International Workshop on

SCGII

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Proceedings of the fifth

International Workshop on Satellite Commmunications in the Global Information Infrastructure

Ottawa, Canada
June 15, 1999

Communications Research Centre
Centre de recherches sur les communications

National Aeronautics and Space Administration

Industrie Canada

Canada

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Co-Sponsored by:

NASA, USA
and Communications
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CRC Communications Research Centre
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Welcome to SCGII

We, the Technical Co-Chairs, wish to welcome all participants to this International Workshop on Satellite Communications in the Global Information Infrastructure. We think we have a wide ranging program in terms of content, and hope that every person here will find something to interest them. When this series of Workshops was initiated, there was a major concern that the technical standards being set for the Global Information Infrastructure would emphasise optical fibre communication, and preclude satellite delivery. Today, at this, the Fifth Workshop, we find that satellite communications provide a healthy percentage of the Infrastructure. We shall also see as the day progresses that the industry has exciting plans to develop further, and maintain its position as a practical complement to wired and wireless terrestrial infrastructure. We especially thank organisers of, and participants in, the Panel Sessions, and those who will be presenting in the Technical Sessions. We appreciate their efforts in preparing for the Workshop.

Kul Bhasin
Technical Co-Chair, NASA Glenn Research Center

Jim Hamilton and **Ted Hayes**
Technical Co-Chairs, Communications Research Centre

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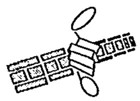
Technical Session 1



Evolution of Satellite Business Services

Presented by
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SpaceBridge Network Corporation
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Submitted to
The 5th International Workshop on Satellite Communications
in the Global Information Infrastructure (SCGII)
June 15, 1999

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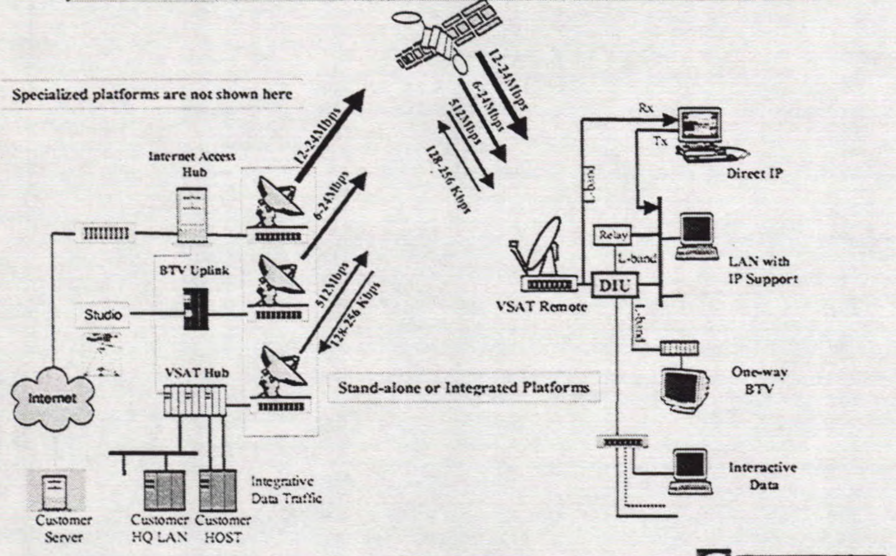
Introduction

- Proliferation of satellite business services began with the delivery of single media services on separate platforms
- These services used VSAT, telephony earth station, video conferencing, and specialized pt-to-pt and mesh technologies
- VSATs are now augmented by Internet access and Business TV services via integrated platforms to offer enhanced services
- Use of DVB, Internet Protocol (IP), and ATM standards are leading to seamless integration of services
- Advanced satellites are expected to facilitate the delivery of cost-effective broadband multimedia services
- All these advancements are paving the migration path from single media to advanced multi media services

Existing Services

- Today, satellite business services are mostly comprised of:
  - VSATs: interactive data and inter-LAN connectivity
  - Internet Access: connection to ISP
  - Business Television: one-way video
  - Broadcast Data
- There are also specialized services
  - Video conferencing, telephony, point-to-point and mesh services
- Stand-alone platforms offer single media services
- Integrated platforms offer enhanced (multimedia) services
  - VSATs & LAN internetworking
  - VSATs & Internet Access
  - VSATs & BTV
- Airtime and terminal costs play a big role in the choices made

Existing Delivery Platforms



SpaceBridge

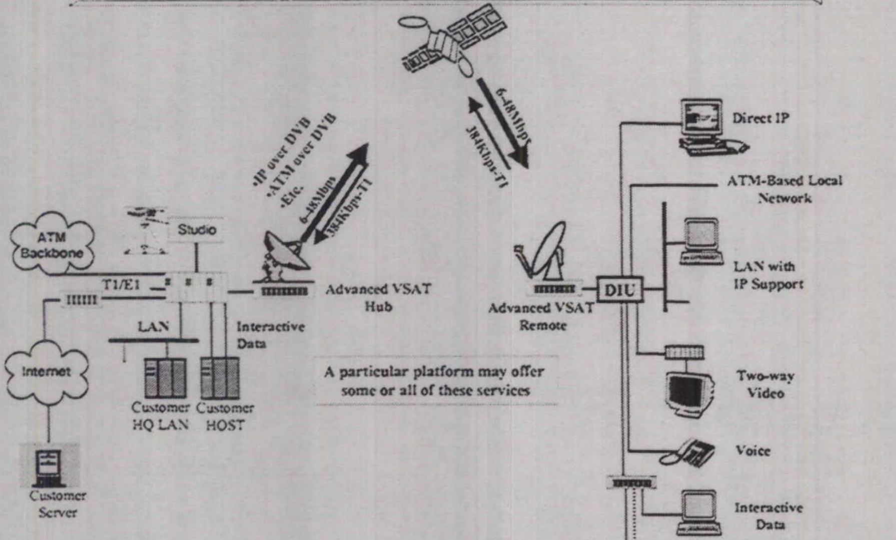
Emerging Services

(Under Existing Satellite Platforms)

- Seamless integration of multimedia services on a single platform
- Integrated transport protocols
  - IP over DVB
  - ATM over DVB
  - MPEG over IP
  - Etc.
- Higher outbound speeds
  - 24-48 Mbps
- Advanced access technologies
  - MF-TDMA, CDMA
- Star & mesh configurations
- Terminal size, inbound speed, and airtime cost are still governed by the characteristics of the existing satellite platforms

SpaceBridge

Emerging Delivery Platforms



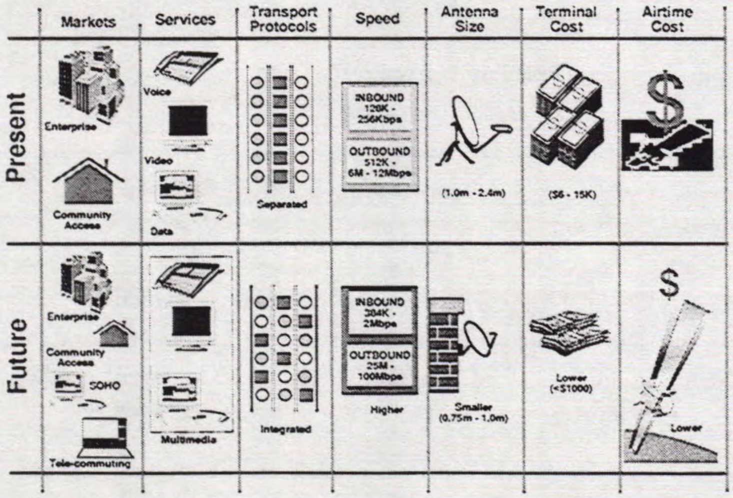
A particular platform may offer some or all of these services

Next Generation Services

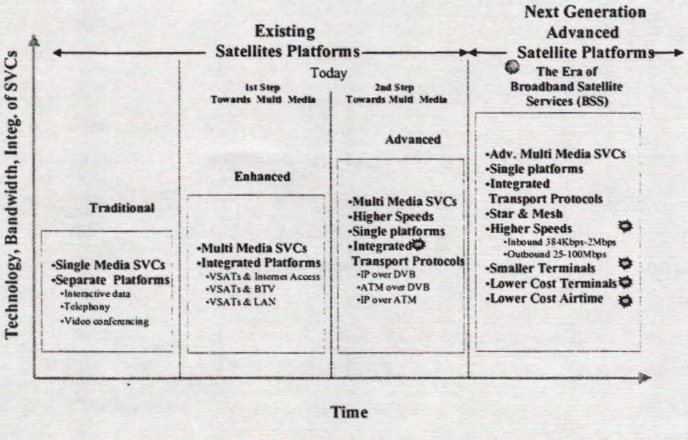
(Under Advanced Satellite Platforms)

- Seamless integration of multimedia services on a single platform
- Integrated transport protocols
- Higher speeds
- Smaller terminals
- Lower cost terminal
- Lower cost airtime
- Economies of scale
  - Enterprise & community services
  - Small office home office & telecommuting services
  - Tele-medicine & tele-education services

Key Service Parameters



Migration Path



Conclusions

- A great deal of capability exists already
  - Variety of platforms & services
- Additional enhancements are emerging
  - Integrated transport protocols, seamless integration
- Quantum advancements are expected in the near futures
  - Smaller & lower cost terminals, lower cost airtime
- Use of satellite business services are expected to accelerate
  - Through the catalysts of lower cost and higher performance
- Many opportunities for equipment suppliers and service providers
  - Capturing early market adapter as well as long term positioning

Conclusions (Continued)

- A great deal can be learnt from the experiences gained in deploying and developing existing services
  - Integration of technology/platforms
  - Competitive pricing and service positioning to meet requirements
  - Provision of seamless end-to-end integrated services to end users
  - Applications development
- An early consideration of pricing and service positioning strategies for multimedia services is highly beneficial
  - Pricing that support integration of services
  - Pricing that meets customers' changing price/performance needs
  - Feedback for optimization of technology solutions
- We need to also consider the realization of a smooth migration path from the present to future

Thank You For Listening

"Infrastructure on Demand" Global Fibre-Optic Capacity From EHF Satellite Communication Systems

Greg Giffin
MacDonald, Dettwiler & Associates Ltd.

Dr. Joseph Bravman
Orbital Sciences Corporation

John Fedak
President and CEO of Infocom Technologies

Outline

- Summary of Niche Markets
- Summary of System
- Overview of Implementation Challenges
- Regulatory Status
- Conclusion and Questions

Orbital Communication Satellite Being Tested at DFL

"Infrastructure On Demand"

	Ka-band 'Bandwidth on Demand'	V-band 'Infrastructure on Demand'
Primary Service	'~T1 To The Home' (1.544 Mbps Level)	'Bulk Data Backhaul' (10's to 100's Mbps)
User Base	ROM hundreds of 1000's	ROM 1000's
Coverage	Broad Areas, Significant % of Land Mass Covered	Select 'Data Intense' Areas, % of Land Mass Covered Is Smaller
Comments	Some Systems Plan To Offer Specialized High Rate 'Gateway' Service (Up To OC12 For Teledesic/Celestri) But This Is Not Primary Focus	Small Beams Result From Increase In Carrier Frequency And Gain Required To Fight More Severe Rain Fade

- Takes Full Advantage of Significant Available Spectrum At V-Band
  - Example: Interconnection of Whole Cities (Data Aggregated By Complementary Terrestrial Systems or High Altitude Systems)
- Began To Identify ORBLINK Niches By Considering Current Means of Providing This Very High Bandwidth Interconnectivity
  - Considered Here As An Example Are Our Top Level Findings On Undersea Fibre Systems

Major Undersea Communication Cables

Identified Trends:

- Strong Growth
  - Doubling Every 2 to 3 Years
- Increasingly Cost Effective
- Rapidly Improving Technology
  - WDM!
- Scope of Systems Increasing Toward Global Scale
- High Useful Lifetime (~25 Years)

Trans-Atlantic Cables: Source: Pioneer Consulting

Year of Launch	*System*	*Total Cost ($ CAD M)*	*Capacity (Circuits)*	*Distance (km)*
1988	TAT-8	540	7560	6705
1992	TAT-9	609	15120	8500
1992	TAT-10	450	22680	7700
1993	TAT-11	420	22680	6900
1995/6	TAT-12/13	1134	120960	13000
1989	PTAT	750	17000	7552
1994	CANTAT-3	580	60480	7500
1994	Columbus 2	N/A	22680	12200

Trans-Pacific Cables:

Year of Launch	*System*	*Total Cost ($ CAD M)*	*Capacity (Circuits)*	*Distance (km)*
1989	TPC-3	900	7560	9070
1992	TPC-4	630	15120	9850
1996/7	TPC-5	1800	120960	25000
1991	NPC-1	638	17000	9531
1993	PacRim East	428	7560	7700
1995	PacRim West	405	7560	7084

Europe-Asia and Global Cables:

Year of Launch	*System*	*Total Cost ($ US M)*	*Capacity (Circuits)*	*Distance (km)*
1994	Sea Me We 2	1050	15360	18190
1998/99	Sea Me We 3	1800	480000	30000
1997	FLAG	1800	120960	28000
~2000	OXYGEN	~15000	> 1 Million	275000

CONCLUSION:

More Than Competitive With Dedicated Satellite Service of Similar Bandwidth In Developed Areas

1 CIRCUIT = 64 kbps

ORBLINK Requirements: Top Level

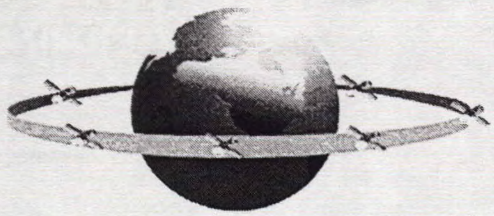
- Provide Links @ 1.2 Gbps and @ 10 to 51.84 Mbps
- Coverage of >90% of the World's Population With 98%-99.99% Availability
- Minimum BER of 10^{-9}
- A Latency Compatible With Real-time Application Support
- System Cost of About 1 Billion
- IOC in the Year 2003
- Operate in the Q/V-band Under Assumed FCC Allocations of 37.5 to 38.5 GHz (Downlink), 47.7 to 48.7 GHz* (Uplink) and 65.0 to 71.0 Ghz for ISL.
- PFD Limits May Not Be Violated
- System Lifetime of 9 Years
- System Reliability of 80% Chance of 90% Functionality at EOL

* May Be Slightly Modified In Light of Recent FCC Report and Order

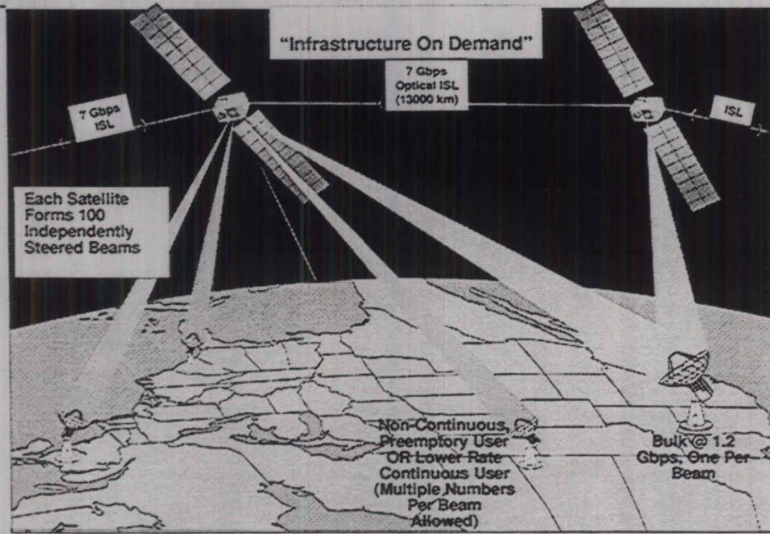
There Is a System Which Meets These Requirements

ORBLINK Baseline: Top Level

- 7 Satellite Constellation in a 9000 Km Equatorial Orbit (Plus One Spare)
  - Nadir Latency of ~1/16 S
  - Achieves Coverage of 93% of Population at Min. Elevation of 10 Deg.
  - Leverages System Power Over GSO's for Better Capacity to Cost Ratio
  - Avoids LEO Complexity and Size
- System Capacity of Up To 400 Gbps
- IOC in 2003
  - Attractive Realistic Capital Cost Structure
  - Adaptation Of Existing Bus



ORBLINK Baseline: Architecture



ORBLINK Challenges

"The ORBLINK Pentagon"

ORBLINK

Develop Market and Anchor Customers
- Substantial Pre-Sell Targeted

Propagation Studies
- Reduce EHF Uncertainty
- Demonstrate Interest In the Spectrum

Early Demonstrator
- Prove Principles and Concepts Needed For High Bandwidth EHF Operation
- Reduce Market Risk

Regulatory Process
- Obtain Commercial EHF License

Obtain Financing And Partnering
- Total Cost of About $1 B US

Overview of Global Commercial Satellite System Regulatory Process

NATIONAL SUBMISSION
- Public process requiring detailed technical and service information

↓

ITU APPROVAL
- National regulatory entity is interface for ITU
- Guarantees that system meets global interoperability requirements

↓

LICENSE GRANTED
- Permission to construct, launch and operate the proposed system (within the nation)

↓

OTHER NATIONS
- Process assisted in other nations since it can build upon the granted ITU approval

Recent FCC Report and Order for V-band

- Released December 23, 1998 And Provides Separate Primary Designations for Terrestrial and FSS Services
- Goal Is to Encourage Commercial Development by Removing Technical Constraints of Co-primary Allocation
  - In Addition, "Underlay" Licensing of Second Services in FSS Not Adopted
- Will Also Speed License Application Process Since Process of Terrestrial and FSS Systems Can Be Separated
- Notice of Proposed Rule Making Prior to This Report and Order Had Also Suggested Separate Designations for GSO and NGSO FSS Systems
  - Not Adopted Yet Since The FCC "Does Not Yet Know The Extent To Which GSO and NGSO Operations Will Occupy The FSS Bands"

New Table of US V-Band Allocations

Current Allocations	EES, SPACE RESEARCH, FIXED, MOBILE	FIXED, MOBILE	FIXED, MOBILE	FIXED, MOBILE FSS, MSS(39 5-40)	FSS, MSS	BSS, fixed, mobile BROADCASTING	BSS, fixed, mobile, BROADCASTING	BSS, fixed, mobile, BROADCASTING
NPRM Band Plan'		Wireless Services (37 0-37 5)	FSS/NGSD (37 5-38 5) Wireless Services (38.5-38.6)	(Wireless Services)	Wireless Services	FSS/GSO	FSS/GSO	Wireless Services
R&O Band Plan'	1000 MHz	Wireless Services 600 MHz	FSS 1000 MHz	(Wireless Services) 1400 MHz	FSS, MSS 500 MHz	FSS, BSS 500 MHz	Wireless Services 500 MHz	Wireless Services 1000 MHz
	36 0	37 0	37 6	38.6	40 0	40 5	41 0	41 5

42.5

Current Allocations	FIXED, MOBILE, FSS, RADIO ASTRONOMY	None - Exclusive Government	MOBILE, MSS, RNSS	MOBILE, MSS, RNSS	MOBILE, MSS, RNSS	AMATEUR, AMATEUR-SATELLITE	FIXED, FSS, MOBILE	FIXED, FSS, MOBILE
NPRM Band Plan'				(Unlicensed Commercial Vehicular Radar)	Wireless Services	(Amateur)	(Wireless Services)	FSS/NGSO
R&O Band Plan'	1000 MHz	2000 MHz	1200 MHz	(Unlicensed Commercial Vehicular Radar) 200 MHz	Wireless Services 100 MHz	(Amateur) 200 MHz	(Wireless Services) 1000 MHz	FSS 1000 MHz
	42 5	43 5	45 5	46.7	46 9	47 0	47 2	48.2

