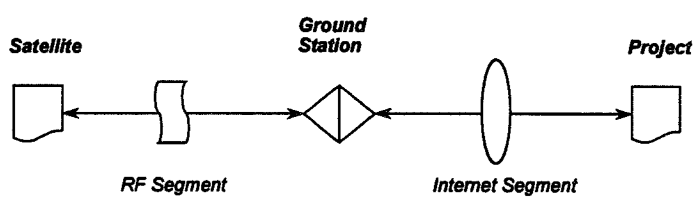
SAFE copies files and copies them successfully even over intermittent connections with a high bandwidth*delay product and high bit error rate.

The copy operation is connectionless - there is no time lost establishing and maintaining TCP connections.



Ground Station Acts As Gateway

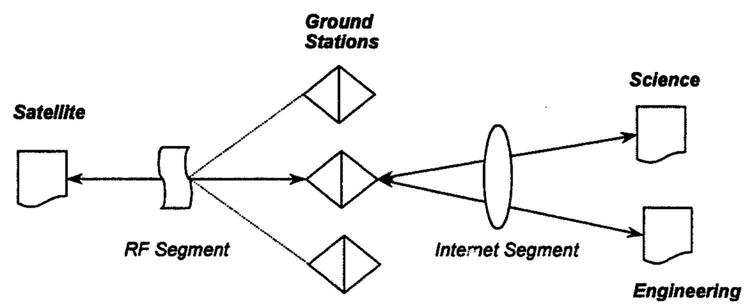
Each connection passes through the ground station, which acts as an intermediate connection point.



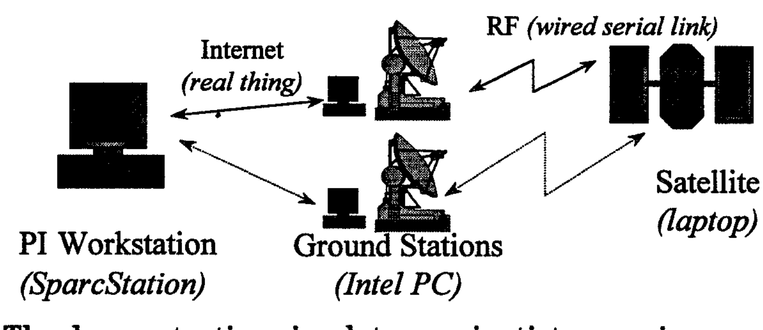
Multiple Ground Stations and Destinations

A satellite may connect with multiple points on the Internet, e.g., the scientists at one location and spacecraft bus engineers at a second.

Moreover, a satellite may use several ground stations at different points in its orbit. Conversely, a ground station may serve several satellites in turn.



Demonstration of SAFE



The demonstration simulates a scientist accessing instrument data and sending commands via file replication.

- **Satellite instrument writes data to onboard file which is automatically replicated to the scientist's workstation.**
- **Scientist writes instrument commands to local file which is replicated to satellite.**

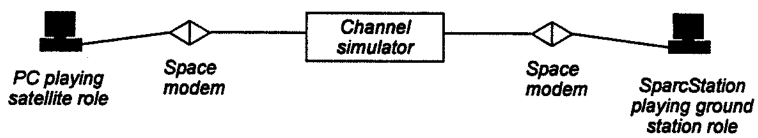
Testing SAFE

Purpose:

- **Run file transfers with realistic light-travel-time delays and bit-error rate and study the effect on the data transfer rate.**

Equipment:

- **Provided by the IPIC project (TCP-over-satellite test suite).**
- **Satellite Modems for IP are COTS but not space-qualified.**
- **FYI, we are using PC to play the satellite role but IPIC runs a single-board embedded computer for better realism during TCP tests.**



Lessons Learned from Implementation

The low-cost operational scenario is realistic and easy to implement with the automatic file exchange system.

UDP is reasonably effective - on a par with other alternatives.

Congestion control is essential but troublesome.

- **Congestion control is built into TCP, but TCP assumes all packet loss is due to congestion and the control overreacts when packets are lost due to line noise and data drop-outs.**
- **No congestion control built into UDP - the nodes can saturate routers.**
- **Congestion control is built into the file exchange software of SAFE and has been optimized for connections that have line errors as well as congestion.**
- **Optimization for a noisy space-link connected to a congested Internet is a difficult problem that needs further research - or better - an avoidance mechanism.**

Feedback

The implementation has been demonstrated for many engineers - who had important comments:

- **The key impediment is the lack of space-qualified hardware that supports any commercial network protocol.**
- **Many existing satellites systems have an uplink bandwidth that is too small to allow an error-correcting protocol of any kind. Tradition is slow to change.**
- **There is an important type of mission cannot be accommodated by an Internet connection because the required bandwidth during a pass is too high. The Internet bandwidth is adequate for the average data rate but not the peak bandwidth during a pass.**

Future Initiatives

Create Opportunities for Use in Space

- **Need to proselytize for IP so that there are customers for commercial, space-qualified, IP hardware.**

Specification of SAFE

- **leading to an acquisition of an implementation from a commercial vendor who currently markets similar SW (any vendor with NFS or RPC protocols).**

Small systems demonstration to show feasibility for very small satellites.

- **Current demonstrations use 486 PCs.**
- **Considering implementation for single-board VxWorks computer.**
- **Considering demonstration on palmtop computers.**

Applications with high bandwidth requirements

- **low priority - imaging sciences tolerate packet losses.**
- **no "simple" solution, see "Details"**

Contact Information

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NASA Goddard Space Flight Center
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We thank David Sames for his support and contributions to this work. He has recently left the project.

Web Sites:

Global Science and Technology: http://www.gst.com

Project Working Papers: http://abita.gst.com/node.htm

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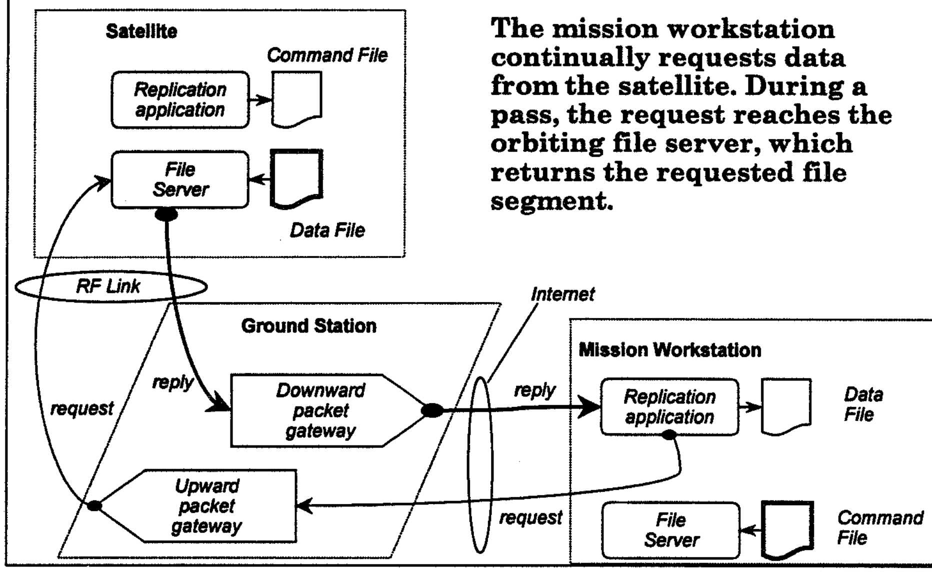
Additional Details

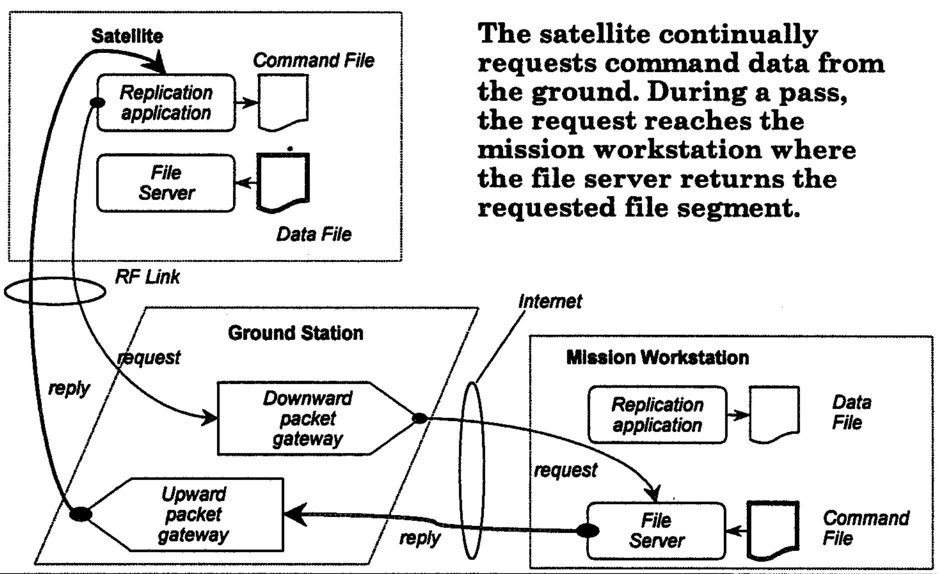
- **File Exchange Operations**
- **Mobile IP Solution**

File Exchange for Satellite to Ground



The mission workstation continually requests data from the satellite. During a pass, the request reaches the orbiting file server, which returns the requested file segment.

File Exchange for Ground to Satellite



The satellite continually requests command data from the ground. During a pass, the request reaches the mission workstation where the file server returns the requested file segment.

Basic Gateway Functions

Upward Packet Gateway:

- **Identify packet as intended for satellite. (Use port number and optional security verification)**
- **Convert to space link format (if different) and forward.**

Downward Packet Gateway:

- **Convert to IP format (if different).**
- **Insert IP address of gateway as source address of packet.**
- **Forward packet to recipient's address on Internet.**

Packet conversions

- **None required if satellite link uses IP Modems.**
- **Generally need to add/remove IP headers if IP was not used on the link to the satellite.**

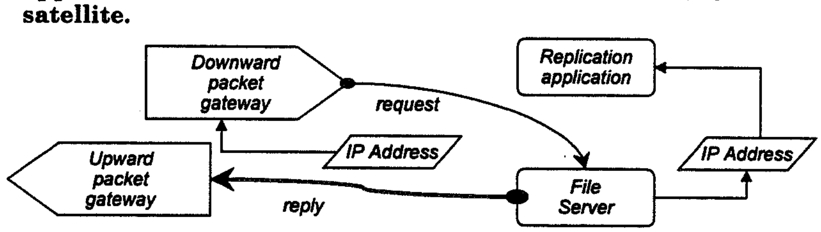
Mobile IP for SAFE

Problem:

- **The satellite connects to the Internet at the ground station and must use a local IP address.**
- **The satellite's IP address changes from one ground station to another.**
- **Future enhancements to IP protocol have been slow to arrive.**

Interim solution

- **Ground station applies local address to packets from satellite.**
- **The file server in the Mission computer notifies the replication application when it learns the current IP address of the satellite.**



Satellite Telemetry & Command Using Big LEO Mobile Telecommunications Systems

Fred Huegel, NASA Goddard Space Flight Center
Code 568

June 2, 1998

Objective

- Use Commercial Global Satellite Mobile Telecommunications Systems (Big LEOs) to provide Telemetry and Command Services to user satellites in LEO
  - The user spacecraft's transceiver would be a space qualified version of the systems User Terminal (mobile phone)
- Globalstar, ICO and Iridium have been studied

Targeted Capabilities

- Provide real time contact to LEO user satellites with a simple phone call
- Provide the capability for the satellite to "phone home"
- Command and telemetry data rates of 8K bits/sec
  - Higher rates with data compression
- At least one 5 minute contact per orbit
- Small, low power, low cost transceiver
- Simple omni antenna system
- Secure link

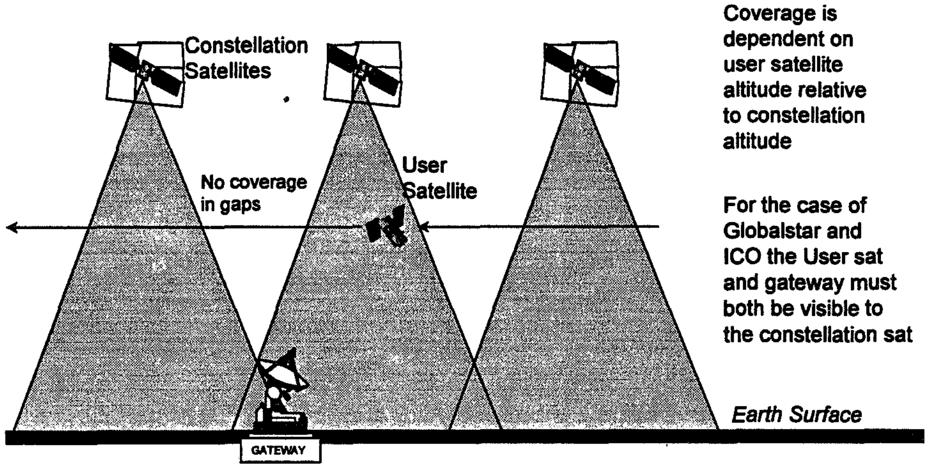
Rational - Make use of the Billions of $ of privately funded infrastructure to provide :

- Reduced Mission Communications System Cost
  - Reduces or eliminates the cost of ground stations and associated infrastructure
  - Eliminates the need for frequency assignments
  - Low cost transceiver, small size, low mass and low power
- Flexibility in Science Operations
  - Event monitoring and immediate reporting
  - Quick look data evaluation
  - Several Contacts per orbit possible
  - Real time access to user satellites from remote locations

Communications Satellite Constellations Studied

- Globalstar - LEO - operational in mid 99
- Iridium - LEO - operational mid 98
- ICO Global Communications - MEO - operational in mid 2000

Contact Limitations



Coverage is dependent on user satellite altitude relative to constellation altitude

For the case of Globalstar and ICO the User sat and gateway must both be visible to the constellation sat

Capabilities - Iridium

- The fairly low constellation orbit (780 KM) precludes significant coverage of user satellites
  - In general contacts are very short with large coverage gaps
  - Polar orbiting user satellites are an exception - adequate coverage is available in this case due to co-orbiting of the user sat with the constellation satellites
  - Data rates limited to 2400 bits/sec
- Possible use of crosslinks has been investigated
  - Could provide excellent coverage and Mbit/sec data rates
  - User Satellite would "take over" the intersatellite link
  - Technically feasible but not deemed operationally feasible by Iridium

Capabilities - ICO Global

- Excellent coverage for orbits up to 900 km
  - One 10 to 30 minute contact per orbit using only one gateway
  - Optimal coverage at 52° inclination
- Front end Doppler compensation required
- Data rates limited to 2400 bits/sec

Capabilities - Globalstar

- Good coverage for orbits up to 600 Km with inclinations up to 57°
  - The lower the orbit the better the coverage. Optimal coverage at 52° inclination
  - Better than one contact per orbit at 400 km using 4 gateways
  - contacts range from 5 to 18 minutes, the average is 11 minutes at 400 Km, 52° inclination
- No front end Doppler compensation required
  - Range rate between Globalstar satellite and user satellite no greater than that experienced for a user on the Earth's surface 90% of the time

Globalstar (Continued)

- Data rates up to 8 Kbits/sec possible
- At an orbit of 400km, 52° inclination
  - Total contact time per day is about 264 minutes
  - Total downlink per day is 127 Mbits
  - Average outage time is 56 minutes
- Initial feasibility study with Globalstar/Space Systems Loral completed 12/96
  - System issues identified
  - Link analysis performed
  - No show stoppers identified

Globalstar Link Analysis

- Assumptions
  - Omnidirectional coverage required
  - Coverage over full Globalstar FOV (108°)
  - Eb/No requirement as specified in FCC filing
  - Maximum link range used for a user satellite in a 300 Km altitude
  - Single Globalstar in view (no signal combining)
  - Maximum transmission rate of 9.6 kbps
  - On average during a pass 0 dB of additional dynamically supplied additional power required.
- Link closes under the following conditions
  - Transmit switch used rather than splitter
  - Low loss cabling used (Gore ~ 0.2dB/Ft)
  - Low noise amplifiers are located at the antennas

Globalstar Issues

- Protection of Radio Astronomy Sites (RAS)
  - Sensitive in the 1610.6 MHz to 1613,8 MHz range (Globalstar return link)
  - Requires operation at the upper end of the assigned L Band frequency range as well as the use of a transmit band reject filter
  - Or restrict operations when near an active RAS site (reduces potential contact opportunities)
- Location information required
  - Normal call handling procedures require the location of the user
    - This is normally determined by the Globalstar system but will not work for Space applications
  - Location can be determined by on board ephemeris or GPS and entered into the transceiver

Flight Transceiver

- Derivative of fixed User Terminal
  - easily adaptable for position input
  - Control and data interface to the spacecraft C&DH
- Size and weight are driven by the band reject filter
  - Approximate size 8 by 6 by 3 inches
  - Approximate weight is 7 pounds
- Power
  - Standby, 1.5 watts
  - Transmit, 20 watts

Security

- Gateway to User Satellite
  - CDMA inherently secure (spread spectrum system)
  - Encryption of traffic channels part of Globalstar baseline
- Ground segment
  - Call acceptance filtering by ground system blocks unauthorized calls
  - Phone numbers can be re-assigned if necessary
  - Use of unlisted phone numbers

Conclusions

- Feasibility study with Globalstar indicates that spacecraft command and telemetry through commercial telecommunications satellite constellations is feasible with little or no modifications to the system architecture
- The user would connect to their spacecraft via telephone/modem
- Frequent contact opportunities would be available
- Data rates are limited but adequate for command/telemetry and quick look science
- Further studies of the Globalstar and ICO systems are needed to better define the capabilities, limitations, and system impacts of the Space Mobile Service

Key Benefits

- Facilitator for low cost LEO missions such as University Explorers (UNEX), Small Explorers (SMEX) and others
  - Could provide significant savings per mission
  - Users pay only monthly access fee and per minute charges
- Provides flexibility and simplification in mission operations
  - Enhanced access to spacecraft

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Session 3
Architectures and Network Simulations

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Satellite System Architectural Issues for:
Broadband Interactive Multimedia Communications

Gary Johanson
Chief Architect
Nortel Satellite Network Solutions

Topics

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- Driving Forces
- What is Webtone? What is Satellite Webtone?
- Terrestrial and Satellite Comparison
- Network Dynamics
- Research Topics
- Planning and Tools
- Challenges

Internet / Intranet Growth

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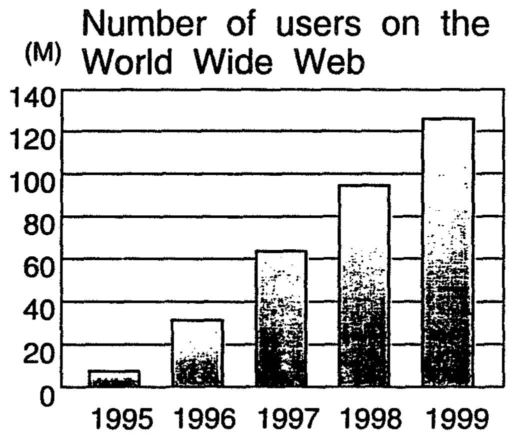

Source: International Data Corporation

VITAL ISSUES
Transport Networks – Increasing SDH & SONET bandwidth
Internet – Access network bandwidth and throughput – Security
Reliability
Service on demand

- **Intranet servers will outsell Internet servers by more than 10 to 1 by the turn of the century**
- **Intranet market will grow to $20 billion by the year 2000**

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The Demand for Multimedia Services

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Internet Users (Worldwide)

	Users (M)
1996	60
2001	300

Source: Data Communications Sep-97

Computers Connected to Internet

	Units (M)
1996	48
1997	82
2001	268

Source: Computer Reseller News Sep-97

Internet Users (Worldwide)

	Users (M)
1997	60
2001	175
2007	1,000

Source: Washington Technology/IDC Oct-97

Fortune 1000 Companies Planning to Implement IP Telephony

	%
1997	12%
1998	29%
1999	42%
2000+	69%
no plan	31%

Source: Computer Reseller News Oct-97

Spending on Intranet & Extranet Products & Comm Services

	US $ Billion
1996	19
2000	55

Source: Beyond Computing/Zona Research Oct-97

Source: Computer Industry Forecasts First Quarter 1998

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Satellite-Terrestrial Convergence

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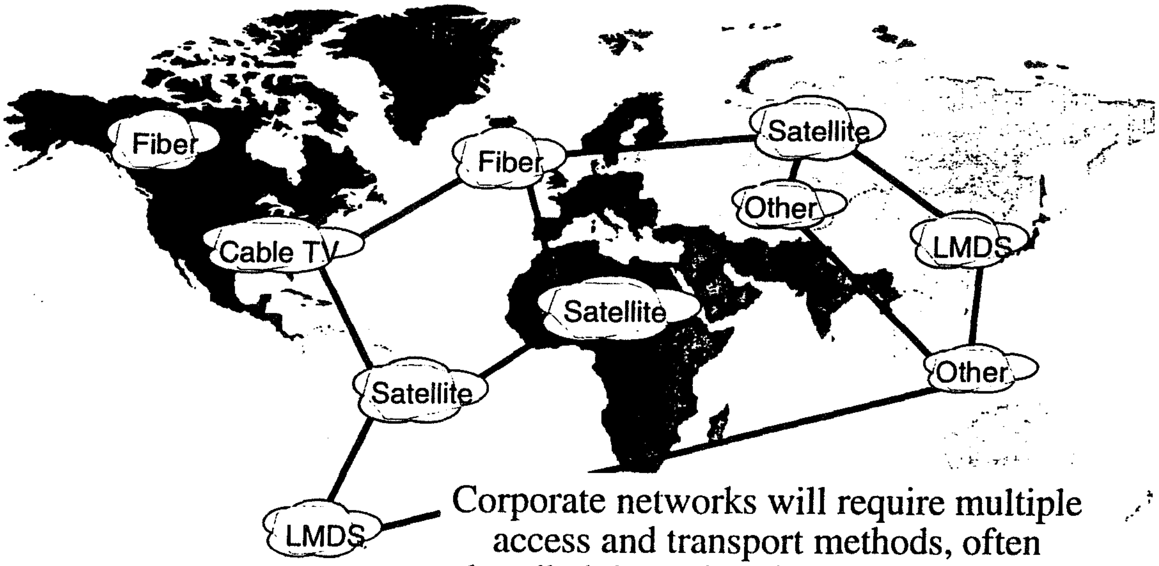

Corporate networks will require multiple access and transport methods, often bundled through a single telecom or IS vendor

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Corporate Expansion Considerations

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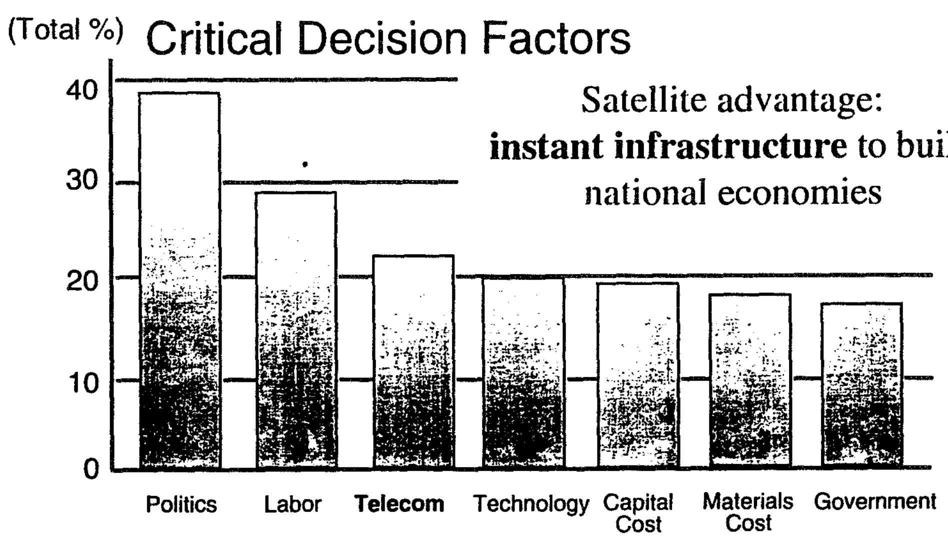

Satellite advantage: **instant infrastructure** to build national economies

SOURCE: Gallup survey for BT/MCI 1996

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Satellite Broadband Market Forecasts

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- Broadband Satellite Systems investments in Space and Ground Segments
  - *$76B over the next 10 years*
- Broadband Satellite Service Revenues
  - *$350B over the next 10 years*
- Broadband Satellite Data Subscribers
  - *36 million over the next 10 years*
- Broadband Satellites Deployed
  - *505 satellites over the next 10 years*

Source : Pioneer Report 1997

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Today's Networks

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	TODAY
	Internet Access
ACCESS	Cumbersome Method/Devices
CAPACITY	Not Dynamic
QUALITY	Intermittent
SECURITY	Intermittent
ECONOMIC EQUATION	Questionable Economics
Private Networks	**Service Capability to Meet Specific Needs and Priorities**
Public Networks	**Early Stages**

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Evolution to Multimedia

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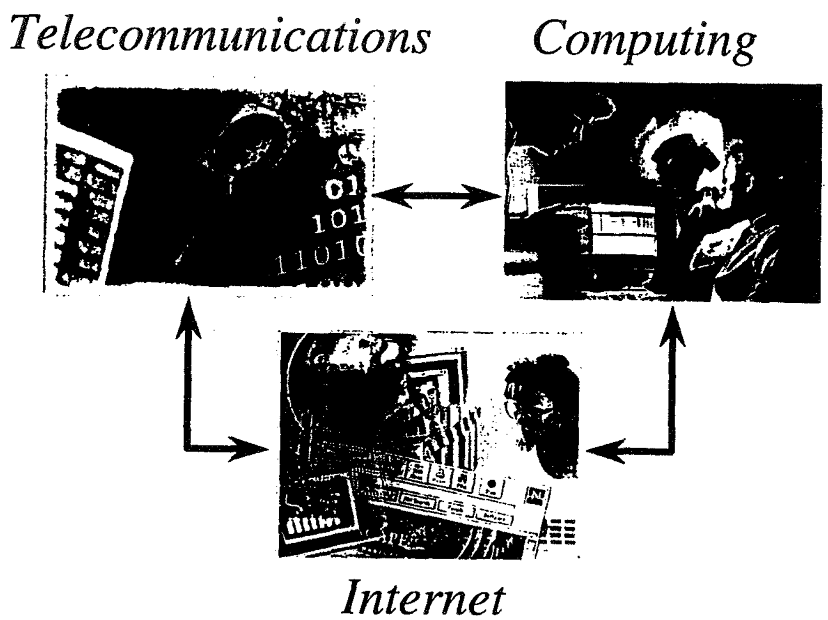

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Dialtone → "Webtone"

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	TODAY Internet Access	TOMORROW "Webtone"
ACCESS	Cumbersome Method/Devices	Easy Access
CAPACITY	Not Dynamic	Dynamic/Flexible On-Demand
QUALITY	Intermittent	PSTN Quality
SECURITY	Intermittent	Security Guaranteed
ECONOMIC EQUATION	Questionable Economics	Viable Business Cases
Private Networks	**Service Capability to Meet Specific Needs and Priorities**	**Enhanced Flexibility**
Public Networks	**Early Stages**	**"Webtone"**

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Supporting Webtone Demand

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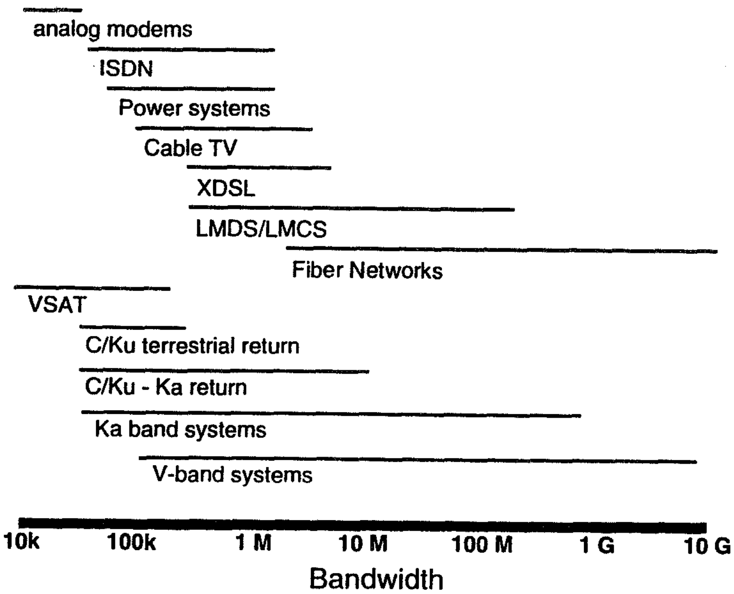
Access Media are:

- Competing and complementary
- Evolutionary
- Capital-intensive

and

- No single solution will help all users



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What is Satellite Webtone?

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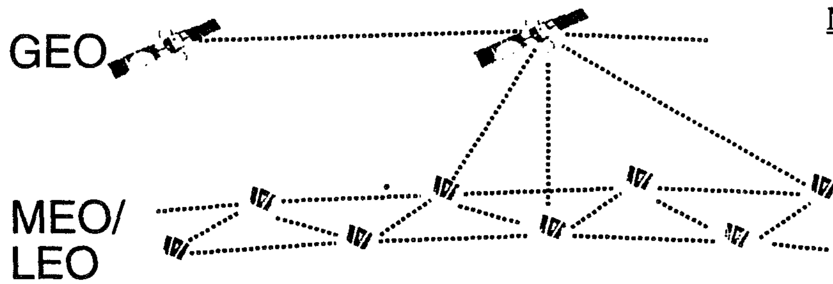


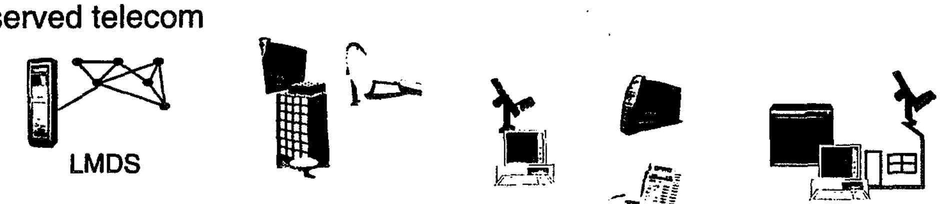
Network Advantages

- ***Ubiquitous coverage***
- ***Instant availability***
- ***Broadcast data***
- ***High capacity***
- ***Spot beam reuse***

- ***Global deployment***
- ***Low latency***

User Applications

Carrier / ISP	Business	SOHO	Consumer
• Network hub	• Inter/intranet	• Internet	• Internet/web
• VPN	• Multimedia	• Multimedia	• Entertainment Convergence
• Interconnection	• Global networks	• Wideband	
• Unserved telecom			



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Fundamental Dynamics of Networks

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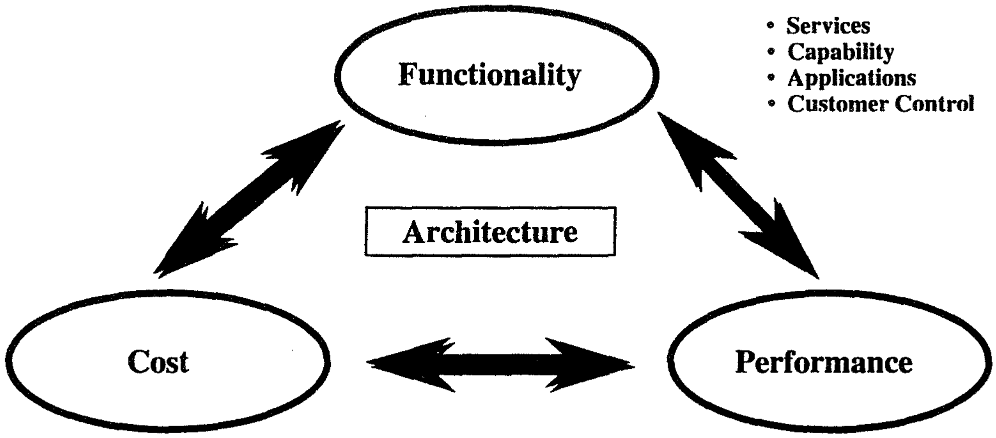
- Services
- Capability
- Applications
- Customer Control



- Capital
- Operations & Maintenance
- Advertising
- Inter-connection

- Blocking
- Post Dial Delay
- Voice Quality
- Bit Error rate

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Nortel's R&D on BSN

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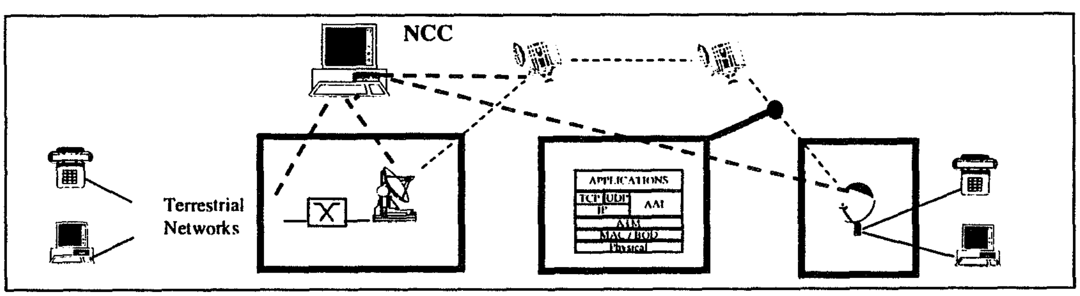

Hub/GW Architecture **MM Air Interface** **SAU**

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Major Network Design Considerations

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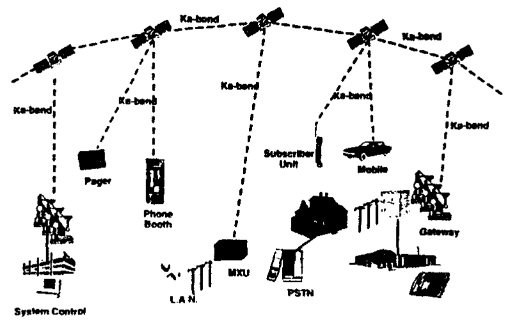
- Traffic Distribution and Load Balancing
- Traffic Smoothing
- Signaling
- Resource Management
- Routing
- Admission and Congestion Control
- Performance Assessment
- Number of Gateways and Their Location
- End-to-End Quality of Service and GoS
- Hand-off Issues
- Distribution of Services
- Distribution of Control
- Interfaces to Terrestrial Networks
- Cost Analysis

Satellite Network
Design & Architecture



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Required Planning Capabilities

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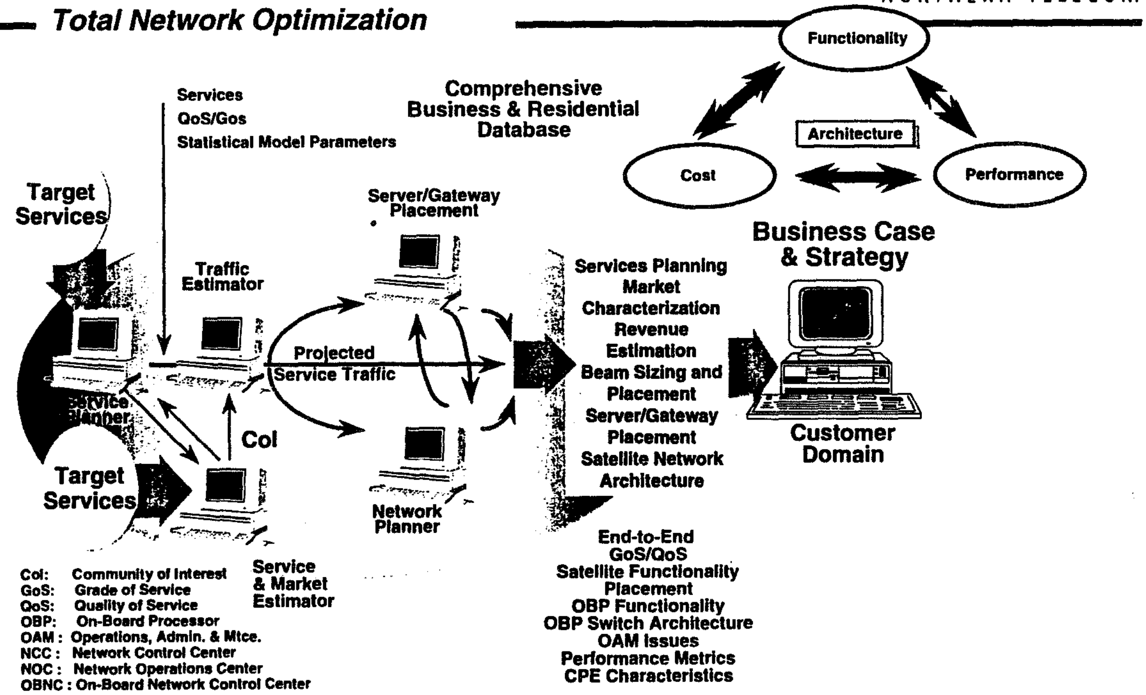
Total Network Optimization



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Tool Requirements

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Examples of Nortel Tools:

- **Service Planner**
- **Traffic Estimator**
- **Market & Service**
- **Server/Gateway Placement Tool**
- **Network Planner**
- **Tools to simulate behavior of target satellite systems**
- **Tools for multi-media traffic models, node models, link models, and satellite mobility models**
- **Tools to assess end-to-end QoS/GoS and subscriber capacity parameters for:**
  - ***variety of Call Admission Control and Routing algorithms***
  - ***variety of medium access algorithms***
  - ***innovative combinations of integrated network architecture***
  - ***variety of transport technology (ATM, Frame Relay, TDM, IP,...)***
- **Tools for OA&M**

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Main Networking Challenges

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Static Architecture Challenges:

- Air Interface: uplink, downlink, ISLs
- Functional Partitioning: on-board vs. on-ground
- End-to-End Resource Management: BOD, CAC, routing, policing...
- Service and Protocols Adaptation: TCP,...
- Performance: billable bandwidth, end-to-end QoS and GoS,...
- Signaling Protocol Design & Verification: message flows, timing
- NCC: number, location, connectivity...
- Dimensioning

Mobile Architecture Challenges: above +:

- Constellation Design: tear drop, coverage areas, ISLs
- Satellite Mobility Effects: path length
- Routing: optimise to decrease on-board processing and storage requirements
- Handover

Exception Handling Risk Areas:

- System Reliability and Robustness
- Availability: assessment, guarantees, verification
- Remote Diagnostics: protocols, satellite vs. terrestrial transport, impact

Network Management:

- Information Architecture: design, test and validation

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Internal Program Thrusts

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- Distribution of functionalities among network elements for networks including satellites.
- Architectures for LEO/MEO/GEO-based BSN.
- Impact of inclusion of satellite in multimedia networks including QoS and performance issues as well as signaling.
- Design of bandwidth on demand protocols, simulation and validation of their performance.
- Charging and dynamic resource control associated with bandwidth on demand.
- End-to-end resource management to provide end-to-end QoS and GoS.
- Design, optimization, simulation, and performance enhancements of routing algorithms for multimedia traffic over satellite (LEOs and GEOs).
- ATM over satellite, IP over satellite.
- Performance assessment of OB switch architecture.
- Dimensioning.
- Network Management & Control.
- Adaptation of existing standards and methodologies to adapt to satellite segment of a global network. Includes signaling (e.g. Q2931).
- Service adaptation.

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Summary

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- Satellite Webtone is coming
  - *Webtone attributes are a necessity*
  - *High connectivity*
  - *Multi-application, multi-network*
- Many new opportunities for operators - old and new for new services
- Results - a large market potential on a global basis
- Many challenges remain

June 2, 1998

Gary Johanson

SIMULATION OF A NASA LEO SATELLITE HYBRID NETWORK

by

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OBJECTIVE

Investigate the performance of TCP/IP in a hybrid network consisting of a global terrestrial network and a LEO satellite by simulation.

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Satellite LEO - circular orbit at 650 km altitude
- 52 degrees inclination
- FTP server
- Transmission and reception at 9600 bps

Houston, United States
- Central node of a star topology
- FTP client
- Terrestrial transmission and reception at DS0 (64 kbps)
- Radio transmission and reception at 9600 bps

Seoul, South Korea; Canberra, Australia; Toulouse, France; India; Saudi Arabia; Central Africa; Brazil
- Above terrestrial nodes connected to Houston
- Terrestrial transmission and reception at DS0 (64 kbps)
- Radio transmission and reception at 9600 bps

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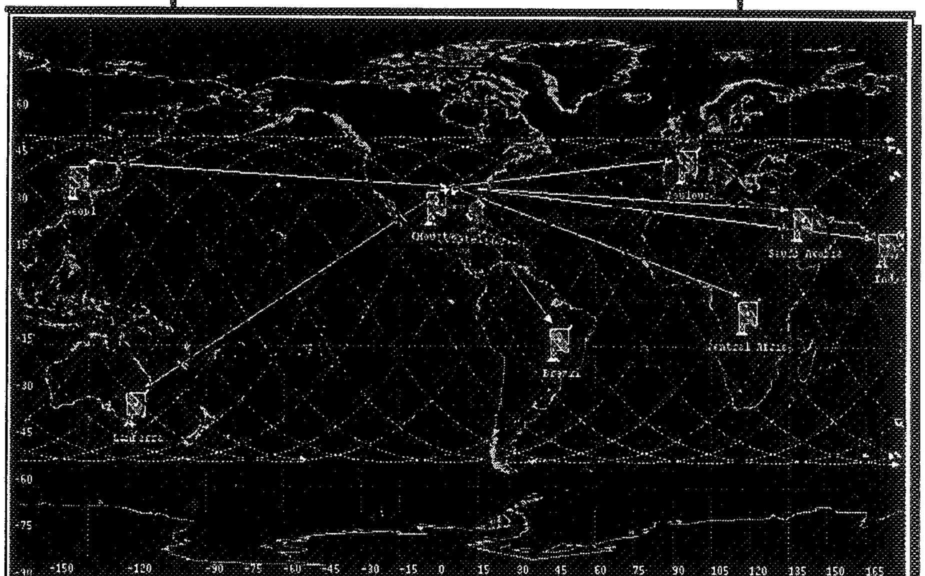

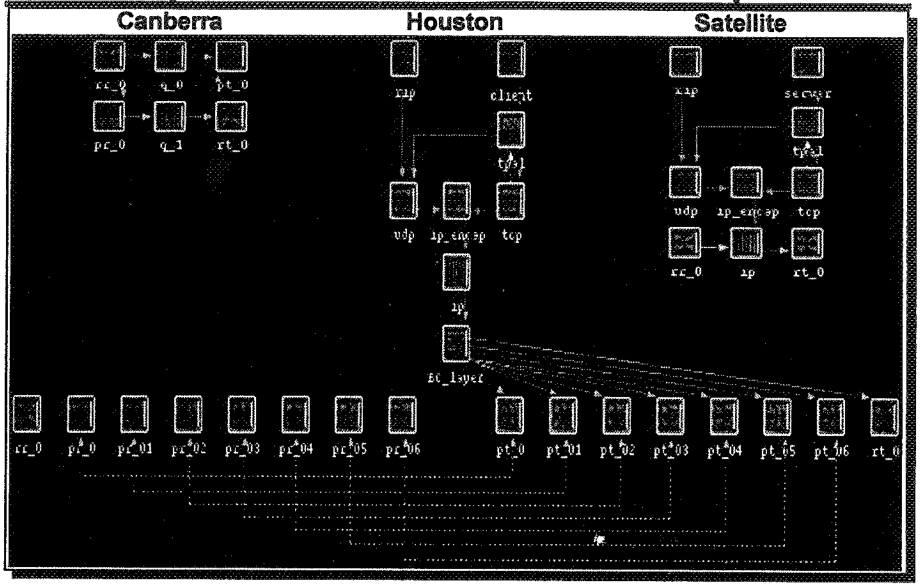

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TCP simulation includes

- Connection establishment and closing using three-way handshaking
- Flow control
- End-to-end reliability
- Reordering of the data at the receiver
- Slow-start congestion avoidance and control

FTP simulations

- Average size of the file modeled using a normal distribution
- Generation rate for sessions modeled using a Poisson process

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Simulation results for 60 KB, 300 KB, and 1500 KB files

- Throughput
- End-to-end delay
- Satellite transmitter queue size (7500 KB files)
- Canberra receiver queue size (7500 KB files)
- Client congestion windows
- Server congestion windows
- Client-server congestion windows

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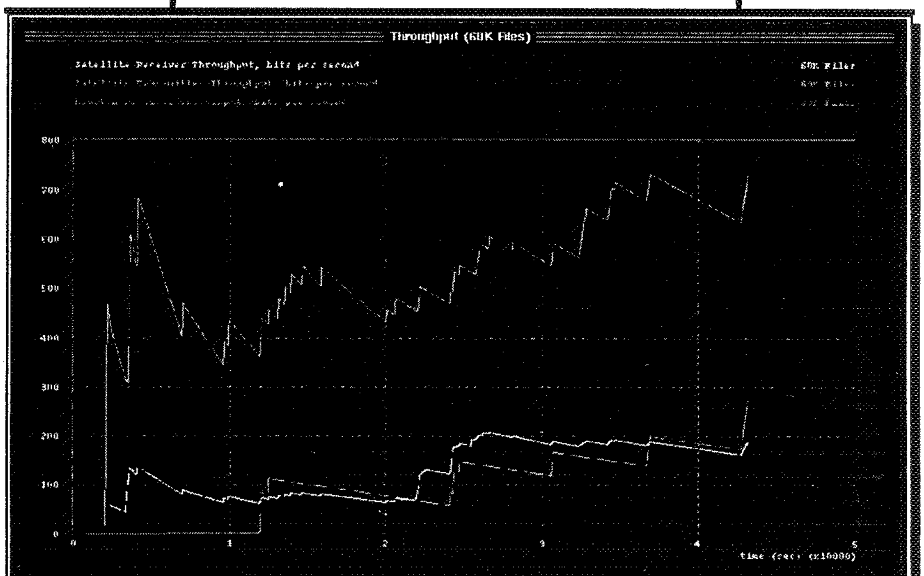

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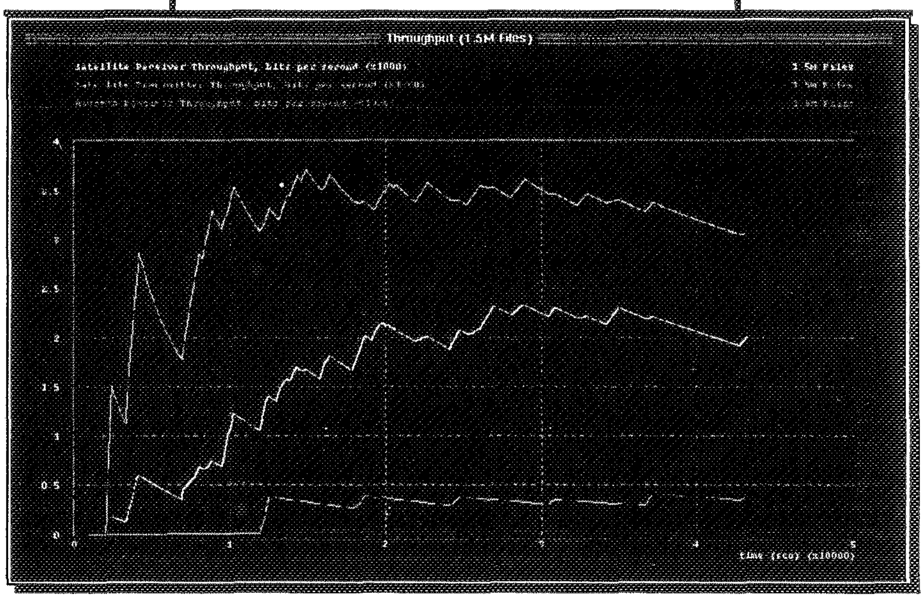

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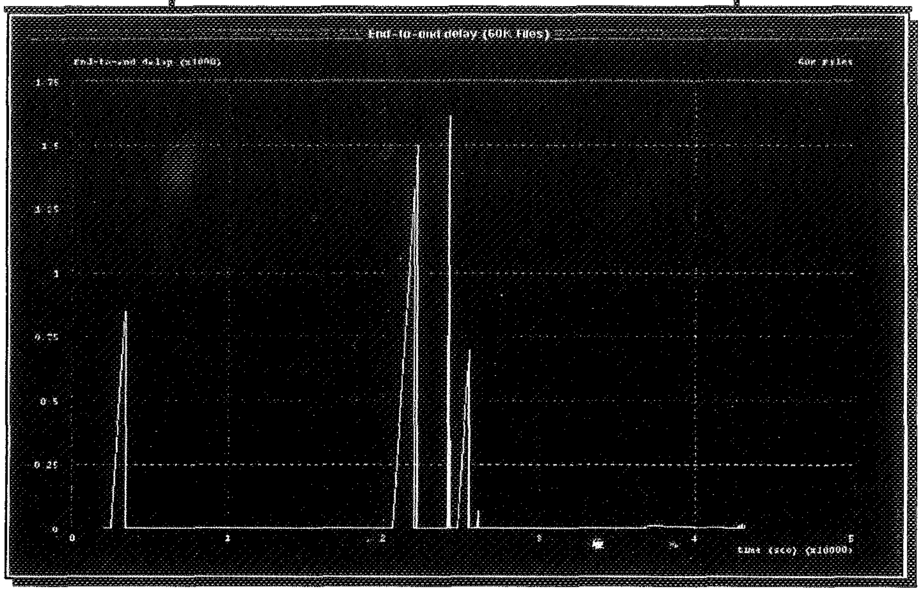

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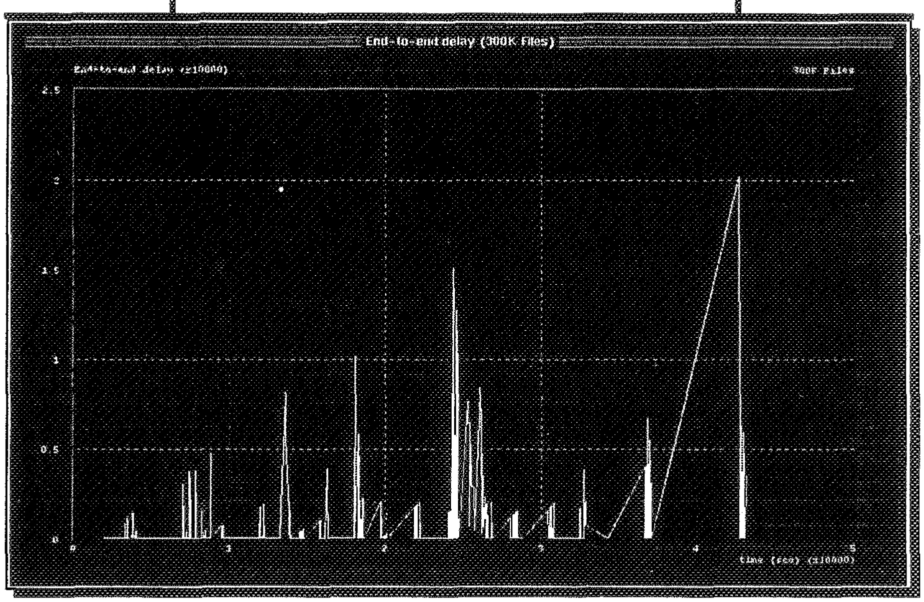

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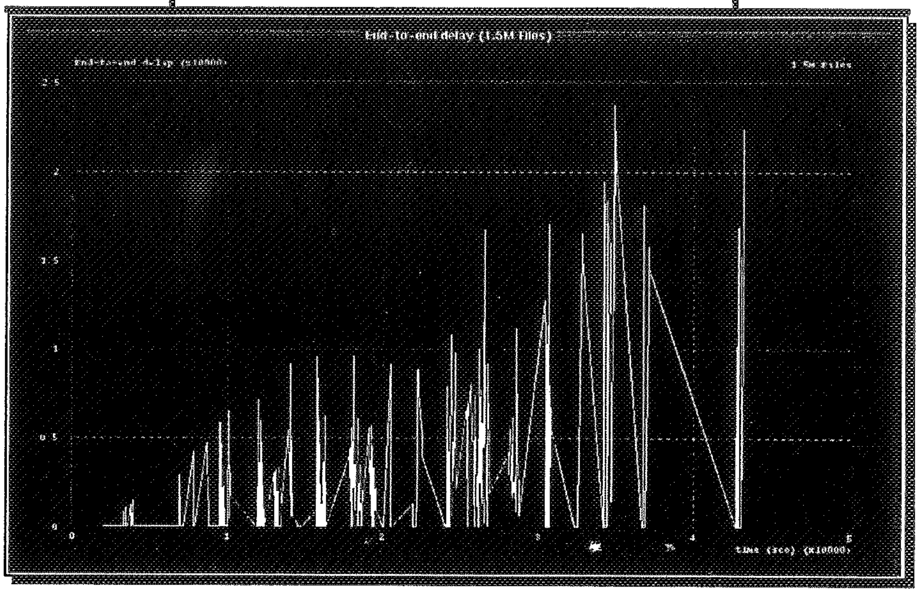

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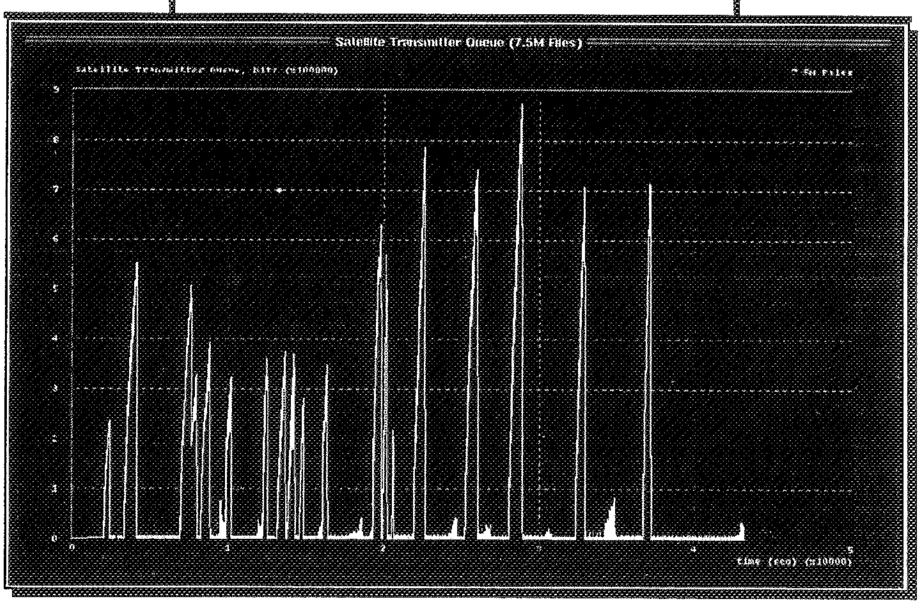

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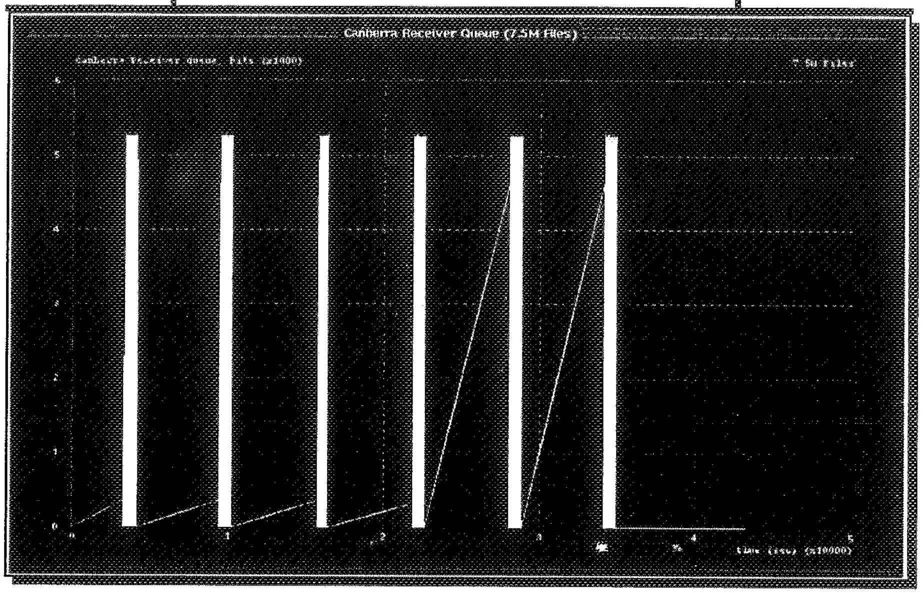

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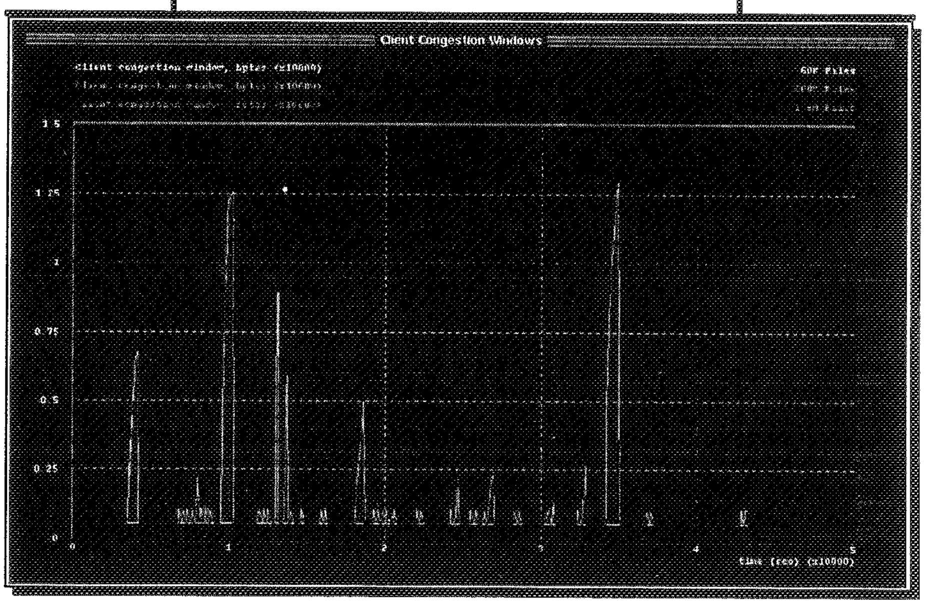

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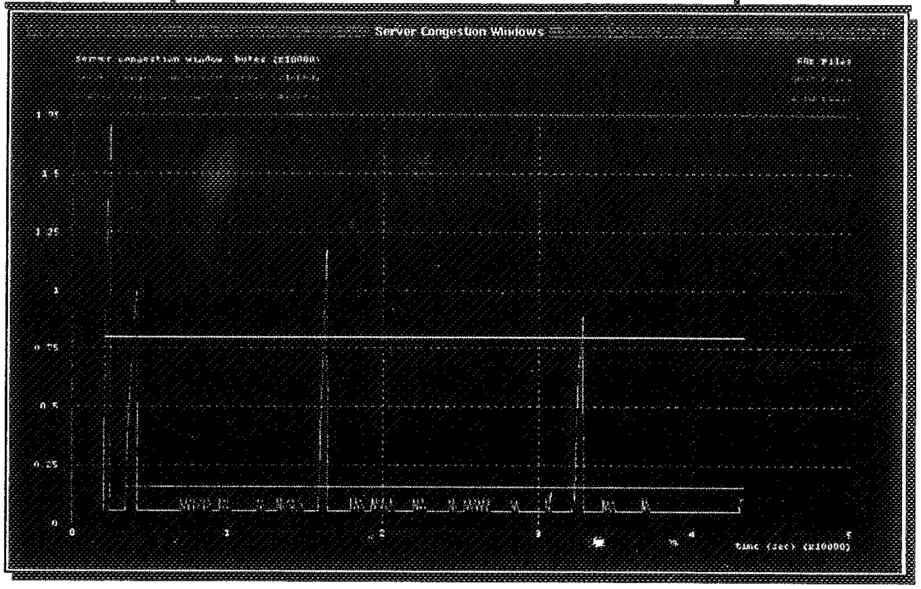

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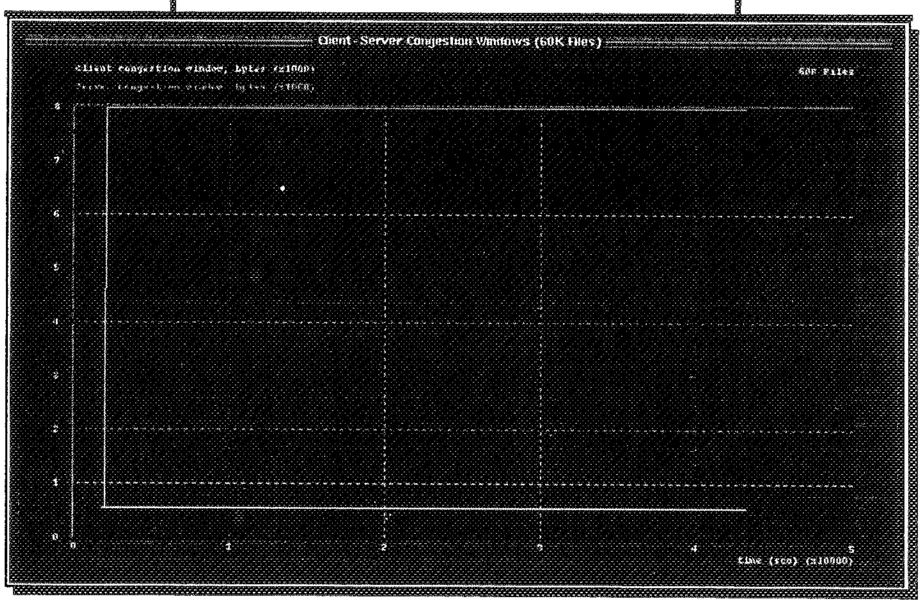

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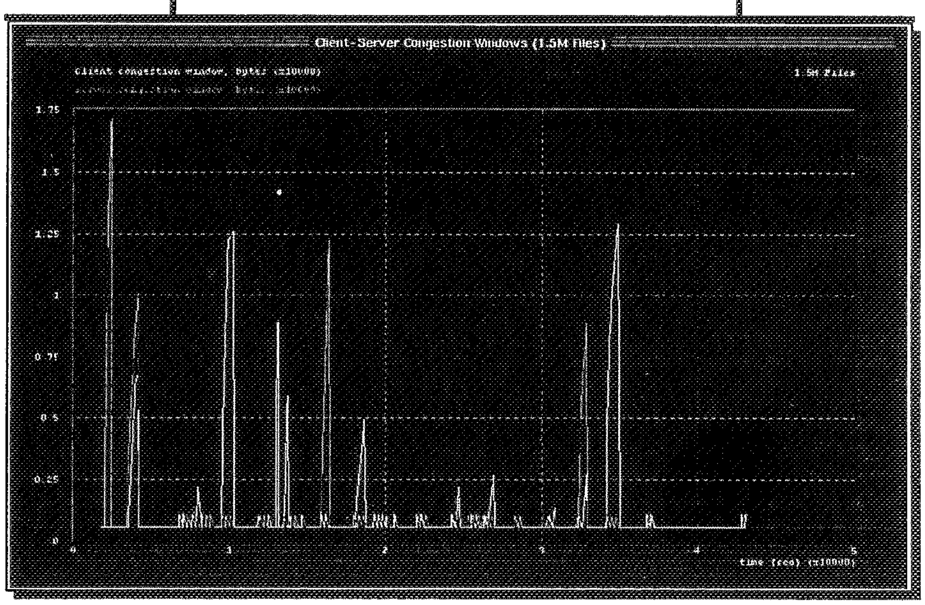

CONCLUSIONS

- The satellite transmitter average throughput saturates for large files.
  (~ 3500 bps)
- Houston receiver average throughput inconclusive.
  (radio reception only)
- Frequent, large End-to-end delays for large files.
  (small % increase for file size increase)
- Infrequent, small End-to-end delays for small files.
  (large % increase for file size increase)
- Queueing delays at the terrestrial nodes are not significant.
- TCP slow-start algorithm degrades the performance for large files.

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Multi-Media Traffic Modeling and End-to-End QoS Evaluation Tools for Satellite Networks

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Modern Network Characteristics

- **Substantial network size**
- **Complex network architecture**
- **Multi-media traffic**
  - distinct statistical features
  - different quality of service (QOS) requirements
  - high data rates
- **Network protocols must guarantee end-to-end QOS for all traffic types**
- **Mixture of transport (switching) modes present**
  - circuit-switching
  - packet switching/cell switching (ATM)
  - hybrid switching

Unique Features of Approach

- **New Class of Accurate and Flexible Models for Multi-Media Traffic**
  - Markov-Modulated Rate Processes (MMRP)
  - Fractal Renewal Processes (FRP)
- **Characterization of End-to-End QOS via Accurate and Time-Efficient Approximations and Confidence Intervals**
  - QOS for circuit-switched networks
  - QOS for packet-switched and cell-switched (ATM) networks
  - QOS for hybrid switched networks
- **Efficient Protocol Design Based on Optimizing End-to-End QOS**
  - connection admission control
  - dynamic bandwidth allocation
  - routing/congestion control
  - switching/buffer management

High Data Rate Satellite Networks

Approach

- Apply multimedia traffic modeling tools to traffic types and data rates of interest (images, video, data, voice) to specific HDR applications
- Use satellite orbit modeling tool to model dynamics of intersatellite links
- Use tools for QoS fast evaluation for comparisons of alternative on-board switching architectures
- Use tools for QoS fast evaluation for end-to-end performance measures (delay, throughput, blocking rate, dropping (loss) rate) and performance measures at intermediate nodes (buffer overflow rate, queuing delay, average queue size, queue length distribution)
- Use sensitivity analysis tools for fast evaluation of variations of QoS w.r.t. traffic loads, link capacities, buffer sizes
- Use optimization-based techniques and efficient simulation for trade-off analysis and systems engineering.

Tool Sets

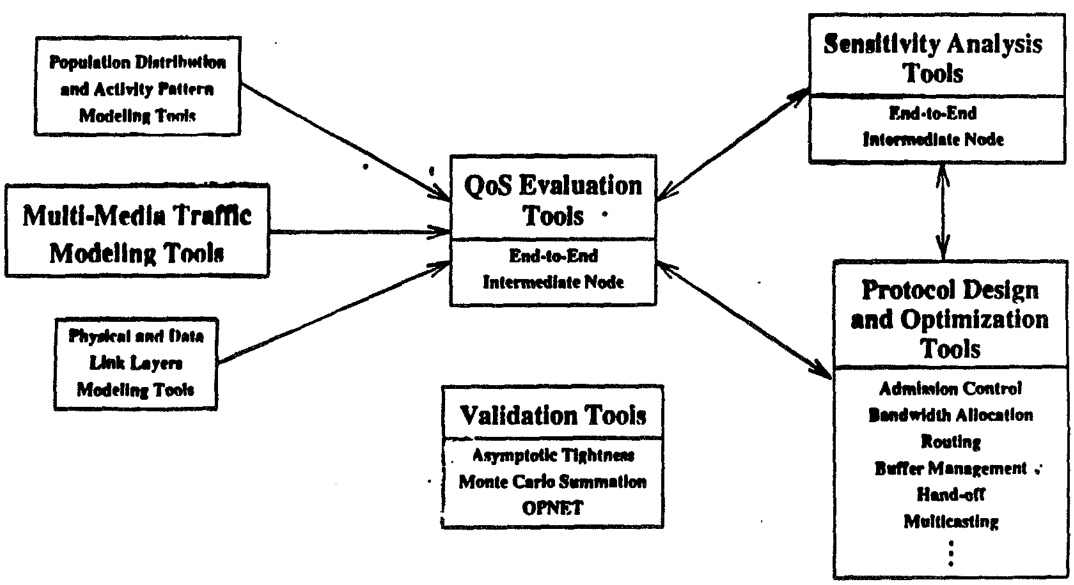
Generic :

- Circuit-switched Multi-media Networks
- Virtual Circuit-switched Multi-media Networks
  (connection-oriented ATM traffic)
- Cell-switched Multi-media Networks
  (connectionless ATM traffic)
- Packet-switched Multi-media Networks
  (datagram-type traffic)

Specialized by Application :

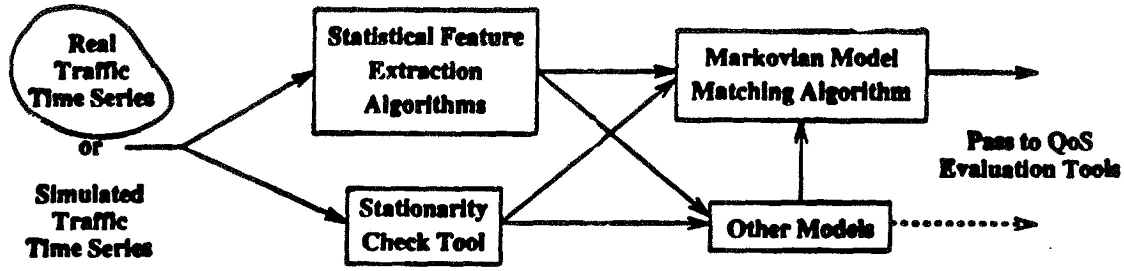
- Networks of LEO, MEO and GEO Satellites
- Wireless Multi-media Networks (indoor, WLANs, cellular and PCS)
- Wireline Multi-media Networks (B-ISDN, ATM, FDDI, DQDB)
- Hybrid Networks

Tool Modules



Modes of Tool Operation:
Stand Alone
Used with Simulation Tools (e.g., OPNET, BONES)

Multi-Media Traffic Modeling Tools



Multi-Media Traffic List:

Arbitrary CBR Traffic
Arbitrary VBR Traffic
Voice
Video
Image
Data
⋮

Statistical Features:

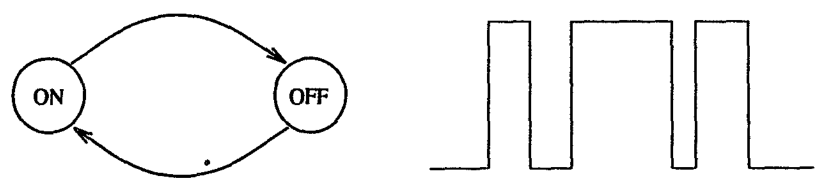
Average Rate
Peak Rate
Frequency of Bursts
Burst Size (Average, Maximum)
Rate Histogram
Temporal Correlation (Time-Domain):
First, Second and Higher Order Autocorrelation
Spectra (Frequency-Domain):
Spectrum, Bispectrum and Trispectrum

Markovian Models Matched to Parameters and Functions:

MMRP
Modified MMRP

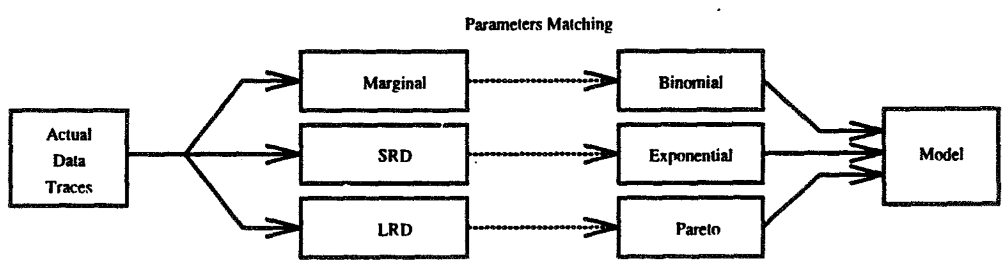
Other Models:

Self-Similar Process
Fractal Renewal Process

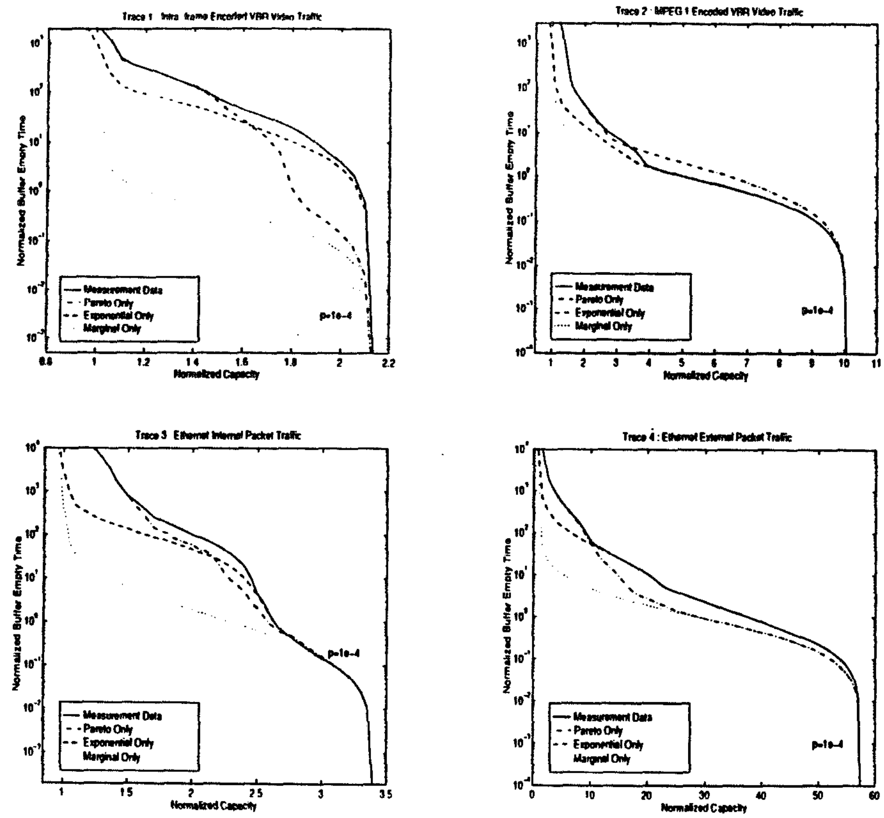


State Diagram A Sample Traffic Process

Characteristics of an On-Off Source



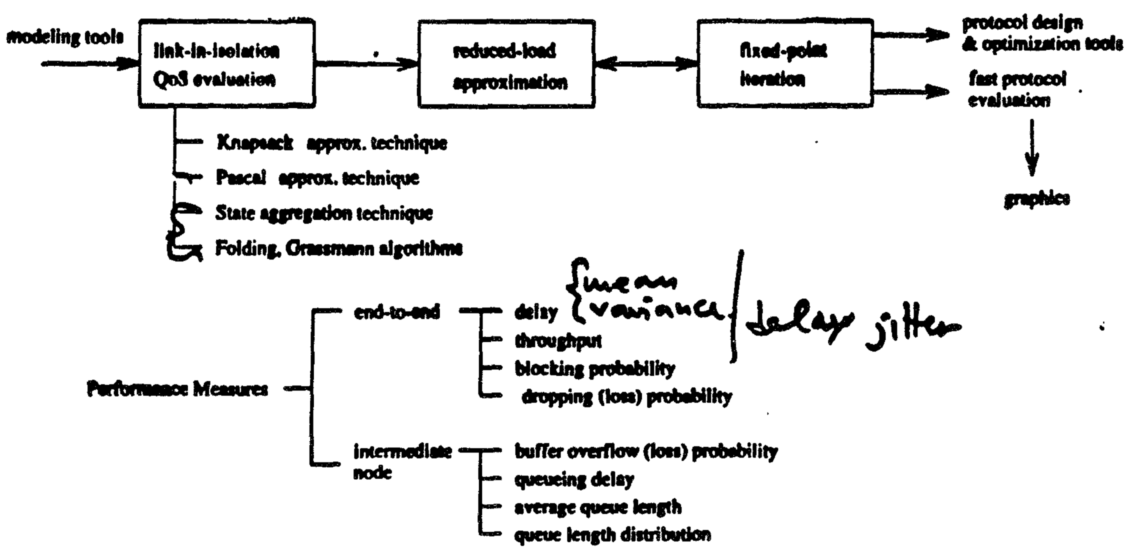
Modeling of Actual Data Traces Using On-Off Sources



Summary of Simulation Results for On-Off Source Modeling

Multi-Media QoS Evaluation Tool

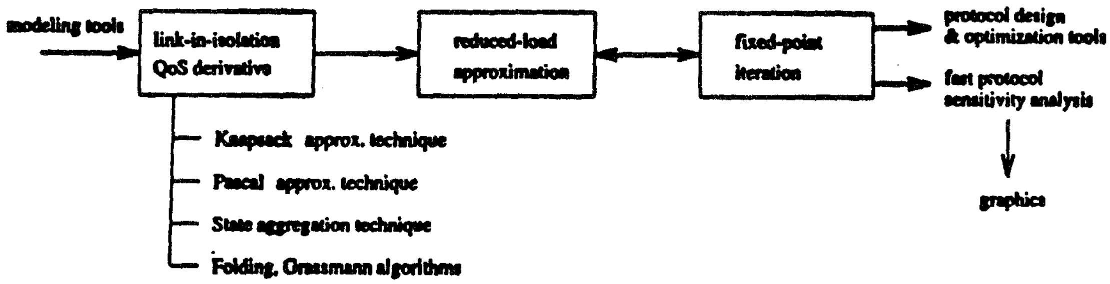
- end-to-end
- intermediate node



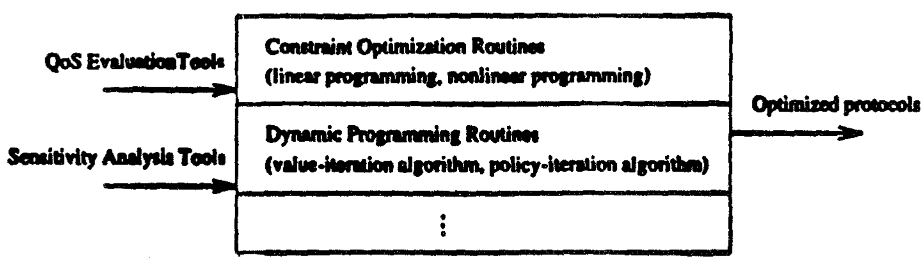
Sensitivity Analysis Tool

— end-to-end
— intermediate node

Compute derivatives of QoS w.r.t. — traffic loads
— link capacities
— model parameters



Tools for Protocol Design and Optimization

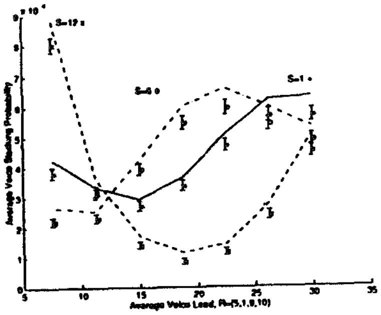


List of Potential Applications :

Admission Control	Multicasting
Bandwidth Allocation	Multiple Satellite Diversity
Routing	Satellite Handoff
Buffer Management	Hierarchical Overlays and Handoffs
Switch Design	Interface with PSTN, Cellular and PCS
Flow Control	Parallel Multi-channel Demodulation

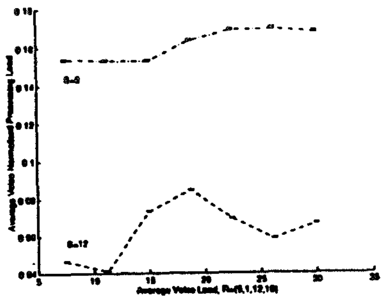
PARADIGM 1:

Near-Optimal Bandwidth Allocation for Multi-Media Virtual Circuit Switched Networks

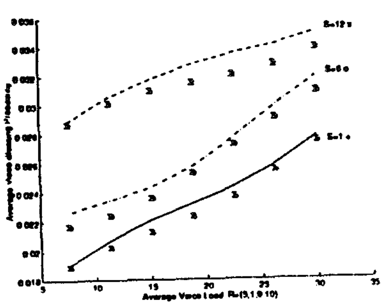


Avg. Voice Block. Prob. $R = (5, 1, 9, 10)$

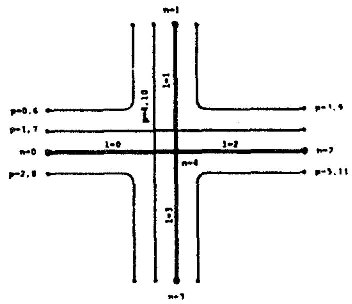
Path p	Nodes n	Links l	Traffic type
0,6	0,1	0,1	Voice; Video
1,7	0,2	0,2	Voice; Video
2,8	0,3	0,3	Voice; Video
3,9	1,2	1,2	Voice; Video
4,10	1,3	1,3	Voice; Video
5,11	2,3	2,3	Voice; Video



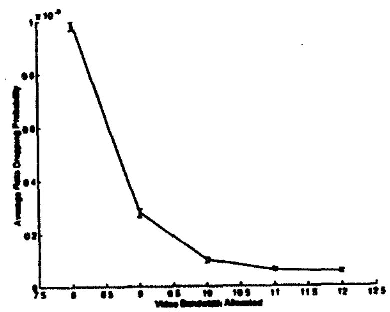
Avg. Voice Normal. Process. Loads $R = (5, 1, 12, 10)$



Avg. Video Block. Prob. $R = (5, 1, 9, 10)$



The Star Network



Avg. Video Rate Drop. Prob. $S = 1, \bar{\rho}^a = 7.5$

Near-Optimal Bandwidth Allocation for Multi-Media Virtual Circuit Switched Networks

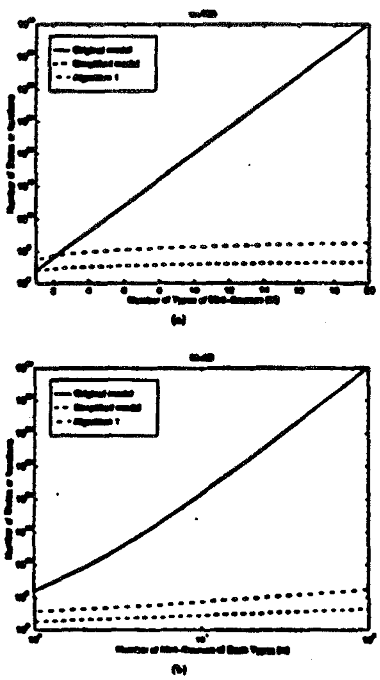
- Voice and video calls are transported in a connection-oriented fashion using virtual circuits.
- Packet switching is used for data traffic.
- Priorities of voice and video traffic are assumed to be higher than that of data.
- Values of the blocking probabilities for voice and video traffic, normalized voice processing loads, video rate dropping probabilities, and data queueing probabilities are obtained using a time-efficient approximation through the reduced-load method.
- The bandwidth allocated to a video call and the step size of a voice virtual path are varied.
- The performance measures of the network can thus be controlled and optimized.

	Approximations	Exact Analysis	Monte Carlo
Complexity	$O(10c^2\|\mathcal{P}\|\|\mathcal{L}\|)$	$O(2\|\mathcal{P}\|c^{(M+3)\|\mathcal{P}\|})$	$O(N(M+3)\|\mathcal{P}\|^2\|\mathcal{L}\|)$
Time	1-2 minutes	Prohibitive	15-30 CPU hours

Table 1: Complexity Analysis

($|\mathcal{P}|$ – number of paths, $|\mathcal{L}|$ – number of links, M – video model's parameter.)

Paradigm 2: Efficient Computation of End-to-End Performance for ATM Network with Multi-Media Traffic



Comparison of Model Dimensionality and Algorithm Complexity

Comparisons of Exact and Approximate Results

$w_1 = 30$, $T_{ON1} = 400$ ms, $T_{OFF1} = 600$ ms, $r_1 = 64$ Kbps,
$w_2 = 20$, $T_{ON2} = 386$ ms, $T_{OFF2} = 765$ ms, $r_2 = 1.14$ Mbps,
Packet Size = 512 bits, Buffer Size = 200 packets.
E: exact A: approximate

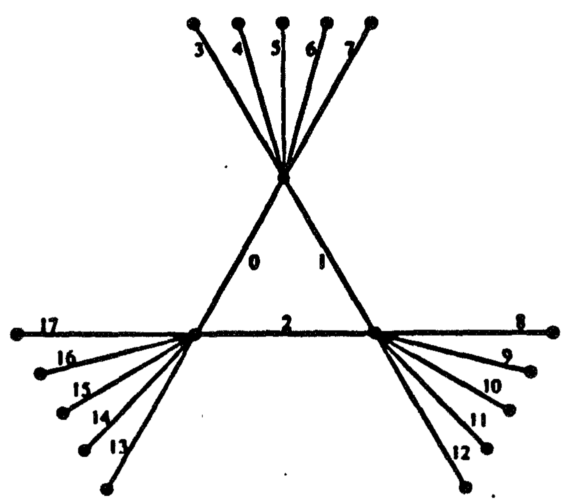
λ		$\bar{Q}$	δ_Q	$\bar{W}(ms)$	P_E	$R_L(\%)$	$R_{L1}(\%)$	$R_{L2}(\%)$
.60	E	1.61	15.26	.098	.400	.053	.029	.055
	A	1.59	15.12	.097	.400	.051	.026	.054
.70	E	11.42	41.64	.699	.304	.565	.341	.588
	A	11.32	41.46	.693	.304	.556	.314	.580
.80	E	34.74	68.98	2.16	.219	2.33	1.53	2.41
	A	34.67	68.81	2.16	.218	2.31	1.42	2.40
.90	E	66.23	86.40	4.27	.151	5.63	3.96	5.80
	A	66.18	86.27	4.27	.150	5.61	3.69	5.80
.95	E	82.30	91.05	5.43	.123	7.73	5.58	7.95
	A	82.18	91.13	5.42	.123	7.70	5.20	7.95

Paradigm 2 (continued)

ATM Loop Network Problem

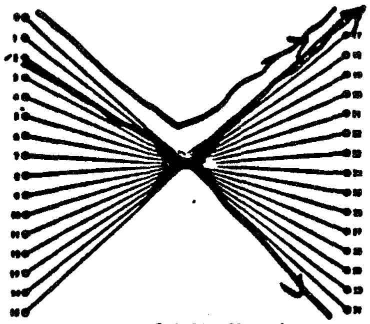
$T_{ON1} = 40$ ms, $T_{OFF1} = 60$ ms, $r_1 = 16$ Kbps,
$T_{ON2} = 400$ ms, $T_{OFF2} = 600$ ms, $r_2 = 64$ Kbps,
$T_{ON3} = 386$ ms, $T_{OFF3} = 765$ ms, $r_3 = 1.14$ Mbps,
Packet Size = 512 bits, Buffer Size = 50 packets,
Link Capacity = 30 Mbps for Link 0-2,
Link Capacity = 3 Mbps for Link 3-17.
A: analysis S: simulation

Path	w_1	w_2	w_3		$\bar{R}_{L1}$	$\bar{R}_{L2}$	$\bar{R}_{L3}$	$\bar{D}$(ms)
3-1-2	6	7	5	A	.0371	.0386	.0766	2.85
				S	.0543	.0468	.0892	2.94
4-1-2	4	5	7	A	.1024	.1050	.1711	4.73
				S	.0913	.0868	.1475	4.32
5-1-2	5	7	4	A	.0184	.0193	.0434	1.77
				S	.0270	.0170	.0449	1.84
6-1-2	3	9	6	A	.0730	.0753	.1324	3.85
				S	.0698	.0850	.1502	4.04
7-1-2	8	6	7	A	.1067	.1094	.1771	4.74
				S	.1266	.1015	.1722	4.83

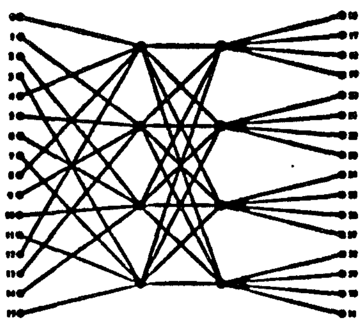


A Loop ATM Network

Paradigm 3: Comparison of ATM Star and Banyan Switching Networks under Multi-Media Traffic



16 × 16 Star Switching Network



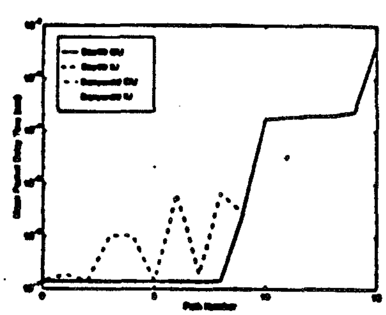
16 × 16 Banyan Switching Network with 4 × 4 Elements

Traffic Pattern for Switching Networks

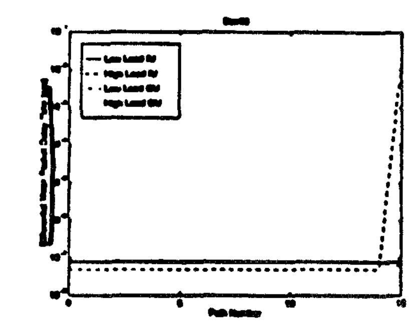
$T_{ON1} = 40\ ms$, $T_{OFF1} = 60\ ms$, $r_1 = 16\ Kbps$,
$T_{ON2} = 400\ ms$, $T_{OFF2} = 600\ ms$, $r_2 = 64\ Kbps$,
$T_{ON3} = 386\ ms$, $T_{OFF3} = 765\ ms$, $r_3 = 1.14\ Mbps$,
Packet Size = 512 bits, Link Capacity = 60 $Mbps$.