49 2

Current Allocations	FIXED, FSS, MOBILE	FIXED, MOBILE, EES, SPACE RESEARCH	FIXED, FSS, MOBILE, MSS
NPRM Band Plan'	FSS/GSO		Wireless Services
R&O Band Plan'	FSS 1000 MHz	200 MHz	Wireless Services 1000 MHz
	49.2	50.2	50.4

51.4

Canadian Regulatory Process

- Described In Detail In Industry Canada Document (CPC-2-6-02) "Licensing of Space Stations in Services Other than the Amateur Satellite Service and the Broadcasting Satellite Service in Planned Bands"
- Designed For Systems With The Following Characteristics:
  1) GSO
  2) Common Carrier
  3) Must Be 80% Canadian Owned And Controlled
- Presently, A Monopoly to Telesat Canada Exists Until March 2000 For Domestic And Canada/USA Traffic In the Fixed Satellite Service
- Regulations Need to Be Updated If Canada Intends to Allow Its Industry To Field Canadian-Based NGSO, Non Common Carrier Systems

Potential Satellite System Competition

- 17 Systems Proposed By 14 Different Companies In The US Alone
- Total Value Of Approx. $ 45 Billion US
  - Not All Systems Will Ultimately Deploy
  - There Is An Almost Even Cost Split Between NGSO and GSO Services
- Several Of These Have Targeted 'Fibre Optic In The Sky Market'

Summary of First Round V-band FCC Filers

Company	System Name	Service Type	Architecture NGSO (No. planes) GEO (No slots)	Communications System		Est Cost (SB US)	Data Rate (Mbps)
				Phased Array?	On-Board Processing		
CAI Satcom	N/A	FSS	1 GEO (1)	No	No	0 3	38
Denali	Pentriad	FSS & BSS	9 HEO (3 at 63 4°)	Yes	No	1 9	10 – 3875
GE Americom	GE*StarPlus	FSS	11 GEO (9)	No	Yes	3 4	1 5 – 155
Globalstar	GS-40	FSS	80 LEO (10 at 52°)	Yes	No	N/A	2 – 52
Hughes	Expressway	FSS	14 GEO (10)	No	No	3,9	1.5 – 155
Hughes	SpaceCast	BSS	6 GEO (4)	No	No	1.7	0.4 – 155
Hughes	StarLynx	MSS	20 MEO (4 at 55°) 4 GEO (2)	Yes	Yes	2 9	2 to 8
LEO One USA	Little LEO	MSS	48 LEO (8 at 50°)	No	Yes	0 3	0 032 – 0.256
Lockheed Martin	Q/V-Band System	FSS & BSS	9 GEO (9)	Yes	Yes	4 7	0 384 – 2488
Lockheed Martin	LM-MEO	FSS	32 MEO (4 at 50°)	Yes	Yes	6 82	10.4 – 113.8
Loral	Cyberpath	FSS	4 GEO (4)	Yes	Yes	1.2	0.4 – 90
Motorola	M-Star	FSS	72 LEO (12 at 47°1	Yes	No	6.2	2 – 52
Orbital	ORBLINK	FSS	7 MEO (1 at 0°)	No	No	0 9	10 - 1250
PanAmSat	V-Stream	FSS	12 GEO (11)	No	No	3.5	1.5 – 155
Spectrum Astro	Aster	FSS	25 GEO (5)	No	No	2 4	2 – 622
Teledesic	V-Band Supplement	FSS & BSS	72 LEO (6 at 84 7°)	Yes	Yes	1 95	10 – 100 up 1000 dn
TRW	Global EHF Satellite Network	FSS	15 MEO (3 at 50°) 4 GEO (4)	Yes	Yes	3 4	1 5 – 1555

ORBLINK - First to Market?

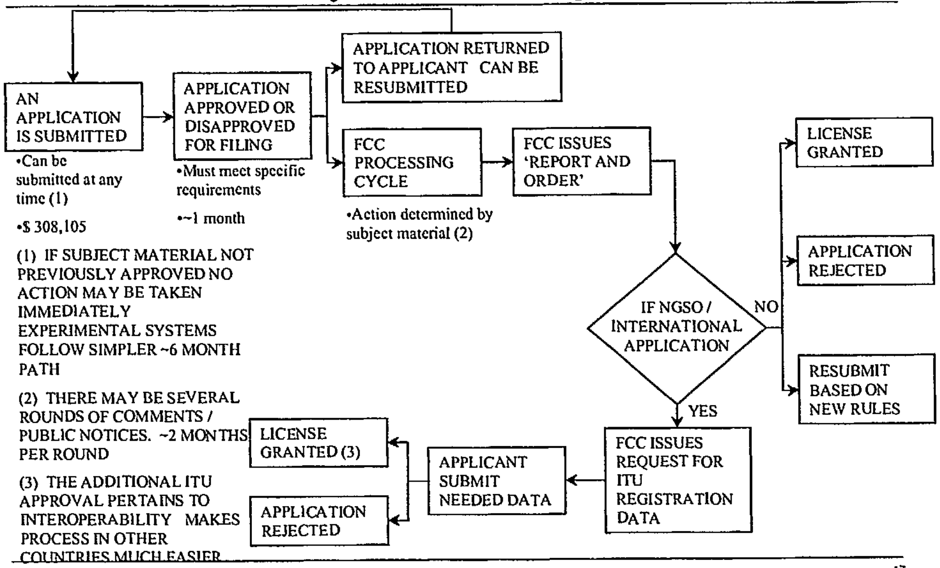
- Comparatively Simple Constellation
  - One Plane of Limited Number of Satellites But Still Achieves Coverage of 90% of the Earth
    - > Easier to Build, Deploy and Replace
  - ISL's Simplified Due to Fixed In Plane Geometry
  - Limited Processing - Just A to B Connections -> We Are Truly Fibre in the Sky
- Orbital Strategic Decision Not to Be a Service Provider at Ka Band.
- Attractive Level of Required Financing
- Pioneering Activity Through Experiment and Demonstration

Conclusions

- Have Defined Primary Market Niches
- Anticipate Being First To Market In Those Niches
- Have Filed With FCC For Baseline System
- Actively Pursuing Multiple Paths Leading To System Implementation
  - Propagation Studies
  - Early Demonstrator
  - Partnering and Financing
  - Customer Development
  - Regulatory Process

Additional (Back-Up) Slides

FCC Satcom System Licensing Process



DEVELOPING ADVANCED INTERNET TECHNOLOGIES AND APPLICATIONS OVER ACTS

International Conference on Satellite Communications in the GII (SCGII)

Ottawa, Canada 6/15/99

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NASA Glenn Research Center
Cleveland, OH 44135 USA

OUTLINE

- Internet via Satellites
  - *Drivers*
  - *Next-Generation Communication Networks*
- Networking Challenges and Issues
- ACTS Overview
- Internet Technology over ACTS
- Internet Applications over ACTS
- Summary

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INTERNET VIA SATELLITES

DRIVERS

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

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NEXT-GENERATION COMMUNICATION NETWORKS

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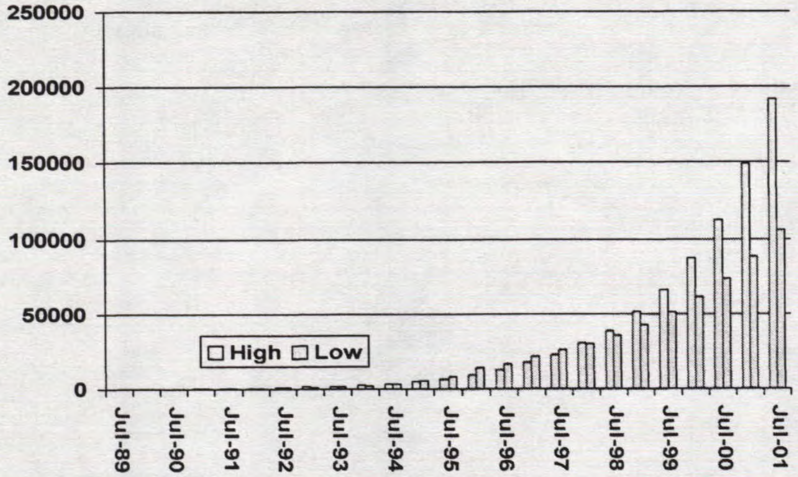
Internet Hosts (000s) 1989-2001



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NEXT-GENERATION COMMUNICATION NETWORKS

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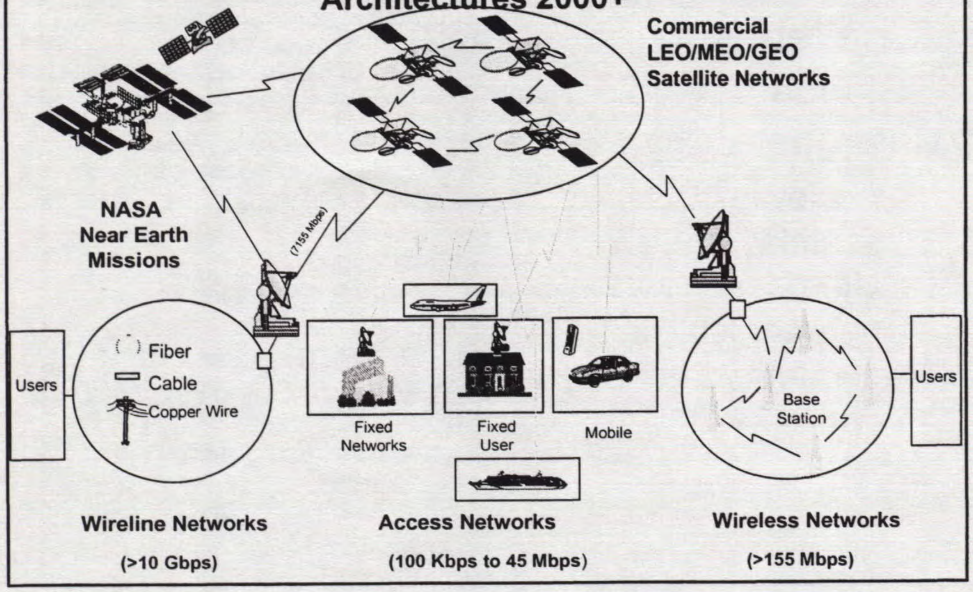
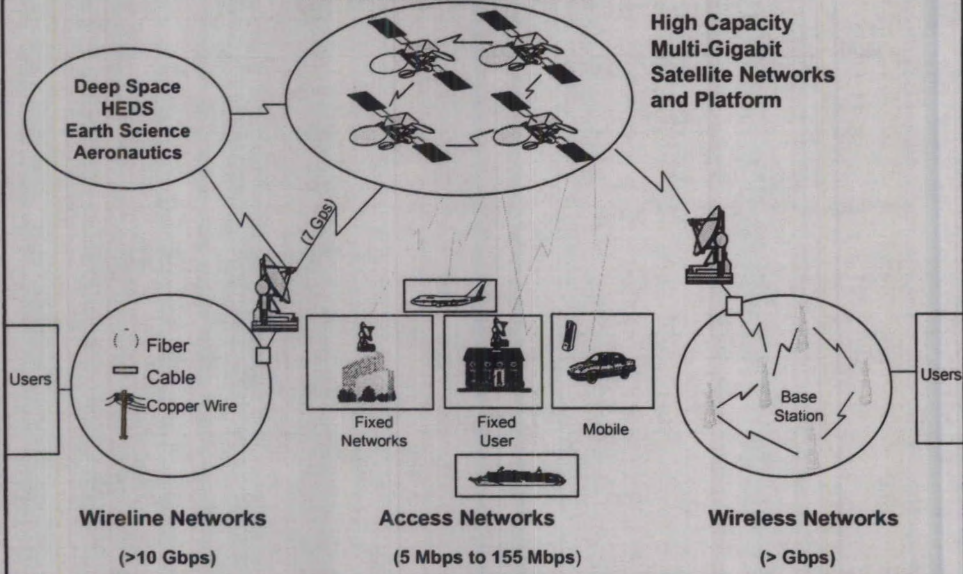
Architectures 2000+



NEXT-GENERATION COMMUNICATION NETWORKS

Architectures 2010+



NETWORKING CHALLENGE AND ISSUES

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

- Issues -
  - Interworking between networks
    - ATM traffic and congestion management
    - ATM quality of service
    - ATM voice
    - ATM wireless
  - Data Protocols
    - TCP/IP over hybrid networks
  - Signaling Changes
  - Mobile Satellite Issues
  - GII Architectures and Reference Models
    - Interfacing of satellite networks
    - Reference model for hybrid networks

*From SITF's challenges presented to V P Gore at the White Meeting 1995 and NASA-SOMO Grand Challenges

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SPACE INTERNET VISION

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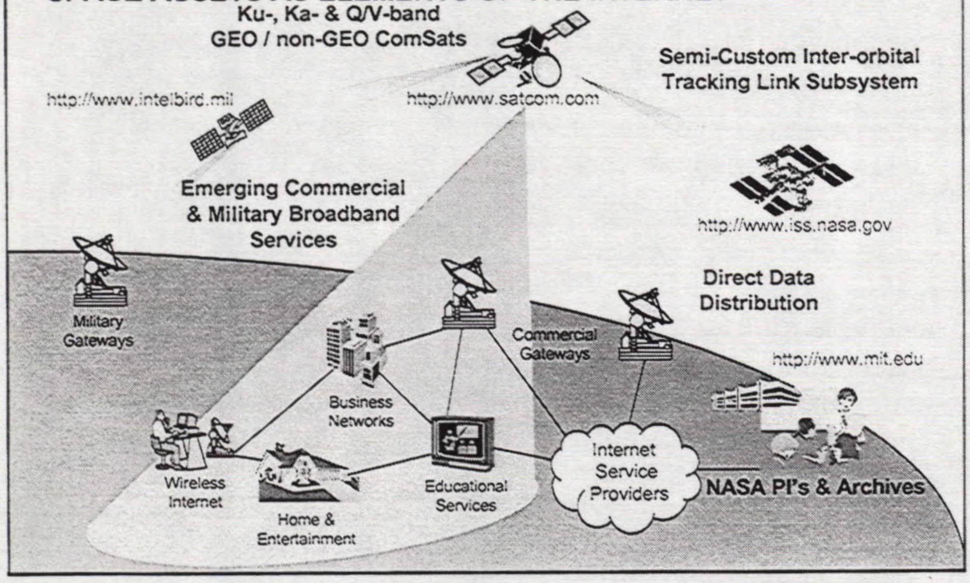
SPACE ASSETS AS ELEMENTS OF THE INTERNET



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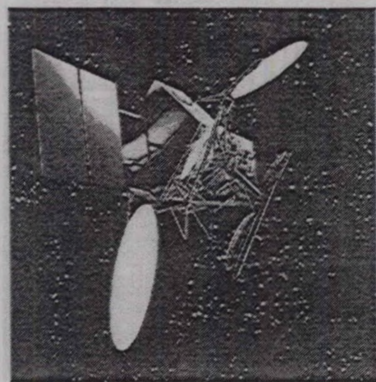
ACTS OVERVIEW

WHAT IS ACTS?

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

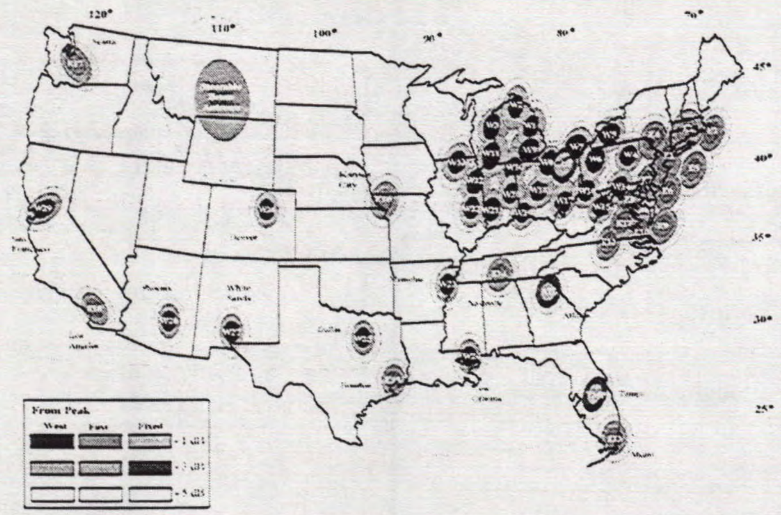


BACKGROUND

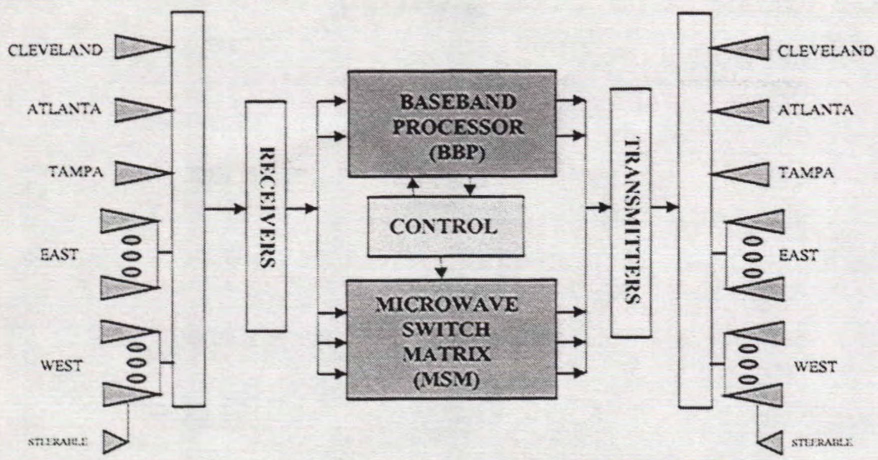
- Original goal:
  - develop high-risk, high cost technology for next generation satellite systems
  - enable growth in capacity and utilization of freq. Spectrum
  - to maintain US pre-eminence in communications satellite technology
- Experiments began December 6, 1993.
- Initial 2 year mission extended (4 yr. design life) - sixth year now underway!

Launched September 12, 1993 aboard STS 51 - Discovery.