Path	v_1	v_2	v_3	Rate($Mbps$)	Output	Intput
0	5	3	4	1.638	28	12
1	5	5	4	1.689	23	7
2	6	5	4	1.696	29	13
3	5	4	5	2.046	24	8
4	6	4	5	2.052	25	9
5	7	5	5	2.084	30	14
6	8	5	5	2.091	16	0
7	5	7	5	2.123	20	4
8	7	7	5	2.136	17	1
9	7	8	6	2.543	22	6
10	4	6	7	2.855	26	10
11	6	6	7	2.868	19	3
12	7	6	7	2.875	21	5
13	3	7	7	2.875	27	11
14	6	7	7	2.894	31	15
15	6	7	8	3.276	18	2

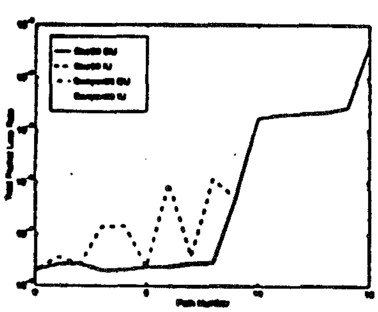
Paradigm 3 (continued)



(a)

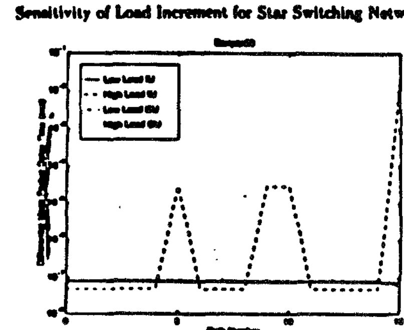


Sensitivity of Load Increment for Star Switching Networks



(b)

Comparison of Star and Banyan Switching Networks



Sensitivity of Load Increment for Banyan Switching Networks

Paradigm 4: Near-optimal Routing for Voice and Data Traffic in Multi-hop Networks

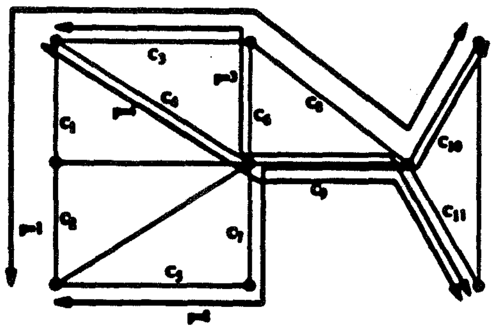


Figure 1 Test network 3 for the routing problem

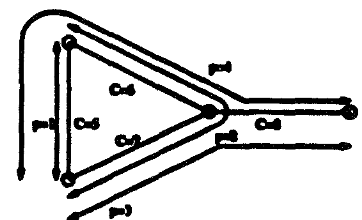


Figure 2 Test network 1 for the routing problem

Table 1 . Computational Effort Required for the Different Approximations and Network Models

Approximation Method	Network Paradigm 1		Network Paradigm 2		Network Paradigm 3	
	$\underline{c} = (90,100,110,120)$		$\underline{c} = (5,6,7,8)$		$\underline{c} = (60,60,60,60,60,60,60,60,60,70,70)$	
	$B_p, p \in \mathcal{P}$	$Q_\ell, \ell \in \mathcal{L}$	W^{vo}	W^{da}	W^{vo}	W^{da}
Exact	prohibitive	prohibitive	20 sec.	2 hr.	prohibitive	prohibitive
Monte Carlo	2 min.	25 min.	-	-	-	-
Knapsack	<1 sec.	2.5 sec.	3 sec.	20 min.	10 sec.	1 hr.
Pascal	<1 sec.	2.5 sec.	-	-	-	-

Paradigm 4 (continued)

Table 2 Comparison of Performance of Alternative Routing Policies for Voice Whose Order Are Obtained by Optimizing the Knapsack Approximation for Network in Figure 1.b.
Voice Activity Factor $\beta/(\alpha+\beta) = 0.4$, Vector of Voice Path Rates $\underline{r} = (2,2,1,1)$,
Capacity $\underline{c} = (5,6,7,8)$, Vector of Voice OD Pair Load $\underline{\rho}^v_\gamma = (1,2)$.

Path	Knapsack-Based Routing Rule					Optimal Routing Rule		
p	ρ^{v}_p	Q^v_l(Knapsack)	$\mu(\cdot)$	Q^v_l(Exact)	$\mu(\cdot)$	ρ^{v}_p	Q^v_l(Exact)	$\mu(\cdot)$
1	0.612417	0.100449	1	0.100468	1	0.571780	0.102006	1
2	0.387583	0.089162	2	0.081204	2	0.428242	0.086309	2
3	1.777150	0.010530	2	0.017813	2	1.722922	0.018615	2
4	0.222850	0.025143	1	0.022724	1	0.277078	0.025453	1
W^{vo}		3.260094		3.265140			3.265826	

Path	Resulting ρ^{v}_p	
p	Knapsack	Exact
1	1.488730	1.380388
2	2.501262	2.619602
3	0.930496	0.963279
4	1.080602	1.016731

Table 3 Comparison of Performance of Load Sharing Routing Policies for Data Obtained by Optimizing the Knapsack Approximation Given The Alternative Routing Rule of Voice Calls for Network in Figure 1.b.
Voice Activity Factor $\beta/(\alpha+\beta) = 0.4$, Vector of Voice Path Rates $\underline{r} = (2,2,1,1)$,
Capacity $\underline{c} = (5,6,7,8)$, Alternative Routing Order ((1,2),(1,2)),
Vector of Voice OD Pair Load $\underline{\rho}^v_\gamma = (1,2)$, Vector of Data OD Pair Load $\underline{\rho}^d_\gamma = (4,2)$.

Link	Knapsack-Based Routing Rule			Optimal Routing Rule	
l	ρ^{d}_l	Q^v_l(Knapsack)	Q^v_l(Exact)	ρ^{d}_l	Q^v_l(Exact)
1	2.469240	0.268851	0.266329	2.397119	0.268099
2	3.651764	0.240245	0.233406	3.636324	0.230150
3	3.330780	0.213672	0.212219	3.602881	0.225419
4	2.000000	0.008613	0.008747	2.000000	0.008745
W^{da}		12.133000	12.187588		12.192792

Characteristics of Internet Traffic for Planning Satellite Networks

Bachittar Singh Sembi
Brian Armbruster
VISTAR Telecommunications Inc.

Background

- The economics of a consumer satellite system heavily depends upon the number of people sharing a fixed amount of satellite bandwidth and the associated cost
- The bandwidth available to each active Internet customer determines the acceptability of the service
- Most Internet traffic numbers are available at the core networks and not at the individual access point to the network
- We need to improve our understanding of the bandwidth required by an individual user to evaluate if a satellite offering is viable

Objective

To improve our understanding of the bandwidth requirements for potential Internet services by the user:

- Search of the current literature
- Measure the traffic patterns of individual users
- Estimation from the consensus process of "Experts"

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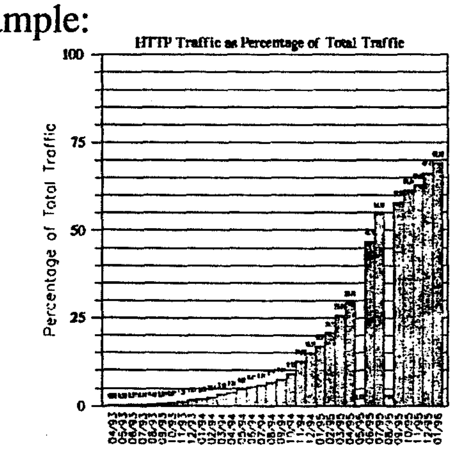
Internet based Communication Services

Various Internet based communication services need to be evaluated to determine overall capacity requirements of an individual user, for example:

- Email
- WWW
- Tele-education
- Tele-banking
-



WWW (http) traffic has grown from 0 to 70% in about 3 years. Internet traffic is predominately www

http://www.nlanr.net/NA/learn/daily.html

- Need to grasp WWW traffic, which is the key indicator with most traffic volume today
- Focus on WWW (http) as a first step

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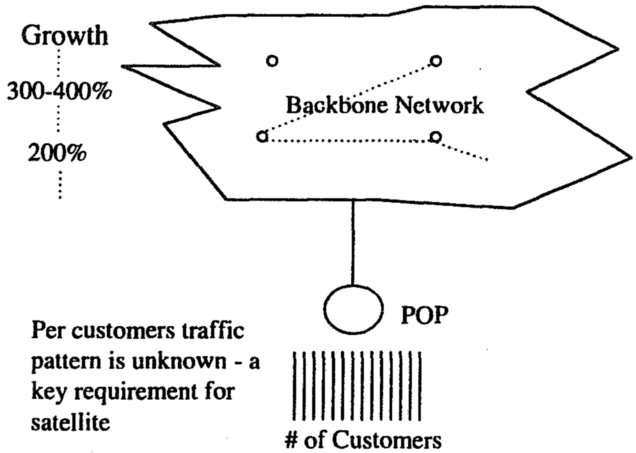
Internet growth patterns

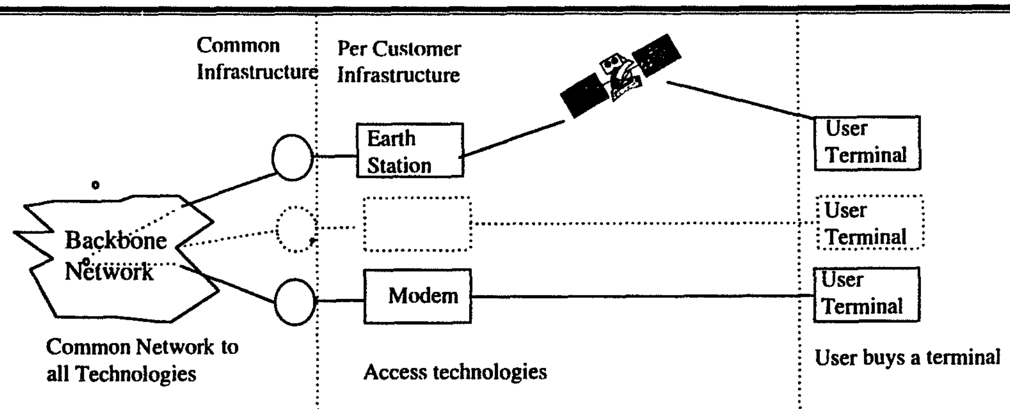


Prediction are subject to uncertainty such as:

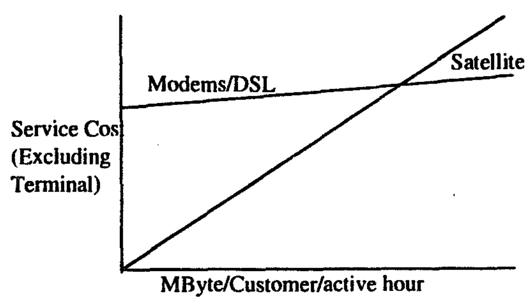
- Bandwidth prediction as services evolves
- Technology evolution impacts
- Role of Internet as compared to TV, phone
- Can the cost be cheap enough for mass market

Key Information for Access Service Providers is the bandwidth per active subscriber ("logged on") in each direction in the busy hour

Access Network Cost Model



- Satellite is a shared medium - Cost amortised over B/W used
- DSL has dedicated facilities to customer



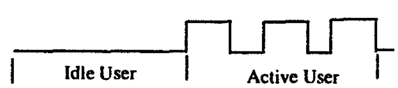
Search from the Current Literature

- Most published statistics about the Internet traffic are measured at the core of the network
- No easy way to determine an individual usage from the core statistics
- However, the search found:
  - One recent study
  - Provisioning information from a Canadian ISP service provider
  - The telco provisioning guidelines for ISP service providers

Model for Internet Browser Traffic

Assumptions for a Browser model

- Active users model
- Response file of 20 Kbytes
- Mean Inter-request time of 20 secs
- Request size is 400 bits
- Non-Modem access to Internet



Traffic is 20bps (w/o protocol o/h) from an active user

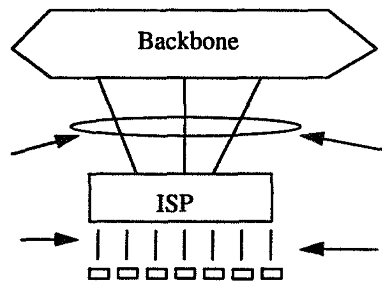
Traffic is 8kbps (w/o protocol o/h) to an active user

Traffic rate experienced by ISPs today is 2 - 4 kbps

Saulnier E.T, Esposito J, et al: Ka-band Satellite communications: The issues attending provision of two-way consumer services - 3rd Ka-band utilization conference. Sept 97

ISP Service Providers

Canadian ISP provisioning (>50k Subs)



Total Modems bw / Total Backbone bw is 10:1

# of Customers / # of Modems is 16:1

Average b/w to a subscriber is 180 bps
Average b/w to an active user is 2.8 kbps

- Access limited to 50-60 Hrs/month for fixed price (adequate for most users)
- No busy-tone provisioning policy

US West guidelines for an ISP

Total Modems bw / Total Backbone bw is 5:1

# of Customers / # of Modems is 10:1 to 20:1

Average b/w to a subscriber is 288 - 576 bps
Average b/w to an active user is 5.7 kbps

- Ratio of 10:1 recommended for high quality ISPs
- These numbers are from a US West's perspective, who sell bandwidth to ISPs

http://www.uswest.com/com/onthenet/connections/internetprovider/becomeIP3.html#anchorratios

Vistar Measurement of User Traffic

- A CNA personal traffic monitor tool was used to monitor the LAN traffic for a number of users on Vistar's LAN
- All users are business users who may use Internet during day time
- CNA traffic monitor is a software tool which runs on a PC and is primarily designed to monitor the performance of the LAN.
- No external hardware monitor was required for tapping the LAN

What was measured

- The number of bytes *to* and *from* a specific user for a period of time in 10 minutes samples.
- The objective here is not to measure instantaneous peaks, but total data over a period of time
- This data includes the Internet access and all other activity on the local LAN, such as printing, file server access

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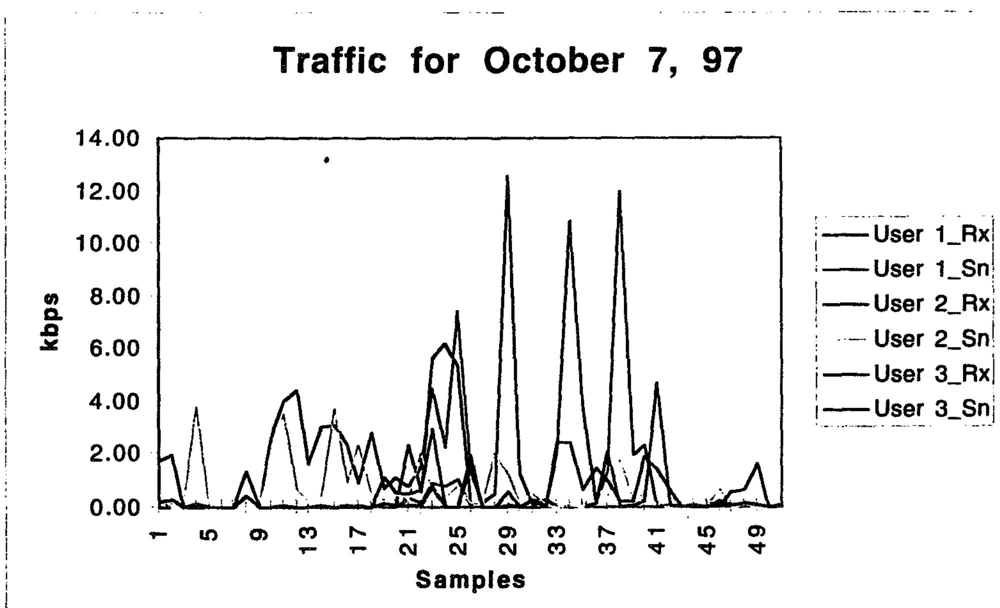
Sample Traffic runs



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Measured Statistics for Average User

Summary of Average Statistics collected - For all the active user for each day
including Downloading

	21-Oct-97	20-Oct-97	7-Oct-97	2-Oct-97	Average
Average bps_Rx	564.39	465.81	947.01	2,108.10	1,021.33
Average bps_Sn	274.82	268.30	483.09	246.68	318.22
Total KBytes_Rx	2,201.13	1,816.00	3,622.33	7,431.04	3,767.63
Total KBytes_Sn	1,071.80	1,046.00	1,847.83	869.53	1,208.79

Summary of Average Statistics collected - For all the active user for each day
excluding Downloading

	21-Oct-97	20-Oct-97	7-Oct-97	2-Oct-97	Average
Average bps_Rx	564.39	465.81	813.12	484.66	582.00
Average bps_Sn	274.82	268.30	436.56	190.13	292.45
Total KBytes_Rx	2,201.13	1,816.00	3,110.18	1,708.44	2,208.94
Total KBytes_Sn	1,071.80	1,046.00	1,669.86	670.20	1,114.46

Measured Statistics for Heaviest User

Summary of Statistics collected - User with highest peak in each day including Downloading

	21-Oct-97	20-Oct-97	7-Oct-97	2-Oct-97	Average
Peak kbps	8.20	9.51	30.11	49.47	24.32
Average bps_Rx	738.00	689.00	1,348.00	5,354.00	2,032.25
Average bps_Sn	187.00	331.00	622.00	359.00	374.75
Total KBytes_Rx	2,878.00	2,690.00	5,158.00	18,876.00	7,400.50
Total KBytes_Sn	731.00	1,291.00	2,382.00	1,268.00	1,418.00

Summary of Statistics collected - User with highest peak in each day excluding Downloading

	21-Oct-97	20-Oct-97	7-Oct-97	2-Oct-97	Average
Peak kbps	8.20	9.51	12.56	5.88	9.04
Average bps_Rx	738.00	689.00	1,521.00	589.00	884.25
Average bps_Sn	187.00	331.00	625.00	267.00	352.50
Total KBytes_Rx	2,878.00	2,690.00	5,818.00	2,078.00	3,366.00
Total KBytes_Sn	731.00	1,291.00	2,393.00	941.00	1,339.00

Key messages from Collected Data

- The average bandwidth to user is between 0.5kbps (no download) to 1kbps (with download)
- The average data transferred to user, in one day, is between 2.2MB (no download) to 3.7MB (with download)
- The average bandwidth of the heaviest user for each day is about 884 bps (no download) to 2 kbps (with download)

NB: These numbers include all traffic (including protocol o/h) to/from computer and hence IP traffic will be a subset of this data

Estimates from Expert Panel

A process was designed to elicit the opinion of a number of 'experts' at Vistar for determining the user traffic characteristics

Initial Mtg to present the process and a list of services → .Experts to provide the Requested data → Second Mtg to Agree/Amended the merged group view → Output Capacity estimates

- Initial meeting to obtain consensus on the list of services and the process involved
- Handout of existing knowledge of traffic characteristics
- Initial discussion of data input

- The Experts to provide data for consolidation and analysis

- Second meeting to review the group data and achieve consensus on the combined data

Results from Experts Panel (Near Term)

Services	Mins of Use /Mth	Ave B/w to User Kbps	Mbytes / Month	Peak B/W to User Kbps	Qos to User	Ave B/w frm User Kbps	Mbytes / Month	Peak B/W frm User Kbps	Qos frm Usr
Enhanced Browsing	900	9	60.75	384	secs	1	6.75	16.00	
Enhanced Multicasting	300	48	108	384	mins	1	2.25	16	secs
Remote LAN Access	1000	64	480	384	secs	16	120	128	secs
E Information Delivery	300	64	144	256	mins	1	2.25	16	secs
Int. Msging system	425	16	51	64	mins	2	6.375	64	mins
Online Commerce	270	32	64.8	384	secs	1	2.025	16	secs
Tele-medicine	600	64	288	384	secs	128	576	512	secs
Multimedia Delivery on demand	800	341.33	2048	1544	min	1	6	16	secs
Distance Education	900	85	573.75	384	secs	9.6	64.8	64	secs

Results from Experts Panel (Longer Term)

Services	Mins of Use #	Ave B/w to User Kbps	Mbytes / Month	Peak B/W to User Kbps	Qos to User	Ave B/w frm User Kbps	Mbytes / Month	Peak B/W frm User Kbps	Qos frm Usr
Enhanced Browsing	900	64	432	1024	secs	9	60.75	48	secs
Enhanced Multicasting	450	96	324	1024	1 min	2	6.75	32	secs
Remote LAN Access	1500	256	2880	1544	secs	64	720	384	secs
E Information Delivery	450	100	337.5	384	mins	2	6.75	64	secs
Int. Msging system	475	64	228	128	mins	12	42.75	128	mins
Online Commerce	360	50	135	512	secs	4.4	11.88	64	secs
Tele-medicine	900	128	864	512	secs	384	2592	1544	secs
Multimedia Download on demand	1000	409.60	3072	2048	mins	1	7.5	64	secs
Distance Education	1100	256	2112	1024	secs	32	264	256	secs

Summary of the Bandwidth Requirements

Source	B/W to User	B/W from User	Data (MB/m)	Comments
ISP Provising[2] (All net Applications)	2.8 kbps		18.9	Provisioned today over large number of business & Res. users
Guidelines for ISPs[2] (All net applications)	5.76 kbps		38.9	Data Telcos would like ISP to provision
Lan Measurements[1] (Browswer Only)	524 bps		39.6	Measured for Business users today
Literature search[3] (Browswer Only)	8 kbps	20 bps	54	Prediction from a recent model
Experts Panel Near Term (E.Browsing)	9 kbps	1 kbps	60.7	Near term predictions from the panel
Experts Panel Longer Term (E.Browsing)	64 kbps	9 kbps	432	Longer term (2010) view from the panel

[1] Average during business hours. Users are "active" during part of the day. Data based on measured values
[2] Actual/Proposed provisioning(symmetric), even though demand is asymmetric
[3] Does not include protocol overhead

Key Findings

- Internet traffic requirements that may be used to introduce service in the near term are:
  - The average bandwidth of 8kbps per user is reasonable bandwidth to introduce service over the near term
  - Data transferred per month to the user is in the range between 25MB/month for residential user to 50MB/month for business user.
- More independent results are required to get statistically significant values and to take into account wider user patterns
- Ongoing tracking is required to better understand the evolving traffic characteristics of IMM services

Interoperability for Space Mission System Monitor and Control: Applying Technologies from Manufacturing Automation and Process Control Industries

Satellite Networks Workshop
6/2/98

Michael K. Jones
818-354-3918
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Outline

- Space Project Mission Operations Control Architecture (SuperMOCA) Goals and Methods for Achieving Them
- Some Specifics on the Architecure
  - Open Standards and Layering
  - Enhancing Interoperability
  - Promoting Commercialization
- An Advertisement
- Status of the Task
  - Government / Industry Cooperation
  - Architecture and Technology Demonstrations
- Key Features of Messaging Services and Virtual Devices

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Space Project Mission Operations Control Architecture (SuperMOCA): Goals and Methods

- **Significantly reduce the monitor and control cost for integration, test, operations and maintenance of ground-based and spaceborne systems used in space missions**
- **Facilitate space industry and government agencies cooperation in the execution of space missions**
- **Partner with industry in a consortium environment to develop**
  - **an architecture and operations concept that is commonly understood by customers and suppliers**
  - **open standards based on technologies and open standards and from manufacturing automation and industrial process control industries**
  - **a lucrative commercial market for space mission monitor and control products**

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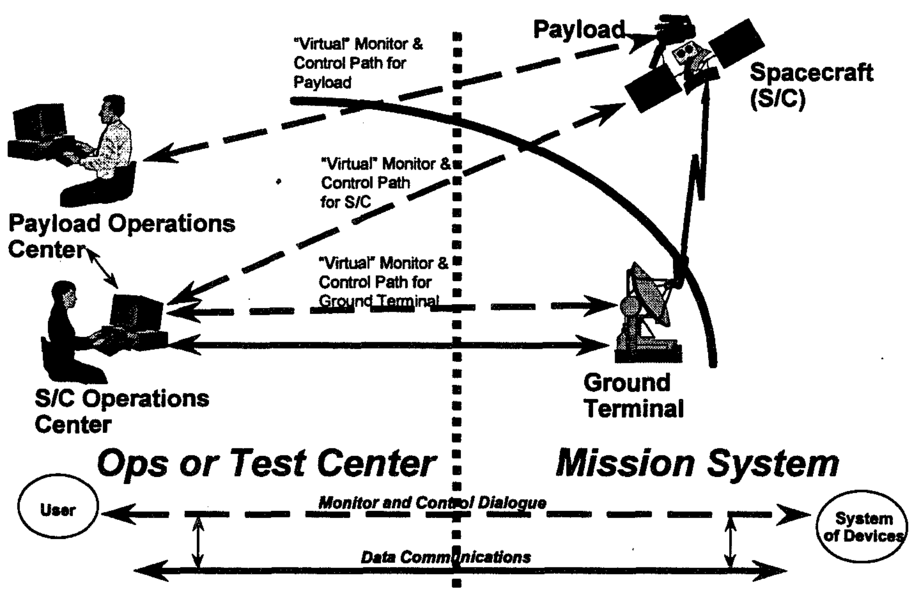
Space Mission System Monitor & Control



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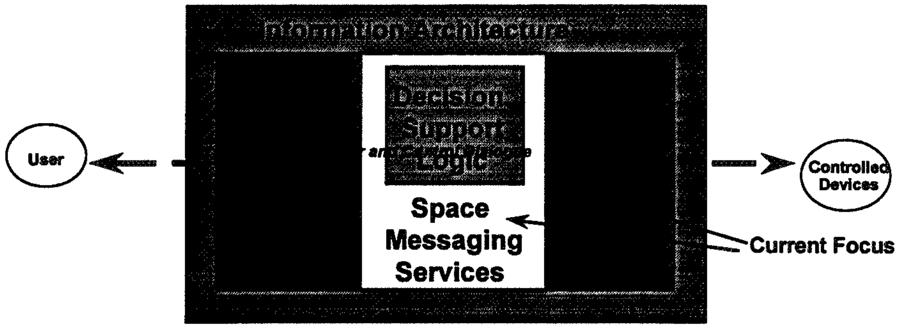
An Architecture and Standards for Space Mission System Monitor & Control



- An architecture for the monitor and control during integration, test, and operations of:
  - spacecraft and launch vehicles
  - launch complexes and ground tracking stations
- A set of open standards that are consistent with the above architecture and apply to the devices used in space missions and the products used to monitor and control those devices.

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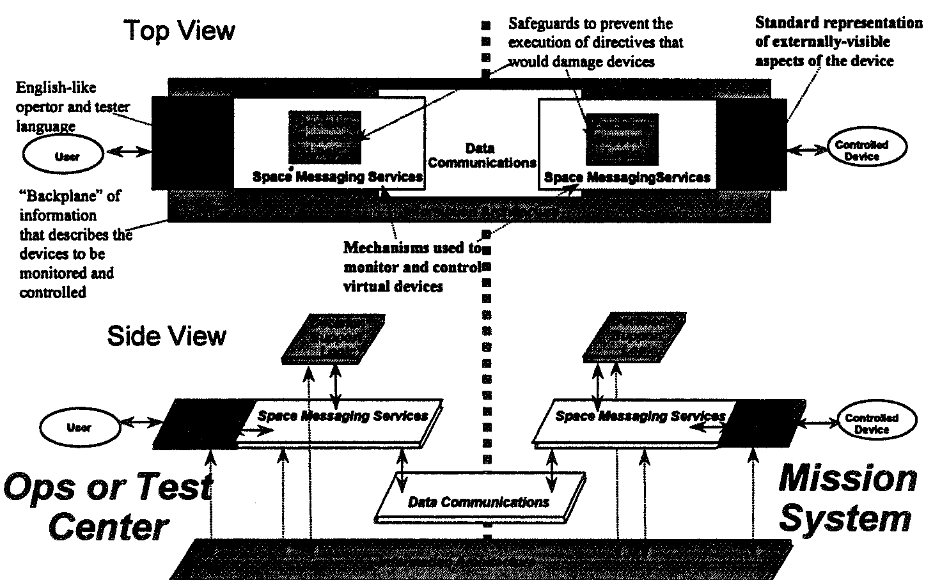
Open Standards and Layering



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Enhancing Interoperability

- **A definition** - Monitor and Control (applications-level) Interoperability: Once connectivity has been established based on communications interoperability, components built by different organizations can operate together to execute an activity by exchanging monitor and control information (i.e., plug and run)
- Advantages for space mission monitor and control
  - simplifies multiple agency cooperative missions
  - shortens system integration and test and training time
  - preserves customer options on component suppliers
- Advantages for commercial products
  - lower customer support costs
  - products are compatible with more systems
- How the architecture enhances interoperability
  - makes mission-specific descriptive information available to monitor and control applications in a standard structure (Information Architecture)
  - decouples device design from monitor and control application design (messaging service and virtual device concepts)

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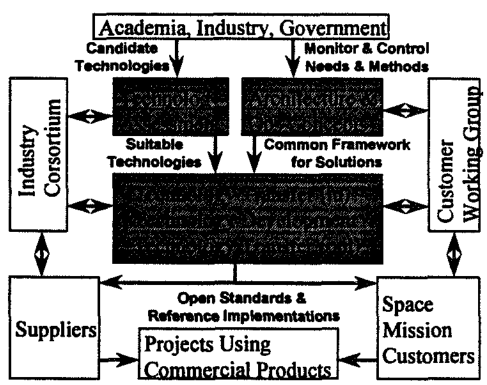
Promoting Commercialization

If we (the customers) want to benefit soon from a commercial market, then we need to participate in creating it. The SuperMOCA task and architecture are intended to promote a commercial market. Specifically they will:

- Provide an understanding of the common cost drivers among government and commercial space missions
- Reduce costs for both government and commercial operators throughout the project life cycle
- Provide business opportunities to a large set of companies
- Promote commerical competition



Path to a Commercial Market

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SuperMOCA Homepage

Web Address: http://supermoca.jpl.nasa.gov/supermoca

Contents:
- News & Announcements
- Papers
- Documents
- Explanation of Demos
- Points of Contact
- Status Reports
- Links to Related Home Pages

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Status of Government / Industry Cooperation

- FY 98 and FY 99 funding from NASA's Space Operations Management Organization (SOMO) standards program
- FY 98 work is being done at JPL and through contracts with SRI and Fieldbus, Inc.
- Will get support from Department of Defense (DOD) in FY 99 to incorporate any DOD-specific needs into the architectural design work
- Negotiated a preliminary Memorandum of Agreement with Fieldbus Foundation (FF) and NASA on for a cooperative program to:
  - demonstrate FF process control technology being developed to operate in ethernet networked environments
  - develop a space monitor and control industry consortium based on the FF experience as a process control industry consortium
- Working with Fisher-Rosemount (an FF member company) in developing a design for remote access to monitor and control systems via satellite links

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What is the Fieldbus Foundation?

Over 100 Companies
Major International Automation Companies
Multi-national End Users

Fieldbus Foundation is:
- Not-for-profit tax-exempt corporation
- Open to all users & suppliers
- Assigned intellectual property rights

Activities:
- Promote FOUNDATION fieldbus the technology
- Provide FOUNDATION fieldbus education
- Provide conformance testing and certification
- Coordinate trade show exhibitions and field trials
- Coordinate development & maintain library of Device Descriptions

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Fieldbus Foundation Members

- ABB Industrial Systems Inc.
- Alfa Laval Automation AB
- Allen-Bradley Co., Inc.
- Allen-Bradley Japan Co., Ltd.
- Alpret (Pty) Ltd.
- Apparatebau Hundsbach GmbH
- Bailey Controls Company
- Bailey Japan Co., Ltd.
- Beamex Oy, AB
- Belden Wire & Cable
- Borst Automation
- Bray International, Inc.
- Bronkhorst High-Tech B.V.
- Brooks Instruments
- Caltex Services Corporation
- Chevron Research & Technology
- Danfoss A/S
- digi table thielen GmbH
- DKK Corporation
- Druck Ltd.
- du Pont Engineering Co.
- EMCO
- Endress + Hauser GmbH
- Enraf
- Exxon Research & Engineering Co.
- Fieldbus International A/S (FINT)
- Fisher Controls International, Inc.
- Fisher-Rosemount Systems Inc.
- Fraunhofer Institute IITB
- The Foxboro Company
- Fuji Electric Co., Ltd.
- Furon Company, Dekoron Div.
- Glaxo Inc.
- GSC Precision Controls
- Hartmann & Braun AG
- Hitachi, Ltd.
- Honeywell Inc.
- Ifak
- Instituto de Investigaciones Eléctricas
- Johnson Yokogawa Corp.
- K-Patents Oy
- K.K. Codix
- Keystone International, Inc.
- Kimray, Inc.
- Knick Elektronische Meßgeräte GmbH &Co.
- Koso Service Co., Ltd.
- KROHNE Messtechnik GmbH & Co.
- Leeds+Northrup
- Magnetrol International
- Masoneilan - Dresser Industries, Inc.

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Fieldbus Foundation Members

- Measurement Technology Ltd.
- Mettler-Toledo, Inc.
- Micro Motion, Inc.
- MILLTRONICS Ltd.
- Mitsubishi Electric Corporation
- Monsanto Company
- Motoyama Eng. Works, Ltd.
- Nagano Keiki Seisakusho Ltd.
- National Instruments Corp.
- NEC Corporation
- Neles-Jamesbury Oy
- NEMA
- Niigata Masoneilan Co., Ltd.
- Norsk Hydro a.s.
- Ohkura Electric Co., Inc.
- Oval Engineering Co., Ltd.
- Pacific Avionics Corporation
- Pepperl+Fuchs
- POHTO
- Politecnico di Torino -Dai
- Presys Instrumentos e Sistemas Ltda.
- R. Stahl Schaltgeräte GmbH
- Ramsey Technology, Inc.
- Ronan Engineering
- Rosemount Analytical, Inc.
- Rosemount Inc.
- Saab Tank Control
- Schneider North America
- Servomex Company Inc.
- Shell Oil Company
- Shimadzu Corporation
- SHIP STAR Associates Inc.
- Siebe ECD
- Sieger TPA Ltd.
- Siemens Industrial Automation, Inc.
- Simrad Albatross AS
- SMAR Equipamentos Industriais Ltda.
- Softing GmbH
- StoneL Corporation
- TMG I-tec GmbH
- Tokyo Keiso Co., Ltd.
- Toshiba Corporation
- Valmet Automation Inc.
- VALTEK International
- VEGA Grieshaber KG
- Vinson Supply Company
- WorldFIP Europe
- Yamatake-Honeywell Co., Ltd.
- Yokogawa Electric Corporation
- Yokogawa Electronics Co., Ltd.

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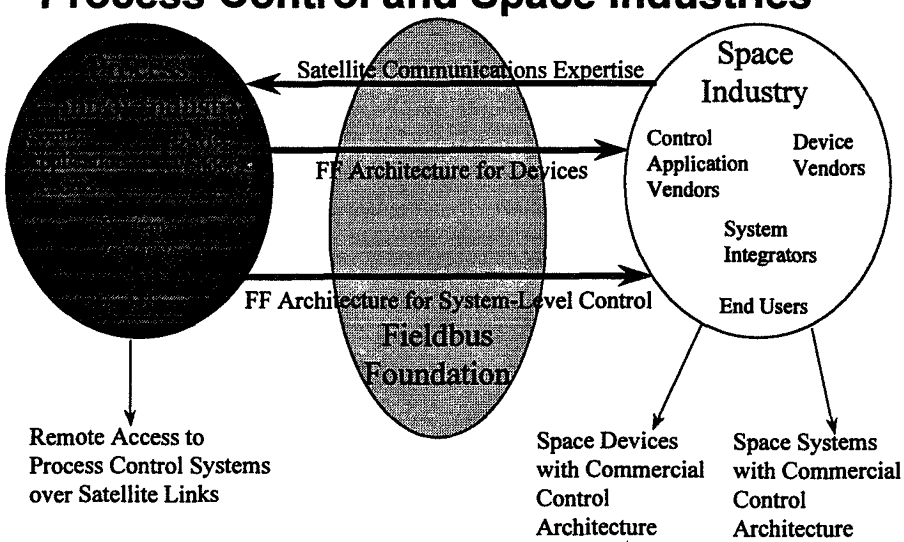
Two-way Tech Transfer Benefits Both Process Control and Space Industries



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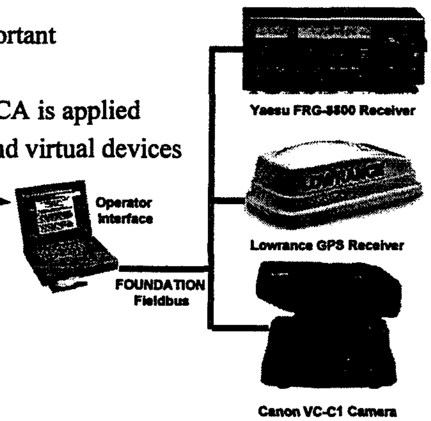
Status of Architecture and Technology Demonstrations

- Overview Documents Available
  - Summary - Why SuperMOCA is important
  - Architecture - What SuperMOCA is
  - Operations Concept - How SuperMOCA is applied
- Current Focus is on messaging services and virtual devices
- Road Show Demo
  - Commercial messaging system
  - ISA Show in Anaheim in Oct. 97
- JPL Demo
  - Commercial messaging system
  - Simulated S/C



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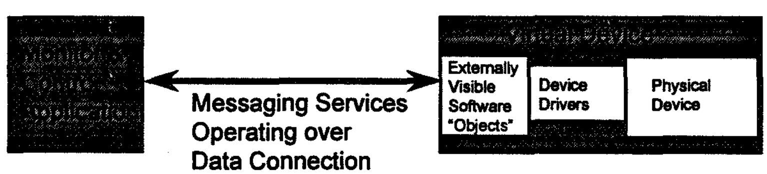
Messaging Services and Virtual Devices

- Virtual devices consist of software-implemented "objects" that represent the externally-visible aspects of the device
- Messaging services provide the capabilities to monitor and control the device through manipulation of the "objects"
- Fieldbus Messaging Service (FMS) is an example of an integrated architecture with which to build a monitor and control system
  - set of messaging services
  - set of virtual device "function blocks"



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Invited Session

NASA Interoperability Experiment Program

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INTEROPERABILITY

WHAT IS IT
and
WHY IS IT SO IMPORTANT ?

ALFRED U. MAC RAE
Consultant
72 Sherbrook Drive
Berkeley Heights, NJ 07922

INSTITUTE FOR APPLIED SPACE RESEARCH - GWU

INTEROPERABILITY ENABLES COMMUNICATION AND INTELLIGENT INTERACTION BETWEEN SYSTEMS OF DISSIMILAR NETWORK ARCHITECTURES AND PROTOCOLS, USING EQUIPMENT MADE BY DIFFERENT VENDORS AND OWNED BY DIFFERENT SERVICE PROVIDERS.

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FACTORS INFLUENCING INTEROPERABILITY

Standards

Compatible Protocols

Cost

Reliability

Customer acceptance

Technical compatibility

Inter-company agreements

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TRENDS ON THE GROUND (I)

Demand for bandwidth is increasing at 50% per year

Data exceeds voice transport in U.S.

Number of Internet hosts is doubling every six months

Customers are obtaining 1 Mbps to home with cable modems

T-1 lines have been on allocation

Customers are ordering DS-3 lines

Customers are requesting OC- 12 (622 Mbps)

Transport has changed from multiples of DS-3 to multiples of OC-48 (and higher)

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TRENDS ON THE GROUND (II)

Optical technology

- DWDM is now offered at 80 channels with 400 Gbps per fiber, increasing to 1 Tbps per fiber, with 25 Tbps possible
- Optical add-drop
- Optical cross-connect

Sub-cable

- Japan to U.S. - by mid year 2000; SONET Ring, 80 Gbps, upgradeable to 640 Gbps
- Project Oxygen - by year 2002; global, 74 countries, DWDM, 80 channels per fiber, distance independent charges

(Bandwidth is plentiful, but access to the home is key)

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TRENDS ON THE GROUND (III)

The global network is becoming IP based
  Convergence of data, voice, video
The network has gone from a hierarchical
  to a distributed architecture
Real Time Network Routing (RTNR)
SS #7 (signaling) is the basis of call set-up,
  new services, and network management
Network management is complex and is
  the key to customer satisfaction
Data base management (as, customer
  profile information) is key for billing,
  new services
Wireless mobile is booming, esp in those
  parts of the globe that use standards (GSM)

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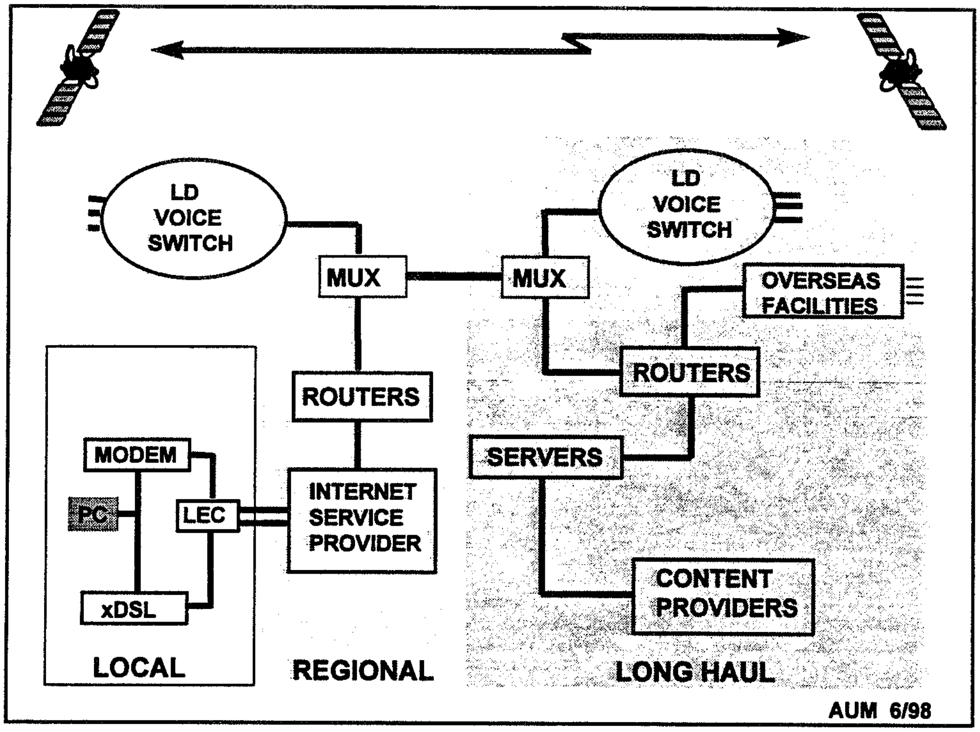
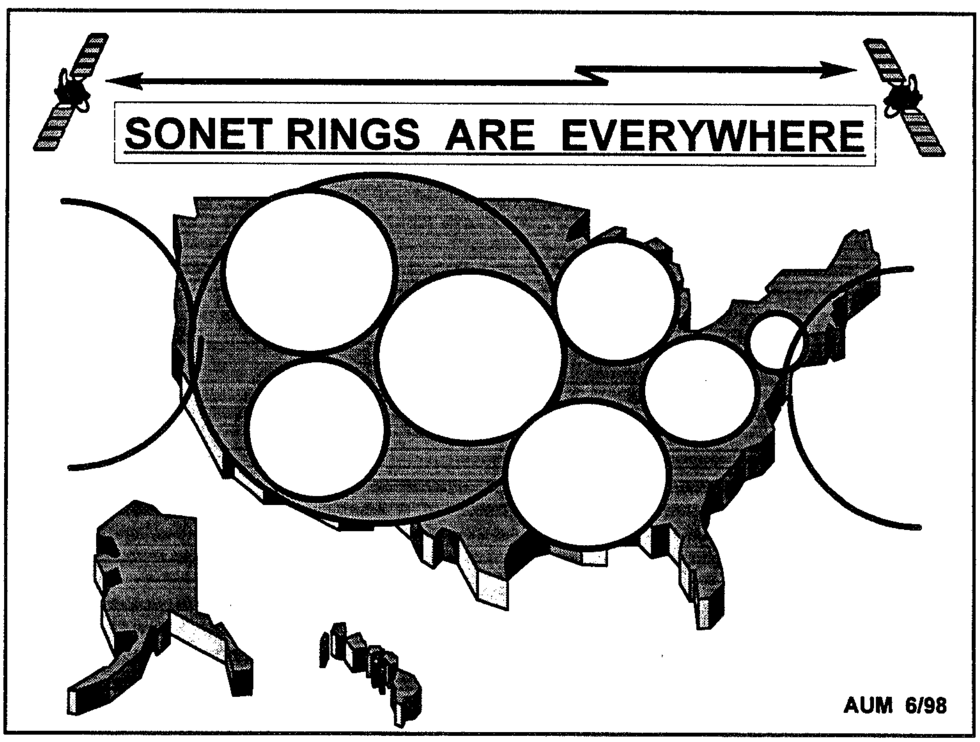

LD
VOICE
SWITCH
MUX
MUX
LD
VOICE
SWITCH
OVERSEAS
FACILITIES
ROUTERS
ROUTERS
MODEM
PC
LEC
INTERNET
SERVICE
PROVIDER
SERVERS
xDSL
CONTENT
PROVIDERS
LOCAL
REGIONAL
LONG HAUL
AUM 6/98


SONET RINGS ARE EVERYWHERE
AUM 6/98

TRENDS IN SATELLITES (I)

Technical

- On board switching
- Multiple spot beam antennas
- Larger antennas
- Intersatellite links
- Higher power
- Multi-satellite constellations at LEO and MEO to minimize delay problem
- Software is becoming increasingly important

Business

- Delivery of services to end-user*, as DBS, mobile telephony, Internet access and DARS

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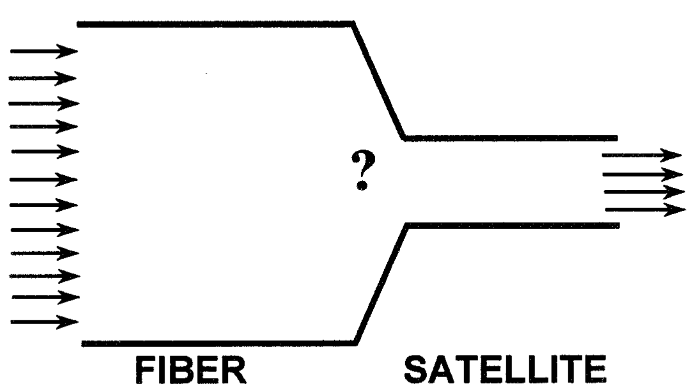

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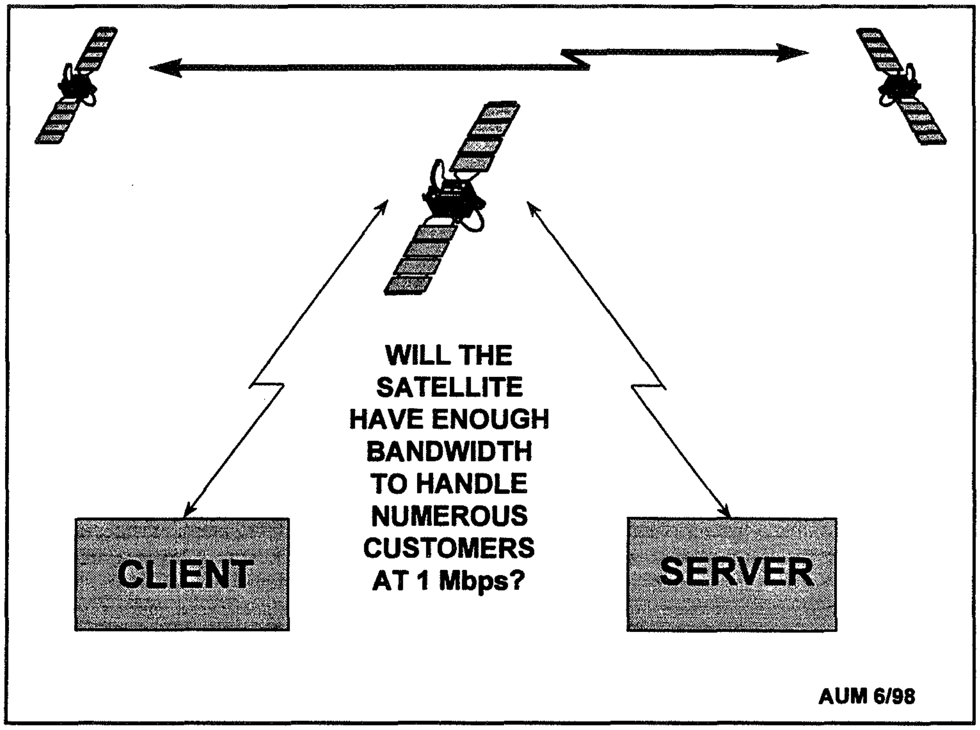
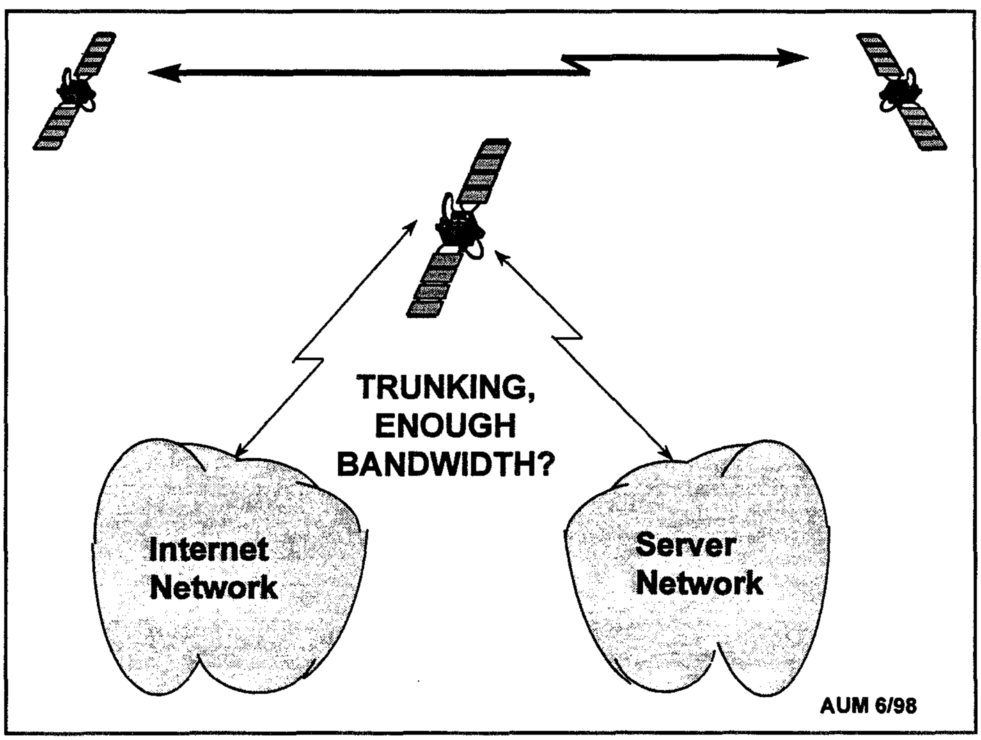

WILL THE SATELLITE HAVE ENOUGH BANDWIDTH TO HANDLE NUMEROUS CUSTOMERS AT 1 Mbps?
CLIENT
SERVER
AUM 6/98


TRUNKING, ENOUGH BANDWIDTH?
Internet Network
Server Network
AUM 6/98

WHAT ABOUT DISTRIBUTION of HDTV?

Distribution of TV to Network Affiliates and Cable Head Ends is Big Business Today

Raw high definition video is ~ 1 Gbps

Contribution Quality for Editing is 160 Mbps

Delivery to home is 19.2 Mbps

(FUTURE SATELLITES WILL REQUIRE HIGHER BANDWIDTH TRANSPONDERS)

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WHAT ABOUT THE 1/2 sec. LATENCY AT GEO?

Voice
Data

Will LEO be the answer for satellites?
But, what about Doppler (Jitter)?
and traffic management?

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ATM over SATELLITES

While initial studies are encouraging, using Reed-Solomon coding and the COMSAT Link Enhancer, continued studies are needed to; determine if satellites can deliver the QOS demanded of present and future ATM services, to understand resource management and application performance.

(AT&T, KDD, Telstra AKT ATM Technical Trial)

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PROTOCOLS and STANDARDS

ATM

Frame Relay

TCP/IP

FTP

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STANDARDS

Enhance Customer Acceptance

Mobile telephony

DBS

DARS

Common air interface standards will be demnded by the customers and will be good for the entire business

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TRENDS IN SATELLITES (II)

INTEROPERABILITY

Trunking and thin route services

- Will require higher bandwidth transponders to carry new services
- Will require solution to the latency problem to carry high bandwidth TCP/IP traffic

Broadcast TV

- Will require higher bandwidth transponders to distribute HDTV
- Will require lower cost (will SONET replace domestic distribution?) and better reliability

Data networks, low bandwidth

- Probably ok - being done now

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TRENDS IN SATELLITES (III)

INTEROPERABILITY

End-User based services (all need improved distribution and service channels)

Internet access - Need to solve latency protocol problem for high bandwidth access, need to utilize conventional signaling and data base management to match services provided by terrestrial counterparts

DBS - Need standard receivers to enhance business, need to provide local programing

Multicast - New protocols needed

Mobile telephony - Signaling, routing, standard terminals, new services - location determination

DARS - Quality is the big issue

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SUMMARY

Global communications are increasing at an unprecidented pace

The network is "going" IP

Data transport exceeds voice

Terrestrial communications is "going" high bandwidth

To be interoperable with the terrestrial network, satellites need;

- higher bandwidth transponders, OC-3?
- solution to the latency protocol issues
- utilization of standard signaling, data base management and network management
- standardization of terminals

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SATELLITE NETWORKS: ARCHITECTURES, APPLICATIONS, & TECHNOLOGIES WORKSHOP

June 3, 1998
Cleveland, OH

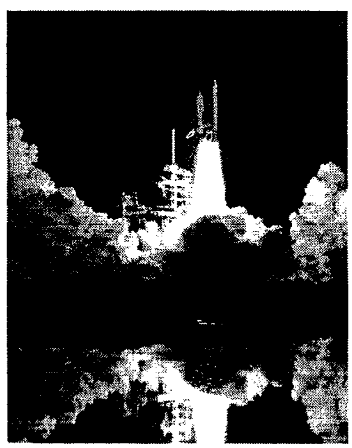
"NEW OPPORTUNITIES WITH THE ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS)"

Robert Bauer
ACTS Project Manager
NASA Lewis Research Center

Lewis Research Center

ACTS PROGRAM OVERVIEW

- Experiments began December 6, 1993.
- Initial 2 year mission life extended to 4 years (design life).
- Fifth year now underway.
- Over 100 organizations involved in 85 experiments; 81 demonstrations to various audiences.



Launched September 12, 1993.

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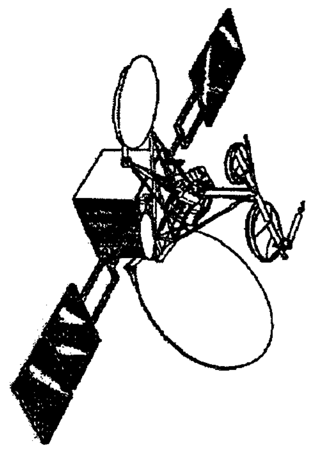
ACTS SPACECRAFT CHARACTERISTICS



- **Weight**: 3250 lbs (on-orbit)
- **Power**: 1770 BOL
- **Frequency Band**: Ka (30/20 GHz)
- **Space Pointing (Pitch & Roll) Accuracy**: $\pm 0.025^{\circ}$
- **Launch Date**: September 12, 1993
- **Stationkeeping Fuel Expended**: Projected July, 1998
- **Inclined Orbit Operations (N/S not maintained)**: Through September, 2000

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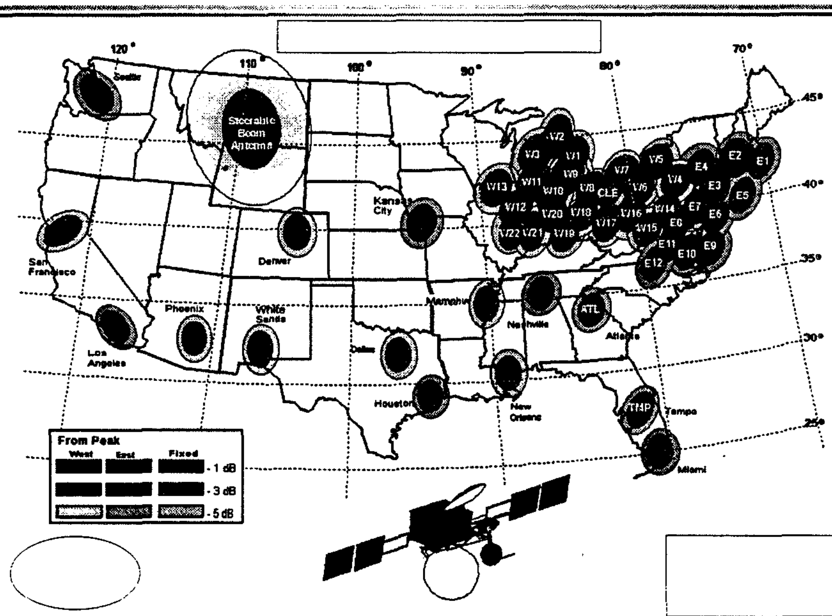
SPOT BEAM LOCATIONS



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KEY ACTS TECHNOLOGIES

High Gain, Fast Hopping Spot Beams

- EIRP >64 dB
- G/T >20 dB/K
- Frequency Reuse > 4

Onboard Processing & Switching

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

Ka-Band

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

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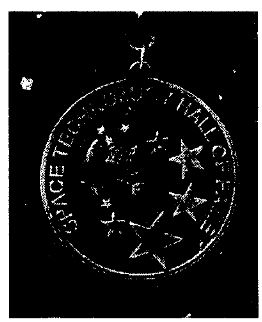
ACTS ACCOMPLISHMENTS (selected)

- Inducted into Space Technology Hall of Fame, April 1997.
- Highest known data rates supported in a single transponder by a non-DoD satellite (622 Mbps).
- Experiments have been supported in 31 states and 6 foreign countries.
    - Using multiple satellites, have linked to Europe and Asia.
- Experiments and demonstrations:
    - from planes, trains, automobiles, and ships
    - from volcanoes, deserts, rain forests, islands, and battlefields
    - with scientists & engineers, patients & doctors, politicians & soldiers, educators & students...



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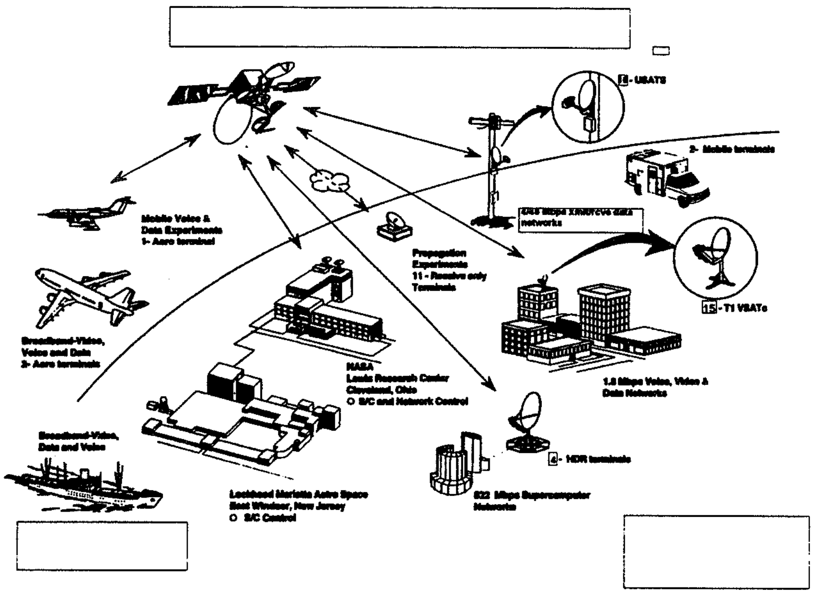
ACTS EXPERIMENTS OPERATIONS



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INCLINED ORBIT OPPORTUNITY

WHY EXTEND THE PROGRAM??

- ✓ Successful experiments program.
  - ✓ Sustained interest and impressive results have driven the desire to continue ACTS as long as reasonable/possible.
- ✓ Minimal further cost to achieve maximum benefit from investment to NASA and Nation.
  - ✓ Program constraints define end of life at September, 2000.
- ✓ Test viability of narrow spot beam system in IO.
- ✓ No failure of primary systems.
- ✓ Efficient stationkeeping
  - ✓ Calculations show sufficient fuel to operate for 30 mos. in inclined orbit.
  - ✓ Maintain spacecraft at $100^{\circ} \pm 0.05^{\circ}$ West longitude.

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INCLINED ORBIT MISSION

- Prepare the system for supporting inclined orbit operations.
  - Implement new spacecraft procedures to maintain attitude.
  - Install and test modified ground segment.
- Continue operations with a tracking ground segment to support program plans and experiment operations requirements through September 2000.

Minimize impact to experiment operations

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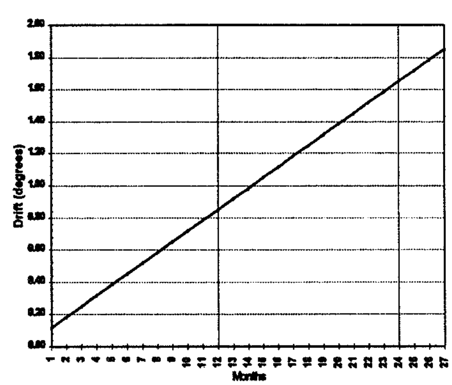
INCLINED ORBIT IMPACT

Spacecraft

- Satellite will drift in N/S direction increasing by ~0.8° per year
- ACTS East/West maintained at ± 0.05° for up to 27 months.
- Last North/South maneuver planned for July, 1998.
- About 1 month for S/C to exceed 0.05°

Ground Segment

- Tracking modifications underway (2 axis)



ACTS Drift Inclination

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MODIFICATIONS SUMMARY

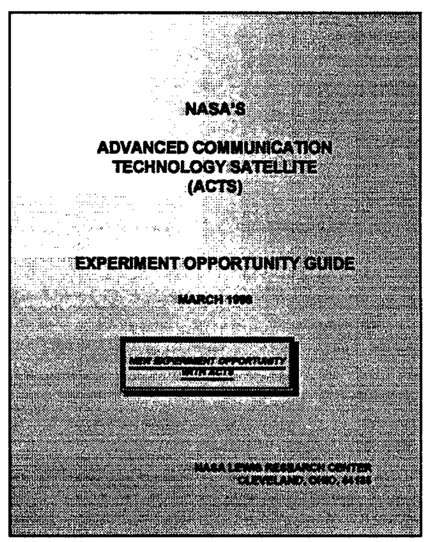
ITEM	SPACECRAFT	MGS	T1VSAT	HDR	USAT	LET
Assets / IO Ready	1/1	1/1	19/15	6/3	10/10	1/1
Contractor	LMAS	Comsat	Harris	BBN	–	–
Ant. Diam. (m)	3.3/2.2	5.0	1.2[1]	3.4	.6 (.35,1.2)	4.7
HPA (w)	46	130	10	120	1	100
Ant. HPBW (deg)[2]	–	.1	.5	.2	1.0 (1.8,0.5)	.12
Trkg. Needed (months past last N/S, -3 dB, 30 GHz)	–	.5	3.5	1	7 (13, 3.5)	.75
H/W Mods	N	N	Y	Y	Y	Y
S/W Mods	Y	N[3]	Y	Y	N[4]	Y
User Data Rates	–	50.2/18.8 Mbps	1.8 Mbps	OC3 -OC12 (155-622 Mbps)	4/45 Mbps (xmit/rcve)	220 Mbps

NOTES
1. 2.4 m dish not being modified for I/O.
2. Calculated values.
3. No impact to BBP for up to 24 months of I/O.
4. TDMA network being developed; S/W mods will be evaluated when implemented.

Lewis Research Center

EXPERIMENT OPPORTUNITY

- **Experiments Opportunity Guide** released March, 1998. (http://kronos.lerc.nasa.gov/acts/eoa/guide.html)
- 4 experiments categories defined.


NASA'S
ADVANCED COMMUNICATION TECHNOLOGY SATELLITE (ACTS)
EXPERIMENT OPPORTUNITY GUIDE
MARCH 1998
NEW EXPERIMENT OPPORTUNITY WITH ACTS
NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO, 44135

Lewis Research Center

EXPERIMENT CATEGORIES

1. Demonstrate transitioning to future commercial satellite services in support of NASA & other government missions.

2. Test, verify & resolve technical issues using Asynchronous Transfer Mode (ATM), Internet Protocol (IP), or other protocols over satellite, including interoperability issues with terrestrial networks.

3. Characterization of the ACTS system and operations in inclined orbit.

4. Verify new satellite Ka-band technology and hardware.

Lewis Research Center

RECENT ACTIVITY

- "Testing New Modalities of Space Communications"
  - Major aerospace firm and team of several networking hardware and software providers.
  - Demonstrate network and protocols that could lead to consolidation of NASA space operations.

- FTP, TCP/IP, HTTP testing over ACTS
  - Ohio University and LeRC collaboration

Lewis Research Center

ONGOING ACTIVITY

#118x ("High Speed Protocol Optimazation")

- Dispell myth that GEO satellites and TCP/IP are incompatible.
  - Investigate protocol performance on a multi-platform, geosync satellite network
  - OC-3 & OC-12 rates; symmetric & asymmetric links
  - Optimize point-to-point transfer of data between two sites across ACTS (HDR's at LLNL and LeRC)
  - Use TCP/IP over Asynchronous Transfer Mode (ATM) among multiple computer platforms and operating systems.
  - Wide variety of partners including top names in industry:
    - Computer Industry - 7 orgs.
    - Communications Industry - 4 orgs
    - Satellite Industry - 6 orgs
    - Government Laboratories - 4 orgs

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EXPERIMENT PROCESS

- Submit **Letter of Intent**, or better yet...
- Submit **experiment proposal**.
- Review for feasibility (S/C, ground segment, schedule), meets goals.
- Space Act or other appropriate agreement developed with all experimenters.
  - ensures requirements defined
  - most agreements are reimbursable
  - benefits Experimenter as well as NASA by clarifying what's expected of both parties.

Lewis Research Center

ACTS EXPERIMENTS POINT OF CONTACT

- ACTS Project

NASA Lewis Research Center
21000 Brookpark Road, MS 54-6
Cleveland, OH 44135
ATTN: Michael Zernic, ACTS Experiments Manager

PH: 216.433.5286
michael.zernic@lerc.nasa.gov

- ACTS Home page

http://acts.lerc.nasa.gov

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Next Generation Internet Overview

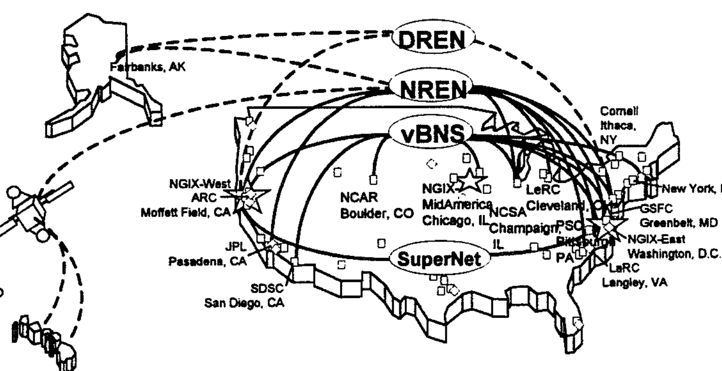
Satellite Networks Workshop
Cleveland, Ohio
June 3, 1998

R.desJardins
NASA NREN/NGI Project Office
rdesjardins@arc.nasa.gov

NGI Overview **Next Generation Internet Architecture**

Goals:

- Promote experimentation with the next generation of network technologies
- Develop a next generation network testbed to connect universities and federal research institutions at rates that are sufficient to demonstrate new technologies and support future research
- Demonstrate new applications that meet important national goals and missions

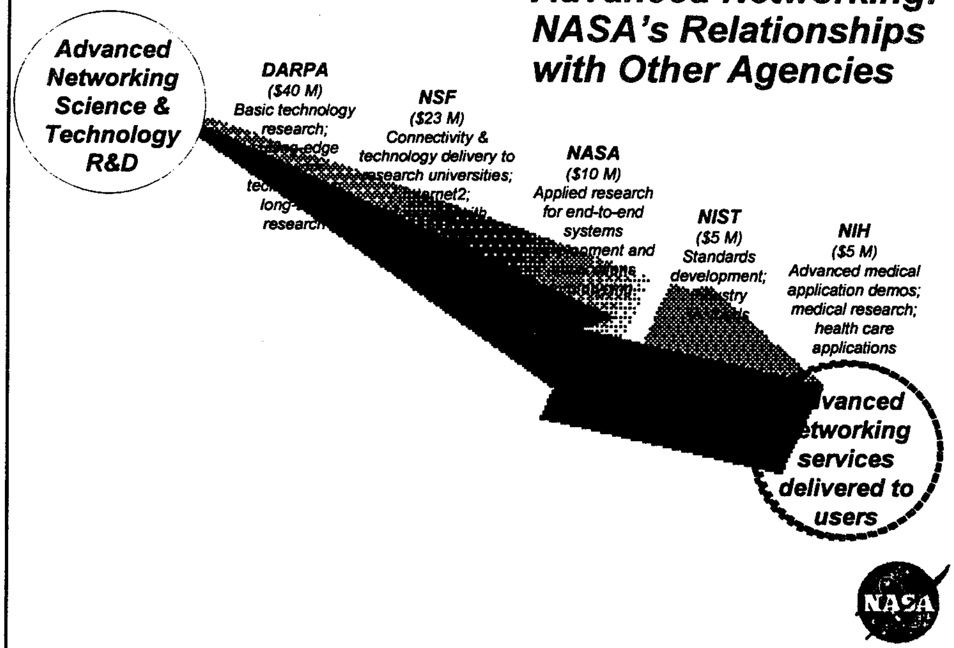


LEGEND

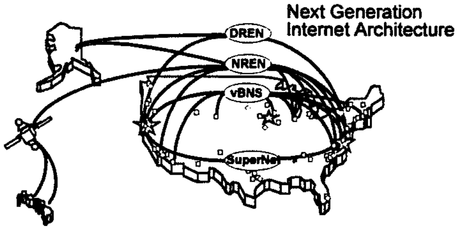
DREN - Defense Research & Engineering Network
NREN - NASA Research and Education Network
vBNS - Very High Speed Backbone Network Service (NSF)
NOTE: vBNS will support initial Internet 2 community
SuperNet - Terabit Research Network (DARPA)

◇ - NREN Application Partner
□ - vBNS Partner
☆ - Next Generation Internet Exchange

Advanced Networking: NASA's Relationships with Other Agencies



NGI/I2 Comparison

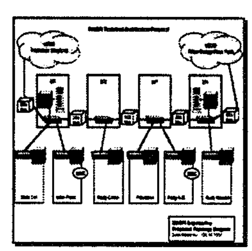


Next Generation Internet

- Federal funding
- Agency mission driven
- R&D in advanced networking technologies, and demonstrations on a wide-area scalable testbed which connects to academic (including some Internet 2 universities) and industry networks
- Develop general-purpose and agency-specific applications

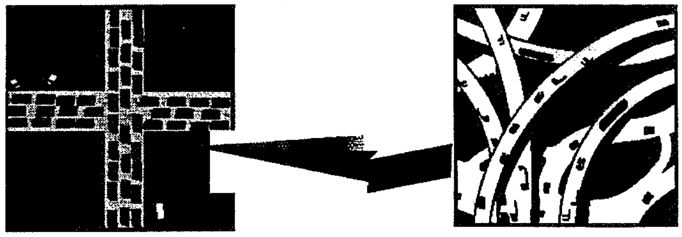
Internet2

- Funded by research universities and communications and computing companies
- Education and research driven
- State-of-the-practice connectivity deployed at universities and GigaPOPs and interconnected using NSF's vBNS as the backbone
- Deploy networking technologies and develop a wide range of applications (many funded by Federal initiatives such as NGI)



Mid Atlantic GigaPOP for Internet2

Capability



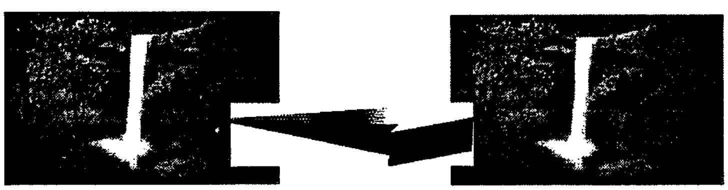
Today

- "Best Effort"
- Unicast (point-to-point networking)
- Lots of human intervention required to manage
- Security handled by host
- Router-to-router performance monitoring

Tomorrow

- Differentiated services
- Intelligent network (scalability)
- End-to-end performance management policies and tools
- Security as part of the network
- End-to-end performance measurement
- Qualities of service
- Multicast
- End-to-end service guarantees

Capacity



Today

- Internet exchange points are bottlenecks
- Newer applications don't have enough bandwidth
- Available bandwidth is poorly utilized
- Duplicate traffic slows growth of advanced applications

Tomorrow

- Robust internetworking exchanges move the traffic
- New technologies provide wide-open bandwidth
- Networks are unclogged by high-speed applications running over high-speed networks
- Multicast reduces traffic exponentially

Revolutionary Applications

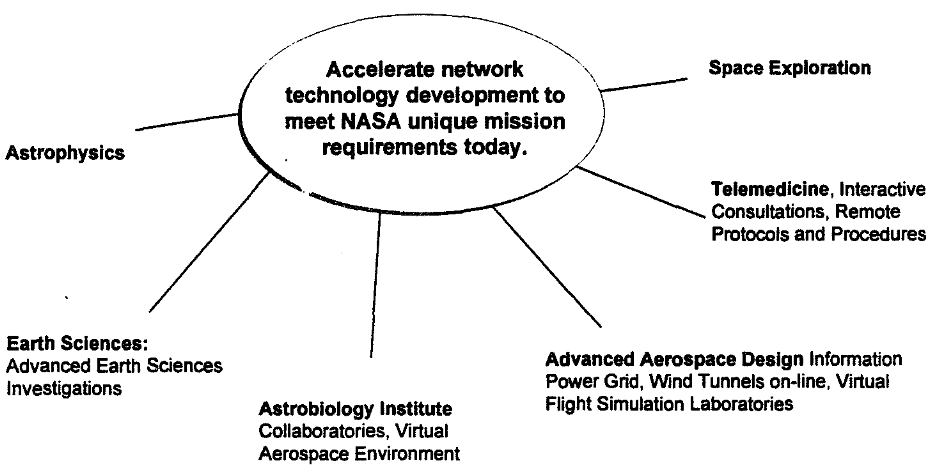
Today

- **Electronic mail**
- **File transfer**
- **World Wide Web**
- **Remote login**
- **Travel to meetings**
- **Isolated design systems**

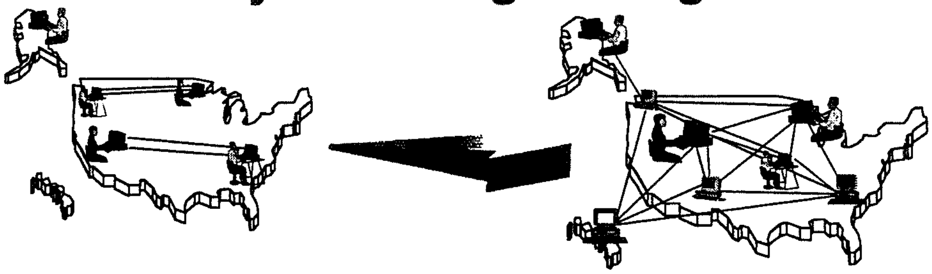
Tomorrow

- **Collaboratories**
- **Metacomputing**
- **Distance learning**
- **Telemedicine**
- **Integrated design systems**
- **Remote operation**

NASA Mission Application Partners



Systems Engineering



Today

- Isolated research
- Many autonomous systems with different architectures and policies
- Uncoordinated, duplicate technology development efforts

Tomorrow

- Collaborative research
- True end-to-end systems technology integration across heterogeneous networks
- Partnerships allow collaboration on large-scale testbeds
- Technology scalable across wide area networks

More Information

- *National Coordination Office for Computing, Information and Communications*
  - http://www.ccic.gov/
- *Internet 2 (university consortium)*
  - http://www.internet2.edu
- *NASA Research and Education Network*
  - http://www.nren.nasa.gov
- *DOE*
  - http://www.es.net
- *DARPA*
  - http://www.ito.darpa.mil/ResearchAreas.html
- *NSF's Connections*
  - http://www.vbns.net

Next Generation Internet
http://www.ngi.gov

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NASA RESEARCH AND EDUCATION NETWORK

NREN

NASA/NREN

Next Generation Internet (NGI) Activities

Richard desJardins

Ken Freeman

Tomorrow's Networking Applications Today

NASA RESEARCH AND EDUCATION NETWORK

NREN

Agenda

- NREN / NGI Architecture
- NREN Applications
- NREN Applied Research

Tomorrow's Networking Applications Today

NGI Architecture

NASA Research and Education Network (NREN)
- NASA Funded
- ATM Backbone

Very High-Speed Backbone Network (vBNS)
- NSF Funded
- ATM Backbone

Earth Sciences Network (ESnet)
- Department of Energy Research & Operational Network
- ATM Backbone

Defense Research and Education Network (DREN)
- ATM Backbone

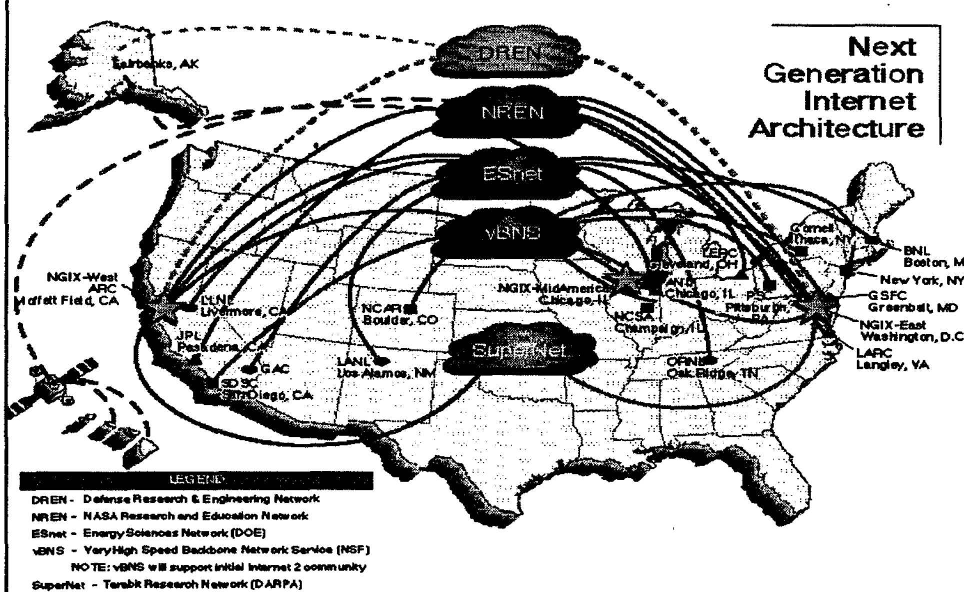
SuperNet (Terabit Research Network)
- DARPA Funded
- Basic Research (ATM, SONET & WDM)

Abilene
- Internet 2 Backbone
- Packet over SONET

Tomorrow's Networking Applications Today

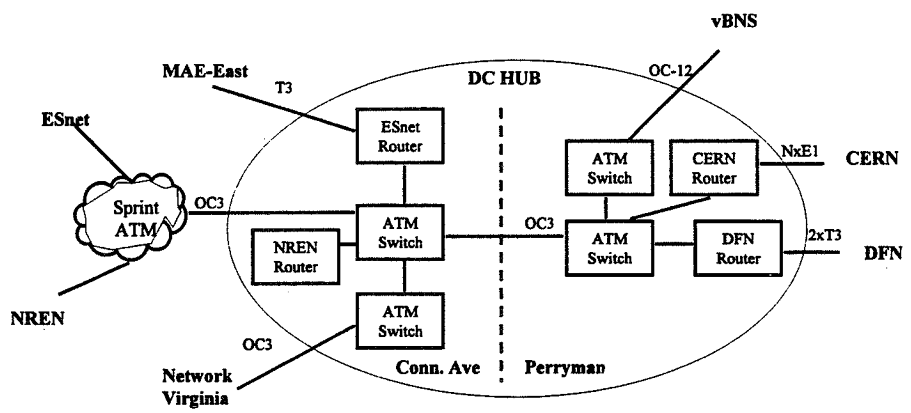
NGI

NGI Architecture



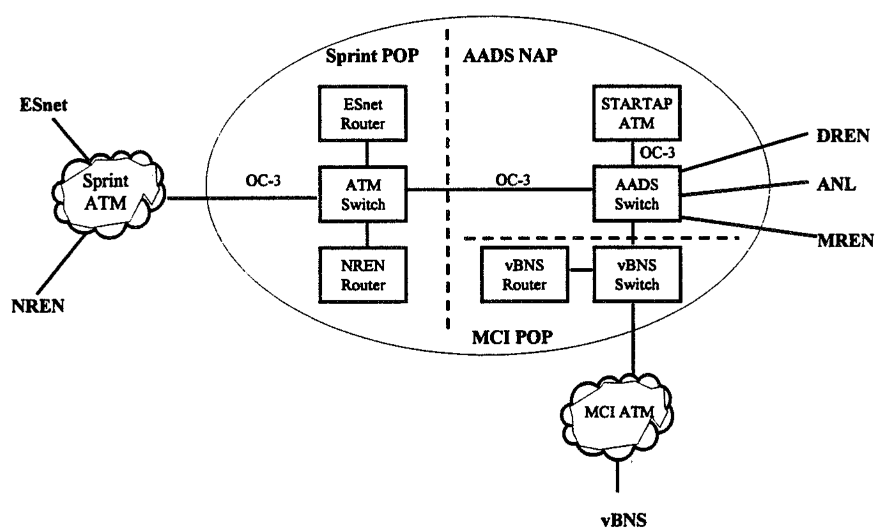
NGI Architecture

DC-NGI Exchange Point (NGIX-East)



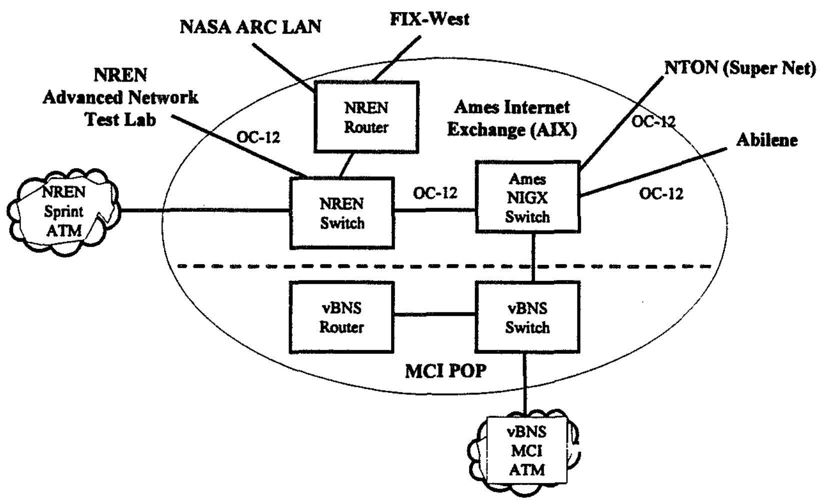
NGI Architecture

Chicago-NGI Exchange Point (NGIX-Mid)



NGI Architecture

Ames-NGI Exchange Point (NGIX-West)

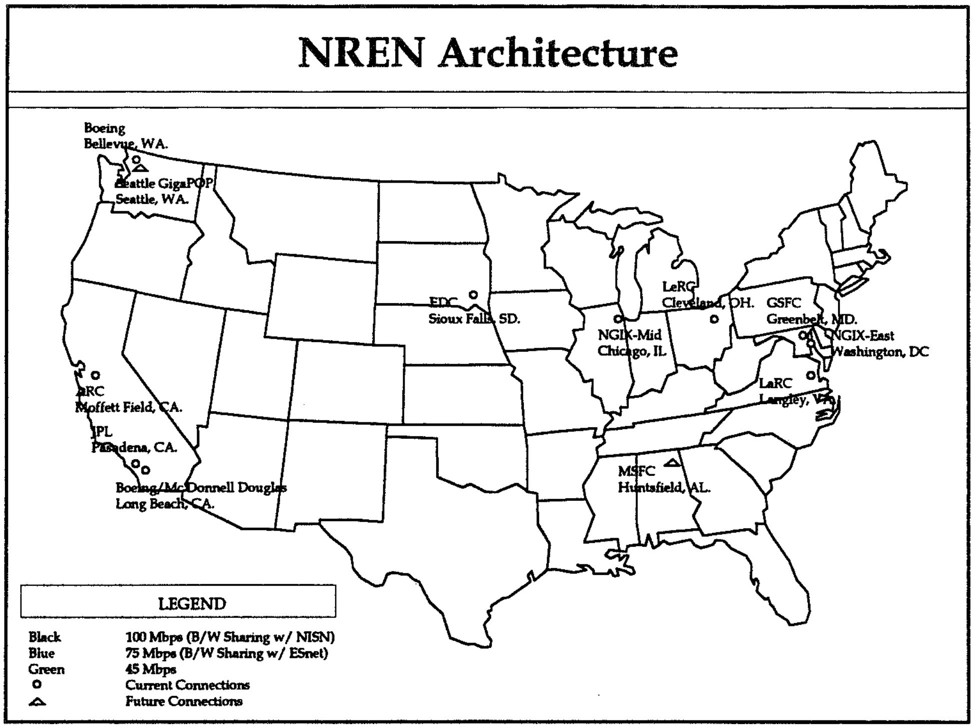


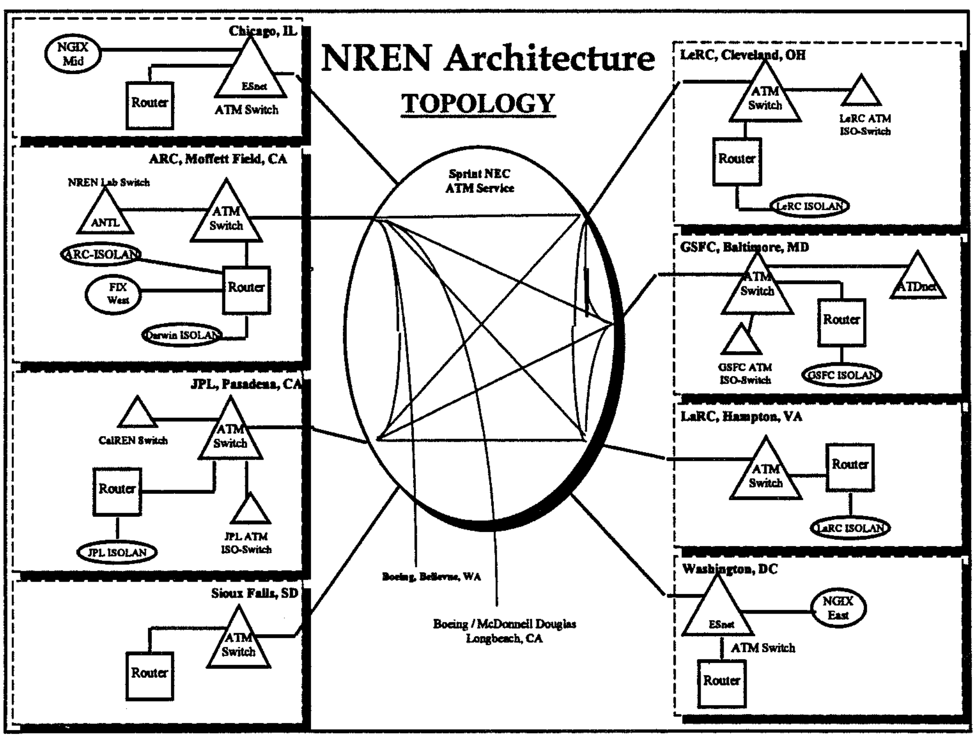
NASA RESEARCH AND EDUCATION NETWORK

NREN Architecture

- **ATM Based Backbone**
- Sprint ATM Service
- OC-3 & DS-3 Circuits
- **ATM & IP Routed Based Connections**
- **Interconnections to NGIX's**
- **Connections to Five NASA Research Centers**
- **Planned Connections to Operational Centers**
- **Connections to Boeing**
- Seattle
- Long Beach (MacDonnel Douglas)

Tomorrow's Networking Applications Today


NREN Architecture
Boeing
Bellevue, WA.
Seattle GigaPOP
Seattle, WA.
EDC
Sioux Falls, SD.
NGIX-Mid
Chicago, IL
LeRC
Cleveland, OH.
GSFC
Greenbelt, MD.
NGIX-East
Washington, DC
LaRC
Langley, VA
ARC
Moffett Field, CA.
JPL
Pasadena, CA.
Boeing/McDonnell Douglas
Long Beach, CA.
MSFC
Huntsfield, AL.
LEGEND
Black 100 Mbps (B/W Sharing w/ NISN)
Blue 75 Mbps (B/W Sharing w/ ESnet)
Green 45 Mbps
o Current Connections
△ Future Connections


NREN Architecture
TOPOLOGY
Chicago, IL
NGIX Mid
Router
ESnet
ATM Switch
ARC, Moffett Field, CA
NREN Lab Switch
ANTL
ATM Switch
ARC-ISOLAN
FIX West
Router
Darwin ISOLAN
JPL, Pasadena, CA
CalREN Switch
ATM Switch
Router
JPL ATM ISO-Switch
JPL ISOLAN
Sioux Falls, SD
ATM Switch
Router
Sprint NEC ATM Service
Boeing, Bellevue, WA
Boeing / McDonnell Douglas Longbeach, CA
LeRC, Cleveland, OH
ATM Switch
LeRC ATM ISO-Switch
Router
LeRC ISOLAN
GSFC, Baltimore, MD
ATM Switch
ATDnet
Router
GSFC ATM ISO-Switch
GSFC ISOLAN
LaRC, Hampton, VA
ATM Switch
Router
LaRC ISOLAN
Washington, DC
ESnet
NGIX East
ATM Switch
Router

NASA RESEARCH AND EDUCATION NETWORK

NREN Applications

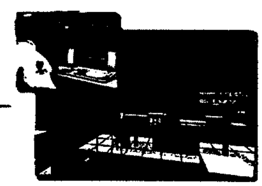
- Prototype revolutionary applications to support future NASA missions.
- Focus is on end-to-end application demonstrations in realistic network environments, pushing limits of scalability.
- Integrate emerging technologies into NASA/NGI Applications.

Tomorrow's Networking Applications Today

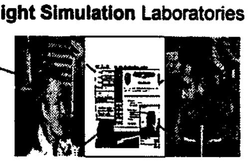
NASA RESEARCH AND EDUCATION NETWORK

NREN Applications

Accelerate network technology delivery to meet unique NASA unique mission requirements today.



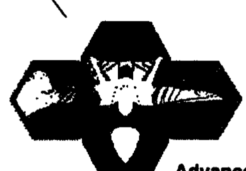
Virtual **Flight Simulation** Laboratories



Telemedicine, Interactive Consultations, Remote Protocols and Procedures

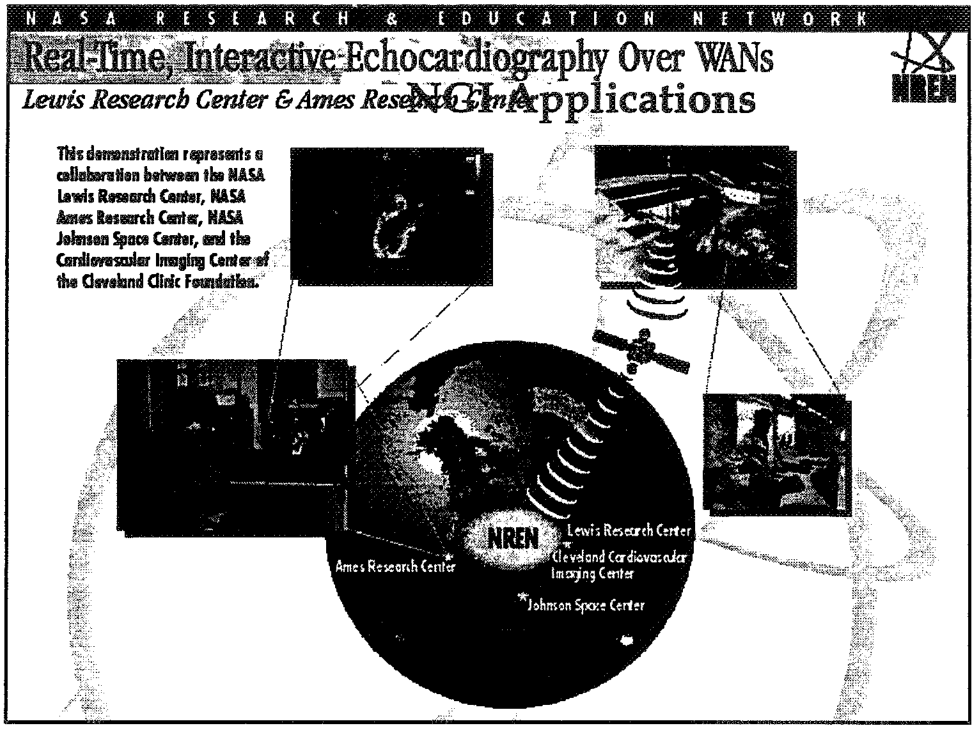
Advanced Science Investigations for **Mission to Planet Earth**

Astrobiology Institute Collaboratories, Virtual Aerospace Environment



Advanced Aerospace Design and Test Tools - Wind Tunnels on-line

Tomorrow's Networking Applications Today


NASA RESEARCH & EDUCATION NETWORK
Real-Time, Interactive Echocardiography Over WANs
NGI Applications
Lewis Research Center & Ames Research Center
NREN
This demonstration represents a collaboration between the NASA Lewis Research Center, NASA Ames Research Center, NASA Johnson Space Center, and the Cardiovascular Imaging Center of the Cleveland Clinic Foundation.
NREN
Lewis Research Center
Cleveland Cardiovascular Imaging Center
Ames Research Center
Johnson Space Center


NASA RESEARCH & EDUCATION NETWORK
Remote Operation: Nomad Rover in Chile
Carnegie Mellon University, Goddard Space Flight Center and Ames Research Center
NREN
"Dewarped" image of panespheric view
Nomad's Virtual Dashboard
Carnegie Mellon University
NREN
Ames Research Center
Goddard Space Flight Center
Panespheric camera provided continuous 360-degree panoramas at one frame per second
Information sent to and from satellite
Atacama Desert
Chilean students with Nomad

NASA RESEARCH & EDUCATION NETWORK

Remote, Interactive Virtual Simulation Laboratory

Johnson Space Flight Center & Ames Research Center

NASA RESEARCH AND EDUCATION NETWORK

NREN Applied Research

QoS: investigation and potential deployment of Class Based Queuing (CBQ) and RSVP. Development of bandwidth broker

Security: Pilot and deployment of a large scale decentralized Public Key Infrastructure (PKI), Certification Authorities, integration of Kerberos and PKI

Multicast: Pilot and deployment of a large scale native multicast network

IPv6: Introduce IPv6 as an enabling technology for scaling QoS, multicast and other new services

Routing-with-Switching: Experiments in high performance core network switching and routing elements

'Tomorrow's Networking Applications Today

NREN Applied Research

NREN

Congestion Control: Deploy ATM based ABR and CBR services, Weighted Random Early Drop (WRED)

Giga/Terabit Technologies: Deployment of gigabit and terabit networking strategies

Network Management: Investigate self healing networking strategies

Performance Benchmarks: Develop an Internet standard suite of performance benchmarks

NGI Exchanges: Interconnect with other NGI networks and with foreign research networks at NGI eXchanges (NGIXs)

GigaPoPs: Connect to selected gigapops for NASA applications requiring high performance connections to university sites.

Tomorrow's Networking Applications Today

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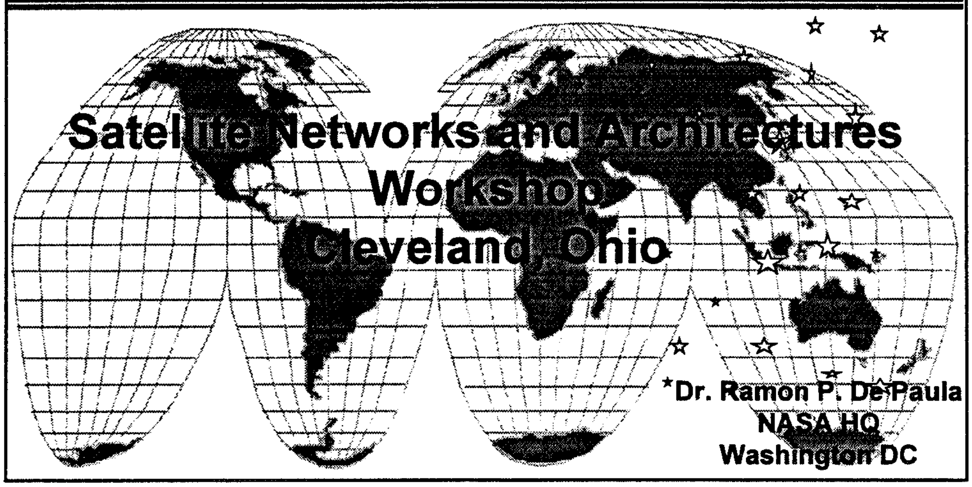
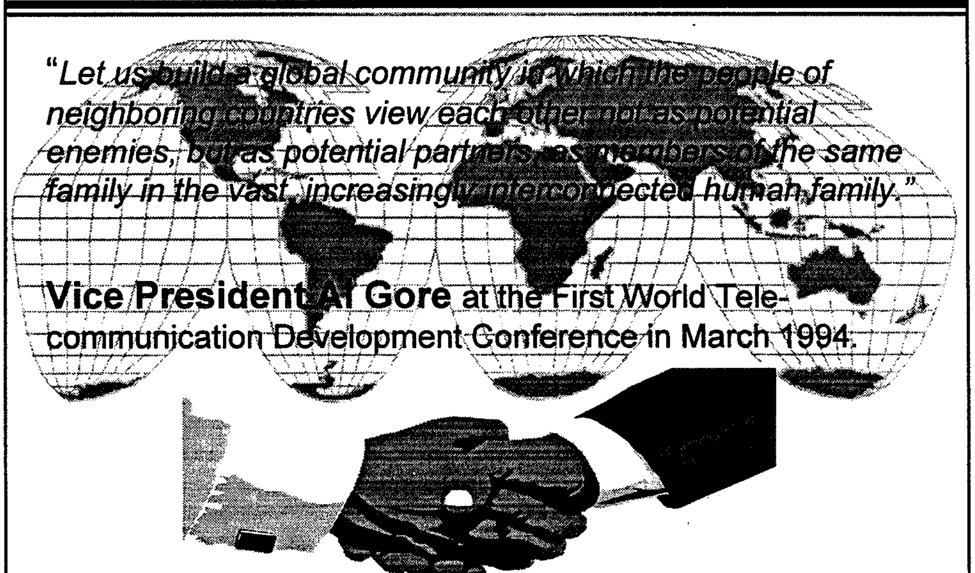
Global Interoperability of Broadband Networks (GIBN) Project Overview



U.S. Vision for the GII



Global Information Infrastructure (GII)

What is the GII?

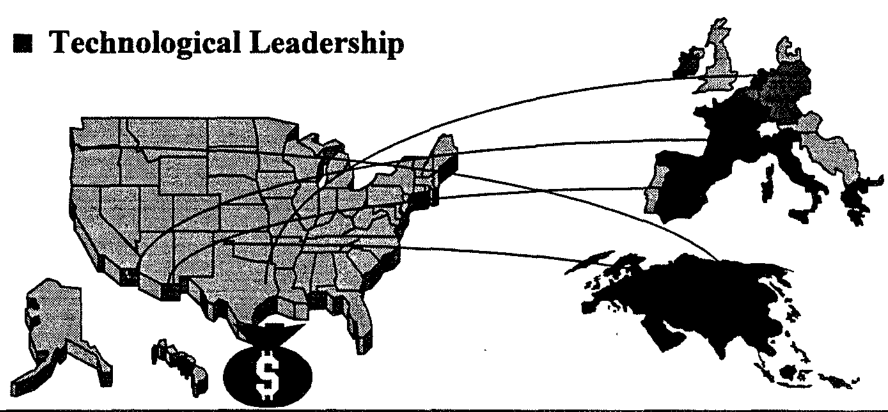
The term GII was defined at the February 1995 meeting of the G7 nations, not by what it is (or will be), but by what it will enable:

"THE GII WILL ALLOW READY ACCESS TO RELEVANT INFORMATION AT REASONABLE COST, BY ANYONE, ANYWHERE, AT ANYTIME"

GII as a whole is worldwide "network of networks" which will create a global information marketplace, encouraging broad-based social discourse within and among all countries.

GII
Benefits to the U.S. Economy

- **Direct and Indirect Employment Benefits**
- **Exports (Positive Trade Balance)**
- **Technological Leadership**



G-8 "Global Information Society" Projects

1. Global Inventory
2. Global Interoperability of Broadband Networks (GIBN)
3. Cross-Cultural Education and Training
4. Electronic Libraries
5. Electronic Museums and Galleries
6. Environment and Natural Resources Management
7. Global Emergency Management
8. Global Healthcare Applications
9. Government On-line
10. Global Marketplace for Small and Medium Enterprises
11. Maritime Information Systems

Global Interoperability for Broadband Networks (GIBN) **Mission**

US Perspective:

- Establish strong Government, industry and academia partnerships.
- Formulate clear objectives for experimentation.
- Emphasis that US Industry is an important partner.
- Foster International cooperation with non-US government agencies, universities and industry partners

Global Interoperability for Broadband Networks (GIBN): "**Principles**"

- To establish experimental intercontinental communications links among the three main geographic areas of the G-8 countries: North America, Europe and Japan.
- To provide a common testbed for the promotion of joint Satcom/Terrestrial Interoperable R&D, demonstrations and pre-commercial trials of advanced high data rate (>45 MBPS) services and applications.
- To encourage research initiatives promoting science, education and commerce, as well as, social and cultural development.
- To develop advanced interoperable communications & information systems and networks that support emerging G8 information society applications
- The GIBN will be the interoperable testbed for the other 10 information society projects.

Global Interoperability for Broadband Networks: "**Objectives and Goals**"

- To promote the role of satellites in the Global Information Infrastructure (GII).
- To analyze the barriers of seamless interoperability between satellite and terrestrial communications systems; promote networks and system modifications to software or hardware to overcome such barriers.
- To integrate US industry products and services as an essential part of applications/demonstrations.
- Recommend changes in standards, where appropriate, to overcome barriers of interoperability between satellites and terrestrial systems.
- Extend connectivity of networks to non G-8 countries

Global Interoperability for Broadband Networks: "**Background**"

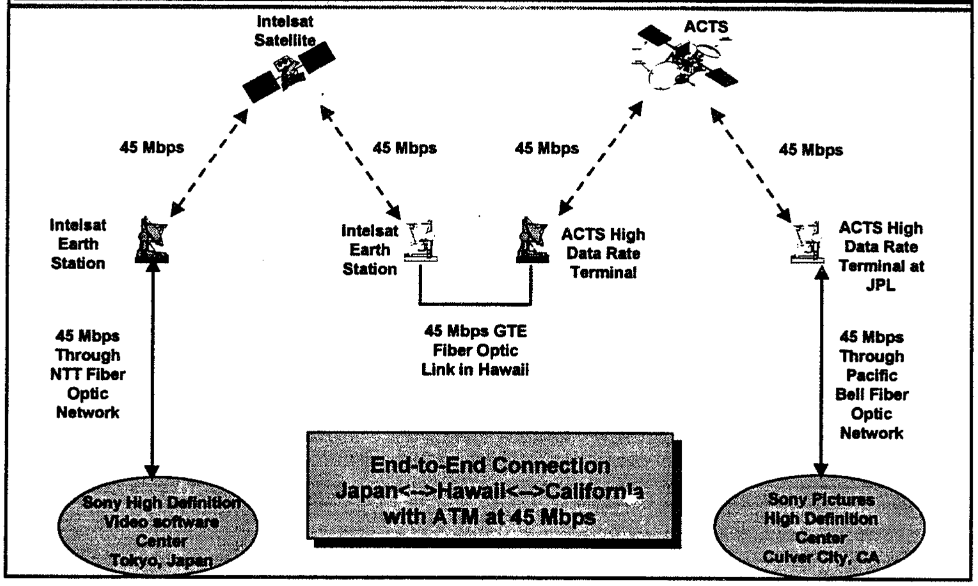
- The White House National Economic Council, invited NASA to formally participate in planning and co-coordinate jointly with NSF the U.S. contribution to the G7 GIBN project.
  - * **"...the series of Trans-Pacific experiments, and others planned for the Atlantic and Asia-Europe regions, will make a very significant contribution to the G-7 Global Interoperability for Broadband Networks project."**
- NASA tasked to undertake planning to support and promote additional Trans-Pacific and Trans-Atlantic GIBN experiments which provide satellite connectivity to NREN and STAR TAP.
- Applications, such as, digital libraries, telemedicine, tele-education, and electronic commerce; that contribute to NGI design and implementation were considered solid candidates for future GIBN contributions.

*** Thomas A. Kalil, Senior Director, National Economic Council, The White House**

Global Interoperability for Broadband Networks: "**NASA Status**"

- NASA LeRC Space Communications Program assigned to lead GIBN projects. Participation by JPL, GSFC, and ARC.
- Successfully completed the first Trans-pacific satellite post-production video experiment and demonstration (March /April 1997, JPL - CRL)
- Assessment of the "Science, Technology and Research-Transit Access Point" (**STAR TAP**) site (at Univ. of Ill.--Chicago) for installation of satellite ground terminal.
- LeRC will host Intelsat compatible Ku-band satellite terminal; scheduled for completion in September 1998.
- Three GIBN project applications currently in works; they are: Radio-Astronomy (Trans-Pacific) [JPL]; Digital Libraries (Trans-Pacific) [GSFC]; and Operation Smile (Trans-Atlantic) [GWU].
- European Commission (EC) interested to establish connectivity with US via satellite. Several other candidate for Trans-Atlantic experiment under review.

Transpacific High Definition Video Experiment



Global Interoperability for Broadband Networks: "**Experiment Selection Criteria**"

- Information exchange with Trans-Atlantic or Pacific partners; not just NASA's demonstration.
- Opportunity for U.S. Industry to contribute hardware, software, intellectual resources and learn about interoperability issues.
- Develop and demonstrate state-of-the-art, unique communications systems, networks and applications.
- Foster ground-breaking use of communications activities in particular wireless.
- Encourage/seek-out NASA mission tie-in.
- Promote connectivity to non G-8 countries via Satellite

Global Interoperability for Broadband Networks: "**Satellite Industry Involvement**"

- SITF Requirements are:
  - » Seamless interoperability between terrestrial and satellite networks which is a major problem in providing emerging broadband services to the end users
  - » In-Space Technology demonstrations are required for timely utilization of advance technologies in future communications satellite systems and applications.
    - o In systems...A series of interoperability demonstrations are needed to achieve integration of satellite and terrestrial networks.

Global Interoperability for Broadband Networks: "**Current Experiments**"

Trans-Pacific Radio-Astronomy [JPL, CRL/MPT]

- Justification:
  - » Science and Education: Interactive image transmission from telescopes in the U.S. and Japan.
  - » builds on the successful Trans-Pacific HDTV demonstration;
  - » potential to demonstrate OC-3 [155Mbps] data rates over commercial satellite.
- Schedule:
  - » Demonstration planned for 4th Quarter FY98;
  - » Virtual Internet Testbed simulations and Final Report, 1st & 2nd Quarters FY99

Global Interoperability for Broadband Networks **Current Experiments**[continued]

Operation Smile--Telemedicine [GWU]

» Justification:
- Trans-Atlantic experiment;
- Global Multicast Internet Distribution
- High level of G-8 telemedicine involvement; positive exposure.

» Schedule:

» 3rd or 4th Quarter FY98

Trans-Pacific Digital Library Experiment [GSFC/JPL]

» Justification:
- builds on the successful Trans-Pacific HDTV demonstration;
- demonstrates one of the G-7 project theme of Electronic Libraries;

» Schedule (tentative):
- 1st demonstration in late CY98

Global Interoperability for Broadband Networks: "**Current Experiments**"[continued]

Trans-Atlantic GIBN Experiment over PanAmSat:

» Networking Trade Show, 22-25 June 1998, at Birmingham, England

» ATM Forum sponsoring booth to present ATM related technologies

» Offered to highlight NASA ATM over Satellite and ATM Forum work

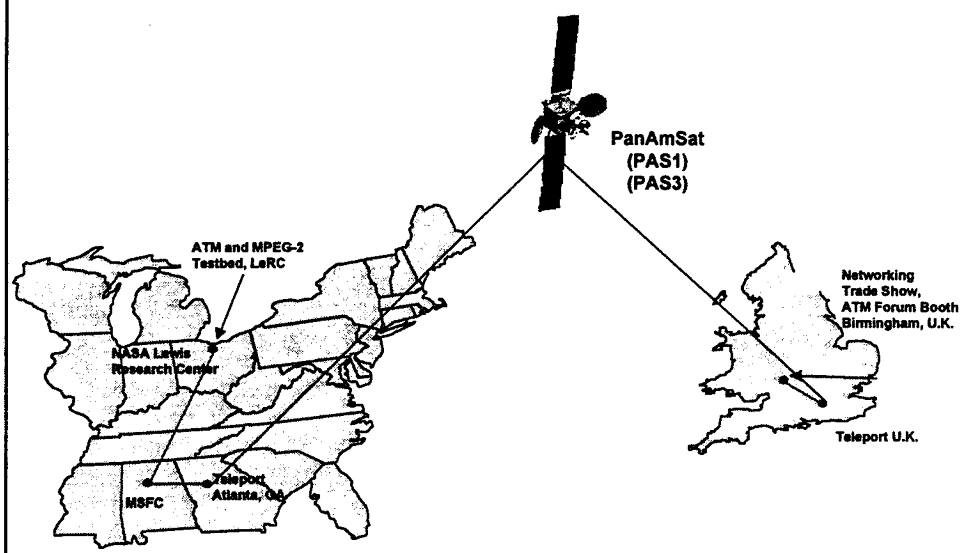
» ATM over Satellite Technologies / Quality of Service Video presentation MPEG2

» During LeRC Conference, several short (5 mins) lectures by Industry leaders will be recorded; then presented at the trade show via the broadband network.

» Voice over IP over ATM

» PanAmSat, MetroData and NASA have partnered to present ATM Technologies Demonstrations over PanAmSat link.

Trans-Atlantic Interoperability Broadband Network Experiment over PanAmSat



Challenge for GIBN Project

- We must view each other as potential partners
  - » Part of the GII Vision
- Eliminate bureaucratic barriers
- Realize that Satellite Systems are a Global Business
- Realize that Satellites offers unique opportunities to many nations
- Provide open access to the network for all information providers and users
- Develop unique demonstrations that address critical issues

Conclusion

- To achieve the full potential of the future GII it will require concerted efforts and ***strong partnership among Industry/Government/Academia***
- Satellite and terrestrial services will be equally important to the success and goals of the GII and GIBN
- GIBN demonstration of ***Seamless integration*** of terrestrial and satellite is very important
- The G-8 nations needs to promote more effective standards and protocols.
- ***International Cooperation a must.*** GIBN project is one way to help promote this cooperation

Plenary Session
Addressing Interoperability

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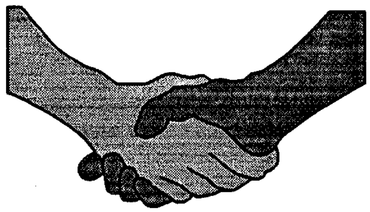
Addressing Interoperability: Issues and Challenges



Raj Jain
The Ohio State University
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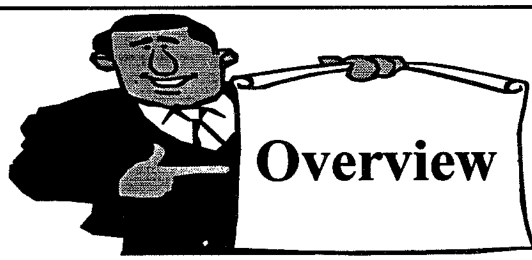
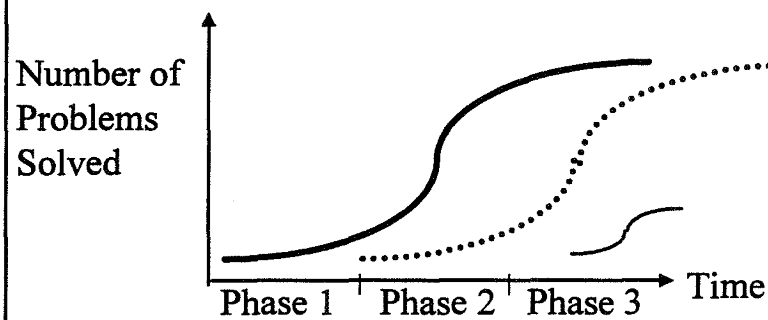
http://www.cis.ohio-state.edu/~jain/



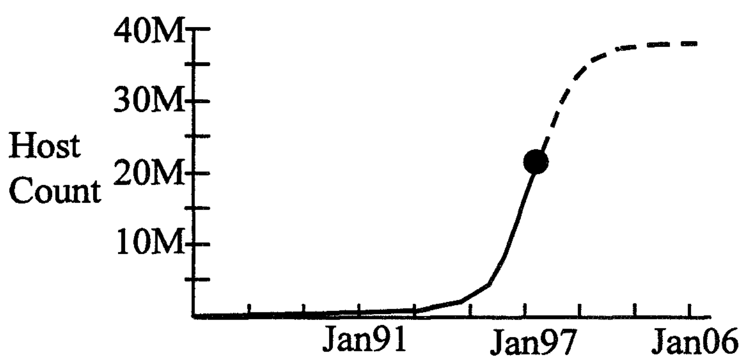
- Life Cycle of Technologies
- Interoperability and Standards Issues
- ATM Traffic Management

Life Cycles of Technologies

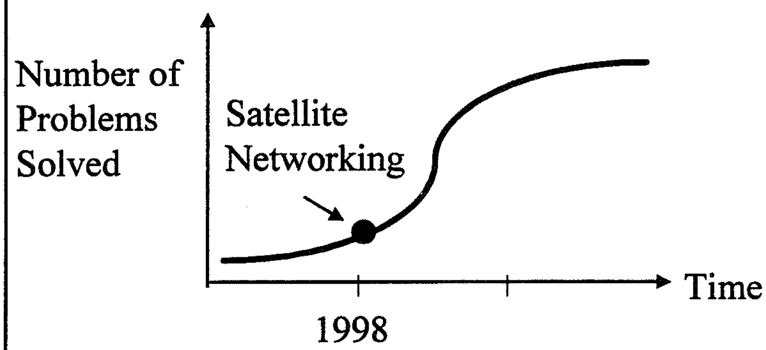


- Phase 1: Research
- Phase 2: Productization
- Phase 3: Transition to the next technology

Internet Technology



Life Cycle: Satellite Networking



- Phase 1: Research Proprietary/competing solutions
- Phase 2: Standard based interoperable solutions

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Networking: Failures vs Successes

- 1980: Broadband Ethernet (vs baseband)
- 1984: ISDN (vs Modems)
- 1986: MAP/TOP (vs Ethernet)
- 1988: OSI (vs TCP/IP)
- 1991: DQDB
- 1992: XTP (vs TCP)
- 1994: CMIP (vs SNMP)

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Requirements for Success

- Low Cost
- High Performance
- Killer Applications (Remote areas, Distance Insensitive, Multicast)
- Timely completion
- Manageability
- Interoperability
- Coexistence with legacy (terrestrial) networks

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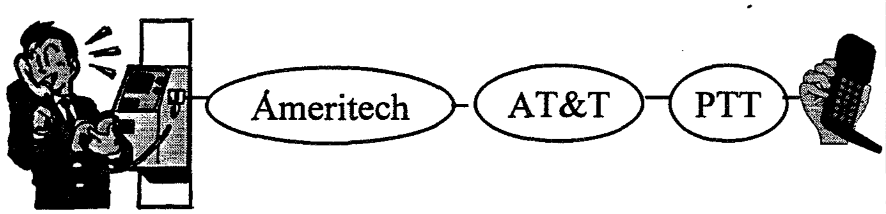
Interoperability: Example



- Phone System: Any phone, any carrier(s), any place

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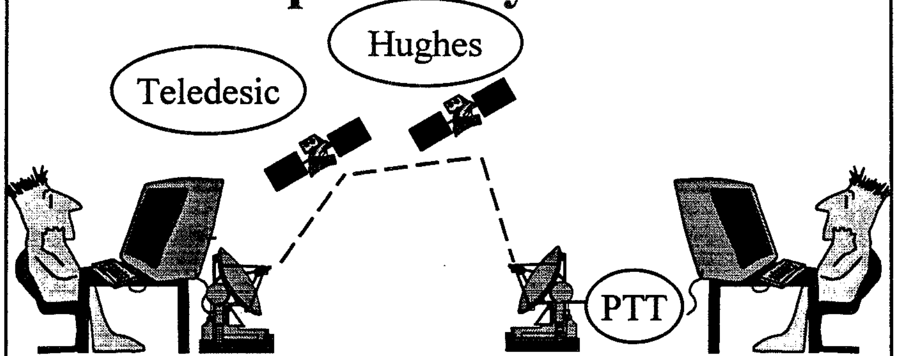
Interoperability?



- Satellite Network: Any dish, any satellite system, any place

Layers of Interoperability

Application	←------------→	Application
Transport	←------------→	Transport
Network	←------------→	Network
Datalink	←------------→	Datalink
Physical	←------------→	Physical

- Physical: Spectrum Management, Common Air Interface
- Datalink: DAMA/MAC
- Network: Mobility, Handoff
- Transport: Satellite/Terrestrial TCP/ATM
- Application: Paging, Data, Messaging

Standards: A Partial List

- Telecommunication Industries Association (TIA)
  - Common Air Interface
  - Spectrum Management
- International Telecommunications Union (ITU)
  - QoS
- ATM Forum
  - Wireless ATM
  - Traffic Management

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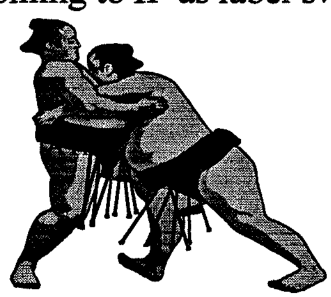
Why ATM?

- ATM vs IP: Key Distinctions
  1. Traffic Management: Explicit Rate vs Loss based
  2. QoS based routing: PNNI
  3. Signaling: Coming to IP in the form of RSVP
  4. Switching: Coming to IP as label switching



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Our Goal

- Ensure satellite/terrestrial interoperability in ATM TM
  - Ensure that the new ATM Forum TM 4.0/5.0 specs are "Satellite-friendly"
  - There are no parameters or requirement that will perform badly in a long-delay satellite environment
  - Users can use paths going through satellite links without requiring special equipment
  - Develop optimal solutions for satellite networks

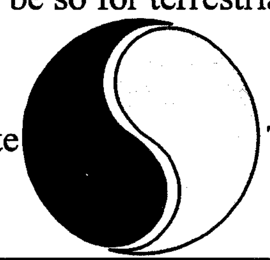
This work is sponsored by
NASA Lewis Research Center

The Ohio State University Raj Jain

Issues

- Binary vs Explicit Rate Feedback
- ABR vs UBR: Available bit rate vs Unspecified bit rate
- Improving performance over ABR: VS/VD
- Improving Performance over UBR: Guaranteed Rate

Note: The alternative that is best for satellite networks may or may not be so for terrestrial networks.

Satellite  Terrestrial

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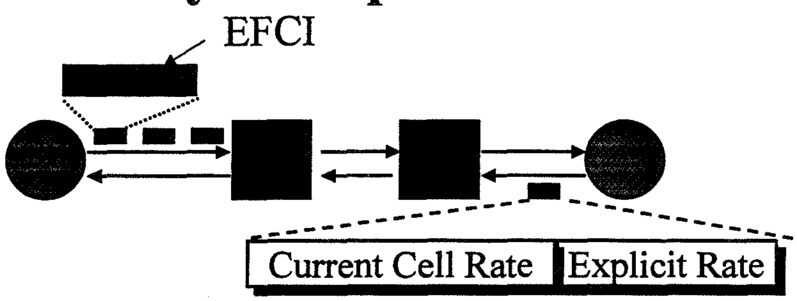
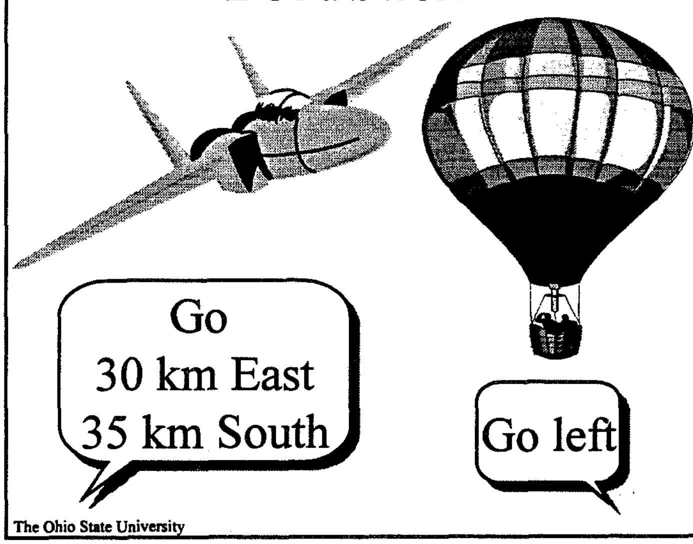
Binary vs Explicit Rate



- Binary: Explicit forward congestion indication (EFCI) bit in the cell header set by congested switches. Based on DECbit scheme.
- Explicit Rate: Sources send one RM cell every n cells. The switches adjust the explicit rate field down.

Binary vs Explicit Feedback

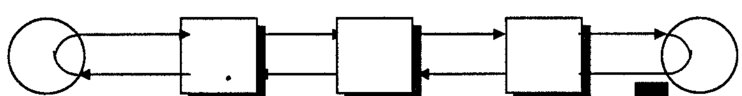


Why Explicit Rate Indication?

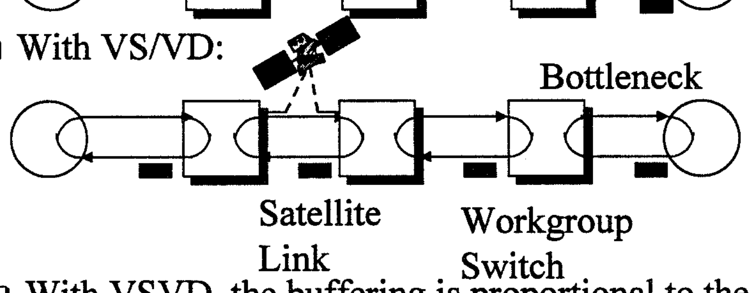
- Longer-distance networks
  - ⇒ Can't afford too many round-trips
  - ⇒ More information is better
- Rate-based control
  - ⇒ Queue length = ΔRate × ΔTime
  - ⇒ Time is more critical than with windows

VS/VD

- Without Virtual Source/Virtual Destination:

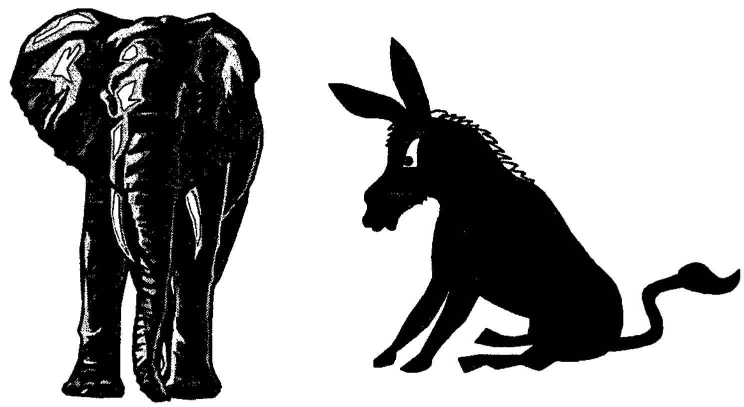


- With VS/VD:



- With VSVD, the buffering is proportional to the delay-bandwidth of the previous loop
  - ⇒ Good for satellite networks

ABR or UBR?



- Intelligent transport or not?

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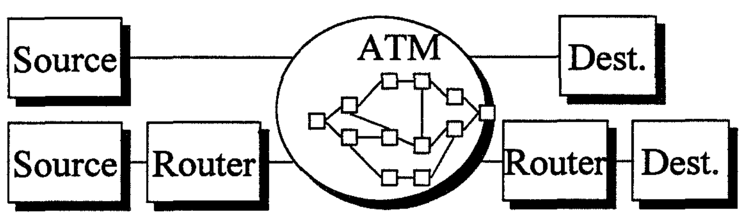
ABR vs UBR



ABR	UBR
Queue in the source	Queue in the network
Network Qs = k RTT	Network Qs = Σ Windows
Pushes congestion to edges	No backpressure
Good iff end-to-end ABR	Good iff TCP.
Fair	Generally unfair

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Ways to Improve UBR over Satellites

1. Reserve a small fraction of bandwidth for UBR class in the switches ⇒ Guaranteed Rate Service.
   - For WANs, the effect of reserving 10% bandwidth for UBR is more than that obtained by EPD, SD, or FBA
   - For LANs, guaranteed rate is not so helpful. Drop policies are more important.
2. Implement "Selective Acknowledgement" in end-systems. Disable "Fast retransmit and recovery" in end-systems.

Summary

- Interoperability is the key to success of a technology
- Layers of interoperability: Air interface to applications
- ER better for satellites than Binary feedback.
- ABR better than UBR for long-delay paths
- VS/VD can help reduce the impact of satellite delays
- Reserving a small capacity helps UBR

Guaranteed Rate Service

- Guaranteed Rate (GR): Reserve a small fraction of bandwidth for UBR class.

GR	GFR
per-class reservation	per-VC reservation
per-class scheduling	per-VC accounting/scheduling
No new signaling Can be done now	Need new signaling In TM4+

Future

When will satellite technology really take off?

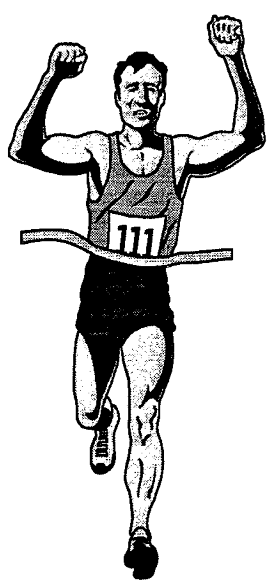
Our Publications

All our ATM Forum contributions and papers are available on-line at *http://www.cis.ohio-state.edu/~jain/*

- Specially see "Recent Hot Papers"

The Ohio State University — Raj Jain

Thank You!



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Transitioning NASA

Space Operations to Commercial Services

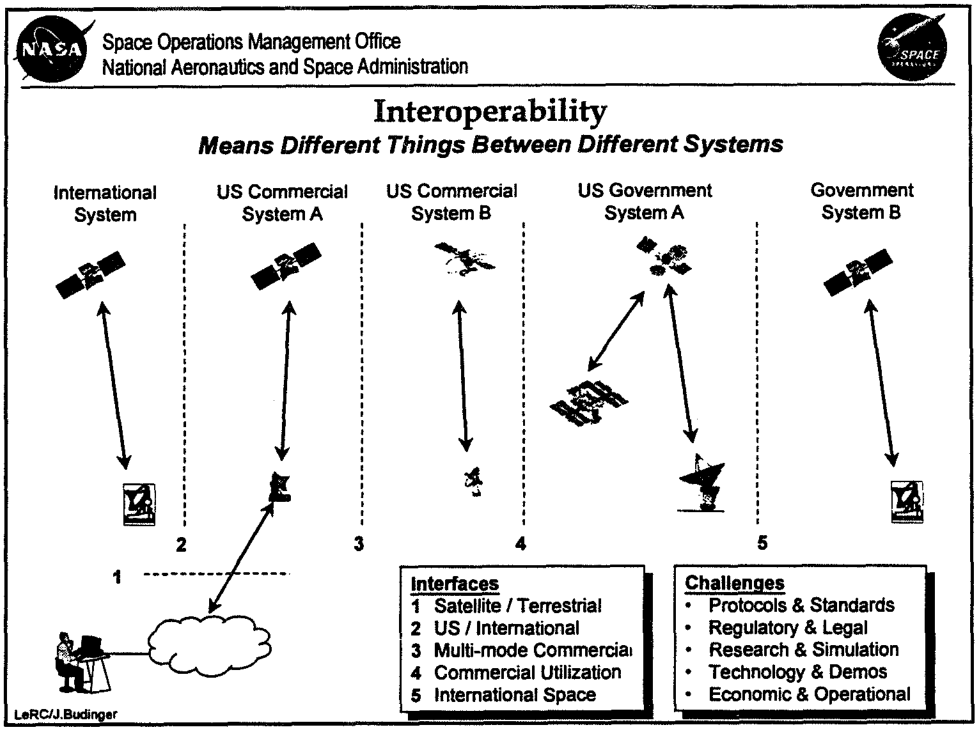
NASA/LeRC Satellite Networks Workshop

June 2- 4, 1998

Charlene E. Gilbert
Space Operations Management Office
Techrology Program Manager
NASA Johnson Space Center
charlene.e.gilbert1@jsc.nasa.gov

Major Considerations in Transitioning NASA to Commercial Services

- Government use of commercial frequencies vs commercial use of commercial frequencies for Government use
- Commercial use of Government frequencies
- Government vs commercial
  - Access techniques
  - Data formats
  - Modulation & coding
- Government need for multiple sources
  - Backup
  - Competition
- Government in perceived competition with commercial service providers if TDRSS is used for commercial purposes
- Coordination required among plans for CSOC, NSCP, and Satellite Industry


Space Operations Management Office
National Aeronautics and Space Administration
SPACE
Interoperability
Means Different Things Between Different Systems
International System
US Commercial System A
US Commercial System B
US Government System A
Government System B
1
2
3
4
5
Interfaces
1 Satellite / Terrestrial
2 US / International
3 Multi-mode Commercial
4 Commercial Utilization
5 International Space
Challenges
• Protocols & Standards
• Regulatory & Legal
• Research & Simulation
• Technology & Demos
• Economic & Operational
LeRC/J.Budinger

IRIDIUM

Satellite Networks Workshop '98
Interoperability Issues
Mark Plecity
June 22, 1998

IRIDIUM

Interoperability Issues

Technology Issues being faced today

- Voice interoperability issues
  - PSTN
  - Wireless
  - Supplementary services
- Data interoperability issues
  - Data rates
  - Fax

June 22, 1998

Interoperability Issues

IRIDIUM

Fundamental Issues

- Development of common interfaces
  - Eliminate proprietary systems
  - International acceptance and development
  - Incorporates advanced features
  - Meets growing data networks
    - ATM
    - TCP
- Evaluate network as a hybrid
- Flexibility and growth

June 22, 1998

Interoperability Issues

IRIDIUM

Example

- Integration of wireless network
  - System designed as a single solution domestic
  - Four network types converging to two
    - DMX
    - GSM
    - IS-41
    - PDC

    → - GSM - IS-41
  - Satellite integration has raised issues
- Interoperability of data networks
  - ATM implementation
  - Frame relay implementation

June 22, 1998

Interoperability Issues

IRIDIUM

Resolution and lessons learned

- Integrate networks at the lower levels and incorporate mediation devices
  - Special development is required
  - Performance and functionality is decreased
  - Network flexibility is reduced
- Develop defined specifications that support seamless use
  - International participation is required
  - Backwards compatibility is required
  - Market drives applications and usage

June 22, 1998

Interoperability Recommendations

IRIDIUM

Focus areas

- Standards committees
  - U.S. entities need to be proactive
  - International development is important
  - Design for hybrid networks and flexibility
- Strategic planning of technical effort is crucial
  - Enhancement of "basic" areas
    - Hardware
    - Network Intelligence
  - Industry involvement and coalescence
- Address all markets -(DoD and Private)

June 22, 1998

IRIDIUM

Satellite Networks Workshop '98
Iridium Services
Mark Plecity
June 22, 1998

IRIDIUM

Flexible Service Offering

Based on his communications needs, the customer chooses:

- A home network
  - Satellite Network
  - Wireless Network
- The appropriate subscriber equipment
  - Satellite subscriber equipment
  - Wireless telephone
  - Pager

These choices then determine which components of the IRIDIUM Service the customer has access to.

June 22, 1998

Subscriber Equipment Choices

IRIDIUM

- **Satellite Phone**
  - Used to access IRIDIUM satellite networ[k]

Kyocera

Satellite-Only Phone

Motorola

IRIDIUM Phone without
Terrestrial Radio Cassettes

June 22, 1998

Equipment Choices (cont'd)

IRIDIUM

- **Dual-Mode Cellular/Satellite Phone**
  - Used to access both IRIDIUM satellite network and cellular networks via a single phone

Kyocera

Cellular Phone*
with
IRIDIUM
Adapter

*3 Types Available at Commercial Activation:
GSM900
CDMA800
PDC
AMPS available October'98
TDMA available in the future

Motorola

IRIDIUM Phone
with
Terrestrial Radio Cassettes**

**2 Types Available at Commercial Activation:
GSM900
AMPS/NAMPS/CDMA800
DCS1800 available in the future

June 22, 1998

Equipment Choices (cont'd)

IRIDIUM

- **Cellular Phones**
  - Used to access cellular networks

Any cellular phone of the following types:

- GSM900 }
- DCS1800 } GSM
- PCS1900 }
- AMPS/NAMPS }
- CDMA } IS-41
- TDMA }

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Equipment Choices (cont'd)

IRIDIUM

- **IRIDIUM Pager**
  - Required for IRIDIUM World Page Service
  - Available from both Motorola and Kyocera

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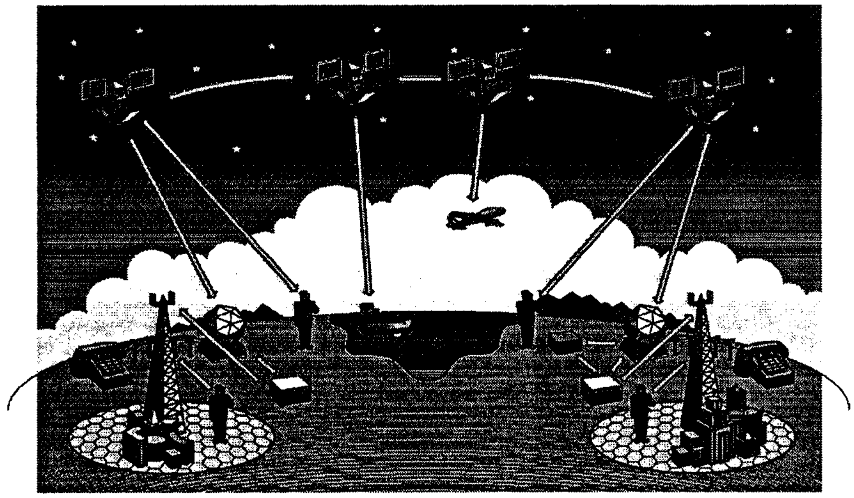
IRIDIUM Aero Service

IRIDIUM



Extends the IRIDIUM service to aircraft

June 22, 1998

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Interoperability

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NASA Lewis Research Center Workshop on Satellite Networks: Architectures, Applications and Technologies
Cleveland, Ohio
June 2-4, 1998

Interoperability for Global Area Network Systems

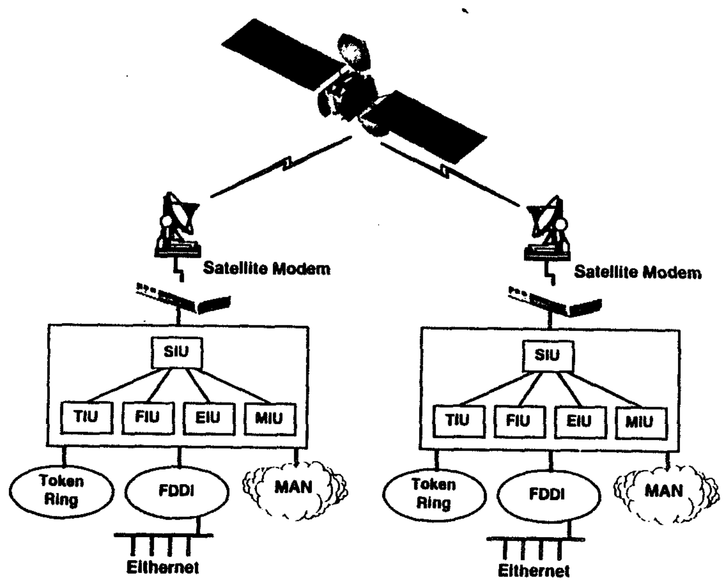
- *Goal: To develop standards, protocols and interoperable network architecture framework for seamless and transparent networking of emerging satellite network systems with terrestrial networks*
- *Satellite industry task force (SITF): SITF was formed in January 1995 to articulate the roles of satellites in the NII & GII and to identify the barriers to achieving those goals*
- *Primary recommendation was to form a standards and interoperability subworking group under TIA*

Interoperability Classification

- *Internetworking of stand alone system with legacy networks of the ground systems*
- *Interoperability of emerging multimedia satellite systems e.g. satellite ATM with non-ATM networks*
- *Interoperabilty of multiple Ka-band systems for multimedia services with "intelligent gateways"*
- *Interoperability of commercial systems with military systems of multiple frequency bands, multiple data rates and multiple waveforms*

Lockheed Martin Telecommunications

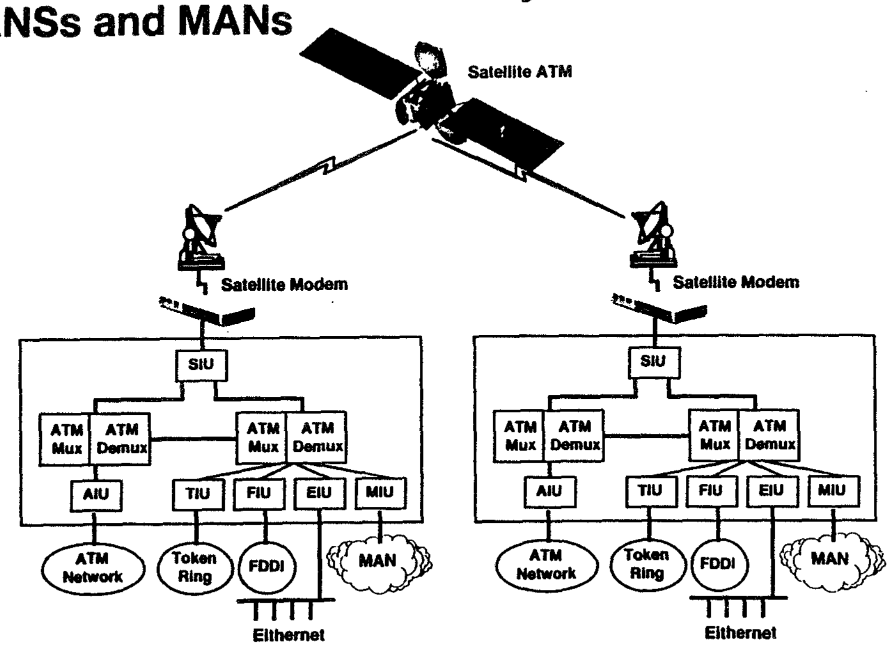
Interconnectivity with Legacy Networks



SIU = Satellite Interface Unit
TIU = Token Ring Interface Unit (IEEE802.5)
FIU = FDDI Interface Unit (ANSIx3t0.5)
EIU = Ethernet Interface Unit (IEEE802.3)
MIU = MAN Interface Unit (IEEE802.6)

Lockheed Martin Telecommunications

Satellite ATM Interconnectivity with LANSs and MANs



AIU = ATM Network Interface Unit

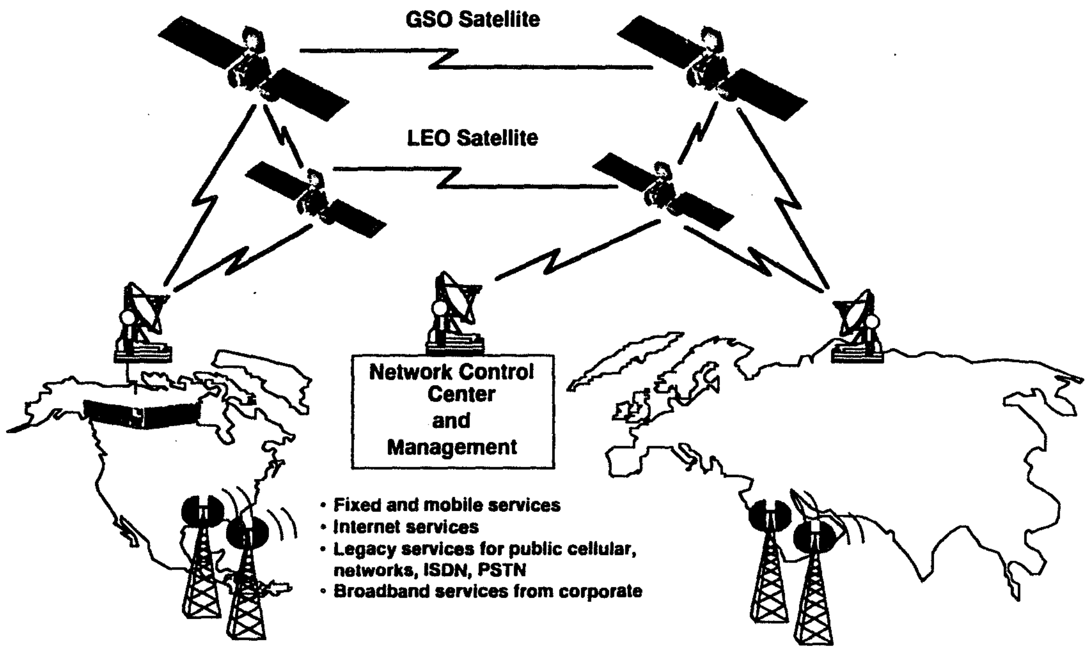
Lockheed Martin Telecommunications

Satellite ATM Interoperabilty Issues

- *Encoding Technologies*
- *Signaling protocols modifications*
  - *Q.2931, UNI 4.0, Q.931*
- *Media access protocol design*
  - *Shared/random*
  - *DAMA*
- *Traffic Management*
  - *CAC,*
  - *Traffic shaping*
  - *Buffering/scheduling*
  - *Frame discard*
- *Quality of service*
  - *ITU.TT.356 versus ATM forum definition*
  - *Frame based QoS definition*
- *Voice over ATM over satellite*
  - *VTOA (ATM forum spec)*
- *TCP/IP over ATM over satellite*
  - *SAC protocol*
  - *ABR, UBR service*
  - *Spoofing*
- *Video over ATM*
  - *MPEG 2*

Lockheed Martin Telecommunications

Global Multimedia Satellite Network (GLOMS)



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HUGHES
COMMUNICATIONS

GEO Satellite Applications for Ka-Band

Jim Justiss, Director of Systems Engineering
SPACEWAY™ Program

June 3, 1998

SPACEWAY

Topics

HUGHES
COMMUNICATIONS

- Satellite system constraints
- When to use satellite ?
- SPACEWAY™ system concept
- Satellite services – video clips
- SPACEWAY™ business model

SPACEWAY

Satellite System Constraints

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1. **Modest data rate with respect to terrestrial alternatives**
   - E.g., OC-12, OC-48, OC-192 fiber (622 Mbps, 2.4, 9.6 Gbps)
   - Constrained by spectrum, power, weight, terminal cost
2. **Not uninterruptable**
   - Due to rain fade, sun outage, etc.
   - Highly reliable links (better than 99.8 %) require backup technology
3. **Modest system capacity**
   - Constrained by RF spectrum

SPACEWAY

GEO Advantages to Users

HUGHES COMMUNICATIONS

Cost of service advantage

- Point-to-point from anywhere in the US
- Especially for broadcast / multicast applications
  - i.e., 'push' multimedia, data, video

Terminal cost advantage

- Fixed-pointing, stationary beam
- Small power amplifier
- Low-end receive-only terminal

SPACEWAY

GEO Advantages to Business Operator

HUGHES COMMUNICATIONS

Capacity goes where return is greatest

- Deploy regionally as markets develop

Quick deployment to start business

- Technology leaps not required
- Design, rather than new technology development

One satellite to start operation

- Expand to multiple satellites per orbit slot

Few gateway sites required

Simple network management

- Simple routing – single node
- Broadcast terminal / interface software updates

SPACEWAY

No Technology is Best for Every Application

HUGHES COMMUNICATIONS

No single technology is best for every application

- Not GEO
  - Expensive for dedicated, full-time, point-to-point leased line
  - Data rates limited by spectrum
- Not LEO
  - Expensive for broadcast / multicast
  - Data rates limited by spectrum
- Not fiber
  - Expensive for broadcast / multicast
  - Expensive for sites in low-density regions

Choose technology appropriate for application

SPACEWAY

When To Use Satellite ?

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COMMUNICATIONS

Prefer satellite vs. terrestrial point-to-point when

- Cost of terrestrial link is high
- Quick deployment needed
- Application has multicast / broadcast nature
- Occasional or intermittent use, different destinations

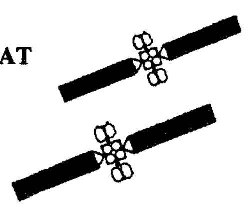
SPACEWAY

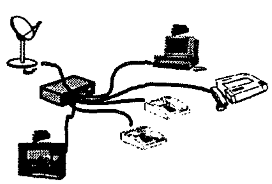
SPACEWAY™ System Concept

HUGHES
COMMUNICATIONS

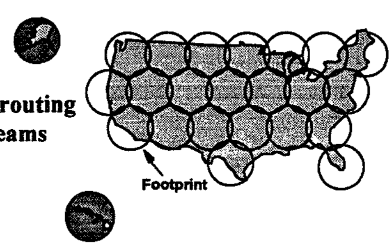
Terminals

- Low cost, easy to install USAT terminals
  - 66 cm, 384 kbps uplink
  - 1.2 m, 1.5 Mbps uplink
  - 2.5 m, 6 Mbps uplink
  - 100+ Mbps downlink
- Standard interfaces
- Bursty and constant bit rate applications





- Collocated satellites
- Spot beams enable small, low-cost terminals
- Spot beams give high capacity via frequency reuse
- On-board routing between beams



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Satellite Experiment Configuration

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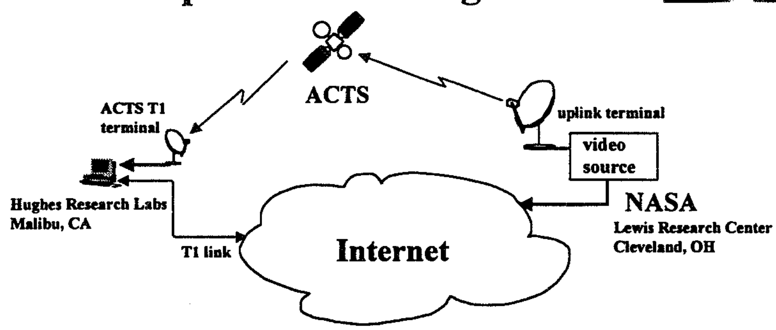

Simultaneous feed on satellite and terrestrial paths

Unknown nodes along terrestrial path

- Lower received rate due to packet losses
- Larger delay due to routing/path effects

SPACEWAY

Satellite Services – Video Clips

HUGHES COMMUNICATIONS

Compare satellite path vs terrestrial Internet:

1. TCP/IP on ATM via ACTS – 1.5 Mbps video
   - Compare satellite vs terrestrial (observe packet losses)
2. Videoconference via ACTS – 1.5 Mbps
   - VIC / VAT (MBONE codec)
3. Internet web browsing via ACTS – 1.5 Mbps
   - HTTP 1.1 via ACTS vs terrestrial HTTP 1.0 at 50 ms RTT
   - HTTP 1.1 via ACTS vs terrestrial HTTP 1.0 at 100 ms RTT
   - HTTP 1.1 via ACTS vs terrestrial HTTP 1.0 with 4 connections at 100 ms RTT
4. TCP/IP on DirecPC with cache layer
   - Cache hit vs retrieval with satellite-optimised protocol at 400 kbps
5. MBONE via DirecPC vs terrestrial MBONE
   - DirecPC ~ 128 kbps, 0 % errors
   - Terrestrial < 100 kbps, 30 % errors
6. MPEG video on IP multicast via DirecPC Enterprise Edition

SPACEWAY

SPACEWAY™ Business Model

HUGHES COMMUNICATIONS

SPACEWAY™ delivers personal broadband service

- Ubiquitous access, quick installation
- Low-cost for part-time service
- 'Push' distribution of multimedia, cache refresh
- Compressed video delivery capability – in real time

Service Goals

- Applications flexibility
  - Support existing and future applications
- Seamless interoperability
  - Application doesn't know or care about satellite path
- Complement other technologies – e.g., 'push' for point-to-point fiber
  - Bulk of traffic will be terrestrial

Strategy

- Standards–based, using standard protocol interfaces
  - For example, IP, ATM, MPEG, etc.

SPACEWAY

Session 4
ATM over Satellite Networks

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AT&T

Overview of ATM Performance and QoS Requirements for Satellite Systems

Presented by:

Dr. Enrique G. Cuevas
Technology Consultant
Satellite Communications
AT&T - Laboratories

Tel. (732)-949-1130
Fax (732)-949-3468
email: cuevas@att.com

5/20/98
E.G. Cuevas

QoS_NASA1.ppt

AT&T

OUTLINE

1- Performance Objectives for ATM satellite connections
2- Impact of satellite characteristics on ATM performance
3- QoS requirements of ATM services and applications
4- Techniques to enhance ATM performance over satellite
5- ATM Availability considerations
6- Pending issues and future work.

5/20/98
E.G. Cuevas

QoS_NASA2.ppt

AT&T

Organizations Involved in the Development of ATM Performance Standards for Satellites

- ATM Forum: Traffic Management Specification (TM 4.0)
- ITU Telecommunications Sector: Study Group 13
  - Rec. I.356 "B-ISDN ATM Layer Cell Transfer Performance" (Q14/13)
  - Draft Rec. I.357 "B-ISDN Semi-Permanent Connection Availability" (Q15/13)
- ITU Radiocommunications Sector: Working Party- 4B
  - Draft Rec. S.atm "Performance for B-ISDN ATM via Satellite"
  - Draft Rec. S.atm-av "Availability Objectives for ATM via Satellite"
- United States Standards Groups:
  - T1A1.3 (Network Performance Aspects)
  - US WP-4B (Satellite Performance, Availability, Network aspects)
  - TR34.1 Communications and Interoperability Section of Satellite Communications Division of TIA.

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QoS_NASA3.ppt

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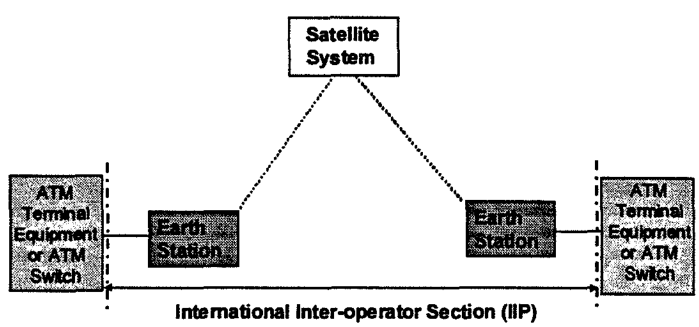
Reference Model for an ATM Satellite Path



NOTES:

•The satellite system may consist of GSO or Non-GSO satellites and may include Inter-Satellite Links and on-board processing and/or switching.

•The earth station includes: RF/IF equipment, modulator/demodulator, error correction, buffer, multiplex equipment and appropriate terrestrial network interfaces. It may also include any satellite-specific ATM processing equipment.

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ITU-T Rec. I.356
QoS Class Definitions and Network Performance Objectives

	CTD	2-pt. CDV	CLR_{0+1}	CLR_0	CER	CMR	SECBR
Default Objectives:	no default	no default	no default	no default	$4*10^{-6}$	1/day	10^{-4}
QoS Classes:							
Class 1 (stringent class)	400 msec	3 msec	$3*10^{-7}$	none	default	default	default
Class 2 (tolerant class)	U	U	10^{-5}	none	default	default	default
Class 3 (bi-level class)	U	U	U	10^{-5}	default	default	default
U class	U	U	U	U	U	U	U

All values are provisional and they need not be met by networks until they are revised (up or down) based on real operational experience.

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ATM Performance Objectives
Class-1 Services

Performance Parameters	ITU Objective End-to-end	ITU Objective Satellite
CLR	3xE-7	7.5xE-8
CER	4xE-6	1.4xE-6
SECBR	1xE-4	3.0xE-5
CMR	1 per day	1 per 3 days
CTD	400 ms	320 ms (max)
CDV	3 ms	Negligible *

*The objective for satellites with ATM OBP is for further study.

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Performance Impacts of Satellite Systems

Satellite Systems present special challenges:

- Occasional burst errors could adversely affect the facility performance and service quality.
- Transmission delay (propagation and processing) could, under some circumstances, impact the following:
  - QOS of videoconference services
  - Efficiency of data protocols
  - Traffic Management and congestion control algorithms

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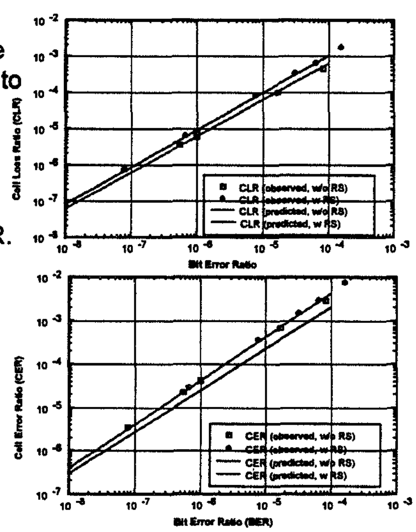
Translation between ATM Layer and Physical Layer Performance Parameters

- Mathematical expressions for the probability of CLR and CER due to burst errors has been derived.
- Computer simulations and laboratory test results were performed to find relationship between BER and CLR and CER.
- SECBR can be computed from CER information.
- CMR is difficult to simulate or measure. However, a mathematical expression that relates BER to CMR is feasible.



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The Impact of CTD and CDV

- The overall CTD results from various sources:
  - Propagation delay
  - Coding and decoding
  - ATM node processing (queuing, switching, routing, etc.)
- CDV depends on several aspects such as:
  - Traffic load structure (number of VPIs, VCIs)
  - Switch buffering capacity and mechanism
  - The number of ATM nodes
  - The amount of internal switch operations.
- ITU-R WP-4B needs contributions that describe the behavior of CTD and CDV on typical satellite networks.

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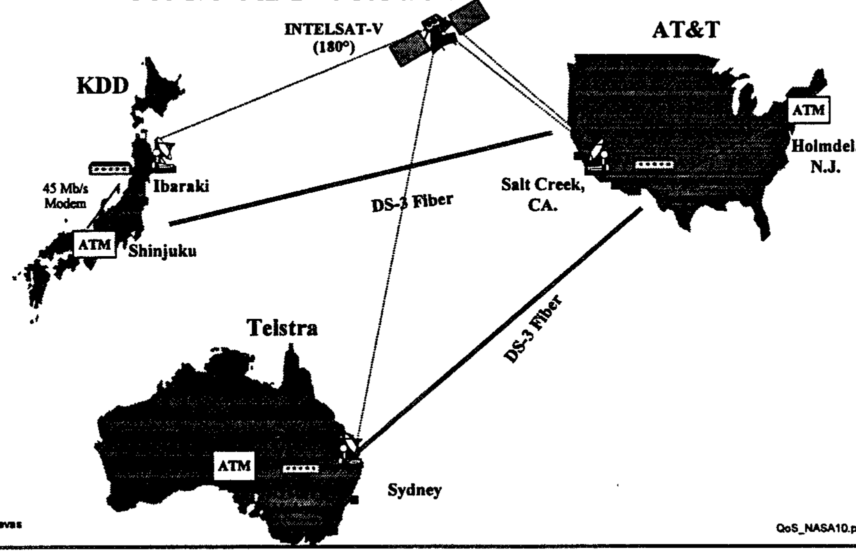
Interoperability Demonstrations AT&T-KDD-Telstra ATM Field Trial



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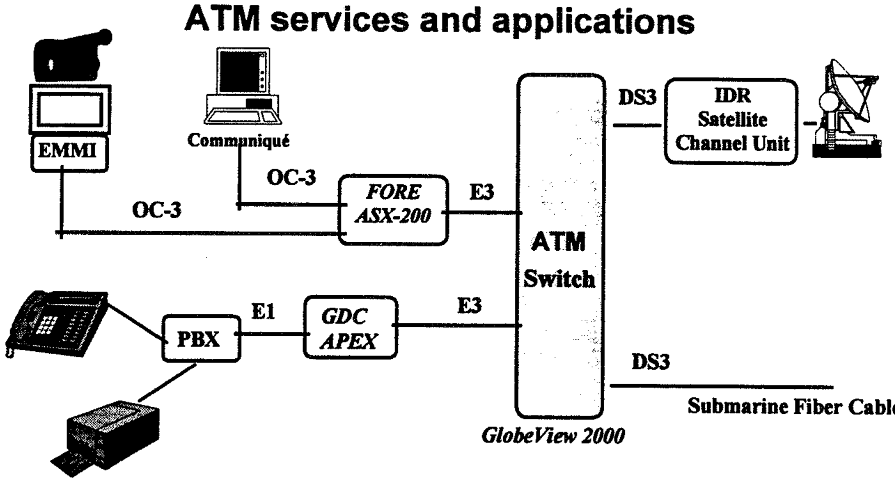
Equipment Set-up for QoS Measurements of ATM services and applications



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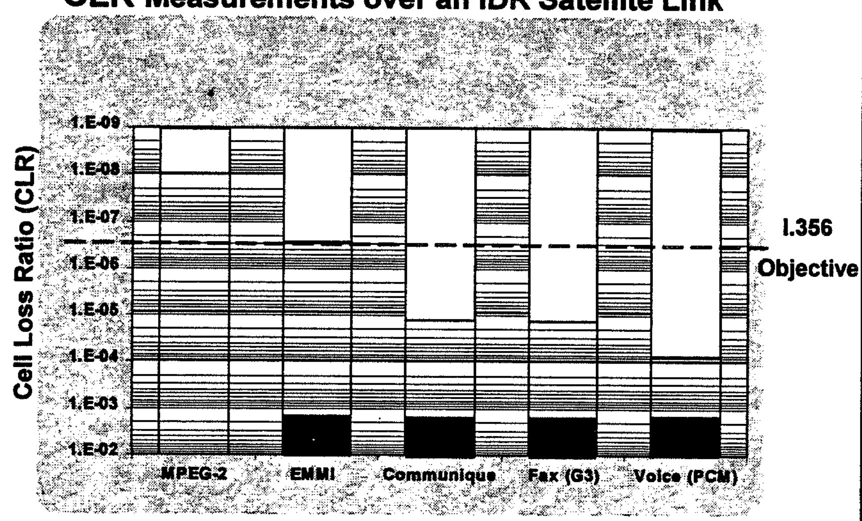
QoS Requirements of Some ATM Applications
CLR Measurements over an IDR Satellite Link



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Techniques to Enhance the Performance of ATM over Satellites

- Forward Error Correction (e.g. Reed-Solomon)
- Selective Interleaving (bit or byte interleaving)
- Adaptive Power control
- Site diversity
- Other

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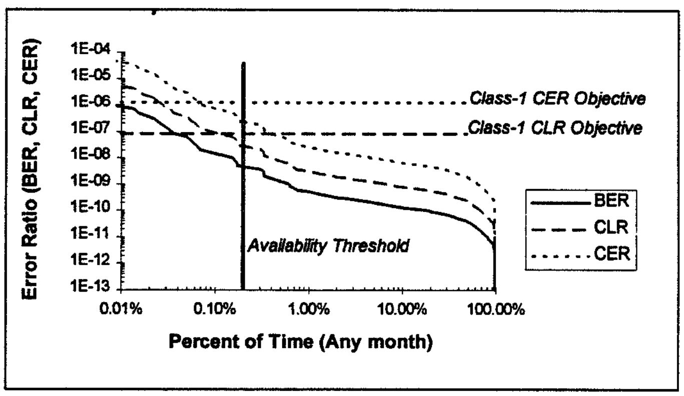
Availability Considerations for ATM over Satellite

$$A_{Total} = A_{Propagation} \times A_{Earth\ Station} \times A_{Spacecraft} \times A_{Congestion}$$



The availability due to propagation (A_p) is 99.96% of the year.

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Pending Issues

Rec. S.atm (ATM Performance)

- Need to specify performance measurement criteria.
- Describe available performance enhancement techniques.
- Describe impact on CTD and CDV of satellite specific ATM equipment used at the earth stations.

Rec. S.atm_av (ATM Availability)

- Evaluate the impact on performance from short interruptions due to equipment failures (including ATM-satellite equipment).
- Evaluate the Mean Time Between Outages (MTBO) characteristics of satellite links.
- Seek (from ITU-T) a better definition of "availability due to congestion" parameter.

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CONCLUSIONS

- ITU-R WP4B plans to complete by October '98 the text of new Recommendations S.atm and S.atm_av.
- These recommendations may be updated in the future as more information about application requirements becomes available to WP-4B.
- Some Geo-stationary transparent satellite systems are now carrying ATM traffic. Designers, operators, and users of ATM satellite services will benefit from new ITU-R standards.

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Future Work

- Study the impact of satellite systems with OBP and ISL on all ATM performance parameters.
- Study the availability characteristics of Ka-Band satellites that are intended to carry ATM traffic.
- Develop a recommendation on Traffic Management for ATM networks that include satellite connections.
- Update S.atm and S.atm_av as new ATM satellite technologies, applications and services emerge.

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ATM Over Terrestrial/Satellite Network - CTD &CDV QoS Laboratory Measurements*

S. Nawrot, T. Saadawi, E. Cuevas

* This work was supported in part by grant from the U.S Army Research Laboratory under cooperative agreement DAAL01-96-2-0002 (ATRIP)

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ATM QoS - Our Research

- **Scope:**
  - Transparent Satellites (no OBP or ISL considered)
- **Goals:**
  - Quantify and Characterize CTD, and CDV for CBR Traffic
  - Compare Published Simulation and Field Results, for the CBR Traffic Case, with Our Empirical Results
  - Modeling* CTD and CDV
- **Why:**
  - Latency and Jitter as well as CLR and BER are the Major Impairments Affecting Guaranteed Performance of All ATM Networks
  - Relatively Few Studies Examined CTD and CDV Over Hybrid Terrestrial/Satellite Networks

** In progress*

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ATM Service Categories - Overview

Service Category	Applications (Examples)	Network Priority	Cell Delay and Delay Variation	Cell Loss	Burst Tolerance
CBR	Video (e.g., MPEG-2), Circuit Emulation (Voice), etc.	1	Low	Low	None
VBR-RT	Desktop Videoconferencing, Compressed Voice with silence suppression, etc.	2	Low	Medium	Some
VBR-NRT	Data Applications requiring high level of performance but tolerant of variable speed, etc.	3	High	Medium	Some
ABR	Data Applications requiring high level of performance but tolerant of variable speed, etc.	4	High	Low	High
UBR	Connectionless Data Transfer, etc.	5	High	High	High

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Relevant ATM Concepts - Overview

- **Quality of Service (QoS) Parameters**

– **Cell Transfer Delay (CTD) the end-to-end delay a cell experiences traveling a computer network from source to destination.**

$$CTD_I = t_{AI} - t_{DI}$$

– **Cell Delay Variation (CDV) or Jitter**
the variance of CTD, or the variation in the end-to-end delay of two successive cells of the same stream, caused by queuing (buffering) and switching, etc.

$$J_I = (t_{AI} - t_{AI-1}) - (t_{DI} - t_{DI-1})$$

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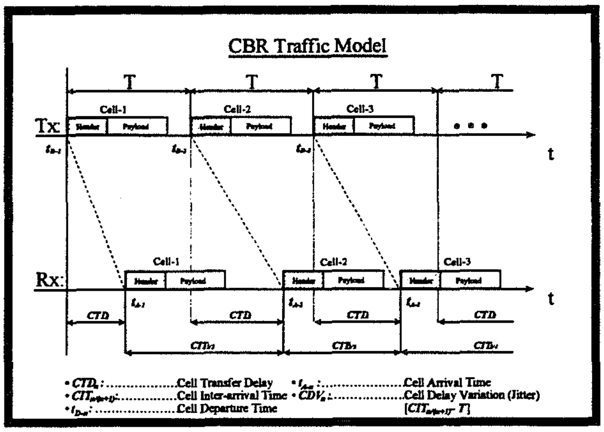
Relevant ATM Concepts - Overview



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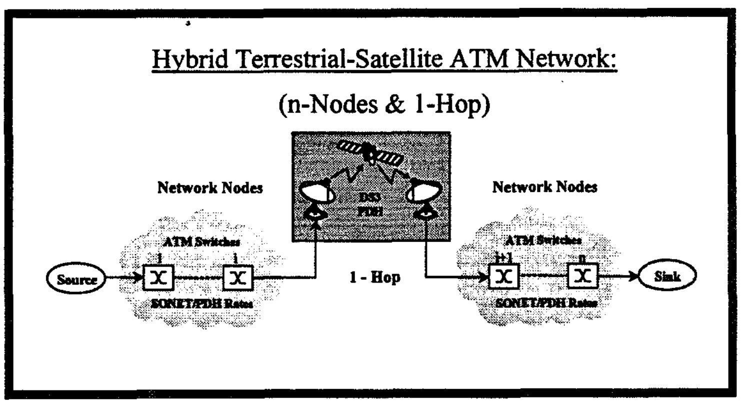
Tested Network Topology

- **Hybrid Network (Emulated)**



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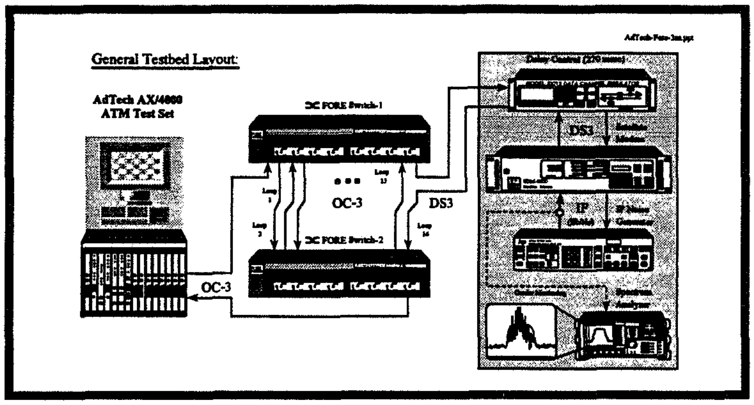
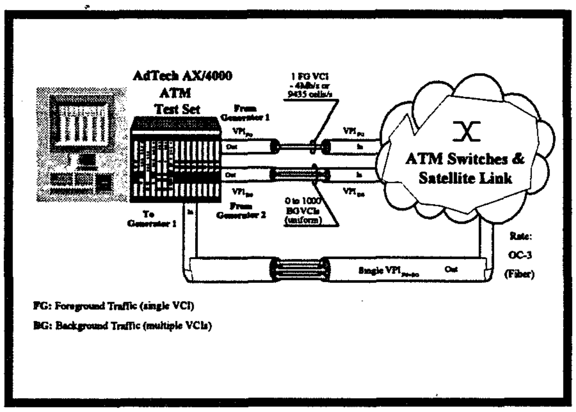
Testbed

- **Hybrid Network - Laboratory Setup**



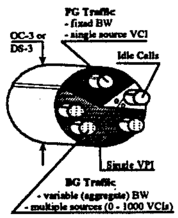
Testbed

- **Hybrid Network - Laboratory Setup "ATM Layer "**



Testbed

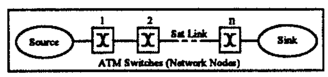
- **Parameters**



BG - Background
BW - Bandwidth
CIT - Cell Inter-arrival Time
CTD - Cell Transfer Delay
FG - Foreground

CBR Case, PVC Connection

#	Parameter	Values/Range
1	FG Traffic	Fixed around MPEG-2 or Full DS-3 rate expected over the Hybrid CBR ATM Network
2	FG Source	Single VCI
3	BG Traffic	Variable: 0.0% to ~90% of the OC3 or DS-3 Bandwidth
4	BG Source	Variable: 0 to 1000 VCIs
5	BG Distribution	• all sources of the same size/BW • combinations (e.g., n x T1, m x E1, etc.)
6	Idle Traffic	0≤ Idle Cells = OC3 or DS-3 BW - (FG + BG) BW



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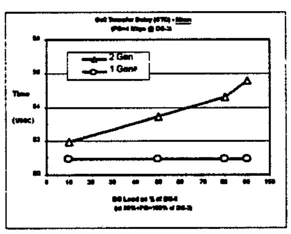

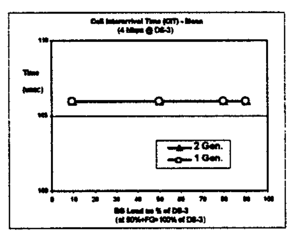

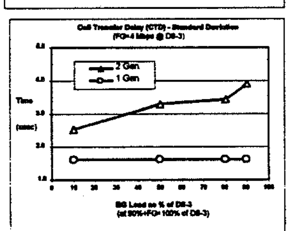

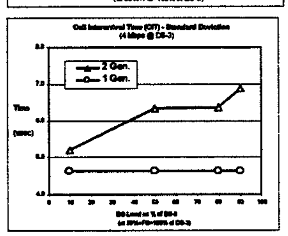

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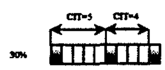
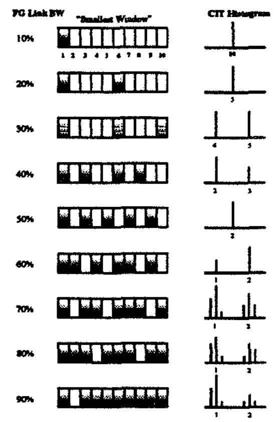
Testbed

- **CBR Traffic Calibration**

e.g.,:





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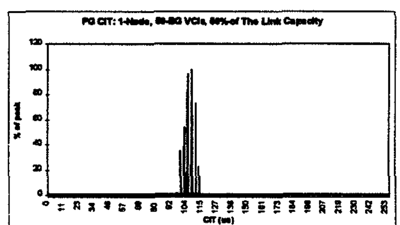
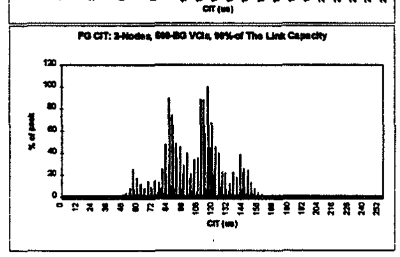
Testbed

- **CBR Traffic Examples:**

  FG=4 Mbps (3% of OC-3 or 10% of DS-3)





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Results:

- **Impact of the Channel Unit on CTD & CDV**

m - Mean, σ - Standard Deviation

CTD - Latency	CDV - Jitter (σ-CIT)
• m-CTD ≠ f (FG bandwidth), • σ-CTD ≠ f (FG bandwidth),	• m-CIT = f (FG bandwidth), • σ-CIT ≈ f (1/FG bandwidth),
• m-CTD ≅ linear f (buffer size), • σ-CTD ≠ f (buffer size),	• m-CIT ≠ linear f (buffer size), • σ-CIT ≠ f (buffer size),
• m-CTD + RS Codec = + 0.2 ms* • σ-CTD ≠ f (RS Codec)	• m-CIT ≠ f (RS Codec) • σ-CIT ≠ f (RS Codec)

*at DS-3 rate

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Results:

- **Non-Homogenous Path (DS-3 & OC-3)**

"NH-Path" = (non-homogenous) link comprised of different transmission rates, e.g., DS-3 & OC-3

CTD - Latency	CDV - (σ-CIT) Jitter
• m-CTD = f (NH-Path), • σ-CTD = f (NH-Path)	• m-CIT = f (NH-Path), • σ-CIT = f (NH-Path

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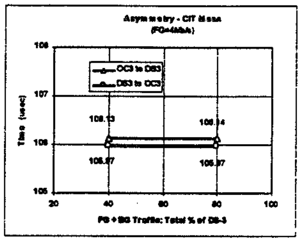
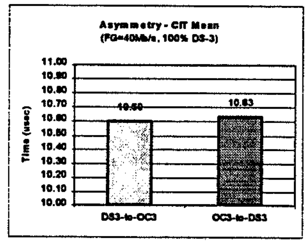
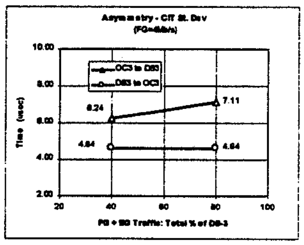
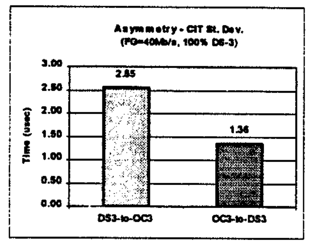
Results: Non-Homogenous Path (DS-3 & OC-3)









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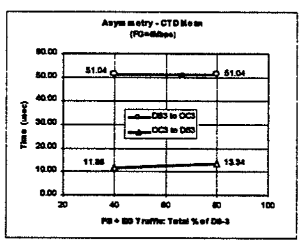
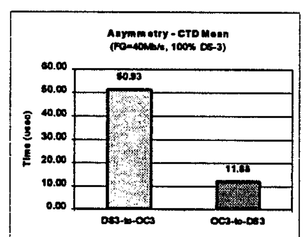
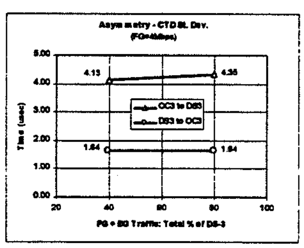
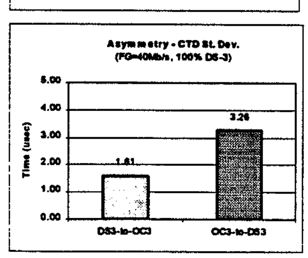
Results: Non-Homogenous Path (DS-3 & OC-3)









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Summary and Conclusion

Delay

- **CTD** - The Channel Unit contribution is negligible compared to the free-space propagation delay; buffer size is the dominant factor *(50 usec < CTD_{Modem} ≅ Buffer/2 < 16 ms* vs. ~270 ms for GEO)*
- **CTD St. Dev.** - The Channel Unit contribution is only a fraction of that introduced by ATM Switches *(e.g., 0.7 usec vs. 3 usec)*

Jitter

- **CDV** - The Channel Unit does NOT contribute to Jitter. The "Jitter-in" ≅ the "Jitter-out" for every modem configuration and feature used.
- **CDV St. Dev.** - The Channel Unit does NOT change the Jitter "spread" either.

Asymmetry

- **CDV & CTD** -impacted by ATM cells transferred from one type of framing structure to another (e.g., OC-3 to DS-3 or vice versa). The impact is NOT "symmetrical" as it depends on the mapping direction.

Suggestion:

- The material presented here may be useful for the development of **ATM Standards.**
- **Similar Studies** should be conducted for every satellite-specific ATM equipment intended for use at the satellite earth stations.
- Further work is required to evaluate the impact on CTD and CDV of Satellites with **ATM-OBP** and **ISL** capabilities (e.g., LEOs & MEOs).

* *Assuming modems with 32 ms maximum buffer depth.*

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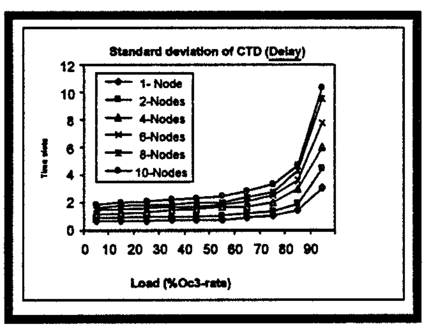
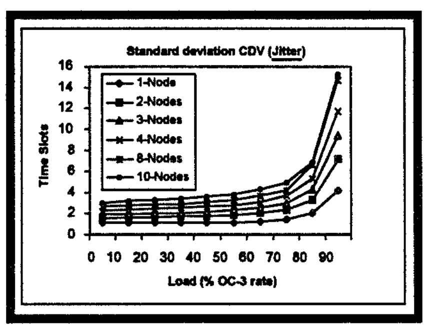
Number of ATM Nodes and Traffic Load vs. Jitter and Delay - Terrestrial ATM Network Analysis





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Satellite/Terrestrial Networks:

End-to-End Communication Interoperability Quality-Of-Service Experiments

William D. Ivancic
Phone 216-433-3494
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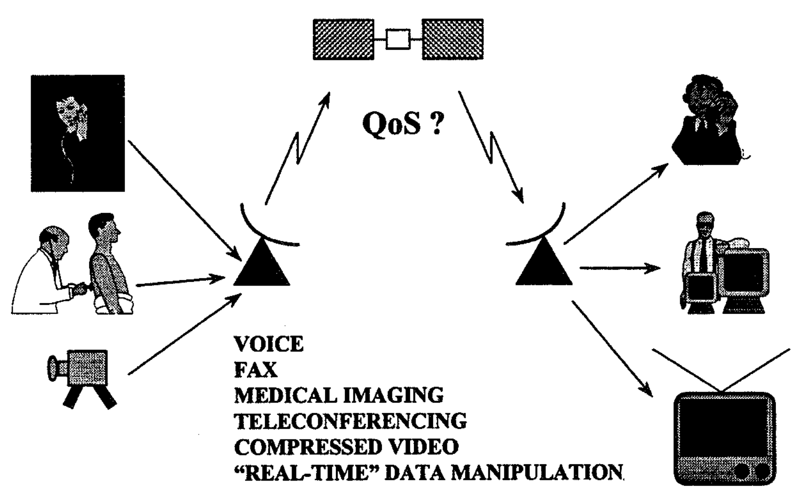
Email wivancic@lerc.nasa.gov

Quality of Service



Goals

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- Determine Quality-of-Service Parameters that Satellites must provide to remain competitive in the Global Information Infrastructure.
- Evaluate the effect of transmission link quality and characteristics on overall QoS for various applications and protocols.

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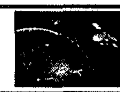

Strategy

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- Evaluate ATM over noisy link.
  - ATM was designed for “near” error free channels such as fiber. We need to understand the effect that various error characteristics have on the ATM QoS.
- Evaluate Digital Video over Satellites
  - Digital Video (particularly compressed video such as MPEG-II) is expected to require stringent QoS.
- Evaluate effect of layer protocols
  - Errors that occur in the lower layer of the protocol stacks tend to get magnified as one propagate through the upper layers.