ACTS COVERAGE



ACTS PAYLOAD



KEY ACTS TECHNOLOGIES

High Gain, Fast Hopping Spot Beams

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

Onboard Processing & Switching

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

Ka-Band

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

ON-BOARD SWITCHING

- Baseband Processing (BBP)
  - Memory mapped processor to receive, store, and forward data
  - 2 channels of 110 Mbps max. throughput each
  - On-board demodulation and remodulation isolates uplink noise from downlink
  - TDMA mode on both input and output
    - 1 msec frame; can visit 40 terminals per frame
    - Spot beams visited only in response to traffic demand (DAMA)
  - 15 dB uplink margin/6 dB downlink for BER of 5E-7 and 99.5% availability
    - Convolutional coding and data burst rate reduction on demand to overcome signal fading due to rain

ON-BOARD SWITCHING

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

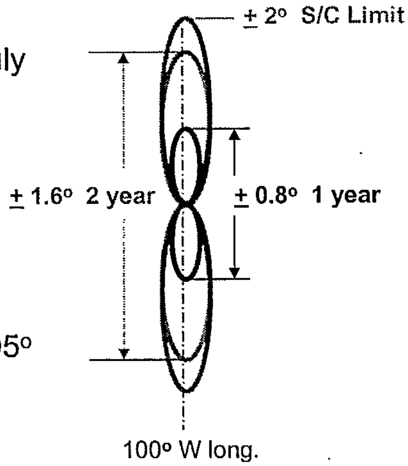
INCLINED ORBIT OPERATIONS

Spacecraft

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

Ground Segment

- Tracking modifications (2 axis) made to experimenter terminals

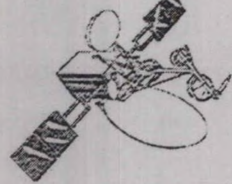


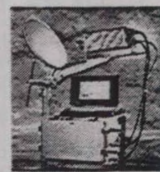
OPERATE THROUGH

JUNE, 2000

FAMILY OF GROUND STATIONS

1.2 m T1 VSAT (12)





0.6 m USAT (10)

3.4 m Gigabit Earth Station (3)

5.5 m NASA Ground Station

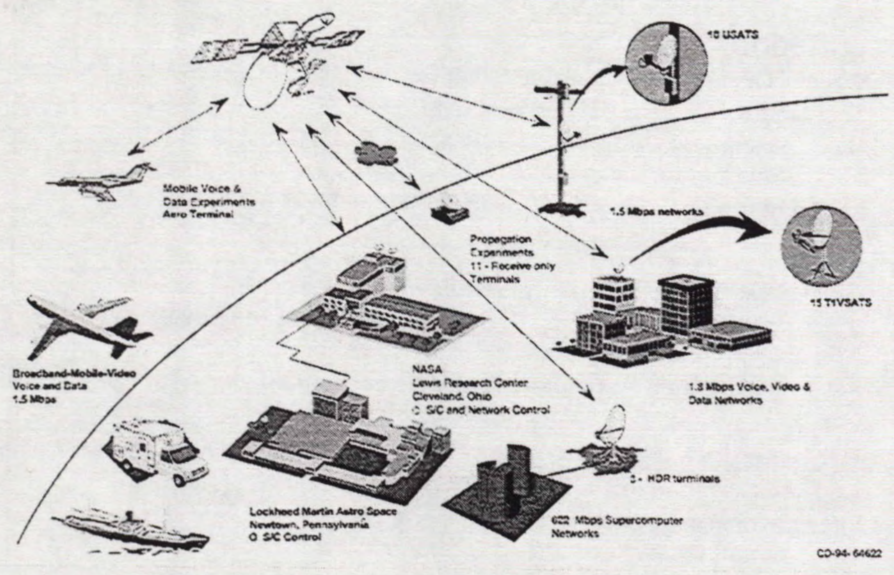
4.7 m Link Evaluation Terminal (LET)

GROUND STATION SUMMARY

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

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

EXPERIMENT OPERATIONS



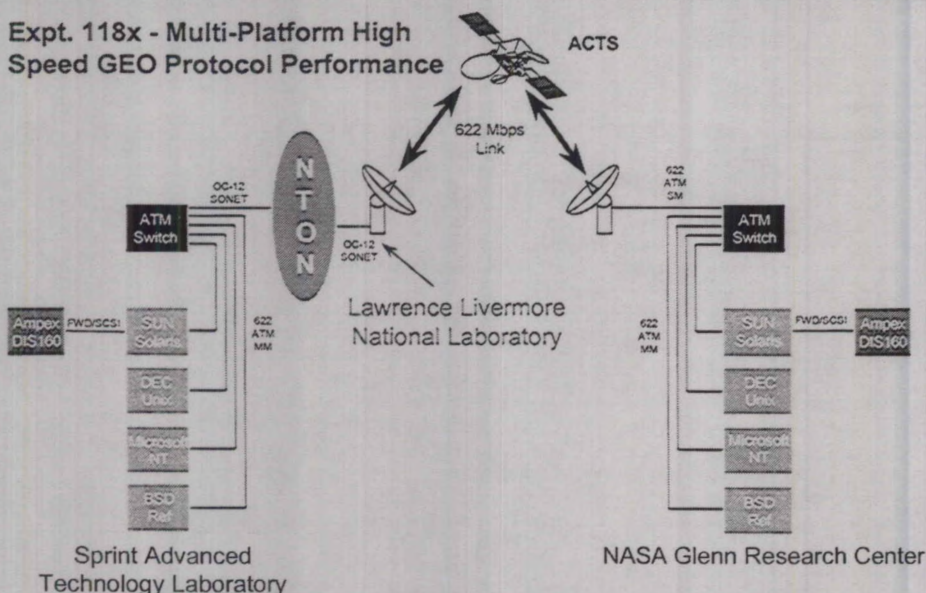
INTERNET TECHNOLOGY OVER ACTS

INTERNET BACKBONE EXPERIMENT

- **Description**
  - Model TCP in a high speed satellite network (622 Mbps SONET OC 12) using the NetBSD TCP stack over ATM
  - Three scenarios: symmetrical balanced links; highly asymmetric links; direct broadcast satellite
  - Experimentation with various TCP enhancements at high speeds
- **Impact**
  - Results will assist in IETF standardization process
  - Illustrates TCP performance in a high speed satellite network in a multi-vendor environment
  - Industry using results to improve commercial products
- **Participants**
  - Satellite Communications Industry
  - Information Technology Industry
  - Government Research Labs

INTERNET BACKBONE EXPERIMENT NETWORK

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



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INTERNET ACCESS PERFORMANCE EXPERIMENT

- **Description**
  - Qualitatively compare performance of MBone video and audio over a satellite network and the Internet
  - Quantitatively compare performance of MBone traffic over a satellite network and the Internet by measuring ATM QoS parameters
- **Impact**
  - Demonstrated the feasibility of delivering real-time Internet traffic (MBone traffic) over a GEO ATM satellite network
  - Multimedia over satellite demonstrated and performance measured in terms of application-layer QoS
- **Participants**
  - Hughes Research Lab
  - GRC/Satellite Networks and Architectures Branch

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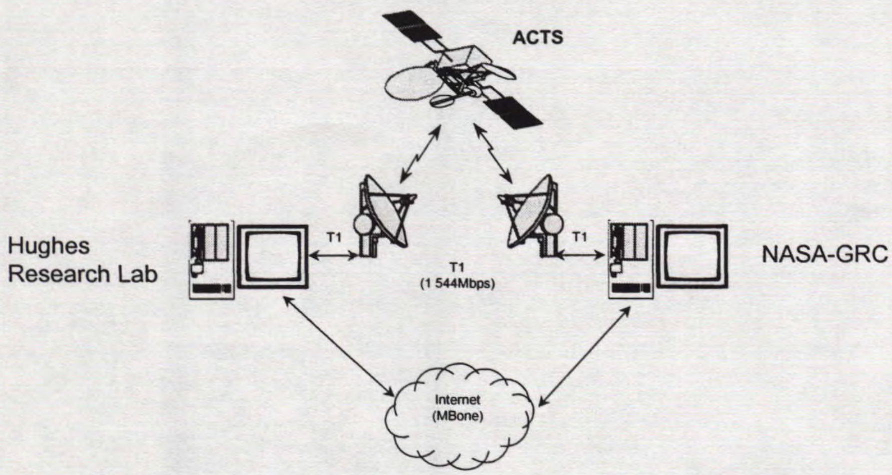
INTERNET ACCESS PERFORMANCE NETWORK



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INTERNET PROTOCOL PERFORMANCE EXPERIMENT

- **Findings**
  - HTTP/1.1 with pipelining makes the transfer time of WWW pages over ACTS at least as fast as transfers over current dialup modems
  - Experimentation with TCP with larger initial windows showed performance improvements. These findings aided the IETF in the standardization of larger initial window
  - A model of TCP/HTTP behavior has been developed which will allow researchers to better analyze TCP implementations
- **Impact**
  - Results assisted in IETF standardization process
  - Illustrated that satellite networks are feasible for a major Internet application
- **Participants**
  - Ohio University
  - GRC/Satellite Networks and Architectures Branch

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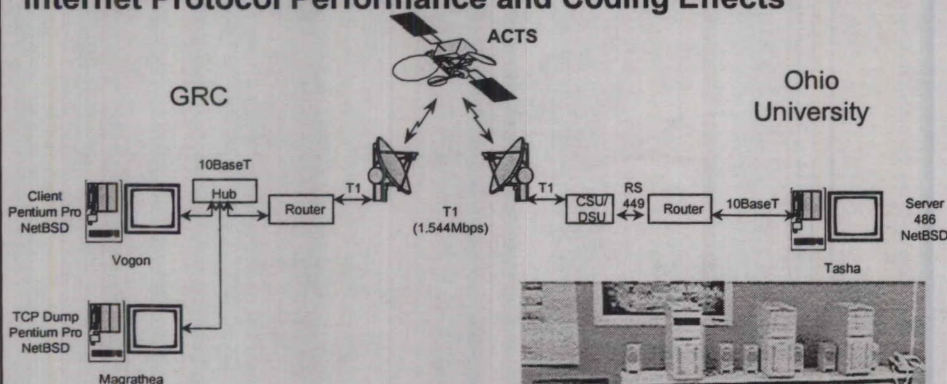
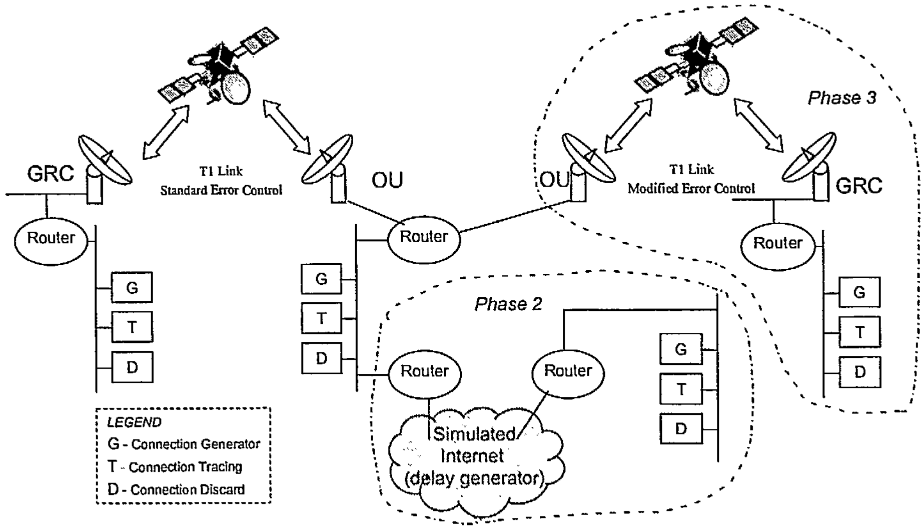
INTERNET PROTOCOL PERFORMANCE NETWORK

Internet Protocol Performance and Coding Effects



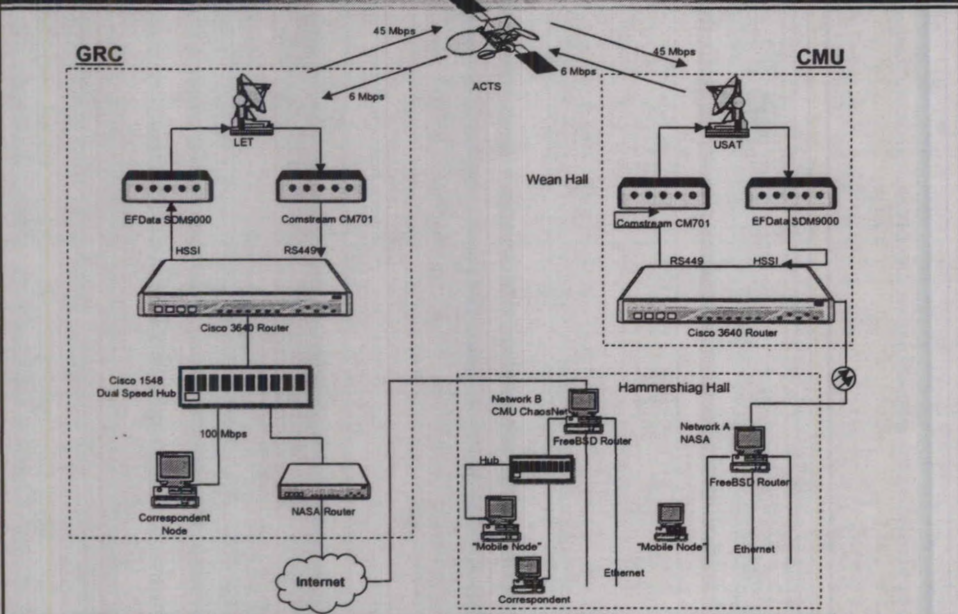
COMPETING INTERNET-LIKE TRAFFIC EXPERIMENTS



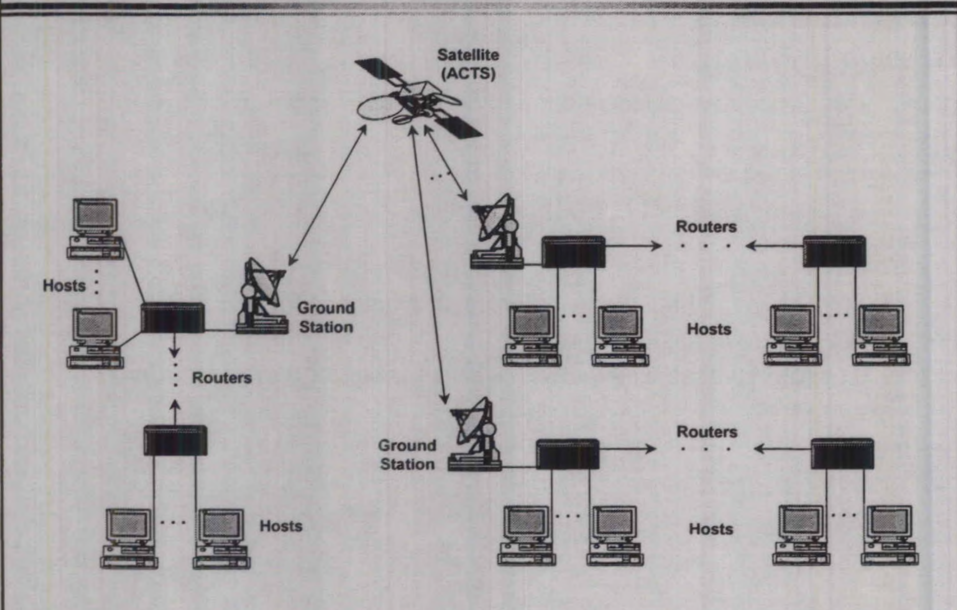
ARCHITECTURES AND PROTOCOLS TESTING

- **Description**
  - Performance analysis and improvement of TCP behavior over ACTS
  - Mobile IP performance over ACTS
  - Error modeling for the ACTS link and fade effects on TCP
- **Impact**
  - Model verified and is usable for research of current and future protocols over similar links
  - Illustrated that satellite networks are feasible for a major Internet application
- **Participants**
  - Carnegie Mellon University (CMU)
  - GRC

ARCHITECTURES AND PROTOCOLS TESTING



MULTICAST CHARACTERIZATION



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INTERNET APPLICATIONS OVER ACTS

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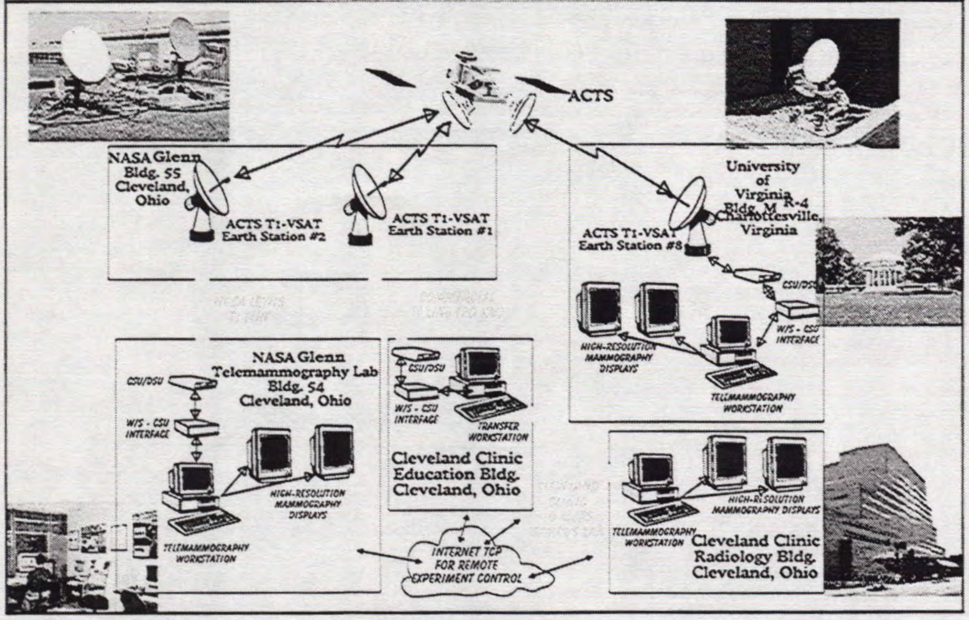
SMALL TELEMAMMOGRAPHY NETWORK EXPERIMENT



STN - MAJOR ACCOMPLISHMENTS

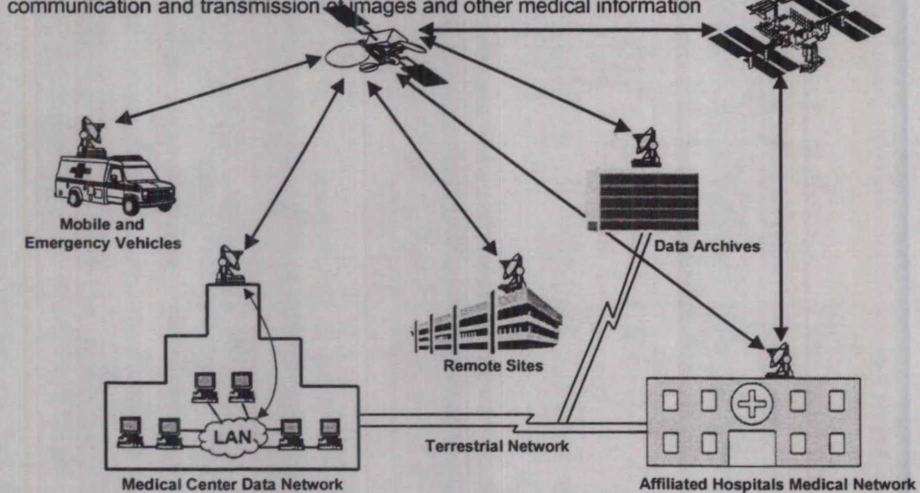
- Three-node hybrid satellite/terrestrial network (NASA Glenn, Cleveland Clinic Foundation, and University of Virginia).
- TCP/IP transmission of digital mammography images over ACTS.
- Image handling software and interpretation approaches for high-resolution digital mammography images.
- Over 4,000 digital mammography images transmitted without error.
- Application of lossy image compression to satellite telemammography.
- Developed, demonstrated, evaluated the satellite telemammography end-to-end process: Image compression, transmission, reception, decompression, display and interpretation by radiologists.
- Clinical studies:
  - Film-based mammography vs. 100 micron digitized film.
  - Evaluation of lossy-compressed, satellite-transmitted, 100 micron digital images.

STN FOLLOW-ON

Telemedicine Hybrid Networks:

Performance of Medical Protocol over Satellite Links

Digital Imaging and Communications in Medicine - DICOM 3.0 - Emerging standard for communication and transmission of images and other medical information



SHIPBOARD INTERNET EXPERIMENT

37

- **Description**
  - High speed TCP/IP file transfers to/from a ship at 45 Mbps Tx/Rx
  - Multimedia network connectivity at constant and variable data rates
  - High data rate WAN to link ship LAN to terrestrial networks
  - Evaluate networking, protocol, terminal, and BOD issues with variable bit rate service
- **Impact**
  - Illustrates mobile high speed TCP performance in a seamless satellite/terrestrial network environment
  - Demonstrate 20x greater rate than current standard ship rates
- **Participants**
  - Naval Research Lab
  - Glenn Research Center
  - Infinite Global Infrastructures, Sterling Software
  - Fore Systems, SeaTel, Xicom, Raytheon, Comsat Labs
  - Hill Mechanical Group

SHIPBOARD INTERNET EXPERIMENT

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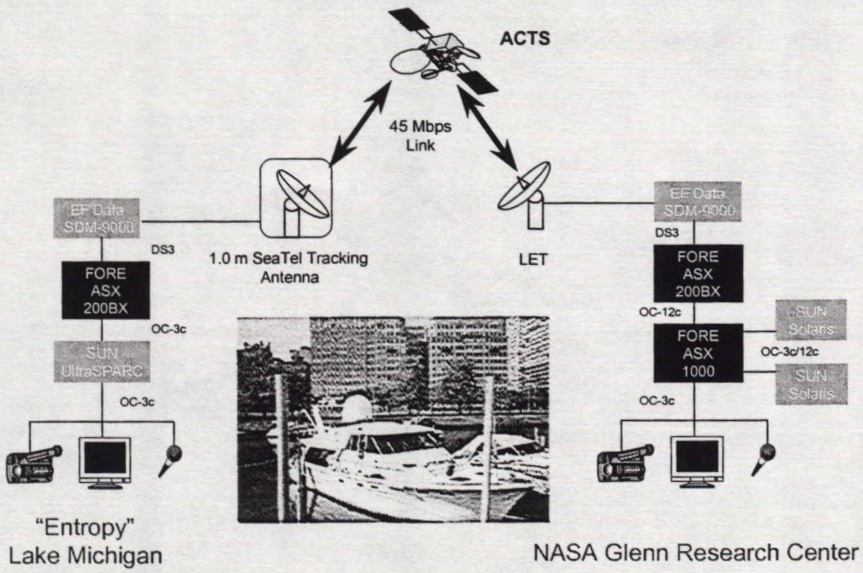

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INTERNET TELE-EDUCATION EXPERIMENT

- **Description**
  - ACTS link from Brazilian rainforest to US at T1 rate
  - Terrestrial interconnect to television production and integration facility
  - Internet access by several elementary/middle schools for Q&A with researchers on-site
  - Re-broadcast of final production via commercial satellite
- **Impact**
  - Illustrates small terminal technology with IPin a seamless satellite/terrestrial network to a remote environment
  - Remote access enhanced by common access protocol in a wide area network
  - Cited by participants as one of most impactful uses of the Internet
- **Participants**
  - Passport to Knowledge, Public Broadcast Service
  - Mississippi State University
  - Smithsonian Institute
  - Brazian Institution for Research in Amazonia (INPA)
  - Glenn Research Center

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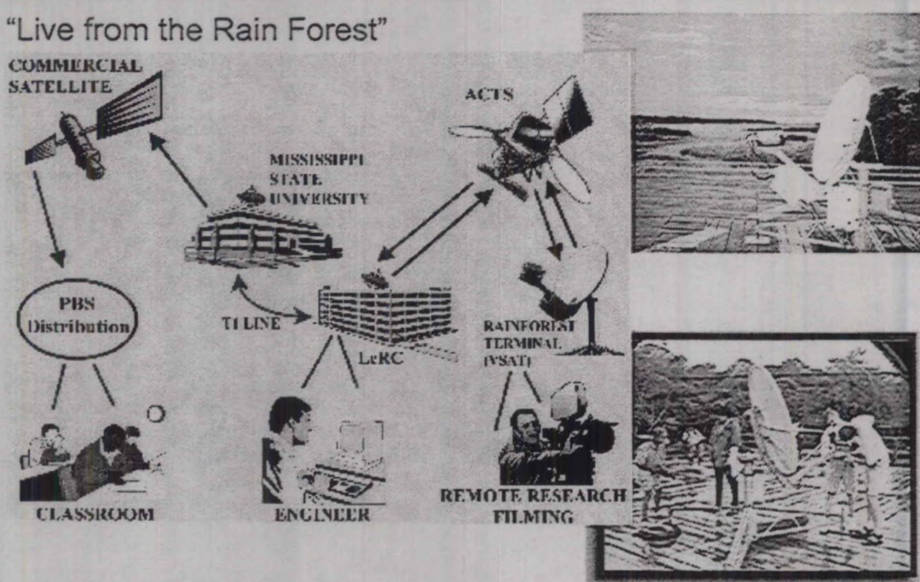
INTERNET TELE-EDUCATION EXPERIMENT

"Live from the Rain Forest"



SUMMARY

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

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

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

Experimenting over ACTS is critical for Government, Industry, and Academia to obtain end-end results

AN OVERVIEW OF CURRENT APPLICATIONS PROJECTS

J.Hamilton E.Hayes

CRC Canada

This paper is intentionally included as an addendum to the Proceedings, as it is intended to be used as a guide to the demonstrations being given by CRCC during the IMSC conference to be held 16 - 18 Jun 99.

Trans-Pacific HDR Satellite Communications Experiment Phase-2 : Experimental Network and Demonstration Plan

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ABSTRACT

The trans-Pacific high data rate (TP-HDR) satellite communications experiment was proposed at the Japan-U.S. Cooperation in Space (JUCS) Program Workshop held in Hawaii in 1993 and remote high definition video post-production was demonstrated as the first phase trial. Following the first phase, the second phase experiment is currently prepared. This paper describes the experimental network configuration, application demonstration, and performance evaluation plan of the second phase experiment.

INTRODUCTION

The trans-Pacific high data rate (TP-HDR) satellite communications experiment was proposed at the Japan-U.S. Cooperation in Space (JUCS) Program Workshop held in Hawaii in 1993. The objectives for the experiment are to demonstrate the usefulness of satellite communications systems for constructing global high data rate (HDR) networks and its operability with actual applications. The remote high definition video (HDV) post-production was demonstrated as an application in the first phase trial[1]-[3]. ATM-based 45 Mbps trans-Pacific link was established with 2 hop satellite link through NASA/ACTS and Intelsat, and three terrestrial networks in California, Hawaii and Tokyo in the first phase. We could achieve almost error free ATM connection, and measured error statistics when the link quality degraded[4]. The remote HDV post-production trial was successfully demonstrated. Following the phase 1 experiment, phase 2 experiment was planned and it is currently under preparation The objectives of the phase 2 expwriments are to demonstrate the effectiveness of modern boardband satellite in a global information infrastructure (GII) using emerging technologies such as multicast applications or distributed file sharing technplogy, and to establish high capacity applications such as a remote astronomical observation system for distance learning and collaborative discussions, In the phase 2 experiments, the transmission rate through the trans-Pacific link will be upgraded to 155.52 Mbps and more technical trials will be carried out compared with the phase 1 which was concentrated the demonstration. Remote astronomy and digital library demonstration will also be done as application trials. This paper describes the experimental network configuration and project plan of TP-HDR experiment phase 2.

NETWORK CONFIGURATION

The experimental network is shown in figure 1. The Intelsat will be used to provide connection between Japan and the United States directly. CRL's Kashima Space Research Center (KSRC) and AT&T's Salt Creek earth station are the gateway stations in both sides of the satellite link. Domestic connections in both sides can be chosen from a few options.

In Japan, we will use NTT's N-STAR to connect application site and KSRC as the primary option. For this connection, transportable Ka-band earth station will be placed in the ap-

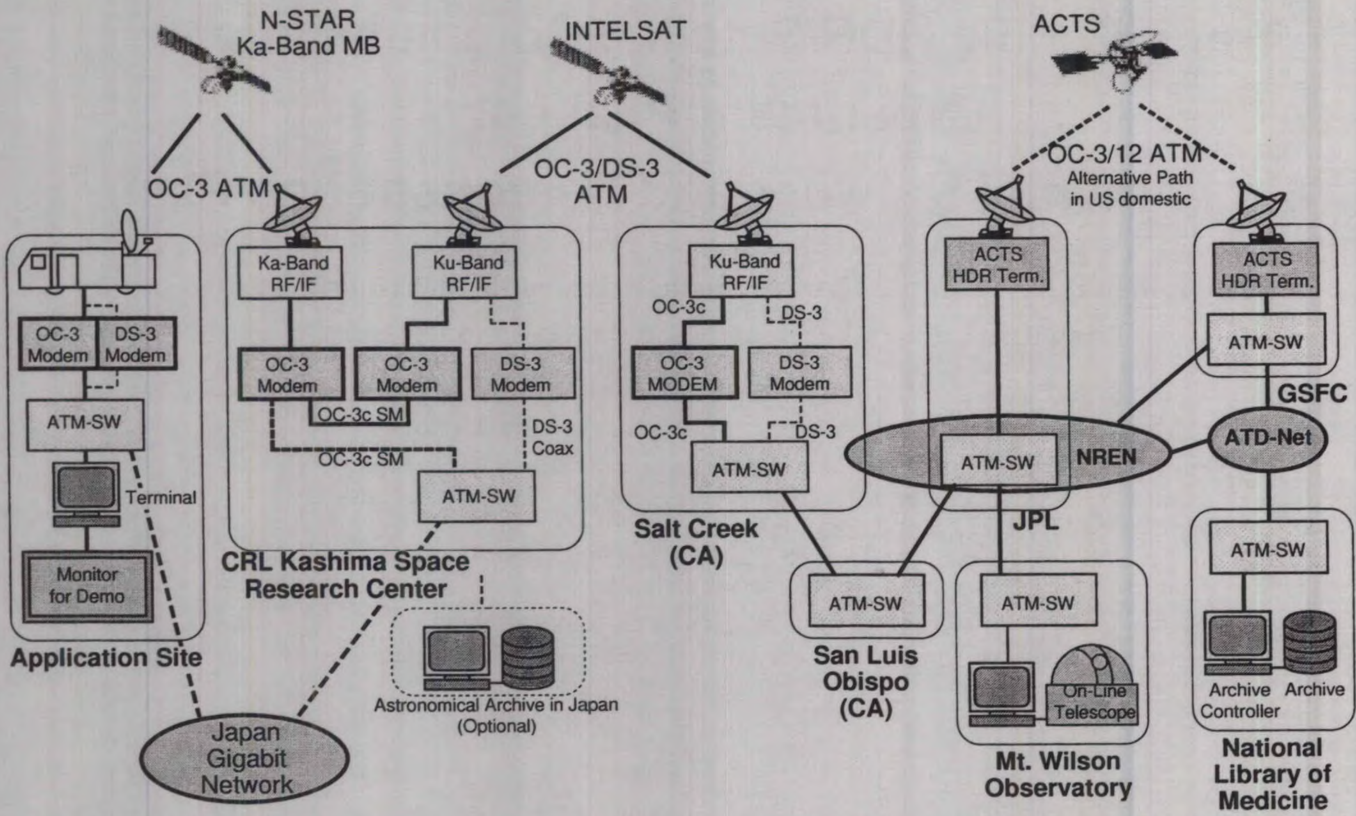

Fig.1 Experimental Network Configuration

Table1 Major Specifications of Transportable ES

Tx Freq :	28.4 ~ 30.3 GHz
Rx Freq :	18.6 ~ 20.1 GHz
Antenna :	1.8 mø
Tx Power :	150 W
IF Freq :	140 MHz
MODEM :	SDM-155 (8PSK, OC-3) SDM-9000 (OC-1, DS-3)
ATM-SW :	Newbridge 36150 OC-3(SM), DS-3(Coax), DS-1(Coax)
Pwr Consm :	17 kVA (200V, 3ø)
Weight :	4.2 t

Fig.2 Exterior of Transportable ES

plication site. The major specifications and the exterior of the transportable Ka-band earth station is shown in table 1 and fig.2, respectively. It has 1.8 mø dish and 150 Watts transmitter. Both of 155.52 Mbps and 45 Mbps modems and ATM switch are installed inside the container and baseband connection is available to application systems.

Alternative option is to utilize terrestrial Gigabit network so called Japan Gigabit Network (JGN) which is provided for research purposes by the Ministry of Posts and Telecommunications. In this case, we should consider the way to connect KSRC and application site to the nearest nodes of the Gigabit network.

In the United States, AT&T's Salt Creek earth station will be connected to NREN backbone via network operation center in San Luis Obispo. Most of the application sites for fundamental experiments and application demonstrations are linked through NREN. Jet Propulsion Laboratory (JPL) is the gateway to Mt. Wilson observatory. Schools participating remote

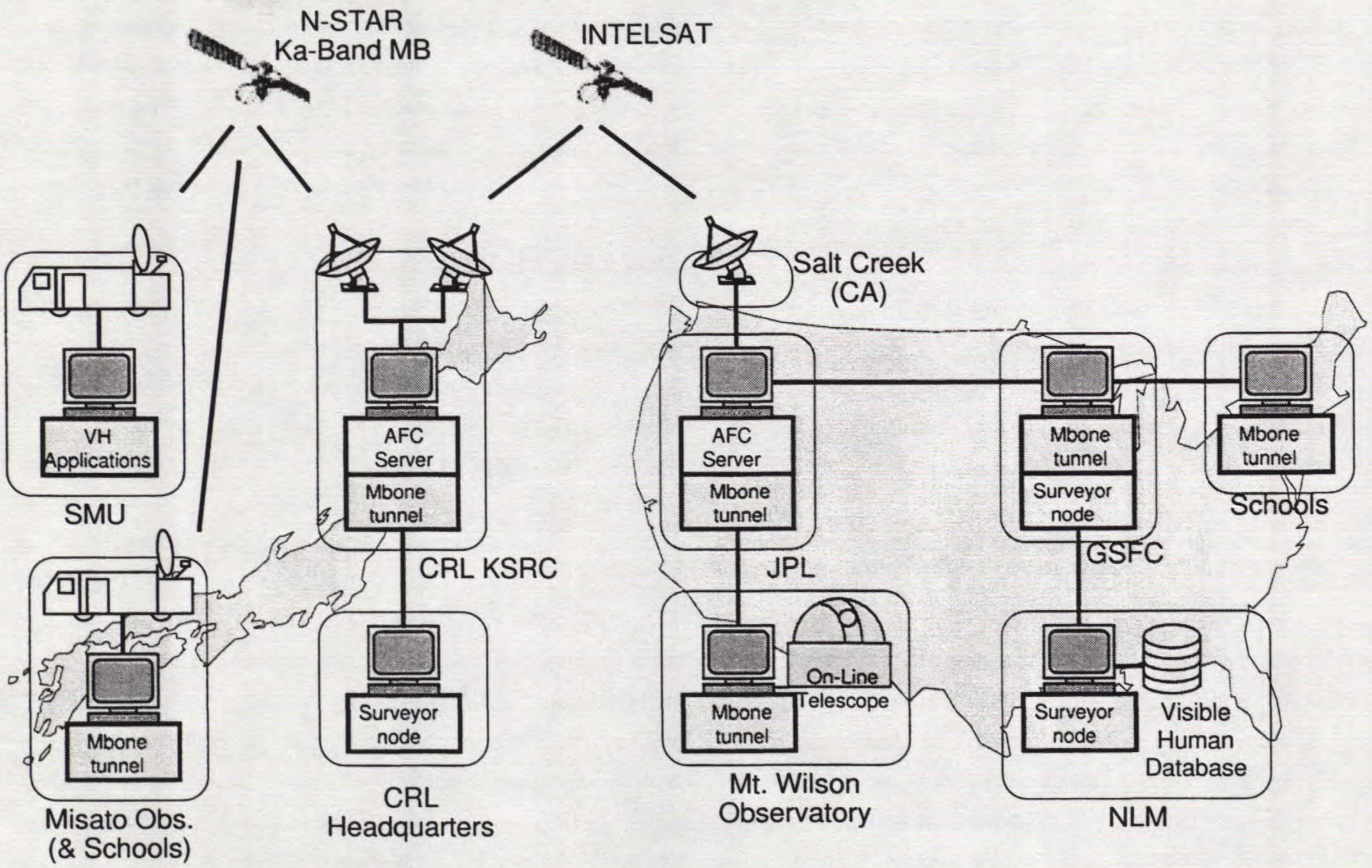

Fig.3 Functional Node Distribution

astronomy demonstration will be connected by lower rate local access line. ATD net is bridging NREN and application sites in Washington D.C. / Maryland area such as Goddard Space Flight Center. The ACTS satellite link is a candidate as a backup link.

Application sites in both sides will be connected through these links at the transmission rate of up to 155.52 Mbps with TCP/IP over ATM or ATM native protocols.

FUNDAMENTAL EXPERIMENTS

Before the applications demonstration, we carry out the fundamental experiments which was not carried out sufficiently in the phase 1. The ATM networking and ATM-based application was prefromed in the phase 1, and we add TCP/IP connection and internet applications will be demonstrated in the phase 2. Therefore, we plan to evaluate the performance of TCP/IP over the trans-Pacific link as well as ATM transmission performance. The functional node distribution in the network is shown in fig.3. Multicast capability, Andrew File System servers and Surveyor measurement equipment are implemented in this network for fundamental experiments.

ATM Performance Test

The experimental network employs ATM protocol in lower layer, the ATM transmission performance should be evaluated. Especially, in large scale network like NREN, traffic burst generated in AAL5 service class faces cell loss and cell delay. We plan to set ATM testers in several points in this network to measure cell loss and delay in conjunction with bit error rate and TCP/IP performance.

TCP/IP Performance Test

Since this experimental network consists of two hop satellite links and large scale terrestrial networks, TCP/IP performance between Japan and the United States is thought to be affected by various factors. Delay and bit errors by satellite links, and congestion in nodes of terrestrial networks degrade TCP/IP throughput. In order to avoid throughput degradation by long round-trip delay of satellite links, TCP extension of RFC 1323 and / or RFC 2018 should be used. We would like to evaluate the performance improvement by these TCP extension protocols with various parameter sets.

We plan to install "netspec" and other software tools for the TCP/IP performance evaluation in workstations at several points. In addition, we will set up the Surveyor tool in Japan and join the Surveyor network in order to measure accurate TCP/IP performance.

Multicast Performance Test[5]

Multicast capability is useful to implement remote collaboration environment. Mbone is planned to be used for this experiment for audio and video distribution. We will gather prehop loss and delay, route i and other information by "mtrace" software tool.

Distributed File System Performance Test

Distributed file system is useful to share large amount of data among users in wide spread locations. We plan to install Andrew File System (AFS) to share astronomical data with unified hierarchical file structure among scientists in both countries. Because the experimental link will be shutdown occasionally, we are interested in that the functions and performance of AFS are maintained. Therefore, we will monitor the behavior of AFS using the "Andrew Benchmark" tool.

APPLICATION DEMONSTRATIONS

As the applications demonstration, the remote astronomical observation and digital library access are planned. Both of those applications are based on a huge database sharing technology and require large bandwidth networking worldwidely. With these applications, we will demonstrate the effectiveness of use of HDR satellite communications systems to deploy a broadband network globally.

Remote Astronomy Observation[5]

The remote astronomical observation is the idea to utilize time difference between Japan and the U.S., which means we can observe night sky in the U.S. staying in Japan in day time, for example. In addition, networking collaboration system such as teleconferencing and white board software will help to realize tele-education or distributed research environment.
As the information servers, Mt. Wilson observatory, GSFC and one of Japanese observatory will be connected. These sites will feed live or stored image of the universe including processed data obtained by Hubble Space Telescope. Several schools in the United States and Japan will participate to this experiment to demonstrate tele-education application. Scientists, teachers and students in these locations can retrieve live images and compare to stored images to learn the objects, for example. Remote collaboration systems based on multicast connection will be implemented in these locations, and they will be able to discuss for research or educational purposes.