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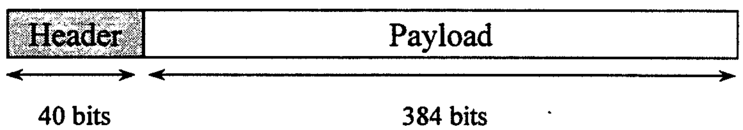
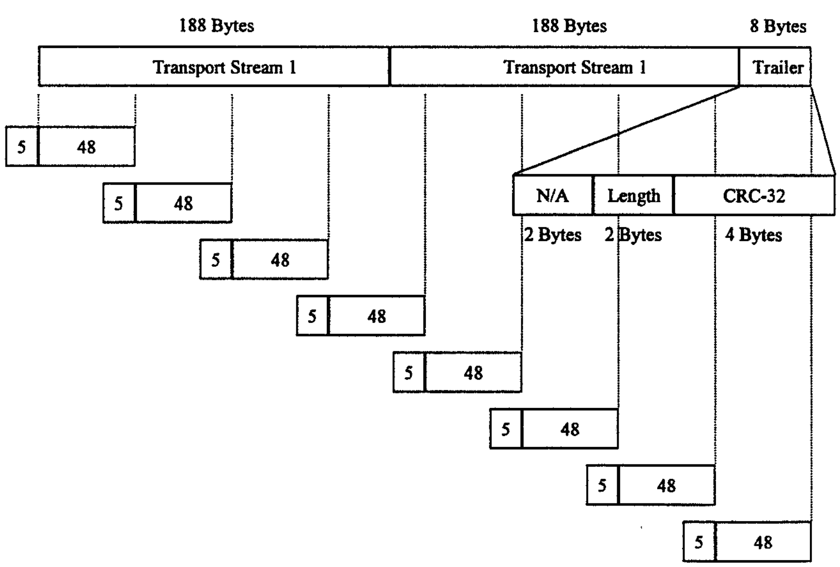
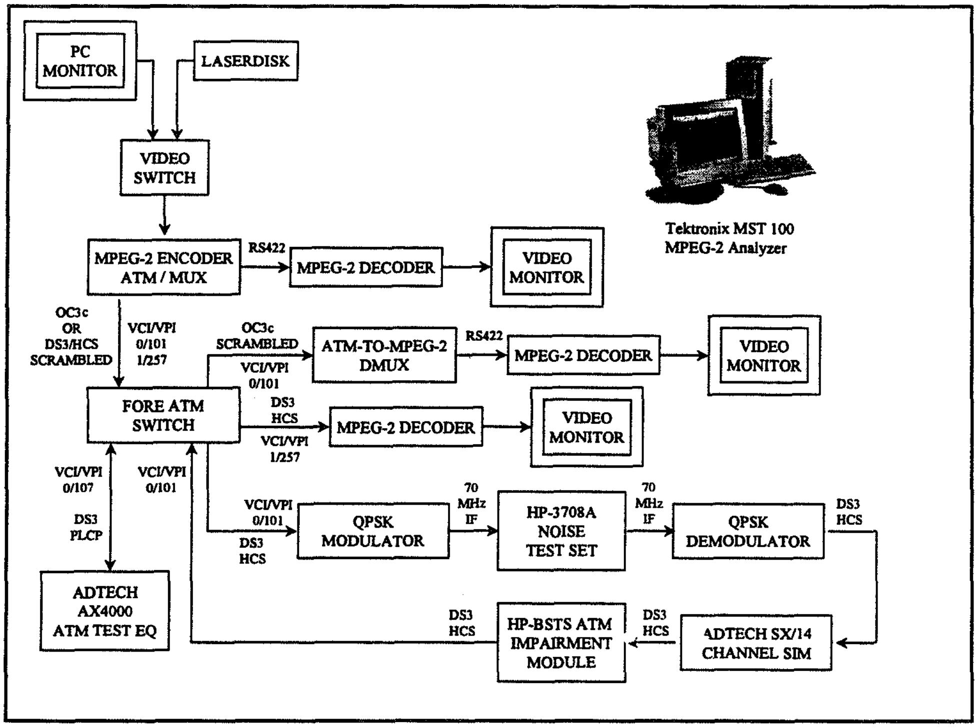
ATM Performance Characteristics

- CER Cell Error Ratio
  - One or more errors in the payload
- CLR Cell Loss Ratio
  - *Generally* 2 or more errors in the header
- SECBR Severely Errored Cell Block Ratio
- CMR Cell Misinsertion Rate
- CTD Cell Transfer Delay
- CDV Cell Delay Variation



MPEG-2 Transport Stream Mapping to AAL-5





Compressed Video Tests Over ATM

- MPEG-2 Transport Stream With Errors
  - Baseline without ATM
- MPEG-2 Over ATM With Binomial Errors
  - Digital Errors
- MPEG-2 Over ATM Over Emulated Satellite
  - Analog Errors
- Dual Decoder Test
  - Variations due to decoder implementation
- MPEG-2 over ATM Channel Characteristics
  - QoS dependence independently on CER and CLR

Observations and Discussion

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- MPEG-2 requires a link quality of 10^{-10} BER or better regardless of underlying protocol.
- Block errors are far easier to tolerate than decoder resynchronization
- Higher encoding rates require slightly higher quality links
- Further study is necessary in order to determine the relationship between the video quality and the ATM QoS parameters - in particular between the visible errors per second and the CLR and CER as well as the affect different CER and CLR distributions have on the video

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Status Digital Video over Satellites

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- Work was completed in September 1997 and reported to ITU-R Working Party 4B and T1A1.3
  - Paper is available via anonymous FTP
    - Site: ftp.t1.org
    - Directory: /pub/t1a1/t1a1.3
    - T1BBS FILE: 7a130840.doc

Workshop 98 — 10 — 6/98

Proposal

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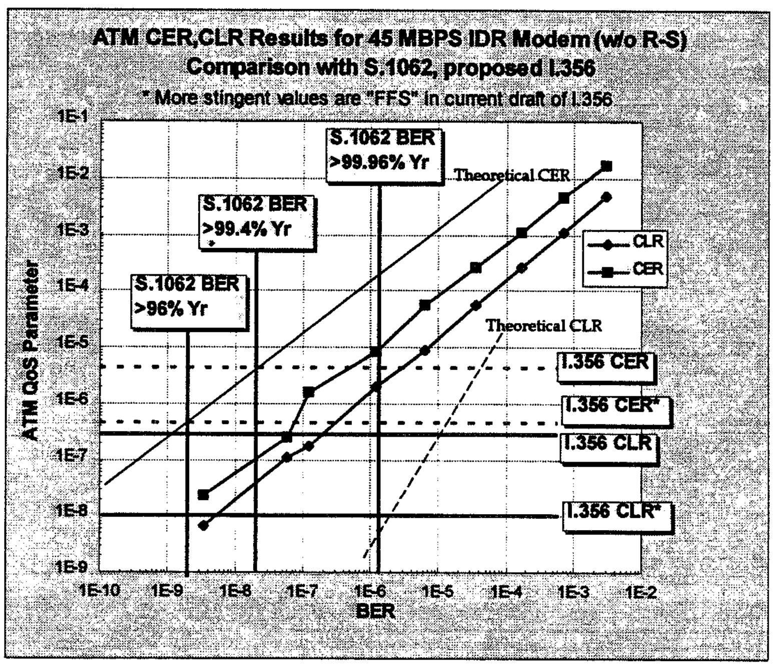
- ITU-T Rec. I.356 Class I, stringent class, objectives for CLR, CER should be at least 1.0E-8 and 1.0E-7 respectively in order to acceptably carry such services as MPEG-2 compressed video and may require even better performance

Workshop 96 — 11 — 6/96



Test Results

Test Interval (Minutes)	E_b/N_o	BER[1]	CLR[2]	EMMI	Communique	Voice	Fax
3	10.3	5.0E-11	0	Excellent	Video and Audio OK	Excellent	Excellent
14	9.4	5.7E-10	0	no change	no change	no change	no change
8	8.7	6.0E-9	0	Maybe flickering on solid color. Still very good quality.	no change	no change	no change
7	8.2	5.0E-8	0	Small amount of shimmering on skin tones. Still very good quality.	Smear	no change	Small font difficult to read
5	7	5.0E-7	2.8E-7	Small amount of shimmering. Acceptable quality.	OK	no change	"
14	6.5	4.2E-6	7.7E-6	Movement is jerky at times. Some shimmering.	Few black streaks, smears, white streaks.	Heard noise burst then lost call. Reestablished call, quality is good when call is up. Heard 2 to 3 seconds of very choppy speech then called dropped.	Third page did not come through and had to be retransmitted. Slight loss of sharpness.
3	5.4	7.3E-5	8.2E-3	Movement breaking up quite a bit. Freezing on video. Bouncing ball appears to freeze in mid bounce and pause as it bounces. Shimmering on skin tones. Blur on letters and name signs.	Streaks, tearing. Audio beginning to break up.	Breaking up. Noise bursts, then connection gone. Now unusable. Stays up less than one minute.	Receive stop. Could not transmit.
3	4.5	2.99E-3	1.2E-2	Video freeze. Maybe 5% of frames received. Audio breaking up.	Picture is frozen.	Cannot set up a call (5 attempts). Secondary dial tone, but no ring back or ringing.	Could not transmit.

NOTES

Bit Error Ratio measured by the satellite modem.

CLR is the Uncorrected or Discarded Cell Ration (DCR) i.e. all cells with two or more errors in the header. Notice that at low BERs there is not enough statistical confidence on the CLR measurement.

SATELLITE LINK CONFIGURATIONS

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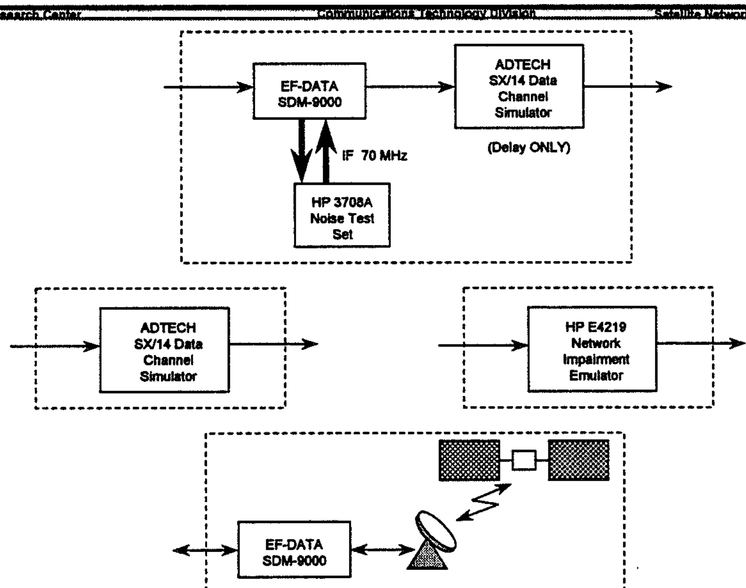
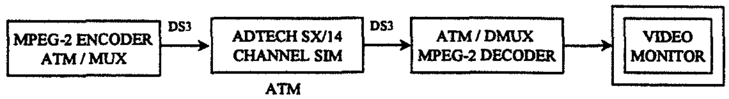


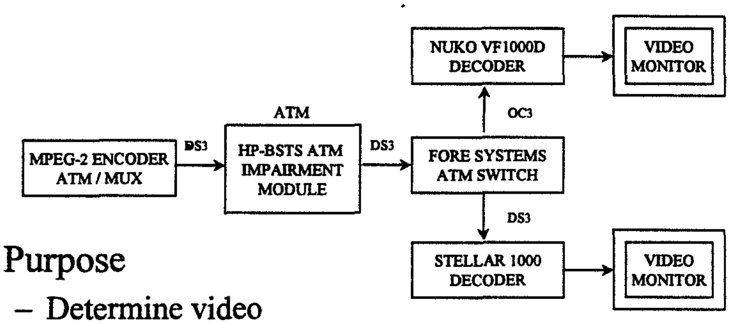
Workshop 98 14 6/98

MPEG-2 Over ATM With Binomial Errors



- Purpose
  - Determine dependance on CLR and CER
  - Determine dependence on encode rate
- Conclusions
  - BER of 1.0E-8 or higher is definitely unacceptable
  - Higher encode rates are slightly less susceptible to errors

MPEG-2 over ATM Channel Characteristics



- Purpose
  - Determine video degradation relative to CLR only and CER only
- Conclusion
  - CLR has far more affect on the video than CER

MPEG-2 Over ATM Over Emulated Satellite

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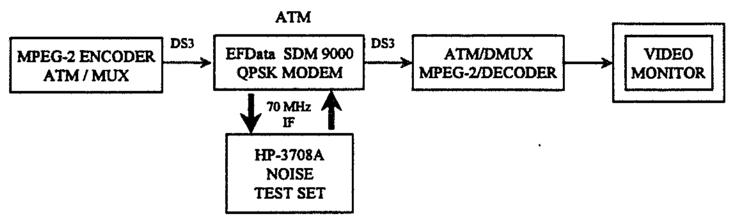

- Purpose
  - Evaluate video quality when errors are inserted at the RF link (different CLR and CER distribution)
- Conclusion
  - Unacceptable link quality at BER 1.0E-8, CLR 1.0E-7 and CER 1.0E-6

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MPEG-2 Transport Stream With Errors

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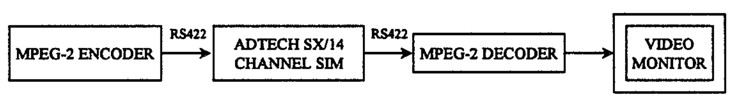

- Purpose
  - Baseline MPEG-2 Video
  - Determine dependence on encode rate (compression)
- Conclusions:
  - BER of 1.0E-8 or higher is definitely unacceptable
  - Higher encode rates are slightly less susceptible to errors

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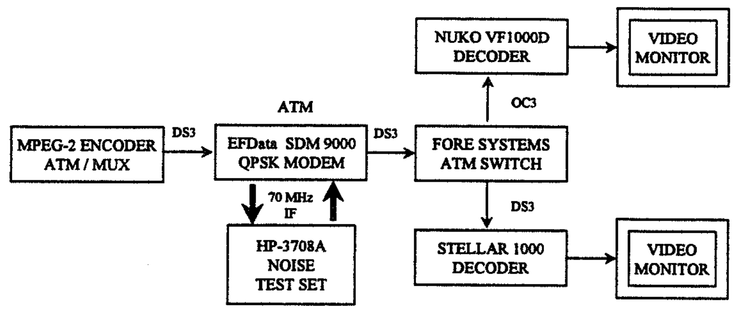
Dual Decoder Test



- Purpose
  - Determine if different decoder react similarly to errors
- Conclusion
  - The two decoders tested degrade at the same point

Efficient and Flexible Link Enhancement Techniques for Wireless ATM

Yung-Lung Ho

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Issues

- Bandwidth efficiency
- Performence
  - Delay, Burst Error, Random Error
- Flexibility
  - Configuration
  - Range of application
  - Adaptability to link condition
  - Future application
- Cost
- Manageability
  - Integration with switch or workstation

Summary

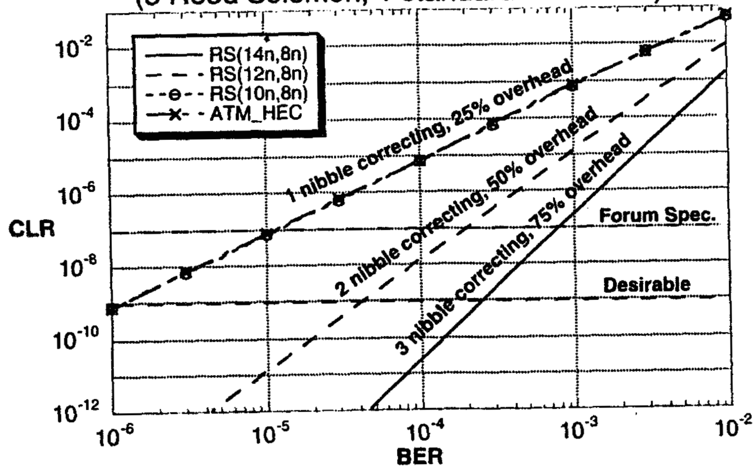
- Per VC FEC maximizes efficiency, performence, and flexibility.

- Yurie FEC illustrates feasibility of per VC FEC
  - Separate handling of VBR versus CBR (no FEC on CBR presently) traffic.
  - Independent per VC FEC rate adaption depending on link condition.
  - TCP/IP operation down to 10^-3 BER
  - Trades some performence for low cost implementation utilizing exiting switch functions where feasible.
  - Integrated in the LDR200 multi-service switch platform.

Per VC FEC Enhances Efficiency

- Expect 50% overhead to protect ATM header above 10^-5 BER with reasonable block error tolerance.

Comparison of Likely Header FEC Schemes
(3 Reed Solomon; 1 standard ATM HEC)



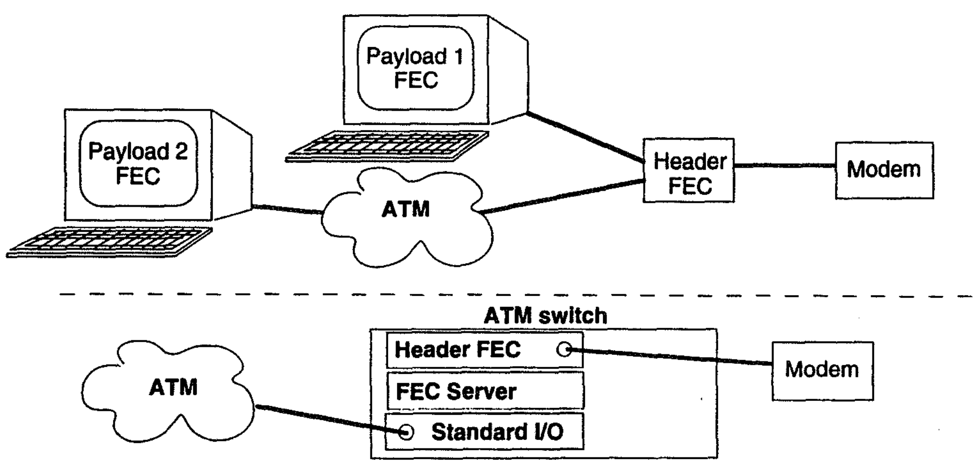
- Same protection too expensive for some applications
  - Voice, Video, Internet surfing

One Size Doesn't Fit All Below T1

- **Random error performence $\propto$ overhead^β**
- **Burst error performence $\propto$ overhead^β * delay**
  - 6.6 ms per cell delay at 64 kbit/sec
- **FEC scheme optimized for high speed links may exceed delay requirement at low speed for some ATM applications.**

Per VC FEC Maximizes Flexbility

- **Application specific FEC**
  - Tie FEC to compression technique and loss tolerance
  - Postpone obsolescence
- **Separate header versus payload FEC increases implementation flexibility**



Yurie FEC's Multi-Layered Structure

- **Reduces cost and maximizes flexibility by adapting a layered structure and utilizing switch resources**
  - Switch architecture and existing ATM standards part of design considerations

OSI Layer	Function
OSI Layer 2	Per VC Payload FEC
	Header Address Protection (Adress FEC or Redundant Addressing)
	Cell Scrambling
OSI Layer 1 (physical)	Cell Delineation (ATM Standard or LANET)
	Convolutional/Viterbi CODEC (Recommend 7/8 or 3/4 rate in modem)

Payload FEC for VBR traffic

a) Per VC, accumulate cells for form group

(i) 1/2 rate: 1 cell / group
(ii) 3/4 rate: 3 cells / group
(iii) 7/8 rate: 7 cells / group

b) Extract payload and segment into 6 blocks.

c) Add one piggyback byte per block for signaling (adaption) and PTI/CLP.

d) Reed-Solomon encode each block (3 byte correcting).

(i) 1/2 rate: 9 bytes -> 15 bytes.
(ii) 3/4 rate: 25 bytes -> 31 bytes.
(iii) 7/8 rate: 57 bytes -> 63 bytes.

e) Interleave (6 way -> 18 byte burst tolerance) and reassemble payload for output.

f) Load delineation byte to separate group.

Address FEC

- 4 configuration based on shortened 1 nibble correcting Reed-Solomon(15,11) or 2 nibble correcting Reed-Solomon(15,13) coding over address field.

(a) Hi-Noise UNI (2 nibble correcting, 255 VC)

```
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| GFC :       Parity          :     VCI     : PTI :    HEC    |
|     :  over 1 byte VCI      :             : CLP :           |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

(b) Hi-Noise NNI (2 nibble correcting, 4K VC)

```
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| VPI :  Parity over 3        :     VCI     : PTI :    HEC    |
|     : 3 nibble VPI, VCI     :             : CLP :           |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

(c) Lo-Noise UNI (1 nibble correcting, 64K VC)

```
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| GFC : VPI :  Parity   :     VCI           : PTI :    HEC    |
|     :     :           :                   : CLP :           |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

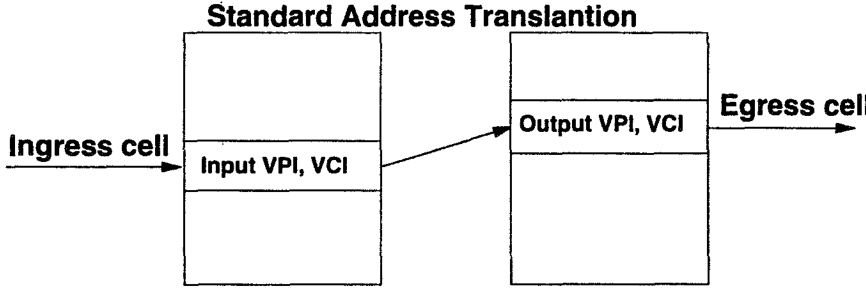
(d) Lo-Noise NNI (1 nibble correcting 1 Meg VC)

```
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|     VPI   :  Parity   :     VCI           : PTI :    HEC    |
|           :           :                   : CLP :           |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
```

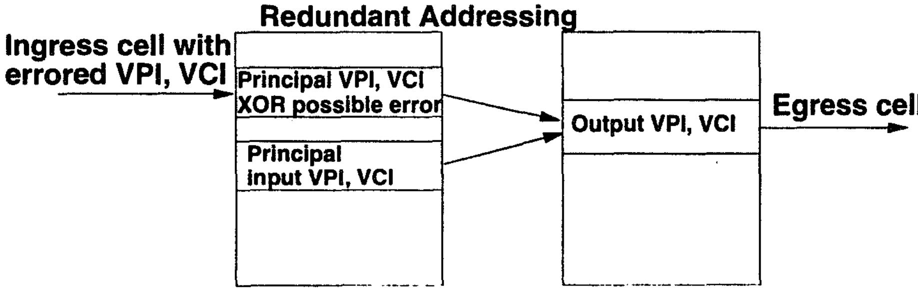
Low Cost Redundant Addressing Option

- Compatible with Header FEC
- No special hardware needed for switch implementation
- For Hi-Noise UNI, costs 385 redundant address to tolerate 2 random bit or 4 bit burst errors.

Standard Address Translantion



Redundant Addressing



Cell Scrambling

- 3 byte swaps followed by 3 nibble swaps.

- Increases header burst error tolerance
  - 121 bits for Hi-Noise UNI and NNI, 57 bits for Lo-Noise UNI and NNI.

```
                 (1) Byte
 +----------------------------------------+
 |                  (2) Byte               |
 |    +--------------------------------------------------+
 |    |               (3) Byte             |                   |
 |    |    +-------------------------------------------------------------+
 |    |    |                               |                   |                |
 v    v    v                               v                   v                v
 ___ ___ ___ ___ ___ ___         ____       ____       ____       ____       ____       ____
/ 0 / 1 / 2 / 3 / 4 [ 5 / -- /12 | -- /20 | -- /28 | -- /36 | -- /44 | - /52 ]
--- --- --- --- --- ---          ----       ----       ----       ----       ----       ----
                                  ^          ^          ^          ^          ^          ^
                                  |          |          |          |          |          |
                                  |          |          |          |          |          |
                                  |          |          |          |          |          |
                                  +-----------------------------------+          |          |
                                  (4) LSN    |          |                     |          |
                                             +--------------------------------+          |
                                             (5) LSN    |                                |
                                                        +--------------------------------+
                                                        (6) LSN
```

Optional LANET Framing

- Extends cell delineation capability down to 10^-2 BER.
- Firmware implementable.
- Speed insensitive.

```
+-+-+-+-+-+-+-+---------+---------+---------+---------+---------+
|F|8|D|D|T|B|B| Cell 1  | Cell 2  | Cell 3  | Cell 4  | Cell 5  |
+-+-+-+-+-+-+-+---------+---------+---------+---------+---------+
            |S|         |         |         |         |         |
            +-+---------+---------+---------+---------+---------+
            |S|         |         |         |         |         |
            +-+---------+---------+---------+---------+---------+
            |S|         |         |         |         |         |
            +-+---------+---------+---------+---------+---------+
            |S|         |         |         |         |         |
            +-+---------+---------+---------+---------+---------+
            |S|         |         |         |         |         |
            +-+---------+---------+---------+---------+---------+
            |S|         |         |         |         |         |
            +-+---------+---------+---------+---------+---------+
            |S|         |         |         |         |         |
            +-+---------+---------+---------+---------+---------+
            |S|         |         |         |         | Cell 45 |
            +-+---------+---------+---------+---------+---------+
```

```
F:  One byte Frame Header = 0x96
8:  One byte BIP-8 computed over the previous frame except F
DD: Two bytes Data Communications Channel (DCC)
T:  One byte Transport Layer Control Channel
S:  One byte Sub-Frame Header = 0xE8
BB: Byte Stuffing Control (default 0xF628)
```

Recommended Implementation