Digital Library (Visible Human) Access

Visible human data retrieval / processing application is one of the digital library applications that we would like to demonstrate in this experiment. The Visible Human (VH) is the anatomical dataset contains 55 GB data (15 GB : male, 40 GB : female) stored in the National Library of Medicine (NLM). This dataset is shared by medical doctors worldwidely for interactive biomedical image segmentation, labeling, classification and indexing. Sapporo Medical University (SMU) in Hokkaido, Japan participate the VH project and developed a software tool to show sagital, longitudinal,coronal sections of a human body, and interactive segmentation. In addition, other medical research related applications such as remote microscope manipulation software via the internet, medical image retrieval from remote Laser Disk database with ATM native transmission scheme are also developed in SMU.
SMU will be connected to NLM via N-STAR / Intelsat satellite links and NREN, and these applications will be demonstrated. If the JGN connection from SMU to KSRC is available concurrently, the delay effect for these application will be compared in both routing situations.

CONCLUSIONS

We are now the finalizing stage of network design, and will start connection verification as soon as the link becomes available. We plan to start trans-Pacific link quality measurement and fundamental protocol test in July. The demonstrations will be done until the end of September, 1999. This experiment will show the effectiveness to use HDR satellite communications systems to deploy broadband networks to the whole globe, and operability for various kind of applications. In addition, the results of fundamental experiment will bring valuable experiences for the future networking not only for constructing the GII but also for space networking including the inter-planetary internet initiative.

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Technical Session 2

Emerging Broadband Satellite Network Architecture and the Major New Developments

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ABSTRACT

The emergence of satellite broadband networks has been forecasted for many years. Ka-Band is seen as the frequency spectrum of choice. Many corporations applied to the FCC for spectrum allocation in September 1995. These systems all employed processing on-board the satellite (OBP satellites). Since then, many operators have studied the possibility of an interim step using a combination of Ka/Ku Band satellites. EMS Technologies Canada has been involved in studying Ka/Ku Band satellite systems and the technologies required to make these systems successful.

The overall satellite network and its architecture are described in this paper. A new Air Interface is mandatory to support these systems and the present activities ongoing in this area are reviewed and elaborated upon. Since these new systems are configured as Star networks, the major elements are a Hub and satellite terminals referred to as Satellite Interactive Terminals (SITs).

The major new developments in the Hub are based on the requirement for providing the subsystems enabling the reception of the signal from the SITs, the transmission of the data from the Hub and to maximize the utilization of the satellite bandwidth. The receiver at the Hub is based on MF-TDMA (multi-frequency time division multiple access) and requires the demodulation of many carriers. The use of multi-carrier demodulators (MCD) is assumed to minimize the amount of equipment required to be deployed at the Hub. The concept of a Scheduler/Controller function is introduced to control synchronization and access to the satellite network. The Scheduler is responsible for the allocation of the satellite bandwidth for the transmission of data to the Hub. The data to be sent to the SITs must first be encapsulated into a MPEG2/DVB format prior to transmission. The subsystem responsible for this is called the Forward Traffic Handler.

The SIT architecture is composed of an indoor unit (IDU) and an outdoor unit (ODU). The IDU is composed of a User Interface Unit (UIU), a Network Interface Unit (NIU) as well as the Power Supply Unit (PSU). The UIU provides the interface to the end user and the OA&M agent for the SIT. The NIU encompasses the MF-TDMA modulator, DVB receiver and the MAC layer controller. The PSU supplies power to both the IDU and ODU. The ODU consists of a Ka-Band transmitter and Ku-Band receiver which is interconnected with the IDU via an interfacility link (IFL). A commercial off-the-shelf (COTS) Ku-Band LNB can be employed for the Ku-Band receiver. The Ka Band transmitter mandates the development of a Ka Band SSPA. A dual feed antenna is required to allow the transmission at Ka-Band and reception at Ku-Band.

INTRODUCTION

EMS Technologies Canada, Ltd. (formerly the Space Systems Division of Spar Aerospace Ltd.) has been studying satellite multimedia networks since the late 1980s. The network architectures proposed from these studies typically involved an On Board Processing (OBP) satellite utilizing the Ka Band spectrum. Numerous filings were made to the Federal Communications Commission (FCC) in the United States for spectrum allocation. Typically these proposed systems incorporated OBP satellites and dictated large capital investments before launching a revenue generating service.

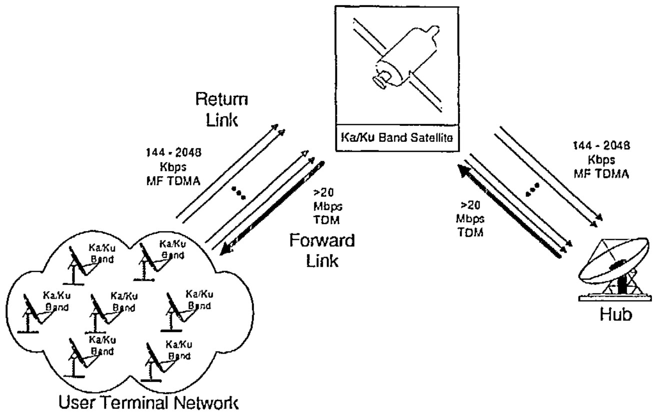
EMS continued its work in the satellite multimedia area and subsequently developed the concept of using standard Digital Video Broadcasting (DVB) in the Ku Band for the transmission of data in one direction and Multi-Frequency Time Division Multiple Access (MF-TDMA) at Ka Band in the return link. The major advantage foreseen of such a system was the reduction in the amount of new development required and the elimination of the requirement to have an OBP satellite as part of the satellite network. This conclusion would indicate a standard DBS satellite supplemented with an additional Ka Band payload could fulfil these requirements. EMS believes this dramatically reduces the risk involved in launching a new satellite multimedia system.

This paper provides an overview of activities on-going in this area.

SATELLITE NETWORK ARCHITECTURE

The satellite network presented is aimed at providing interactive multimedia services to a large subscriber base of satellite terminals. The total number of terminals supported can be in the range of 500,000 to 1,000,000, with the number of simultaneously activated terminals in the 100,000 range.

The system is a star network where each terminal interworks with a Hub to gain access to a wide variety of multimedia services. The communication between the Satellite Interactive Terminal (SIT) and the Hub is done solely through satellite links, a Return Link (from SIT to Hub) and a Forward Link (From Hub to SIT). The following figure provides a top level overview of the satellite network configuration.



Satellite Network Configuration

The Forward Link is based on a standard DVB/MPEG2 broadcast link using Ku Band. It is assumed that any existing services based on DVB/MPEG2 can continue to be provided using this new system and Internet would be considered as an additional service. The Return Link is MF-TDMA based using a Ka Band payload. An Air Interface needs to be developed to support this architecture. Present work in this area is described later in this paper.

The control of the Return Link is performed by a dedicated sub-system at the Hub called the Return Link Sub-System (RLSS). The RLSS is composed of a MF-TDMA Receiver, a Scheduler and a SIT Controller. The remaining components of the Hub consist mainly of a DVB/MPEG2 Mux and Up-Link facility, and a gateway to the multimedia service provider (typically Internet through a router or an ATM switch) and all necessary elements to perform Network Management and Subscriber Management (including Conditional Access).

AIR INTERFACE

With this expected rapid growth in the use of the Ka band for satellite multimedia communications, applications for spectrum allocation are exceeding the available capacity. Therefore, any system planned must incorporate an efficient utilization of the available bandwidth. Terminals developed for these emerging systems must implement a satellite access protocol which ensures bandwidth can be allocated to a particular terminal as expeditiously as possible and at the same time, the terminal is not occupying bandwidth even though it has completed transmission of all its data.

Since the proposed users of these systems are potentially consumers, the low cost of the terminals is crucial to the successful launch of these new services. The fulfilment of this criteria is mandatory if these systems are to be financially successful. The development of an open Air Interface standard for these systems is therefore essential.

Recognizing this requirement, a number of the satellite operators set up an AdHoc group to develop an Air Interface. This group was chaired by the European Space Agency (ESA) and included SES Astra, Eutelsat, Hispasat, Telenor, Intelsat, Telesat and others. The outcome of their work was a submission to DVB for the adoption of their recommendation into a DVB standard. At present, a DVB working group called DVB-RCS (Return Channel over Satellite) has been set up to address their submission and eventually adopt an Air Interface as the DVB standard for satellite networks of this type. Meetings are on-going within DVB with the goal of reaching agreement and have an agreed upon DVB standard as soon as is feasible.

CONDITIONAL ACCESS AND SECURITY

An important feature of a system like the one described, is the capability to control the access to information. This feature ensures that only subscribers entitled to receive the information, actually receive the service. Security, which encompasses antipiracy and privacy protection, is also an important requirement, especially in a wireless environment.

There is a need to control the access to the service and to ensure security. This translates in requirements to perform scrambling of the transport streams and to perform encryption of the satellite signalling, scrambling control word and the user traffic. The satellite signalling necessary to control the Return Link, needs to be protected since the operation of the whole MF-TDMA System depends on it.

There is currently a great effort for standardization on Conditional Access and Security. The rational for this is the requirement for low cost terminals. Defining an open architecture that can be widely adopted by set-top-box designer. This would in practice increase manufacturing volumes of standard components used, therefore reducing the receiver manufacturing cost. However, service providers generally like to retain proprietary information on Conditional Access and Security system. The current DVB standard defines a functional model for Conditional Access that enables both open architecture systems and service provider proprietary systems to be complementarily implemented.

At least two levels of security can be considered. The first one, or level-1, is the Access control itself. It is referred to here as Conditional Access. The second one, level-2, is the encryption of data. It is referred here as Security.

Conditional Access in DVB Standards

The DVB standard suite provides specifications for supporting Conditional Access. It defines a functional model supporting the distribution of Conditional Access management information to the terminals, using the standard DVB/MPEG2 framing structure.

Access control to service content is ensured by the scrambling of the transport streams at the output of the transport multiplexer and by distribution of descrambling control word, in an encrypted form, to terminals. The SimulCrypt system, specified by DVB, enables multiple keys to be used to decode the same scrambled transport stream. With this system, each terminal can have its own set of keys to access services to which its user are entitled to.

The keys themselves are made of two parts. The first part is a public key transmitted in an encrypted form, the Entitlement Control Message (ECM). The ECM is inserted as part of the adaptation field in transport packets. The second part of the keys are subscriber specific and generally resides in the terminal's Conditional Access Sub-System (CASS), more precisely on a SmartCard which has been mailed to the subscriber. The second part of the keys are activated by means of management messages, also encrypted, the Entitlement Management Messages (EMM). EMMs are transmitted in dedicated transport packets, to the terminals. The PID value for the transport packets carrying EMM data is indicated in the Conditional Access Table (CAT). This table is part of the standard PSI tables required in any DVB system.

Security

Security is ensured by the encryption of user traffic data. It provides a second level of security on top of the conditional access. This is generally done at the user protocol level.

In the IP realm, a set of recommendations have been issued, covering security of IP traffic. These recommendations are the RFC 1825,1826 and 1827, more commonly referred as IPSec. The following issues are addressed in these documents:

a) Authentication: ensuring that the data received is the same as the data sent by the source and that the source is in fact the one it claims to be.
b) Integrity: ensuring that the data received has not been altered along the way.
c) Confidentiality: ensuring that only intended recipients are able to decrypt the data.

There are two options in the implementation of such a security mechanism. The first option is to let the level 2 security, (i.e., encryption of user data) be the responsibility of the end user protocol stacks. This would mean that at the end-user computer, a secured TCP/IP stack has to be installed. A similar secured TCP/IP stack also has to be implemented at the Hub or at the content provider servers. This option may lead to non-practical implementation aspects.

The second option would be to secure the user data by implementing a secured TCP/IP stack in every terminal and at the Hub. With this option, all traffic that transits on the satellite system is secure. The drawback of this option is the increased complexity, therefore cost, of the terminals, and the hit in performance in terms of delay introduced by the Encryption/Decryption algorithm.

Alternate Level-2 Security Option

Another option to implement level-2 security, is to perform Encryption/Decryption as part of the Air Interface, regardless of the user protocol. This implies different Encryption systems can be used on the return and forward links, and that no knowledge of user protocol connections is required at the terminal level. This option would simplify the terminal.

There are no existing standard to support this model but a proprietary system could be derived from existing security standards like RSA. The performance impact on the system is likely to be comparable to the solution using IPSec.

Subscriber Authorization System

The Subscriber Authorization System (SAS) is the centralized element that generates all Entitlement messages (i.e., ECMs and EMMs). The SAS operates under control of the Subscriber Management System (SMS) which holds all the necessary information about subscribers (including entitlement status and terminal serial numbers). In general the SAS is kept separate from the SMS since only the SMS contains sensitive information about subscribers and the SAS only needs serial numbers associated with subscribers entitlements status.

The SAS must generate in the proper sequence all ECM and EMM and provide them to the DVB/MPEG2 Mux. In a more global definition , the SAS also includes the

Scrambling control word generation as well as the ECM and EMM encryption function.

Scrambling

The purpose of the Scrambler is to encode the transport stream at the output of the DVB/MPEG2 Mux. in order to make it unintelligible to any receiver which does not have the suitable service key. This function is straight forward and can follow a standard algorithm or one proprietary to the service provider.

SIT Conditional Access

The SIT conditional access functions are gathered in the Conditional Access Sub-System (CASS). The CASS includes, the descrambler, the ECM and EMM decryption, the SmartCard reader and any processing functions required.

The DVB Standard committee has defined a Common Interface between the CASS and the remaining functions of the receiver. This Interface is defined in the document : "Common Interface Specification for Conditional Access and other DVB Decoder Application" (CENELEC prEN 50221). The main advantage of following this specification is the possibility to keep totally separate the design and development of the CASS and the remaining receiver functions. The complete CASS can be developed on a PCMCIA card which includes a SmartCard reader. The actual implementation choice is subject to trade-off that addresses terminal procurement cost.

HUB DEVELOPMENTS

Under the primeship of Nortel Networks, a highly qualified international team of high technology companies is developing the first Hub compliant to the system architecture presented in the first part of this paper. The Hub consists of three major subsystems and each company is responsible for its own subsystem. These subsystems are:

a) Return Link SubSystem (RLSS) under EMS Technologies Canada, Ltd.
b) Forward Link SubSystem (FLSS) under Philips.
c) Network Management System (NMS) under Nortel.

To round out the team, Nortel Dasa is responsible for the Integration and Test of the complete system. The network is planned to be delivered to SES Astra before the end of 1999.

Return Link Subsystem

The RLSS is responsible for the control of the MF TDMA based Return Link. The RLSS is made up of 3 major elements. These elements are the MF TDMA Receiver, the Scheduler and the SIT Controller.

MF-TDMA Receiver: The purpose of the MF-TDMA Receiver is to perform the following functions:

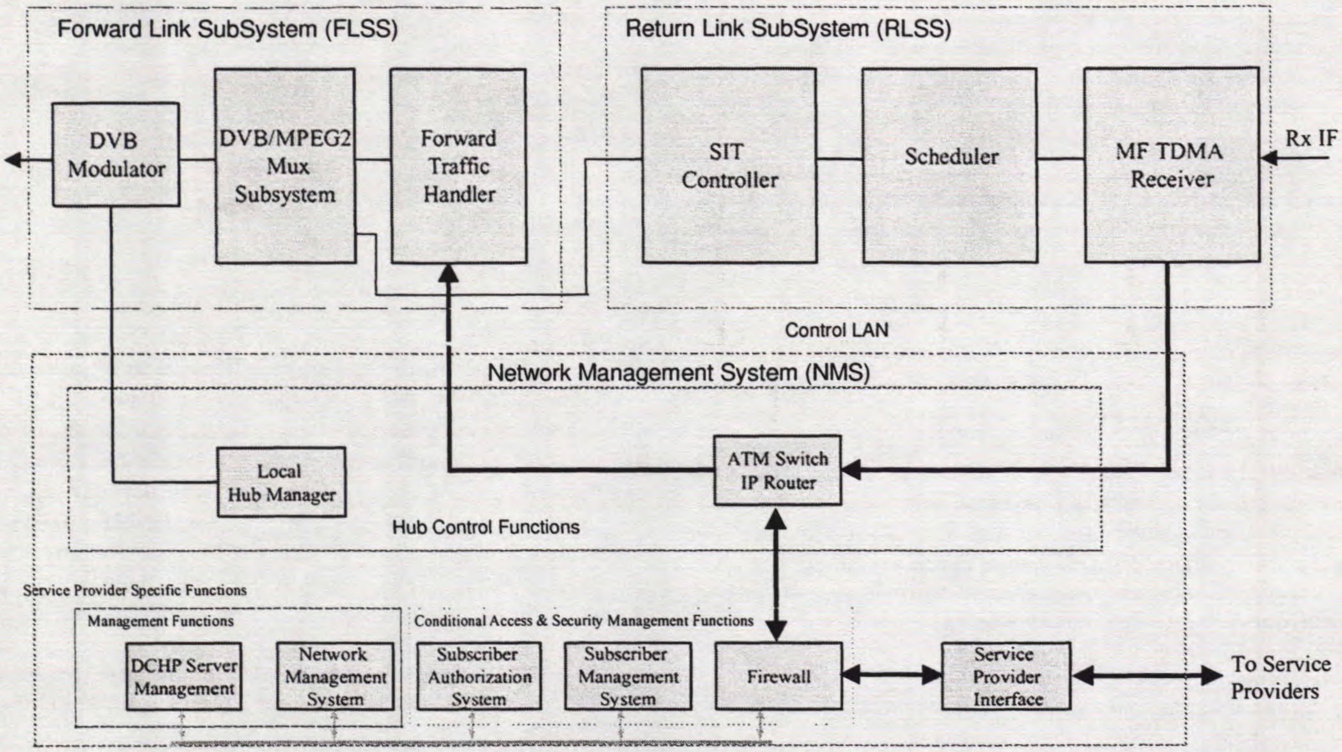
a) Interface with the IF Interface from the Ka Band Receive RF equipment.
b) Generate the Frequency Standard and Reference Clocks (Frame Count and Symbol Count) based upon the station clock locked to a Rubidium standard.
c) Burst Demodulation for all received carriers (Acquisition, Maintenance and Traffic bursts).
d) Forward Error Correction on all received carriers.
e) Received Bursts position monitoring.
f) Acquisition and Sync Bursts position Error Correction.
g) Interface with the SIT Controller to transmit signalling in the Forward Link.
h) Interfaces with the Scheduler to transmit related signalling (timing, power level, and frequency correction).
i) Support the SIT OA&M function for command and control of the receiver.
j) IP traffic reassembly or ATM cell extraction from Return Link cells and interface to Service Provider through a router or an ATM Switch.

The MF TDMA Receiver is based upon a MultiCarrier Demodulator (MCD). Since the Hub is expected to be able to receive many TDMA carriers simultaneously, a MCD provides a significant advantage over single carrier demodulators in the Hub. Its major role is to receive all terminal carriers and, after demodulation, demultiplex information related to traffic and satellite signalling. The Receiver performs as well all burst processing required to make the MF-TDMA system work (Acquisition and Maintenance monitoring and control).

Scheduler: The main requirements of the MF-TDMA Scheduler are the following:

a) Receive capacity requests from SITs and from the NMS for constant rate assignment (CRA) traffic.
b) Develop the Burst Time Plans for MF-TDMA Return Link.
c) Provide the BTP for distribution to the SIT Controller.

This element is the key for efficient use of the Return Link bandwidth. It implements the CF-DAMA (Combined Free and Demand Assigned Multiple Access) protocol and has provision for handling Reserved Capacity (RC) as well as Dynamic Capacity (DC). This protocol developed by EMS has shown extremely efficient usage of the return satellite bandwidth even under very heavy traffic load for multimedia traffic.



Hub Block Diagram

Reserved Capacity for the Return Link is guaranteed by the Scheduler for the duration of a connection. Admission Control is performed at the Network Management level. Requests for Reserved Capacity are sent to the Scheduler through a Network Management Interface. Dynamic Capacity is return link assignment that can be modified by SIT/Scheduler signalling called In-Band Requests (IBR) and Out-of-Band Requests (OBR).

BTPs are developed based on network constraints, existing capacity reserved, SIT requests (IBR and OBR) and a free capacity assignment algorithm for the remaining unassigned capacity. In practice a full new BTP is issued every frame period (26.5 ms).

SIT Controller: The main functions of the SIT Controller are the following:

a) Terminal Management Functions (Initialization, Acquisition, Maintenance and general SIT monitoring and control).
b) Interface with the MF-TDMA Receiver to receive satellite signalling.
c) Interface with the Scheduler to receive the Burst Time Plan to be sent for the next frame period.
d) Forward signalling handling:
   i) Generation of SYNC, FREQ, ULPC and BTP Section Signaling.
   ii) Generation of DSM-CC sections for all other signalling destined to SITs.
   iii) Interface to the Uplink MPEG2 Mux at the Transport Stream level.
e) Interface with the NMS.

The main role for the SIT Controller is to perform Network entry functions, basic management for the SITs and distribution of all satellite signalling to the SITs through the Forward Link. Satellite Signalling is transmitted through the DVB/MPEG2 Mux for distribution on the Forward Link.

Forward Link SubSystem

This section describes all elements at the Hub involved in the handling of the Forward Link. This includes the following major elements: the Forward Traffic Handler, the DVB/MPEG2 Mux and the DVB Scrambling.

Forward Traffic Handler: The purpose of the Forward Traffic Handler is the following:

a) Receive the IP traffic that has to be forwarded to the SITs.
b) Perform the IP to DVB/MPEG2 encapsulation with two options:
   i) Data streaming, where IP datagrams are encapsulated into MPEG2 PES.
   ii) Multiprotocol Encapsulation, where IP datagrams are encapsulated in DVB/MPEG2 DSM-CC Section with User Private Data.

c) Interface with the Uplink DVB/MPEG2 Transport Mux, to transmit the Forward Traffic Transport Streams.
d) Interface With the Network Management and the SIT Controller for configuration of the IP addresses to SIT MAC Address mapping table.

By extension the Forward Traffic Handler could generate several Transport Streams, on different PIDs for grouping of SIT traffic into distinct streams. This feature could be used for IP multicasting .

DVB/MPEG2 Transport Mux: The DVB/MPEG2 Transport Mux. is a standard DVB compliant Mux. Its role is to form a Transport Stream that embeds all traffic and satellite signalling data provided respectively by the Forward Traffic Handler and the SIT Controller (Forward Signalling Handling function). The output of the Mux goes through the Scrambling function when Conditional Access is implemented and to the Uplink modulator. Other services like MPEG2 Audio/Video could be also inputted at the Mux or at another re-multiplexing stage inserted between the Mux and the Modulator.

Statistical multiplexing can be implemented in order in increase the bandwidth usage on the Forward Link. Statistical Multiplexing can be very efficient on burst traffic like IP and the satellite signalling. Nominally, the statistical multiplexing function would be implemented in a Transport remultiplex.

SIT DEVELOPMENTS

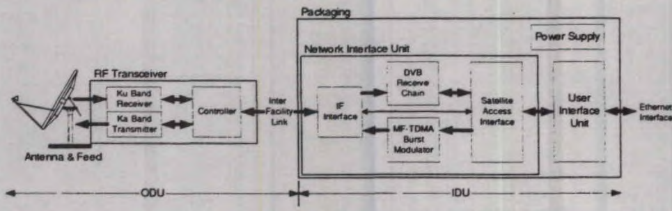
The availability of a Hub as described in the previous section would meet only half the requirements for a complete satellite system. Therefore, two independent companies are developing SITs to inter-operate with the Hub. Nortel Networks and Philips are currently well into their development of compliant SITs. Terminals will become available for Beta testing in the 3rd quarter of 1999. Production SITs are planned to become available in 1st quarter 2000. EMS is partnered with Nortel for the development and delivery of terminals. The responsibility of EMS is for the NIU subsystem.

Architecture

The SITs provide users access to the satellite network. A SIT will nominally be attached to a single users, however, multiple users can also be supported.

The SIT consists of two units:
a) An OutDoor Unit (ODU), including a dual band antenna and the Ka/Ku band RF functions.
b) An InDoor Unit (IDU), similar to a set-top-box with an Ethernet connector to Interface with the End User, an IF (S-Band) connector to interface with the ODU.

A block diagram of a SIT is supplied in the next column.

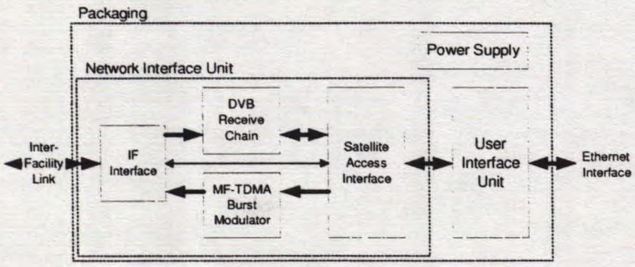


SIT Block Diagram

The terminal includes all necessary functions to perform the following:
a) Communicate with the end-user (receive and transmit User traffic on the User interface) and perform all segmentation, reassembly and convergence functions.
b) Acquire the satellite network, get synchronized and request capacity on the Return link, in order to be able to transmit user traffic to the Hub on the MF-TDMA Return Link.
c) Receive the DVB Forward Link signal, and demultiplex satellite signalling and user traffic from the Transport Stream.
d) Perform filtering of received information based on the SIT MAC address or Broadcast MAC address when applicable.
e) Perform OA&M (Operations, Administration & Maintenance) functions as required.
f) Receive the Ku Band DVB Forward Link signal.
g) Transmit the Ka Band Return Link signal.

InDoor Unit (IDU): To perform the requirements stated above, the IDU includes the following functional blocks:
a) A Network Interface Unit (NIU) consisting of:
   i) A DVB/MPEG2 receive chain (tuner, demodulator, FEC decoder, descrambler, deinterleaver and demultiplexer).
   ii) A MF-TDMA modulator (MF-TDMA burst modulator, frequency synthesizer to allow for frequency hopping on a slot to slot basis).
   iii) Satellite Access Interface (burst controller, CF-DAMA access protocol function, terminal management, SIT timing generation).
   iv) IF Interface (multiplex the Tx IF with the DC power and the OA&M signals to the ODU and extract the Rx IF and reference clock from the ODU).
b) A User Interface Unit (Interface with the Tx/Rx chains, IP functions if required, SIT OA&M function, interface with End-User through Ethernet).
c) A Power Supply (Provides power to the IDU and the ODU via the IFL).
d) Packaging (Housing for the NIU, UIU and Power Supply).

A block diagram of the IDU is shown below.

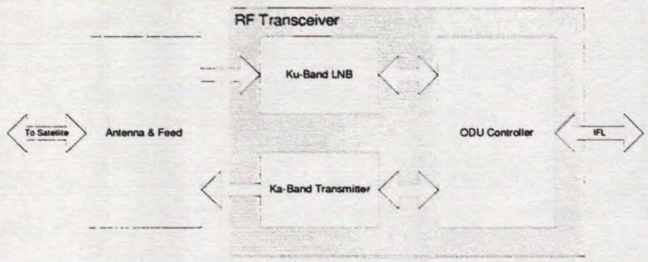


IDU Block Diagram

OutDoor Unit (ODU): The ODU includes the following functions:

a) Dual Band (Ka and Ku Band) antenna and feed.
b) Ka Band Upconverter.
c) Solid State Power Amplifier (SSPA).
d) Low Noise Block converter (LNB).

A high level block diagram of the ODU is included.



ODU Block Diagram

CONCLUSIONS

The satellite network architecture presented in this paper presents several advantages to proposed OBP satellite systems. EMS believes in a gradual evolution as opposed to a revolution to OBP based satellite multimedia systems. A planned evolution with increasing complexity allows verification of new technology in smaller increments helping to minimize risk. This provides confidence in the technologies being adopted and allows early entry into the broadband multimedia market for satellites.

This progressive approach first proposed by EMS is being adopted by satellite operators. One operator will launch a service based on this architecture in early 2000 and other similar systems are being planned by other operators.

ACKNOWLEDGEMENT

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Evolution of Regional Multimedia Satellite Architectures for Future Internet Services

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ABSTRACT

In the years ahead the Internet is expected to increasingly support emerging video based applications such as video-email, Internet TV, and desktop video conferencing. In general these applications will need to rely on an improved quality of service and higher speed access to ensure widespread user acceptance and adoption of these services. To achieve this, improvements are inturn required to the global information infrastructure (GII) with respect to both protocol design and the transmission system. The satellite component of the GII, the SCGII, is seen as a key technology to achieving these goals.

Although there has been much publicity surrounding the launch of satellite multimedia services via global LEO constellations, the first generation of multimedia satellite networks will be based on Geosynchronous Regional Broadcast Satellites. This presentation examines how these systems are likely to evolve to accommodate the future Regional Internet services based on Video and how these systems can co exist and enhance the later deployment of Global LEO constellations.

FUTURE INTERNET SERVICES

Broadly speaking, the future of the Internet will be increasingly dominated by video services of some kind, just as the public telephone system was dominated by voice. Examples of this today are various applications such as Internet TV, and video email utilizing low speed streaming IP transport for either video clips or conferencing. It is surprising that even in this limited way, broadcast television programming is being adapted as a service on the Internet. At present the quality of service for most users of these pseudo-realtime services, is seriously affected by network congestion as well as the limited bandwidth of most residential access via the PSTN.

The key objectives to effectively support these future services are the provision of more economical bandwidth to support the higher transmission speeds and improved protocol design to control the quality of service, in particular network congestion. A number of multimedia access technologies are either planned or under deployment to meet these objectives as shown in Figure 1 below. These include: the Telcos FSAN (fixed services access network) shown shaded, the Cable TV HFC (hybrid fiber coax) and cable modems, Local Multipoint Distribution / Communications System (LMD/CS), and Satellite

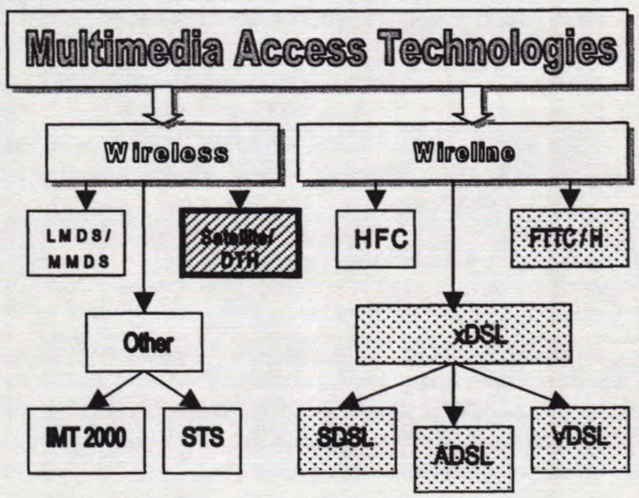

Figure 1: Multimedia Access Technologies

Direct to Home (DTH) shown hatched. Just as for video broadcasting, the latter technology holds great potential to provide a high quality of service with nearly universal coverage at low cost.

REGIONAL MULTIMEDIA SATELLITE NETWORKS

The initial deployment of an Internet over satellite service has already been achieved with the Hughes DirecPC Turbo Internet service [1] which provides a one-way high speed (forward) link and a POTS return link to support interactivity. Today the typical speed of this return channel is limited for most areas of the PSTN and even the availability of higher speed alternatives such as ADSL will depend on the reach of the FSAN in the future.

The next step in the evolution of these systems is the provision of a high-speed return channel over the satellite itself, which represents the first generation of an all satellite based multimedia network. This first commercial rollout of this service will be offered by SES on the regional broadcasting satellite ASTRA 1H [2].

These regional networks are designed to efficiently support a star configuration which utilizes an essentially transparent satellite architecture to interconnect satellite users with an ISP connected to the satellite hub station. The broadcast, or forward link, encapsulates both traffic (IP or ATM) and satellite network signaling into a standard MPEG/DVB downlink to the user terminals. The MPEG transport supports broadcast, multicast and unicast services to a large user terminal population (> 100,000). The return link, from user to hub, uses an Multi Frequency (MF) TDMA based multiple access protocol to provide the interactive connection to the serving host.

The ARCS network posses significant challenges for satellite designers, being the first time that a combination of MF TDMA, Ka Band and low cost terminals has been deployed. This makes ARCS a significant step along the technology development and service path. Combinations of these three attributes are present in all but a few of the ventures proposed for satellite broadband access.

A key element of this type of network is the efficient use of return link bandwidth by the multiple remote terminals and the proper control and synchronisation of the MF TDMA system through a forward link control loop. The protocols used on the return link, within the basic MF TDMA structure, are derived from access protocols previously deployed on satellite systems. However, these protocols are specially adapted to work efficiently in a multimedia traffic environment, where there are multiple thousands of potential access points.

PROTOCOL IMPROVEMENTS

Protocol improvements will include provision for comprehensive quality of service (QoS), in particular for realtime applications, at the higher layers of the protocol stack for end-to-end transport. These in turn need to be supported by efficient medium access control (MAC) and physical layers at the communications subnet level, in particular for wireless and shared access networks.

These protocol improvements include: 1) the use of both new and specialized versions of current transport and network layer protocols, such as TCP/IP, 2) the use of dynamic multiple access schemes such as Multi-Frequency (MF) -TDMA with second generation MAC protocols, and 3) the use of enhanced control of network congestion at intermediate points in the subnetwork. The harnessing of ATM quality of service is likely to support these improvements.

For IP, the main improvements are made to better support the higher layer protocols such as Real Time Protocol (RTP), which support the transport of realtime applications. The key improvements to IP which are contained in IP version 6 [3] are specified routing and a 16 level congestion priority. In general this will permit control of the path and the buffering at each intermediate router. Specialized versions of IP, such as multicast and streaming IP, have been developed to handle stream-oriented services.

At the transport layer, improvements are required to support a mix of traffic including interactive multimedia applications which require throughput and timing guarantees. Specialized transport protocols such as RTP [4] feature integrated layer processing to achieve a closer coupling to the application layer to better provide adequate realtime response and data integrity. For realtime applications RTP ride on top of UDP since TCP retransmissions are generally not supported for these applications.

For TCP itself a well-known issue has been the window associated with binary flow control; a potential limitation of throughput in networks with a high bandwidth-delay product, such as a Geostationary satellite networks. TCP extensions [5] have been developed to increase the throughput of TCP beyond about 1 Mbps for a GEO satellite. To further improve performance in networks in general, an alternative approach is the use of explicit rate flow control either by way of ATM or the Express Transport Protocol (XTP). Protocols such as ERICA (Explicit Rate Indication for Congestion Avoidance) have been developed for underlying ATM networks [6].

TRANSMISSION IMPROVEMENTS

Transmission improvements to the global Internet infrastructure include higher speed access and physical layer support for the QoS associated with realtime applications in particular as described above.

For the satellite component of the GII, related network architecture requirements will have a significant impact on the evolution of multimedia satellite communications. These systems will need to: 1) provide links with a minimum time delay to support interactive services such as video conferencing and 2) efficiently support the expected future trend towards increased peer to peer communications. Both these factors point to a satellite architecture with some form of on-board processing (OBP) incorporating onboard switching. This achieves both improvements by supporting direct single hop mesh connectivity between satellite user terminals instead of a double hop through a hub station. Both the transmission time delay and the satellite bandwidth utilization are halved. The OBP alternatives are reviewed later in this paper.

A SATELLITE AIR INTERFACE

As part of the deployment of multimedia satellite systems and to facilitate low cost user terminal development, efforts are underway to standardize the air interface of these systems. This primarily covers the bearer service and control signalling of the physical and media access control (MAC) layers. As noted above such an interface utilizes some form of MF-TDMA shared wireless access governed by a dynamic access protocol.

Based on current work on the development of an air interface standard for wireless multimedia access technologies in general, such as LMDS and multimedia satellites [7], it is planned that the satellite protocol will utilize a combination of DVB/TDM transport over the forward path and an ATM-like MF-TDMA in the return path. The user plane of the satellite protocol stack is shown in Figure 2. The return and forward paths are shown terminating at either the gateway for a "bent-pipe" system or the onboard processor for an OBP system.

The access protocol is based on the Combined Free and Demand Assigned Multiple Access (CF-DAMA) class of protocols. This is optimized for contentionless allocation of return path capacity except for initial network entry which utilizes an S-Aloha channel. The protocol features scheduling handling mechanisms which are selected singly or in combination according to the class and QoS of traffic. These include constant rate assignments for CBR traffic and both rate and volume based dynamic capacity allocation for ABR and UBR classes of traffic.

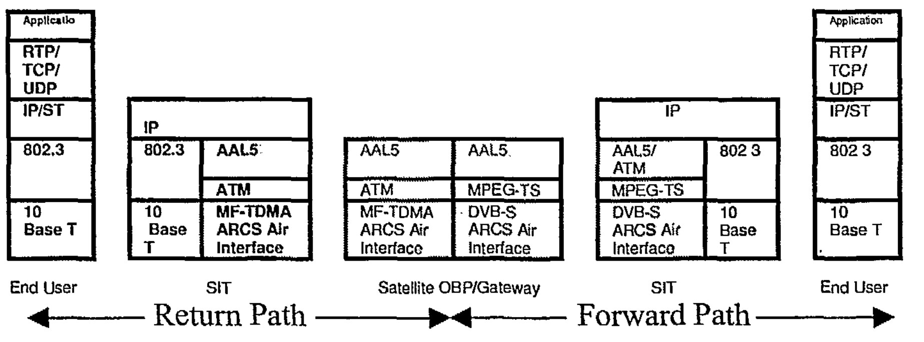

Figure 2 : Satellite Return Path Protocol Stack

One of these mechanisms, referred to as Free Capacity Assignment (FCA), serves to assign any remaining unused capacity to the terminals not currently assigned capacity. At low network loading, this mechanism effectively emulates the delay performance of random access without the inefficiency due to collisions. Equipped with these scheduling mechanisms this MAC layer protocol can effectively support the higher layer ATM and IP QoS requirements of emerging and future multimedia traffic

SATELLITE OBP ARCHITECTURE

As previously noted above, to meet the improvements and expected evolution of multimedia networks, in particular peer to peer conferencing, an OBP type of satellite architecture is required.

In general, the specific form of OBP and overall system architecture will be determined by a number of key system parameters including the satellite orbit, air interface, and end-to-end performance. Systems are planned for a range of possible orbits including low, medium and geostationary earth orbits (LEO, MEO, and GEO). And although for LEO and MEO orbits, the double hop time delay is not as significant an issue, the improvement in bandwidth utilization achieved by direct connectivity is the same.