```
                         +----------------+
Bit Stream --+------>| Cell Extractor |-----> Cells
             |           +----------------+
             |             |        ^
             |             | LOS    |  Frame/Sub-Frame Alignment
             |             v        |
             |        +----------------+
             +-->|     Framer     |
             |        +----------------+
             |                 ^
             |                 |
             |        +-----------------------------------+
             +-->|  5 Cell History Buffer              |
                      +-----------------------------------+
```

- Declare LOS on 2 consecutive frame or sub-frame header plus 5 HEC errors.

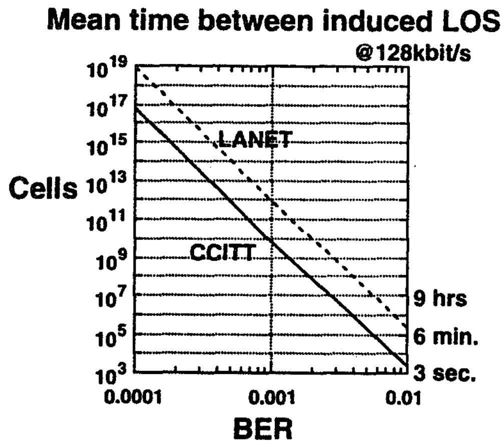
LANET Cell Delineation State Machine

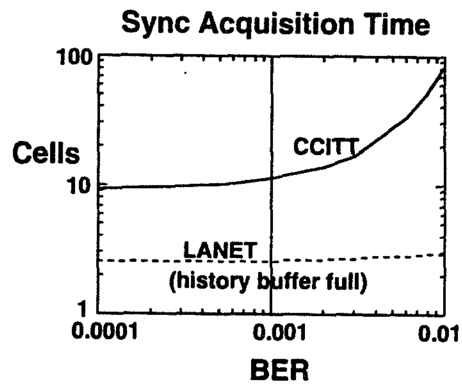
```
                                (LOS)
                                  |
                                  v
+-------------+          +------------+          +-------------+
|  Pre Frame  |          | Bit by bit |          |Pre Sub-Frame|
|    Sync     |   0x96   | hunt for   |   0xE8   |    Sync     |
| (set bit    |<---------| frame or   |--------->| (set bit    |
| alignment)  |          | sub-frame  |          | alignment)  |
+-------------+          | headers    |          +-------------+
       |                 +------------+                 |
       v                       ^                        v
+-------------+                |                 +-------------+
| Check 5 HEC |   3 bad HEC    |    3 bad HEC    | Check 5 HEC |
| in History  |----------------x-----------------| in History  |
|   Buffer    |                                  |   Buffer    |
+-------------+                                  +-------------+
       | 3 good HEC                         3 good HEC |
       v                                               v
+-------------+                                  +-------------+
| Frame Sync  |                                  | Sub-Frame   |
|             |                                  |   Sync      |
+-------------+                                  +-------------+
```

- Easy to find 0xE8 or 0x96 provides initial cell alignment (no need for bit by bit HEC check)

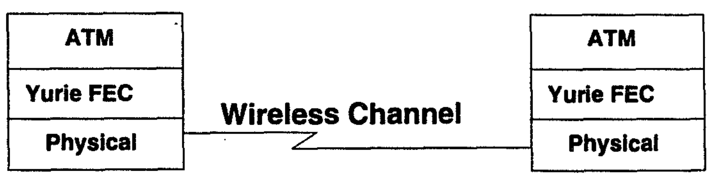
Derived LANET Performence

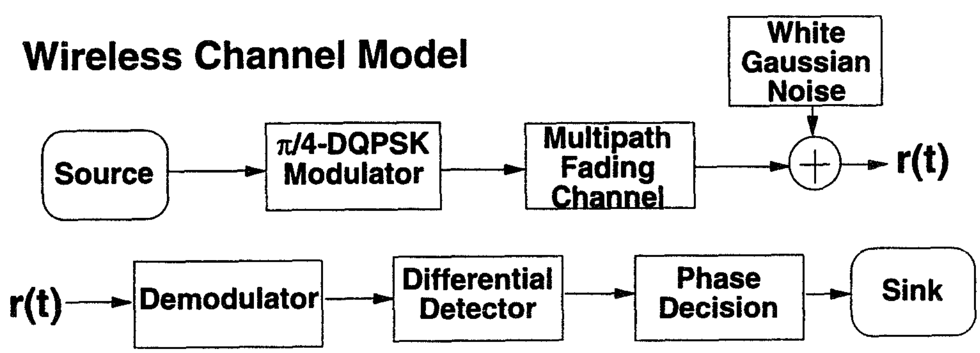
- 2 orders of magnitude improvement in mean time between noise induced LOS
- Can acquire sync quickly @ BER 10^-2





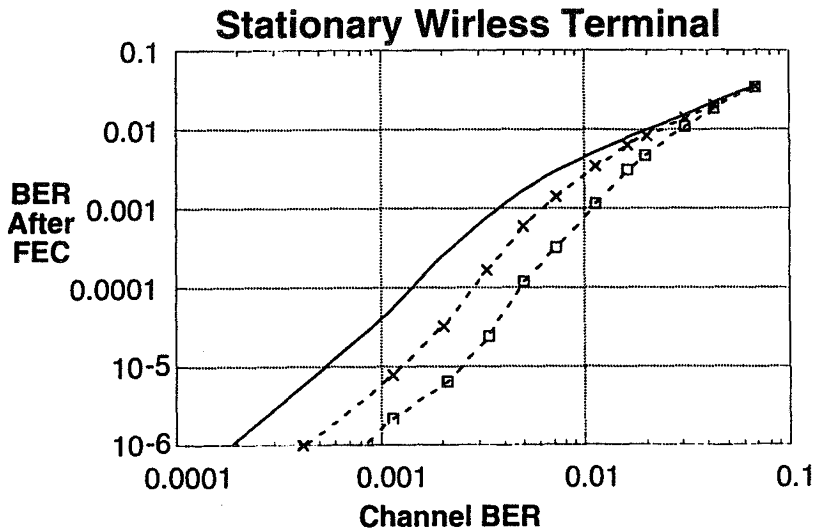
Simulation Model





- Can model mobile station via Doppler shift in each path

Simulation Result



- Without Doppler effect, results close to pure random BER performence derived and tested

Conclusion

- Per VC FEC maximizes efficiency, performence, flexibility and can be implemented cost effectively

Future Work

- Extend simulation to include mobile terminals and other wireless channels.

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Session 5
Multicasting

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StarBurst Communications

Unsurpassed in Information Delivery ---
fast, efficient, and guaranteed

Reliable Multicasting over Satellite: Issues & Applications

Satellite Networks:Architectures, Applications, & Technologies Workshop, June 2-4, 1998

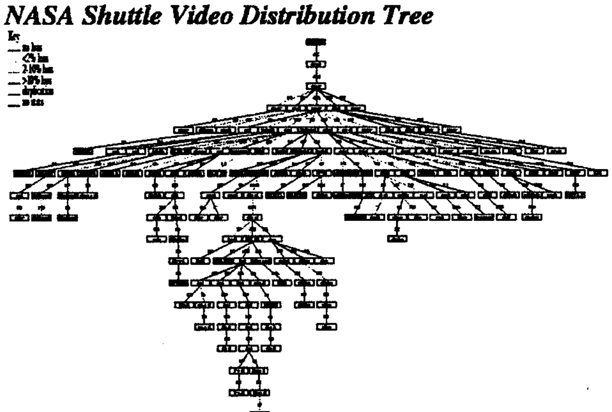
Ken Miller, CTO

www.starburstcom.com

Satellite is an Ideal Transport for Multicast Applications

- Landline networks can have complex trees

NASA Shuttle Video Distribution Tree



Sat. Workshop 2

StarBurst
COMMUNICATIONS

Multicast Applications Come in Many Flavors

- Thus, multicast does NOT mean multimedia

	Real-time	Non-real-time
Multimedia	• Video server • Video conferencing • Internet audio • Multimedia Events	• Replication: • Video & web servers • Kiosks • Content delivery • Intranet & Internet
Data-only	• Stock quotes • News feeds • White boarding • Interactive gaming	• Data delivery • Server-server • Server-desktop • DB replication • SW distribution

Sat. Workshop 3

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Reliable Multicast Requirements

App. Type	Latency Req.	Reliability	Scalability
Collaborative	**Low**	**Semi/strict**	**<100**
Message Str.	**Low /medium**	**Semi/strict**	**to millions**
Bulk Data	**Not real time**	**Strict**	**to millions**

Sat. Workshop 4

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Specialized Protocols Needed to Handle Multicast Applications

- TCP is unicast only; thus, multicast operates over UDP
- UDP provides only minimal transport layer services
  - Error detection
  - UDP port multiplexing
- Solution: specialized transports needed to be added at application layer to support multicast application

Sat. Workshop 5

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Reliable Multicast Protocols are not yet Standardized

- Being studied by Reliable Multicast Research Group in IRTF
  - IRTF recommends technique(s) for a working group in IETF to use in standards
- Problems considered hard -- especially, methods to provide congestion control and "fairness" to TCP
- Scaling and coping with different network infrastructures also important

Sat. Workshop 6

StarBurst COMMUNICATIONS

Most Available Reliable Multicast Protocols do not Scale Over Satellite

- Focused on terrestrial routed networks
  - Today's mainstream Internet
- Many depend on "local repair" and hierarchy for scaling
  - Do not have a place in satellite (except when there are terrestrial network extensions)
- Others depend on routed infrastructure for scaling

Sat. Workshop 7

StarBurst COMMUNICATIONS

Current Prominent Reliable Multicast Protocols

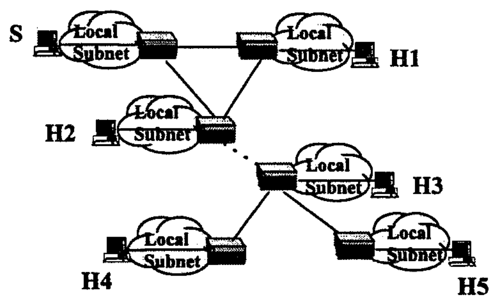
- Scalable Reliable Multicast (SRM)
  - Favorite of researchers; used in wb tool on Mbone
- Reliable Multicast Transport Protocol (RMTP)
  - Developed by Bell Labs/Lucent offered in toolkit by Globalcast
- Pretty Good Multicast (PGM)
  - Recently proposed by Cisco
- Multicast File Transfer Protocol (MFTP)
  - Developed by StarBurst -- most widely used

Sat. Workshop 8

StarBurst COMMUNICATIONS

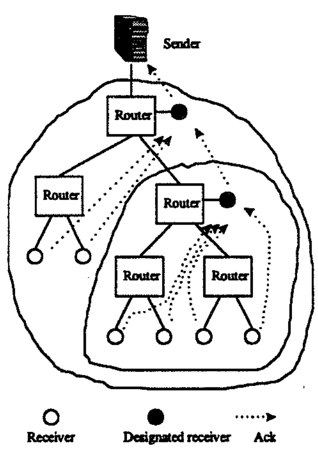
SRM

- Developed for data conferencing (wb tool)
- 1st protocol to use "local" repair
- All members in same group



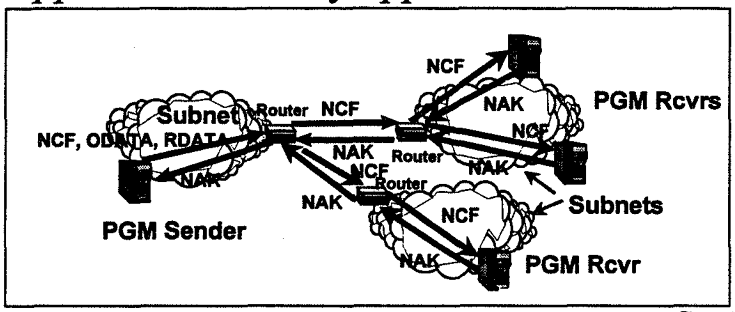
RMTP

- Uses hierarchy (Designated Receivers) to gain scaling



PGM

- Depends on routers in network infrastructure to provide scaling
- Supports low latency applications



StarBurst COMMUNICATIONS

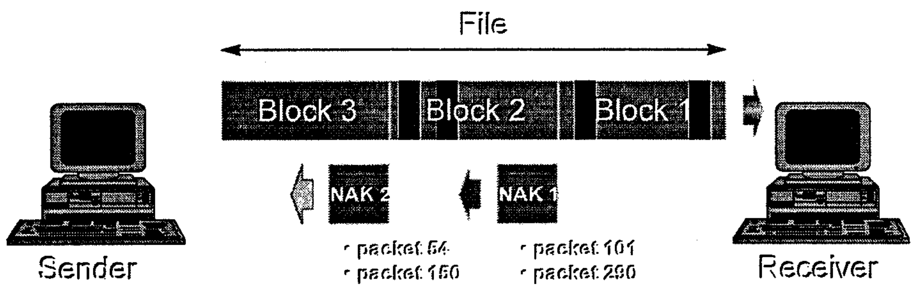
SRM, RMTP, PGM Focused on Terrestrial Infrastructures

- SRM
  - Does not work in any asymmetric network
- RMTP
  - Depends on hierarchy for scaling which often does not exist with satellite networks
- PGM
  - Requires router assist in infrastructure to gain scaling, which does not exist over satellite -- a flat network architecture

StarBurst COMMUNICATIONS

MFTP

- Trades off latency for time aggregation of NAKs for scaling



Sat. Workshop 13

StarBurst
COMMUNICATIONS

MFTP Disadvantages

- Targeted to file transfer applications
  - No strict latency requirement

However, operates with scaling in ALL network environments including satellite

Sat. Workshop 14

StarBurst
COMMUNICATIONS

Protocols Need to Cope with Different Network Infrastructures

- Traditional land line routed networks
  - Internet model, highly meshed routers
  - Symmetric links
- Asymmetric land line networks, e.g. cable
- Satellite networks
  - Asymmetric and high latency
  - Inherently multicast ready
- Hybrids of the above

Sat. Workshop 15

StarBurst COMMUNICATIONS

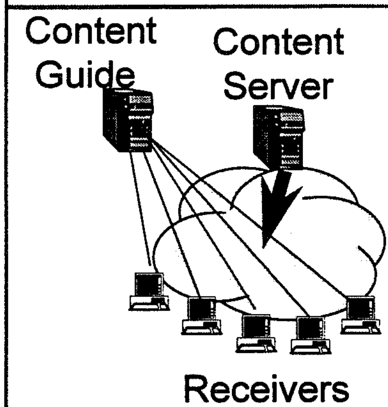
The Reliable Multicast Situation

- For non-real time delivery applications, MFTP is superior other reliable multicast protocols
  - Most scalable without relays or requirement of retransmission from nearest neighbor
    - MFTP only one that works well with satellite
    - Scalable to > 10,000 without relays or network assist
- MFTP also includes a group management protocol

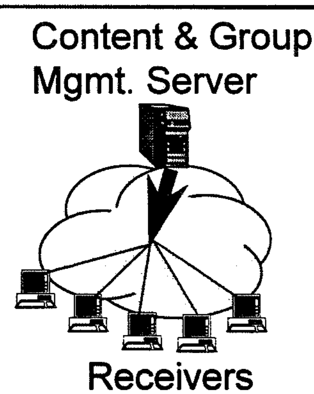
Sat. Workshop 16

StarBurst COMMUNICATIONS

"Channels" vs. StarBurst Closed Group Model



Broadcast TV like Model: Receivers "tune" to content



E-mail like Model: Sender determines group

Sat. Workshop 17

StarBurst
COMMUNICATIONS

How do These Models Fit to Applications?

Broadcast TV Model (Push)

- Non-critical content
- Sender does not need to know content was delivered

StarBurst Closed Group model

- Critical Content
- Sender needs to guarantee delivery

Sat. Workshop 18

StarBurst
COMMUNICATIONS

Customer Examples

- **GM-US - 8500 dealers - car locator program, software updates**
- **Toys 'R Us - 900+ stores - business data, kiosks, software updates**
- **Ford - 6000 dealers - software updates, business data**
- **Promus Hotels - 650+ hotels - reservations, front desk apps**
- **Wal-Mart - 2500 stores - video distribution application**
- **Ohio Companies - 200 clients - stock and bond inventories**
- **Dow Jones - remote printing of Wall Street Journal**
- **The Box - distribution of 10 GB MPEG files to 100 remotes**
- **The GAP - 1800 stores - delivery of business data**

Sat. Workshop 19

StarBurst COMMUNICATIONS

Conclusions

- Reliable multicast over IP multicast enabled networks provides ROIs that are no-brainers
- Satellite is ideal for offering multicast services
- Reliable multicast enables new business processes to improve competitiveness
- Closed Group model essential for critical information delivery

Sat. Workshop 20

StarBurst COMMUNICATIONS

Organizing Data Transmission for Reliable Multicast over Satellite Links

Antoine CLERGET, Walid DABBOUS
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1 Introduction

Intrinsically broadcast communication channels, satellite links offer a natural way of multicasting data over a large geographical region. Using such links, one can benefit from an environment where adding thousands of new recipients does not cost anything in terms of network resources. There are a lot of potential applications such as software distribution, database updates, information broadcast (weather forecast, financial data, ...). However, some constraints are associated with satellite links : first, for geosynchronous satellites, transport protocols must be able to cope with very important delays. Important delays lead to a poor system reactivity and combined with link's asymmetry, or even unidirectionality, feedback from receivers may be quite difficult to implement efficiently. Second, satellite links, as all other wireless links, undergo an important Bit Error Rate (BER). To lower that error rate to levels comparable to that of wired-links, one must add an important link-level bit redundancy, reducing the useful throughput of the link. This could be avoided if the transport layer supported corruption losses. The problem is therefore to deal with congestion in an environment where feedback is quite inefficient and losses are not all due to congestion.

Having a very large number of recipients, some receiving the data directly from the satellite link, others receiving it relayed by an antenna through the M-Bone (the best is for each receiver to receive the data from the satellite through the closest antenna available), we will suppose that we have an important heterogeneity of paths leading to them in terms of bandwidth and error rate. Our aim is to ensure reliable data transmission and to minimize for each receiver its transmission time.

To match the constraints méntioned earlier, as well as scalability considerations, we study feedback-free mechanisms, which means that the recipients do not acknowledge the data received. To ensure reliability, we must therefore adopt a Forward Error Correction (FEC) technique, where lost data can be recovered with redundancy packets. Using this high-level FEC - i.e. packet redundancy - we hope to be able to reduce the low-level FEC - i.e. bit redundancy - on the satellite link and to increase the overall useful throughput. Even without feedback, we can bring the failure probability as low as we want by transmitting for a long enough time. We can make sure that introducing so much redundancy has no impact nor on the receivers, since they end the reception as soon as they have enough information, nor on the network, which thanks to pruning, will not relay the surplus of packets.

2 Related Work

The issue of reliable multicast over satellite links has already been studied, giving birth to protocols such as MFTP [?]. In MFTP, the file is transmitted entirely on the first pass, and missing pieces on subsequent passes. However, it considers that all recipients receive the file directly through the satellite link, and therefore does not deal with problems such as rate and congestion control, or receiver's heterogeneity. A number of other reliable multicast protocols using feedback deal with congestion control, by adapting the sender's rate to the worse or to a given proportion of the receivers in reply to "congestion reports".

As outlined in Receiver-driven Layered Multicast (RLM) [?] (which does not raise the issue of reliability) it is interesting to use multiple multicast groups to deal with receiver's heterogeneity. The transmission rate is receiver-driven since it is the receiver that adjusts it to avoid congestion by joining or leaving one of the multicast groups called "layer". In [?], Lorenzo Vicisano, Luigi Rizzo and Jon Crowcroft present a protocol based on FEC and layered multicast that uses little or no feedback for congestion control and error correction. However, our work is focused on a context where we experience corruption losses, as observed on the satellite link, and therefore we do not make the assumption that losses are due to congestion. Moreover, we propose another way of organizing data within layers that does not impose an exponential distribution of rates. To mimic the behavior of TCP, some protocols that deal with congestion adopt a strategy of multiplicative decrease in rate when congestion is detected, and additive increase otherwise. Others estimate the "equivalent" throughput, using the relation between throughput and loss rate for a TCP connection : $\textit{Throughput} \sim 1/\sqrt{\textit{Loss rate}}$. These protocols are said to be "TCP-friendly", because they should behave like TCP when confronted to a congested network. For such protocols, an exponential distribution of rates leads to a slow and imprecise reaction to congestion.

3 Data Organization

To correct errors without acknowledging sent data, we introduce redundancy within sent packets : k packets of data are encoded into n packets in such a way that receiving any k among these n is sufficient to rebuild the original k packets. Forward Error Correction gets more and more efficient compared to retransmit queries as the number of recipients grows since they can all correct $n-k$ errors, eventhough these errors are different. It is interesting to use large values of k and n, (ideally, k is the number of packets in the file to be transmitted, and $n >> k$). Unfortunately, known FEC techniques for large values of k and n are slow to compute. The file to be transmitted is therefore split into B "blocks" of k packets. Each block is then "fec-encoded" into a block of n packets. The end-user ends the reception when he receives k different packets from each of the B blocks.

In a totally feedback-free environment, and even in general, it is interesting to manage receivers' late arrival. In an application transmitting informations day long, we would like to be able to have users join at any time and receive the data in minimum time. Given a reception window of $B.k$ packets, we should then have k (different) packets of each block (Characteristic C_1). To ensure quick recovery of lost data, we must also have a good block interleaving, which means that given any reception window of k packets, we should have a packet of each block (Characteristic C_2).

We send packets through "channels" at the same rate and group these channels within the different layers, defining their respective rates. The sending rate of a layer is therefore proportional to the number of channels sent on it. The following

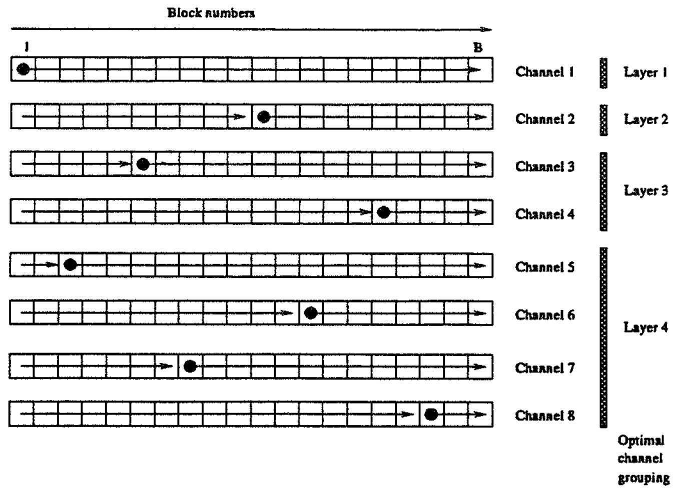

Figure 1: Block numbers of packets transmitted on the channels over time

data organization tries to meet the characteristics defined above for the $B.k$ and k packets reception windows (C_1 and C_2), no matter how many channels the receiver is listening to.

The packet sent at date t on channel number c is defined by the pair ([block number b_c^t], [packet number p_c^t]) (fig. 1) :

- $b_c^t = \underbrace{\lfloor B.I(c) \rfloor}_{\text{offset}} + t \; [mod \; B]$ and $I : x = \sum_{i=0}^{m} b_i.2^i \mapsto I(x) = \sum_{i=0}^{m} b_i.2^{-i}$
- p_c^t is the index the first non-sent packet in block b_c^t.

The idea behind layered multicast is to reduce congestion by leaving some of the multicast groups ("higher" layers), pruning preventing their packets from being forwarded through the bottleneck. But for pruning to work, receivers behind a same bottleneck must unsubscribe to the same layer. Recipients must then follow this rule : *To subscribe to layer L_i, a recipient must first subscribe to layer L_{i-1}* .

Whatever the data organization, meeting characteristics C_1 and C_2 for all receivers, or, in other words, for all receivers to finish in minimum time when there is no loss (i.e. *File size* $= B.k/\cdot\sum$ *Subscribed layers' rate*), and to recover from losses as quick as possible (without feedback), layer's i rate must be a multiple of the sum of layer's 1 thru $i-1$ rate :

$$\exists p \in \mathbb{N}, r_i = p.\sum_{j=1}^{i-1} r_j$$

This means that the layers' rate distribution must be exponential.

With our data organization, a receiver (possibly arriving late) will finish in minimum time if it listens to 2^m channels, $m >= 0$. Since we do not want to have an exponential rate distribution, we must accept a slight overhead (between 0% and 12%) when listening to n channels, $n \neq 2^m, \forall m$, and will have an optimal receiving time otherwise.

We have therefore proposed a data organization that :

- Is optimal for all receivers, whatever the number of layers they are listening to, if we accept to have an exponential distribution of rates.
- Is optimal for the receivers that listen to a number of layers that, grouped, contain 2^m channels, $m > 0$ and slightly suboptimal (overhead between 0% and 12%) for others if we wish to be able to set arbitrary layer rates.

3.1 Detecting and avoiding congestion

In standard transport protocols used on the Internet, detecting congestion consists in detecting lost packets. On a satellite link, we have bursty losses, due to external factors such as bad weather conditions. When such errors occur, there is no need to reduce the transmission rate. This is why it is useful to be able to distinguish corruption losses from congestion losses. Moreover, we would like this mechanism to work without modifying the routers on the M-Bone, which means that it should be an end to end mechanism.

Packet loss is not a good congestion signal. If we consider that the traffic generated by the source is negligible in regard with the total traffic induced by all the other users, variations of the Round Trip Time (RTT) is not a good congestion signal either [?]. Using an approach similar to that of packet pair rate control [?], we propose to send the data as a series of bursts and try to detect the "flattening of the burst" as a sign of congestion. But we work here in open loop and there are no acknowledgments for the sender to measure delays. It's up to the receiver to measure congestion. Moreover, with packet pairs, no measurement is possible when one of the two packets gets lost. Since the loss is not in itself a congestion signal, we lose information and therefore reactivity when corruption losses are frequent. This is why we do not send pairs of packets but bursts of $b = 8$ packets.

The position of the packet within the burst is included in the packet's header. Let $D(p)$ be the inter-packet delay preceding packet p, HB be the group of packets that are at the head of a burst (i.e. position within the burst = 0). We evaluate the ratio :

$$Q = \frac{\sum_{p \in HB} D(p)}{Total\ Time}$$

and use the test $Q < threshold$, where $threshold < 1$, as a congestion signal.

We then use a multiplicative decrease - additive increase scheme to join and leave layers. When the receiver has subscribed to layers 1 thru i, he tests for a congestion signal

- after $\frac{N}{log(r_{i-1}/r_i)}$ packets received and leaves layer i if congestion was detected.
- after $\frac{N}{r_{i+1}-r_i}$ packets received and joins layer $i+1$ if no congestion was detected.

N is chosen large enough to take into account join and leave delays, and not too large to have enough reactivity.

4 Conclusion

When trying to reliably send data to a large number of receivers using a satellite link and the M-Bone, we face a certain number of difficulties, due to the long delay, asymmetry, and high bit error rate of the satellite link, and the heterogeneity of the M-Bone. To solve the problem of asymmetry, we chose an a feedback-free approach, replacing retransmission requests with Forward Error Correction, and proposed a mechanism that enables receivers to detect congestion and then adapt their own

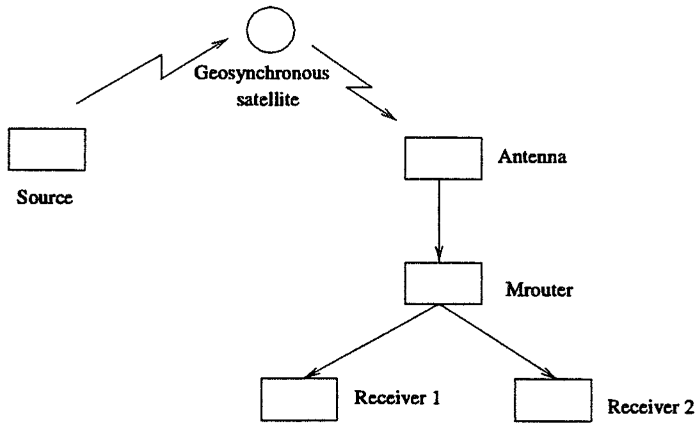

Figure 2: Experimental framework

receiving rate. In a heterogeneous environment, the data organization proposed here enables them to receive the data in an almost optimal time, taking into account late arrivals, and is still adapted to a good reactivity to congestion signals. To experiment these mechanisms, we have setup an experimental framework as shown on figure (2).

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Satellite-Multicast Enhanced Consumer Internet Services

Doug Dillon

June 3, 1998

1P0000
6/19/98

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Direct Broadcast Satellite To The Personal Computer

New Media with great potential:

- True Broadband, e.g. ~30 Mbps pipe
  324 GB/day
- Conditional access supports subscription services
- Low-cost receiver
- Nationwide access
- Installed base of 7M antennas in USA today

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Critical Requirements

- Compelling Content
- Ease Of Installation
- Minimal Impact On PC's Normal Use

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New Medium Chicken And Egg Content Problem

Can't get:

- subscribers without content
- content without subscribers

You need about ~1M subscribers to interest content providers in creating custom content.

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Solution: Repurposing Existing Content

Broadcast Medium	Content	
	Repurposed	Custom
Radio	Music, Newpaper, Plays	Series:Gunsmoke, Sports...
Television	Radio series, Sports, Movies	Mini-series, Sit-com, talk-show...
Cable TV	TV, Movies, TV-reruns	CNN, Weather Channel
DBS Satellite	Cable TV	Pay-Per-View Movies

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Repurposable Content For DBS PC

Content Type	Good Initial Candidate?	Issues
DBS Video/Audio		Hardware Cost/Installation/Value Add
Data Enhanced Video		Hardware Cost/Installation/Content
Web Sites	√	Advertising, Dynamic Content
Usenet News	√	10-15 GB/day
Software Downloads	√	Selecting/Licensing
IP Video/Audio	?	Content availability/licensing

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DBS PC Initial Service Package

Service Package Which Supplements Dialup Internet

- WebCast - subscribe to name-brand web-sites.
- Usenet NewsCast - access to the entire usenet newsfeed.
- Software Downloads - shareware, etc.
- Email Alert - notification when email has been received

Many different opportunities for package/bundling with other services.

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Critical Building Blocks

- Conditional Access Protected IP Multicast
- Conditional Access Integrated Multicast File Transfer Protocol
- Efficient hardware filtering

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WebCast Value Proposition

- Value Proposition To Web-Site Operators:
  - "Sign here and you'll get more hits" OR
  - "Sign here and turn your site into a true broadband experience"
- Value Proposition To Users:
  - "No hassle web-content at hard-disk speed without tieing up your phone line"
  - seamless transition between cached and interactive content

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WebCast Critical Requirements

- Content Integrity - user is given a consistent snapshot of a channel
- Usability - must not interfere with normal PC use
- Usage Reporting - to sustain an advertising based business model
- Electronic Program Guide - to promote content, allow easy access to all services

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Channels, Packages Architecture

- Channel - typically a web-site. Set of frequently updated content. User subscribes to a channel
- Package - a subset of a channel's content. Contains a header, hash table and the URLs.
- Base Package - contains a complete snapshot of a channel. Typically broadcast overnight with occasional rebroadcasts throughout the day
- Delta Package - contains just what has changed/been added since the previous Base Package

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Channels, Packages Benefits

- Operates over any multicast file transfer transport
- Always presents user with a consistent, complete channel
- Minimizes impact on webcast receiver resources
- Minimizes satellite bandwidth - some really great things you can do with compression
- Allows a receiver to be brought quickly back up-to-date

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Channels, Package Architecture Minimizes Receiver Impact

- Uses multicast file-transfer, very efficient (no bulk filtering in the PC)
- No preparation prior to accessing content (breaking it into individual URLs)
- Individual Compression:
  - uses less disk space
  - decompression happens when user is accessing content
  - only URLs accessed are decompressed

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Base/Delta Packages Minimizes Receiver Impact

- Base packages can be scheduled for when the PC is idle (overnight)
- Delta packages are much smaller, inherently less impact
- User can turn off multicast file transfer receiver (for games) and quickly be brought back up-to-date via delta packages

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Electronic Program Guide

- A channel everyone is subscribed to
- HTML/CGI Based -content changes with no programming
- For all services, supports:
  - promotion,
  - subscription,
  - launching of the service.

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WebCast Receiver Functions

- HTTP Proxy
- Web-Server For Local Processing
- Automatic browser configuration
- Phone-line control on cache-miss
- Disk space management - each channel has a budget. Total budget is never exceeded
- Channel subscriptions - conditional access transaction for "premium" channels
- Usage reporting - piggybacks Internet access, middle-of-night as fall-back

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NewsCast Overview

Usenet News consumes 40% of DirecPC traffic.

30% of DirecPC users are "heavy" Usenet users.

Traffic categories:

- Music
- Software
- Images
- Discussion groups

Usenet News - 10 to 15 GB/day, 1.4 Mbps

No retransmissions

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Personal News Server

- interacts with user to define newsgroups of interest
- efficiently stores only articles of interest
- expires articles based on age and/or disk space
- operates as a news server to an unmodified news client
- relays postings through dialup to news server

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Software Downloads

- Integrate with WebCast by offering download channel - with a few different shareware offerings on a daily basis
- Software vendors will pay for premium placement with sufficient subscribers
- Overnight multicast file transfer of other software downloads
- For non-shareware software, send encrypted software which is decrypted via Internet E-Commerce transaction

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Email Alert

Requirements:

- Notification within a few minutes of email receipt
- Must recover from PC outages
- Anonymity
- Low bit-rate (< 1 bps/mail account)

One solution:

- Periodic multicast of cryptographically protected timestamp

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Installation Issues

Low monthly service charge requires low equipment cost, easy installation, low support costs

"PlugNPlay" PCI adapters are not easy enough for the low-end consumer

Target retail price should be similar to previous high-end modems (< $200)

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Universal Serial Bus Receiver

- Available with all recent (1997 or newer) desktop PCs.
- Available with many current laptop PCs.
- PlugNPlay without opening the PC.
- Adequate throughput for data applications (up to 4 to 5 Mbps).
- Supported by Win95 OSR 2.1 (1997 or new PCs)
- Fully supported by Win98
- Not supported by WinNT until NT5.0

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Conclusion: The Time Is Ripe

Each of the critical requiresments can be satisfied:

- Content - repurposed Internet content initially
- East Of Installation - use existing dishes + USB receiver
- Minimal Impact On Receiver PC - w/2nd generation applications

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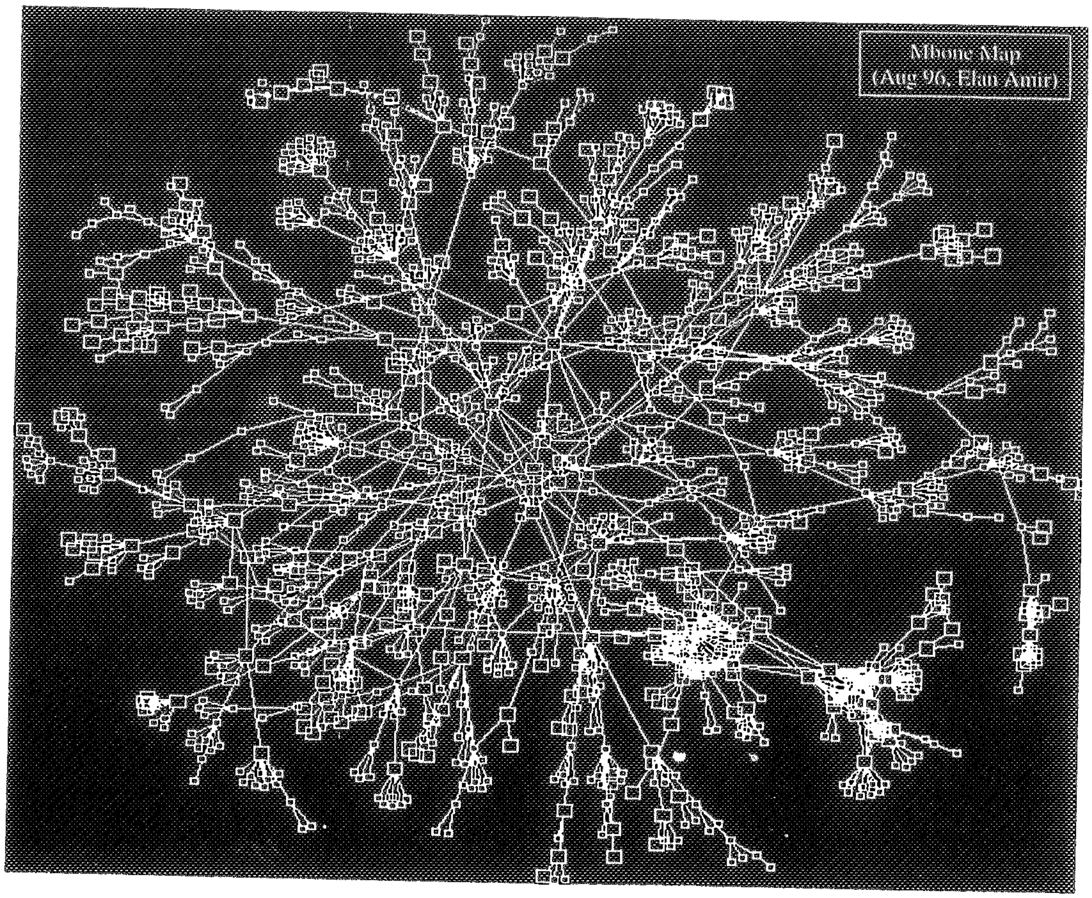
Integrating Satellite Networks with Internet Multicast Backbone (MBone)

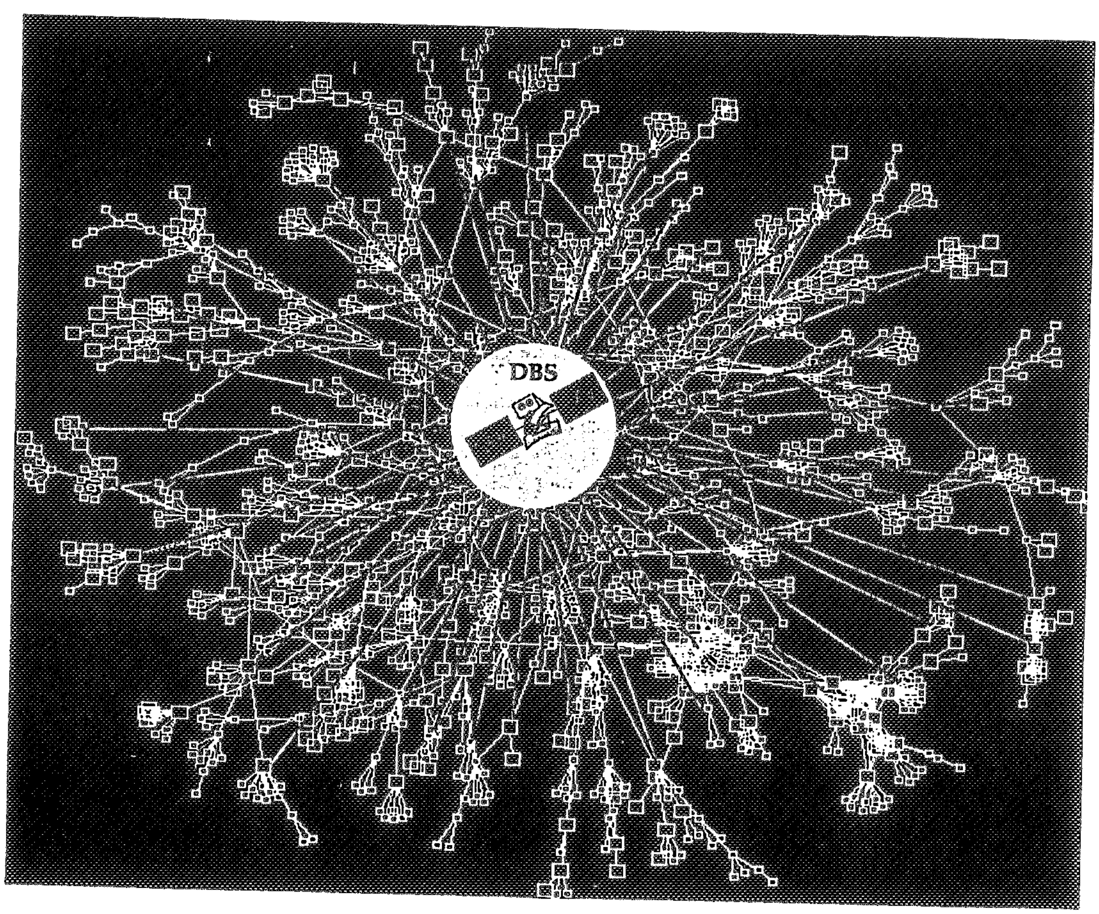
Yongguang Zhang and Son K. Dao
HRL Labs. (formerly Hughes Research Labs.)

email:ygz@hrl.com
http://www.wins.hrl.com/people/ygz

What is MBONE?

A (virtual) backbone network that provides datagram routing services for multicast applications over Internet


Mbone Map
(Aug 96, Elan Amir)


DBS

GEO Satellite Makes the Best Internet Multicast Backbone (MBONE)

Lower cost

Fewer router states

Uniform performance among members

Purpose of the Experiments

- Feasibility of Mbone over DBS
- Performance comparison with current Mbone (over terrestrial Internet)
- How DBS may change the way we do
  - multicast routing
  - reliable multicast

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A HUGHES ELECTRONICS COMPANY

MBONE over DirecPC Satellite

(IETF-40, Dec 8 - 11, 1997)

I E T F

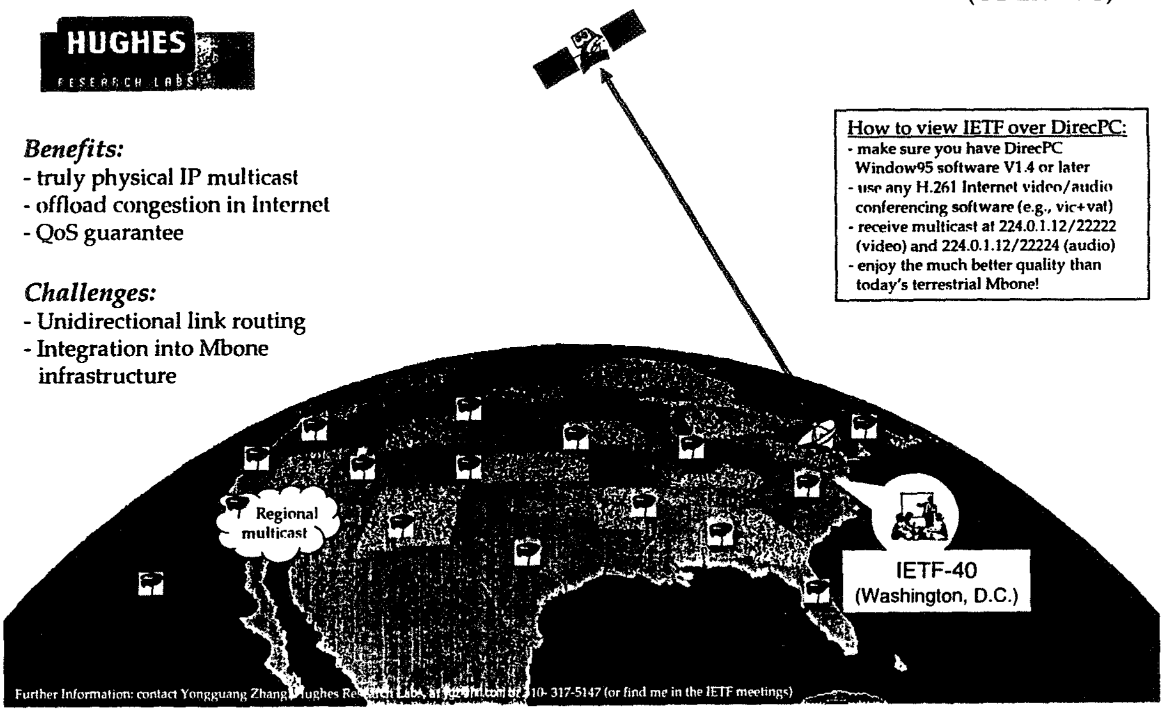
(UDLR WG)

HUGHES
RESEARCH LABS

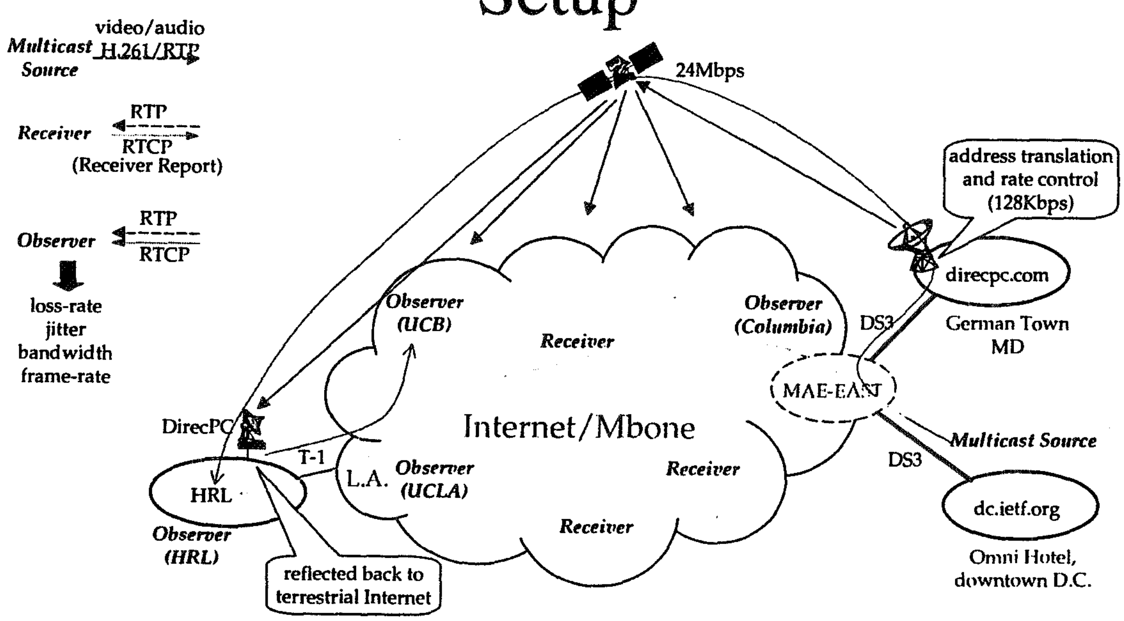
Benefits:
- truly physical IP multicast
- offload congestion in Internet
- QoS guarantee

Challenges:
- Unidirectional link routing
- Integration into Mbone infrastructure

How to view IETF over DirecPC:
- make sure you have DirecPC Window95 software V1.4 or later
- use any H.261 Internet video/audio conferencing software (e.g., vic+vat)
- receive multicast at 224.0.1.12/22222 (video) and 224.0.1.12/22224 (audio)
- enjoy the much better quality than today's terrestrial Mbone!

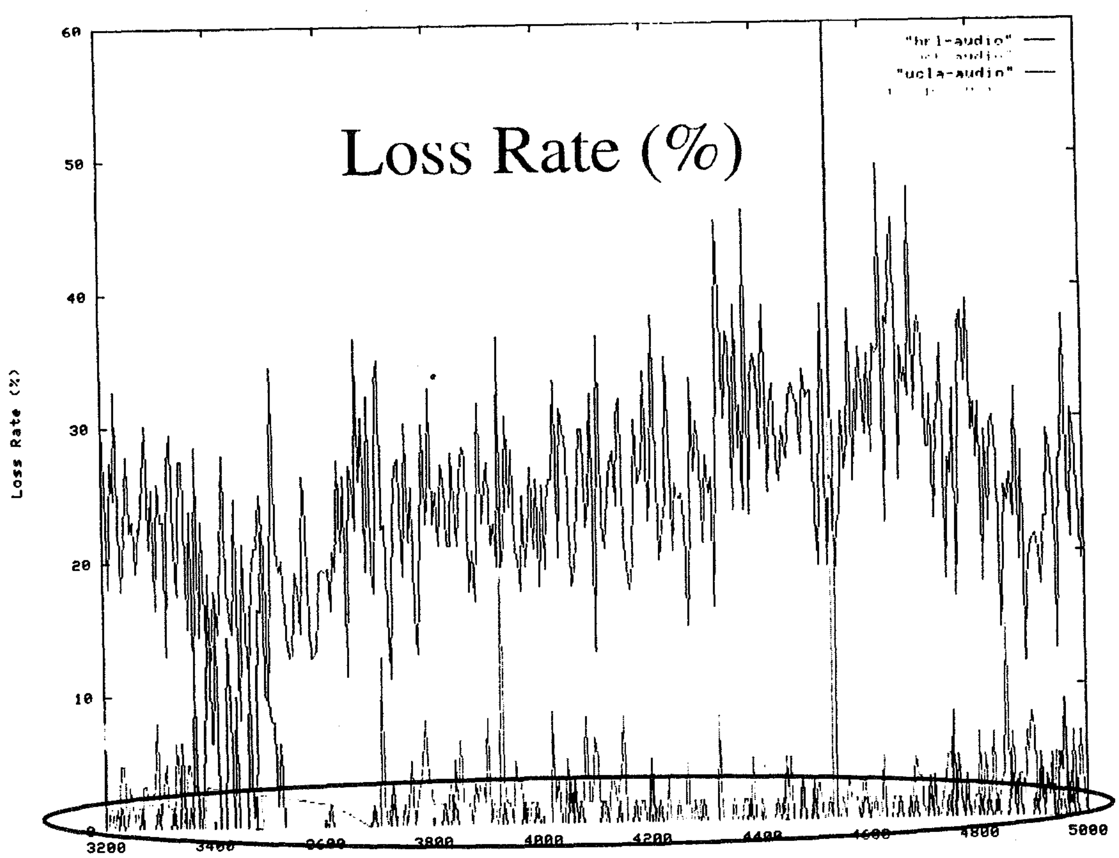


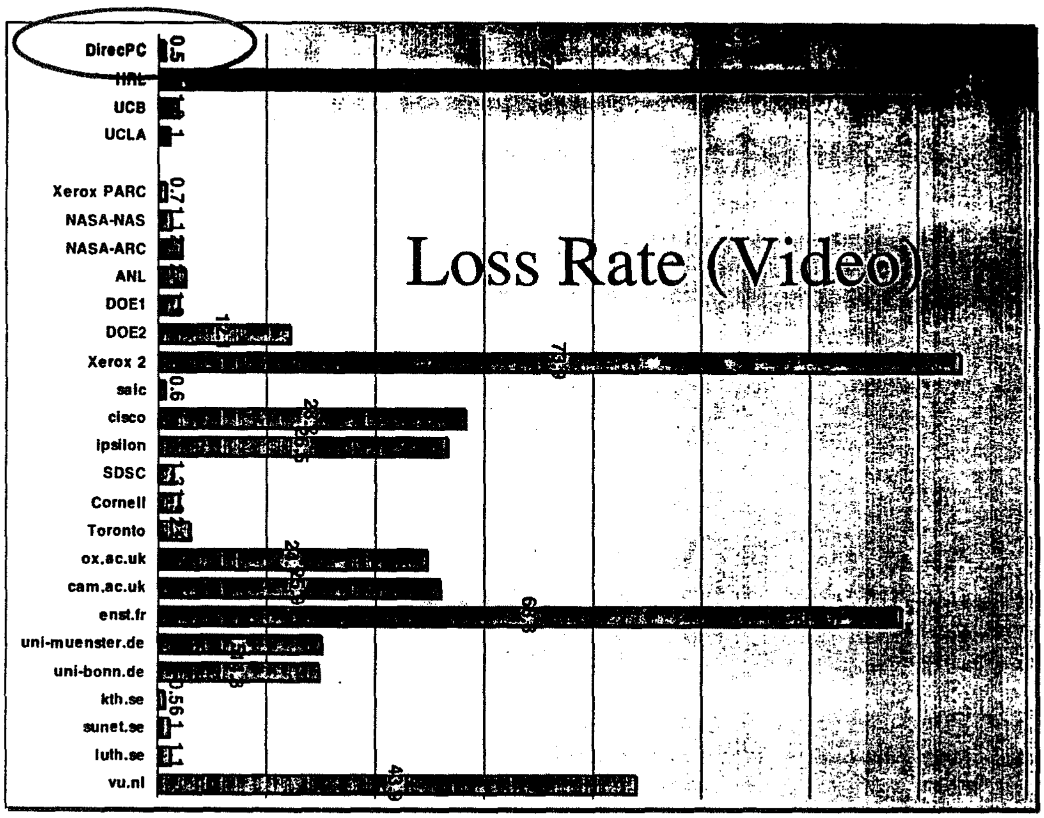
Setup



Data Collection

- 6 data set collected at observer sites:
  - over Mbone: HRL, UCB, UCLA, Columbia
  - over DirecPC: HRL
  - over DirecPC+Mbone: UCB
- Sampling the Mbone:
  - periodic Receiver Reports from each receiver
  - over 30 core samples (> 20 min, RR freq < 10s)
  - sample may be skewed




Loss Rate (Video)
DirecPC
HRL
UCB
UCLA
Xerox PARC
NASA-NAS
NASA-ARC
ANL
DOE1
DOE2
Xerox 2
saic
cisco
ipsilon
SDSC
Cornell
Toronto
ox.ac.uk
cam.ac.uk
enst.fr
uni-muenster.de
uni-bonn.de
kth.se
sunet.se
luth.se
vu.nl

Center for Satellite and Hybrid Communication Networks

Error Control for Satellite Multicasting

Daniel Friedman and Anthony Ephremides
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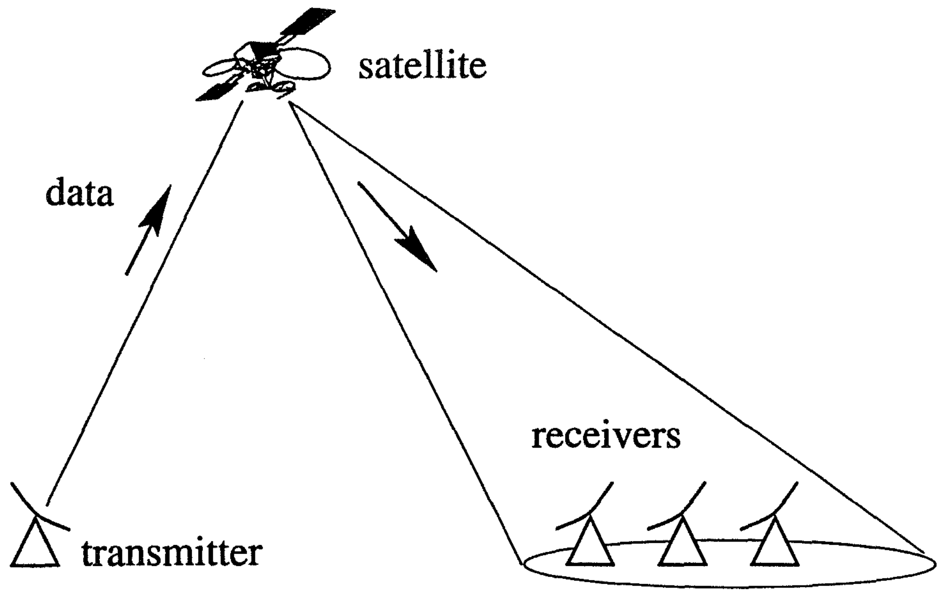
Presentation Outline

1. Multicasting in Satellite and Hybrid Networks
2. Analysis: Point-to-Point Communication
3. Analysis: Point-to-Multipoint Communication
4. Numerical Example
5. Additional Considerations

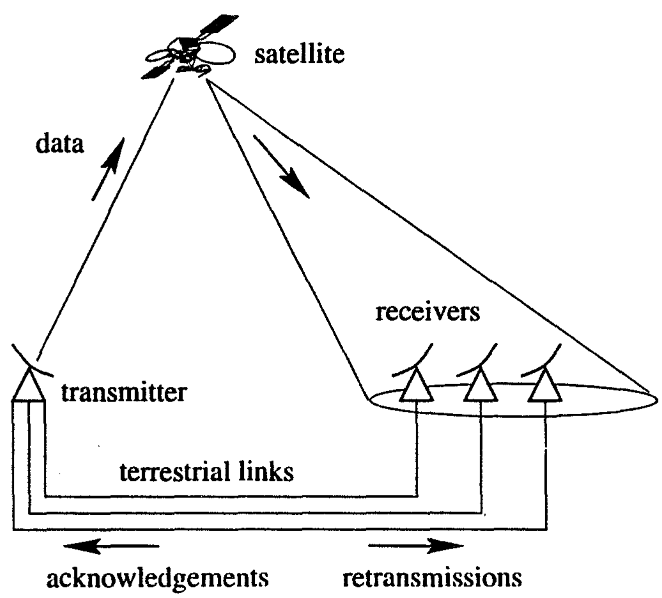
Multicasting in a Satellite Network



Each multicasted transmission may reach some of the receivers in error.

Problem: Each multicasted retransmission typically benefits few receivers;
more receivers $\Longrightarrow$ less throughput

ARQ Multicasting in a Hybrid Network



Retransmissions are directed only to appropriate receivers;
greater throughput possible than in a satellite network.

Initial Analysis Assumptions and Definitions

1. Unlimited buffer size, unlimited window size; ideal selective-repeat ARQ protocol.
2. All acknowledgements are delivered without errors.
3. Satellite channel frame error rate = p_s.
   Terrestrial channel frame error rate = p_t.
4. ARQ information frame = { h header (overhead) bits ; ℓ information bits }.
   (Same composition for satellite and terrestrial transmission.)
5. Bandwidth consideration:
   Satellite channel transmission rate = $r_s > r_t$ = terrestrial channel transmission bit rate.
6. In the hybrid network, all retransmissions are sent terrestrially.
7. Acknowledgements are sent only for frames received without errors.
8. Performance measure:

$$\text{throughput, } \nu = E\,[\text{\# information bits transmitted successfully/s}]$$

   Related quantity (primarily for pure-satellite networks):

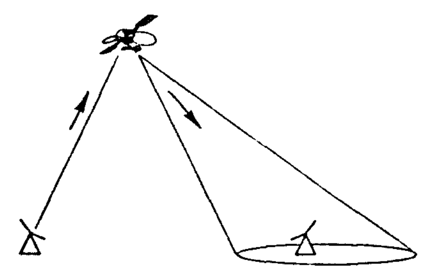
$$\beta = E\left[\frac{\text{\# frames sent/s}}{\text{\# frames delivered/s}}\right] = \text{measure of "inefficiency"}$$

Analysis for Point-to-Point Communication

Satellite System:

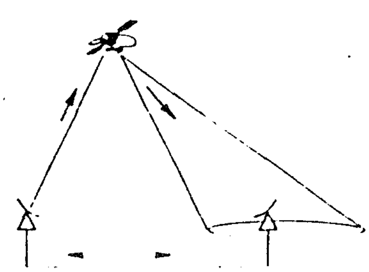
$$\text{inefficiency} = \beta = \sum_{i=1}^{\infty} i\,(1-p_s)\,p_s^{\,i-1} = \frac{1}{1-p_s}$$

$$\text{throughput} = \nu_{satellite} = \left(\frac{\ell}{\ell+h}\right)\frac{r_s}{\beta} = \left(\frac{\ell}{\ell+h}\right)(1-p_s)\,r_s$$



Hybrid System
—assuming terrestrial link can accommodate all retransmissions:

$$\nu_{hybrid} = \left(\frac{\ell}{\ell+h}\right) r_s$$



Terrestrial Link Bandwidth Requirements

Acknowledgement traffic rate:

$$\begin{aligned} r_t &\geq K_{ack}\left(\frac{r_s}{\ell+h}\right)(1-p_s) + K_{ack}\left(\frac{r_s}{\ell+h}\right)p_s \\ &= K_{ack}\left(\frac{r_s}{\ell+h}\right) \end{aligned}$$

where K_{ack} = average acknowledgement length in bits (hybrid network).

Retransmission traffic rate:

$$\begin{aligned} r_t &\geq (\ell+h)_t \frac{r_s}{(\ell+h)_s} p_s (1-p_t) \sum_{i=1}^{\infty} i {p_t}^{i-1} \\ &= r_s\left(\frac{p_s}{1-p_t}\right) \end{aligned}$$

Average Acknowledgement Length (Hybrid Network)

Acknowledgement =

{ h_{CRC} error-detection bits ; h_{seq} bits per sequence number ; [$h_{seq} \cdots$;] }

$$K_{ack} = \frac{h_{CRC} + h_{seq}\left\{1 + \frac{r_s p_s}{\ell+h}\left[\frac{\ell+h}{r_s} + \tau_s + \tau_t + p_t\left(\frac{\ell+h}{r_t} + 2\tau_t\right)\left(\frac{1-{p_t}^{\omega-1}}{1-p_t}\right)\right]\right\}}{1 - h_{seq}\frac{r_s p_s}{r_t(\ell+h)}\left(\frac{1-{p_t}^{\omega}}{1-p_t}\right)}$$

where:

- τ_s = one-way propagation delay through satellite channel
- τ_t = one-way propagation delay through terrestrial channel
- ω = maximum possible number of transmission attempts possible for a frame without exhausting ARQ window ($\omega \in \{1, 2, \ldots\}$)

Also: The ARQ window size, N, is given by:

$$N = \left\lceil \left(\frac{r_s}{\ell+h}\right)\left[\left(\frac{\ell+h}{r_s} + \tau_s + \frac{K_{ack}}{r_t} + \tau_t\right) + (\omega-1)\left(\frac{\ell+h}{r_t} + \tau_t + \frac{K_{ack}}{r_t} + \tau_t\right)\right]\right\rceil$$

Point-to-Multipoint Communication: Additional Assumptions

1. $M > 1$ receivers.
2. Noise processes on the satellite link are independent and identical for all receivers.
3. Noise processes on the terrestrial link are independent and identical for all receivers.
4. No competition for accessing the acknowledgment channel.
5. Both terrestrial and satellite propagation delays are common to all receivers.
6. The transmitter maintains a history of which stations have acknowledged which frames.

Analysis for Point-to-Multipoint Communication

Satellite Network:

$$\begin{aligned}\gamma(j) &= \Pr\{\text{A frame is delivered to } M \text{ receivers with} \leq j \text{ transmissions}\} \\ &= \left(1-(p_s)^j\right)^M\end{aligned}$$

$$\text{inefficiency } = \beta_M = \sum_{j=1}^{\infty} j[\gamma(j)-\gamma(j-1)]$$

$$\text{throughput } = \nu_{M,satellite} = \left(\frac{\ell}{\ell+h}\right)\frac{r_s}{\beta_M}$$

Hybrid Network:

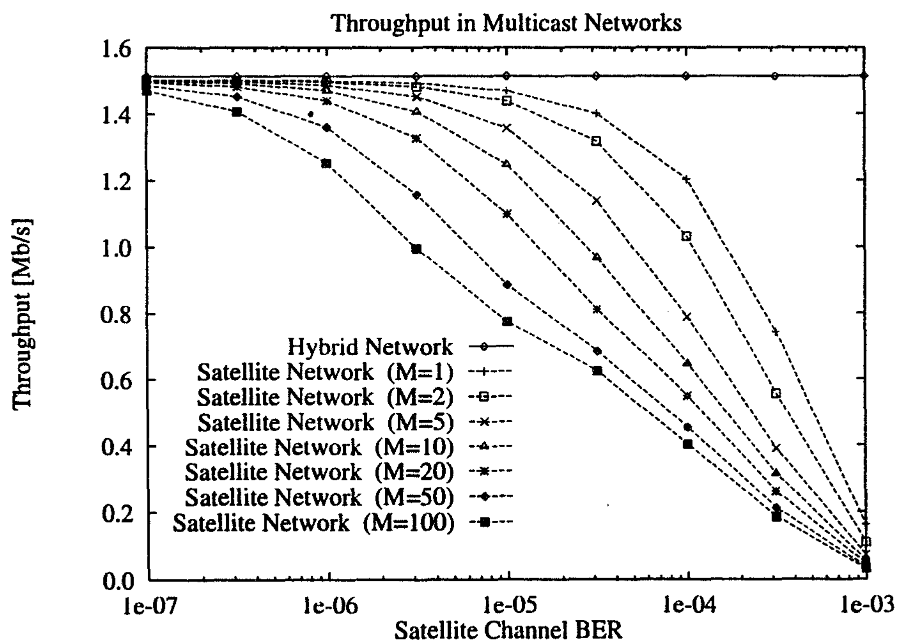
$$\nu_{M,hybrid} = \nu_{hybrid} = \left(\frac{\ell}{\ell+h}\right) r_s$$

Numerical Example: Assumptions

1. $r_s = 1536000$ b/s; $r_t = 33600$ b/s.
2. $h = 32$, $\ell = 2176$ for all ARQ information frames ($h_{CRC} = 16$, $h_{seq} = 16$).
3. Satellite and terrestrial channels modeled as binary symmetric channels (BSCs) with crossover probabilities (BERs) q_s and q_t, respectively.
4. $q_s = [10^{-7}, 10^{-3}]$; $p_s = 1 - (1 - q_s)^{\ell+h} = [2.2 \times 10^{-7}, 8.9 \times 10^{-1}]$
   $q_t =$ (discussed below) ; $p_t = 1 - (1 - q_t)^{\ell+h}$
5. $\omega = 3$. (Note: require $\omega \geq 2$ for efficient SR-ARQ operation.)
6. $\tau_s = 300$ ms; $\tau_t = 125$ ms (includes 95 ms modem processing delay*).
7. Infinite sum for $\beta_{M,satellite}$ approximated by truncating at the minimum j such that $\gamma(j) > 1 - 10^{-7}$.

*Result from an ACTS experiment.

Numerical Example: Results



Applicability of Hybrid Network

Acknowledgement traffic rate:

$$K_{ack} \leq (\ell + h)\frac{r_t}{r_s} = 48.3$$

$$\text{(with formula for } K_{ack}\text{)} \implies p_s < 2 \times 10^{-2}$$

$$\big(\text{Also: } N \approx 740 \text{ frames}\big)$$

Retransmission traffic rate:

$$p_t \leq 1 - \frac{r_s}{r_t}p_s \approx 1 - 45.7\, p_s$$

$$\implies p_s < 2 \times 10^{-2}$$

Note: $p_s = 2 \times 10^{-2} \implies q_s \approx 10^{-5}$.

$\implies$ Hybrid network applicable for $q_s < 10^{-5}$.

Additional Considerations

- Refinements to allow operation at higher BERs
- Packet length (throughput efficiency sensitivity; fixed vs. variable)
- Other network topologies (in particular, tree topology)
- Wireless terrestrial network
- Hybrid ARQ

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Session 6
Interoperability Experiments and Applications

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Applying Heritage Internetworking Solutions to ATM Satellite Systems

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Summary

This paper discusses the internetworking of IP over ATM satellite systems as part of SpaceBridge's focus on the development of terrestrial interfaces and adaptation functions for broadband satellite systems. It gives an overview of our heritage internetworking solutions and their potential for being applied to ATM satellite systems.

Introduction

The unique networking characteristics of satellites enjoy the strategic advantage of allowing widespread delivery of services independent of geographical locations and population density. They have the advantage of jumping some of the technological and regulatory hurdles that have so far been preventing cost-effective delivery of interactive broadband services, by terrestrial means, to rural, small urban, and even some densely populated areas of the world.

The spectrum of satellite services can be viewed in the context of traditional, new, and emerging services, as shown in Figure 1. High capacity trunking and broadcast of TV programming to cable head-ends and radio distribution are among the so-called traditional services that started in the early 70's. Although trunking is gradually being replaced by fiber, broadcast still remains the main source of revenue for the satellite industry. The so-called new services include interactive data service for enterprises (VSATs), direct-to-home TV broadcast, business television (BTV), Internet access, rural telephony, and mobile voice and data services. These services were conceived in the early 80's and are now reaching the stage of widespread service offering in the market place. Broadband interactive multimedia service to consumers and enterprises is among the emerging services, and one that has been key in providing the impetus for development of on-board processing satellites, the use of frequency allocation at Ka-band, and increased inter-operability with terrestrial systems. These services started their development phase in the early 90's and are now being pursued at a very fast pace by the satellite industry with the expectation to reach the market in the early years of the next century.

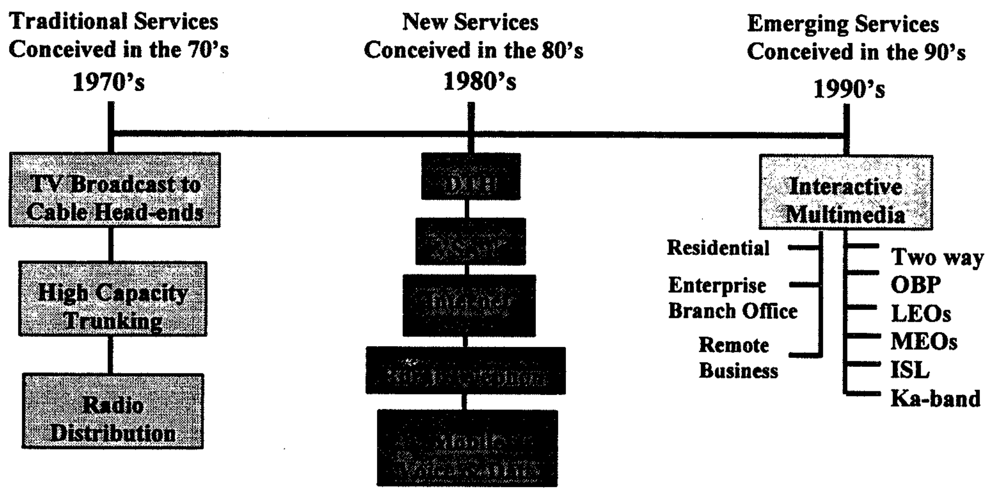


Figure 1: Evolution of Satellite Services

As part of these emerging services and to take advantage of the fundamental principles of satellite communications, multimedia satellite systems, some carrying on-board ATM functionality, are emerging to complement the terrestrial networks in meeting the increasing demand for broadband services. These systems plan to offer enterprise and consumer-affordable multimedia communications services to regions beyond the economic reach of terrestrial systems at user-perceived performance levels comparable to those offered by terrestrial systems (ATM or data services in general).

Convergence of satellite and terrestrial networks is now becoming a key factor in forming the foundation for an efficient Global Information Infrastructure (GII) that is going to be supported by a wealth of information sources offered by content providers. This infrastructure has to accommodate new applications with expanded communications requirements that are creating an environment with a whole new set of networking challenges. One of the key challenges of addressing the fundamental tenants of this global information infrastructure is the ability to internetwork efficiently across all domains. This inter-operability requires dynamic and transparent connectivity to join local and wide area, public and private networks which are characterized by a diverse mix of topologies, physical media, transmission speeds, carrier services, geographical coverage, interfaces, etc.

ATM offers multimedia services directly under a single framework and has isochronous support built in, and allows quality-of-service guarantees. However, until native ATM applications are fully developed, a significant percentage of end-user devices continue to be directly connected to legacy media such as Ethernet and Token Ring. In addition, because of the unprecedented variety of legacy applications and the vast installed base of related networks these devices will continue to use legacy network layer protocols, of which IP is a prominent example. This means that the key to the success in the short to medium term lies in ensuring the availability of efficient methods to operate internetwork layer protocols over heterogeneous networks that include an ATM infrastructure.

The industry, including the working groups of the ATM Forum and the Internet Engineering Task Force (IETF), has spent an enormous amount of effort in addressing the internetworking of IP over ATM. Also, a significant level of effort has been spent by the industry on optimization of TCP traffic for large bandwidth and long latency applications over satellite networks. This paper considers IP, ATM, and satellites in a single context and discusses internetworking of IP applications over ATM satellite systems as part of SpaceBridge's focus on the development of terrestrial interfaces and adaptation functions for broadband satellites.

One example of this corporate heritage is the Carrier Scale Internetworking (CSI) platform, which is an assortment of technology solutions for adding internetworking services to the ATM multi-services switching fabric. CSI is a carrier class solution that consolidates service, accounting, and performance management for IP-based services and has many similarities in its intended functionality to those of the ATM satellite systems that have to internetwork with terrestrial systems.

A number of topics will be addressed during the course of this paper. These topics include requirements and criteria for internetworking over satellite, routing of IP over ATM in a satellite environment, choices of standards for carrying IP over ATM, and the potential of CSI solutions for application to ATM satellite systems.

2.0 The Satellite Advantage

Before we begin the topic of internetworking over satellite, it is important to highlight, as shown in Figure 2, where the satellite advantage lies in order to keep those features that contribute to the competitive advantage of satellite in the foreground. Awareness of these features would help ensure that they are not compromised as alternative internetworking solutions are investigated. The key to increasing the satellite advantage lies in full utilization of such features as shared access, implementation of large numbers of nodes, dynamic resource allocation, fast response, wide area coverage, and, of course, extension of terrestrial networks to rural and geographically unsaved areas. These are the features that bring down the cost per unit of capacity and competitively position satellite solutions in the market place. Cost-effective realization of these features, particularly given the scarcity of bandwidth and space segment resources in a satellite environment, require that the overhead and signaling traffic be kept as low as possible. Internetworking solutions have to be very conscious of minimization of overhead traffic as functionality is partitioned between the MAC, ATM, and IP layers.

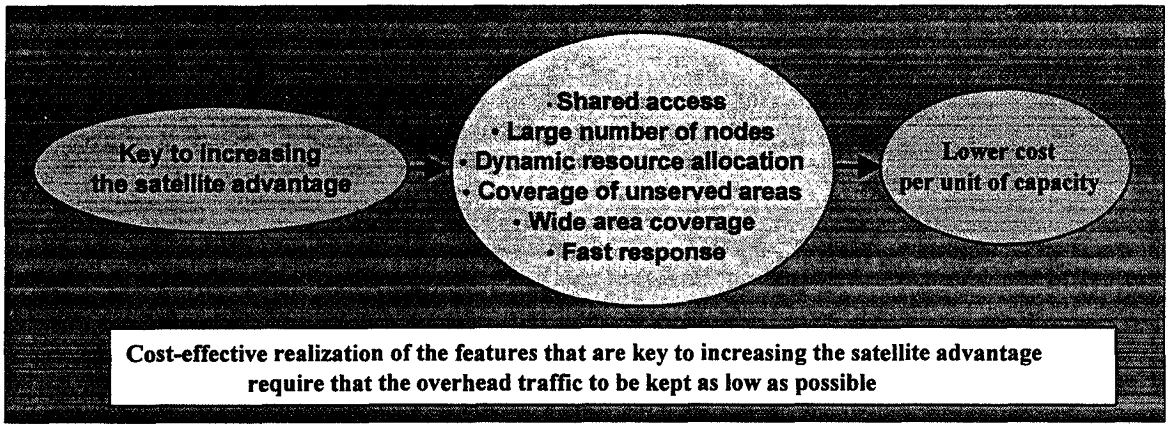


Figure 2: The Satellite Advantage

3.0 Inter-networking Solutions

3.1 Requirements and Design Criteria

Internetworking within the scope of this paper refers to transport of network layer protocol (IP as an example) and its related applications over ATM. The basic internetworking requirements include exploiting quality of service (QoS) offered by ATM, internetworking with legacy equipment, efficient transport, and expandability to larger networks.

In order to optimize design criteria specific to internetworking over satellite, it is essential to incorporate an end-to-end system approach that takes into account the unique networking characteristics of satellite as well as terrestrial systems. Characterization of realistic internetworking applications, how they are routed to the terminal, terminal interfaces, media access control (MAC) options in conjunction with demand assigned multiple access (DAMA), space segment characteristics, interconnects to terrestrial networks, and the network management entities are among the elements to be considered. The need to have an end-to-end system perspective becomes even more critical when one is considering regenerative satellites where terminals, gateways, network management entities, and the on-board switch are closely interwoven in their functionality.

Insight into the overall system is required in order to allow optimum partitioning of functionality across the network. How functionality is partitioned among the various network elements has a major bearing on the choices that are made with respect to standards for carrying IP over ATM, address resolution mechanisms, QoS, etc. These elements include clients and edge devices at the satellite terminals and gateways, and servers at the network control centers and network operations center. In a satellite environment, the golden rule is to minimize the ratio of over-the-air routing traffic to data traffic in order to economize the scarce space segment resources and therefore bring down the service cost per unit of capacity. The trade-offs in functionality partitioning to meet the internetworking requirements and at the same time achieve an efficient utilization of space segment resources is very complex and has to take into account, among other things, the functional entities in a satellite system.

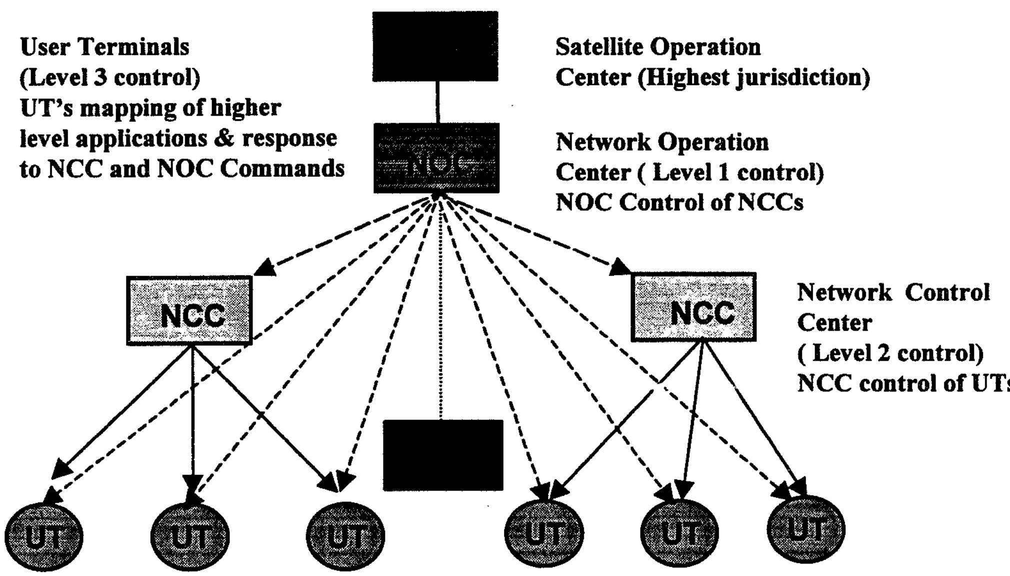


Figure 3: Functional Entities in an Advanced Satellite System

For example, as shown in Figure 3, the internetworking server functionality at the network control center (NCC), can be mapped to that of the network operation center (NOC, also known as master control center) to reduce certain inter-subnet routing traffic associated with address resolution enquiry. However, it would be at the expense of larger server functionality at the NOC. Partitioning of layer-3 and layer-2 functionality between the edge devices and the network is another important factor. For example, layer-3 routing capability can be given to the edge devices to query the route servers and thus ensure QoS guarantees. But this could lead to unnecessary routing traffic that can be dealt with differently in a satellite environment. Within the satellite network, as shown in Figure 4, inter-subnet address resolution does not necessarily require layer three routers and can be done at the ATM and MAC levels. Satellite inherent broadcast capability makes certain functions, such as multicast, much easier. This unique characteristic of satellites lends itself to modified internetworking server functionality at the NCCs. DAMA is the system arbitrator that deals with physical network resources that the MAC layer would use. How much functionality is given to the network and how much to the terminal through the MAC layer is an important trade-off consideration that does impact internetworking requirements.

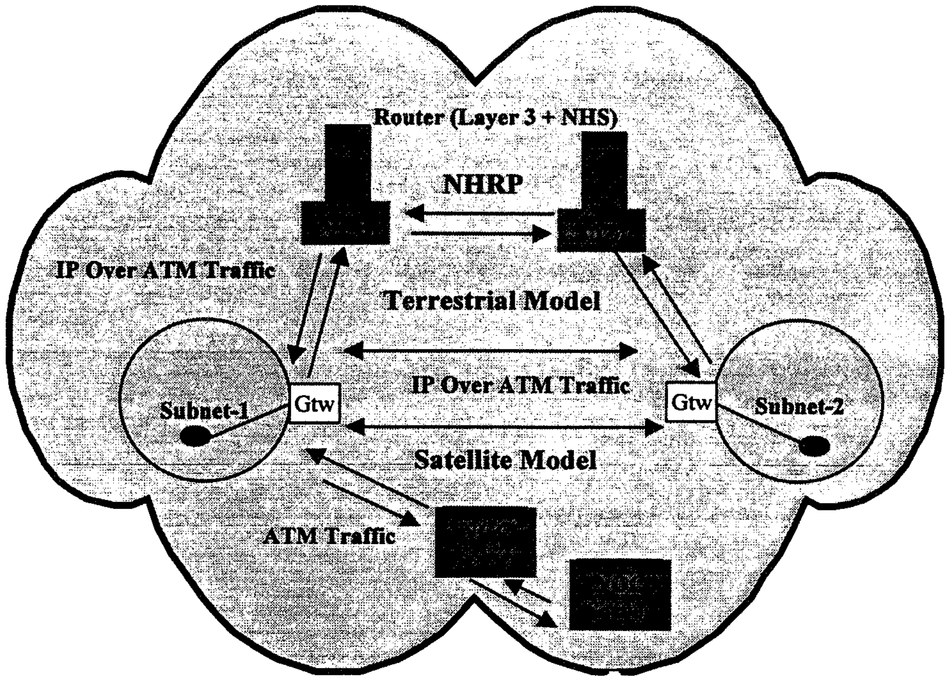


Figure 4: Comparing a Layer 2 Versus Layer 3 Functionality in an ATM Cloud (a Satellite Model Versus a Terrestrial Model)

Consideration of functionality partitioning between the satellite and terrestrial networks is also a critical element of an end-to-end system approach to internetworking solutions. As it stands today, TCP latency performance requirements necessitate segmentation of satellite and terrestrial networks at layer 4. This current reality, driven by the limitations of a legacy layer 4 protocol, lends itself to partitioning of functionality between the satellite and terrestrial networks at the gateways. Of course, there is the possibility that future TCP modifications would remove the need for separate treatment of satellite and terrestrial links, and if we further assume ubiquitous deployment of ATM, then there is no need to make a distinction between the satellite and terrestrial networks. Nonetheless, irrespective of the latter happening in the near future or not, it is evident that optimum functionality partitioning is a two dimensional process, one involving the physical entities including edge devices/terminals, gateways, terrestrial interconnects, NCCs, and NOC, and the other involving the layer protocols.

Figure 5 depicts the concept of distribution of functionality across protocol layers as a function of physical entities. The challenge is to determine how to glue all pieces together and achieve optimum partitioning such that the internetworking requirements are met with a minimum utilization of space segment resources.

3.2 Quality of Service (QoS)

There are a number of dimensions to the QoS guarantees when it comes to internetworking of IP over ATM satellites. One is to support QoS flows which refers to the ability to establish a cut-through connection in an ATM cloud between sub-networks and therefore position IP traffic to take advantage of quality of services offered by an ATM network. It is worth noting here that the QoS that is often referred to in the literature in comparing various IP over ATM standards is this particular aspect of QoS.

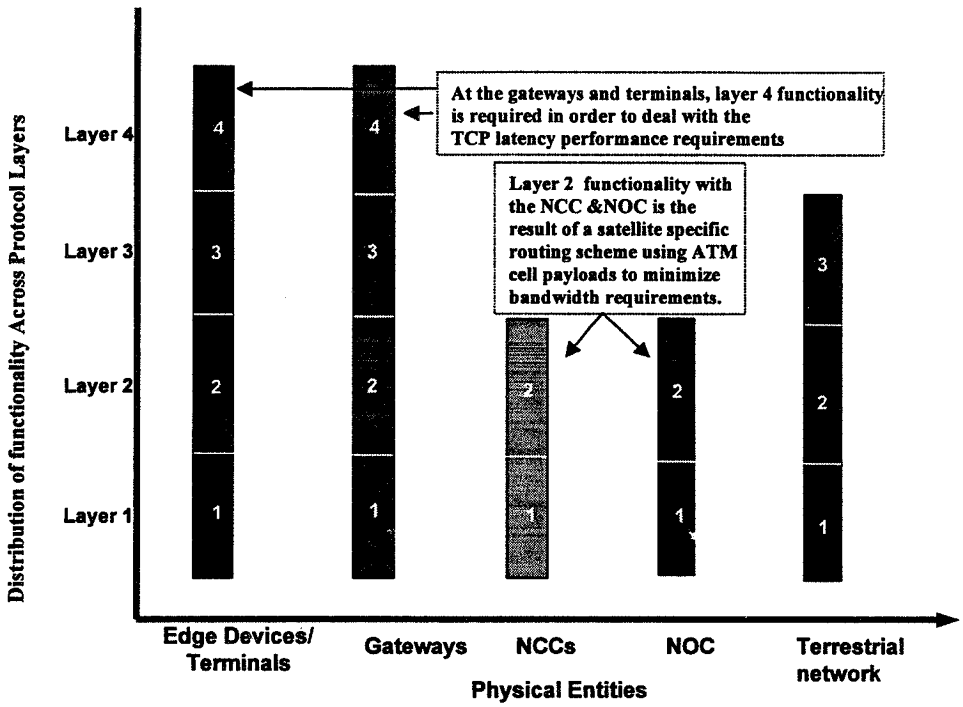


Figure 5: Optimum Functionality Partitioning

The other dimension is the flexibility to have various QoS options available once the cut-through is established. The latter translates into the issue of mapping classes of IP traffic (best effort, guaranteed, and predictive delay) to that of ATM (CBR, VBR-RT, VBR-NRT, UBR, and ABR). The information for the desired IP class of traffic can be obtained from the RSVP (Resource reservation protocol) which acts as the IP level signaling protocol for QoS. In an ATM internetworking environment, QoS management would be limited to the utilization of RSVP as an indicator of IP QoS requirements that can be mapped onto ATM QoS. In such cases, RSVP is not required to manifest its full capability as it does in a non-ATM environment and has to be de-coupled from its IP network implications.

However, in a heterogeneous environment, the issue becomes more complex and has to be looked at in the context of how the partitioning of functionality is achieved. In a heterogeneous environment we have to reconcile the fact that in ATM, resource reservation is made at the connection setup time using signaling protocols, and thus is sender-driven and relies on hard-state in switches to maintain connections. Whereas, in the connectionless world of IP, resource reservation is not permanent, but times out after some period and can be changed at any time.

In satellite networks, QoS has another dimension and that is the efficient utilization of network resources when various flows above IP are mapped into connections below the IP layer. For example, when one looks at the classes of application one sees quite a variety. We can have short duration UDP (for example DNS applications), short duration TCP, file transfer, and real time audio/video applications. It may be advantageous to use a separate ATM VC for certain applications that are not of short duration. There are other IP services such as DNS that are ill suited for connection oriented delivery due to their normally very short duration. ATM with basic AAL 5 service is connection oriented whereas the IP layer above ATM is connectionless. At layer 4 on top of IP, the traffic is supported by TCP, which is a connection-oriented protocol. This raises the question as to what degree it is beneficial to map different flows above IP into separate connections below IP. This means that a mechanism should be in place to ensure that different ATM classes of services are utilized in such a way as to lead to an efficient utilization of network resources. In the context of efficient satellite network resource utilization, one should, at least, be open to also examining encapsulation methods other than "VC Multiplexing" and "LLC/SNAP". For example, there are some proposals for an encapsulation referred to "TCP and UDP over Lightweight IP" (TULIP) which assumes single hop reachability between the IP entities and largely eliminates IP header overhead.

3.3 Address Resolution

From an internetworking perspective, a satellite network can be regarded as a single large IP network. This single network view is realizable for two reasons, one is the inherent satellite physical architecture, and the other is that a satellite network is an autonomous entity governed by one system of network management. In a satellite IP network (SIPN), by the virtue of the features of a single autonomous network, there is no need for next hop servers (NHS), next hop resolution protocols (NHRP), or layer 3 routers associated with internetwork communications. In addition, routing within the SIPN can be achieved using purely ATM traffic directly to minimize overhead traffic. With these principles in mind, a satellite implementation of IP address resolution can be envisaged as indicated in the following:

1) Terminal looks into its IP routing table to see if the destination address is within the SIPN, as shown in Figure 6. If the destination address is not within the SIPN, the terminal searches the IP routing table within its local database for the appropriate gateway (this might just be a default gateway for destinations not on the SIPN).

2) If the destination address is within the SIPN, the satellite address resolution process kicks in. If no response is received, the host is considered unreachable (either an unassigned IP address or disconnected).

3) As part of the satellite address resolution process, an IP_ARP (MAC & ATM) is sent to the NCC server which contains its own IP routing table. Note that, on registration, the terminals have already registered their ATM addresses and all

layer 3 and MAC addresses reachable through them with the NCC server. The NCC responds with the destination address and then a direct VCC is established. If the destination address is outside of the NCC domain, the NCC could initiate request for this information from the regional NOC.

Other variations of this concept can be thought of as well. Any possible enhancement to the IP routing table within the terminal that can reduce or eliminate the routing traffic between the terminal and the NCC and NOC should be considered. As can be seen, this satellite implementation of the address resolution process is simpler compared to standard terrestrial implementations that will be further explored in sections 3.4.1 and 3.4.2.

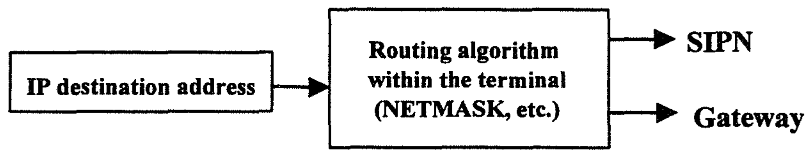
3.4 Choices of IP over ATM Standards

There are 3 main standards that can be considered for carrying IP over ATM. These are classical IP over ATM (CLIP), LAN emulation (LANE), and multi protocol over ATM (MPOA). LANE and MPOA have been proposed by the ATM Forum and CLIP by the IETF. There are also related protocols and servers such as next hop resolution protocol (NHRP) which is used in MPOA (also in CLIP for inter-subnet communications) to provide cut-through connections as well as ATM ARP queries, and multicast address resolution server (MARS) which is needed with MPOA for mapping multicast function. From the point of view of terrestrial networks the following attributes apply consistently with what appears in most relevant literature:

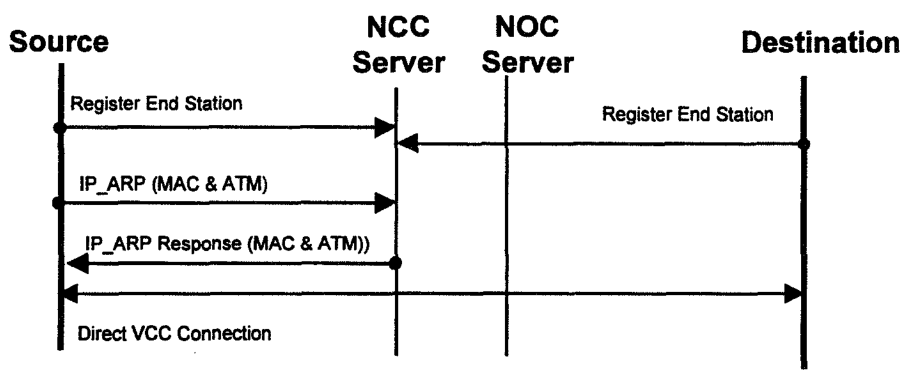
- **Classical IP over ATM (CLIP):** simple, limited to IP, limited to smaller networks, not scaleable, requires very large and fast routers, no QoS guarantees for inter-subnet communications without NHRP.
- **LAN Emulation**: layer 2 bridging solution, allows any layer 3 protocol to be supported, requires very large and fast routers for inter-subnet communications, no QoS guarantees for inter-subnet communications.
- **Multiprotocol over ATM (MPOA)**: includes LANE for subnets, but allows inter-subnet communication, distributed functionality to edge devices, QoS guarantee.

However, some of these attributes may change their merits/emphasis, lead to duplication of certain connection set-ups, or not fully apply in a satellite environment. A satellite IP network can be regarded as a single network capable of providing ATM VCCs anywhere within the network including smaller sub-nets within it. Therefore, LANE and CLIP that are conventionally referred to as not being able to support QoS guarantees for inter-subnet communications can, in fact, be implemented in an ATM satellite system with QoS guarantees even without NHRP.

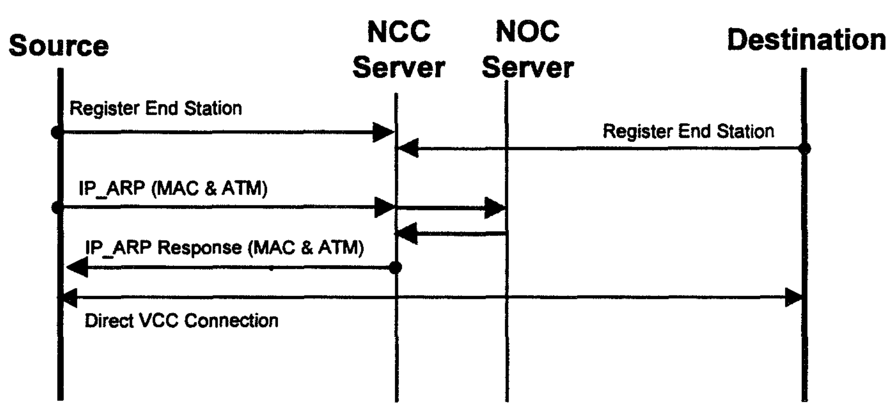
A modified implementation of LANE or CLIP within the satellite IP network and perhaps MPOA at the gateway for interface to the terrestrial ATM network is a near-to-mid term solution that should be considered. However, MPOA, or a modified version of it, should also be further examined for implementation within the satellite network as long as its control and data flows do not lead to increased over-the-air traffic in the satellite network.



Stage 1: Terminal looks into its IP routing table



Stage 2: The destination is within the NCC domain



Stage 3: The destination is outside of the NCC domain

Figure 6: A Satellite Implementation of Address Resolution Mechanism

The higher software implementation complexity is something that can be acceptable if it is widely used in the terrestrial environment and mitigated by the economies of scale. Further examination of MPOA for the satellite network is warranted because of two important factors. One is that it does offer additional advanced performance features and the other is the fact that it is the future inter-networking protocol that is likely to be used by carriers. The latter attribute offers an advantage of strategic dimension that can not be ignored. SpaceBridge, as part of its in-house R&D and drawing on its extensive heritage in this area, is currently looking at this very issue.

3.4.1 LANE

LANE offers transparent emulation of LAN protocols (currently Ethernet and Token Ring are defined) over ATM and as such is a layer 2 forwarding solution. LANE emulates a bridged LAN on top of an ATM network by offering a service interface to layer 3 that is similar to existing LANs. LANE allows all network layer protocols (layer 3) and applications to be supported without any modifications. It is particularly appropriate for Enterprise or Small Office /Home Office (SOHO) type terminals that usually feed into a local area network of workstations. It requires fast routers for inter-subnet communications in the terrestrial environment. QoS guarantees are limited to the subnet for terrestrial networks. However it is important to note that within the satellite network QoS guarantees, in so far as establishment of direct ATM connections between satellite smaller subnets are concerned, are achievable.

A satellite implementation of LANE, as shown in Figure 7, can be envisaged where on one end LANE is implemented on ATM hosts (for example on the ATM NIC card) forming an emulated LAN (ELAN) or on LAN switches (layer 2 LAN bridge). The satellite ATM terminal will include a LANE emulation client (LEC) where LEC would run the LANE protocol stack that performs encapsulation, address resolution, and data forwarding. For the LAN section, the terminal LEC's user network interface (LUNI) at the data link layer can be attached to a bridge (layer 2) with an RJ 45 interface for external connection to the LAN. The function of the bridge is to avoid unnecessary forwarding of packets that are not destined for satellite routing. For the emulated LAN section representing the ATM hosts, the satellite terminal will have an ATM interface (such as ATM 25). Therefore, LANE can be used in two ways. One way is as an interface to the LAN through a bridge, and the other way would be to run LEC directly on the workstation as part of an emulated LAN where LEC provides a direct interface to the upper layers.

LANE servers for address resolution would be located at the NCCs and NOC. All routing traffic between the terminal and the NCC, and between the NCC and NOC is purely ATM and therefore no LEC client is required. However, at the gateway a LEC client is required because there is IP traffic involved heading for or arriving from the terrestrial network.

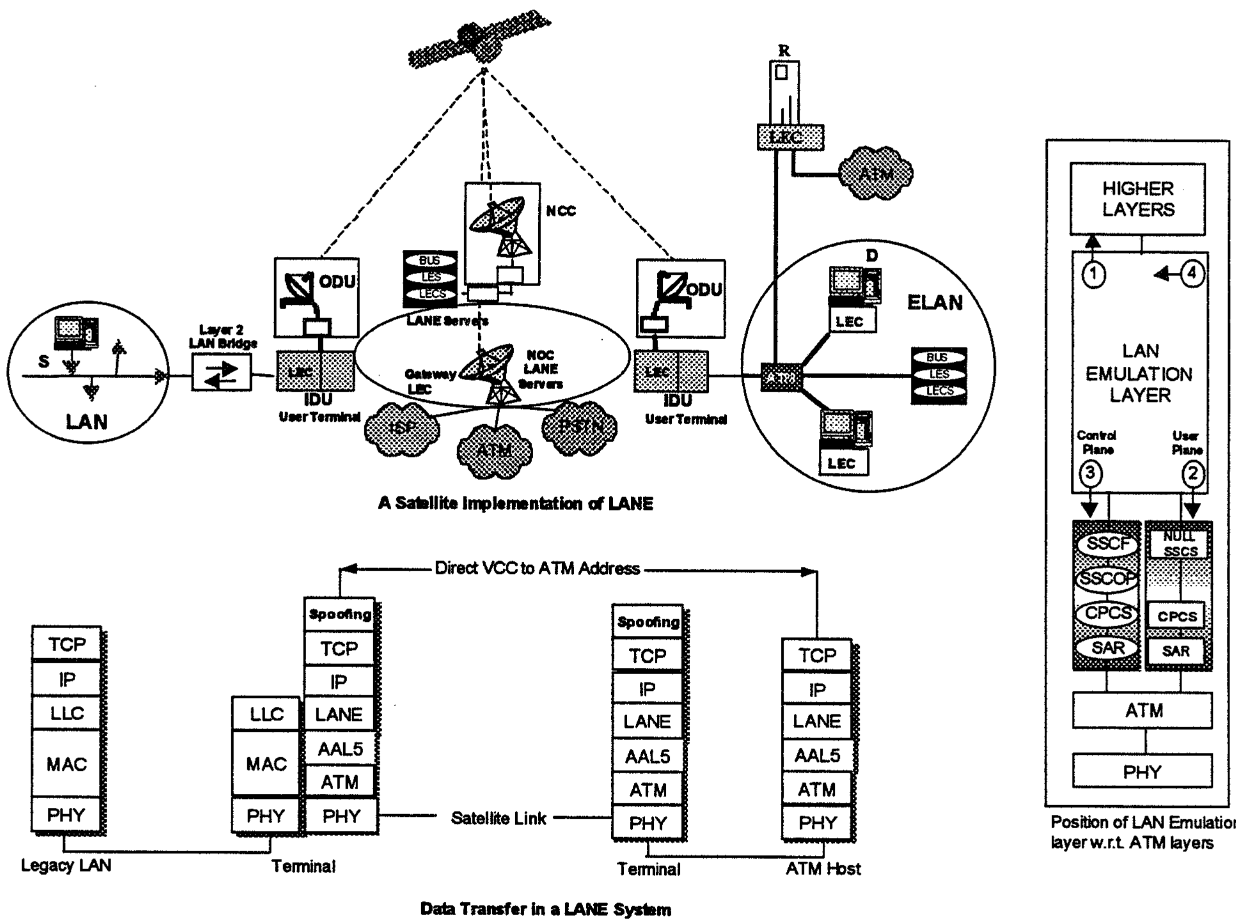


Figure 7: A Satellite Implementaiton of LANE

With respect to address resolution, MAC and ATM address resolutions are separate processes as shown in Figure 8. The LEC transmits MAC broadcast frames to the BUS (Broadcast Unknown Server) which in turn transmits IP_ARP to all its multicast nodes. The destination MAC address responding to the BUS enquiry is sent to the source S'LEC which now sends an LE_ARP request to the LES (LAN emulation sever) for MAC to ATM mapping. The LES responds with an LE_ARP response with the destination's ATM address leading to the establishment of an ATM VCC to the target. It is evident that the LANE address resolution process needs to be modified to fit into a satellite IP network, particularly with respect to the broadcast mechanism used for the IP to MAC address resolution.

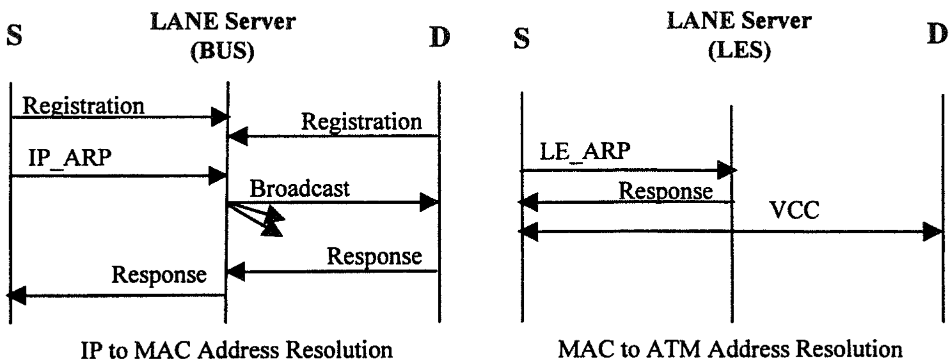


Figure 8: LANE Address Resolution Within a Subnet

3.4.2 MPOA

MPOA in effect integrates LANE, NHRP, and MARS to preserve the benefits of LAN emulation while overcoming the shortcomings of LANE (i.e. router hops are required for inter-subnet, and inter-network layer protocol communication over ATM VCCs). In other words, it provides end-to-end layer 3 connectivity between the hosts attached to the ATM fabric. An MPOA solution in the terrestrial ATM environment, facilitated by NHRP, would lead to lower latency compared with LANE and CLIP, by allowing direct cut-through across subnet boundaries.

Switching functionality is distributed in edge devices in so far as they query the route server for layer 3 information and the routing function is more centralized. MPOA lends itself to QoS guarantees as it allows mapping of specific traffic flows (i.e. layer 3 packet headers in RSVP) to ATM connections with the appropriate QoS. It supports multiple clients and protocols such as a legacy Ethernet host running IP and an ATM attached host running IPX or SNA.

In addition, MPOA supports an efficient forwarding function where it overcomes the connection set-up latency. It consists of flow detection, temporary (virtual) circuit use, and cut-through connection. For data transfers of short-duration, a cut-through connection is not efficient because of the increased inter-nodal effort involved in the address resolution process. Instead, MPOA offers what is referred to as the Default Forwarding function that provides layer 3 forwarding through a MARS-based multicast server. In MPOA, a cut-through connection is established only when a certain flow exceeds a pre-defined threshold, such as the number of packet counts. MPOA is a very promising technology providing a universal approach to layer 3 protocol over ATM including multicast and broadcast and has many advanced features.

A satellite implementation of MPOA is possible, as shown in Figure 9. The terminal connected to a LAN will have an MPOA client that includes the edge device capable of forwarding packets between LAN and ATM interfaces. The terminal connected to ATM workstations will only need an MPOA host without the edge device. The NCC and NOC will have MPOA servers and the gateway will have an MPOA client.

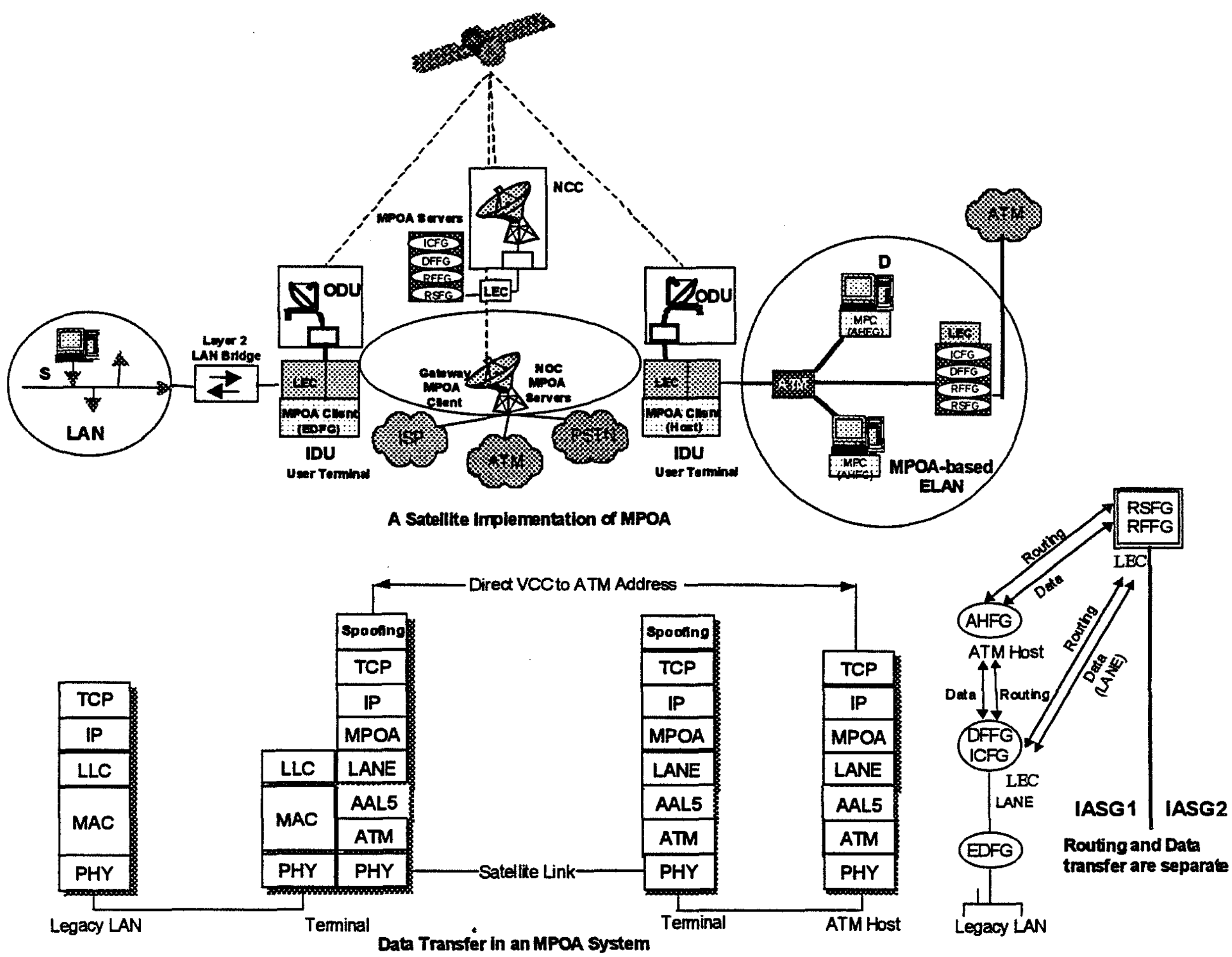


Figure 9: A Satellite Implementation of MPOA

With respect to applicability to a satellite network, an examination of control and data flows in MPOA would show that there are some functions that are not needed or would have to be modified for a better fit into the satellite network. In a wireless satellite network, the path to the destination is identified as part of layer 1 and 2 resource allocation and its appropriate utilization by the MAC layer. For example, MAC layer solutions for satellite networks include secondary access schemes that provide for virtual circuits for short duration data traffic, a feature that is also provided in MPOA. In MPOA, traffic between an edge device and an ATM host uses LANE as the mode of transmission to the default forwarder (DFFG) and from there uses an ATM connection. The DFFG is responsible for forwarding traffic within a subnet if no client to client connection exists and performs the multicast server function within the subnet. The edge device, after detecting that the flow qualifies to have a short cut support can initiate an NHRP request to the ICFG. The ICFG is the IASG coordination functional group, which is responsible for coordination of layer 3 addresses within the subnet. IASG itself refers to an internetwork address sub-group.

Whether these functions would lead to significant increase in over-the-air traffic is an area that needs to be further explored. The MPOA address resolution process is shown in Figure 10 where NHRP is used as a cut-through technique even within a subnet. Similar to the case of LANE, the address resolution process would have to be modified to fit into a satellite IP network.

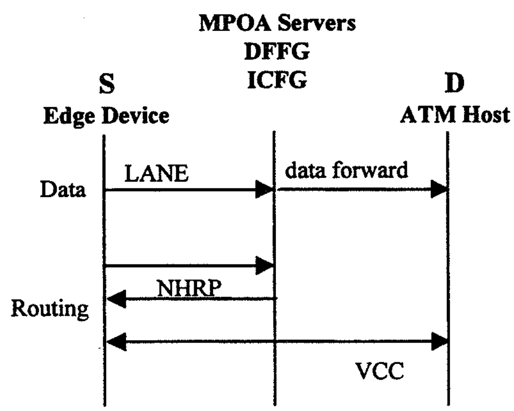


Figure 10: MPOA Address Resolution Within a Subnet

3.4.3 CLIP

CLIP's original definition is limited to only IP and does not intrinsically offer multicast and inter-subnet communications support without MARS and NHRP. Its address resolution mechanism may require minor modification of the IP protocol stack, which is not an issue if implemented within the satellite terminal. QoS guarantees can be supported within the satellite network because the satellite network is in reality a large single network that can utilize the functionality of the NCCs and NOC for address resolution.

In one of the CLIP options we can avoid the unnecessary Ethernet encapsulation by simply specifying the IP protocol layer as the VCs endpoint and place IP packets into AAL-SDUs for transmission. This method is referred to as "VC Multiplexing" because it involves terminating a VC on a layer 3 endpoint. In this case, of course, the traffic is limited to a single protocol per VC. From a technical standpoint, LANE and CLIP are very close, with both being overlay models that use ATM as a fast packet transmission system. In fact CLIP can, through LLC/SNAP encapsulation allow any set of protocols that may be uniquely identified by the LLC/SNAP header to be multiplexed into a single VC. In this sense, CLIP can be extended to carry non-IP traffic as well. A satellite implementation of CLIP is shown in Figure 11. In addition, Figure 12 shows the address resolution process for CLIP within a subnet. CLIP lends itself well to modification for a satellite IP network because it is a simpler concept and does not carry the sophistication of other protocols such as the MPOA that is designed to meet all the internetworking requirements in a terrestrial environment. The question, that needs more research, is whether we take a simple standard and build on that to develop a version for satellite IP networks, or a take a more sophisticated model such as the MPOA and modify it to fit in for satellite applications.

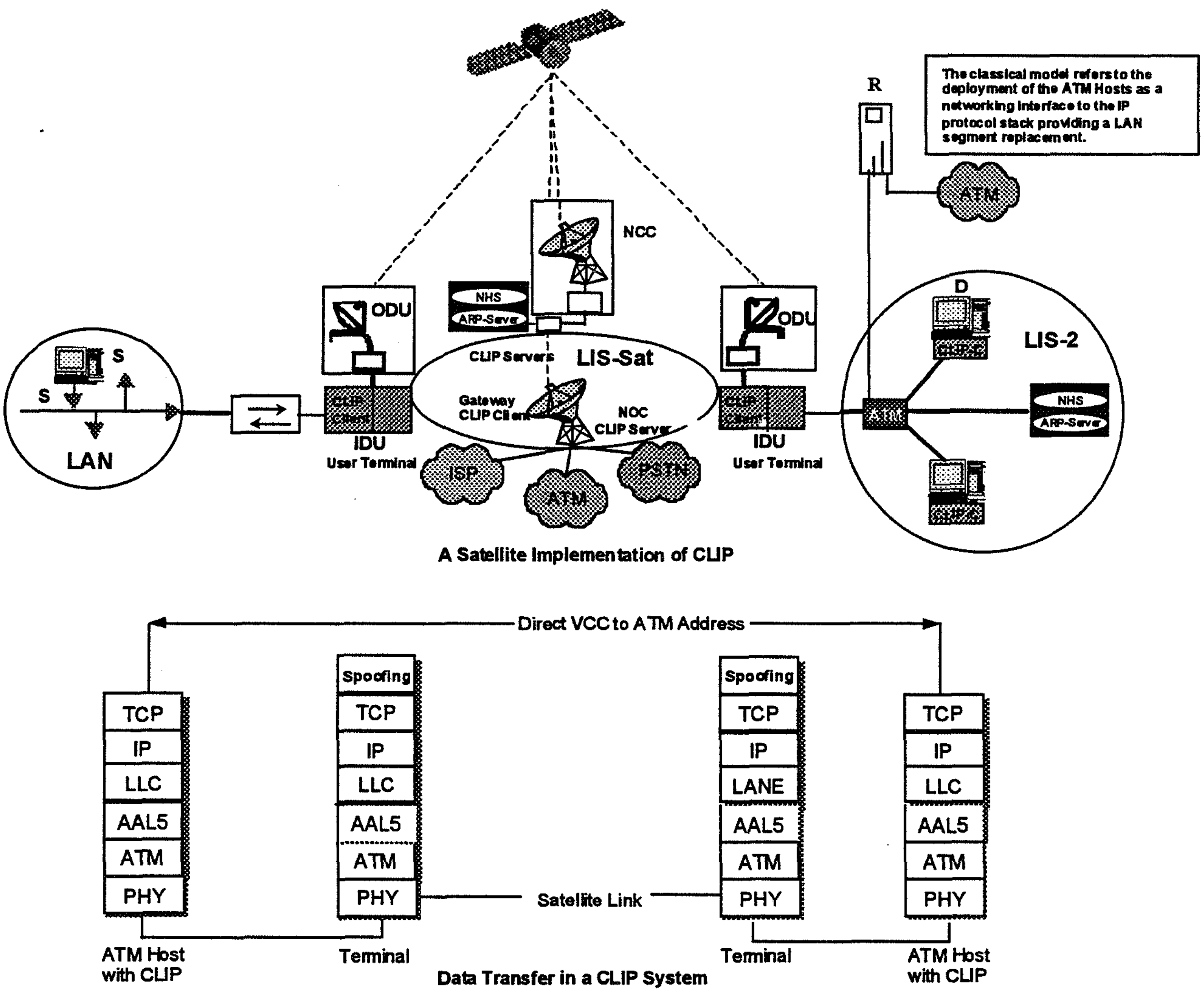


Figure 11: A Satellite Implementation of CLIP

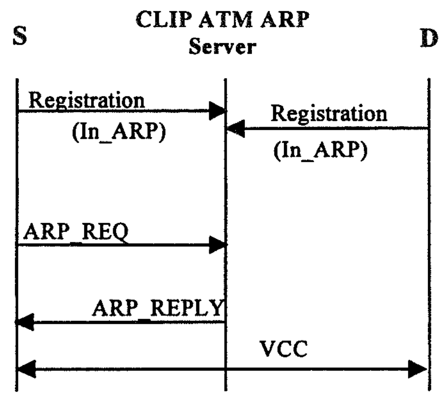


Figure 12: CLIP Address Resolution Within a Subnet

4.0 Applying Carrier Scale Inter-networking (CSI) Concepts to Satellite Systems

CSI is an integrated system solution, leveraged for satellite applications by SpaceBridge, which meets all the internetworking requirements in the terrestrial environment. It is a next generation, high performance, managed IP services infrastructure that can be used by service providers to differentiate their service portfolio with options such as QoS, managed virtual private network services, and other new value-added services. The CSI architecture consolidates service, accounting, and performance management for IP-based services by accomplishing the addition of IP services over an ATM multi-services core. It interworks with the existing router based IP networks using standard routing protocols. In addition, its architecture is very scalable because the data transfer, routing, and management functions are separated. It also uses open standards that allow for value-added applications.

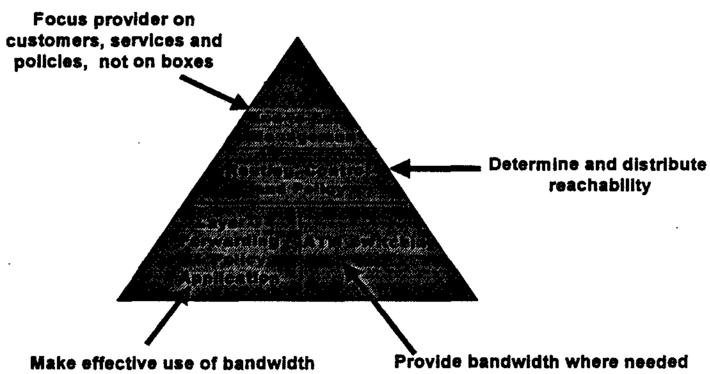
CSI is of significant interest when it comes to internetworking over ATM satellite systems because it is, at a functional level, a terrestrial version of internetworking over ATM satellite systems. Consolidation of service, accounting, and performance management for IP-based services, scalability in terms of separation of data transfer, routing, and management are features that are also required for satellite systems. Whether certain services and design aspects within the CSI architecture are used directly or somehow modified for implementation over the satellite, the overall heritage experience and the know-how associated with CSI is of significant advantage in shaping optimized end-to-end solutions involving satellite networks. The CSI network consists of four entities as shown in Figure 13:

- ATM network: corresponds to the ATM satellite system.
- Service points (SPs): access terminations with separate or integrated edge forwarding. This is analogous to some of the satellite terminal functionality.

- Routing services control points (RSCPs): forward policy information and support routing protocols. This is analogous to some of the NCC's level 2 jurisdictional functions.
- NMS: element, network, and service management, similar to some of the NOC's level 1 jurisdictional functions.

CSI user interfaces and related functions which include standards for carrying IP over ATM can be leveraged for satellite applications. Of course, proprietary adaptation and air interface functions including provision of layer 1 synchronous access as well as MAC layer satellite related functionality has to be added to replace the terrestrial network interface portion of the CSI products.

The services provided by CSI include both virtual private networks (VPN) and public Internet. There are multiple instances of these services over a variety of interfaces. Frame Relay, ATM, PPP links, Ethernet, and FDDI LANs are examples of service interfaces that are supported by CSI, most of which are also candidates for satellite terminals. For the VPN traffic, the service point (SP) will forward traffic using short-cut



CSI Framework Solution

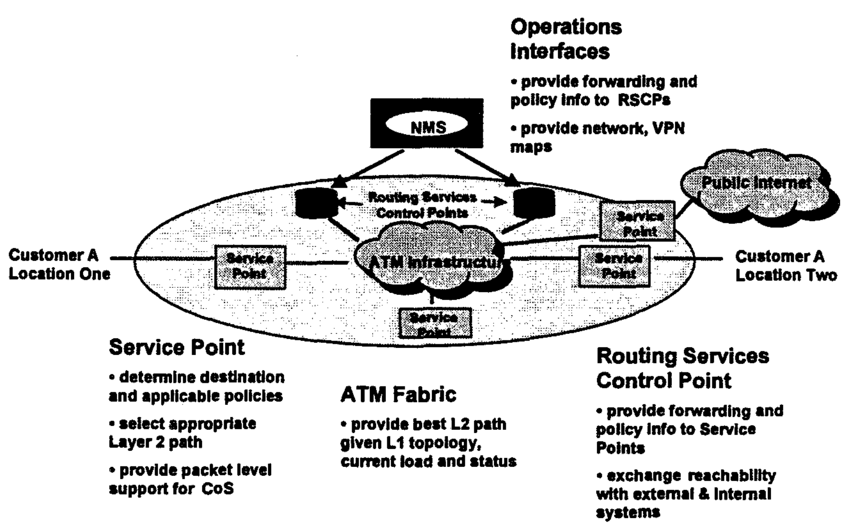


Figure 13: CSI System Architecture

SVCs between the source and destination SPs. The ATM fabric provides data path interconnection of the CSI components. The connection-oriented nature of ATM allows for cut-through connections to be established on demand by the internetworking layer and the QoS features of ATM. An MPOA client is run in the SPs to perform address resolution for shortcuts via RSCPs. RSCPs run NHRP to support SP-to-SP short cuts. SPs maintain a cache of most frequent connections to minimize SP-to-RSCP activity. For public Internet traffic, the SPs will use pre-provisioned virtual connections to forward traffic.

5.0 Conclusions

In this paper we discussed the inter-networking of IP over ATM satellite systems addressing issues such as QoS, address resolution and routing, and standards for carrying IP over ATM. It was highlighted that an end-to-end perspective is required to arrive at optimum partitioning of functionality. The satellite broadcast nature lends itself to optimized solutions and therefore those inherent features must be fully utilized in order to maintain the satellite competitive advantage in the market place. When applied to satellite networks, terrestrial standards for carrying IP over ATM would need to be modified/optimized in their server functionality and address resolution mechanism. More research is required to identify other areas for modifications. CSI is a related heritage of significant advantage for internetworking over ATM satellites, whether certain design aspects within its architecture are used directly or somehow modified for implementation over the satellite.

6.0 Acknowledgement

The author would like to thank SpaceBridge management for their input and support. Special thanks to my colleagues Dr. Robert Craig, Mr. Neil Graham, and Mr. Radu Iorgulescu for their diligent review of the paper, comments, and encouragement.

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ATM Over Satellite For The Warfighter

Lieutenant Tom Stephenson
4th Space Operations Squadron
Air Force Space Command

Overview

- The Need For ATM Over Satellite
- SHF and EHF
- Crosslinking
- Military/Government Initiatives
- Proposed Solution
- Further Research Required

The Need For ATM Over Satellite

- Mixed Traffic Types
- Heterogeneous Platforms
- Global Connectivity
  - DISN Mandate
  - DOD Space Architect "Objective Architecture"
- Joint Vision 2010

SHF and EHF

- Low Probability of Intercept/Detect (LPI/D)
- Smaller Antenna Size
- Less Contention for Spectrum
  - Though greater commercial interest in Ka-Band
- Atmospheric Attenuation

Crosslinks

- Avoids Ground/Sea Entry Points in Hostile Territory
- Provides Worldwide Connectivity
- Proven Success on Milstar

Military/Government Initiatives

- JWID Demonstrations
  - ATM Over DSCS (JWID 95)
  - Airborne Phased Array Antennas (JWID 95, 96, 97)
- UAV EHF Uplinks and Crosslinks

Military/Government Initiatives

- US Army Mobile Subscriber Equipment
- NASA ACTS
- DISA CSCI
  - COMSAT's ATM Link Accelerator

Proposed Solution

- 4-6 Geosynchronous Satellites
- EHF/SHF Uplink/Downlink
- EHF Crosslink
- On-Board Switching Matrix
  - Dynamic Bandwidth Allocation
  - Large Buffer Space

Proposed Solution

- Command and Control by Air Force Space Command
- Experience in EHF/SHF Crosslinked Satellites

Further Research Required

- Crosslink Latency
- Encryption Over ATM (FASTLANE)
- ATM and EHF
- ATM and Low-Data-Rate Ground Mobile Radios
- Laser Crosslinks

Conclusion

- The Need For ATM Over Satellite
- SHF and EHF
- Crosslinking
- Military / Government Initiatives
- Proposed Solution
- Further Research Required

Bellcore

ATM Traffic Measurements
over the ACTS OC-12c HDR Channel with a Distributed Test System

Daniel F. Daly, Shikhar Bajaj,
Thomas J. Robe, Faramak Vakil

Bellcore Contact: D. F. Daly
(973) 829-4339
daly@bellcore.com

June 3, 1998
NASA Workshop
Satellite Networks

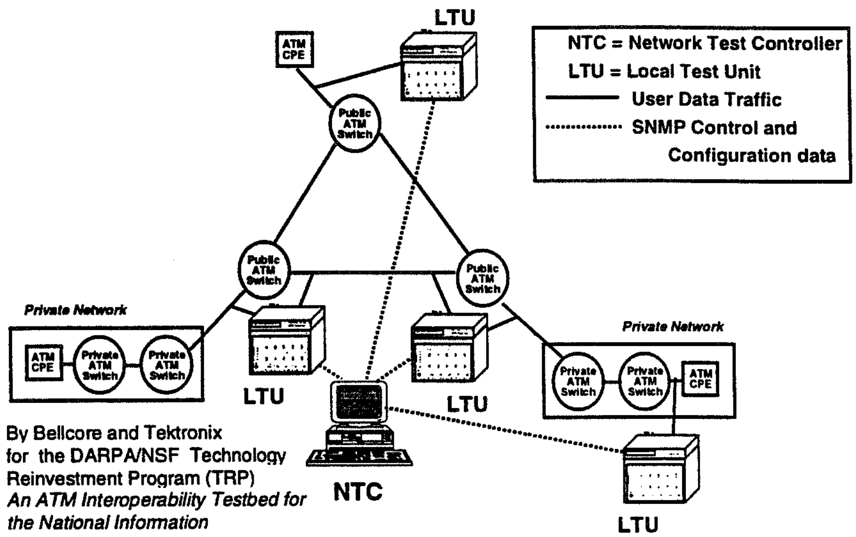
ATM Traffic Measurements
Interoperability and Impact on Satellite Network Performance

- Network traffic management must be interoperable between terrestrial and satellite legs of the network.
- Unique satellite delay characteristics impact terminal equipment requirements
- Cell Delay, Cell Loss and Cell Error impact QoS
- Statistical distribution of cell stream affects terminal multiplexing
- Detailed traffic data with absolute time stamps can help to identify the cause of performance problems
- Combined traffic measurements and signaling message data enable analyst to correlate network performance with demands placed by the signaling system

  Bellcore

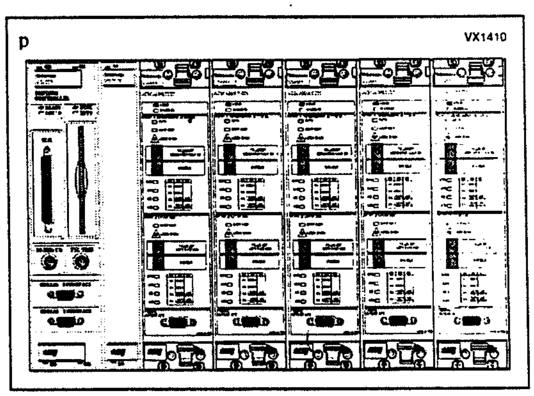
ATM Interoperability Test System

Distributed Architecture



By Bellcore and Tektronix
for the DARPA/NSF Technology
Reinvestment Program (TRP)
An ATM Interoperability Testbed for the National Information Infrastructure

ATM Interoperability Test System
Local Test Unit

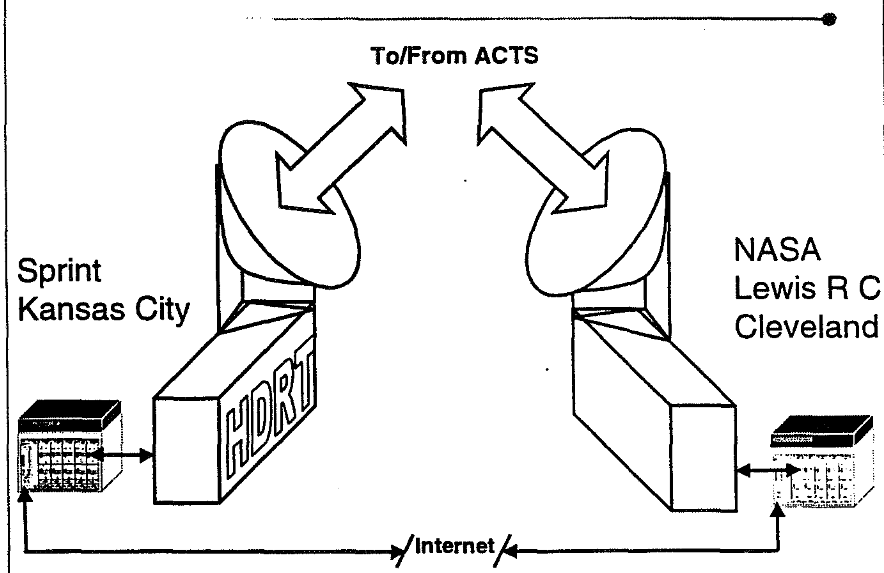


VXI ATM Modules
- VXI Two-Wide "C" Size Module
- VXI Command Message/Data Interface
- Local Test Script Execution
- "C" Scripting SW Library
- VPI/VCI Filtering, Cell/PDU Capture
- GPS Time Stamping
- Signaling and Traffic Analysis
- 2 - OC-3c/OC-12c Receive Ports
- 2 - OC-3c/OC-12c Transmit Ports
  - 1 - CBR/VBR Traffic Generator
  - 1 - Loop Thru Port
- 1 - 68330 µP - VXI Interface/Control
- 2 - PowerPC 603e RISC µP - Analysis
- RS232 Script Debugging Port

VXI Embedded Controller
- 2 Slot Wide "C" Size
- Pentium µP
- Test Script/Data Storage
  - Hard Disk
- Ethernet/RS-232

By Bellcore and Tektronix
for the DARPA/NSF Technology Reinvestment Program (TRP)
An ATM Interoperability Testbed for the National Information Infrastructure

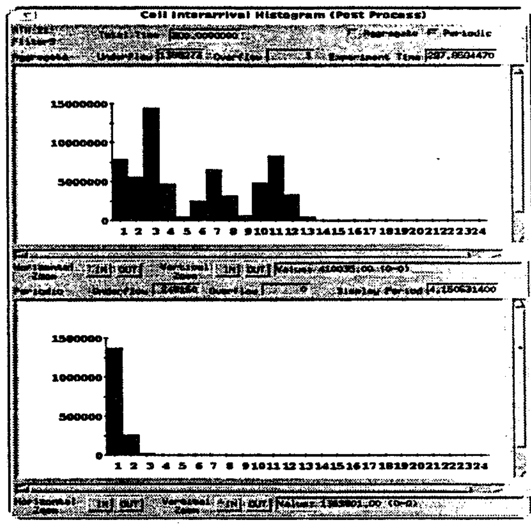
Experimental Configuration



Traffic Measurements

- ATM Cell Statistics
  - interarrival time
  - transport delay
  - burst length
  - silence length
- AAL5 Protocol Data Unit Statistics
  - PDU length
  - PDU interarrival time
  - cell dispersion

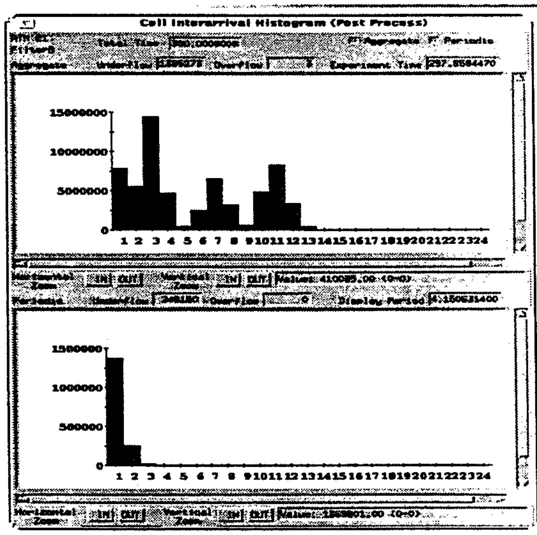
Cell Interarrival Histogram



Aggregate
(from beginning of test)

Periodic
(last period)

Cell Interarrival Time Histogram



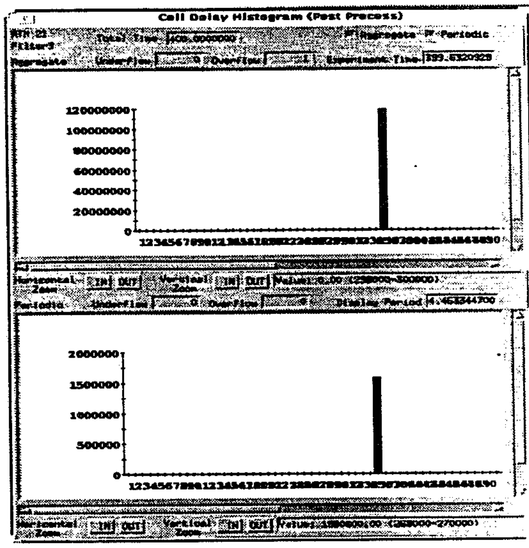
Range: 0 - 24 cell slots

Bin Size: 1 cell slot

Source: Sequence of CBR traffic at:
50.24 Mb/s, 75.05Mb/s, 154.97 Mb/s, 310.79 Mb/s

Source IAT only in bins 2, 4, 8, 12

Cell Transfer Delay Histogram



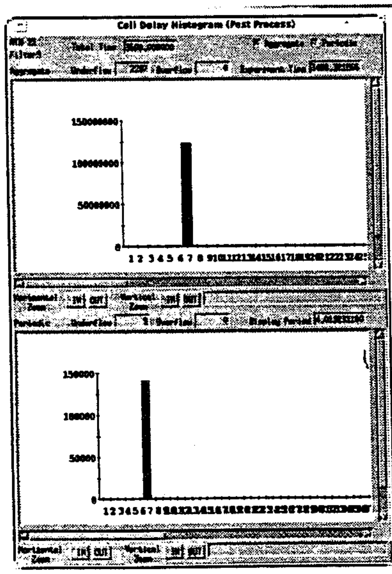
Range: 0.2 - 0.4 sec.

Bin Size: 20 msec.

Mean CTD: 0.267 sec

Source: Sequence of
- VBR traffic w. PCR 150 Mb/s
- CBR traffic at: 150 Mb/s

Cell Transfer Delay Histogram



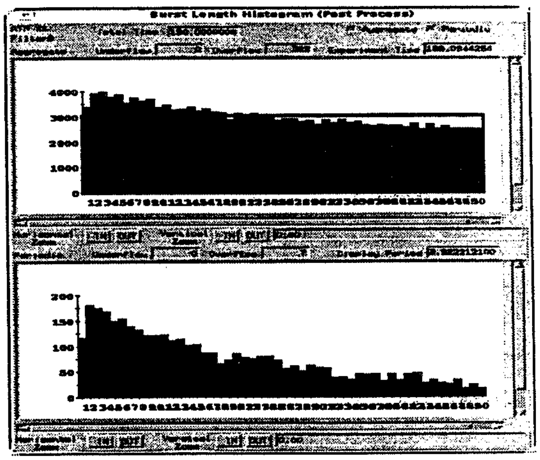
Range: 266,930 - 267,180 μsec.

Bin Size: 10 μsec.

Mean CTD = 267,063 μsec.

Source: 15 Mb/s CBR for 35000 sec.

Cell Burst Length

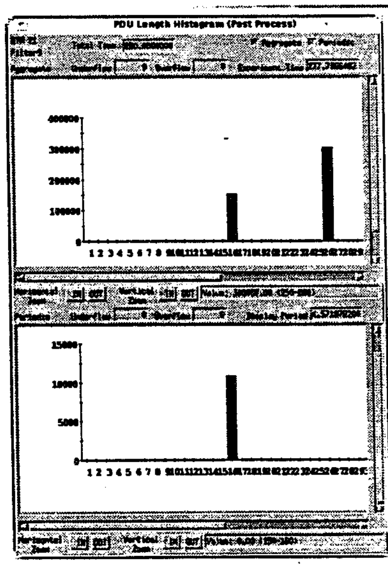


Range: 0 - 1000 cells

Bin Size: 20 cells

Source: Uniform distribution of burst lengths between 1 and 1000 cells.
PCR = 622 Mb/s

AAL5 PDU Length

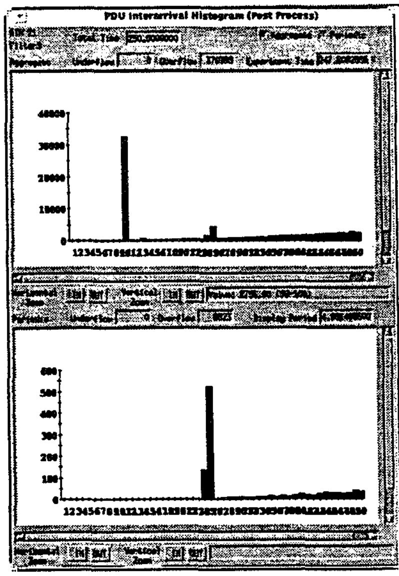


Range: 0 - 300 cells

Bin Size: 10 cells

Source: Sequence of PDUs with fixed length of 250 cells followed by PDUs with a fixed length of 150 cells

PDU Interarrival Histogram - VBR

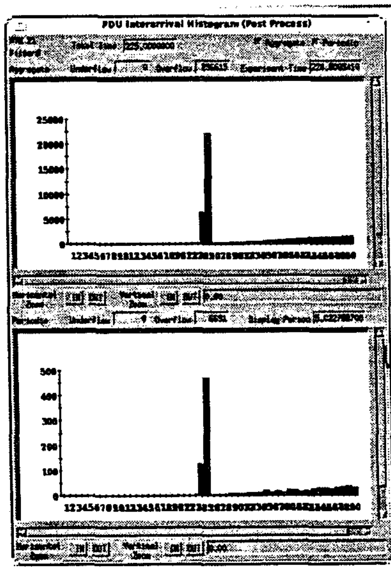


Range: 0 - 500 cell slots

Bin Size: 5 cell slots

Source: VBR
with mean PDU length of 50 cells
PCR = 622 Mb/s
Average = 70 Mb/s

PDU Interarrival Time - VBR

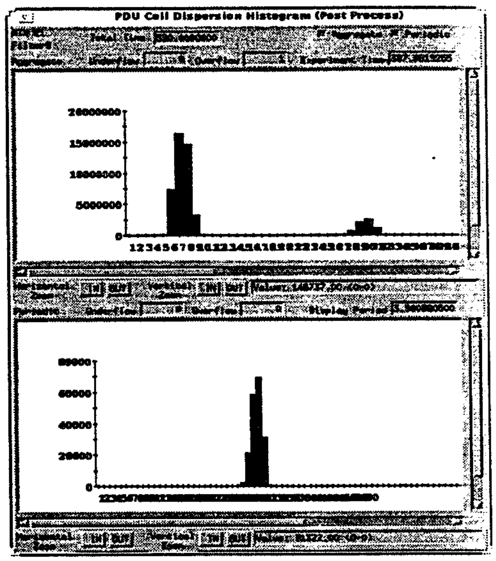


Range: 0 - 500 cell slots.

Bin Size: 5 cell slots

Source: VBR
with fixed PDU length of 125 cells
PCR = 310 Mb/s
Average = 103 Mb/s

PDU Cell Dispersion - CBR



Range: 0 - 100 cells

Bin Size: 1 cell

Source: sequence of
- 75 Mb/s CBR stream
- 20 Mb/s CBR stream

both transmitted via fixed size 50 cell long PDUs

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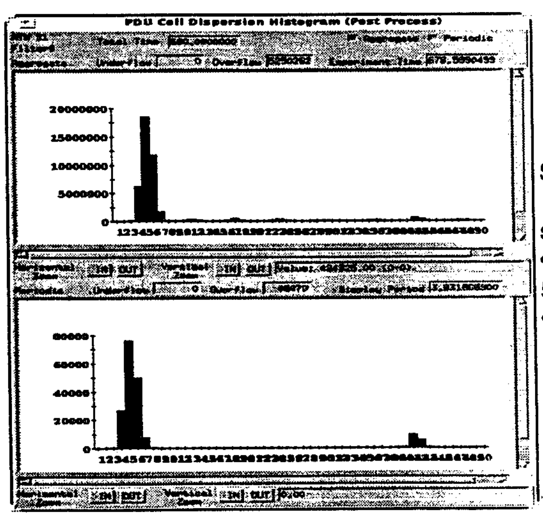
PDU Cell Dispersion - VBR



Range: 0 - 50 cells

Bin Size: 1 cell

Source: VBR stream with PCR = 100 Mb/s sequence of
- ON/OFF with a mean of 5 slots on and 10 slots off
- GCRA with SCR = 25 Mb/s
  - MBS = 20 cells
  - MBS = 5 cells

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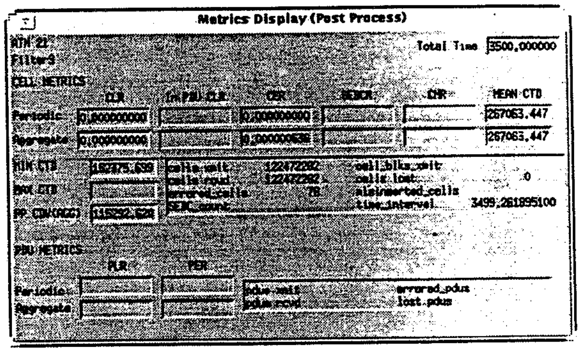
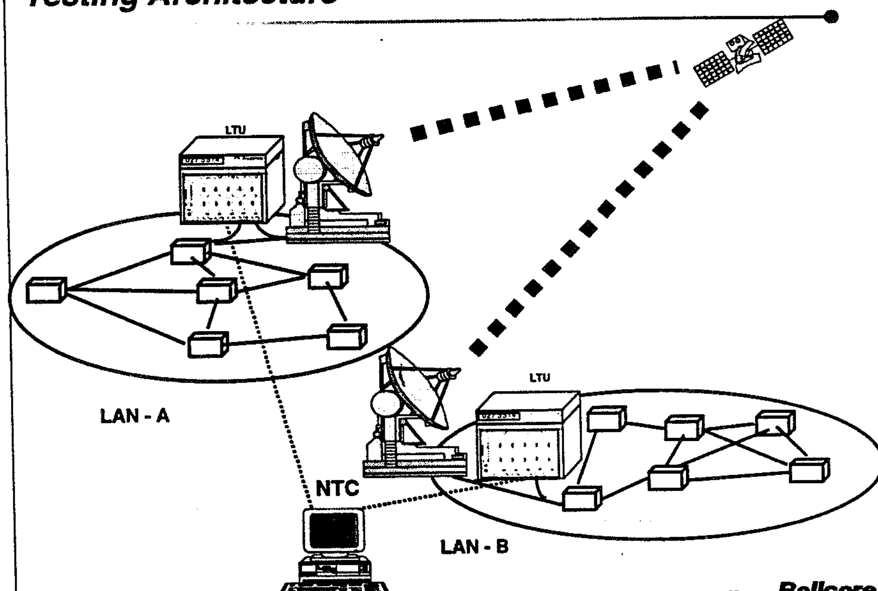
Cell Transfer Delay - Metrics



Terrestrial-Satellite Network Interoperability

Testing Architecture



Conclusions

In these experiments (which only had one session on the link):

- ACTS satellite link introduces less than 3 cell slot jitter in transmitted traffic
- cell traffic tends to clump during transit through the satellite terminals and on-board processor
- cell transport delay dominated by path length

Testbed for Satellite and Terrestrial Interoperability (TSTI)
A FY98 Program Product of 632-50-50 Communications - Terrestrial

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301-286-9539

June 5, 1998

Presentation at
Satellite Networks: Archectitures, Applications, and Technologies
Workshop

Testbed for Satellite and Terrestrial Interoperability (TSTI)

Objective

Develop and demonstrate high degree of interoperability between satellite- and terrestrial-based networks

- Develop and evaluate enhancements to protocols such as ATM and TCP/IP
- Test and demonstrate new interface equipment hardware and software
- Utilize and showcase ACTS performance, especially its high data rate capabilities
- Extend HPCC network research program in Large Scale Networks
- Open to U.S. satellite and terrestrial communications carriers, equipment suppliers, and network providers

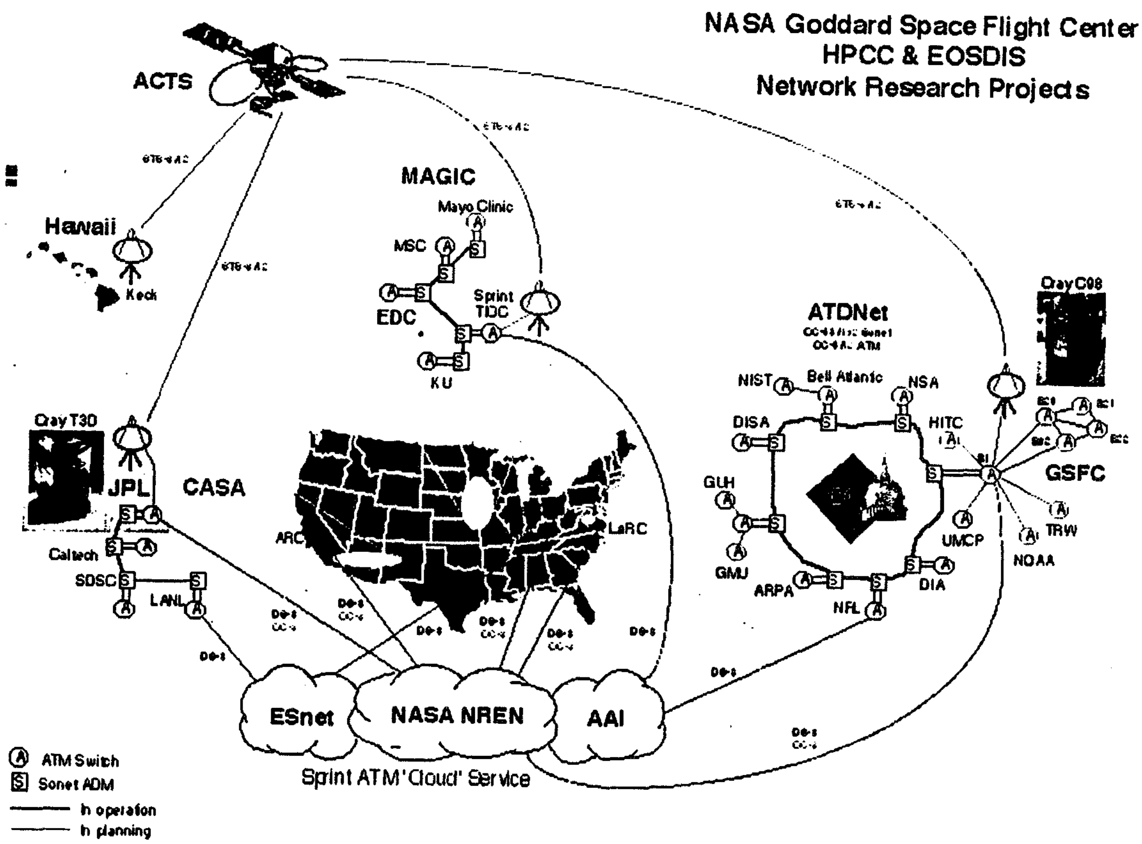
JPG 12/10/96

Testbed for Satellite and Terrestrial Interoperability (TSTI)

Specific Technical Objectives

Facilitate and conduct research and evaluations of new computer networking protocols and related technologies which improve the interoperability of satellite and terrestrial networks, e.g.,

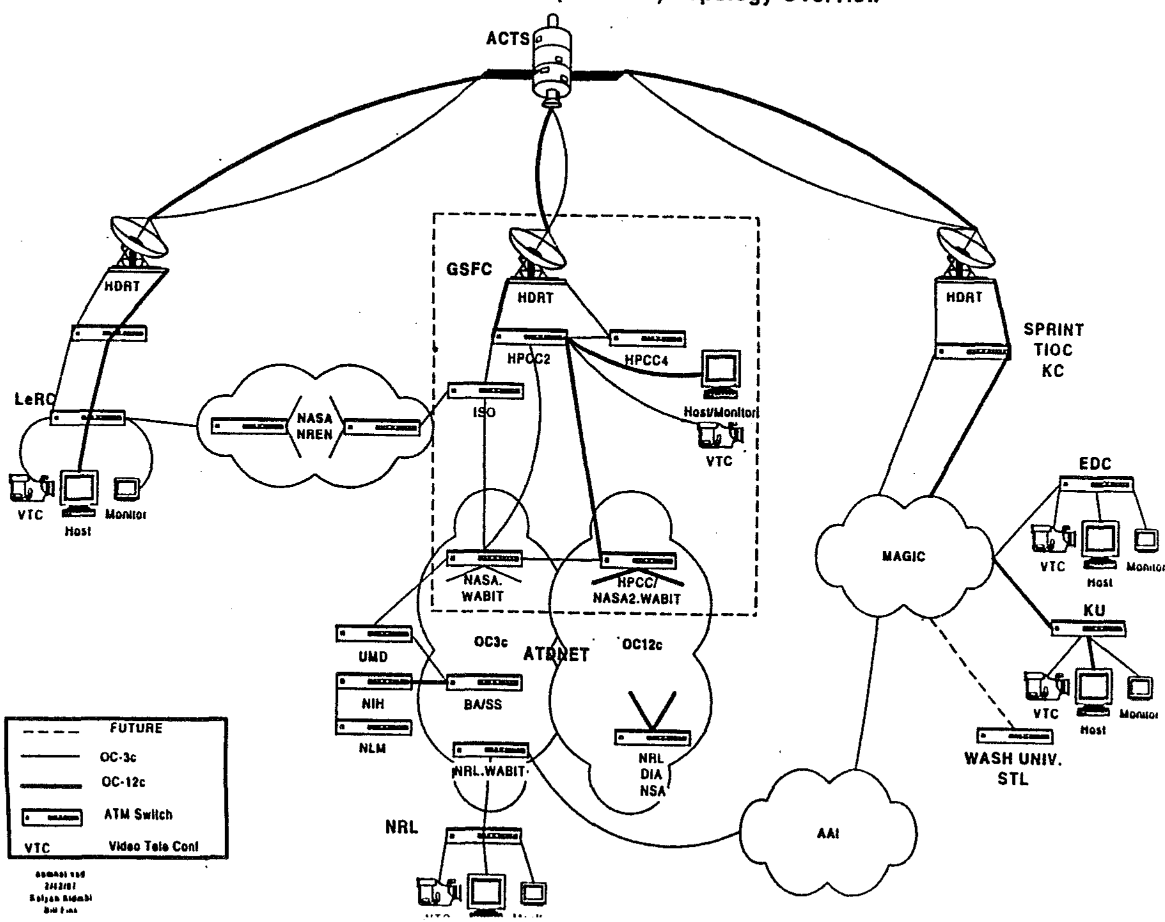
- » TCP: large windows (RFC 1323), SACK (RFC 2018), XTP (RFC 1453)
- » IP: TAG (cisco), flow (Ipsilon), multi-protocol label switch (IETF), RSVP, multicasting, IPv6
- » ATM: MPOA, PNNI, available bit rate traffic management



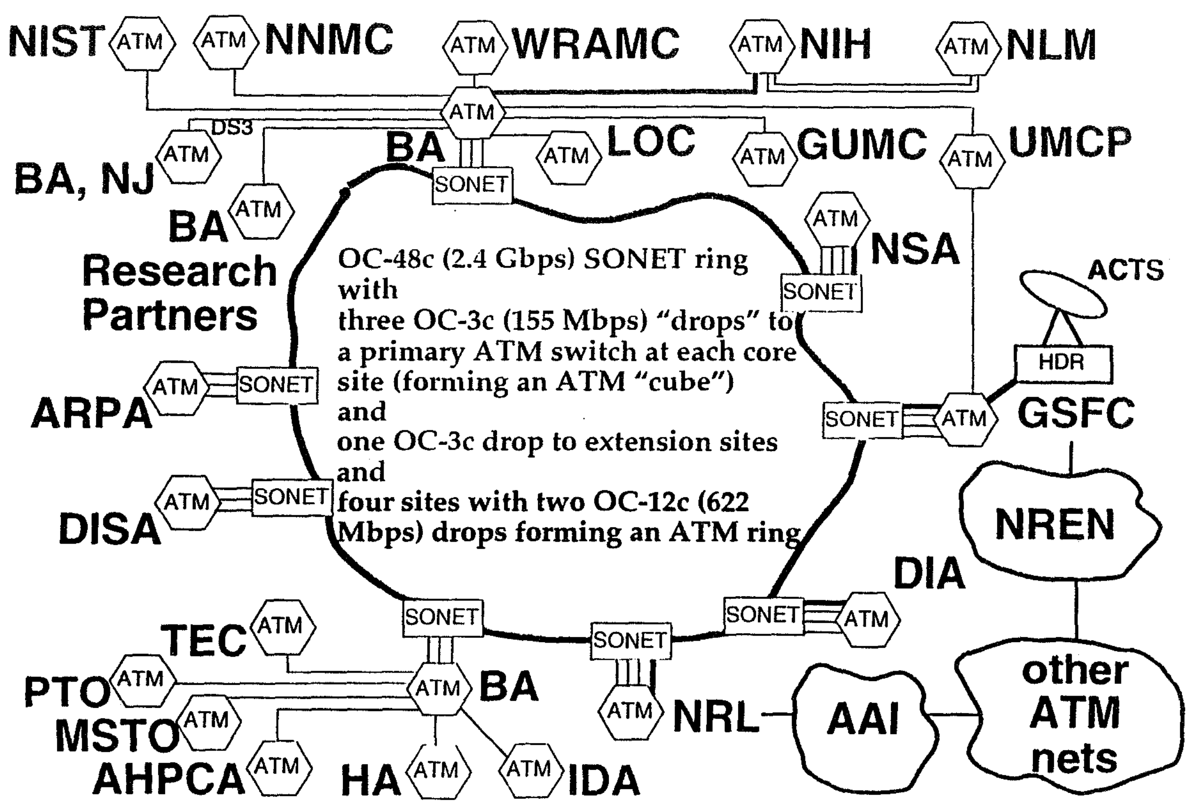
2.0 Network Test Suites for the ATDNet-ACTS-MAGIC Network (AAMnet)

- 2.1 Assessment of Satellite Links on ATM Signaling (Co-I: Rich Verjinski/Fore @ NRL)
- 2.2 Tuning TCP over High Speed Satellite Links (Co-I: Pat Gary/GSFC)
- 2.3 Evaluation of ATM Flow Control and Traffic Monitoring Techniques in a 622 Mbps Hybrid Satellite/Terrestrial Network (Co-I: Victor Frost/KU)
- 2.4 Demonstration and Evaluation of Everyday Internet Applications across the AAMnet at 622 Mbps (Co-I: Pat Gary/GSFC)
- 2.5 Demonstration and Evaluation of TerraVision/ISS Operating over the AAMnet (Co-I: Jay Feuquay/HSTX @ EDC)
- 2.6 Multimedia Telemedicine Applications Operating over the AAMnet (Co-I: Kenneth Kempner/NIH)
- 2.7 Telemedicine-enabling R&D Testbed Experiments Operating over the AAMnet (Co-I: Mike Gill/NLM)
- 2.8 Testbedding of New Applications at 622 Mbps (Co-I: Pat Gary/GSFC)
- 2.9 Native ATM Application Programmer Interface Testbed for Cluster-based Computing (Patrick Dowd/NSA & UMD)
- 2.10 ARIES / ACTS 622 Mbps Experiment (David R. Beering/Amoco)
- 2.11 Multiplatform Evaluation of TCP/IP over ATM Interoperability Issues in a Hybrid Satellite Environment (Dave Brooks/Sterling @ LeRC)
- 2.12 Assessment of Effects of Hybrid Satellite/Terrestrial Networks on ATM Signalling (Tom von Deak/LeRC)

ACTS-ATDnet-MAGIC Network (AAMNET) Topology Overview



ATDNet SONET/ATM Gigabit Network



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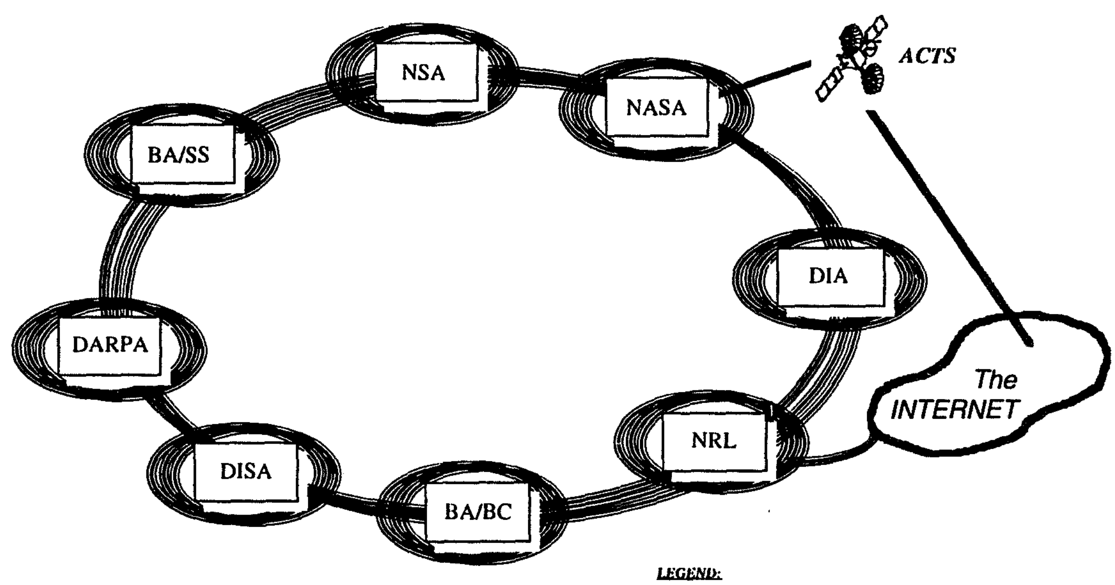
ATDNet with Multiwavelength Optical Network (MONET)- the system of the future

Department of Defense:

***ATDnet++** . . . A fully switched Wavelength Division Networking Testbed*



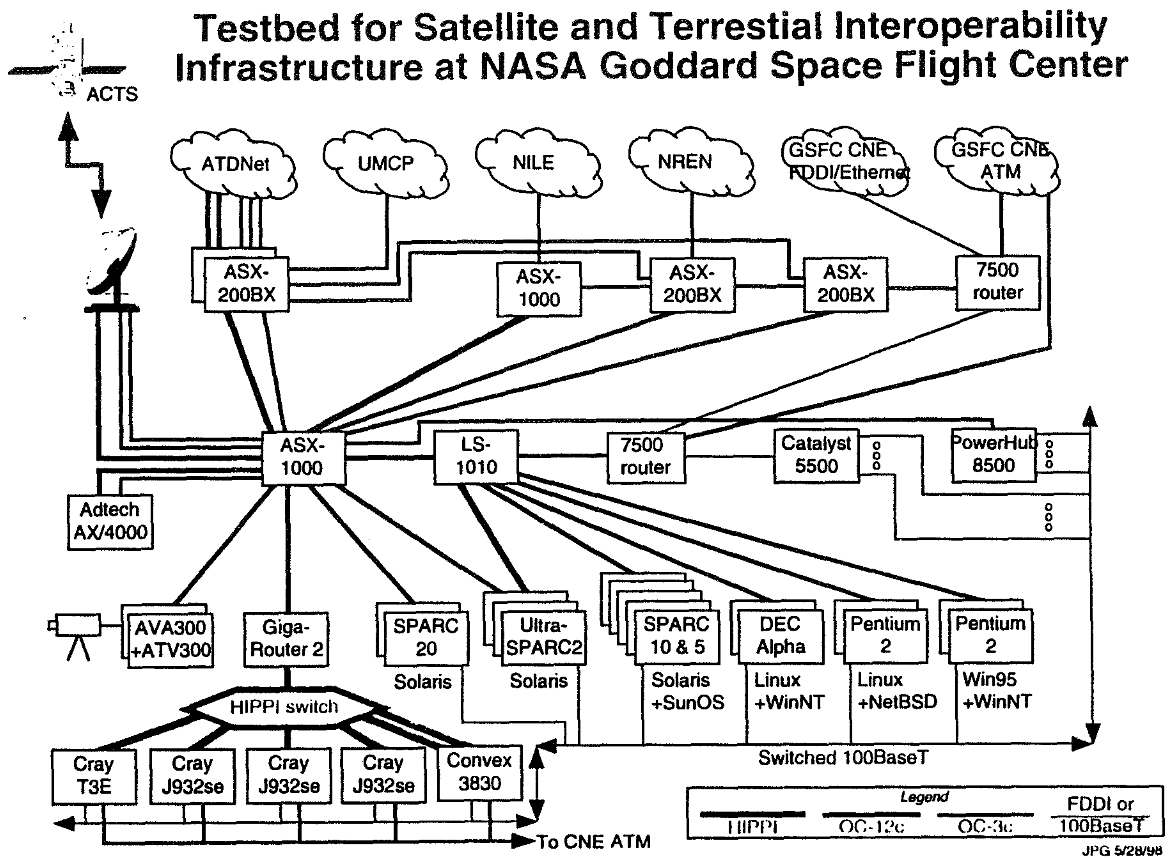
Proposed late 1999-2000 : Mixture of wavelength interchange & wavelength select devices

LEGEND:

WDN (n x 10.0 Gbps)

Autonomous Networks

BA- Bell Atlantic
SS - Silver Spring
BC - Barcroft



Collaborations/End Sites with GSFC/930 In TSTI-based Evaluations - Present

Applications	Sat./Terr. Carriers	Academia	Federal
DGCM	ACTS Exp. #92	UCLA	GSFC/910, JPL
Telemedicine Teleradiology TerraVision	AAMnet/#118g AAMnet/#118f AAMnet/#118e	[SFU] [WashU]	NLM NIH EDC, LeRC
Teleradiology	ATDNet-ACTS/#110	UHI, GUMC	[TAMC]
GLIN Trans-Pacific DL	ATDNet, Comsat/Intelsat ATDNet, Comsat/Intelsat, ACTS/NREN, MPT/CRL	UMD(Balti.County)	LOC LOC, NLM, [Smithsonian,] National Library of Japan

JPG 07/07/97

Collaborations/End Sites with GSFC/930 In TSTI-based Evaluations - Present

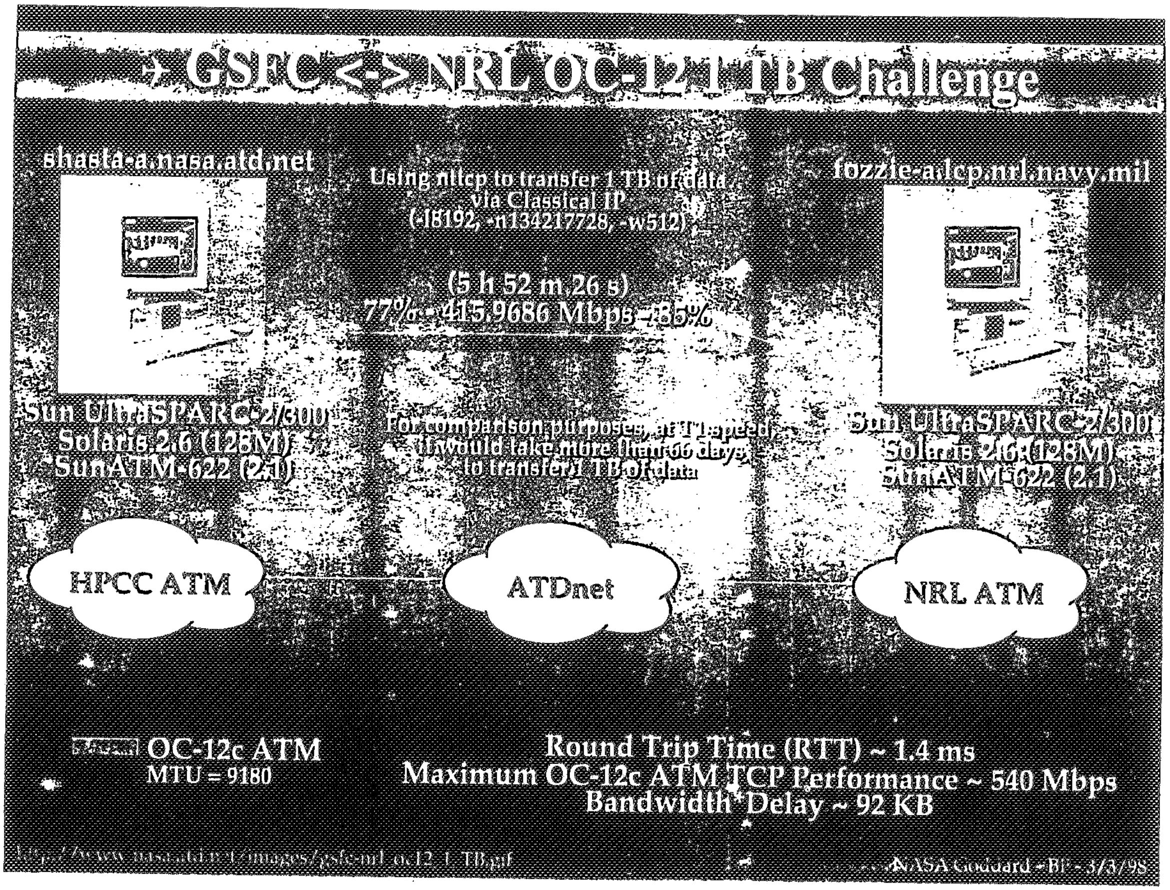
Technology	Industry	Academia	Federal
TCP LFN (RFC 1323)		KU	LeRC, JPL
TCP SACK (RFC 2018)	PSC	UCLA	GSFC/505 & 540
XTP (RFC 1453)	Mentat	Concordia U. (Quebec)	Sandia N.L.
IP/TAG Switching (IETF MPLS WG)	Ipsilon, Cisco		GSFC/505, ARC
IPv6/RSVP			GSFC/505
ATM Transport Drivers		UMD(College Park)	NSA
ATM OC-3c Firewall	STK/NSC, SPOCK		NSA
ATM OC-12c Encryption	SECANT, SPOCK		NSA

JHS 07/07/97

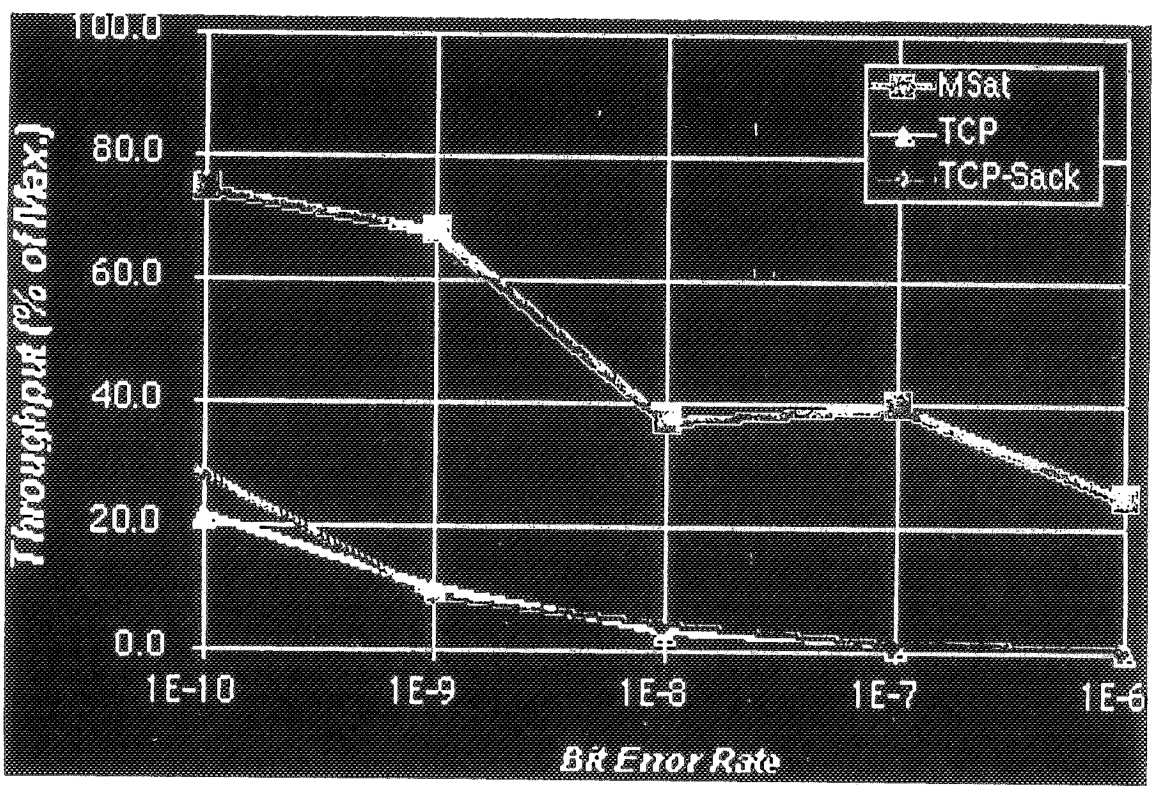
Testbed for Satellite and Terrestrial Interoperability (TSTI)

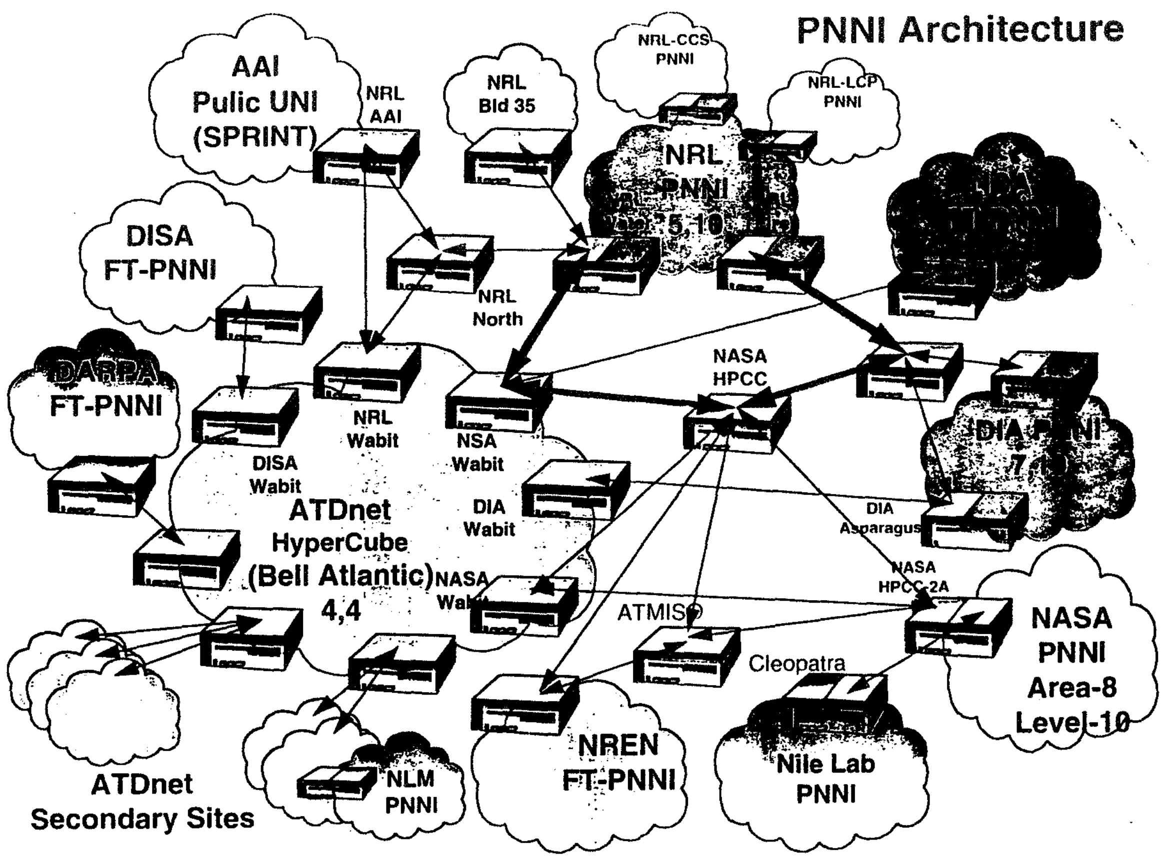
A FY98 Program Product of 632-50-50 Communications - Terrestrial

- Recent Major Accomplishments
  - » Enabled first use of ACTS high data rate capabilities by GUMC, KU, NIH, and NLM
  - » Monthly highlights online at http://everest.gsfc.nasa.gov/month.html
  - » Charalambos, C., et al., "Experimental and Simulation Performance Results of TCP/IP over High-Speed ATM over ACTS", http://www.ittc.ukans.edu/~ccharala/research.html
  - » LeRC set ACTS highwater throughput performance
    - 520 Mbps memory-to-memory
    - 320 Mbps aggregate (3 streams) tape-to-tape
  - » Protocol performance baselining by GSFC
    - TCP, TCP-SACK, XTP
    - BER: 0, 10E-11, 10E-10, 10E-9, 10E-8, 10E-7, 10E-6, 10E-5
    - Delay: 0, 5, 71, 540 ms



Satellite Conditions (RTT = 540 ms)





Trans-Pacific Digital Library Experiment

Objectives

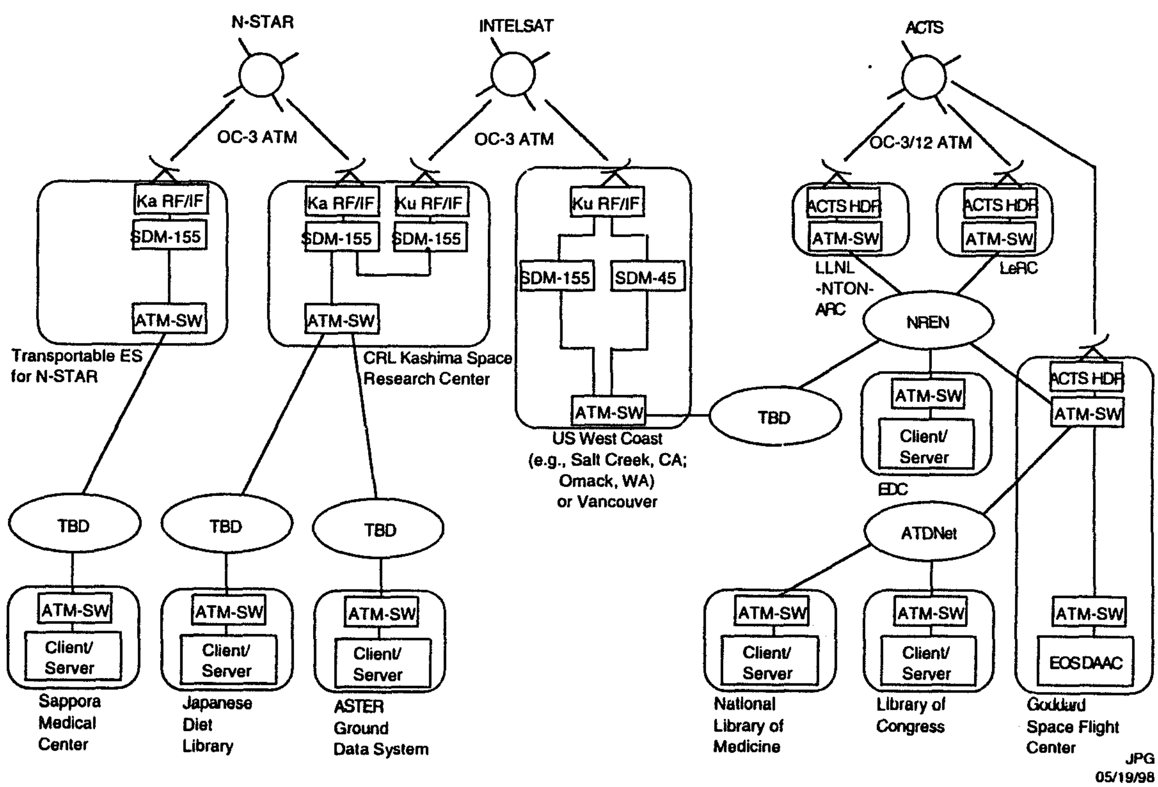
- Demonstrate and evaluate use of high performance satellite communications and advanced data communications protocols to enable interactive digital library data access between the U.S. Library of Congress, the National Library of Japan, and other digital library sites at 155 Mbps
  - » The satellite links demonstrate effective use of geostationary satellite-based communications in the Global Information Infrastructure
  - » The data communications protocols will include both standard protocols with recently specified options for performance enhancements and experimental protocols designed for improved performance
  - » Access will include interactive searches and retrievals of new on-line digital library data, and will promote an understanding of the need for ready access to these data

Trans-Pacific Digital Library Experiment

U.S.-led Applications

- Law Library of the Library of Congress
  - » Global Legal Information Network
- NASA Goddard Space Flight Center
  - » Trans-Pacific Access to GLOBE Visualizations in Real Time
- NIH National Library of Medicine
  - » Multi-Lingual Digital Anatomical Data Base
- USDA National Agricultural Laboratory
  - » Plant Genome Databases

Configuration of Networks for Trans-Pacific Digital Library Experiment



Testbed for Satellite and Terrestrial Interoperability (TSTI)

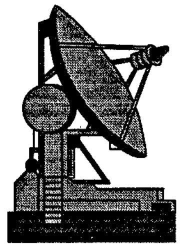
A FY98 Program Product of 632-50-50 Communications - Terrestrial

- Major Milestones
  - » FY98: TSTI development and instrumentation; Support for PI & Co-I's at GSFC, KU, LeRC, NIH, and NLM in 622 Mbps Network Tests between ATDNet and MAGIC via ACTS (Exp. #118) and for others (e.g., GUMC and GIBN Trans-Pacific Digital Library Experiment)
  - » FY99: Complete evaluations of IP switching and ATM traffic management 4.0 explicit rate control in ABR; Enable/expand testbed for use by other GIBN projects and Satellite Alliance USA
  - » FY00: Initiate evaluations of IP RSVP and ATM QoS parameters
  - » FY01: Complete evaluations of IP RSVP and ATM QoS parameters

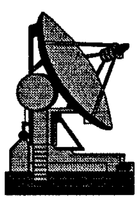
ESDCD On-Going Network Projects More Info

- AAMNet: ADTNet-ACTS-MAGIC Network (622 Mbps)
  - http://everest.gsfc.nasa.gov/SCTB/AAMNET_plan.html
- ATDNet: Advanced Technology Demonstration Network
  - http://www.atd.net/
- GIBN DLE: Global Information Broadband Network Dig. Lib. Exp.
  - http://dlt.gsfc.nasa.gov/gibn/
- GLIN: Global Legal Information System
  - http://lcweb2.loc.gov/law/GLINv1/GLIN.html
- HECN: High End Computer Networking (for HPCC/ESS)
  - http://everest.gsfc.nasa.gov/
- TSTI: Testbed for Satellite and Terrestrial Interoperability
  - http://everest.gsfc.nasa.gov/TSTI/TSTI.html

Satellite Interoperability

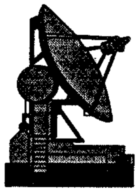


Dan Shell
CISCO Systems Federal
dshell@cisco.com



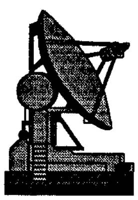
Satellite Interoperability Issues

- TCP/IP congestion controls with ATM congestion controls over high data rate/high delay links.
  - Bandwidth * Delay = Buffer
  - Random Early Detection
  - Weighted Fair Queue
  - ABR EFCI, RR
  - RSVP (Resource Reservation Protocol)
  - IP Precedence



Satellite Interoperability Issues

- PNNI using SVC links over high delay links.
  - Cell routing
  - Convergence
- Classical IP / LANE
  - Call setup
  - ARP server placement, LEC/LES/BUS
  - Congestion controls



Satellite Interoperability Issues

- DICOM 3.0 standard
  - Generates high volumes of data.
  - Uses TCP/IP as its transport.
  - High speed data links needed.
  - Standard enables communication between various medical sources and users (computer workstations, MR imagers, film digitizers, archives, etc.)

Satellite Interoperability Questions

- Does TCP/IP congestion control work effectively in a High Data Rate/ High Delay network ?
- Does ATM congestion control work effectively with TCP/IP congestion controls in a High Data Rate / High Delay Network ?

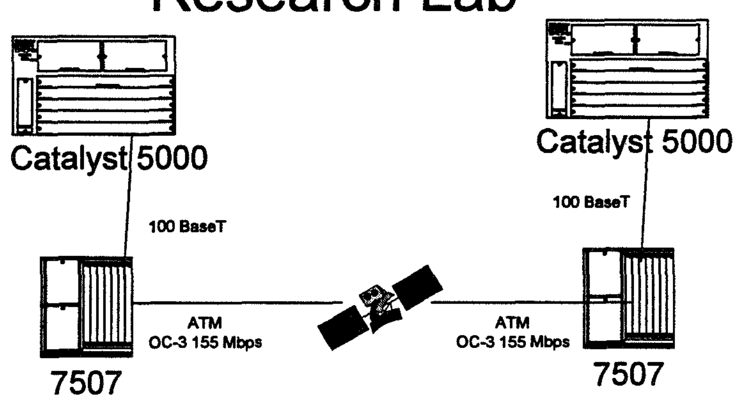
Satellite Interoperability Questions (continued)

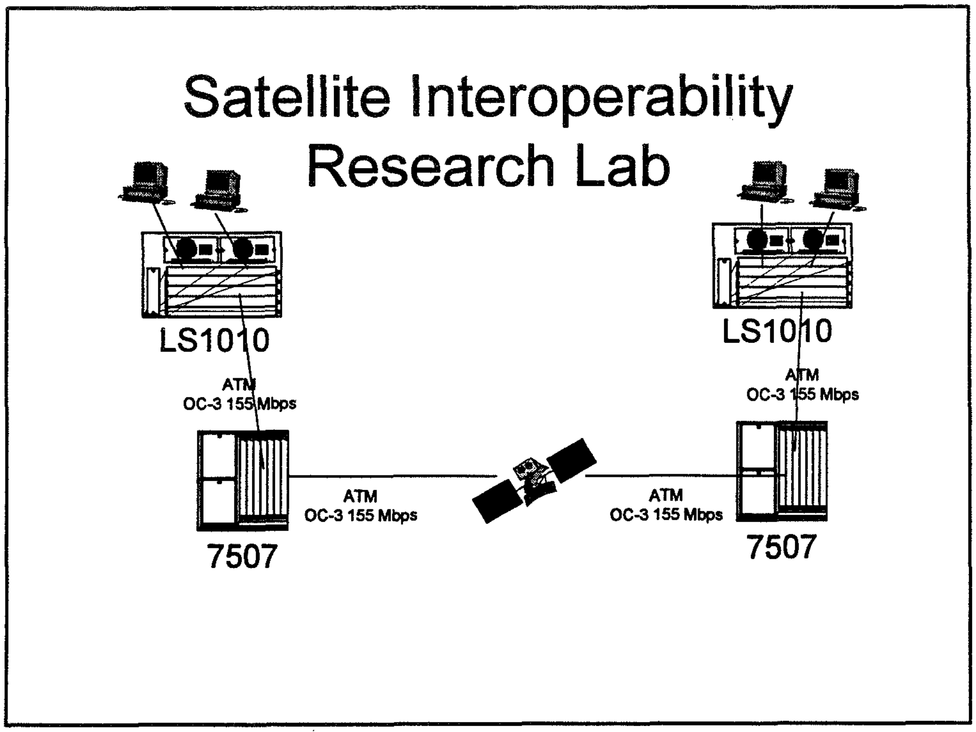
- Does PNNI work effectively over a High Data Rate / High Delay Network ?
- Does Classical IP have any problems ?
- Does LANE work over satellites ?
- Does DICOM need some modifications to work effectively over satelliltes?
- BW*D=Buffer, How much is enough?

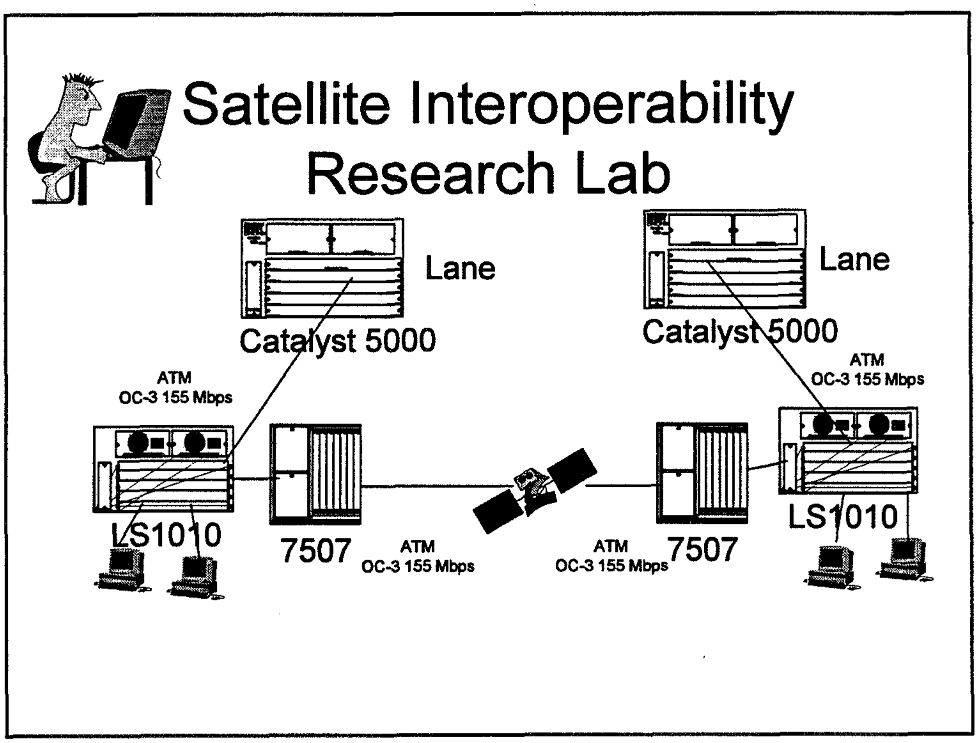
Satellite Interoperability

BWD = BUFFER	NOTE: CELLS are 53bytes				
Bandwidth Bits	Bandwidth Bytes	Cells	Delay ms	Buffer Size Bytes	Buffer Size Cells
1,544,000	193,000	3,642	0.500	96,500	1,821
10,000,000	1,250,000	23,585	0.500	625,000	11,792
45,000,000	5,625,000	106,132	0.500	2,812,500	53,066
100,000,000	12,500,000	235,849	0.500	6,250,000	117,925
155,000,000	19,375,000	365,566	0.500	9,687,500	182,783
622,000,000	77,750,000	1,466,981	0.500	38,875,000	733,491

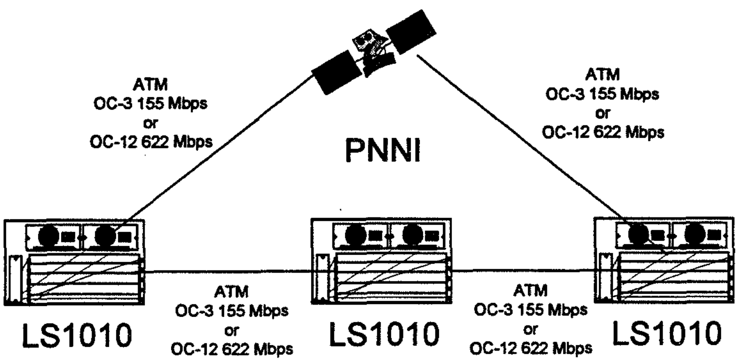
Satellite Interoperability Research Lab




Satellite Interoperability
Research Lab
LS1010
ATM
OC-3 155 Mbps
LS1010
ATM
OC-3 155 Mbps
ATM
OC-3 155 Mbps
ATM
OC-3 155 Mbps
7507
7507

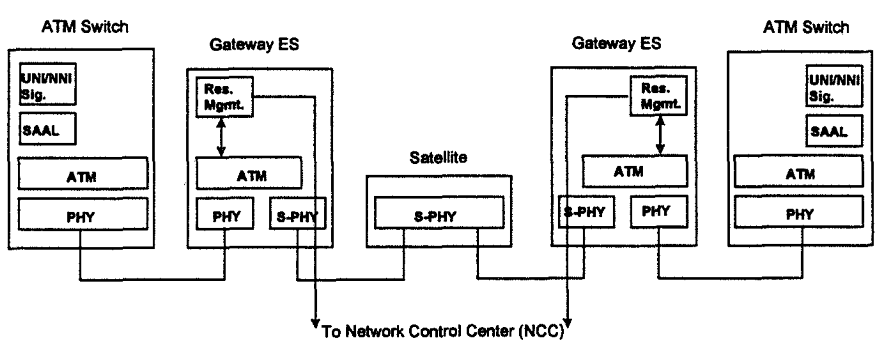

Satellite Interoperability
Research Lab
Lane
Catalyst 5000
Lane
Catalyst 5000
ATM
OC-3 155 Mbps
ATM
OC-3 155 Mbps
LS1010
7507
ATM
OC-3 155 Mbps
ATM
OC-3 155 Mbps
7507
LS1010

Satellite Interoperability Research Lab



Satellite Interoperability Standards

SATATM 1.1 Protocol Reference Model for Network Access

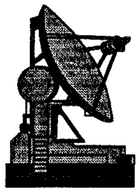


Satellite Interoperability Expectations

- TCP/IP congestion controls will work a High Data Rate/ High Delay network but may need to be adjusted.
- SVC's using Classical IP and LANE will be useable but possible some timing parameters may need to be adjusted.
- BW*D will be a combination of congestion controls, timers, and buffers.

Satellite Interoperability Expectations

- ATM congestion control and IP congestion control interaction in this environment is an unknown.
- PNNI parameters will probably need to be adjusted for the high delay network.
- DICOM applications will need adjustments for this network.



Satellite Interoperability Team

- Members of the Team
  - Dan Glover — NASA SAA3-131 Technical Manager
  - Dan Shell — CISCO SAA3-131 Technical Manager
  - Dave Pleva — SAA Network Engineer
  - Greg Kubat — LANE PI
  - Tom Von Deak — PNNI PI
  - Mark Allman — RED PI
  - Cindy Tran — TCP Over ABR PI
  - Jim Griner — High Speed TCP PI
  - Paul Mallasch — DICOM PI
  - Bob Dimond — Network Engineering Support
  - Mike Zernic — ACTS HDR Coordinator
  - Will Ivancic — NASA Technical Coordination

Satellite Interoperability

Thank You

Session 7

ATM over Satellite Network Quality of Service

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Traffic Management for Satellite-ATM Networks

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The Ohio State University
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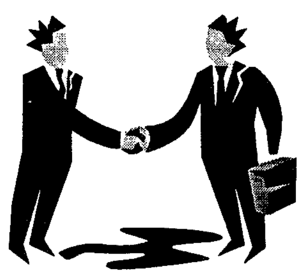
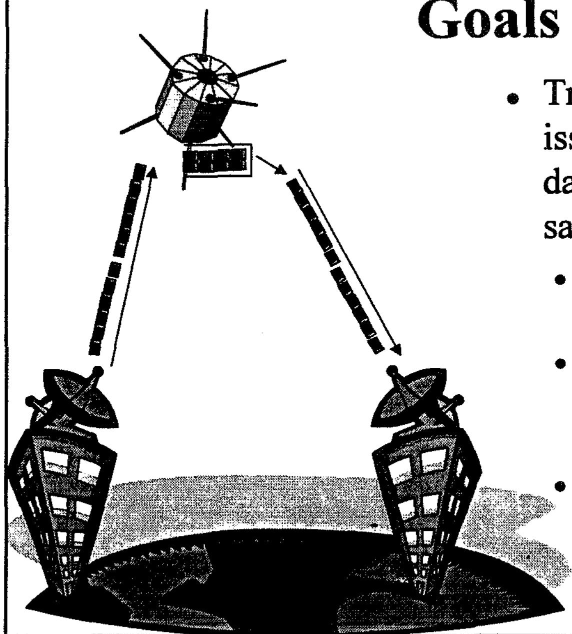
Acknowledgements



This research has been partially sponsored by NASA Lewis Research Center, under contract number NAS3-97198

Goals



- Traffic management issues for TCP/IP based data services over satellite-ATM networks
  - Discuss design issues for TCP/IP over ATM
  - Optimize the performance of TCP/IP over ATM for long delay networks
  - Evaluate ATM service categories for TCP/IP traffic

ATM Service Categories for Data

- **Unspecified Bit Rate (UBR):** User sends whenever it wants. No guarantees made by network
- **Guaranteed Frame Rate (GFR)**: User sends whenever it wants. Network guarantees a minimum frame rate, and fair usage of excess capacity. Needs frame delineation info
- **Available Bit Rate (ABR):** User follows network feedback. Network guarantees a minimum cell rate, and fair usage of excess capacity. Network guarantees cell loss ratio
- **Non-Real Time Variable Bit Rate (nrt-VBR):** User declares peak and average rates. Network guarantees cell loss ratio

Designed for best effort and non-real time traffic

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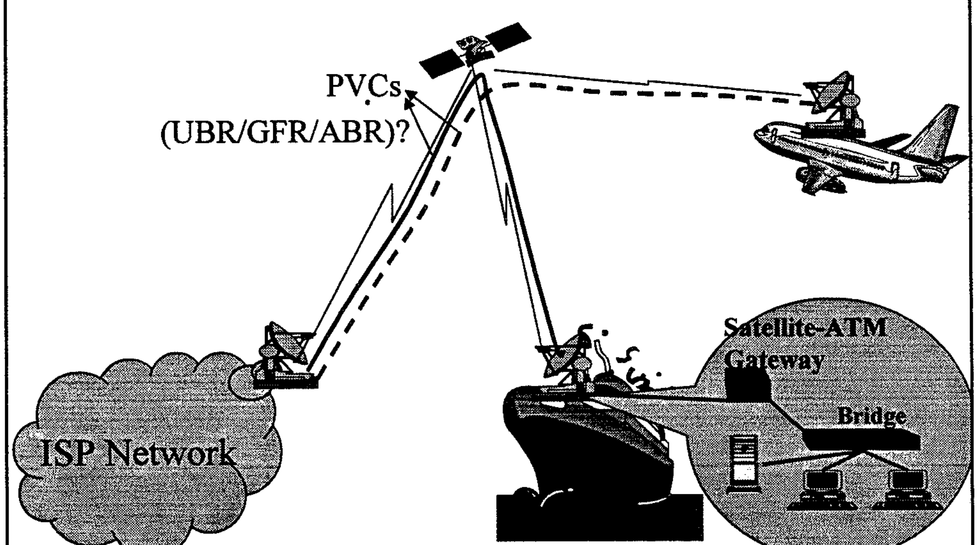
ATM Service Categories (contd.)

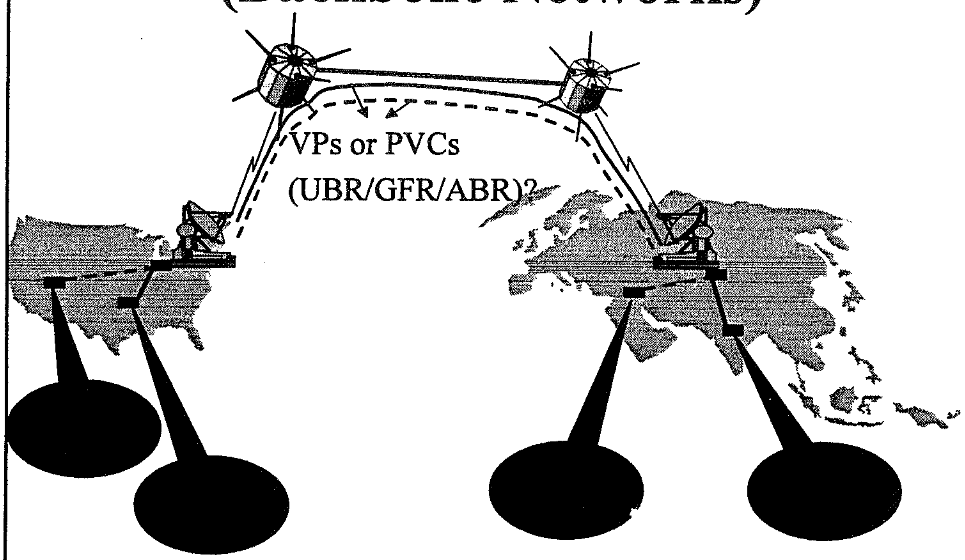
- **Real Time Variable Bit Rate (VBR):** User declares peak and average rates. Network guarantees cell delay, cell delay variation and cell loss ratio
- **Constant Bit Rate (CBR):** User declares peak rate. Network guarantees cell delay, cell delay variation and cell loss ratio

Designed for real time traffic

Satellite-ATM Deployment (Access Networks)



Satellite-ATM Deployment (Backbone Networks)



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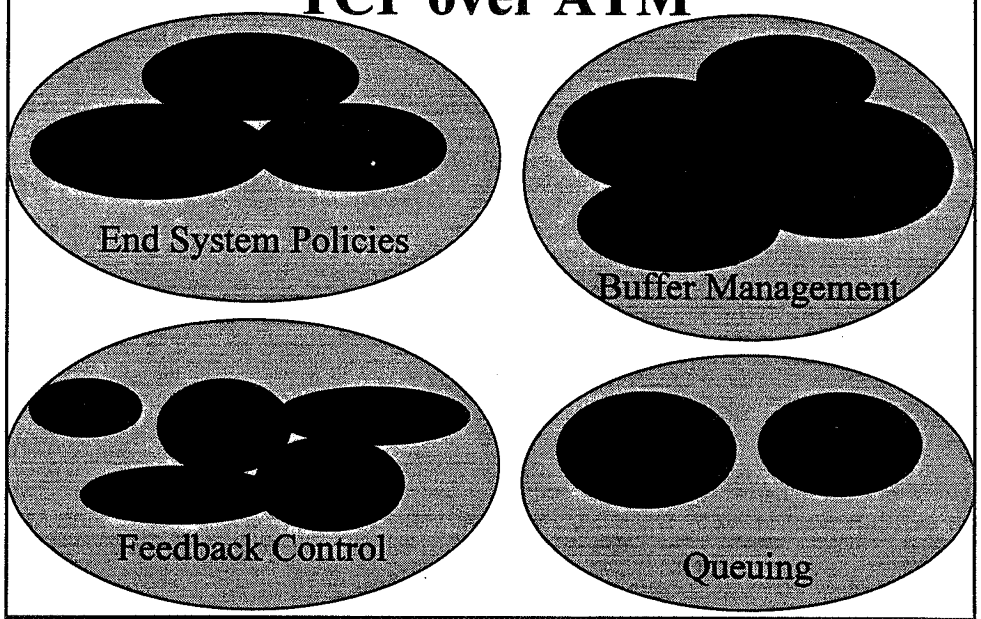
TCP over ATM



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Unspecified Bit Rate (UBR)

- Queuing: Single UBR queue
- Buffer Management
  - *Tail Drop*: Low efficiency, low fairness
  - *Early Packet Discard*: Low fairness
  - *Per-VC accounting*: High efficiency, high fairness
- End-system Policies
  - *Vanilla TCP*: Poor performance
  - *Fast Retrans. & Recov.*: Bad for long latency
  - *Selective Ack*: Good performance for long latency
- No control over sources ⇒ Potentially Large queues in network

UBR with Guaranteed Rate (GR)

- Queuing:
  - Single queue with guaranteed minimum service rate
- Buffer management: Same as UBR
- End system policies: Same as UBR
- Improved performance of TCP due to guaranteed rate
- Cannot isolate traffic from different organizations
  - Will not work for backbone networks
  - May be OK for access networks