Another key system aspect, the air interface standard selected for these systems, will directly impact the ground segment design as well as the design of the OBP architecture. In addition to the protocol aspects of the air interface, other key issues here are the link margins required to directly interconnect small user terminals operating at T1/E1 rates with sub-meter antennas

While the approach is dependent on the satellite orbit, for a GEO system there are two major OBP architecture alternatives: regenerative digital OBP with time multiplexed downlinks or a transparent OBP channelizer. The former approach is an evolution of the protocol architecture presented in figure 2 and described in the satellite air interface, in which some of the key functionality of the gateway station is placed onboard. The digital OBP utilizes a baseband circuit or packet switch to route satellite cells to the required downlink beam of a multibeam satellite coverage. In general such a system architecture will support both star networking to a number of gateways and mesh networking between user terminals. For the star network an ARCS type bent-pipe satellite architecture is utilized. Such a hybrid OBP satellite system architecture is shown in Figure 3 and described in the following section

Alternatively, the objective of the transparent OBP channelizer is the routing of sub-bands of spectrum at IF to beams in a fixed or changing pattern according to the traffic patterns in a given beam.

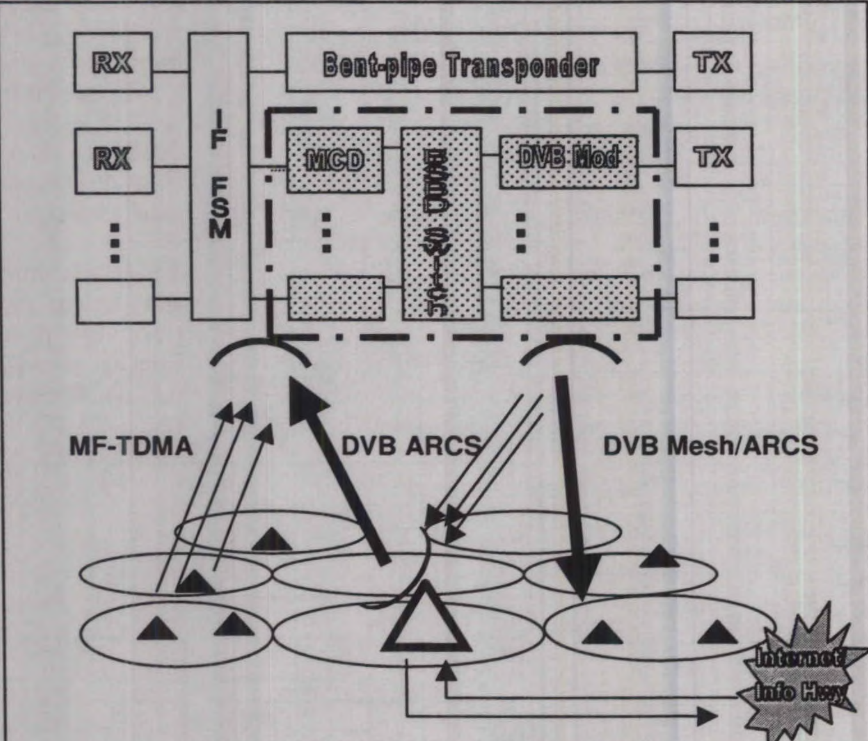

Figure 3: Hybrid OBP Satellite Architecture

The digital OBP achieves link gain by onboard regeneration and coding, while the OBP channelizer needs to achieve this by either an increase in terminal sizing or smaller spot beams generated by larger spacecraft antennas. From a payload standpoint the former is more complex electronically with higher power consumption while the transparent payload is simpler but with increased mechanical complexity associated with larger antenna structures at high RF frequencies, typically at ka band for these systems to obtain the bandwidths needed.

The future form of these OBP architectures may well depend on the way in which the initial rollout of the multimedia services evolve over the first generation transparent satellite networks and the associated development of the air interface standards and ground segment.

The next section proposes an evolution of the regional multimedia satellite system and how these services may be rolled out and interwork with future LEO satellite systems.

REGIONAL MULTIMEDIA SATELLITE EVOLUTION

Following on from the initial deployment of DirecPC, ARCS is a critical second step in regional broadband access via satellite. ARCS also forms the basic platform on which the third step is likely to evolve; including a staged improvement in space based technology.

ARCS is an important second step on the evolutionary path, but its star topology limits the applications that it can support to those that are deemed remote to host. As video and voice become a more dominant aspect of the multimedia mix, there will be an increasing need to support peer to peer applications. A number of proposals before the regulatory bodies concentrate on ambitious deployment of a fully regenerative Ka Band payload with "ATM Like" on board switching. These proposals concentrate on full service access via a single satellite hop. However, these systems propose to use proprietary protocols and do not build on the existing satellite broadcast infrastructure. An alternative logical next step in the evolution of broadcast based regional services is to add peer to peer capability to an existing "ARCS Like" infrastructure. This can be achieved by migrating some elements of the ARCS ground hub into the satellite, as a partial OBP payload. The technology to support this concept has been developed in EMS and figure 3 shows the top level diagram of a Space multiplexer OBP that adds peer to peer capability to an "ARCS Like" system. In this evolution, multicarrier demodulators, previously deployed in the ground hub of an ARCS system, are provided in the OBP payload. This OBP payload has a percentage of the ARCS uplink carriers directed to it by an IF Processor to facilitate "mesh" connectivity. Within the mesh digital processor, the traffic is demodulated and routed to an appropriate downlink DVB carrier. On board encapsulation of the uplink TDMA payload into the MPEG downlink packets enables deployment of standard "ARCS Like" terminals capable of both remote to host and peer to peer operation.

This third step in the evolution is an important step in regional service development. It combines modest and achievable space technology development with the ability to use a ground terminal based on existing broadcast protocols. It does however, have limitations. These can be overcome by further deployment of more sophisticated space technology in a fourth evolutionary step.

Within a regional system, the deployment of an "ATM Like" on board regenerative and switching payload will increase the efficiency of the system in supporting peer to peer applications. It also will enable a more efficient ground infrastructure deployment, in support of remote to host applications. Most importantly it will enable multiple downlink beams (> 10) thus removing a further limitation of the space multiplexer based approach. The major questions that arise with regards to this fourth step in the evolution are:

1) Should the downlink remain a recognised open standard?
2) Should the service be bundled with broadcast services within the same user terminal?
3) Should peer to peer and remote to host applications be supported within the same OBP switching infrastructure?

It appears that many of the proponents of these types of system are advocating the deployment of proprietary protocols. This tactic can be successful only if terminal manufacturers are able to produce cost reductions based on this market alone. It is certain that the broadcast industry will need to develop evolutions of DVB standard protocols that satisfy the need for higher throughputs and better data support. Adoption of these protocols in fourth generation systems is a wise step towards guaranteeing the availability of low cost user terminals.

In resolving the issue of shared space infrastructure and broadcast/unicast service bundeling it may be useful to consider satellite payloads that are somewhat customised to the application and to consider the use of multiple payloads per spacecraft or shared orbit locations. This could achieve service bundling in a single user terminal.

The final question in this evolution is the role of LEO constellations in support of regional based satellite services. By their nature, LEOs are neither regional nor adept at offering broadcast services. However, as a final step in the evolution of a global satellite infrastructure it is certain that LEO constellations and regional satellites will co exist. The only issues are the level of integration possible between the two systems, the shared use of frequency bands, the bundling of services, the sharing of ground infrastructure and the integration of the user segment. At some level the high throughput, low delay and increased EIRP of the LEO solution will be an important aspect in rounding out a regional operators service portfolio. In that sense a LEO overlay to a regional system is a logical fifth step in the evolution of regional services.

CONCLUSION

This paper has considered that aspect of the evolution of the SCGII as one of the wireless access technologies for the Internet. The first generation of these multimedia satellite systems are to be rolled out shortly [2].

The evolution of these first generation systems is targeted to support the key improvements in performance and functionality needed to handle the forecasted Internet traffic of the future which is forecasted to be dominated by various video based applications such as conferencing. This in turn points the way to a satellite mesh network architecture supported by onboard processing as an add-on to the star network bent-pipe architecture of the first generation systems.

In preparation for this add-on architecture, studies have already begun for these systems to utilize higher rate downlinks, such as OC3, to achieve better efficiencies both for the space segment and ground segment.

In the nearer term, a standard will be adopted for the two-way satellite air interface, followed by the development of low cost user terminals, ultimately a consumer item, as the commercialization of the Internet over satellite services gets fully underway.

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MENTAT
PERFORMANCE NETWORKING

Improved TCP/IP Performance over Satellite Using the Mentat SkyX Gateway

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PERFORMANCE NETWORKING

Outline

- Mentat Background
- TCP and Satellite Conditions
- SkyX Gateway Design Constraints
- SkyX Gateway Network Architecture
- SkyX Protocol Design
- Mentat Performance Data
- NASA Performance Data
- Conclusions

Mentat Background

Mentat is a provider of networking protocols to operating system vendors:

- SkyX Gateway
- Mentat TCP
- Mentat Portable Streams
- Mentat XTP

Mentat TCP is an integral component of:

Hewlett-Packard HP-UX	Sun Solaris
Apple Mac OS	Stratus FTX
Concurrent PowerMaxOS	Sony NEWS

TCP and Satellite Conditions

Factors Which Reduce TCP Performance Over Satellite

- **Large Latency**
  Link round trip time of ~0.5 seconds
- **High Error Rates**
  Bit error rates of $1x10^{-12}$ to $1x10^{-6}$
- **Asymmetric Bandwidth**
  Return channel bandwidth usually a fraction of the forward channel

Factors Which Allow Performance Optimization

- **Point-to-Point Connection**
  Link has no intermediate routing
- **Fixed Bandwidth**
  Link bandwidth is fixed and known

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SkyX Gateway Design Constraints

- **Transparent**
  - ▲ Transparently intercepts all TCP traffic
  - ▲ No changes to TCP stacks on end hosts
- **Application and Network Safe**
  - ▲ Maintains TCP connection reliability and TCP end-to-end semantics
  - ▲ Maintains congestion control, slow start, etc., over terrestrial links
  - ▲ All TCP applications continue to run without change
  - ▲ Non-TCP packets flow through the system unmodified

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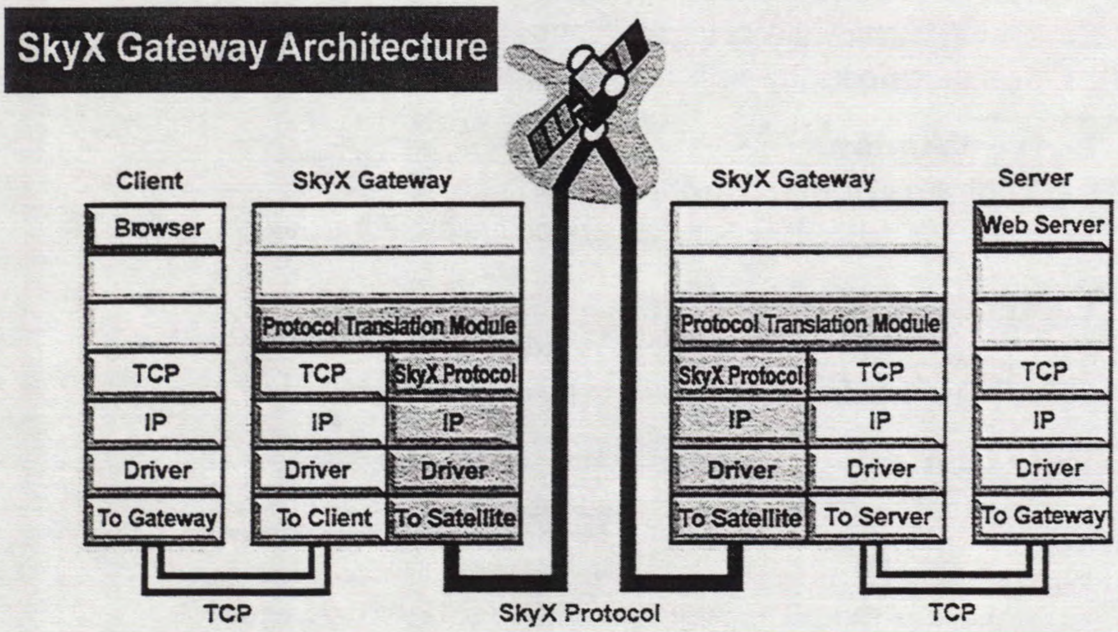
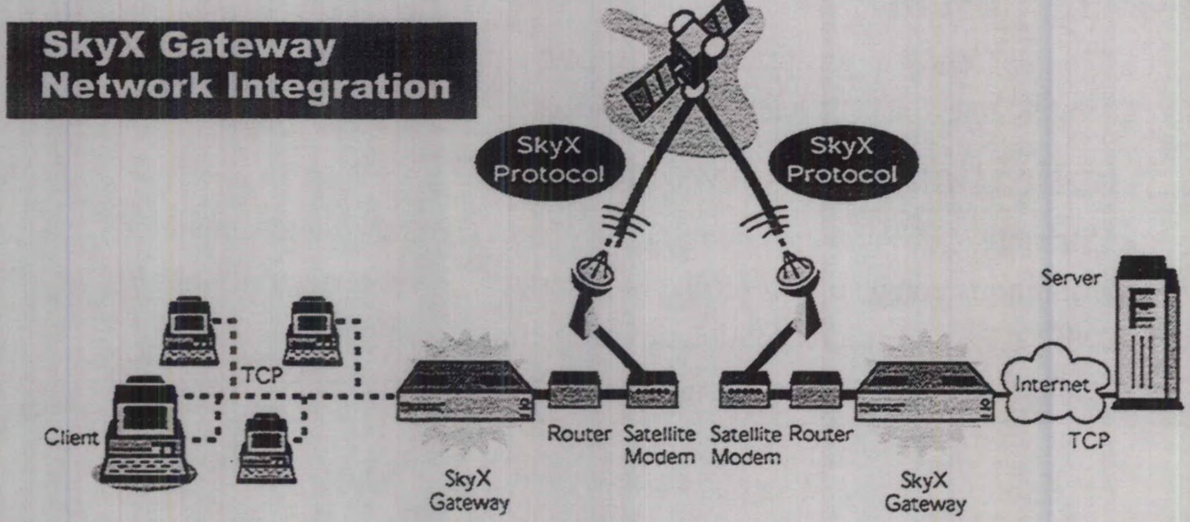
SkyX Gateway Network Architecture



SkyX Gateway Network Architecture



SkyX Protocol Design

- **Selective Retransmission Algorithm**
  - ▲ Lost or corrupted data triggers immediate NACK and retransmit.
  - ▲ Sender periodically polls receiver for data acknowledgment.
- **Large Windows**
  - ▲ 32 bits used to specify window size.
  - ▲ Removes dependency of network on bandwidth-delay product.
- **Congestion Avoidance**
  - ▲ No Slow Start or Congestion Avoidance used over satellite.
  - ▲ All TCP mechanisms remain in place over terrestrial connections.
- **Rate Control**
  - ▲ Explicitly set transmission rate to the available bandwidth.
- **Runs over IP**
  - ▲ Runs over IP for compatibility with existing infrastructure.

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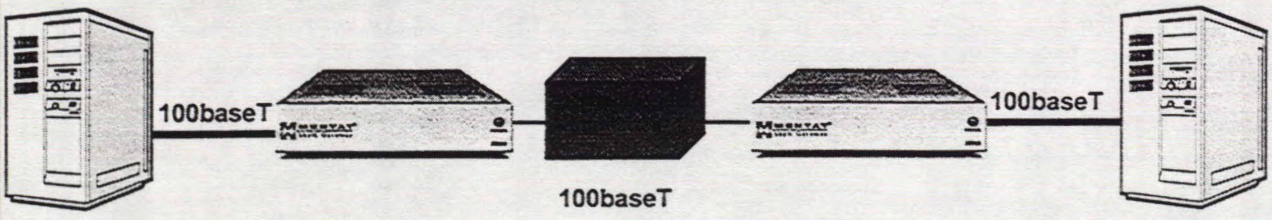
SkyX Gateway Performance

SkyX Gateway Test Network



Webstone Client	SkyX Gateway	SkyX Gateway	Web Server
200 MHz PentiumPro			200 MHz PentiumPro
Solaris x86			Linux

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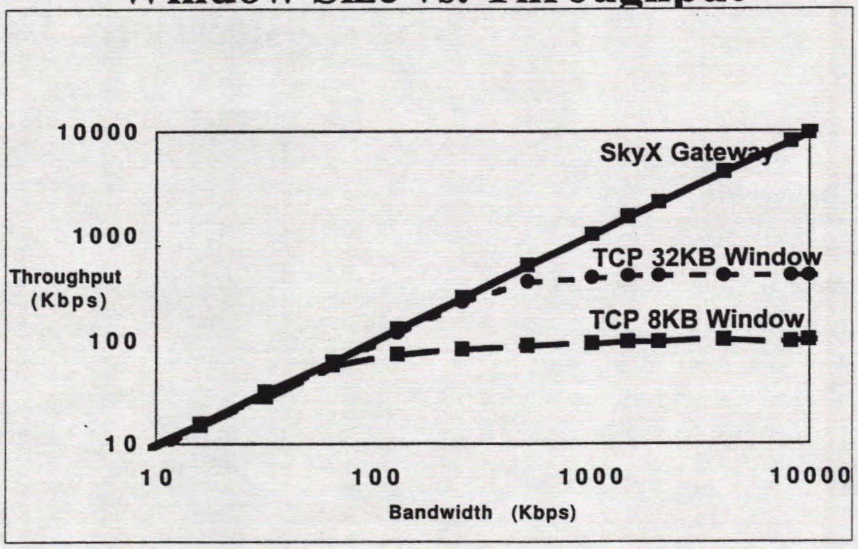
SkyX Gateway Performance

Window Size vs. Throughput

Conditions:

Forward link	10 Mbps
Reverse link	10 Mbps
BER	none
Test type	single ftp
RTT	540 ms
TCP Window	8 KB, 32 KB

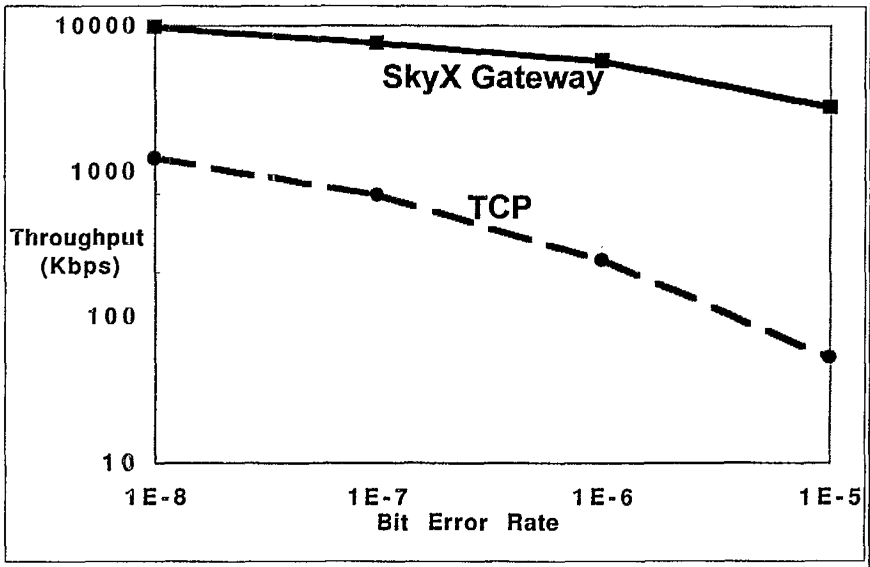
SkyX Gateway test used window of 8 KB on client