Guaranteed Frame Rate (GFR)

- Minimum rate guarantee for frames
- Complete frames are accepted or discarded in the switch
- Traffic policing is frame based
- Traffic conforming to MCR is served with low cell loss
- Traffic above MCR is served as best effort
- CLP=0 frames given higher priority than CLP=1 frames
- Network can optionally tag frames exceeding MCR (GFR.2)
- Good for backbone as well as access networks

GFR (contd.)

Queuing	Per-VC	FIFO
Buffer Management	Per-VC Thresholds	Global Threshold
Tag-sensitive Buffer Mgmt	2 Thresholds	1 Threshold

- Equal MCR allocation
  - Can do with FIFO and per-VC thresholds
- Unequal MCR allocation
  - Difficult to provide per-VC MCR with FIFO for TCP/IP traffic with high MCR allocation
  - Easy to provide per-VC MCR with per-VC queuing

Available Bit Rate (ABR)

- Queuing: Single ABR queue or per-VC queues
- Feedback Control:
  - *Bit Based*: Slow control, bad for long latency networks
  - *Explicit Rate*: Fast control, bounded buffer requirements
  - *Virtual Source/Virtual Destination*: Allows hop-by-hop control & isolates terrestrial switches from effects of satellite latency
- Buffer Management:
  - Less important with a good explicit rate scheme like ERICA+
  - Bounded buffer requirements (Constant × round trip delay × bandwidth) for zero loss for TCP/IP over ABR
  - UBR-like buffer requirements at the edges of the ABR network

UBR vs GFR vs ABR

UBR	GFR	ABR
No guarantee.	Minimum rate + fair excess	
Unfair	Fair	
Queue in network		Queue at network edges
Simple for user		Good for provider
Same end-to-end or backbone		Good if end-to-end ATM

Summary

- Design issues for TCP over ATM
  - *End system policies*: Vanilla TCP, Fast Retr. Recov., ***SACK***
  - *Feedback control*: Explicit rate, binary, end-to-end, VS/VD
  - *Buffer management*: tail drop, EPD, per-VC acc., tag sensitive
  - *Queuing*: Per-Class, per-VC
- **UBR**: No guarantees, poor performance
- **UBR w/ per-VC accounting**: Good efficiency+fairness
- **GR**: Cannot isolate different VCs
- ***GFR***: Per-VC minimum rate guarantees
- **ABR**: Congestion shifted to edge of network
- **VS/VD**: Isolate terrestrial segments from satellite

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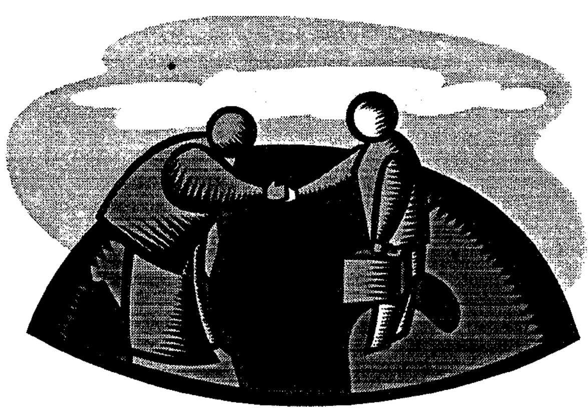
Thank You



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ATM Via Satellite: Link and Networking Technologies

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1

COMSAT LABORATORIES ATM Via Satellite: Link and Networking Technologies

ATM Via Satellite: Link and Networking Technologies

- ATM Via Satellite: Key Challenges
- ATM Over (point-to-point) Satellite Links
- ATM Satellite Networks
- Conclusions

2

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ATM Via Satellite: Key Challenges

Providing Fiber-like Quality (Cell Loss Ratio and Cell Error Ratio)
- Time-varying bit error rates and bit error distribution

Effect on throughput Performance due to geosynchronous satellite delay
- ATM Traffic Management, Congestion Control
- End-to-end protocols, e.g., TCP

Efficient Bandwidth Use
- ATM and other ATM related protocols (such as ATM speech) are not bandwidth efficient
- Satellite resources are relatively expensive
- Dynamic Bandwidth-on-Demand Concepts

Meeting Cell Delay Variation QoS Requirements
- Satellite TDMA framing can result in unacceptable cell delay variation

3

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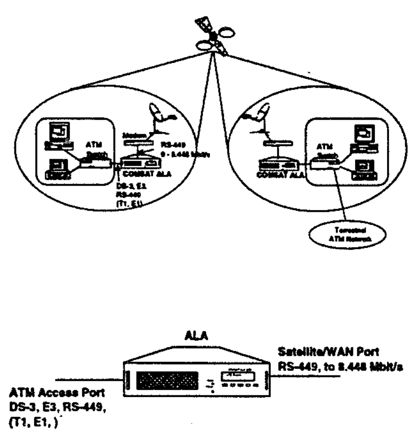
ATM Via Satellite: Link and Networking Technologies

COMSAT ATM Link Accelerator - CLA-2000/ATM



Provides fiber-like quality over satellite links for ATM traffic

Improved BER (10-9 or better), low Cell Loss/Error Ratio
- Cells protected using powerful Reed-Solomon coding
- Interleaving to combat burst errors
  - Can correct 640 bit burst error
- Errored cells not delivered

Bandwidth Expansion
- Adaptive Coding based on Measured Error rate
- Reed-Solomon coding overhead 0% - 7%
- Idle cells not transmitted
- Header compression option (4% savings)

Traffic management
- High priority, Low jitter for CBR/VBR traffic (e.g., video)
- Low priority, Large buffers for UBR/ABR traffic (e.g., LAN data)

Lossless Data Compression for traffic on selected VCs
- 2:1 compression ratio typical
- Up to T1 link rate

DS-3, E3, RS-449, *(T1, E1)* ATM Interface

Satellite Interface, RS449, up to 8.448 Mbit/s

4

Additional CLA-2000/ATM Features

Unique Framing, Acquisition and Synchronization scheme
- Low overhead
- Fast Acquisition

Cell buffering
- User configurable queue sizes for different traffic types

Header compression
- Compresses ATM header
- Loss-less, adaptive
- 4% bandwidth savings

Transparent Mode Option
- Turns off Reed-Solomon coding, Interleaving and Compression

Support for Simplex links
Support for Asymmetric Rate/Delay Links

Support for Low Speed Links
- Configurable Interleaver depth and Reed-Solomon frame size

Support for KG Encryption units

Support for RS-530 and V.35 Interfaces

1:1 Redundancy option with automatic switchover

Plug and Play
- Default configuration useable across wide range of link conditions

Management using local console or remotely over IP network

Automatic self-test on start-up

Diagnostics, Loopback capabilities

Performance statistics, link quality monitoring

Configuration Parameters
- Saved in flash memory
- Console commands for editing
- Factory configured defaults

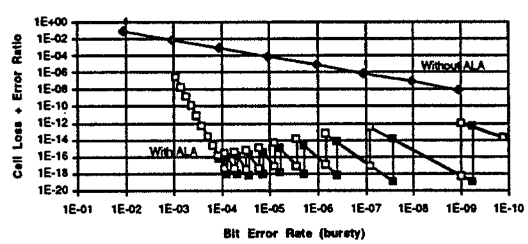
Front panel LCD display

Flash memory for software storage
- Software updates can be done in the field

Sun workstation based tools for software upgrade over ethernet
- Can also be done using PC over console port

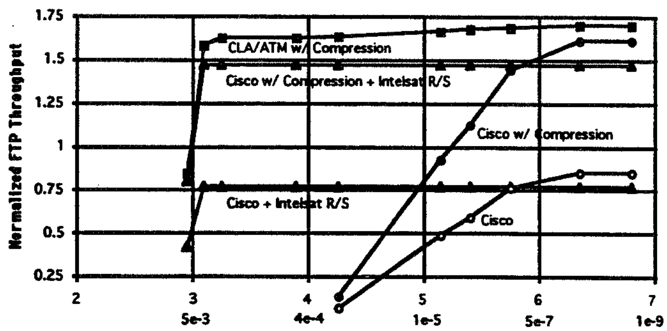
5

CLA-2000/ATM Performance v/s BER



6

CLA-2000/ATM Performance



Viterbi Rate 3/4
Satt. Data Rate = 1.544 Mbit/s
Compression = 50%

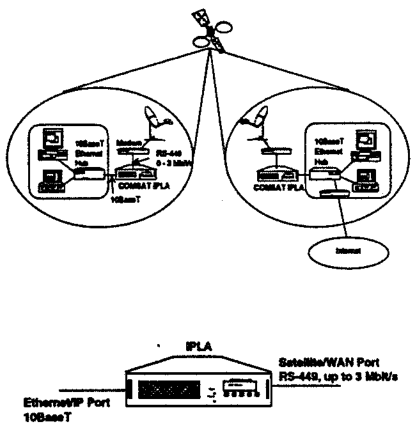
Number of parallel ftp's = 7
TCP Window Size = 24 kbytes
SunOS 4.1
Throughput < 1 on low BERs due to TCP/IP + framing overhead, TCP slow-start effects

7

Example Operational Network

8

COMSAT Link Accelerator / IP - CLA-2000/IP



IP Routing over satellite and wireless links

Provides fiber-like quality over satellite links for IP traffic

Improved BER (10-9 or better)
- Packets protected using powerful Reed-Solomon coding
- Interleaving to combat burst errors
  - Can correct 640 bit burst error

Bandwidth Expansion
- Adaptive Coding based on Measured Error rate
- Reed-Solomon coding overhead 0% - 7%

Lossless Data Compression Option
- 2:1 compression ratio typical
- Up to T1 link rate

Satellite Interface, RS449, up to 3 Mbit/s

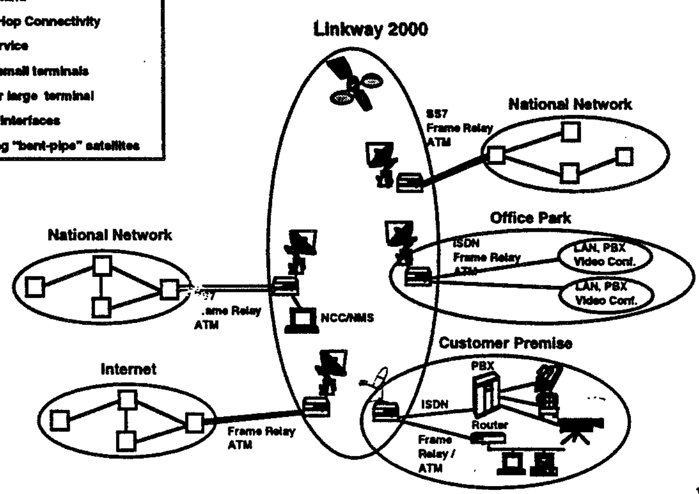
Support for asymmetric rate links, low-speed links

RED Queue Management

Coming Attractions -
- Proxy-TCP
- RSVP

Linkway 2000 Service Overview

- Bandwidth on Demand
- Full Mesh, Single Hop Connectivity
- High Quality of Service
- Up to 2 Mbit/s for small terminals
- Up to 32 Mbit/s for large terminal
- Industry standard interfaces
- Works with existing "bent-pipe" satellites



Linkway 2000 Service Features

ATM Service
- DS3, E3 Interface
- Up to 8 Mbit/s of user data per interface
- Support for CBR, VBR, ABR and UBR traffic
- PVCs initially; SVCs later

Packet Service
- Frame Relay interface
- Serial Synchronous Interface, 64 Kbps - 2 Mbps
- PVCs initially; SVCs later
- LAN Support using external Routers

Digital Circuit Service
- ISDN PRI Interface, 23B+D (T1), 30B+D (E1)
- Switched on-demand nx64 Kbit/s circuits
- Full ISDN signaling support
- SS7 Signaling support for carrier interconnect
- T1/E1 interfaces using external converters

Future Services
- ISDN over BRI 2B+D Interface
- Direct LAN (TCP/IP) connection
- Analog 2W/4W telephone interface with compressed voice

All interfaces and services concurrently supported in all terminals!
Bandwidth on Demand for all services

11

Linkway 2000 Key Product Features

Network Capabilities
- Multi-carrier, TDMA
- Mesh, Single hop connectivity
- Carrier Rate: 2.5 Mbps
- Demand assigned switched services
- Concurrent Voice/Video/Packet Services
- Global and Spotbeam operation
- Ku and C Band Operation
- Compact, low-cost hardware
- Support for 1000's of terminals

Fault Tolerance
- Redundant terminal option
- Backup Reference Stations

Scaleable Terminal Sizes
- Customer Premise Terminals
  - Low cost unit
  - Small Antenna (2.4 m)
  - Up to 2 interfaces
  - Optional Redundancy
- Gateway Terminals
  - Up to 32 interfaces
  - Full redundancy
  - Uses "stack" of small terminal units
- Intermediate Size Terminals
  - 2 to 32 interfaces in increments of 2
  - Field Upgradeable
  - Optional Redundancy

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Linkway 2000 Bandwidth Management Features

Dynamic, Real-Time, Bandwidth on Demand

Bandwidth Management done centrally by NCC

- NCC is a Sun workstation, connected to the Reference Terminal

Handles SVCs and PVCs

Handles ATM classes of services - UBR, VBR, CBR (ABR future)

Adaptive bandwidth allocation for UBR ATM circuits and for frame relay
- Based on actual traffic measurements and network state
- Fairness algorithms

Traffic Policing

Traffic aggregation

Multi-carrier, TDMA bandwidth management Algorithm
- Variable sized bursts
- Modem pooling for multi-modem terminals
- Fast execution algorithms

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Linkway 2000 Key Technical Challenges

TDMA Architecture to support multiple services with BoD
Modulation/Coding/Interleaving
Adaptive Modulation/Coding
Acquisition and Synchronization
Stable Clock Generation using low cost oscillators
Frequency Offset Management
Doppler Management
Power Control
Adaptation of Different Protocols
- ATM, Frame Relay, ISDN, (IP)

Guaranteed QOS, Priorities
ATM Cell Delay Variation Control
Inverse muxing
Bandwidth Management Algorithms
Congestion Control Algorithms
Standards, Inter-operability
Network Management
Redundancy
Software Architecture - size, cost, complexity
Hardware - size, cost, complexity, modularity

On-Going R&D
- ATM Multicast
- IP over ATM
- IP Multicast
- Addressing/Routing
- Direct IP/RSVP support
- TCP Performance Issues
- Security

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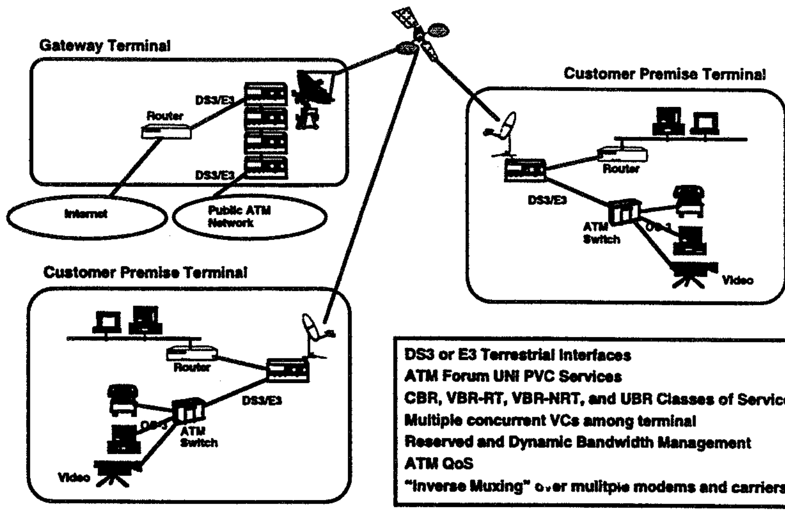
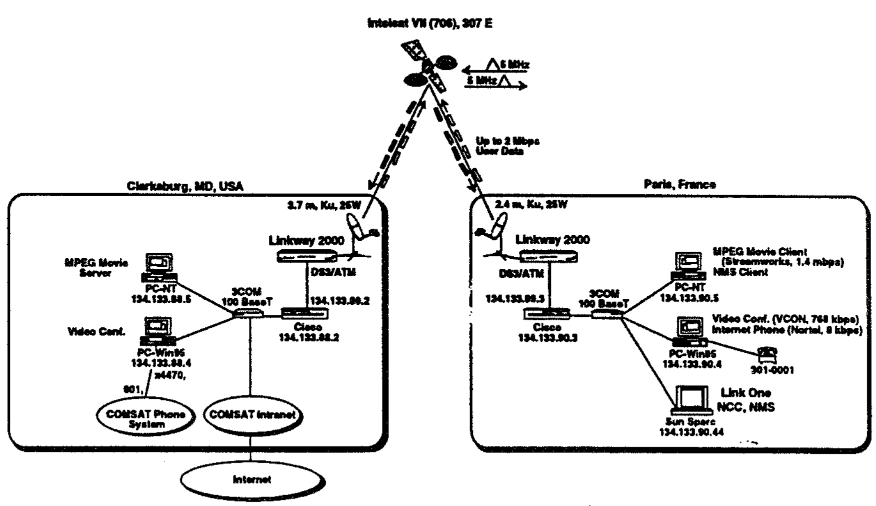
Linkway 2000 ATM Service Architecture



- DS3 or E3 Terrestrial Interfaces
- ATM Forum UNI PVC Services
- CBR, VBR-RT, VBR-NRT, and UBR Classes of Service
- Multiple concurrent VCs among terminal
- Reserved and Dynamic Bandwidth Management
- ATM QoS
- "Inverse Muxing" over mulitple modems and carriers slots

INTEROP '97 Demonstration



Ka Band Operation

Network Capabilities

COMSAT responding to NASA RFQ for TDMA/FDMA Network System

Will initially supply 4 units with ATM, FR and ISDN interfaces

Additional features for operation over ACTS :
- Lower carrier rate option (0.5 to 1 Mbps)
- Asymmetric rate option (2.5 Mbps->, 0.5 Mbps <-)
- Support for On-Board Microwave Switch Matrix
  - TDMA synchronization
  - Dynamic Bandwidth Management

Linkway modem has been tested over ACTS satellite using USAT terminal

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COMSAT LABORATORIES
ATM Via Satellite: Link and Networking Technologies

Conclusions

New generation of satellite link and networking products -

- Provide High Quality ATM Service over satellite links
- Provide Efficient use of satellite bandwidth
- Meet Customer Demands

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Satellite ATM Networks: Architectural Issues and Challenges

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NASA Lewis Research Center Workshop on Satellite Networks: Architectures, Applications and Technologies
Cleveland, Ohio
June 2-4, 1998

NS-01243-1

Lockheed Martin Telecommunications

Satellite ATM Networks: Architectural Issues and Challenges

Sastri Kota
Lockheed Martin Telecommunications

Abstract

In this paper we present an overview of the Ka-Band satellite systems and broadband services and applications which drive the broadband network architectures. We describe a Satellite ATM Network model and discuss various architectural options including on-board versus ground switching and processing, and GSO versus NGSO. For an integrated Satellite ATM network model design issues such as traffic management, quality- of -Service (QoS) and media access protocols are discussed. The current standard development activities for satellite networks is presented. We then illustrate structure of the TCP protocol stack, as an example of a popular end system protocol, over the ATM Unspecified Bit Rate (UBR) category. We present simulation results for end -to-end delay performance of GEO and LEO systems for a sample connection from New York to Paris and concluded that while GEO systems have a large propagation delay, buffering delay can be significant in LEO networks.

Subsequently, we present an overview of Lockheed Martin's Astrolink System as a Satellite ATM network example. Astrolink system is currently under active development. Astrolink will provide global bandwidth -on - demand utilizing a constellation of nine Ka-Band geosynchronous satellites deployed in five orbital locations. The Astrolink will employ intersatellite links, high gain spot beams, adaptive coding in response to rain, and on-board ATM switching. Astrolink will enable global broadband communication services at an affordable price.

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Outline

- ***Broadband services***
- ***Broadband applications***
- ***Satellite ATM network architectures***
- ***Satellite ATM - issues and challenges***
- ***Astrolink™***
- ***Conclusion***

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Broadband Services and Applications

What Interactive Broadband Services do Users Want? - an Asia Pacific Survey*

- **Size Asia-Pacific market potential for select interactive services:**

Entertainment	Business	Transactions	Data / Communications
Broadcasting (DTH)	Telework	Teleshopping	Internet Access
Video on Demand (VOD)	Telemedicine	Home Banking	Electronic Messaging
Near VOD	Video Conferencing	Electronic Commerce	News on Demand
TV Co-Transmissions		Interactive Ads	Virtual CD-ROM
Karaoke on Demand		Home Security	Distance Learning
Games		Utility Monitoring	
Gambling			

- **Gauge consumer acceptance in 15 Asia-Pacific countries at 4 price points (10 to 70 $USD per mo) over short term (3 yrs) and long term (7-10 yrs)**
- **Conclusions - Top Tier of Desired Applications**

Distance Learning
Government and cultural support; business case (TBD)

Internet Access
Explosive demand by gov, business and consumers

Electronic Messaging
Same as Internet

DTH Broadcasting
Pent-up demand for multichannel TV, minimal cable TV infrastructure

Video Conferencing
Strong business demand; several services currently offered

Home Banking
Strong business demand; several services currently offered

Telemedicine
Gov support of central hospitals to serve dispersed communities

* Conducted during the period Jan to Mar 1997

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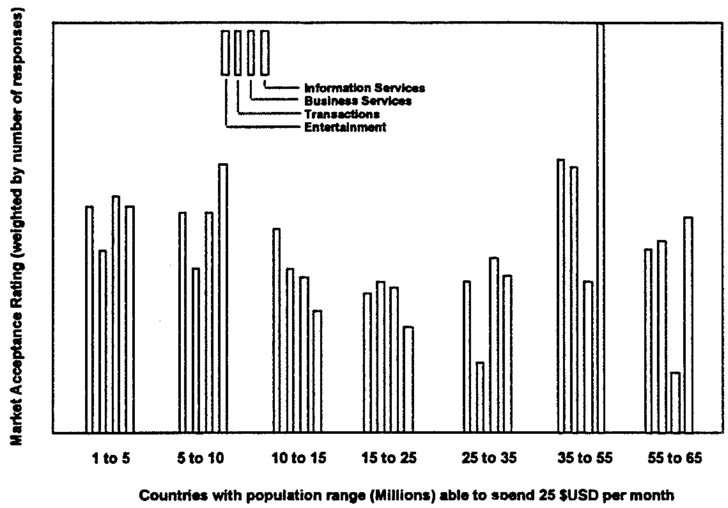
Interoperability Requirements



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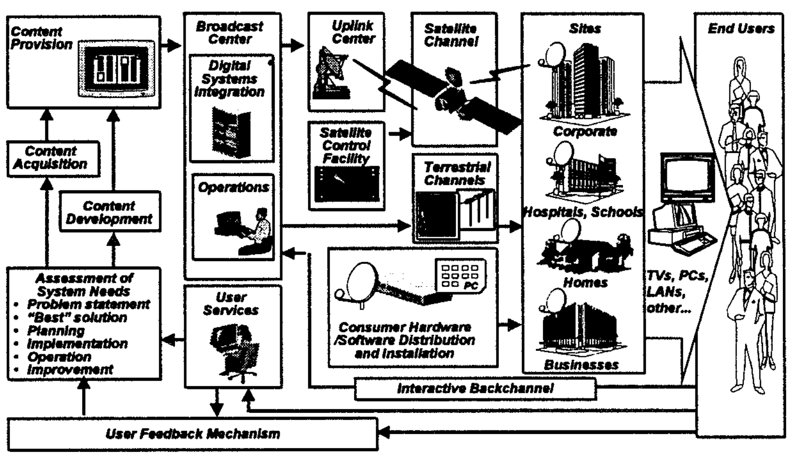
Broadband System Applications



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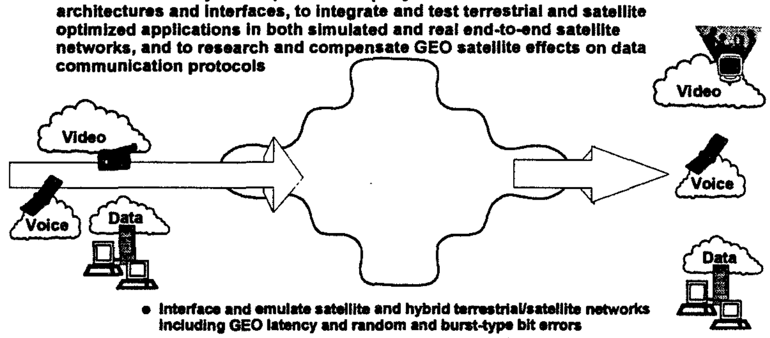
Satellite Integration Lab

Provides the ability and expertise to rapidly simulate satellite network architectures and interfaces, to integrate and test terrestrial and satellite optimized applications in both simulated and real end-to-end satellite networks, and to research and compensate GEO satellite effects on data communication protocols



- **Interface and emulate satellite and hybrid terrestrial/satellite networks including GEO latency and random and burst-type bit errors**
- **Interface Ethernet, ATM, and telephony over satellite**
- **Set up live satellite links using commercial Ku-, Ka-band transponders**
- **Send video and data over live satellite links**
- **Set up satellite video conferencing.**
- **Integrate, test, and analyze performance of various network protocols and applications over emulated and real satellite links**
- **Test performance of satellite and hybrid networks under traffic loading**
- **Development of TCP/IP and TCP/IP-ATM satellite g-'eways**

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Ka-Band Satellite Systems

- ***High data rate services***
  - ***More bandwidth available – 1 GHz set aside for GSO primary use in U.S., 2.5 GHz available worldwide***
- ***High capacity***
  - ***Multiple beam antenna technology and dual polarization***
- ***Efficient routing***
  - ***Onboard processing and switching provide ability to route calls efficiently***
- ***Dynamic resource allocation***
  - ***Satellite capacity can be allocated to the region depending on peak demands***
- ***Small terminals***
  - ***Allows smaller but higher gain antennas***
- ***14 frequency filings; some of them are:***
  - ***Astrolink™ (Lockheed Martin)***
  - ***Cyberstar (Loral)***
  - ***GE* Star (GE American Comm)***
  - ***M-Star (Motorola)***
  - ***Spaceway (Hughes)***
  - ***Teledesic (Teledesic)***

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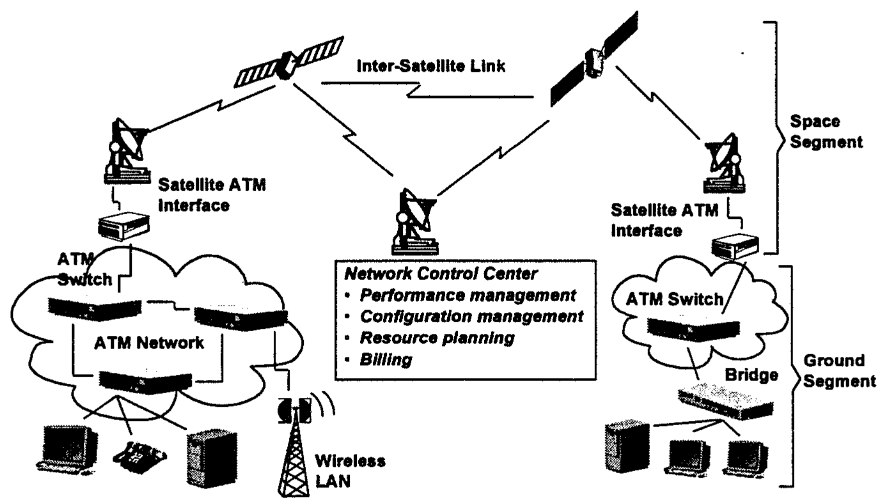
Satellite ATM Network Model



Sastri Kota, R. Goyal, and Raj Jain, "Satellite ATM Network Architectural Consideration and TCP/IP Pe formance" Proc. Third Ka-Band Utilization Conference, September 15-18, 1997, Sorrento, Italy

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Architectural Options and Issues

Options

- ***GSO vs NGSO (e.g., LEOs, MEOs)***
- ***No onboard processing or switching***
- ***Onboard processing with ground ATM switching***
- ***Onboard processing and ATM switching***
- ***Applications***
- ***Services***

Issues

- ***Media access control protocol***
- ***Traffic management***
- ***Interoperability with legacy networks***
- ***QoS management***

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Satellite ATM Versus Terrestrial ATM

Attributes	Terrestrial ATM	Satellite ATM
• Encoding for error performing	HEC only	Link encoding powerful
• Signaling	Standards Q.2931	Requires modifications
• DAMA	No	For efficient resource utilization
• Traffic management	Standard ATMF V.4.0	Requires modifications
• User protocol interface	UNI, NNI, etc. standards	ST and Gateway implementation
• Switching	VP and VPI/VCI	VPI/VCI
• Propagation delays	Less impact, but number of hops during the path	IETF developing efficient algorithms (IPOS)
• Standards	Have progressed well	ITU 4B draft Due October 98

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Onboard Processing and Switching

- *Improved performance for error rates*
  - *Separation of uplink and downlink*
  - *Effective encoding techniques*
- *System efficiency*
  - *Efficiency can improve from 37% to nearly 99.5% with packet or cell switching*
- *Delay improvements*
  - *Routing decisions onboard or via intersatellite links*
  - *No end-to-end retransmissions*
- *Capacity improvements*
  - *Multiple beams with dual polarization*

"70% of the Ka-band programs forsee an onboard switch, 53% use fast packet switch" – Proc. Third Ka-band utilization conference, pp. 281-285

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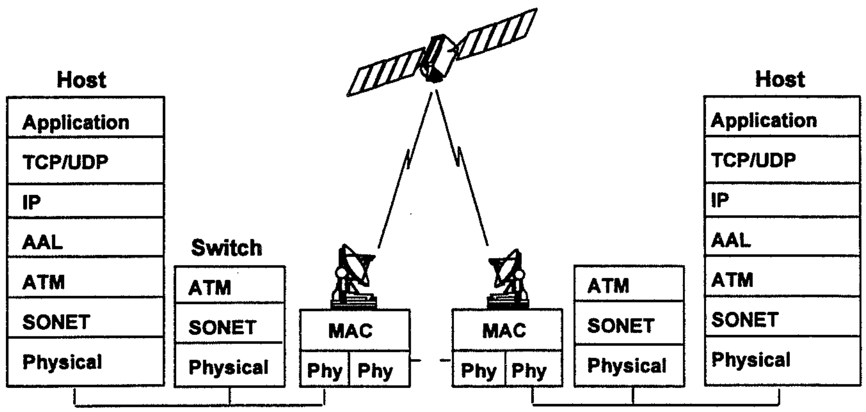
TCP/IP Over Satellite ATM Example



How does the TCP/IP protocol stack work with satellite ATM?

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Satellite ATM Services Classes

- ***CBR (constant bit rate)***
  - ***User declares required rate. Throughput, delay, and delay variation guaranteed. Circuit emulation***
- ***VBR (variable bit rate)***
  - ***Declare average and maximum rate***
    - ***rt-VBR (real time): Conferencing. Max delay guaranteed***
    - ***nrt-VBR (non-real time): Stored video***
- ***ABR (available bit rate)***
  - ***Source follows network feedback***
- ***UBR (unspecified bit rate)***
  - ***User sends whenever it wants. No feedback. No guarantee. Cells may be dropped during congestion***

Most important benefit

Flexibility of ATM to allocate resources appropriate to each application's needs while allowing sharing where possible to lower networking costs

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Traffic Management Functions

- *Connection Admission Control (CAC): Verify that the requested bandwidth and quality of service (QoS) can be supported*
- *Traffic shaping: Limit burst length. Space-out cells*
- *Usage Parameter Control (UPC): Monitor and control traffic at the network entrance*
- *Network resource management: Scheduling, queuing, resource reservation*
- *Priority control: Cell Loss Priority (CLP)*
- *Selective cell discarding: Frame discard*
- *Feedback controls: Network tells the source to increase or decrease its load*

Traffic management version 4.0, requires modifications to reflect Satellite ATM

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Satellite ATM Attributes on QoS

Attribute	Max CTD	Peak-to-Peak CDV	CLR	CMR	SECBR	CER
Propagation delay on transmission media	X					
Error characteristics of transmission media			X	X	X	X
Switch architecture	X	X	X			
Processor and buffer capacity	X	X	X			
Traffic load	X	X	X	X		
Maximum nodes allowed in a route	X	X	X	X	X	X
Resource allocation strategy	X	X	X			
Network failure and restoration strategy	X	X	X			

CLR: Cell loss ratio
CTD: Cell transfer delay
CDV: Peak-to-peak cell delay variation
CMR: Cell misinsertion rate
SECBR: Severely erred cell block ratio
CER: Cell error ratio

S. ATM attributes consistent with terrestrial ATM

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TCP Issues

- *Basic TCP: Slow start and congestion avoidance*
  - *Large retransmission timer granularity*
    ⇨ slow recovery from packet loss
- *Reno TCP: Fast retransmit and recovery*
  - *Fast recovery from single packet loss*
  - *Very inefficient with multiple packet loss*
- *SACK TCP: Selective acknowledgments*
  - *Fast recovery from multiple packet loss*

For satellite networks, SACK TCP has the best performance

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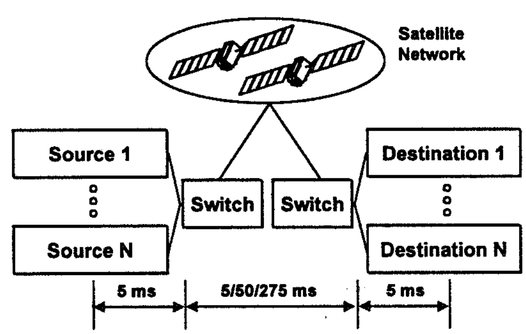
End-to-End Delay Peformance

- *End-to-End Delay = Packet Transmission Delay*
  + Propagation Delay
  + Buffering Delay
  + Switching and Processing

- *Delay Variation:*
  - *Handovers*
  - *Satellite Motion*
  - *Buffering and processing*
  - *Adaptive routing*



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New York to Paris: Delay Analysis*

Delay	GEO (ms) 1 Satellite	6x11 (ms) 5 Satellites	12x24 (ms) 10 Satellites
Transmission	Negligible	Negligible	Negligible
Propagation (up+down+ISL)	250	60	77
Switching and Processing	Negligible	Negligible	Negligible
Buffering (N queuing points)	0 to N*250	0 to N*60	0 to N*77
Total Delay	250 to 500	60 to 420	77 to 924

Simulation results indicate that a buffer size of about 0.5 RTT to 1 RTT is sufficient to provide over 98% throughput to the SACK TCP traffic for long latency networks and a larger number of sources*

* R. Goyal, S. Kota and R. Jain et al., "Analysis and simultion of delay and buffer refinements of Satellite ATM networks for TCP/IP traffic summited to IEEE journal of selected areas in communication

** S. Kota, R. Goyal, and R. Jain, "Satellite ATM Network Architectural Considerations and TCP/IP" performance, Third Ka-band utilization conference, Sorrento, Italy, September 1997, pp. 481-488

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Satellite ATM: Standards Activities

- *ITU-R WP 4B – Developed draft new recommendation on S. ATM and S. ATM availability (to be approved by October 1998)*
- *ITU-R WP 4B – Initiated draft new recommendation on Ka-band performance, March 1998*
- *TIA/EIA released "Satellite ATM Networks: Architectures and Guidelines"*
- *ATM forum: Wireless ATM Working Group initiated a Mobile Switching Subworking Group in ATM forum meeting, April 19-24, 1998, Berlin*
- *IETF: Internet protocol over satellite (IPOS) has released a draft specification*

A good coordination requires to be established via liaison

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Astrolink™ is ...

... *a Global Satellite Network*

Employing

- *Up to 9 GSO satellites*
- *Satellite onboard processing*
- *Ka-band (20/30 GHz) frequencies*
- *3 Classes of user terminals*
- *Gateway earth stations*
- *Intersatellite links*

Providing

- *Interactive 2-way services - data, voice, video ,and multimedia*
- *Bandwidth-on-demand - 16 kbps to 10.4 Mbps*
- *Quality of service options tailored to applications*
- *Secure private virtual circuits*
- *Interoperability with terrestrial networks*
- *Connectivity to and from external users via gateways*

Based On

- ***ATM Protocol***

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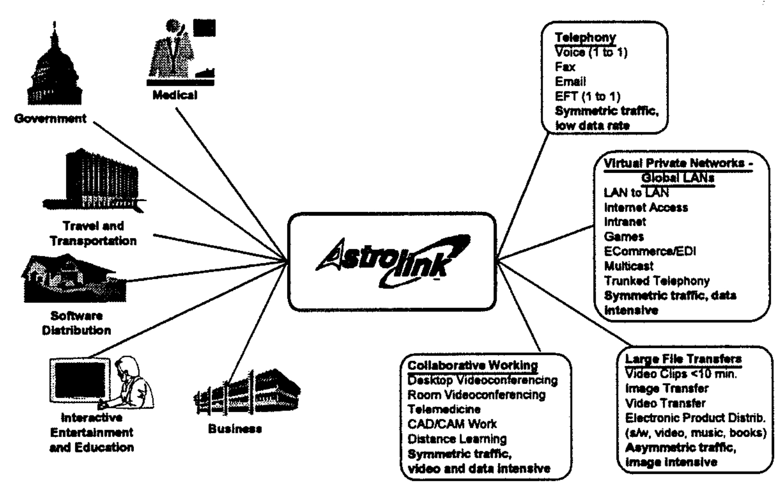
Astrolink™ Services



Astrolink™ will provide wideband global connectivity for enterprise applications

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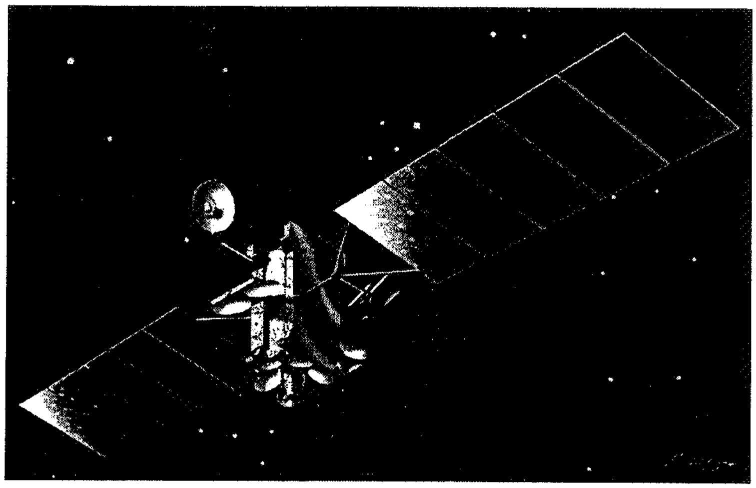
Astrolink™ Satellite



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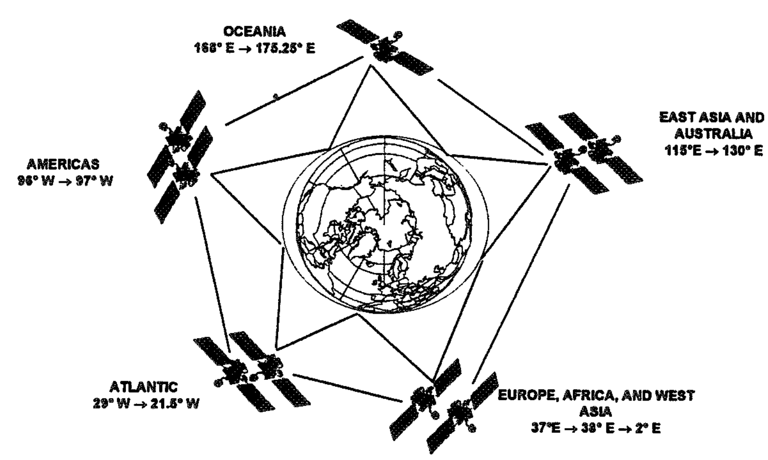
Astrolink™ 9 Satellite Constellation



New orbital locations are result of coordination process

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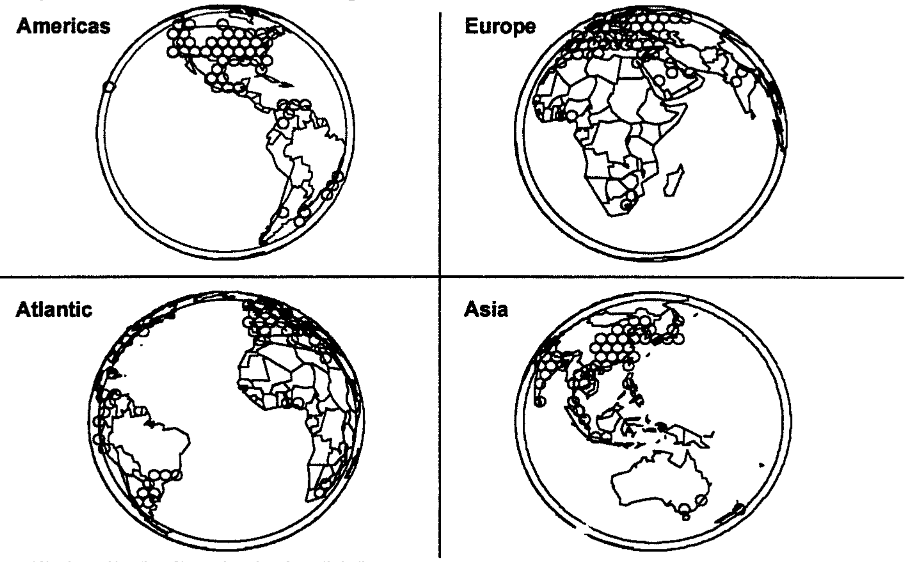
Typical Beam Coverage*



* Number and location of beams is undergoing optimization

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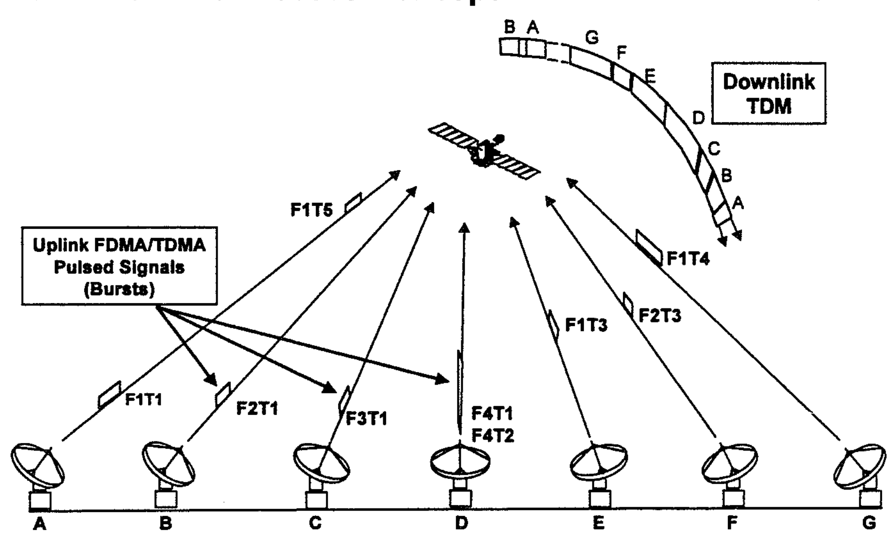
User Terminal Access Concept



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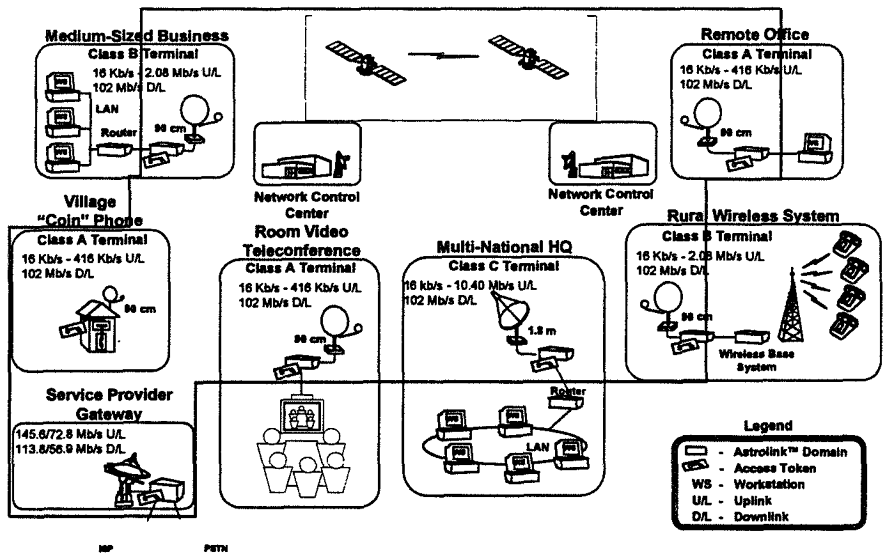
Network Architecture



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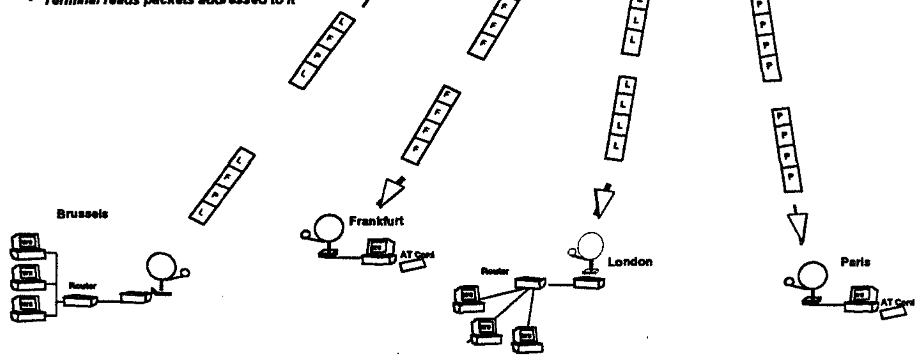
User Networking

Satellite Payload Cell Routing

- *Unpacks cells and reads cell header for destination address*
- *Routes cells to destination port*
- *Cells repackaged into packets*
- *Packets addressed to appropriate beam*
- *Terminal reads packets addressed to it*



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Ground Operations

- Master Network Control Center
  - Performs overall network resource management
  - Collects usage statistics
  - Operates as clearing house between regional NCCs

- Regional Network Control Center (NCC)
  - Manages and allocates satellite resources as required
  - Controls all satellite payload operations
  - Controls all traffic within a given satellite
  - Validates users
  - Provides call setup and tear-down, data rate, frequency, and time slot (DAMA) assignments
  - Collects billing information
  - Provides billing and system utilization data to local ASP and Master Network Control Center

- Spacecraft Operations Center
  - Performs satellite housekeeping functions
    - Attitude control, thermal and power management
    - Monitors and evaluates spacecraft health
  - Plans and executes stationkeeping maneuvers
  - Plans for contingencies
    - Implements backup redundancy recovery

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Conclusions

- ***Satellite ATM architectural options exist in terms of onboard processing and switching***
- ***Trade-off analyses for performance, complexity, and cost dictate the selection of the system architecture***
- ***Standards organizations are progressing well with recommendations and baseline documents***
- ***Astrolink™ is an example of such a satellite ATM network for broadband services***

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FPGA Based Reconfigurable ATM Switch Test Bed

Pong P. Chu
Electrical and Computer Engineering Dept
Cleveland State University

Robert E. Jones
NASA Lewis Research Center

Network Performance Evaluation

- Seeking optimal configuration
- Difficult in general:
  - performance effected by switch architecture, network topology, protocols, incoming traffic patterns etc.
  - system characterized by many stochastic processes

Traditional Approach

- Theoretical model with closed-form solution
  - extremely simple model; e.g., M/M/1 queue
- Theoretical model without closed-form solution
  - with an analytical procedure to obtain solution
  - more realistic, but still with lots of assumptions and approximations
- Prototyping physical system
  - expensive, inflexible
  - technology may not exist yet

- Software simulation
  - can model at any level of abstraction
  - require several orders of magnitude of CPU clocks to simulate 1 real-time clock
  - e.g., experience from an earlier ATM switch project
    - » it takes 0.1 to 1 m sec to simulate the operation of one cell (using BoNES Designer Software in Sun Sparc II)
    - » it will require more than 100 days to measure a buffer with a cell loss probability of 10^{-7}

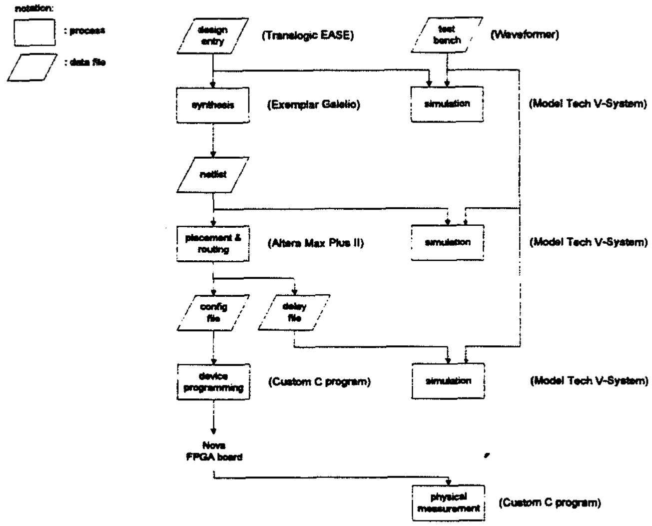
Hardware Emulation

- Use hardware to accelerate simulation
- Construct customized circuit to model various network components
- Recent advances in FPGA (Field Programmable Gate Array) technology make this possible
  - FPGA: "generic logic" that can be configured to different functions by loading different files
  - a chip can accommodate circuit with 100,000 gates
  - synthesis CAD software simplifies implementation

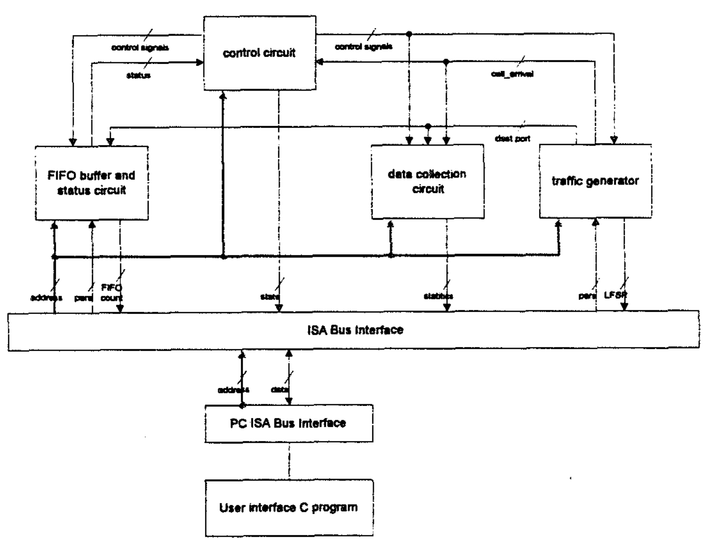
Test Bed Highlights

- Model the operation of an ATM-like switch based network in an FPGA board
- Model data-link level functionality (such as buffer management, congestion control etc.)
- Use a host PC to control and monitor the operation of the FPGA board
- Most design, synthesis, and simulation are based on industrial standard VHDL language
- Design goal: modular, scalable, reconfigurable

Design Environment



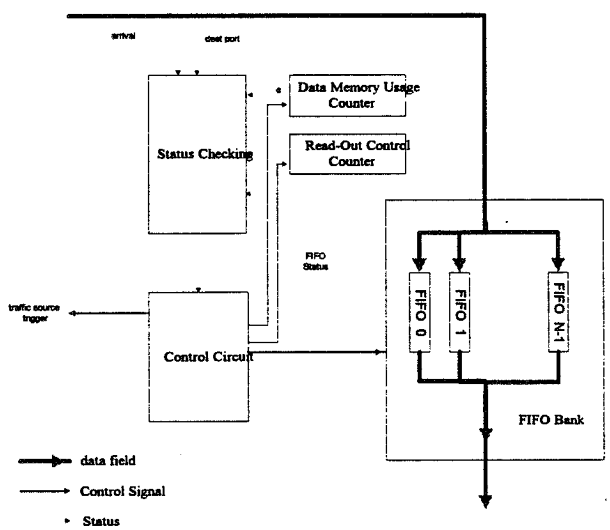
Test Bed Architecture



Abstract Sheared-Memory Switch

- Model after a shared-memory ATM switch
- Process only the cell header
- Perform only data-link level functionality
- Include control circuit, FIFO buffer and status circuit.
- Incorporate three buffer management schemes: complete sharing, complete partition, and sharing with maximal queue length

Detailed Switch Diagram



Traffic Generator

- Cell format:
  - header only (destination port etc.)
- Traffic generator
  - Cell trigger generator
    - » deterministic arrival
    - » Poisson arrival
    - » Markov modulated Poisson arrival
  - Cell destination port generator
    - » uniformly distributed
    - » unbalanced

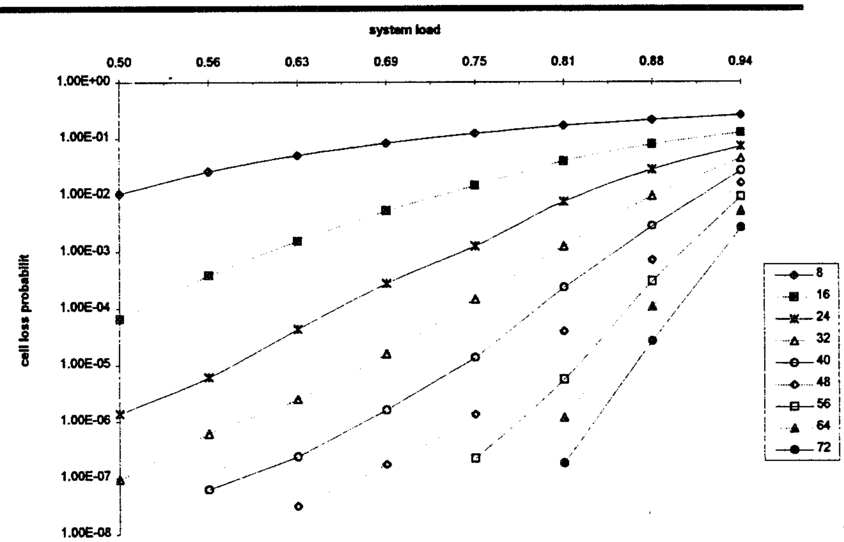
Data Collection Circuit and User Interface

- Data collection circuit
  - gather statistics on total cell arrival, cell loss due to global buffer overflow, and cell loss due to FIFO overflow
- User interface
  - Hardware: PC ISA bus interface in FPGA board; all registers of test bed can be accesses as PC's memory
  - Software: C routines to download configuration file to the FPGA board, to set up the test bed, to monitor the board operation and to retrieve collected data

Initial Results

- Test bed was designed to study cell loss probability of various memory management schemes
- It was fitted into one 100,000-gate FPGA board
- Performance
  - max clock about 15 MHz
  - can emulate about 3 M cell arrivals per sec (1.2 G bits per sec)
  - 5.5 min to emulate 10^9 cell arrivals
- Emulation increases speed by a factor of 10^3 to 10^5

Example: System Load vs Cell Loss Probability w/ Different Buffer Sizes in an 8x8 Switch



Conclusions

- Advances in FPGA make hardware emulation feasible for performance evaluation
- Hardware emulation can provide several orders of magnitude speed-up over software simulation
- Due to the complexity of hardware synthesis process, development in emulation is much more difficult than simulation and requires knowledge in both networks and digital design

Session 8
Access Technology and Protocols

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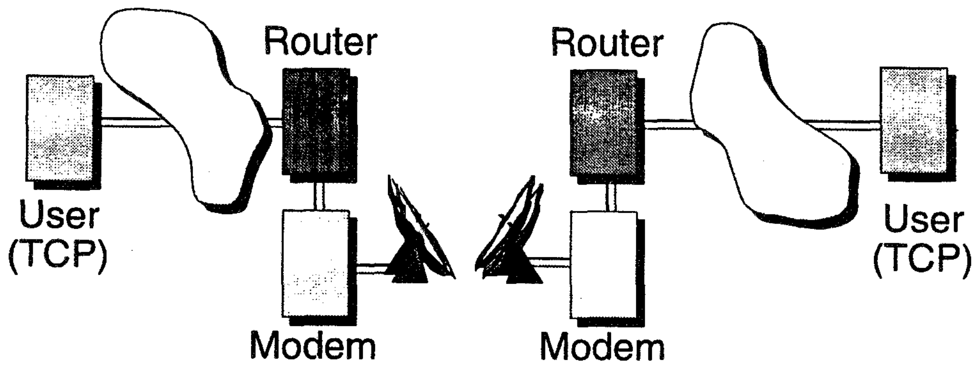
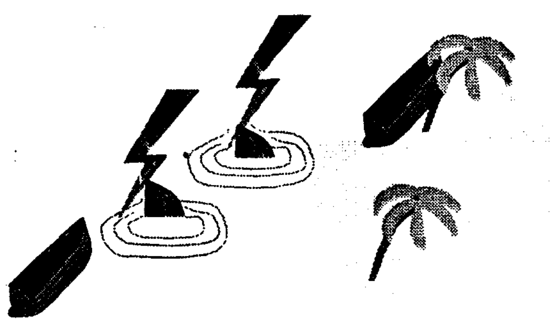


Integrated Packet / Modem Processing for Transportable Terminals

Gorry Fairhurst
Department of Engineering
University of Aberdeen

Who needs to know this?

G. Fairhurst



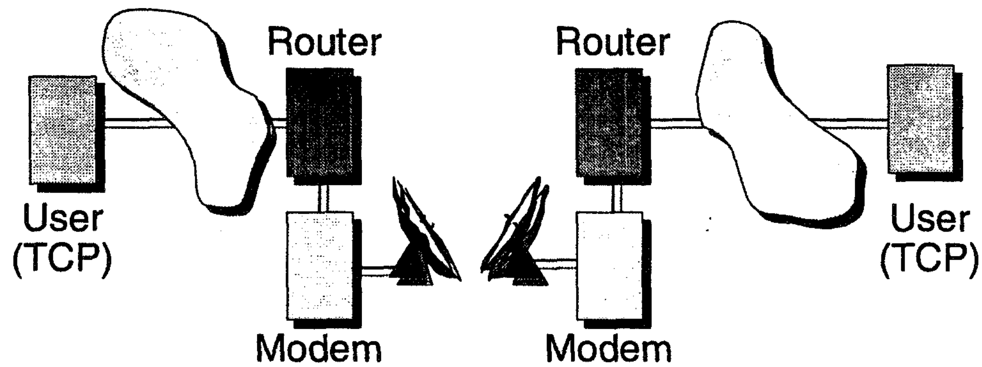
People designing modems

- Mobile terminals
- Transportable / rapid deployed terminals
- Terminals suffering interference
- High availability systems

People refining TCP

"Normal" Satellite Links

G. Fairhurst



TCP, routers and modems operate independently

TCP Link Performance

G. Fairhurst

Observation

Packet loss due to link errors significantly reduces performance

TCP Issues

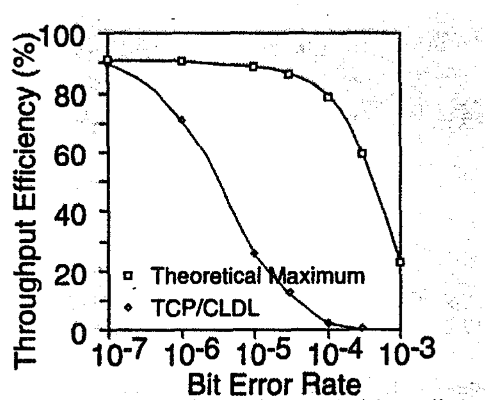
Optimised for congestion loss

Can be improved by

Modifying TCP

Improving modem

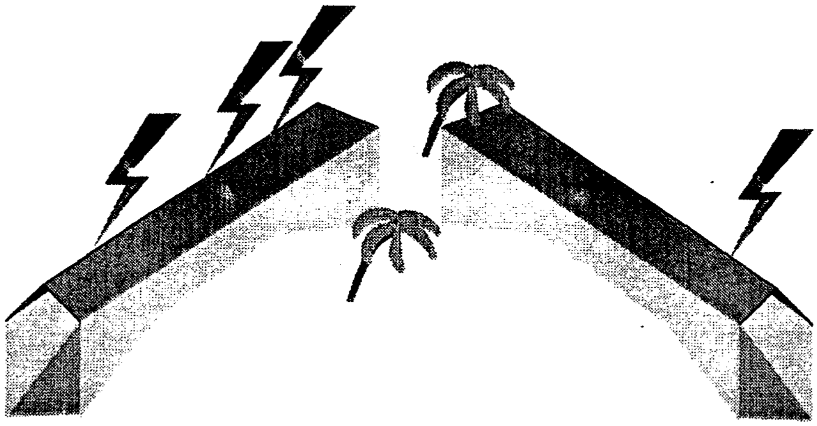
Link layer ARQ



Simulation results using a 64kbps link with 280ms propagation delay

Solution 1: FEC

G. Fairhurst



May achieve any BER

Need to identify worst case Eb/No

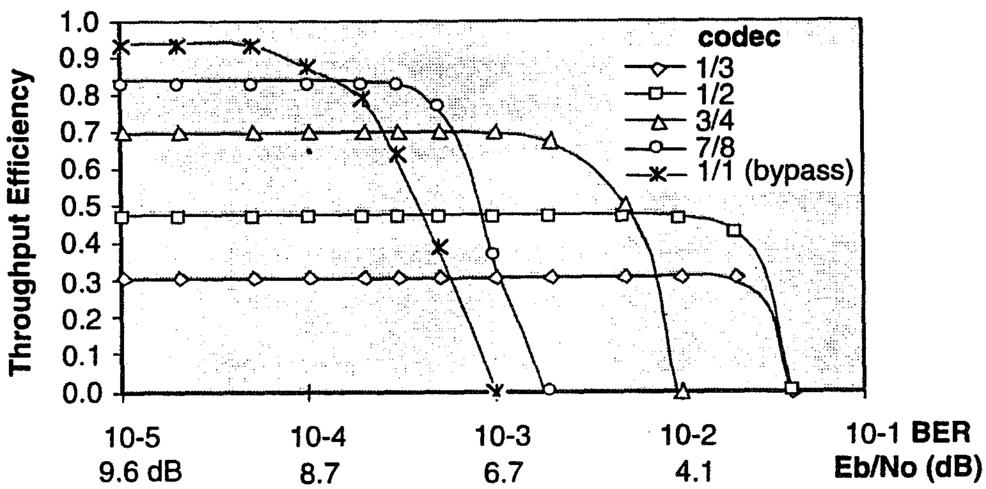
Issues

Overhead

Outages

How Much FEC?

G. Fairhurst

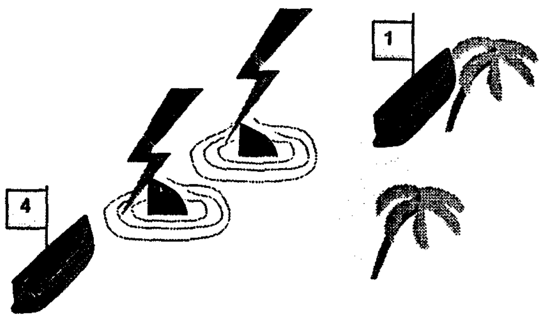


Use as much FEC as you like
- but still pay for it when you don't need it.

For 99.9% of time little may be needed

Solution 2: Link ARQ

G. Fairhurst



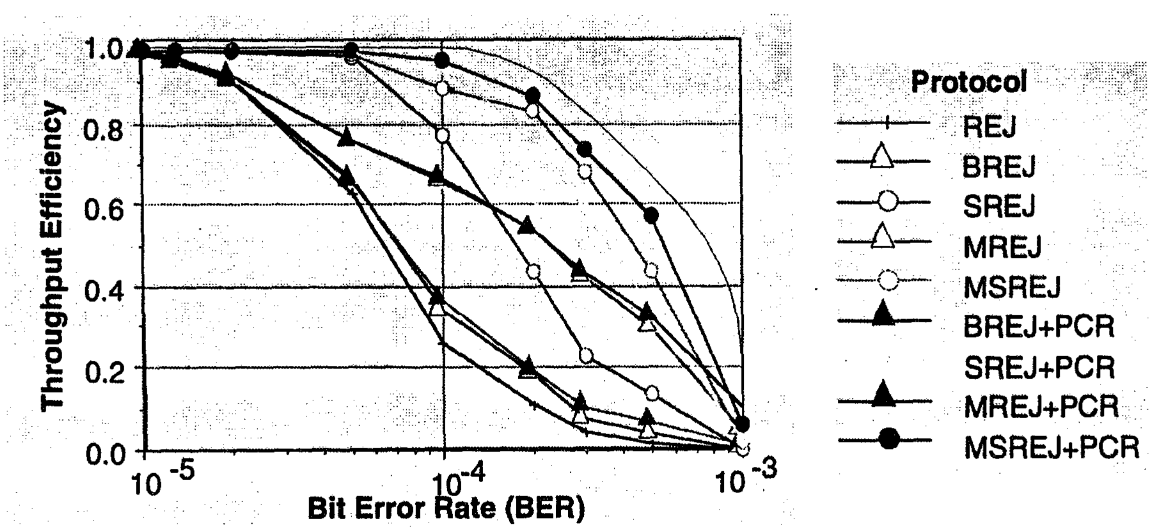
Link ARQ may provide reliability

Issues

- Packet overhead
- Variable delay
- Utilisation

HDLC Link ARQ

G. Fairhurst



Large selection of known ARQ techniques

Strictly Reliable Link Protocol

G. Fairhurst

Observation

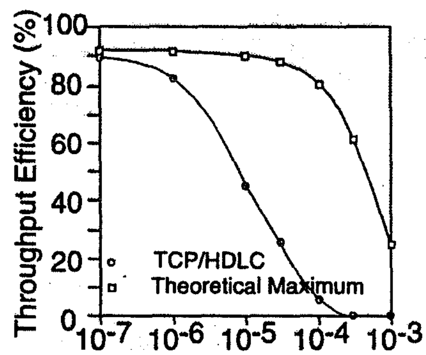
Performance not much improved

Strict reliability guarantees

No loss (i.e. error recovery)

No duplication

Sequence delivery



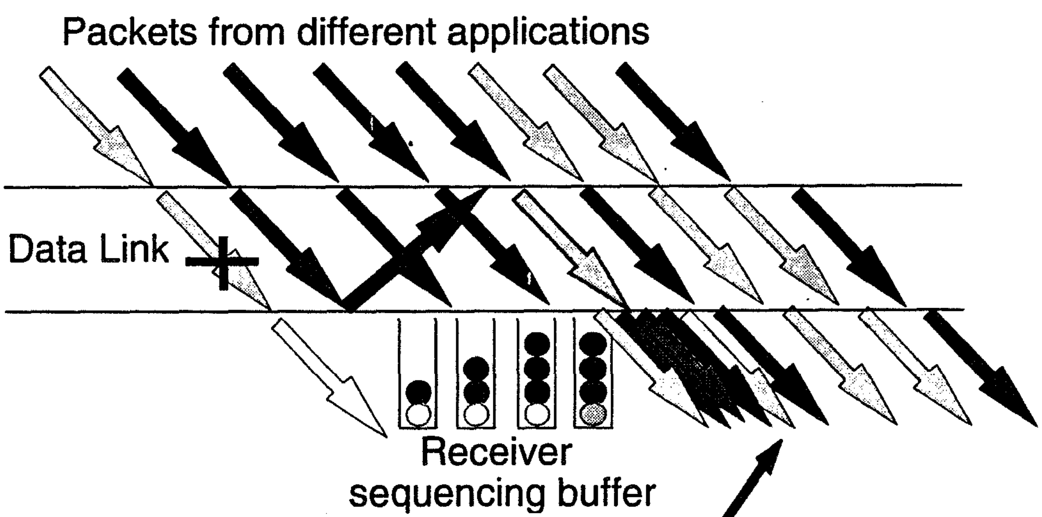
Simulation results using a 64kbps link with 280ms propagation delay

Issue

Delay due to link protocol sequencing and recovery

Sequencing and Recovery Delay

G. Fairhurst



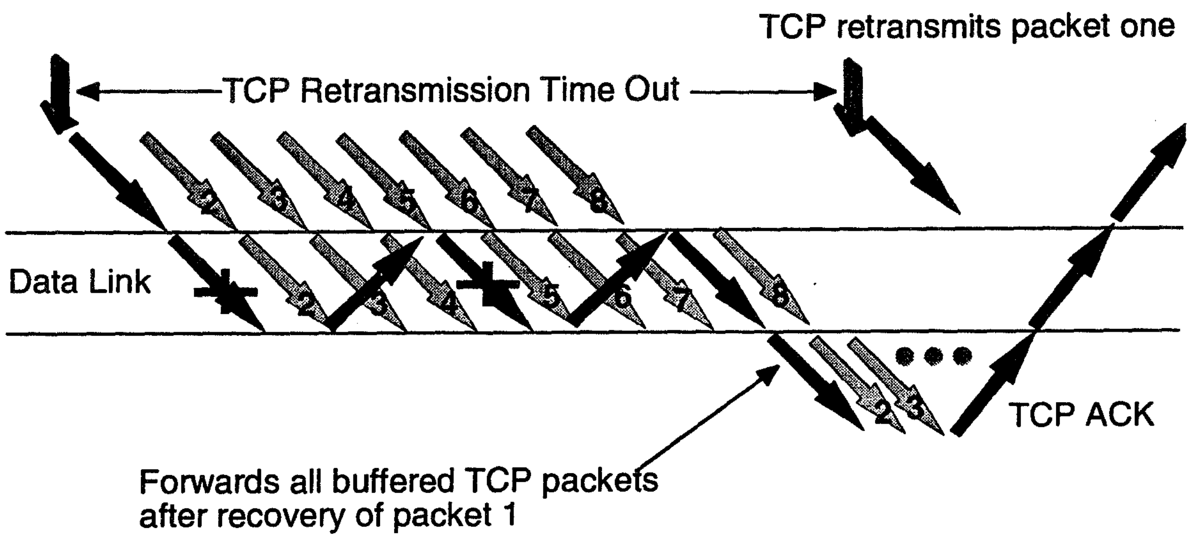
Delay due to error recovery

Delay due to sequencing

Interaction between different applications

TCP / Link Interaction

G. Fairhurst



End-to-end (e.g. TCP) and link (e.g. HDLC) error recovery interac

A Robust Data Link

G. Fairhurst

TCP doesn't need strict reliability

Needs timely delivery

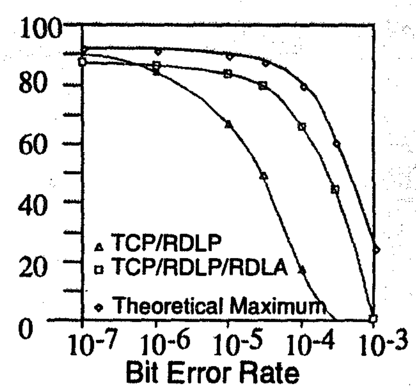
Efficient error recovery (RDLP)

Limit number of retransmission requests

Provides out of order delivery

Segmentation (RDLA)

Transparent segmentation



Simulation results using a 64kbps link with 280ms propagation delay

Solution 3: Integrated Modem

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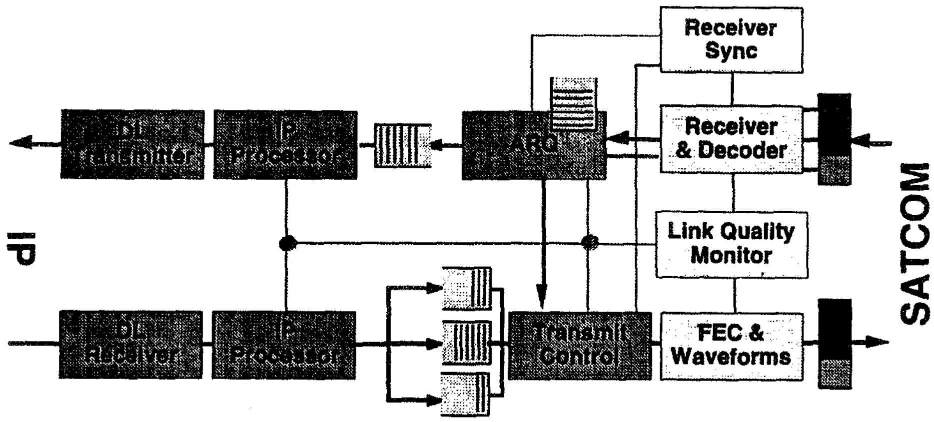


Options

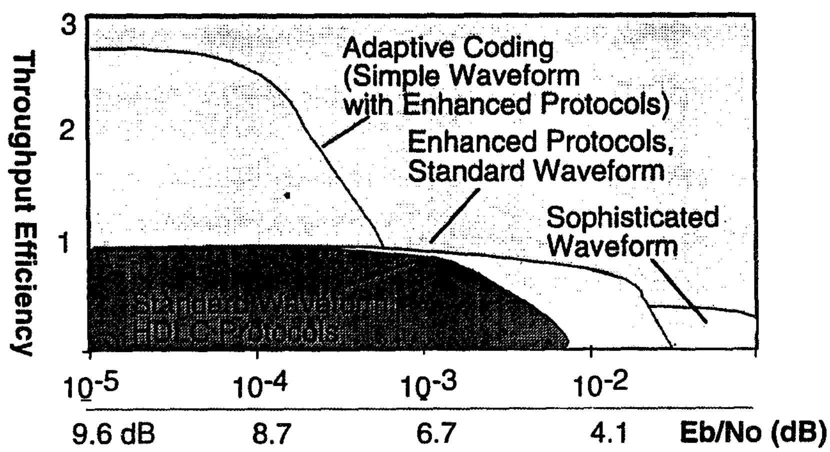
Modulator may pick from range of options (Eb/No)

Demodulator knows much about channel state

There is a great deal of synchcnisation

Adaptive FEC: Smart Codec

G. Fairhurst



May adapt modem waveform to channel state

For 99% time the channel may be benign

Issues

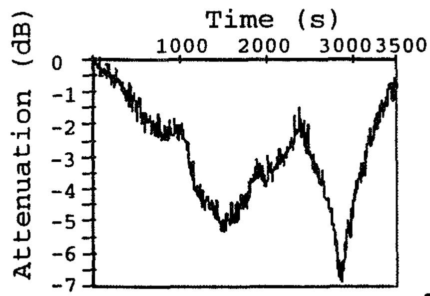
Channel state estimation

Best effort service (also needs FEC/ARQ)

Capacity of link varies

Adaptive FEC

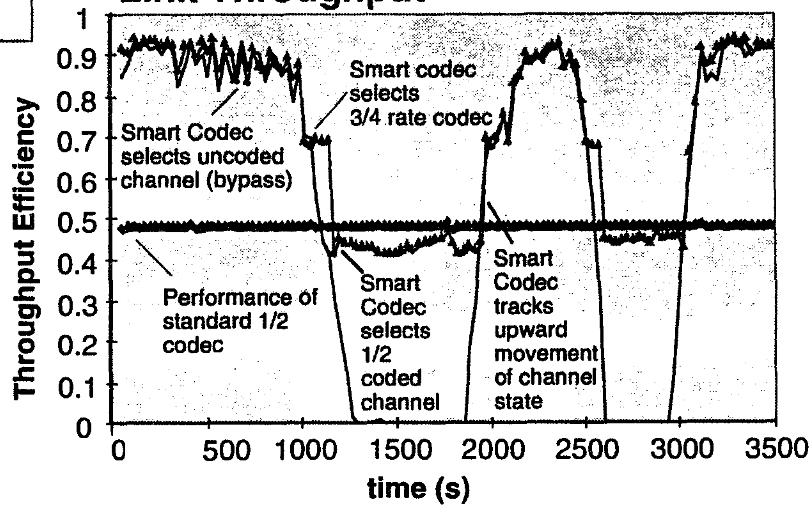
G. Fairhurst

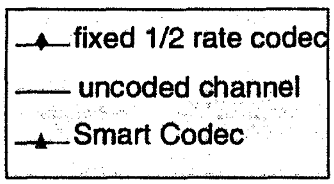


Typical Rain Fade

Adaptive FEC:
- Improves clear sky performance
- Varies path capacity
- Accepts some loss

Link Throughput





Where Next?

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Link Adaption (with partial reliability)
- Modulation
- FEC
- ARQ

Link Indication to TCP
- Explicit loss
- Path change indication
- Congestion indication

TCP Modifications
- SACK
- RTO calculation
- Loss differentiation
- Start-up behaviour

Conclusions

G. Fairhurst

Satellite links may be made error-free

FEC

Strict Reliability

Outages may still be possible

Performance tradeoffs exist at various layers

Link must complement TCP behaviour

TCP doesn't need strict reliability

Delay variation should be limited

Interaction between applications minimised

It would be nice if TCP were smarter :-)

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G. Fairhurst

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Multiple Priority Distributed Round Robin ATM Satellite MAC Protocol

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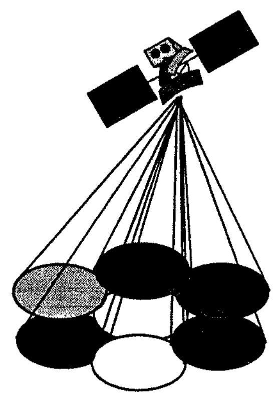
Multiple Priority Distributed Round Robin Introduction

- ATM Processing Satellite Description
- Traffic Types
- Satellite ATM MAC Challenges
- Proposed MAC Protocols for Satellite ATM
- MPDRR Description
- MPDRR OPNET™ Simulation Results

Multiple Priority Distributed Round Robin
Processing Satellite Technology

- Multiple Spot Beams
- Digital On Board Processing
- On Board Fast Packet Switch
- MF-TDMA Uplinks, TDM Downlinks
- Many Terminals Sharing the Uplink Bandwidth



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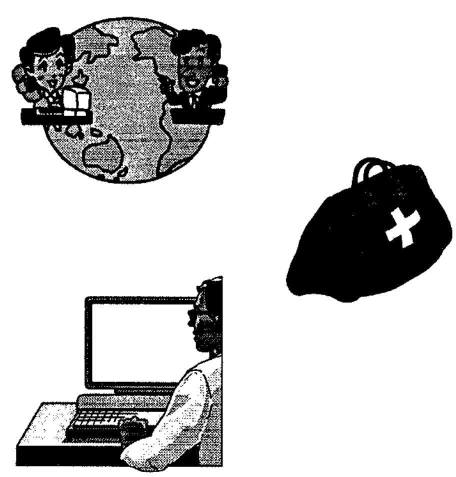
Multiple Priority Distributed Round Robin
Examples of Services

- Voice
- Video
- LAN Interconnection
- Telemedicine
- Internet Access
- Telecommuting



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Multiple Priority Distributed Round Robin ATM Traffic Classes

- Constant Bit Rate (CBR)
- Variable Bit Rate - real time (VBR-rt)
- Variable Bit Rate - non real time (VBR-nrt)
- Available Bit Rate (ABR)
  - Higher Priority for Minimum Cell Rate (MCR)
- Unspecified Bit Rate (UBR)
  - Higher Priority for UBR+ Guaranteed Rate
- ATM Signaling

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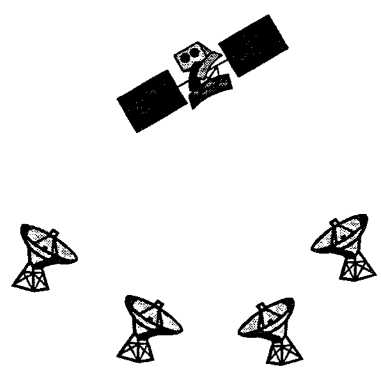
Multiple Priority Distributed Round Robin Satellite ATM MAC Protocol Challenges

- Satellite Terminals Need to Share Uplink Bandwidth
- Bursty Data Traffic Requires Flexible Bandwidth Allocation (Bandwidth-on-Demand)
- Random Access Protocols Perform Poorly During High Utilization and Cannot Provide QoS Guarantees
- MF-TDMA Uplinks Increase MAC complexity compared to TDMA



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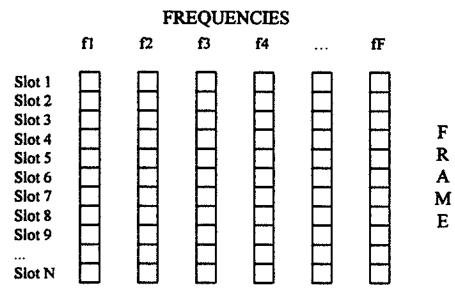
Multiple Priority Distributed Round Robin Satellite ATM MAC Protocol Challenges (cont.)

- MF-TDMA Frame Structure
- Terminals Can Only Transmit on One Frequency at a time, i.e., Slot Assignments Must Not Overlap in Time
- Each Terminal Can Be Assigned Up to N Slots



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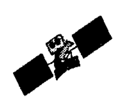
Multiple Priority Distributed Round Robin Satellite ATM MAC Protocol Challenges (cont.)

- Satellite Mass and Power Restrictions Limit On-Board Complexity
- Terminals Complexity is Limited by Cost Constraints
- The Propagation Delay of Geostationary Satellites Impacts MAC Performance



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Multiple Priority Distributed Round Robin
Proposed ATM Satellite MAC Protocols

- **Protocols**
  - CFDAMA[1]
  - Distributed Access Protocol[2]
  - Hierarchical Round Robin[3]
  - Round Robin Reservation DAMA[4]
- **Areas for Improvement**
  - Most Protocols Designed for TDMA Uplinks
  - MF-TDMA Slot Assignments Not Addressed in the Literature
  - Only Round Robin Reservation Designed for Distributed Control

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[3] A. Hung, M.-J. Montpetit, G. Kesidis, "ATM via Satellite: A Framework and Implementation," *Wireless Networks*, Vol. IV, No. 2, 1998
[4] S. L. Kota, J. D. Kallaus, "Reservation Access Protocol for Multiplanar ATM Switched Satellite Network (MASSNet)," *MILCOM '94*

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Multiple Priority Distributed Round Robin
MPDRR Overview

- **Multiple Priority Distributed Round Robin (MPDRR) Protocol Developed**
- **Designed for (But Not Limited To) Use in ATM Over Geostationary Satellites With MF-TDMA Uplinks**
- **Designed for Distributed Control, but Will Also Work With Centralized Control**
- **OPNET Model Built for MPDRR Simulation**

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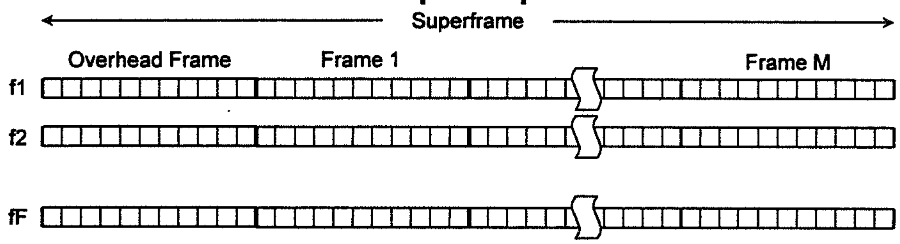
Multiple Priority Distributed Round Robin
MPDRR Superframe Structure

- F Frequencies
- N Slots per Frame
- M Data Frames per Superframe
- One Overhead Frame (Request Slots) per Superframe
- NxF Total Data Slots per Frame
- NxFxM Total Data Slots per Superframe



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Multiple Priority Distributed Round Robin
MPDRR Slot Allocation and Assignment

- MPDRR Performs Slot Allocation First, Then Slot Assignment. All Slots Are Re-allocated and Assigned Every Superframe to Simplify Assignment Processing.
- Slot Allocation: Calculate the Number of Slots to be Assigned to Each Terminal
  - Terminals Assigned up to N Slots
  - Slots Allocated Based on Request Priority
- Slot Assignment: Slot Frame Position (Time) and Frequency for Each Terminal Is Calculated
- Slot Assignments Are the Same for Every Frame in the Superframe

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Multiple Priority Distributed Round Robin
Sequential Slot Assignment

- Sequential Slot Assignment Guarantees No Frequency Overlap
- No Wasted Slots Because All Slots Re-assigned Every Superframe
- Simplicity Enables Distributed Control
- Terminals Must Change Frequencies Within a Frame

F1	T1	T1	T1	T1	T1	T1	T1	T1	T2	T2
F2	T2	T2	T2	T2	T2	T2	T3	T3	T3	T3
F3	T3	T3	T3	T3	T4	T4	T4	T4	T4	T4
F4	T4	T4	T5	T5	T5	T5	T5	T5	T5	T5

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Multiple Priority Distributed Round Robin
MPDRR Overview

- Terminals Calculate the Number of Slots to Request for Each Priority
- Terminals Transmit Request Messages in Assigned Overhead Slots
- The Satellite Receives Request Messages and Transmits Them on the Proper Downlink
- Terminals Receive and Sort Request Message From All Terminals in Their Group
- Terminals Calculate the Slot Allocation for Each Terminal, for Each Level of Priority Using a Round Robin Algorithm
- Terminals Calculate the Slot Assignment for Each Terminal (Time and Frequency) Using the Sequential Assignment Algorithm
- Terminals Transmit on Their Assigned Slots Starting With the Next Superframe

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Multiple Priority Distributed Round Robin
MPDRR OPNET Preliminary Simulation Results

- **One, Two, Four and Eight 384 kbps Uplink Channels**
- **Markov Modulated Poisson Process (MMPP) Used as Bursty Traffic Sources**
  - Peak Bit Rate = 128 kbps
  - Mean Burst Length = 16250 bytes
  - Activity Factor = 0.1
- **Uplink Delays Only on Charts**

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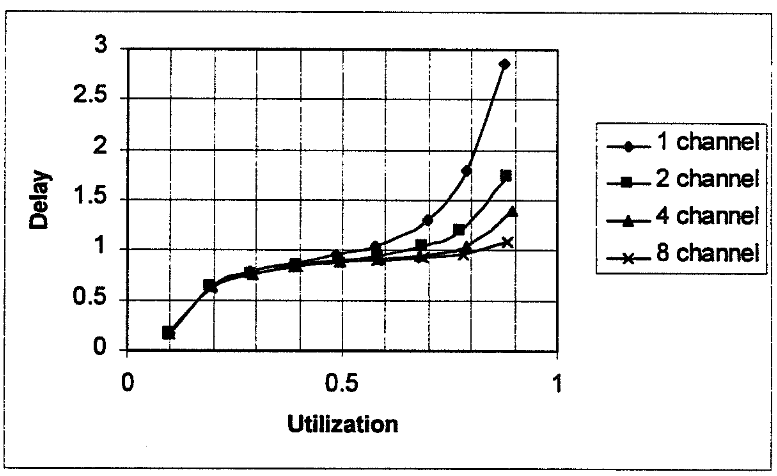
Multiple Priority Distributed Round Robin
Extra Slots Allocated Fairly to all Terminals



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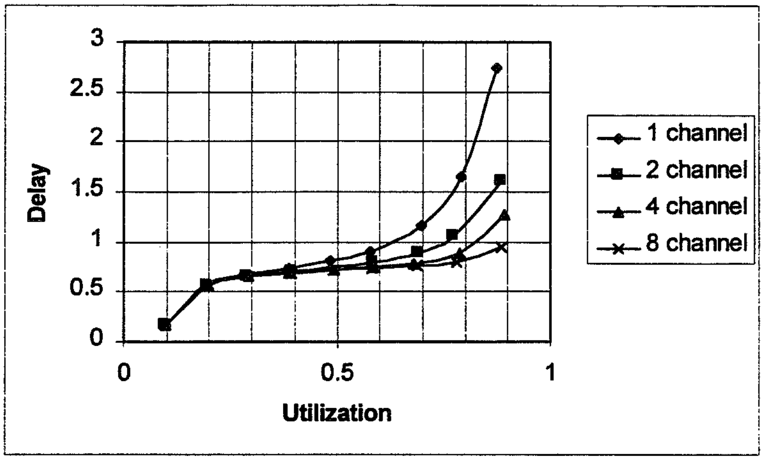
Multiple Priority Distributed Round Robin
Extra Slots Allocated to Active* Terminals First



* Terminals with pending slot requests

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Multiple Priority Distributed Round Robin
Conclusions

- **ATM Processing Satellites with MF-TDMA Uplinks Require a New MAC Protocol**
- **MPDRR Is a Candidate MAC for Satellite ATM**
- **Preliminary Simulation Results Demonstrate the Benefit of Sharing Uplink Channels**
- **Further Analysis and Simulation Planned**

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Center for Satellite and Hybrid Communication Networks

Flow Control and Dynamic Bandwidth Allocation in DBS-Based Internet

John S. Baras
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University Of Maryland
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and

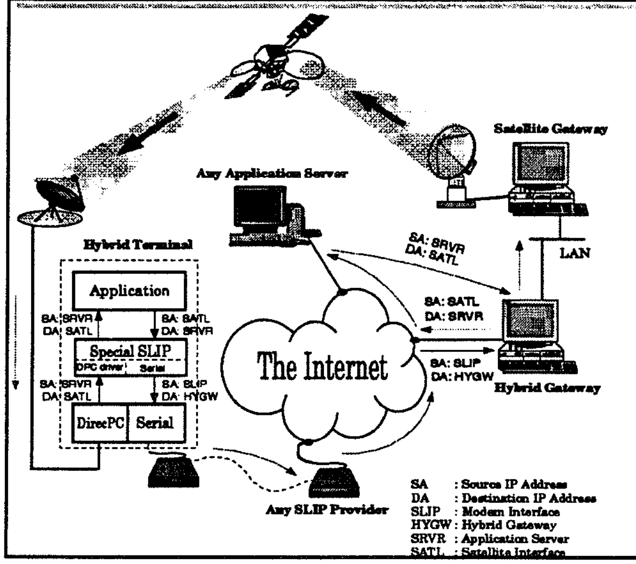
Gabriel Olariu
Hughes Network Systems

Satellite Networks: Architectures, Applications and Technologies
NASA Lewis Research Center
June 3, 1998

DBS - based Hybrid Internet Service

- **Conventional Internet access either too slow or too expensive**
- **DirecPC Turbo Internet™**
  - conceived and designed by the University of Maryland
  - productized and marketed by Hughes Network Systems
- **Awards**
  - 1994 Outstanding Invention of the Year, Univ. of Maryland
  - ComNet '96 New Product Achievement Award (wireless)
  - 1996 "Hot Product", network services, Data Comm. Magazine
  - 1996 Technical Excellence Award (Net. Hardware), PC Mgzine

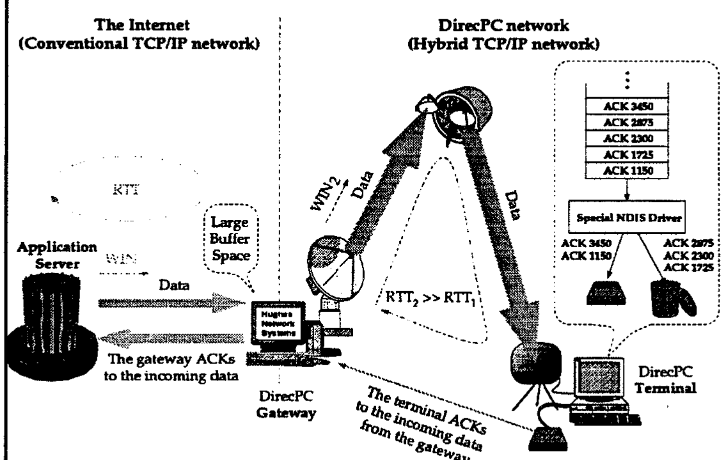
DBS-based Hybrid Internet Service



- Works with any COTS TCP/IP stack, ISPs
- Attached to the Internet through any SLIP
- Traffic to HGW using IP- within -IP encapsulation
- Hybrid Gateway
  - Decapsulates traffic
  - Performs tasks on behalf of HTs for better throughput
- 500 kbps return

DBS-based Hybrid Internet Service: Performance Bottlenecks

A partially observed control problem

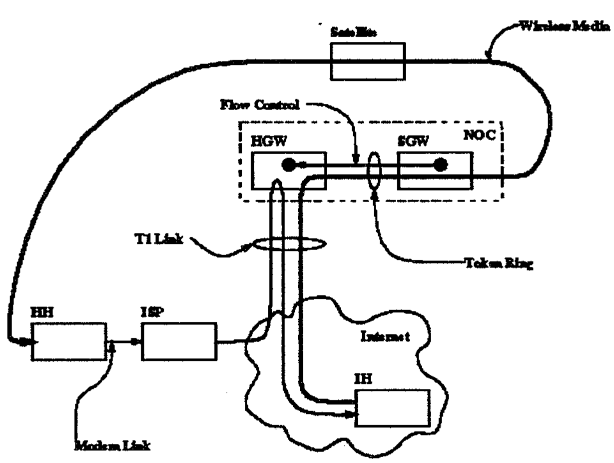


- Problems:
  - TCP over large delay-bandwidth product channels
  - Large No of ACKs
- Solutions:
  - TCP spoofing
  - SACK

Hybrid Internet Service: Extensions

- **Two IETF WGs: TCP over Satellite and Unidirectional routing**
- **Intelligent asymmetric data transmission**
  - Low data-rate (or "short length") via terrestrial
  - High data-rate (or "bulky") via satellite
- **Terrestrial LAN extension of DBS-based Internet**
  - Distribute DBS services from a single receiver to multiple users
  - Satellite hybrid hosts can redistribute data to mobile users
  - "Local loop" anything: Ethernet, ATM, cable TV, wireless
- **Reliable multicast over hybrid networks**
- **Hybrid Internet service over other hybrid network architectures**

Architecture of the Hybrid Internet Service Network

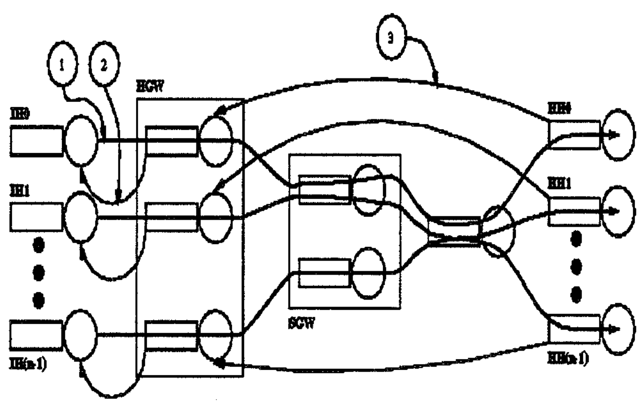


- •HH: Hybrid Host
- •IH: Internet Host (Server)
- •ISP: Internet Service Provider
- •HGW: Hybrid Gateway
- •SGW: Satellite Gateway
- •NOC: Network Operations Center

Network Operations Center (NOC) for Hybrid Internet Service

- **Congestion control :** TCP and TCP Spoofing
  Satellite channel bandwidth allocation
- **HGW : first NOC object that receives data (Router)**
  - HGW prioritizes Hybrid Internet traffic
- **SGW jobs : mixture of Internet and exogenous traffic**
  - Exogenous traffic: package delivery and data feed traffic
  - SGW maintains four queues : two for package delivery and data feed
    two for the two priority levels of Internet
- **Exogenous traffic high priority : fluctuations in bandwidth allocated to Hyhrid Internet**
- **Self-similar traffic: Interactive users as ON-OFF processes**

Flow Control Analysis Model



(1) Data connection:
IS sends data to corresponding HH

(2) Acknowledgments:
From HGW to IS

(3) Acknowledgments:
From HH to HGW

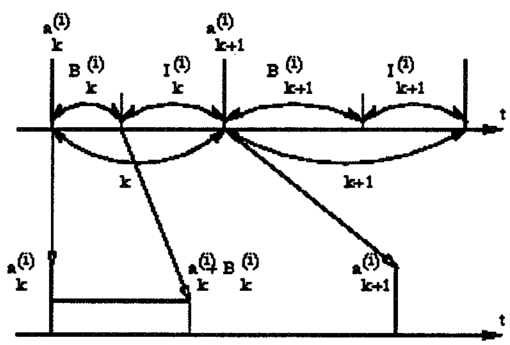
SGW has two queues:
High priority
Low priority

SGW policy: if the number of un-acknowledged bytes for a connection is less than a configurable, but fixed, threshold value, then these packets are high priority

Source Traffic Model

Problem:

- **Independent sources $IS^{(i)}$, i=1, 2, ..., M, send data to HHs via NOC**
- **Find maximum M allowed without producing overflow in the NOC**



$O_k^{(i)} = B_k^{(i)} + I_k^{(i)}$

$B^{(i)}, I^{(i)}$: **Pareto, fin. mean, inf. variance**

Arrival epochs : $a_k^{(i)}$

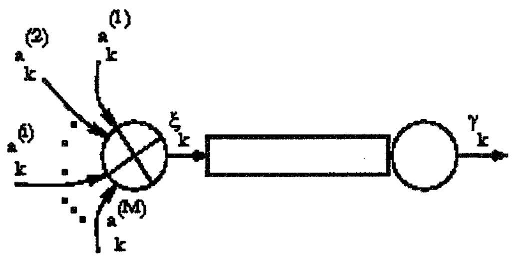
Packet generation rate

$$\lambda_k^{(i)} = \begin{cases} \mu_{IS}, & \text{if IS busy} \\ 0, & \text{if IS iddle} \end{cases}$$

The Aggregate Process in the Limit of Many Sources

- **Average rate :** $E\left[\lambda_k^{(i)}\right] = \mu_{IS} \dfrac{\mu_B}{\mu_B + \mu_I}$
- **Aggregate arrival traffic: integer valued random point process**
  $$a(M) = \{a_k(M) | k \in Z\}$$
- **Marked point process (Mark = duration of busy period)**
  $$(a(M), B(M)) = \{a_k(M), B_k(M) | k \in Z\}$$
- **Likhanov *et al (1995)*: Take limit as $M \to \infty$, so that**
  $\lambda = M/(E[B]+E[I]) = const.$, $E[B] = const.$ **and** $E[I] \longrightarrow \infty$
  - $\xi_k(M)$ = **No of busy periods arriving at a generic queue at time k**
  - $\xi_k(M)$ **tends to a Poisson with rate**
  - In (a_s, B_s), B_s **is independent from** a_s **and** ξ_s

The Service Facility (NOC)



- **Each arrival has service requirement γ_k**
- **Aggregate traffic shares buffer space**
- **Source level analysis**

- **For individual source we have a G/D/1 queue (constant packet size)**
- **Aggregate traffic is Poisson for large M: So we have a M/G/1 queue**
  - Solve for the stationary state-occupancy probabilities
  - State $X=\{x_{k_i} | k_i \in Z$ = No of sources in the queue at time k_i
  - Arrival process : the aggregate process ξ_{k_i} with rate λ
  - Service process, heavy tailed, Pareto; Stationarity if $\rho = \lambda\mu_B < 1$

The Service Facility (NOC)

- **Probability that *i* new sources will enter queue during one busy period; Used in network dimensioning: An estimate for the No of connections that can be busy during a typical ON period**

$$p_i = \sum_{j=1}^{\infty} P[B=j] \frac{(j\lambda)^i}{i!} e^{-j\lambda}$$

- **Balance equations**

$$q_i = P[X_k = i] \qquad q_0 = 1 - \lambda\mu_B$$

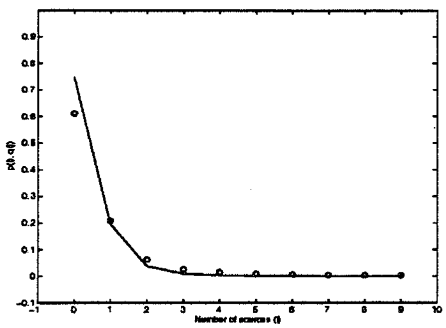
$$q_{j+1} = \frac{1}{P_0}\left[q_j - \sum_{j=1}^{j} p_i \, q_{j-i+1} - p_j \, q_0 \right]$$

- **Packet level analysis: loss probability in finite capacity queue (Likhanov)**

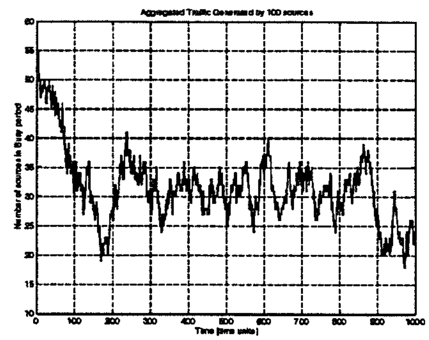
$$P_{loss} \approx \frac{c}{\alpha(\alpha+1)} \lambda^{\alpha} (R\mu_B)^{1+\alpha} L^{1-\alpha}$$

L = buffer length in packets

NOC Simulation Results



Probability that a large number of sources will joint the queue during a busy period
Prob. of No of sources in queue decreases algebraically fast



100 sources aggregated.
Each source: 1 packet / simulation clock
No of sources in busy state at any moment

NOC: Bandwidth Allocation Strategies

- **All strategies: controller knows (per connection) queue status**
  - Demand at time t : No of packets in queue not sent and unACK, and No of packets that have just arrived
  - Queue length used to determine buffer availability for newly arrived packets
- **Three strategies investigated:**
  - Equal Bandwidth allocation (EB)
  - Fair Bandwidth allocation (FB)
  - Most Delayed Queue Served First Bandwidth allocation (MDQSF)
- **In EB demands may be zero for many instants: waste of BW**
- **FB better for connection requests and min. waste of BW**
- **MDQSF is best**

NOC: Bandwidth Allocation Strategies

- **Equal Bandwidth Allocation (EB)**
  - Step 1: Find the number of connections with non-zero demand
  - Step 2: Allocate the whole bandwidth equally to connections in the set generated at Step 1
- **Steps 1, 2 performed on-line. Necessitates large computing resources for simulation and for real-world implementation**
- **Demands may be zero for a large set of clock instants**
- **Positive impact on delay, but significant waste of bandwidth**

NOC: Bandwidth Allocation Strategies

- **Fair Bandwidth Allocation (FB)**
  - Step 1: Find number of connections with non-zero demand
  - Step 2.1: If sum of individual demands ≤ total bandwidth, allocate as requested; END
  - Step 2.2: If sum of individual demands > the resource capacity, go to Step 3
  - Step 3: Divide the total bandwidth to the number of connections in the set generated at Step 1: This generates the ***Fair Share***
  - Step 4.1: For all connections with individual demand ≤ ***Fair Share***, allocate bandwidth to cover the entire individual demand
  - Step 4.2: If cannot perform 4.1, allocate the ***Fair Share*** to all connections
  - Step 5: Find remaining bandwidth after allocating in Step 4.1, go to Step 6
  - Step 6: Re-start from Step 3 with non-zero demand connections for which bandwidth not allocated yet, and the total bandwidth as calculated at Step 5
- **Better than EB in satisfying connection requests and in minimizing the waste of bandwidth**

NOC: Bandwidth Allocation Strategies

- **Most Delayed Queue Served First Bandwidth Allocation (MDQSF)**
  - Step 1: Sort connections in the decreasing order of the delay encountered by the packet in the head of the queue
  - Step 2: Allocate bandwidth starting with the first queue in the ranking generated at Step 1
  - Step 3: Repeat Step 2 until either the entire bandwidth is allocated or, all connections have received service

NOC Simulation Experiments

- **C++ and Matlab environment**
- **Queue model accuracy:**
  - Addition of packets to the queue
  - Keeping copies of unACK messages
  - De-queueing packets
  - Packet delay monitoring
  - Queue length monitoring
- **State: queue length at the service facility**
- **Testing the three strategies:**
  - **Common input data to all strategies**
  - **Test with the same buffer space**
  - **Same total bandwidth**
  - **Same number of sources having**
    - Same succession of ON-OFF periods
    - Same const. arrival rate

- **Service facility has 5 queues, 1 for each connection**
  - Allocation of buffer space to each connection the same
- Packet received service is sent over the satellite channel; a copy is maintained for acknowledgment

NOC Simulation Experiments

- **Following quantities computed, stored and shown graphically**
- **Connection State:** Busy (1) or Iddle (0); All connections use the same constant rate
- **Queue Length (per connection)**
- **Demand:** No of packets admitted in the queue; either new packets or ones that have not received yet service
- **Bandwidth:** No of packets that a queue is allowed to output at a time; It depends on the bandwidth allocation policy; Packets sent to satellite link not deleted from queue until ACKed
- **Delay:** Delay by a packet sent out and not yet ACKed
- **ACKed:** No of packets sent and acknowledged
- **UnACKed:** No of packets sent and un-acknowledged

NOC Simulation Results

- **Comparison of Bandwidth allocation strategies**

Buffer per Connection	500 packets
Total Bandwidth	15 packets/unit time
Number of Connections	5 connections
Constant Arrival Rate	10 packets/unit time
Mean of the Uniform Arrival Rate	5 packets/unit time
Delay Imposed to Queued Packets	0.1 unit time

Common Input Data

Conn1:	1.4469	1.4468	0.0
Conn2:	2.0720	2.0720	0.5298
Conn3:	1.6941	1.6689	0.204
Conn4:	2.0541	2.0524	0.0741
Conn5:	1.7182	1.7088	0.8847
	EB	FB	MDQSF

Average Delays

- **Analytical models and simulation can be used for Network Dimensioning:**
  Estimate No. of sources that can be in the system at the same time

Session 9
TCP/IP over Satellites

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Automatic TCP Buffer Tuning

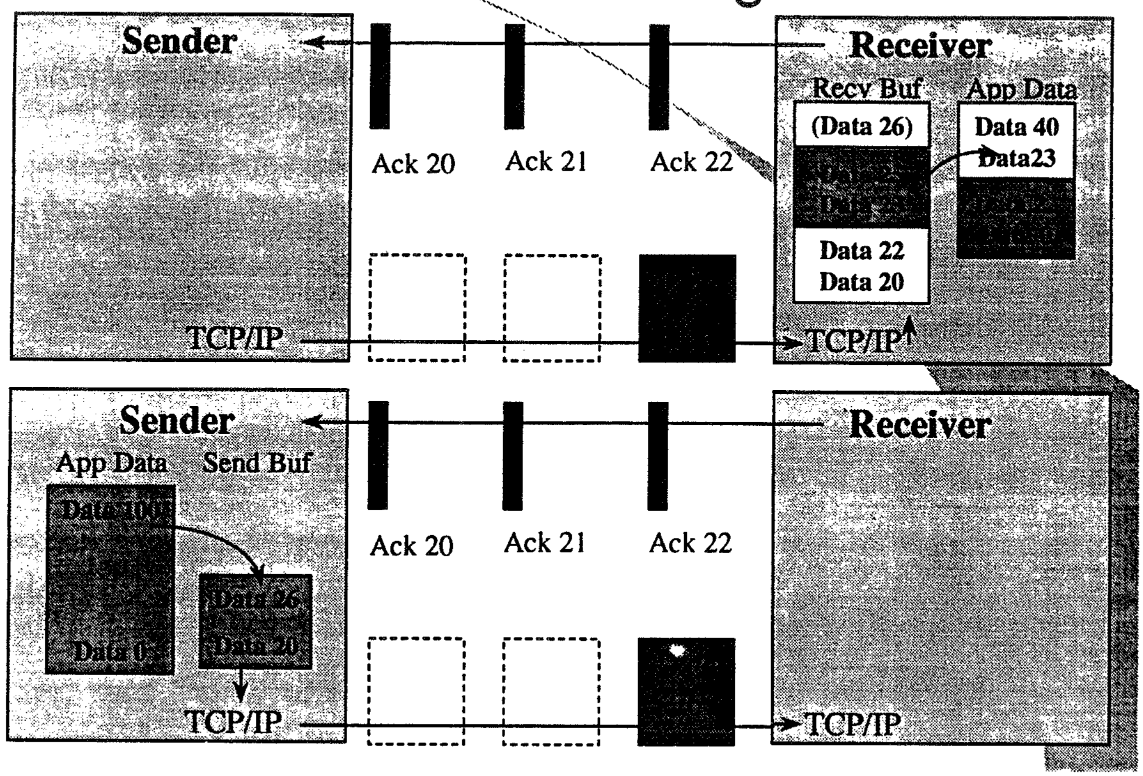
Jeffrey Semke
Pittsburgh Supercomputing Center
June 3, 1998

http://www.psc.edu/networking/auto.html

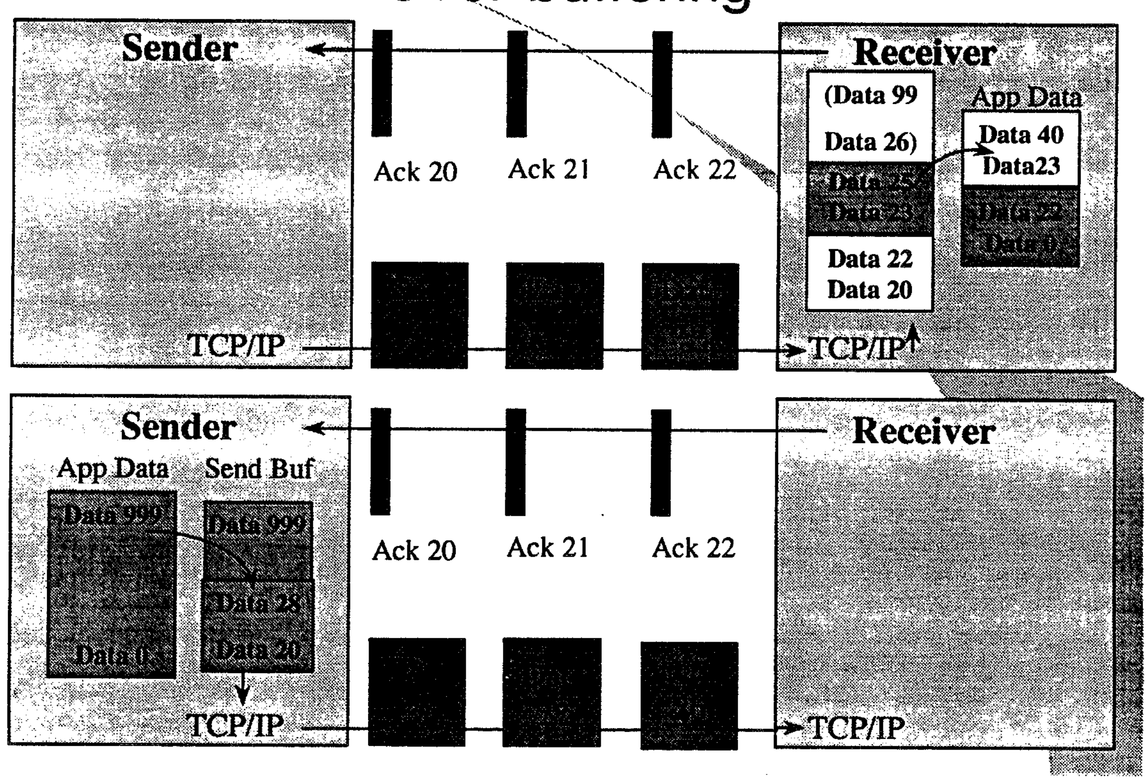
Motivation/Goals

- Conventional Tuning is not adequate
  - System-wide tuning by System Administrator
  - Hand-tuning of individual connections
- Want each TCP connection to get the best possible performance without any manual configuration
- No need to modify existing applications

Under-buffering



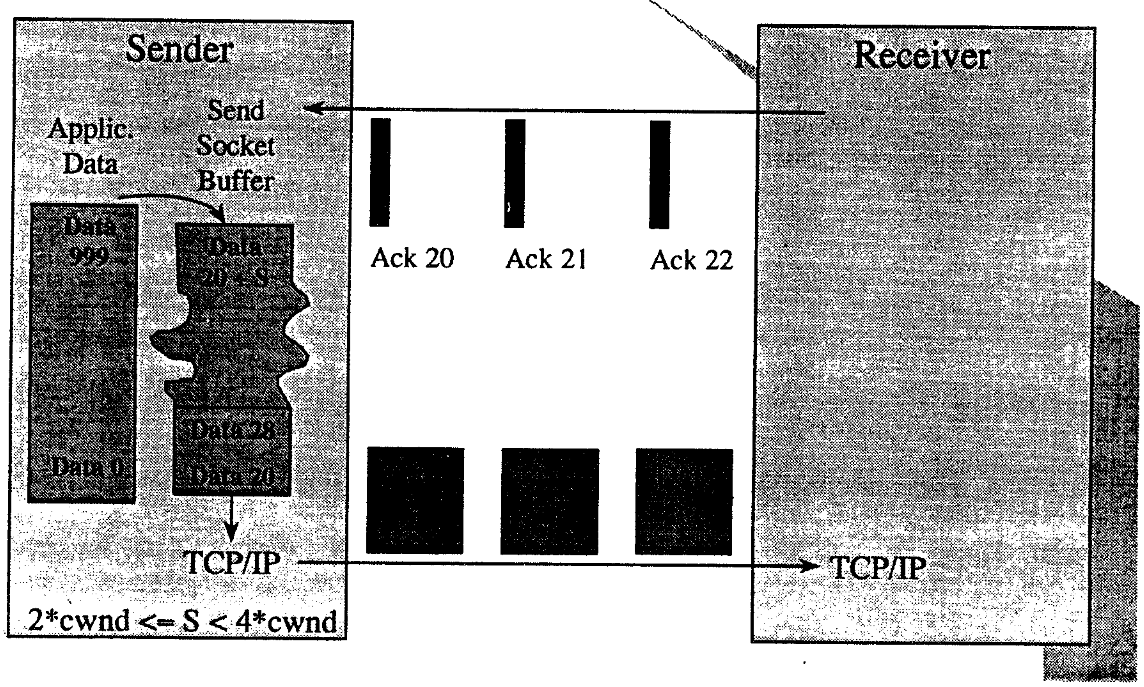
Over-buffering



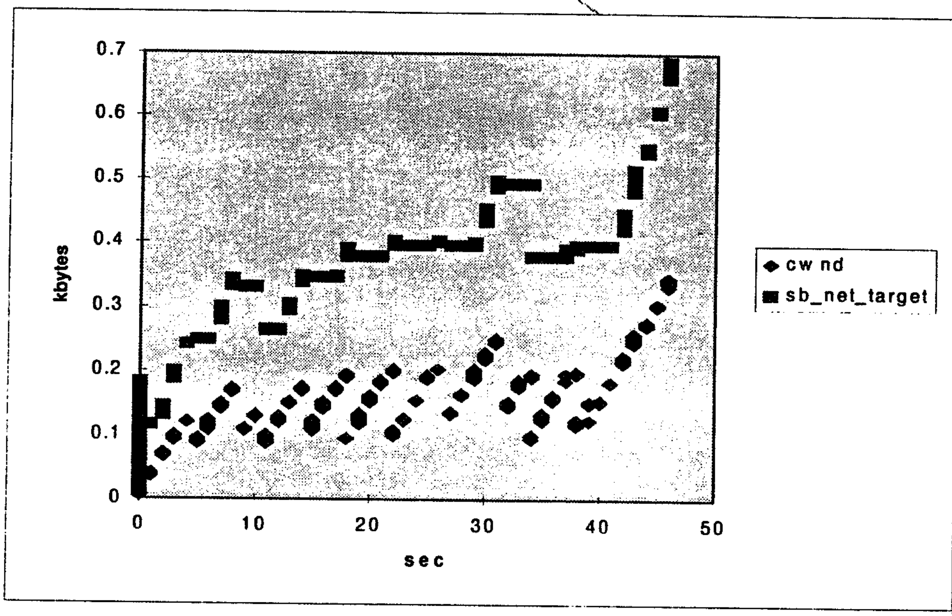
Auto-tuning

- Automatic sizing of socket buffers for TCP connections
  - no manual configuration necessary
  - prevents slow transfers resulting from inappropriately small socket buffers
  - prevents mbuf exhaustion when many concurrent connections exist
- Receiver auto-tuning same as over-buffered receive socket buffer!
  - Only the occupied part of the buffer uses memory, not the full advertised buffer size
  - Never holds more than one cwnd of data (just like if it were hand-tuned for performance!)

Sender auto-tuning based on cwnd



sb_net_target vs. cwnd over time

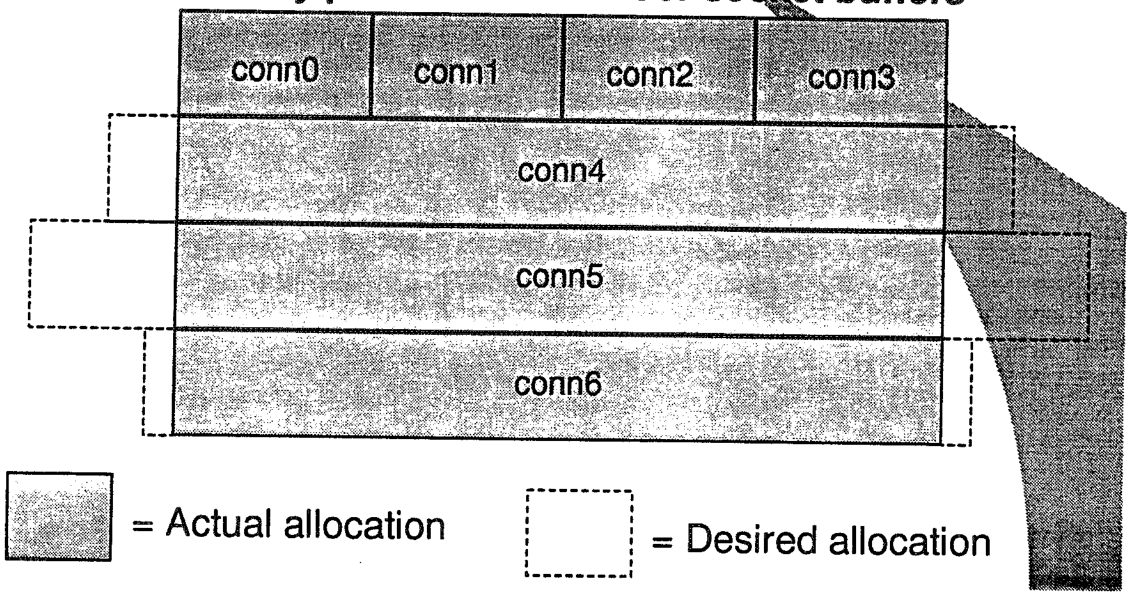


Fair Share Algorithm

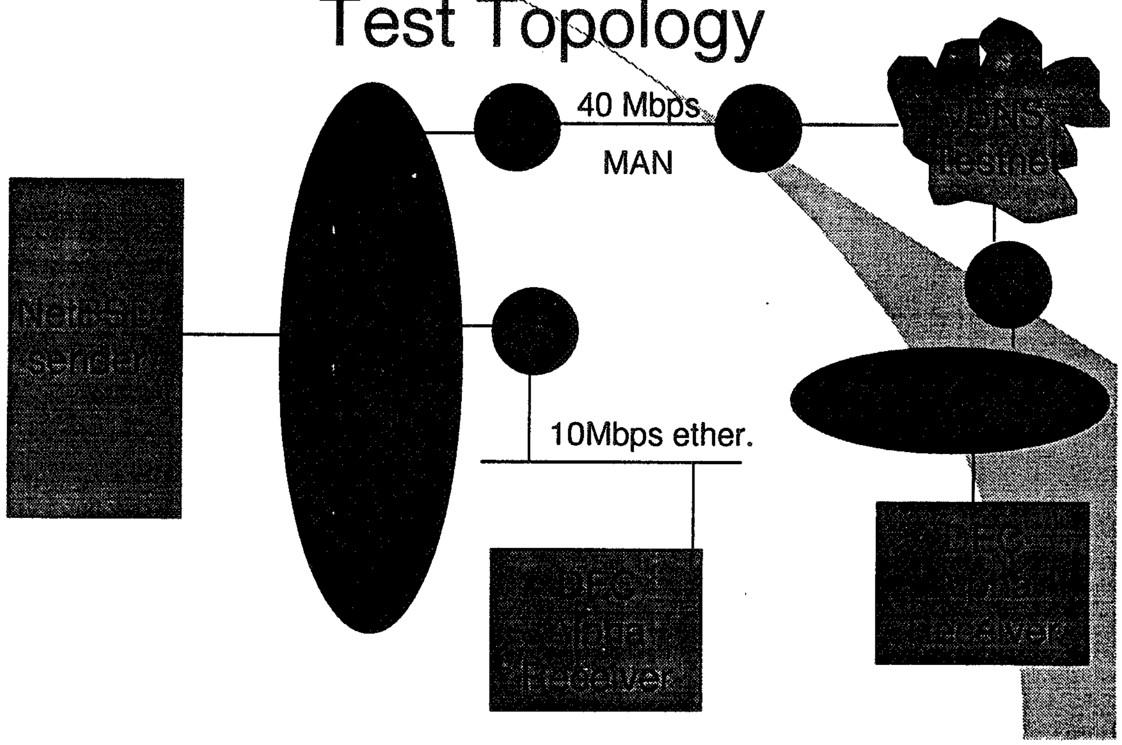
- sb_net_target indicates the intended send buffer size for a particular connection based on cwnd, but may not be attainable if memory is limited compared to needs of connections
- Small connections (sb_net_target < fair share) get the allocation they want, donating the difference to the pool for other connections to use.
- Large connections (sb_net_target >= fair share) get only the fair share.

Illustration of fair share algorithm

Memory pool for TCP sender socket buffers



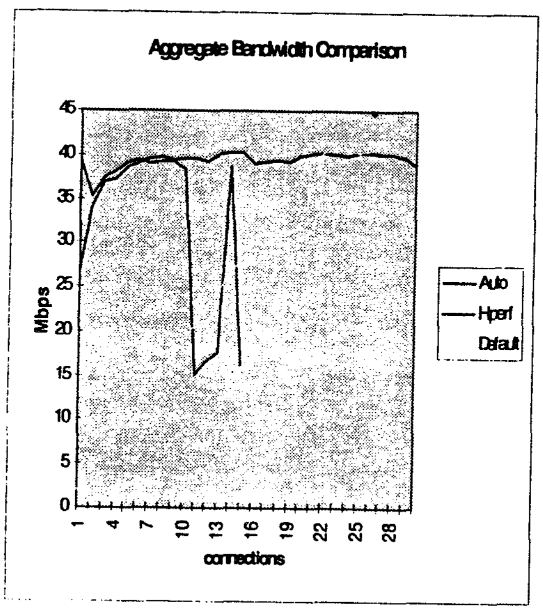
Test Topology

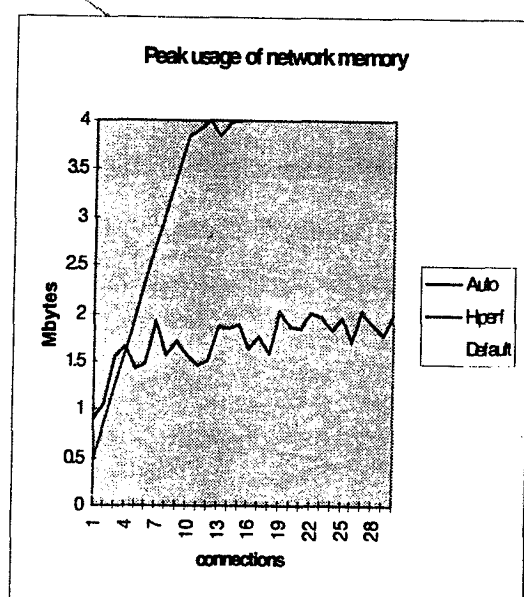


Basic Functionality Test

- From 1 to 30 concurrent connections from sender in Pittsburgh to receiver in San Diego
- 40 Mbps bottleneck link, 68 ms delay
  - 340 kB bandwidth delay product
- Under-buffered (default) tuning = 16kB send socket buffer
- Over-buffered (hiperf) tuning = 400kB send socket buffer
- Automatically tuned buffers

Basic Functionality Test

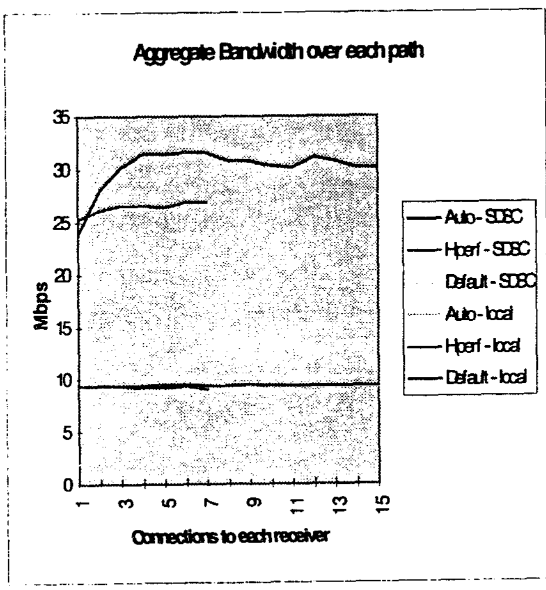


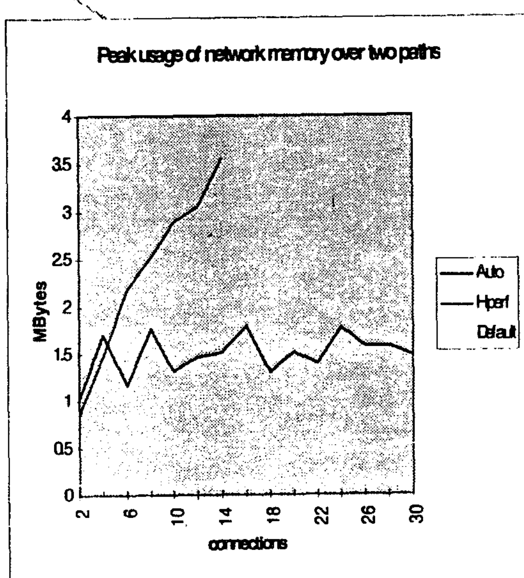


Diverse concurrent connections

- Similar to Basic Functionality Test, but half the connections now go from the Pittsburgh sender to a local Pittsburgh receiver
- Local connections have a 10Mbps bottleneck link, with ~1ms delay
  - 1.25 kB bandwidth delay product
- Same connection types

Diverse concurrent connections





Conclusion

- Better performance
- More concurrent connections
- Great for servers that have many connections over very diverse bandwidth*delay paths

Improving TCP Performance Over Mobile Satellite Channels: The ACKPrime Approach

Keith Scott and Stephen Czetty
Jet Propulsion Laboratory, California Institute of Technology
http://eis.jpl.nasa.gov/~kscott

NASA Lewis Satellite Networks Workshop
June 1998

Outline

- TCP Over Mobile Satellite Links
  - Target Application: Once a packet crosses the satellite link it's gone forever.
  - Control Loop Includes Satellite Delay
- Ways of Breaking the Control Loop at the Groundstation
  - Proxy
  - I-TCP
  - Spoofing
  - ➪ ACK'
- ACK' Implementation
  - Doesn't Break TCP End-2-End Semantics
  - Requires Few Resources at the Groundstation
  - Requires Minimal Changes to Sending TCP
  - ACK' Can Provide Corruption Notification at Little *Extra* Cost
  - IPSec Breaks ACK' Too
- Ack' Performance
  - Not as good as Proxying
  - Most Gain During Slow-Start
  - Increased ACK Traffic
  - Be Careful To Not Violate Congestrion Control

TCP

- TCP is responsible for reliable, in-order, end-2-end delivery of information without duplications.
  - Number every byte; transmit bytes along with numbers, get acknowledgments from the receiver.
- Window-Based Flow Control & Congestion Control
  - Receiver's Offered Window (Flow Control)
  - Sender's Congestion Window (Congestion Control)
  - Sender can have at most MIN(cwnd, awnd) unacknowledged packets outstanding at any one time.
- Slow-Start
  - To keep a pair with a large awnd from injecting huge bursts of traffic into the network. cwnd starts at 1 and opens by 1 packet for every ACK received.
    - Sender sends 1 packet, waits for ACK, sends 2 packets, waits for ACKs, ...
- Congestion Avoidance
  - When a loss is detected, halve the sending rate and open cwnd by 1 packet for every window of data.
- Assumptions:
  - All losses are due to congestion within the network (i.e. overflows in router queues).
  - Delay * Bandwidth product is < 64k bytes (Can be circumvented)
  - Delay is small

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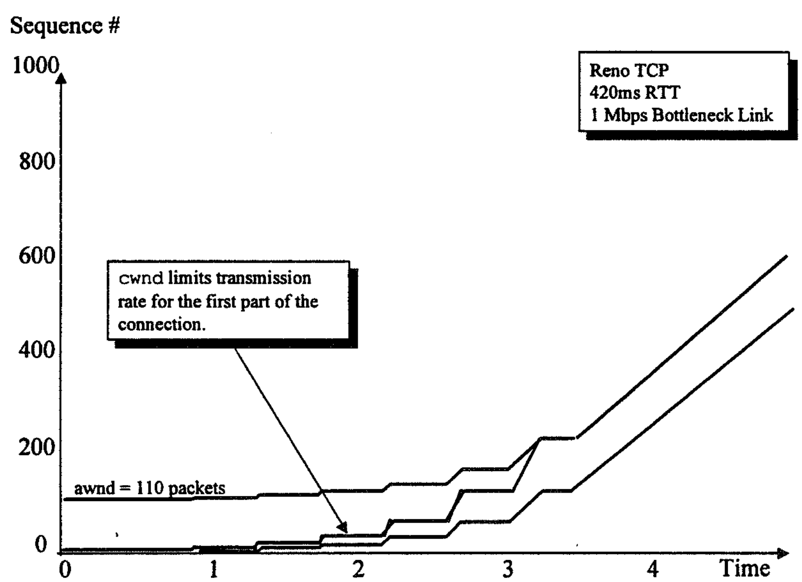
TCP Slow-Start



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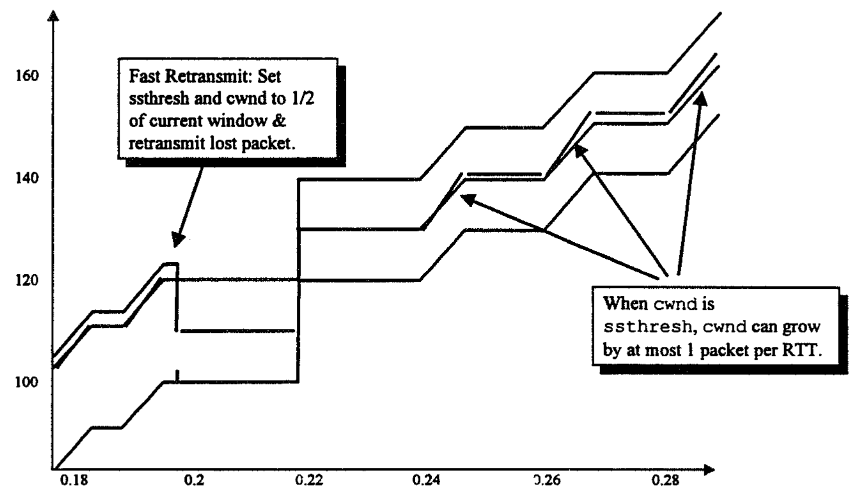
Congestion Avoidance



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TCP Over Mobile Satellite Links

- Large BW * Delay Product
  - Use RFC 1323
- Higher BER
  - Use FEC
  - Depending on *f*, can have drop-outs of 10s to 100s of ms.
- ⇨ Large Delays
  - Slow-Start is really slow.
  - Short transfers may never get out of slow-start.
  - The pipe refills at a rate of 1 packet per RTT during congestion avoidance. It can take 30s or more to recover from a loss when the session is using a geosynchronous satellite.

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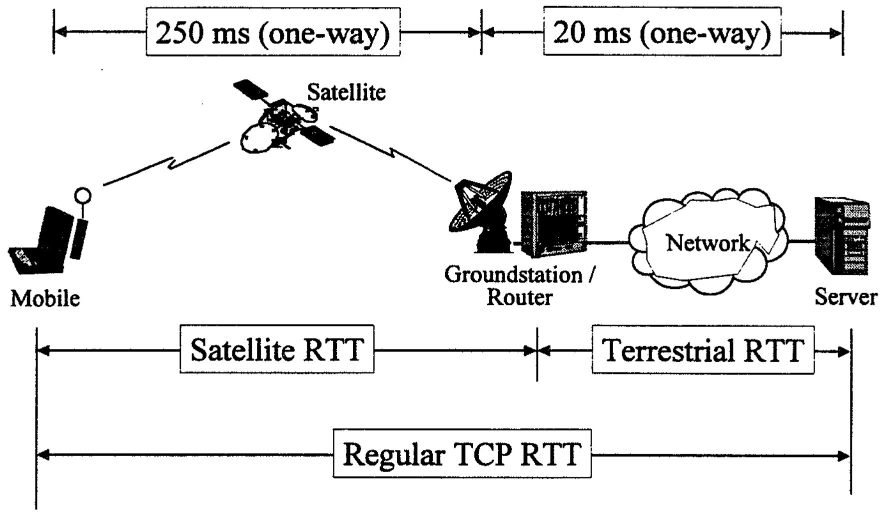
Target Application: End Users Of Satellite Links



Target Application Properties

- Once a TCP packet is forwarded towards the mobile, it has left the terrestrial network.
  - ACK' is not designed for backhaul satellite links.
- Satellite channel contains most of the delay.
- Satellite channel has higher BER than terrestrial.

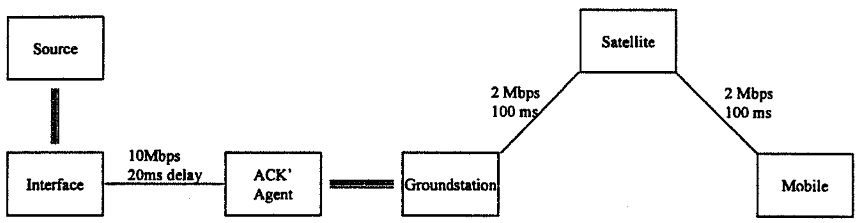
Ways of Breaking The TCP Connection At The Groundstation

- Proxy
  - The mobile places a request with the proxy, the proxy executes the request and retrieves the information, the proxy passes the information back to the user.
- Indirect-TCP (I-TCP)
  - Similar to proxying; source sets up connection with intermediate node which terminates the connection and opens a new one to communicate with the destination.
- Spoofing
  - The groundstation / gateway actually acknowledges data flowing towards the mobile and suppresses acknowledgments from the mobile towards the server. The groundstation really should take responsibility for delivering packets it has acknowledged.
- ACK'
  - The groundstation / gateway provides *extra* information to the sender, in the form of ACKPrime's.
    - Sender treats ACK' like a regular acknowledgment for the purposes of increasing `cwnd`.
    - Mobile is still responsible for acknowledging data receipt.

ACK' Implementation

- Simulated a version of ACK' in lbl's network simulator (ns).
  - Modified snoop and NewReno elements to be an ACK' gateway and an ACK'-capable sender.
  - Gateway keeps no state, it simply generates ACK' packets whenever it forwards a TCP packet across the satellite link.
  - Topology includes 10Mbps terrestrial network with 10ms delay and 2Mbps satellite network with 200ms delay.
    - No contention for the terrestrial network or buffer space yet.
    - Assumes properly tuned windows & socket buffers (http://www.psc.edu/networking/auto.html)
- Planned Improvements
  - Don't violate congestion control!
  - Use ACK' information along with regular acknowledgments to get (expensive) corruption notification.
  - Modified ACK' scheme to reduce acknowledgment traffic
  - Ways around IPSec...
- Plan a kernel implementation on JPL's mobile satellite protocol testbed later this summer.

ns implementation



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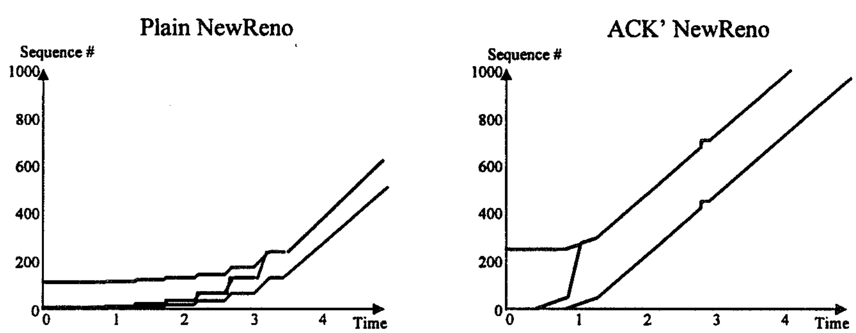
Performance During Slow-Start



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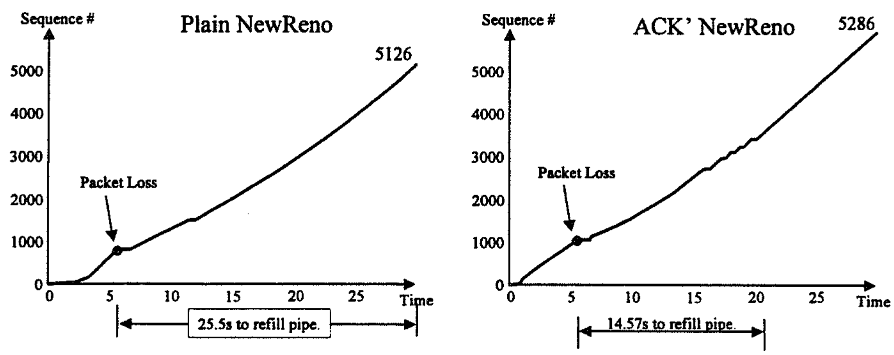
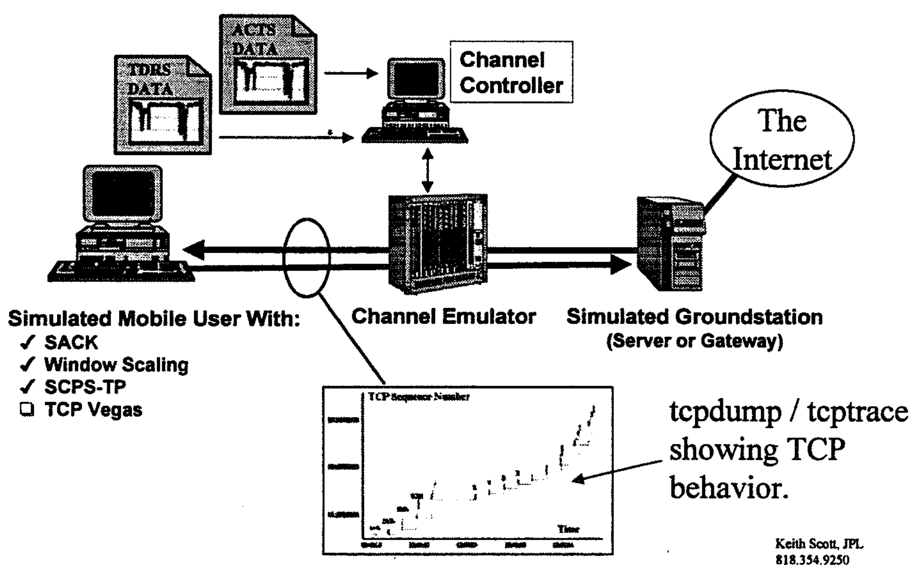
Performance During Congestion Avoidance



JPL Mobile Satellite Protocol Testbed



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Transport Protocols for IP-Compatible Satellite Networks

Tom Henderson
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and
Randy Katz (randy@cs.berkeley.edu)

NASA Lewis Satellite Workshop: June 2-4, 1998

Dept. of Electrical Engineering and Computer Science
University of California at Berkeley

Future broadband satellite systems

Last-hop IP access is our service focus

- Hybrid GEO/LEO systems are envisioned
- Potentially highly asymmetric access
- GEO assumptions
  - Low BER (improved coding, higher power), high availability, but high RTTs
- LEO assumptions:
  - Lower average RTTs (< 200ms), but higher RTT variance (due to handoffs), higher BER and lower availability (fading links)

TCP tradeoffs

- Two basic strategies for improving satellite TCP performance:

End-to-end changes

- Preserves end-to-end semantics

but

- deployment is a major problem
- some RTT-related problems cannot easily be solved for heterogeneous networks

TCP gateway

- Minimizes host changes
- Reduces RTT problems

but

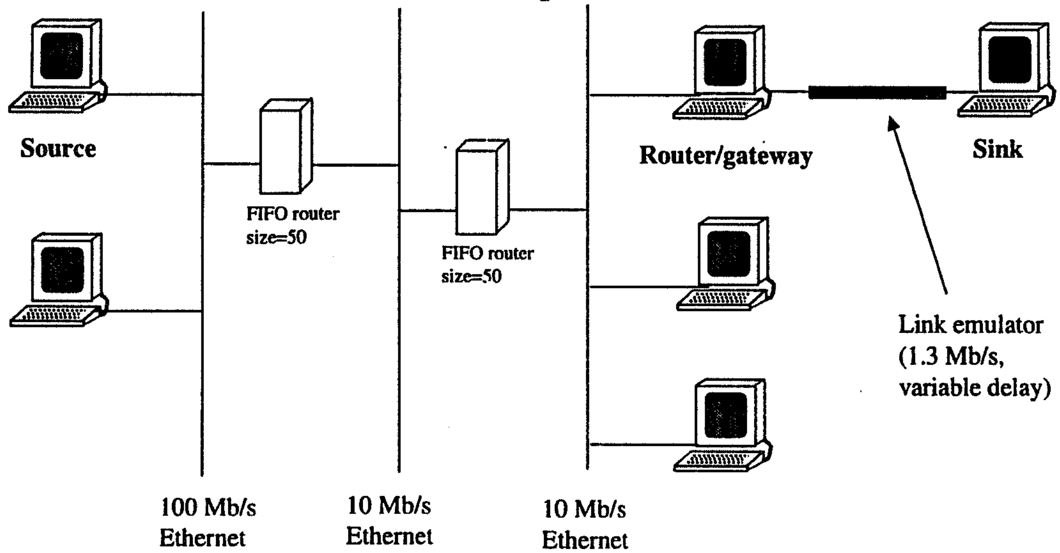
- adds complexity to satellite networks
- may be hindered by IP security protocols

Outline

- End-to-end TCP performance
  - implementation performance of SACK
  - TCP congestion avoidance problems
- Satellite Transport Protocol (STP)
  - design goals
  - file transfer performance
  - HTTP 1.0 performance

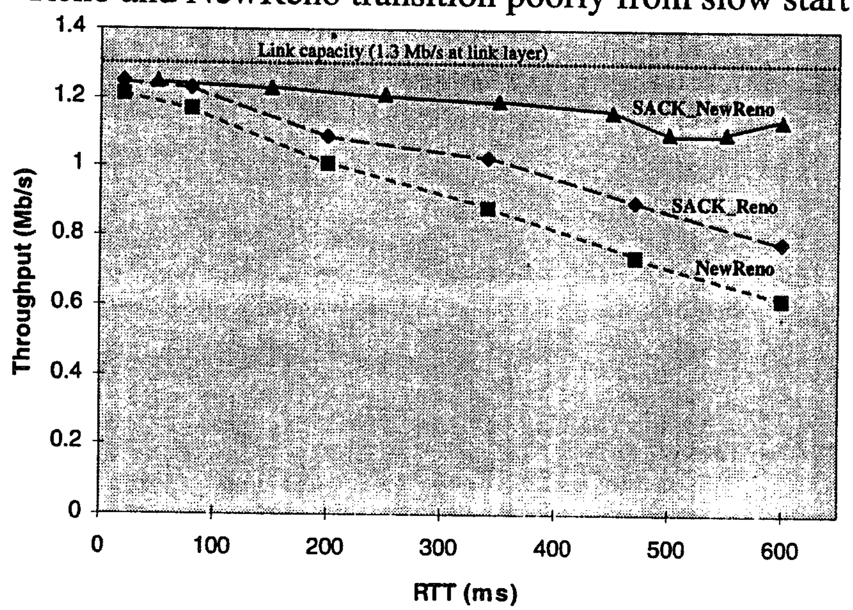
Experiment methodology

- Tests conducted on active (lightly utilized) networks
- All machines running BSD/OS 3.0 with large windows
- Routers do not send source quench



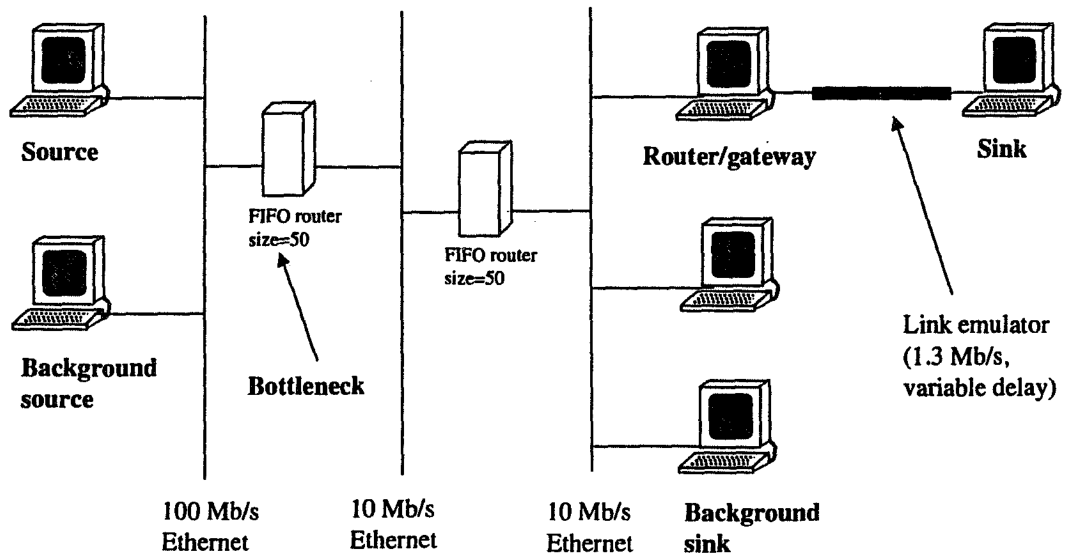
Performance of 3 TCP variants

- Averages of 20 file transfers of 10 MB each
- SACK NewReno maintains high throughput, while SACK Reno and NewReno transition poorly from slow start



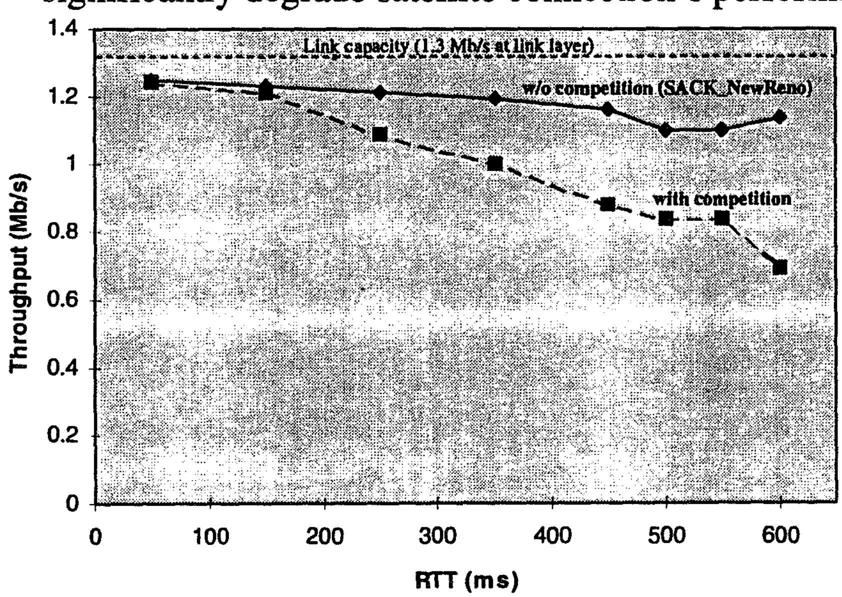
Experiment methodology

- Ran single persistent file transfer (20 ms RTT) with large windows across the same two queues



Effect of short-delay flows

- A single short-RTT (20ms), large window flow can significantly degrade satellite connection's performance

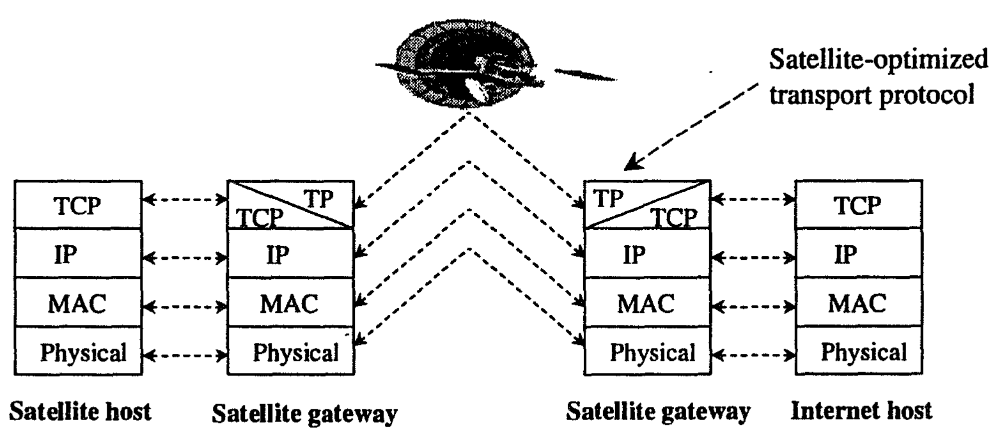


Summary

- For GEO links, small variations in TCP implementations can have major effects
- Even light congestion in wide area network can significantly degrade satellite TCP
  - well-known fairness problem of TCP congestion avoidance
  - multiple (slow-starting) short flows have an even worse effect
- Short (HTTP) satellite connections perform even worse than file transfers due to slow-start

Alternative transport solutions

- What type of protocol is best for split connections or internal satellite traffic?

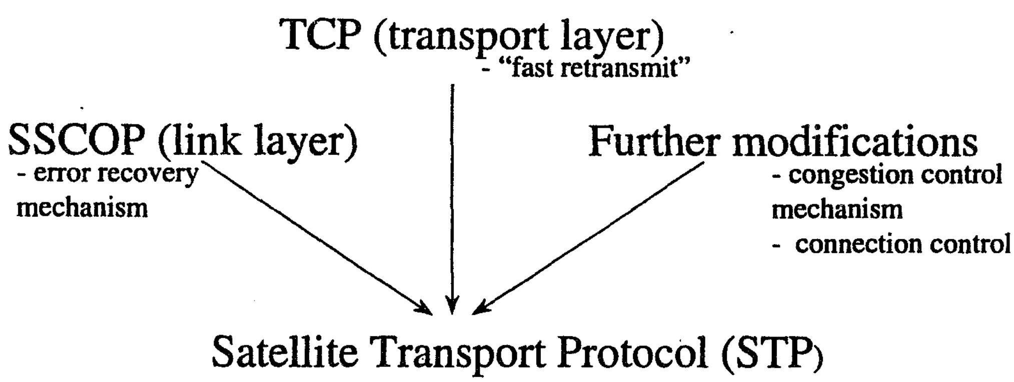


Satellite protocol requirements

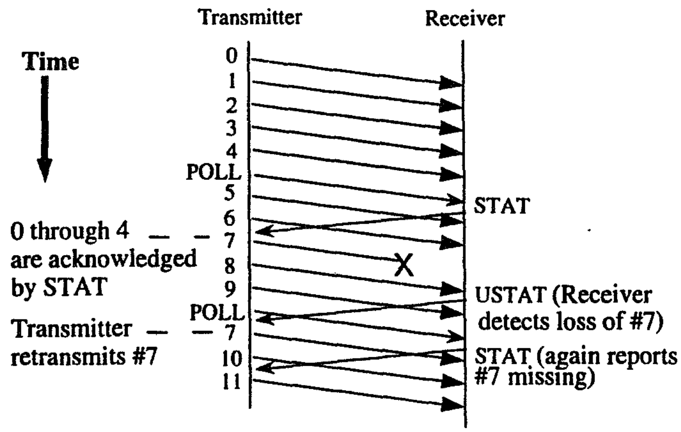
- High efficiency in forward direction
  - selective acknowledgments (very few unnecessary retransmissions)
- Minimize bandwidth in reverse direction
  - better for asymmetric environments
- Minimize protocol handshaking latency
- Allow for rate controls in addition to window controls
- Compatible with TCP (interworking and API)

Satellite Transport Protocol (STP)

- An ATM link layer protocol known as SSCOP already has many of these attributes



Basic STP operation



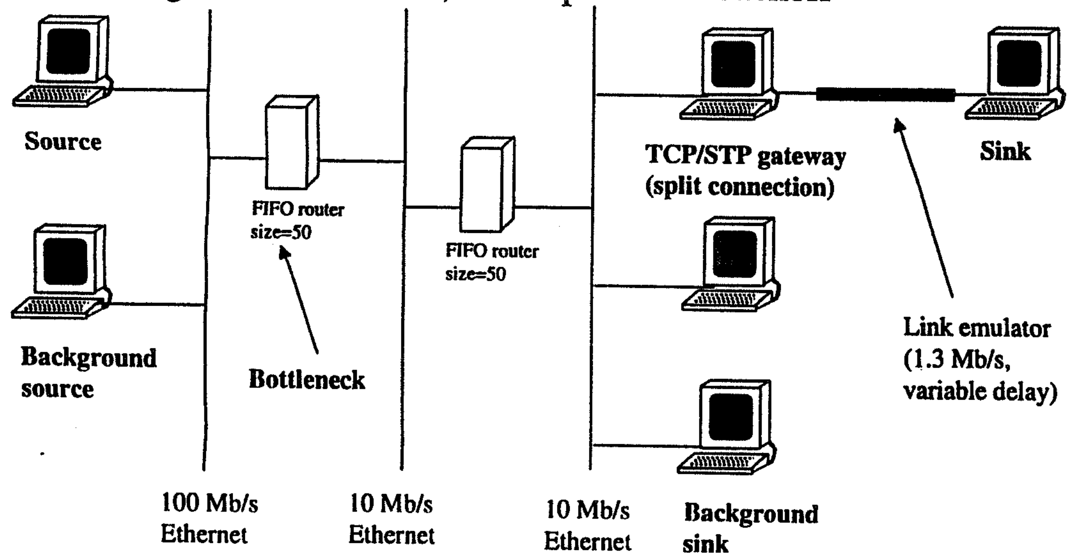
Full, periodic state exchange is the basic design philosophy

STP improvements over SSCOP

- STP handles data misordering by network
- For congestion control, STP implements traditional TCP-like window control, rate control, or hybrid approaches
  - no congestion control for SSCOP
- Fast connection setup (like T/TCP) is the default behavior
- Concatenation of PDUs (e.g., piggybacked POLLs) performs better in Internet
- STP supports full TCP API

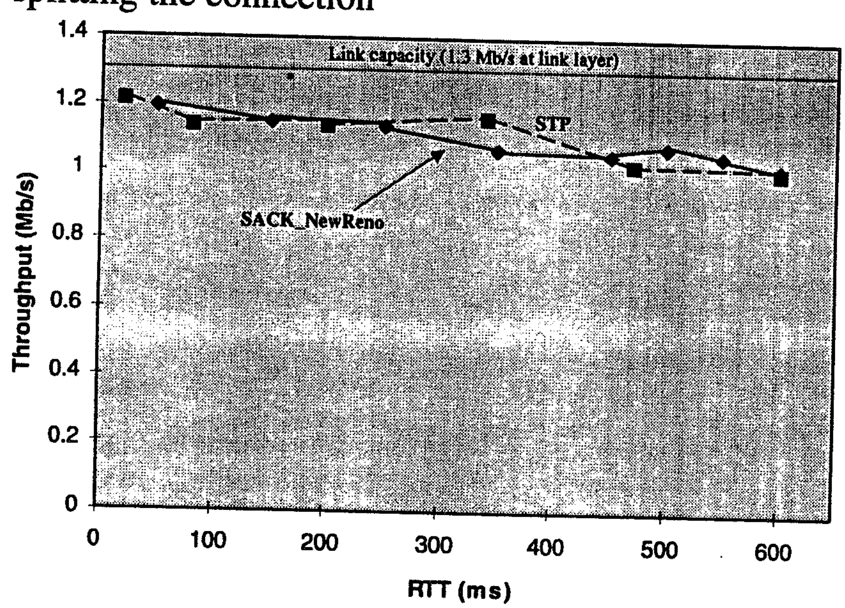
Experiment methodology

- Split end-to-end connection at user level at gateway
- For fair comparison, STP implemented TCP slow-start, congestion avoidance, and exponential backoff



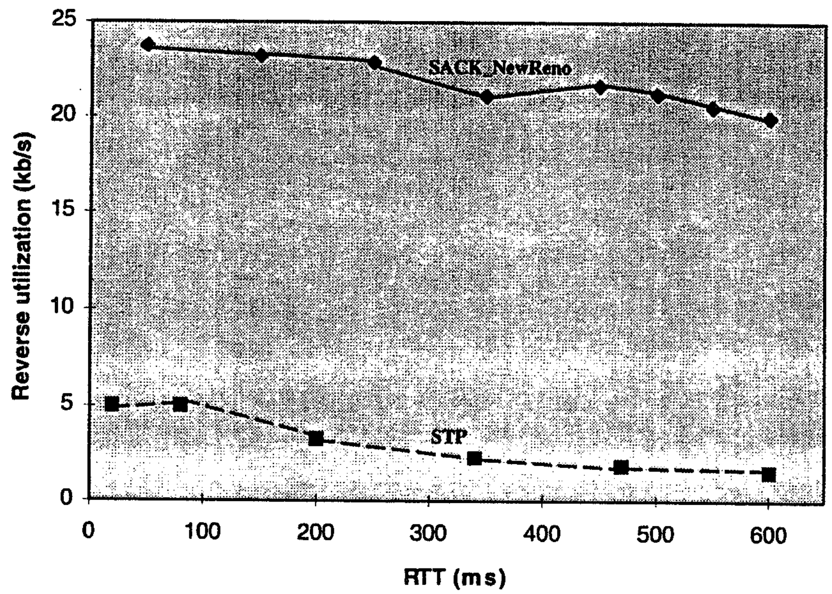
STP performance: bulk transfers

- Both TCP SACK and STP can reduce fairness problems by splitting the connection



STP performance: bulk transfers

- However, STP uses much less of the reverse channel



STP performance: transactions

- Average of 1000 simulated HTTP transfers over 600 ms channel
- Traffic generated based on empirical distributions derived from HTTP traces
- STP performance approaches that of T/TCP
  - Traffic smoothing accounts for larger latency
  - To speed window buildup, every packet had a piggybacked POLL if the congestion window <= 10 segments

	Avg. latency (s)	Avg. packets
TCP	2.0	12.3
T/TCP	1.4	7.3
STP	1.7	8.9

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Internet Services Over A Direct Broadcast Satellite Network: Challenges And Opportunities

Cheryl DeMatteis, Michael O'Brien, James Stepanek, Scott Michel, Cauligi Raghavendra and Michael Campbell
The Aerospace Corporation
Robert Lindell and Joseph Bannister
USC Information Sciences Institute

An Opportunity

- High Bandwidth
- Small Low Cost Reception Devices
- Internet Connectivity and Interoperability
- Large Base of Application Software
- USAF Global Broadcast Service (GBS) Program

Direct Broadcast Satellite Characteristics

- High Power Transponders
- Small Antenna With Fixed Orientation
- Wide Geographic Range
- Unidirectional Broadcast Bandwidth

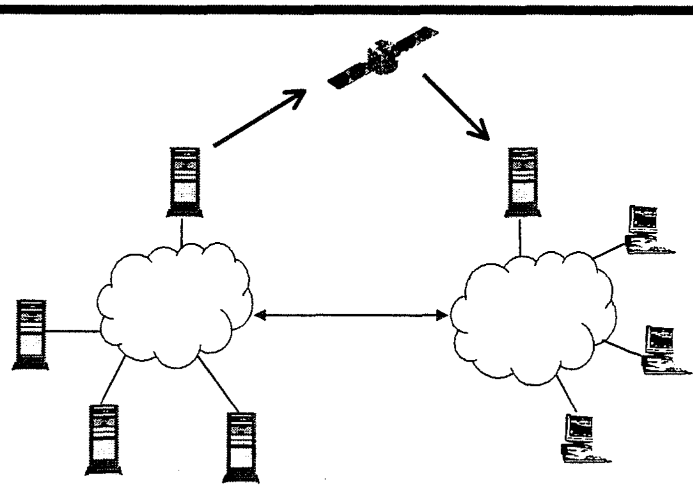
Consumer DBS Equipment

- 18″ Dish, Set-Top Box, Smartcard
- Reed Solomon and Viterbi Convolution Codes for Forward Error Correction (FEC)
- 40 Mb/sec Without FEC
- 20 - 30 Mb/s With FEC (10e-8 BER)
- High Speed Serial Port Interface

Battlefield Awareness and Data Dissemination (BADD)

- DARPA/ISO Advanced Concept Technology Demonstration (ACTD)
- 6 Months of Development, 1 Year to Deployment for Each Phase
- Our Focus is on the Advanced Data Dissemination Methods
- DBS Links are Part of a Larger Internet
- Exploit Multicast Capabilities

Basic Architecture



The Problem

- IP depends on a bi-directional link
- Routing Protocols depend on a symmetric link
- Long delays affect TCP/IP performance
- Reliable Multicast Transport
- QoS

Other Approaches

- BC2A: "Spray and Pray"
- UDLR: change all routing protocols

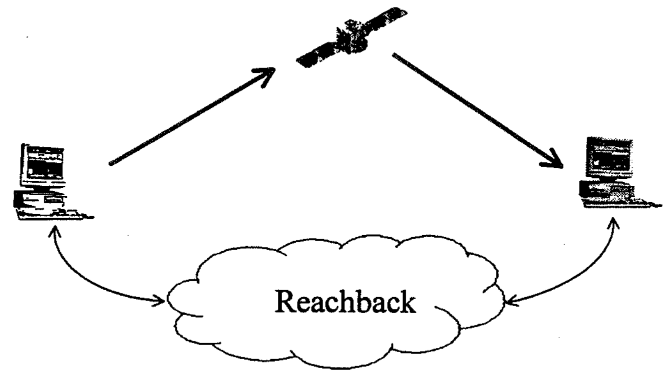
Our Approach

- Provide the illusion of a bi-directional link
- use TCP-lfn to increase the window size

Proposed Solutions

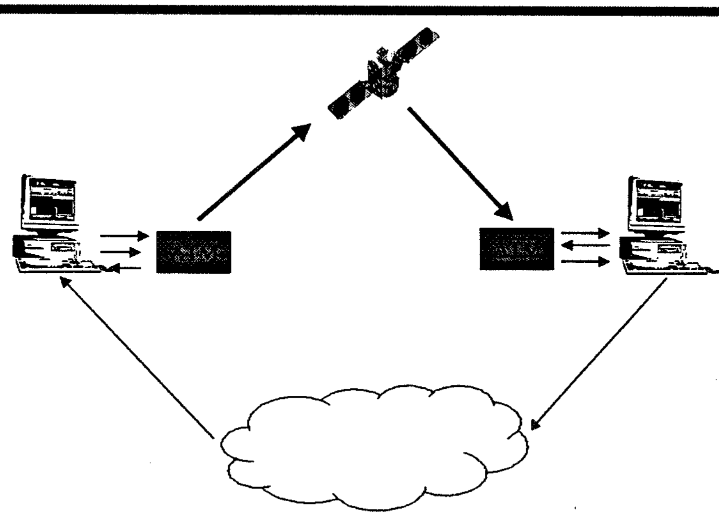
- Split-IP
- VIPRe
- Pit-Vipre

Split-IP

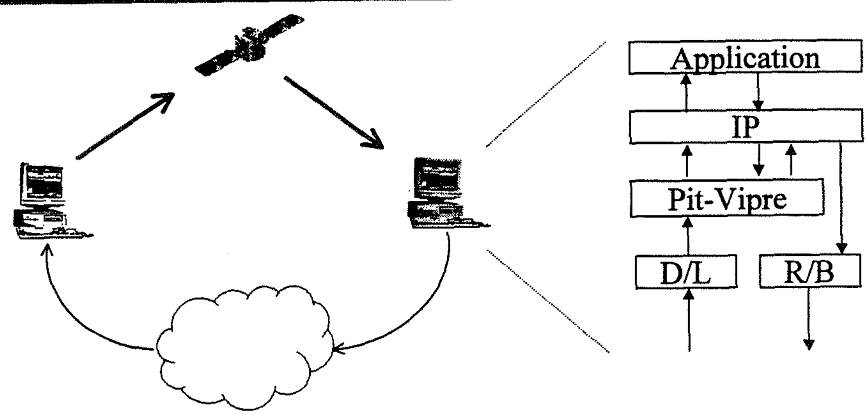


• Add route on downlink

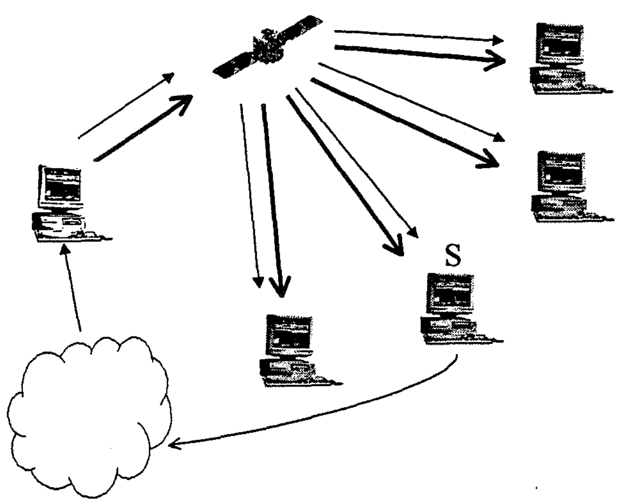
VIPRe



Pit-Vipre



Multicast



QoS Issues

- Per flow basis
- ATM limitations
- Contractor solution

Current Work

- RSVP
- CBQ
- TCP-SACK
- Heterogeneous Networks

Mentat

Improved Satellite Networking Using the **Mentat SkyXpress Protocol**

DC Palter

Mentat Inc.

dc@mentat.com

http://www.mentat.com

NASA Lewis Workshop June 1998

Satellite Networks: Architectures, Applications, and Technologies

Mentat

SkyX Presentation Outline

- **Mentat Background**
- **Satellite Conditions**
- **SkyX Design**
- **SkyX vs. TCP Performance Testing**
  - ▲ By NASA Goddard
  - ▲ By Mentat
- **SkyX to TCP Integration**
- **Q & A**

Mentat

Mentat Background

- **Leading supplier of TCP/IP and other networking source code to computer and embedded operating system vendors since 1987**
- **The native TCP/IP in the following operating systems is based on Mentat TCP:**
  - ▲ Hewlett-Packard HP-UX
  - ▲ Sun Solaris
  - ▲ Apple MacOS
  - ▲ Sony NEWS
  - ▲ Motorola SVR4 Unix, VMExec
  - ▲ Concurrent PowerMaxOS
  - ▲ Others

Mentat

GEO Satellite Conditions

- **Large Latency**
  - ▲ Satellite hop round trip time of ~0.5 seconds
- **High Error Rates**
  - ▲ Bit Error Rates of $1x10^{-10}$ to $1x10^{-6}$
- **Asymmetric Bandwidth**
  - ▲ Back channel bandwidth generally a fraction of the forward channel bandwidth
- **Point-to-Point Connection**
  - ▲ Satellite link generally point-to-point connection with no routing

➡ **Causes Poor Performance of TCP over Satellites**

Mentat

Mentat SkyXpress Protocol Design

- **Selective Retransmission Algorithm**
  - ▲ Lost or corrupted data triggers immediate NACK and retransmit.
  - ▲ Sender periodically polls receiver for data acknowledgment.
- **Large Windows**
  - ▲ 64 bits used to specify window size.
- **Appropriate Start-Up Strategy**
  - ▲ No start-up ramp for point-to-point hop over satellite.
- **Rate and Burst Control**
  - ▲ Maximum allowable bandwidth can be set on per-connection basis.
  - ▲ Avoid overrunning known bandwidth bottleneck.

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Mentat SkyXpress Protocol Design (Con't)

- **Efficient Design**
  - ▲ Streamlined handshake reduces connection overhead.
  - ▲ 64-bit design.
- **Reliable Multicast**
  - ▲ Transport level reliable multicast for efficient point-to-multipoint communications.
- **Runs over IP or Link Layer**
  - ▲ Runs over IP when routing required.
  - ▲ Runs over link layer for maximum efficiency on point-to-point link.

Mentat

SkyX Performance Testing

NASA GSFC

SkyX vs. TCP Performance Comparison

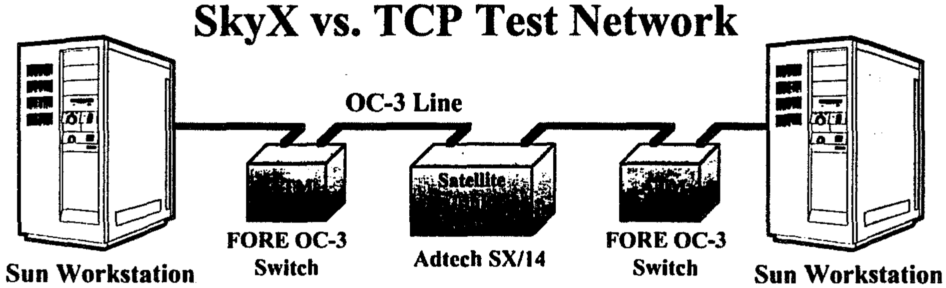
- **Compared SkyX to TCP and TCP-SACK**
  Testing by NASA Goddard Space Flight Center
  High Performance Computing and Communications Group
  Testbed for Satellite and Terrestrial Interoperability Project
  http://everest.gsfc.nasa.gov/
- **Simulated large file transfer over satellite link**
- **50 test runs for each BER and latency data point**
- **Data normalized by max. measured throughput of 128 Mbps**

Mentat

SkyX Performance Testing

NASA GSFC

SkyX vs. TCP Test Network



CPU	Sun UltraSparc
Operating System	Solaris 2.6
TCP Implementations	TCP new-Reno, TCP-SACK
Network	FORE NICs, ATM switching
Line Speed	OC-3 (155 Mbps)
Satellite Link Simulator	Adtech SX/14

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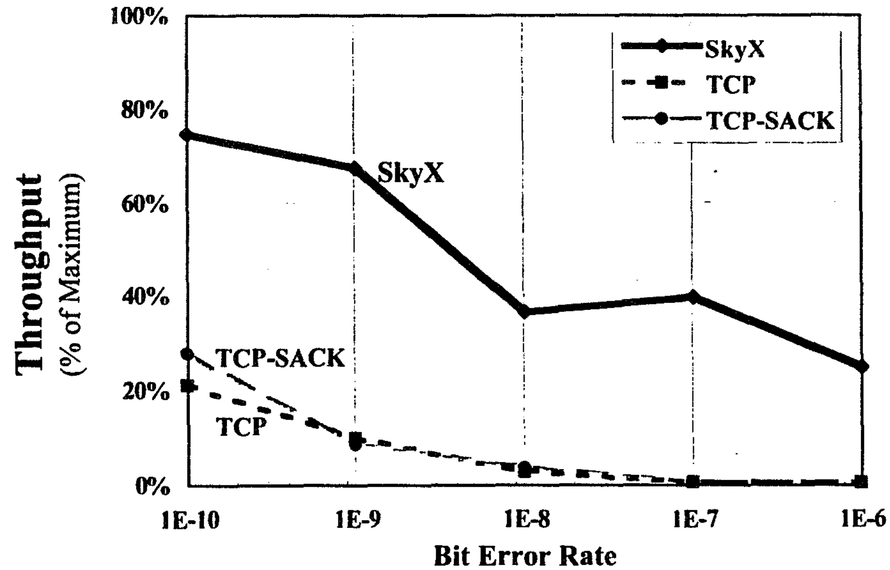
SkyX over the Satellite

SkyX and TCP Throughput vs. BER

Satellite Conditions: RTT = 540 ms



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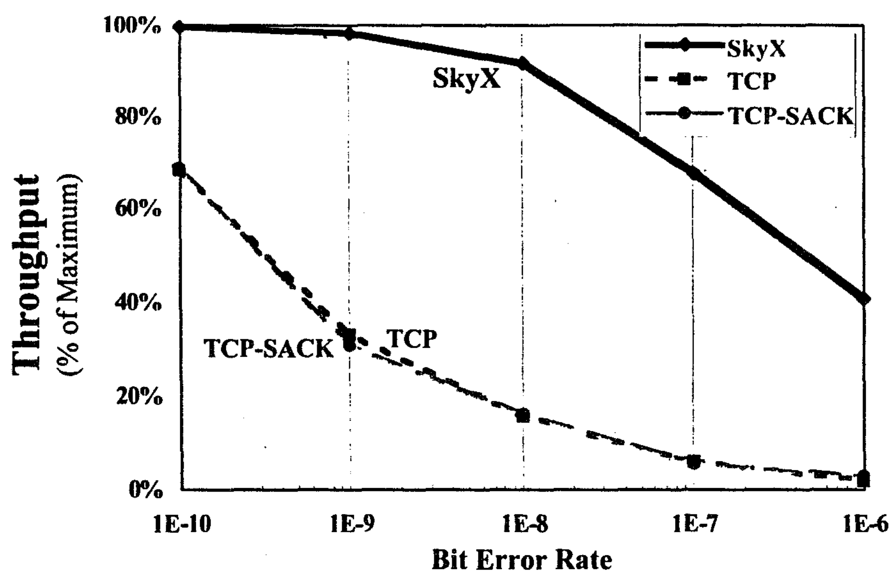
SkyX on the WAN

SkyX and TCP Throughput vs. BER

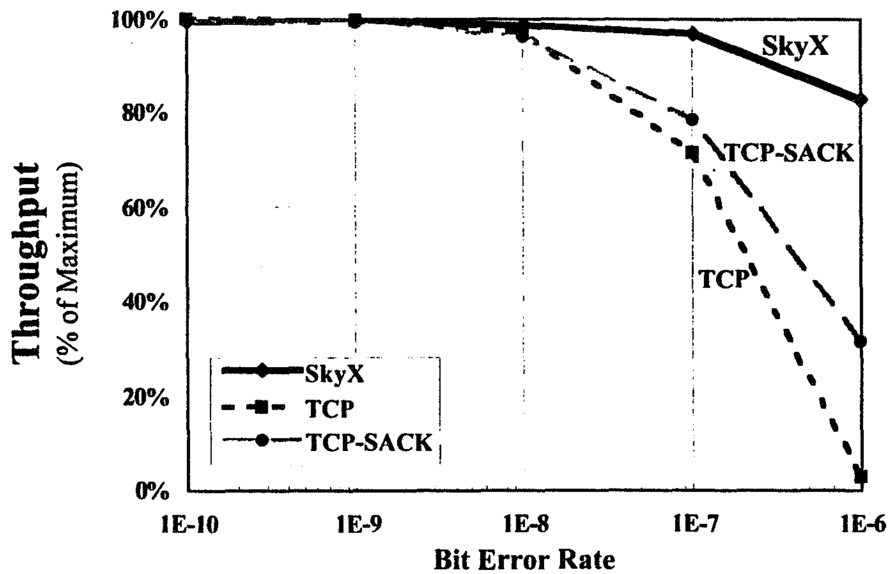
WAN Conditions: RTT = 70 ms



SkyX on the LAN

SkyX and TCP Throughput vs. BER

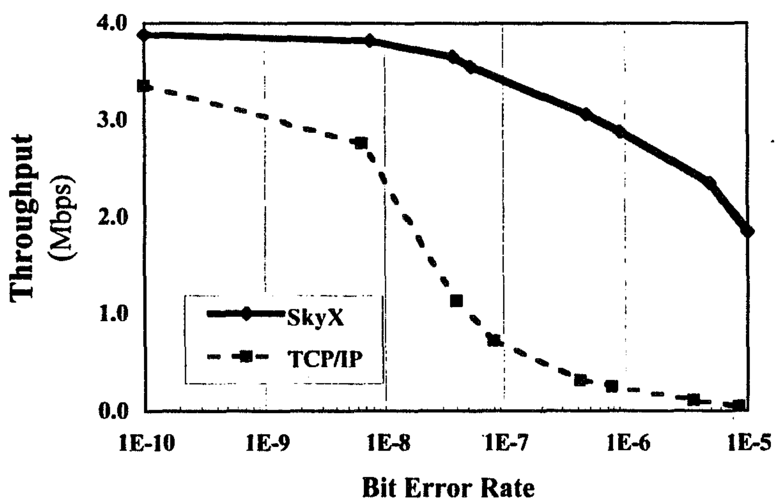
LAN Conditions: RTT = 1 ms



Additional SkyX Testing

Performed at Mentat

SkyX and TCP Throughput vs. BER



Test Conditions

Max. Link Speed:
4 Mbps

Round Trip Time:
540 ms

Window Size:
540 KB

Network:
Ethernet

TCP Implementation:
Mentat TCP

Operating System:
Windows NT 3.51

Sat. Link Simulator:
Mentat HAVOC

Mentat

SkyX to TCP Integration

SkyX Gateway System Design

- **Transparent**
  - ▲ No changes to end client and server TCP stacks.
- **Available**
  - ▲ Does not require wide-spread roll out of modified TCP.
- **Safe**
  - ▲ Maintains TCP connection reliability and end-to-end semantics.
- **Internet Friendly**
  - ▲ Maintains congestion control, slow start, etc., over terrestrial links.
- **Supports All Data Traffic**
  - ▲ Provides bridging for UDP, IPX, SNA, all other protocols.

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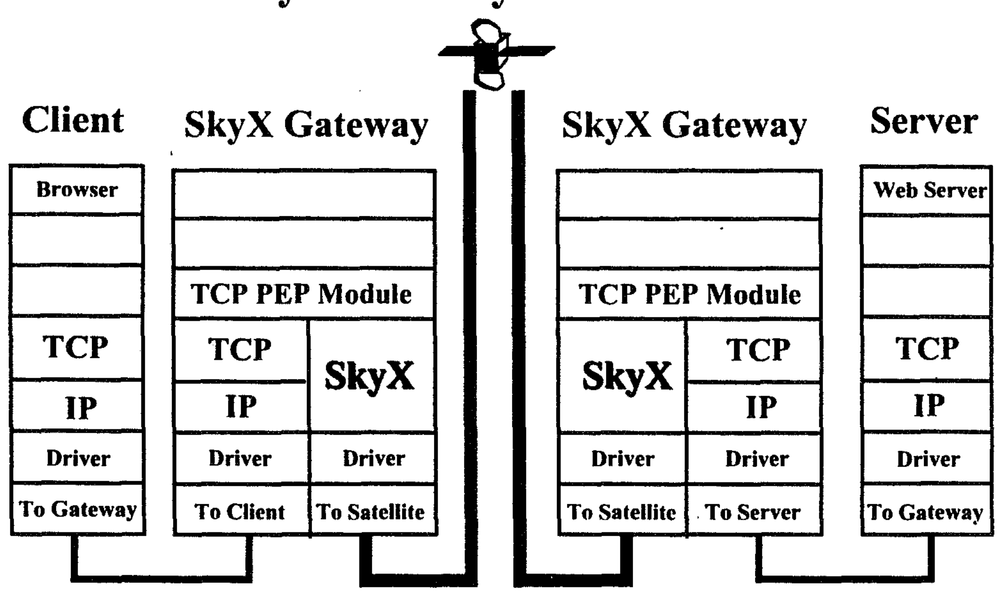
SkyX to TCP Integration

SkyX Gateway Architecture



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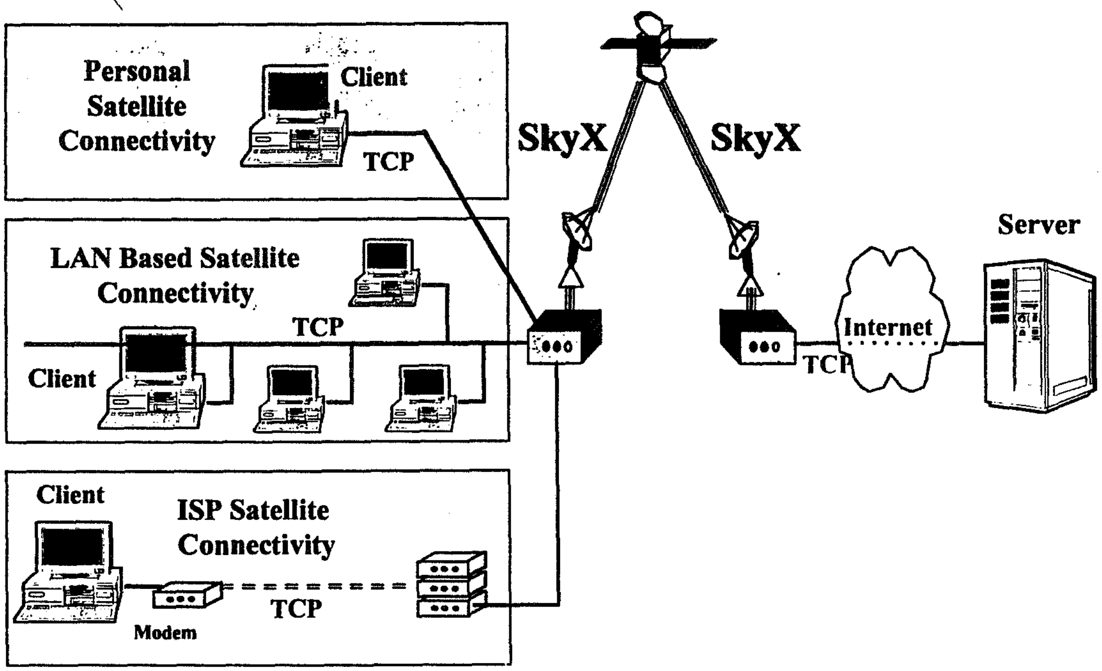
SkyX to TCP Integration



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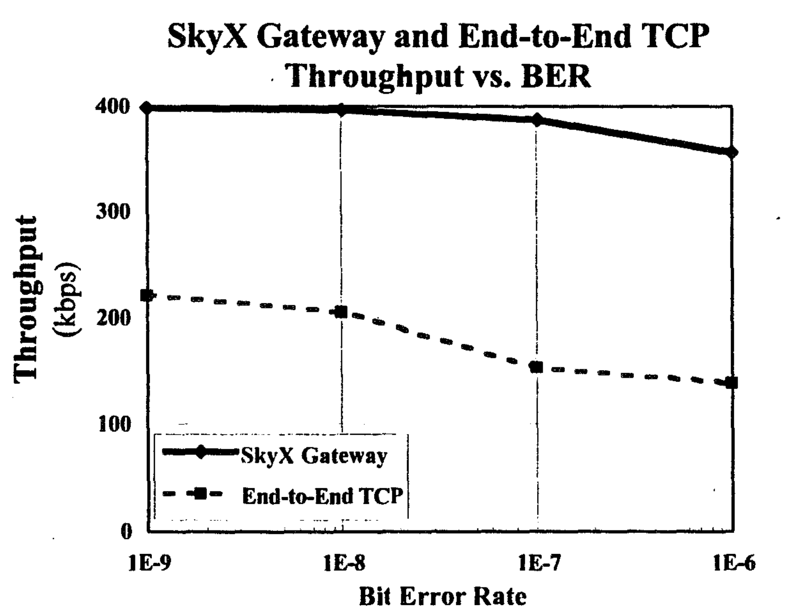
SkyX Gateway System Testing



Test Conditions

Max. Link Speed:
forward: 400 kbps
reverse: 128 kbps

Round Trip Time:
540 ms

TCP Window Size:
48 KB

Test Network:
Ethernet

TCP Implementation:
Mentat TCP

Operating System:
UNIX

Sat. Link Simulator:
Mentat HAVOC

Mentat

Conclusion

Mentat SkyXpress Protocol
provides a transparent,
high-performance solution for
Internet access over satellite links.

SkyX is available now from Mentat.

more information available at:
http://www.mentat.com/Documentation/white_papers/skyx.html

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Visionary Session
Architectures, Applications and Technologies

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Future Applications, Technology and Architectures

Edward W. Ashford
Lockheed Martin

June 4, 1998

FUTURE APPLICATIONS, TECHNOLOGY AND ARCHITECTURES

- "IT IS EASIER TO PREDICT THE PAST THAN THE FUTURE" (AND EVEN THEN, SOME GET IT WRONG!)

- "THOSE WHO DO NOT KNOW HISTORY ARE CONDEMNED TO REPEAT IT" (AND THOSE THAT DO...SOMETIME REPEAT IT AS WELL!)

- THEY SAID TO CHEER UP, SINCE THINGS COULD BE WORSE. SO I DID, AND SURE ENOUGH, THEY WERE RIGHT...THINGS GOT WORSE.

FUTURE APPLICATIONS, TECHNOLOGY AND ARCHITECTURES

- "THROUGH A CRYSTAL BALL DARKLY", OR "THE PITFALLS OF TREND PROJECTIONS"
  - THESE ARE SUBJECT TO SEVERAL (OFTEN INTER-RELATED) EFFECTS WHICH CAN MAKE A PREDICTION COMPLETELY WRONG, INCLUDING:
    - LACK OF UNDERSTANDING OF THE DETAILS OF THE SYSTEM CONCERNED
    - INADEQUATE DATA
    - OGIVE TENDENCY
    - BUBBLE BURST EFFECT

FUTURE APPLICATIONS, TECHNOLOGY AND ARCHITECTURES

- GIVEN THE ABOVE EXCUSES FOR MAKING INACCURATE PREDICTIONS, AND WITH APOLOGIES FOR THE "NOSTRODAMUS OUT"..........

FUTURE APPLICATIONS, TECHNOLOGY AND ARCHITECTURES

- THE ARCHITECTURES OF THE FUTURE WILL BE THOSE THAT SUPPORT:
  - ANYWHERE TO ANYWHERE CONNECTIVITY
  - SATELLITE SYSTEM TO SATELLITE SYSTEM INTEROPERABILITY
  - SEAMLESS INTEGRATION WITH TERRESTRIAL SYSTEMS (INCLUDING SEAMLESS PRICING!)

FUTURE APPLICATIONS, TECHNOLOGY AND ARCHITECTURES

- WHAT IS THE "KILLER APPLICATION" OF THE FUTURE FOR SATELLITE COMMUNICATIONS?
- ANSWER:
  - AN INTERNET ROUTER IN THE SKY, COMBINED WITH...
  - REAL TIME LANGUAGE TRANSLATION FROM AND TO ANY LANGUAGE

FUTURE APPLICATIONS, TECHNOLOGY AND ARCHITECTURES

- WHAT TECHNOLOGIES WILL BE NEEDED?

- THE FIRST WILL BE A CHANGE OF MIND-SET IN THE REGULATIONS, TO RECOGNIZE THAT, IN A DIGITAL WORLD, THERE IS NO DIFFERENCE BETWEEN BITS THAT CARRY FIXED, MOBILE, BROADCASTING, NAVIGATION OR DATA RELAY SERVICES INFORMATION. FOLLOWING THAT:

FUTURE APPLICATIONS, TECHNOLOGY AND ARCHITECTURES

- TECHNOLOGY NEEDED:
- ON-BOARD:
  - OPTICAL SIGNAL PROCESSING AND BEAM FORMING
  - GREATLY IMPROVED ON-BOARD TRANSMITTER EFFICIENCIES AT Ka-BAND AND ABOVE
  - PROTOCOL/STANDARDS CONVERSION
  - DYNAMIC BANDWIDTH ON DEMAND ALLOCATIONS OF RESOURCES
- ON-GROUND:
  - CHEAP AND EFFICIENT MULTI-BAND TERMINALS
  - FAST AND ACCURATE LANGUAGE TRANSLATION ALGORITHMS
  - (IMPROVED) MULTI-SYSTEM TERMINALS

Lewis Research Center

NASA's Commercial Communications Technology Program

Presented to:

The Workshop on Satellite Networks:

Architectures, Applications, and Technologies

Cleveland, Ohio

June 2-4, 1998

by

James W. Bagwell
Lewis Research Center

Vision

Lewis Research Center

"Changing the way NASA and the Nation communicate through space"

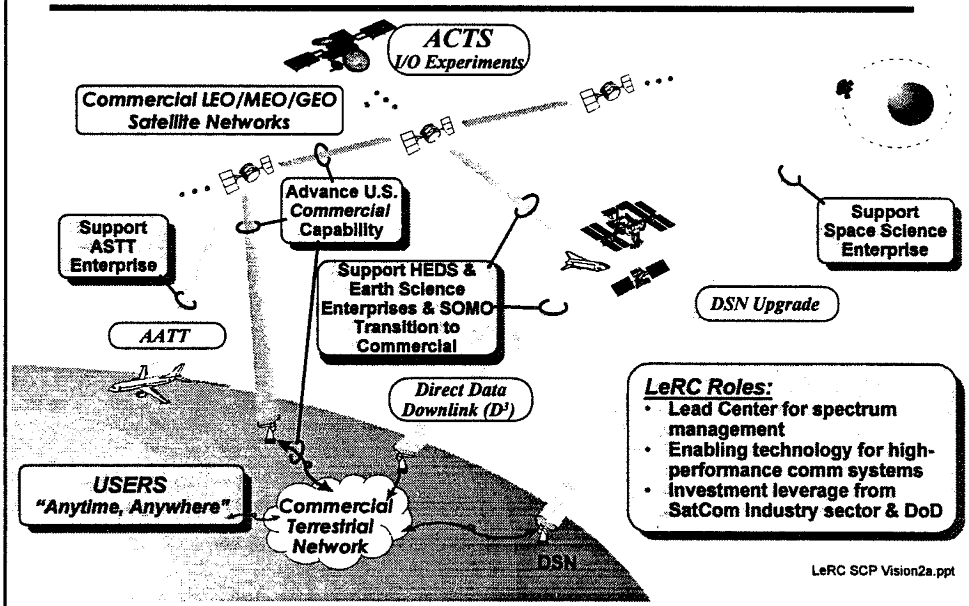
Commercial Satellite Communications Program

Lewis Research Center

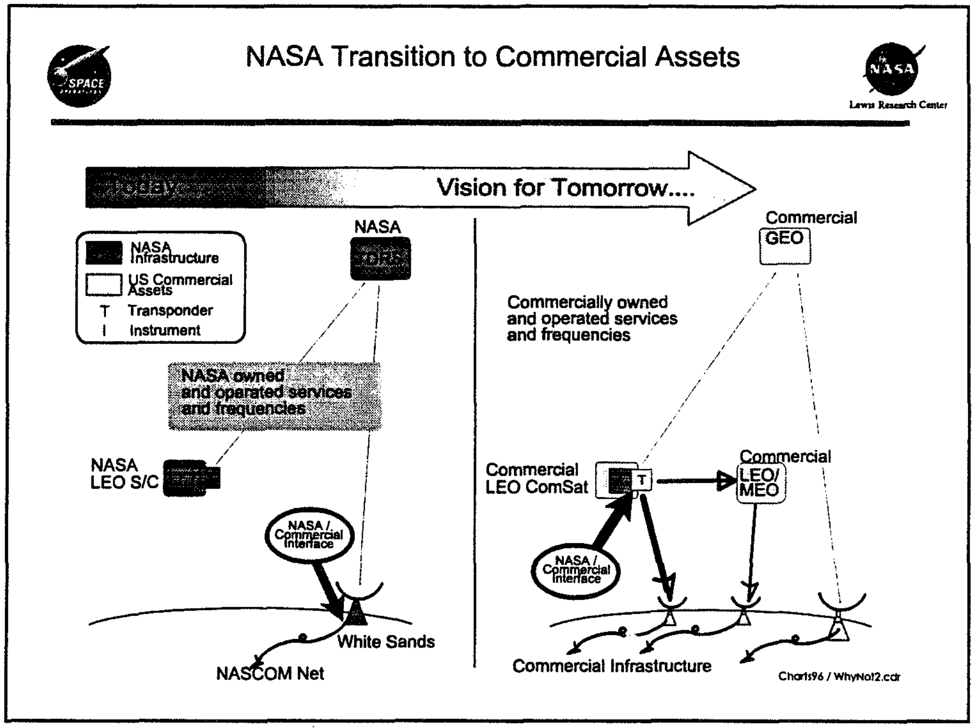
- **Mission**
  - **Enable NASA's Use of Commercial Satellites for All Its Operational Needs In and From Space**
    - Ensure Availability of Commercial Assets
    - Reduce NASA Operations Costs
  - **Promote Communications Satellites for the Maximum Benefit to Society through:**
    - Increased Economic Security
    - Cost Effective Services
    - Universal Availability
    - Capable, Reliable Communications for All Government Users

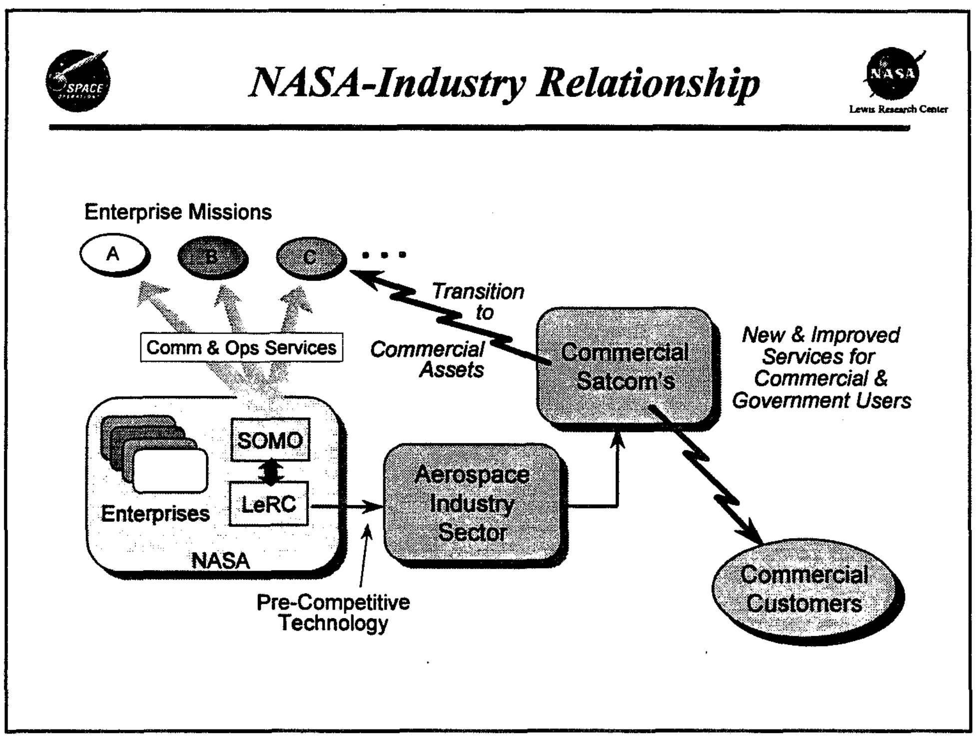
LeRC Space Communications Program

Lewis Research Center



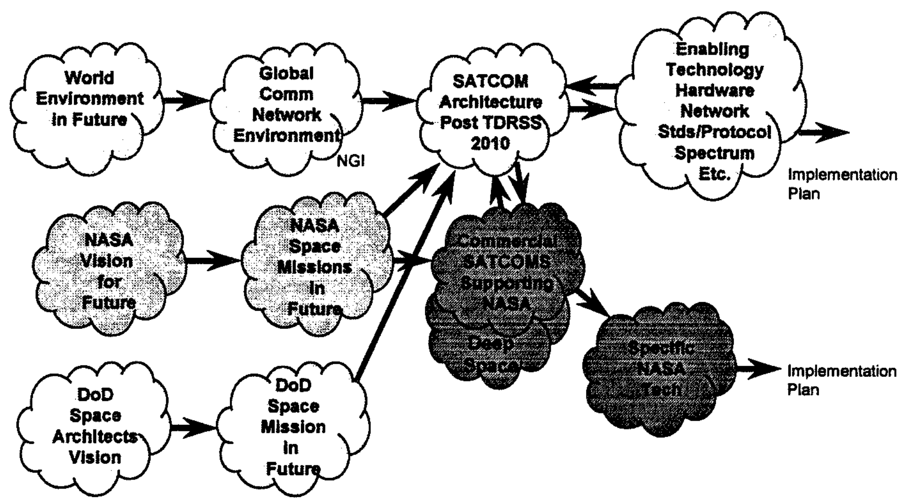
LeRC SCP Vision2a.ppt


NASA Transition to Commercial Assets
Lewis Research Center
Today
Vision for Tomorrow....
NASA Infrastructure
US Commercial Assets
T Transponder
I Instrument
NASA
NASA owned and operated services and frequencies
NASA LEO S/C
NASA / Commercial Interface
White Sands
NASCOM Net
Commercial GEO
Commercially owned and operated services and frequencies
Commercial LEO ComSat
Commercial LEO/ MEO
Commercial Infrastructure
Charts96 / WhyNot2.cdr


NASA-Industry Relationship
Lewis Research Center
Enterprise Missions
A
B
C
Transition to Commercial Assets
Comm & Ops Services
Commercial Satcom's
New & Improved Services for Commercial & Government Users
SOMO
LeRC
Enterprises
NASA
Aerospace Industry Sector
Pre-Competitive Technology
Commercial Customers

Components of Strategic Plan

Lewis Research Center



Government Led Programs Elements and Objectives for Satellites in Global Information Infrastructure

Lewis Research Center

A. Coordinate/Integrate Government Program (NASA, DoD, etc.)

- Use government "Space Technology Alliance" - AF Research Lab, NASA, NRO, DDR&E, BMDO, ONR
- Coordinate with "Satellite Alliance" for industry/academic/government interaction and program development.
- Government led workshops

Government Led Programs Elements and Objectives for Satellites in Global Information Infrastructure

Lewis Research Center

B. Achieve Seamless Interoperable Satellite & Terrestrial Networks

- Implement via architectures, standards, & protocols.
- Develop and adopt commercial standards in close cooperation with industry (e.g. Telecommunications Industry Association)
- Perform experiments & validation testing (GIBN, ACTS, etc.)
- Develop next generation architectures with goal of global interoperability.

Government Led Programs Elements and Objectives for Satellites in Global Information Infrastructure

Lewis Research Center

C. Establish Program to Enhance Satcom Professional, Technical Workforce

- Meet needs of Communications Satellite Industry.
- Involve Universities, Govt. Research Labs, and Industry.
- Integrate with Precompetitive Technology Program

Program Development Discussion - Tue. June 2
O'Hare Room, 3:30pm
Ms. Joanne Poe, Moderator

Government Led Programs Elements and Objectives for Satellites in Global Information Infrastructure

Lewis Research Center

D. Precompetitive Technology Development

- Vision - Global Information Infrastructure
- Target - Next generation space-based networks.
- Integrated commercial and government customers
- Goal - Prioritized program plan
- Participants - Academia/Government/Industry

Program Development Discussion - Wed. June 3
O'Hare Room, 3:30pm
Dr. Charles Raquet, Moderator

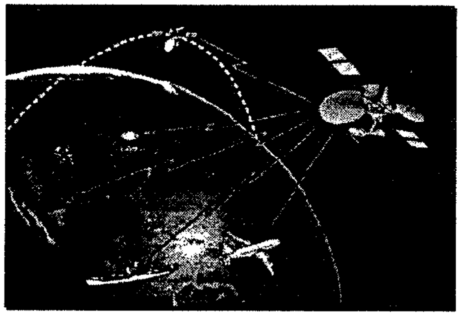
Government Led Programs Elements and Objectives for Satellites in Global Information Infrastructure

Lewis Research Center

E. Effective Utilization of Spectrum & Orbit Assets

- Create commercial satellite conducive national/international regulatory environment.
- Advance government/non-government shared spectrum
- Share satellite/wireless terrestrial communications services

Cisco Systems Network Technology Directions



Satellite Networks: Applications, Architectures, and Technologies Session, June 4, 1998

William Bailey
Business Development, New Markets & Technologies

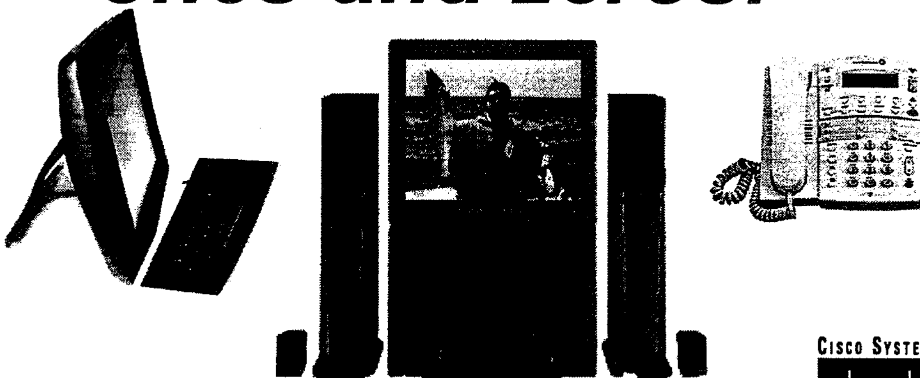
CISCO SYSTEMS

"Calm down, it's only ones and zeros"

Bumper sticker seen in Silicon Valley

CISCO SYSTEMS

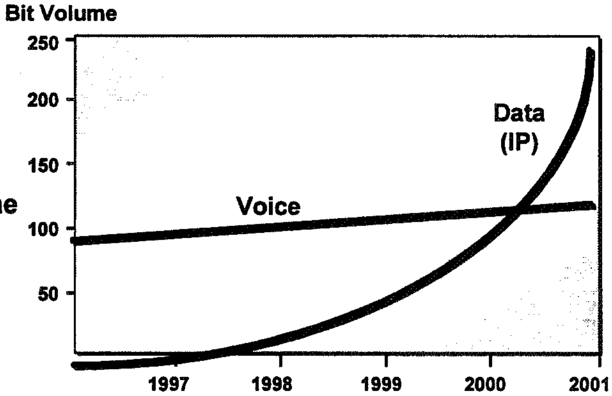
Convergence - it's all ones and zeros!



CISCO SYSTEMS

Waves of IP Traffic Growth

- Web Access, E-mail
- Business to business Ecommerce
- Voice Over IP/ATM/Frame Relay
- Business Video
- Consumer Ecommerce
- Entertainment
  - Digital Video, gaming



Traffic Projections for Voice and Data

"From 2000 on, 80% of service provider profits will be derived from IP-based services. — CIMI Corp.

CISCO SYSTEMS

Growth Enabling Technologies

- **DSP + processor cores**
  - Driven by wireless handset market
  - Enables low cost voice/video/data gateways
- **Faster packet engines/architectures**
  - Complex, high performance ASICs
  - Parallel computing architectures
- **Optical technologies**
- **Network Techniques**

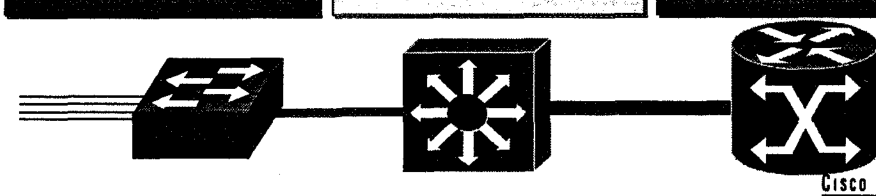
CISCO SYSTEMS

Cisco Systems

WEB New Markets and Technologies 5

Networks Today

LAN	Campus	Internet
	Multigigabit, Wire speed, Layer-3 (IP, IPX) Switching IP Multicast support Full service routing support Extensive QoS capabilities Feature rich access Control Lists (SW and HW)	



CISCO SYSTEMS

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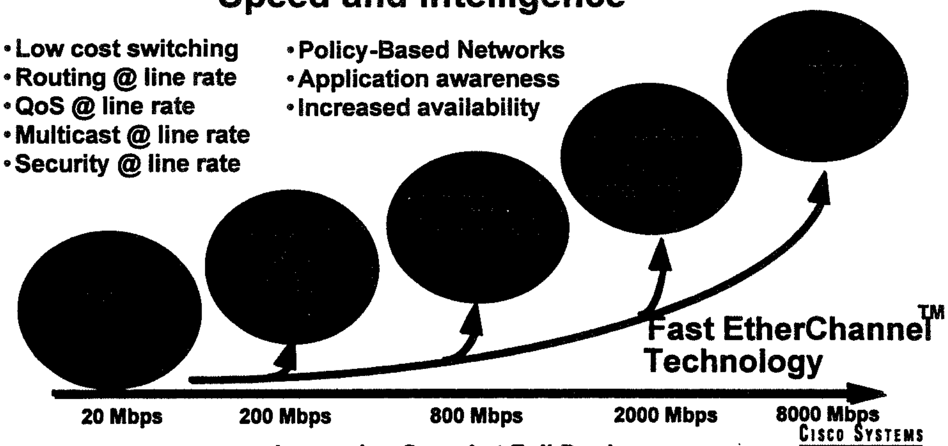
WEB New Markets and Technologies 6

LAN Performance Directions

Speed and intelligence

- Low cost switching
- Routing @ line rate
- QoS @ line rate
- Multicast @ line rate
- Security @ line rate

- Policy-Based Networks
- Application awareness
- Increased availability



Increasing Speed at Full Duplex

WAN Enhancements

- **Terabit speed Hybrid Switch/Routers**

  Packet over SONET OC192 Interfaces in the near future...

  High-speed architectures allow IP QOS, multicasting, etc

- **Direct WDM Optical Internetworking**

  Replaces TDM, lowers costs by at least 2/3, increases "fiber gain" capacity in the order of 8-32x

  Will eventually extend to customer premises

  Optical technology will be integrated into core of hybrid switch/routers

Network Techniques

- Quality of Service (QOS)
  - Tagging, Coloring, Labeling
  - ToS precedence bits allows traffic classes
  - Congestion Management (WRED, WFQ)
- Policy Networking
  - Priority/QOS Enforcement
  - GUI Applications
- Multicasting
- Web and Application Caching

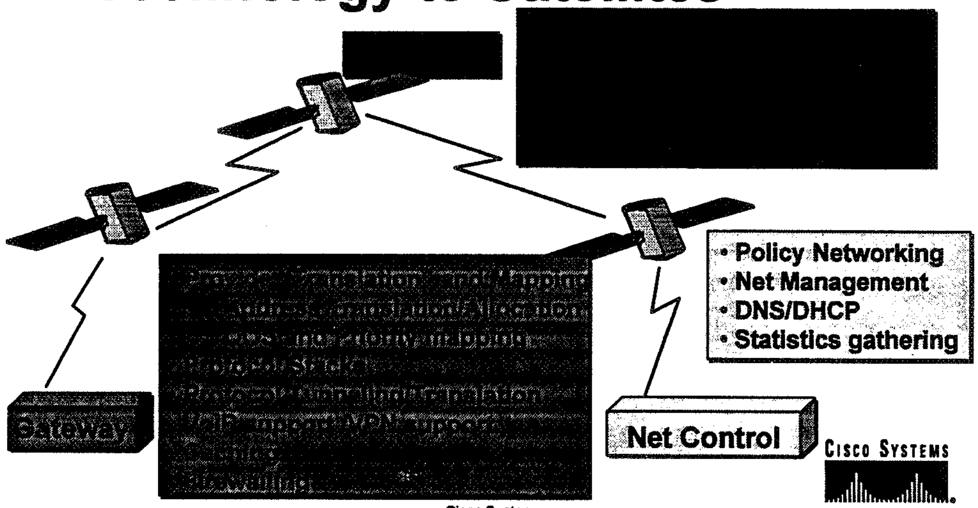
CISCO SYSTEMS

The Leaves on the Tree

- Local loop is a potential gold mine
  - Small business are waiting
  - Positive consumer spending indications
  - Applications & content are waiting
- Someone PLEASE fix the local loop!
- Regulation, a potential dark cloud over growth

CISCO SYSTEMS

Applying Terrestrial Network Technology to Satellites



Cisco Systems

CISCO SYSTEMS

WEB New Markets and Technologies 11

Closing Opinions

- **Terrestrial networking is booming**

  Technology is advancing rapidly

- **Satellite system designers and terrestrial network vendors need to engage and partner**

  Too long of a delay from state-of-the-art terrestrial networking to the "top of the rocket"

- **Space is a dangerous place - stray atomic particles, or is terrestrial competition the danger?**

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WEB New Markets and Technologies 12

Next Generation Space-Based Architectures

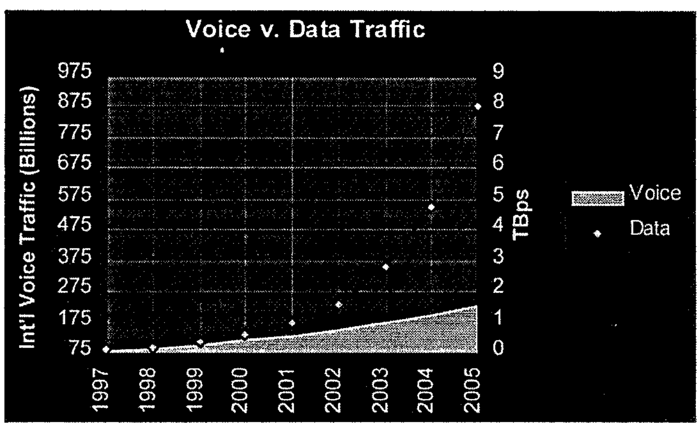
Architectures, Applications, and Technologies

NASA Lewis Research Center
June 4, 1998

Dr. Joseph Bravman

Orbital Sciences Corporation

Data Is the Driver



Source: ITU, Pioneer Consulting

Future Trends

Orbital

- All Digital Format
- Massive Growth in BW
- Moore's Law Lives (Computing Power, Storage, Transmission)
- Ubiquitous Connectivity
- Convergence of Services
- Merger of Technology & Life

Dr. Joseph Bravman June 4, 1998 NASA Lewis Research Center

Applications

Orbital

- Telepresence (Virtual Office, Telemedicine, Exploration)
- Bulk Transfers / Backhaul
- Entertainment
- Commerce
- Remote Sensing
- Remote Monitoring (Multipoint to Point; Traffic, Environment)

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Future Trends Continued

Orbital

- Applications Dominate
- Capital Markets Are Available
- Massive Satellite Population in Space
- Rationalization Between Fiber / Terrestrial Microwave / LMDS, Satcom, Etc.
- Giga-Internet Creation
- Evolution of Standards

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Satellite Advantages

Orbital

- Supports Global Mobility
- 'Instant Infrastructure' - Solves 'Last Mile' Problem
- Cost-Effective Over Large Areas
- Flexible Distribution
- Flexible Capacity - 'Bandwidth On Demand'
- Reliable Once On Orbit

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Technologies

Orbital

- LEO & MEO Systems
- Hybrid Network Architectures
- Digital Compression, Encryption
- Chips Reduce Size & Cost of Portables
- On-Board Processing
- Ka & Higher Band Components
- Inter-Satellite Links: RF and Optical
- Narrow Spot Beams & Phased Arrays

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Trade Space

Orbital

- LEO / MEO / GEO / Other
- ISL or Not
- Number of Planes-Coverage / Augmentation
- Match to LV Size
- Technology Drivers and Enablers
- Choice of Spectrum
- Choice of Standards
- Symmetric? , Real-time?
- On Board Complexity

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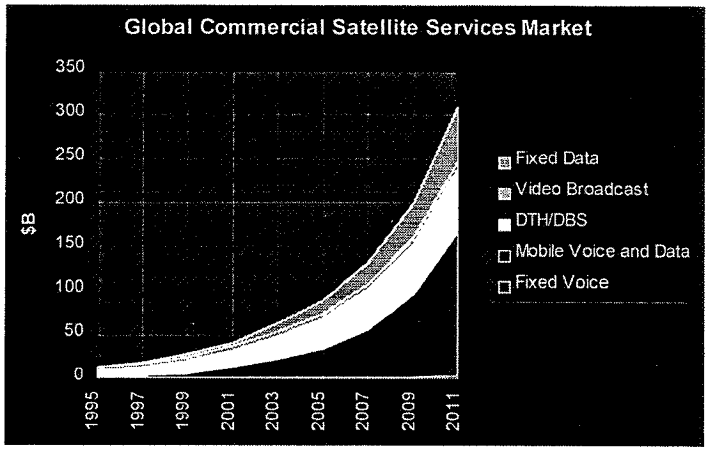
Satellite Services Market



Source: Pioneer Consulting

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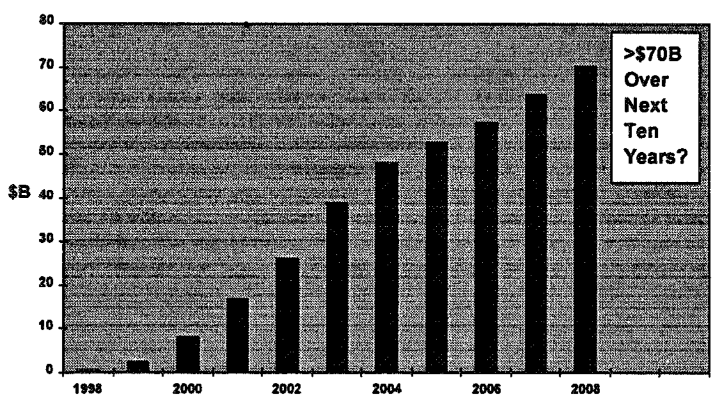
Cumulative Broadband Satellite Systems Investment



Source: Pioneer Consulting

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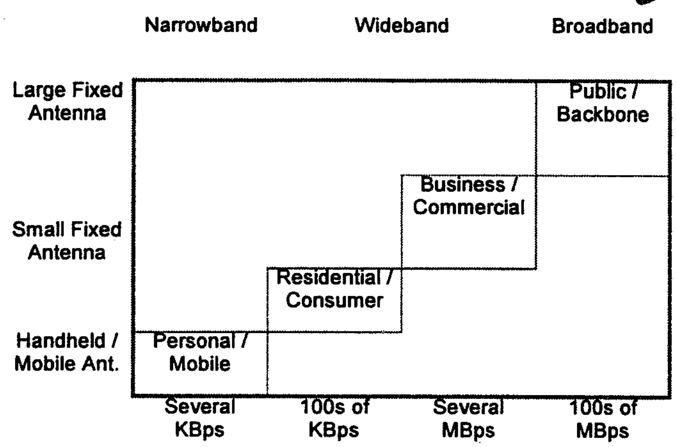
Satellite Two-Way Communications



Source: Ali Grami & Ken Gordon, Telesat Canada

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Access Technologies Compared

	Standard Line	ISDN Line	ADSL/T-1	Cable Modem	Ka Satellite	Q/V Satellite
Simple Still Image (2 Megabits)	1.2 min.	35.7 sec.	1.3 sec.	0.5 sec.	.25 sec.	2 ms
Complex Still Image (16 Megabits)	18.5 min.	4.8 min.	10.7 sec.	4 sec.	2 sec.	13 ms
Short Animation / Video (72 Megabits)	1.4 hrs.	21.5 min.	48 sec.	18 sec.	9 sec.	60 ms
Long Animation / Video (4.3 Gigabits)	3.5 days	21.4 hrs.	48 min.	18 min.	9 min.	4 sec.

Source: Forrester Research, PanAmSat

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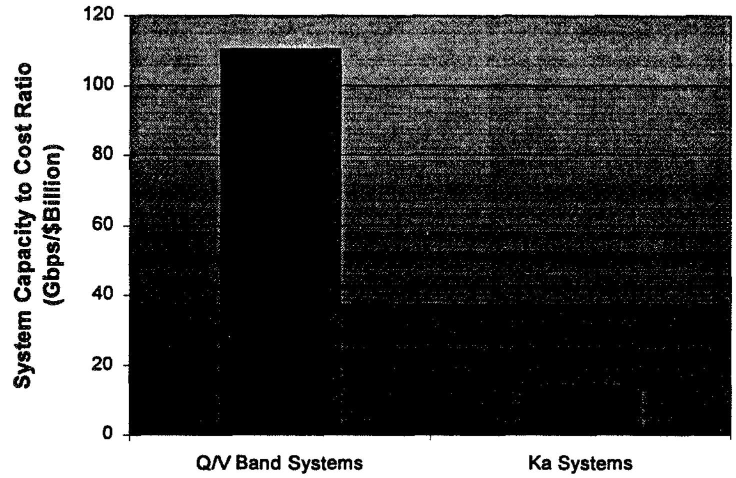
Q/V and Ka Systems Compared



Source: Pioneer Consulting, FCC Applications

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OrbLink Trades

- Q/V for Highest BW
- MEO As Compromise Between GEO Latency/power Needs and LEO Quantity/complexity
- Keep It Simple: High Usable Capacity to Cost Ratio
- Consistent and Complementary With Terrestrial Standards

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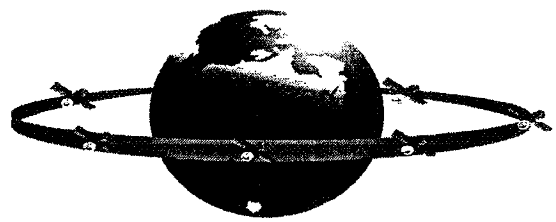
OrbLink Baseline: Architecture

7 satellite constellation in a 9000 km equatorial orbit (plus one spare)
- Latency of ~1/16 s
- Achieves coverage of 93% of population at min. elevation of 10 deg.
- Leverages system power over GEO's for better capacity to cost ratio
- Avoids LEO complexity and size

System capacity of 150 to 250 Gbps (limited by system cost)

IOC in 2003
- End-to-end ability
- Simplicity
  - Bent pipe



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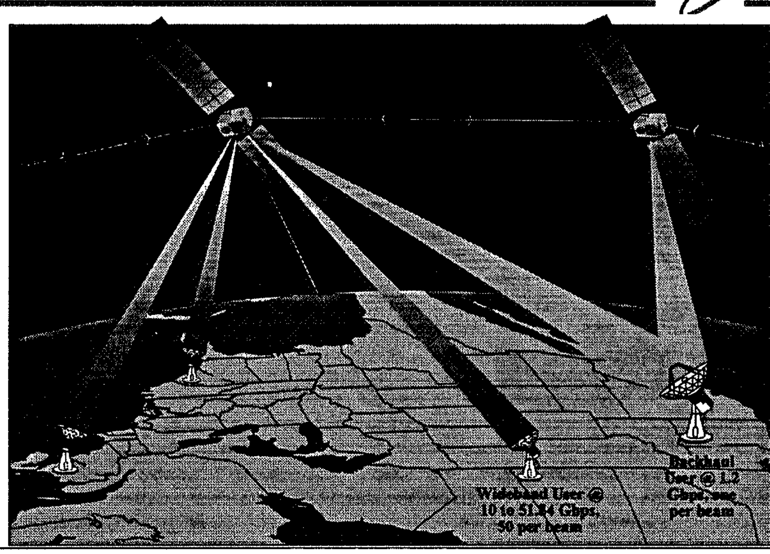
OrbLink Baseline: Architecture



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TELEDESIC LEO NETWORK ARCHITECTURE

Dr Marie-José Montpetit
Network Design Team

Teledesic

Future Network Requirements

- **Broadband Capacity**
- **Ubiquitous Access**
  - **Enable capacity everywhere**
- **Quality of Service**
  - **Allow for service differentiation in quality and pricing**
- **Seamless integration into existing protocols and infrastructures**

Teledesic

Satellite Networks

NASA Lewis Workshop - June 4 1998

- Regional/Global coverage
- Wireless Interfaces
  - No need to install "wired" infrastructure
- Onboard Switching
  - Reduces delay for BOD
  - Allows multiple beams (smaller terminals)
- Can be deployed faster than most terrestrial infrastructures into regions with little or no existing infrastructure
- Can bypass clogged terrestrial networks and is oblivious to terrestrial disasters
- Increase existing network reliability

Teledesic

LEO Satellite Networks Features

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- Fiber-like delays
- Global coverage
- Integration in the Network of Networks
- Advanced communication services almost everywhere, all the time
- Low implementation cost per site
- Can grow naturally as markets develops
- Support both symmetrical and asymmetrical applications
- Flexibility while keeping a manageable complexity

Teledesic

Teledesic: Internet-in-the-Sky

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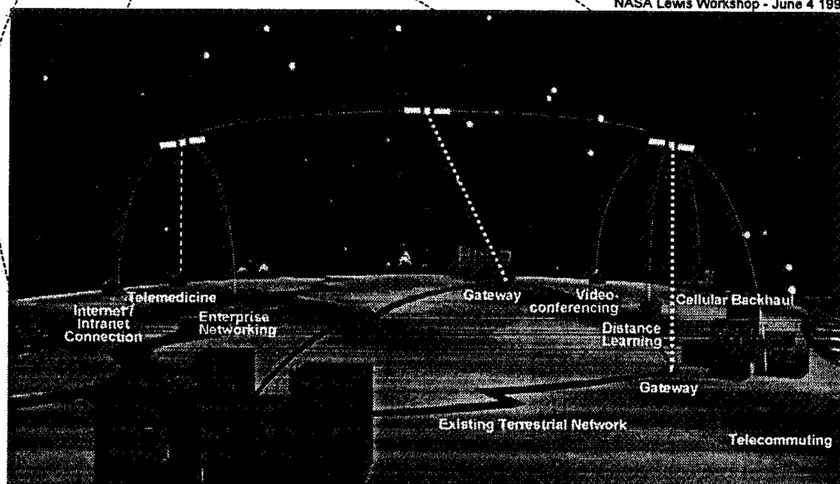

Teledesic

The Teledesic Network Architecture

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- Low delay
  - Autonomous nodes
  - No need for changing terrestrial protocols
    - Impacts on congestion control
    - Impacts on IPsec
    - Impacts on client server applications
  - Interactive/real time applications
- Seamless interworking
  - IP
  - ATM
  - SNA
  - New protocols
- Global access with high availability
  - High mask angle
  - Dense meshed Network
- High Capacity
  - High frequency re-use added to bandwidth on demand (BoD)
  - Small cells/footprints
  - High level of statistical multiplexing in the air interface
  - Low delay allows very resource efficient BoD
- Reliability
  - Engineer reliability
  - Implements connectionless protocols
  - Keep state information at the edges

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Low Latency is Essential to the Internet

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- GEO latency can significantly degrade performance on client/server applications such as Oracle and Exchange Server resulting in slow downs of 10 times or more
  - Small transaction-oriented queries get queued up by GEOs' high delay
- Companies on the Internet today are guaranteeing maximum allowable latency:
  - ANX guarantees < 125 msec end-to-end for service provider certification
  - UUNET guarantees < 150 msec end-to-end latency for two sites on its network
  - AT&T Worldnet guarantees < 100 msec latency on its backbone
  - Sprint guarantees < 140 msec latency on its backbone
- GEOs do not work well with fundamental Internet protocols like TCP/IP
  - Most implementations of TCP today provide unacceptable performance (e.g., wasting 93% of bandwidth on a 2 Mbps connection) because they lack "large window" support
  - TCP's essential congestion control mechanisms degrade performance over GEOs. These mechanisms cannot be removed without potentially causing the "congestive collapse" of the Internet.
  - One proposed solution, ACK spoofing, is incompatible with Internet Protocol security (IPsec) and will not work at all with the next generation protocol, IPv6.
- Transaction-oriented Internet protocols also suffer from GEO delays because signaling exchange is necessarily sequential
  - HTTP/1.0 and HTTP/1.1, POP3, IMAP4
  - Hand-shaking portions of real-time protocols such as H.323 also suffer

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Low Latency and High Bandwidth are Necessary for Fiber-Like QOS

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- Voice is still one of the most important network applications and customers will not accept GEO latency on voice calls
- GEO latency makes efficient scheduling of Bandwidth-on-Demand much more difficult
- Latency also adversely affects legacy protocols like DEC LAT and SNA
- By contrast, Teledesic's LEO Network will be seamlessly compatible with the Internet and other terrestrial networks

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LEO vs. GEO Comparisons

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Category	Reference (fiber-optics)	GEO	Teledesic
	Comparable characteristics		
High channel bandwidth	yes	yes	yes
Bandwidth-on-demand	no	yes	yes
	Teledesic Advantages		
Optimized for high-performance Internet access	yes	no	yes
Supports high-quality voice	yes	no	yes
Ubiquitous global coverage	no	no	yes

Network Models

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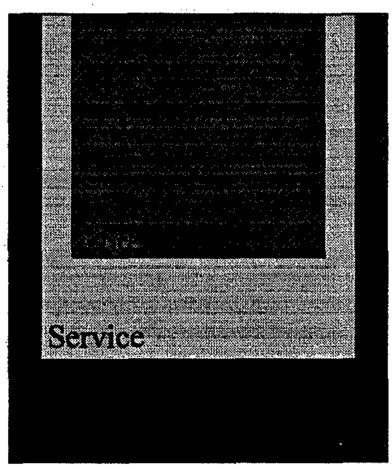

- Core Network
  - Global Switching Fabric that includes terrestrial and space elements.
  - Enables Teledesic control of:
    - Resource Allocation
    - Internal Traffic Management
    - Internal Accounting (Billing)
    - Internal Security
- Service Layer
  - Access point.
  - Responsible for translating and encapsulating external network protocols.
- External Networks
  - Teledesic is one component in the "network of networks".
  - Defines the performance requirements

Components in the Core Network

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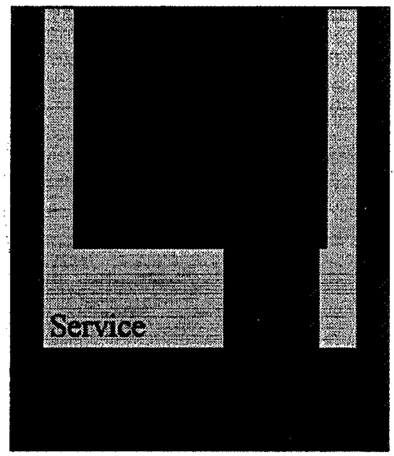

- Satellite Payload
  - Uplink and Downlink Services
  - Table Driven QoS Routing
  - Network Management
- UE - Core functions
  - Conceptual Division in UE between Core component and Service Layer Component.
  - The UE core element manages low-level access levels to the Teledesic Network.
    - Uplink and BoD management
    - Downlink
    - Network Management
    - Security

Components in Service Layer

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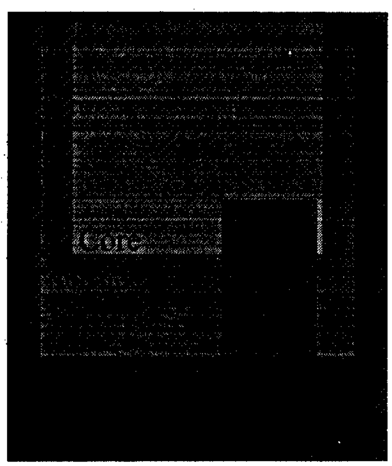

- UE - Service layer functions
  - Provides adaptation of external protocols for transport across Core network and initiate BoD requests as needed.
- Network Management
  - Teledesic Management System and Constellation Operation and Control Center.
  - Teledesic controlled services that are used to program the Core.
- Customer
  - Reseller of Teledesic services.

Addressable Elements

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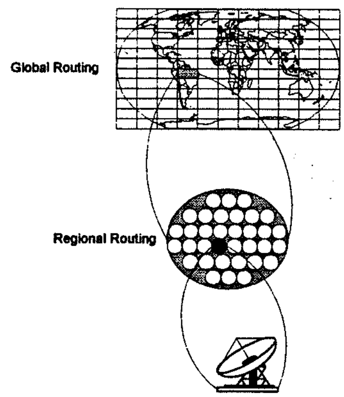
- Nodes in the Network
  - Satellites
  - Terminals and gateways
  - Interfaces



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Interworking and Access

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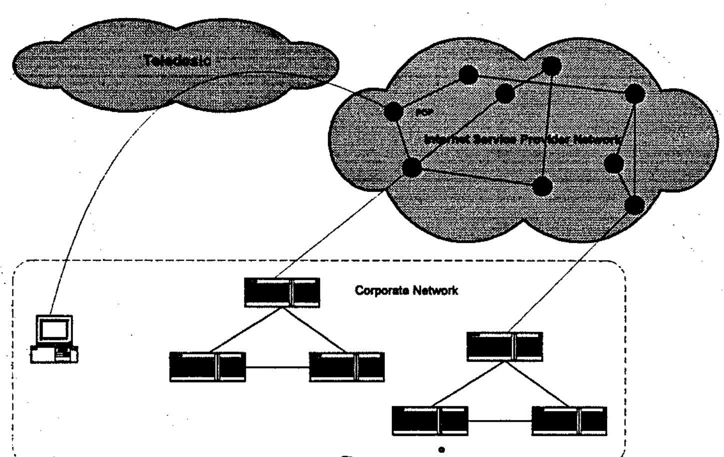

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Future Directions

- Integrated multi-tiered Networks
- LEOs essential part of integrated service offerings
  - Other networks used in the context of their optimal performance
- Network of Networks
  - Access independent of the platform
  - Emphasis on global network management
- Environment of integrated broadband network services.

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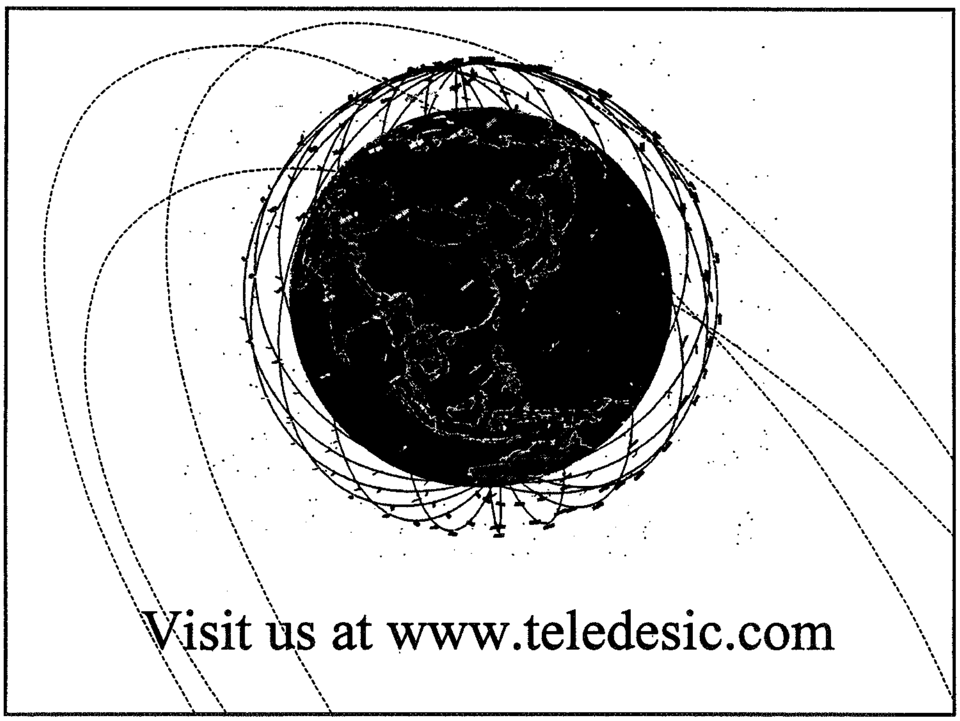

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Since global satellite networks are moving to the forefront in enhancing the national and global information infrastructures due to communication satellites' unique networking characteristics, a workshop was organized to assess the progress made to date and chart the future. This workshop provided the forum to assess the current state-of-the-art, identify key issues, and highlight the emerging trends in the next-generation architectures, data protocol development, communication interoperability, and applications. Presentations on overview, state-of-the-art in research, development, deployment and applications and future trends on satellite networks are assembled.

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