Mentat Performance Data

MENTAT PERFORMANCE NETWORKING

Bit Error Rate vs. Throughput



Conditions:

Forward link	10 Mbps
Reverse link	10 Mbps
BER	1E-8 to 1E-5
Test type	single ftp
RTT	540 ms
TCP Window	1 MB

Mentat Performance Data

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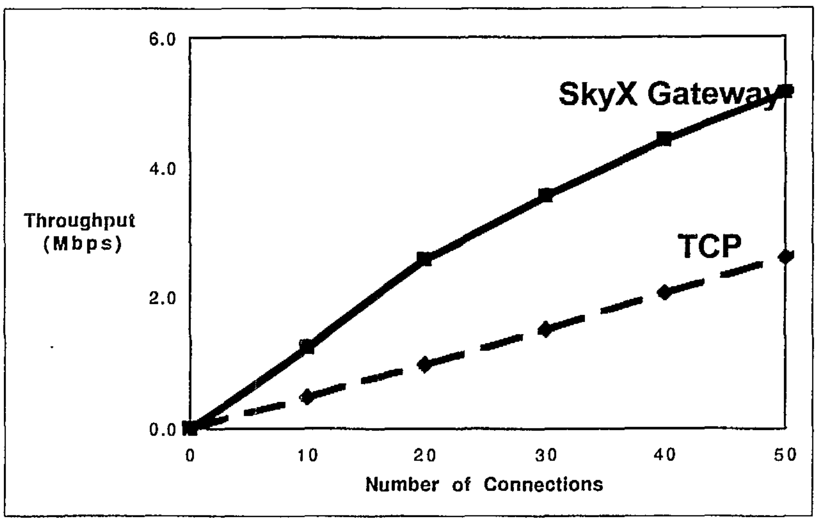
Multiple Client Web Traffic Aggregate Throughput



Conditions:

Forward link	8 Mbps
Reverse link	2 Mbps
BER	1E-6
Test type	webstones
RTT	540 ms
TCP Window	8 KB
File sizes	500 bytes to 5 MB

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Mentat Performance Data

Efficiency Testing
Hybrid System

	TCP	SkyX	Improvement
Time to transfer	28.0 sec	7.1 sec	3.9 x
Throughput	188 Kbps	739 Kbps	3.9 x
Forward traffic	771888 bytes	690526 bytes	11%
Reverse traffic	18632 bytes	6074 bytes	67%

Conditions:

Forward link	1.5 Mbps	RTT	380 ms
Reverse link	33 Kbps	TCP Window	56 KB
BER	1E-6	File size	640 KB
Test type	ftp		

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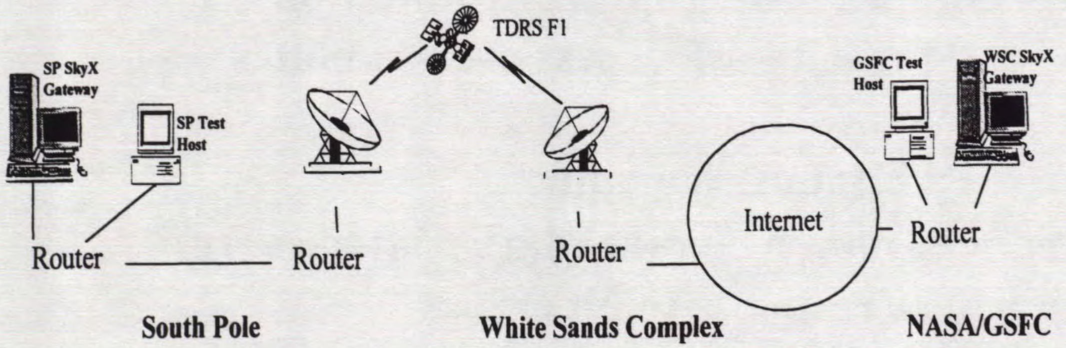
NASA Performance Data



Data rate = 1.024 Mbps each direction over TDRS

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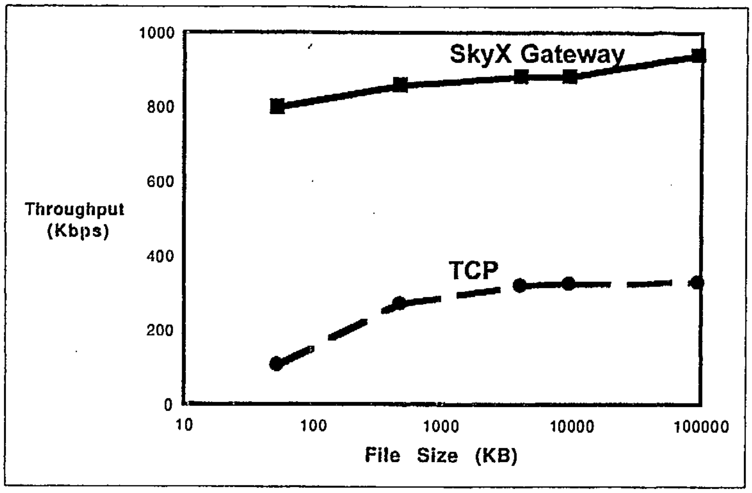
NASA Performance Data

File Size vs Throughput



Conditions:

Forward link	1.0 Mbps
Reverse link	1.0 Mbps
Test type	ftp
File sizes	53 KB to 95 MB

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Conclusions

SkyX Gateway overcomes the limitations of TCP for network access over satellites

- **Increases data throughput**
- **Reduces return channel data traffic**
- **Improves response to bit errors**

Multi Protocol Simulation System for HDR Satellite Network

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ABSTRACT

High data rate (HDR) satellite communications systems have become one of the most important media in the development of the Global Information Infrastructure (GII). In the effort to promote this development, Communications Research Laboratory (CRL) carried out an ATM-based HDR satellite communications experiment and we have obtained the fundamental transmission characteristics of the ATM protocol over an HDR satellite link and evaluated HDTV transmission quality by utilizing the HDR ATM satellite link. In addition, we are currently involved in the research and development of a gigabit satellite communications network, which has a gigabit-class transmission rate and on-board ATM switching capability. On the other hand, higher layer protocols such as TCP/IP are widely used and new protocols such as multi protocol over ATM (MPoA) have also been developed. As the next step, communications performance of a combination of ATM and higher layer protocols over HDR satellite links should therefore be studied.

From these points of view, we developed a multi protocol simulation system for HDR satellite networks in order to evaluate several sets of communication protocol stack. This paper describes the configuration and performance of the simulation system.

INTRODUCTION

CRL has already measured ATM fundamental transmission characteristics, such as bit error rate and cell loss, over satellite links and studied performance of a few ATM applications [1][2]. However, we have not sufficiently evaluated higher layer protocols than ATM. In order to evaluate actual service quality, the performance of higher layer protocols should therefore be evaluated. In addition, many global multimedia satellite communications systems have planned to have on-board switching capability. To evaluate the network performance of these environments, we developed a multi protocol simulation system for HDR satellite communications networks. This system can simulate on-board switching functions and support multiple higher protocol stacks. It can also set a wide range of C/No and delay time for each leg of links. The simulation performance will be utilized in the design of a gigabit satellite communications system, which has a gigabit-class transmission rate and on-board ATM switching capability.

CONFIGURATION OF SIMULATION SYSTEM

The system can simulate connection over an HDR satellite communications link with several sets of protocol stacks. The major specifications of this system are listed in Table 1 and its functional block diagram is shown in Fig. 1. This system consists of five blocks, parts: a ground terminal block, a modem block, a satellite link simulation block, an on-board ATM switch simulation block, and a data gathering and analysis block.

ATM connection type	Permanent Virtual Connection (PVC) Switched Virtual Connection (SVC)
Higher layer protocol	Classical IP over ATM (IPoA) Multi Protocol over ATM (MPoA)
data rate	1.544 Mbps 44.736 Mbps 155.52 Mbps
TCP extension	RFC1323 RFC2018
transmission delay	0-220 msec (up/down link respectively)
noise addition	up/down link respectively

Table 1 major specifications

Ground terminal block

This block consists of UNIX-based workstations with an ATM interface card and an ATM switch. The protocols implemented in the workstations are traditional TCP/IP, TCP extension such as RFC1323 and RFC2018, IPoA and MPoA. The ATM interface card can handle PVC/SVC connection with AAL5 at a transmission rate of 155.52 Mbps. The ATM switch is used not only to convert transmission rate between 1.5, 45, and 155.52 Mbps but also to simulate private LAN on the ground.

Modem block

The modems provide three data rates (1.5, 45, and 155 Mbps) for satellite and ground and the modulation schemes are QPSK for 1.5 and 45 Mbps and Trellis-Coded 8 phase PSK for 155.52 Mbps. A Reed-Solomon error correction code is used for all modems.

Satellite link simulation block

In this block, it is possible to insert a delay for simulating the GEO satellite link and establish a link quality (C/N_0). The delay time is added in the ATM layer between each satellite-ground terminal. Delay time for each leg is arbitrary set in the range from zero to 220 msec. The one-way transmission delay for the GEO satellite link is 125 msec. The maximum delay through the ground terminal–GEO satellite-ground terminal is therefore 250 msec. The C/No can be set by adding white Gaussian noise to the signal transmitted from the modems.

On-board ATM switch simulation block

An ATM switch is installed between the two ground terminal blocks in order to simulate a satellite on-board ATM switch. This switch also supports IPoA, MPoA, and PVC/SVC. This system can be expanded to three or more multiple connections in order to add modem blocks and ground terminal blocks to this on-board ATM switch simulation block.

Data gathering and analysis block

This block can gather and analyze ATM cell transmission data by using an ATM analyzer and a personal computer. Higher layer performance is measured by workstations in the ground terminal block.

Now, the simulation system has only two grand terminal blocks. Then, we can simulate only point-to-point connection. In the future, we plan to add a ground terminal block and simulate point-to-multi point connection.

SIMULATION

We had ever measured ftp (file transfer protocol) performance by using an actual 155 Mbps satellite link. In this trial, we used a traditional TCP/IP protocol over ATM and a bent-pipe satellite link. The maximum throughput achieved was about 60 kbps in such a situation, though the transmission rate of the satellite link was 155.52 Mbps as shown in Fig. 2. The theoretical calculation shows that the maximum throughput achievable over a geostationary satellite link with a traditional TCP/IP protocol is about 117 kbps. The reason to limit the measured performance seems that overhead process such as buffering in the workstations takes time other than data transmission. In order to make the ftp performance over the

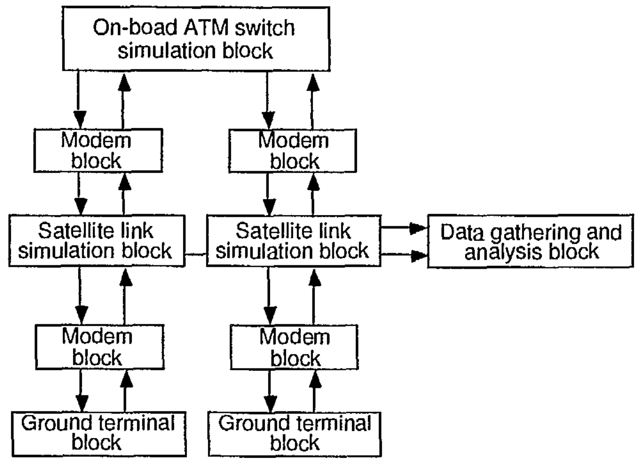

Fig. 1 functional block diagram

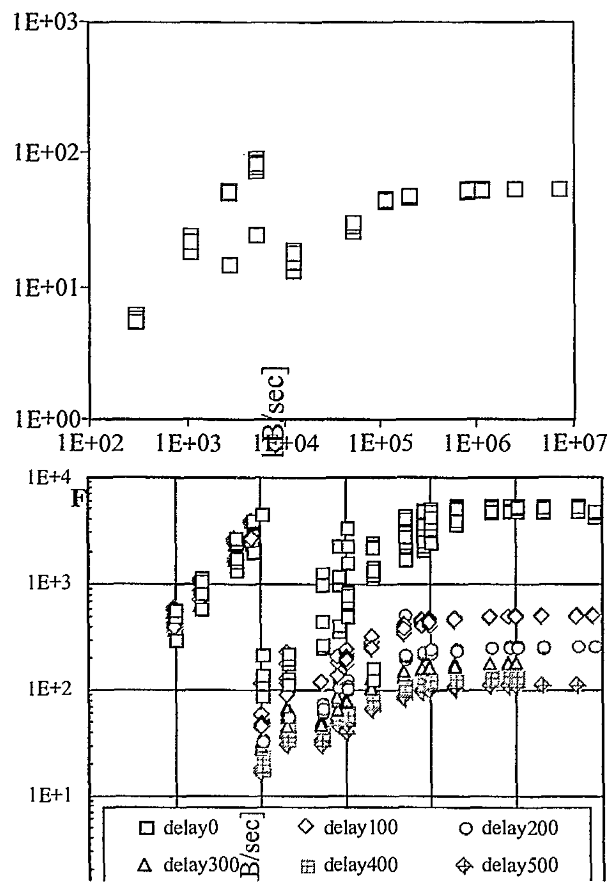

Fig. 3 ftp performance by simulation

geostationary satellite link clear, we simulated on the same situation as before experiment.

In the simulation, we measured ftp performance when the ATM connection type was PVC and the transmission rate was 155 Mbps. In addition, we measured by changing transmission delay. These results are shown in Fig. 3. The delay noted in figure means round trip delay between two ground terminal blocks

In each measurement of different transmission delay, the throughput for a file size less than 10 kB is very high, but the throughput for a file size more than 10 kB become decline by step. The reason for this difference is related to the MTU (maximum transmission unit). The MTU for ATM is 9180 bytes. When the file size is more than the MTU, the datagram is divided and embedded in plural MTU. The throughput decreases because the data since the second transfer unit is send after arrival of ACK.

Figure 3 shows that the throughput decreases by increasing transmission delay. In the delay for GEO system (round trip delay between ground terminals is 500 msec), the throughput is about 110 kbps. This result almost corresponds with the calculated maximum throughput of a GEO satellite system with a traditional TCP/IP protocol.

Next, we measured the TCP extension. We used a window option of RFC1323. The window size of a traditional TCP/IP is 65,535 bytes and the default send/receive buffer size is 60 kbytes. In this simulation, we set the window size option to 2 or 3 and the send/receive buffer size to 120 or 180 kbytes. In order to simulate the GEO satellite system, the delay of each leg was set to 125 msec. The measured TCP extensions performance is shown in Fig. 4. A parameter of sim 1 is window size 1, buffer size 60 kbytes. This is traditional TCP/IP parameter. A parameter of sim 2 is window size 2, buffer size 120 kbytes, and that of sim 3 is window size 3, buffer size 180 kbytes.

This figure shows that increasing the window and buffer size is effective in order to improve a throughput in the system having large delay. We plan to simulate an effect of TCP extension for a high data rate GEO satellite communications system by changing conditions such as window size and buffer size.

CONCLUSIONS

Using this simulation system, we evaluated the network performance of several kinds of communication protocols implemented over an HDR satellite link. In addition, the simulated performance will be utilized in designing gigabit satellite communications systems. In addition, these simulation results are very useful because it is applicable into the networking with utility value in the existing state such as satellite Internet.

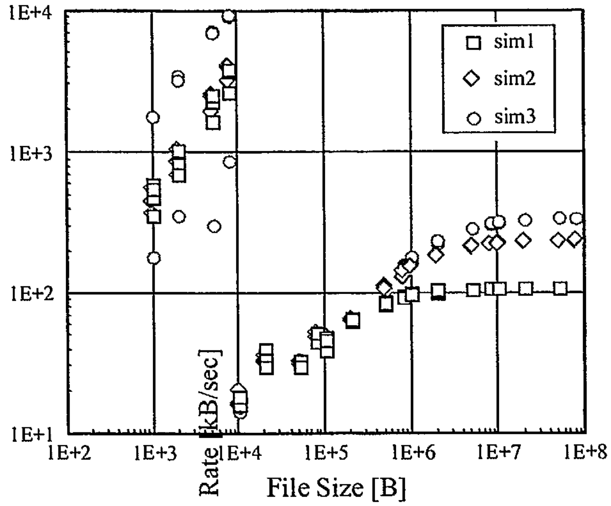

Fig. 4 ftp performance by TCP extension

First, we simulated a traditional TCP performance in a high data rate and large delay links and compared this performance with that of a satellite link. The simulated performance almost corresponds with the calculated maximum throughput for GEO satellite system.

Next, we carried out simulation of throughput performance by TCP extension. Then, we showed effective of TCP extension for large transmission delay.

In the future, we will test the network performance by using TCP extensions and on-board ATM switching performance.

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Traffic Modeling and Protocol Simulation for Multimedia Satellite Networks

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June 15, 1999

Outline

- Why simulations?
- Overall satellite network considered
- Simulation Model (in OPNET)
- Traffic Models Supported
- MAC Protocol Supported
- Congestion Control Protocols Supported
- Typical results obtained
- Conclusions

Why Simulations?

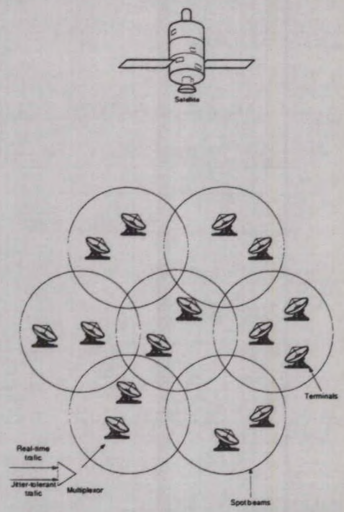
- Broadband satellite networks are becoming an important part of GII due to the advantages they offer over their terrestrial counterparts:
  - wide geographic coverage
  - distance insensitivity
  - rapid and cost-effective deployment
  - star and mesh capabilities
  - mobility, etc.
- They are required to provide seamless integration of application & services offered by terrestrial networks.
- They need to interface with the terrestrial networks and require satellite-specific protocols, capable of providing flexible & efficient use of satellite resources.

Why Simulations?

- Development of protocols requires hardware emulation (based on trial test-beds) or software simulation.
- Simulation models are very useful in early stage of the design. They allow to:
  - test the functionality of network protocols
  - evaluate the performance of network protocols under various traffic loading conditions
- Realistic and accurate traffic models are required, commensurate with the multimedia applications and services being offered (both real-time and jitter-tolerant).

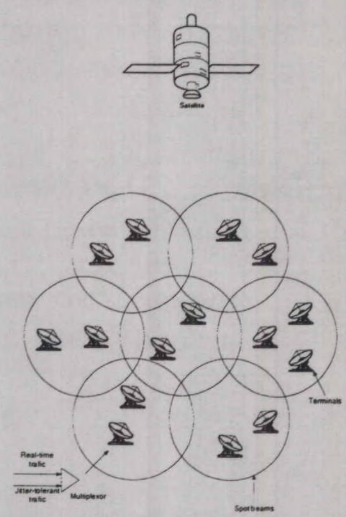
Satellite Network

- The satellite network architecture supports multiple spot beams and a large population of terminals.
- The satellite can be in any orbit. We concentrated in our simulations mostly on GEO.
- The satellite has on-board processing capability, allowing resource sharing (bandwidth, buffers) and flexible connectivity.



Satellite Network

- Each terminal supports a number of services and a mixture of traffic types (real time, jitter tolerant)
- Protocol layers supported:
  - physical
  - link
    - satellite-specific MAC protocols
    - satellite-specific congestion control protocols
  - Extension to higher layers is possible (e.g. CAC), but not yet implemented.



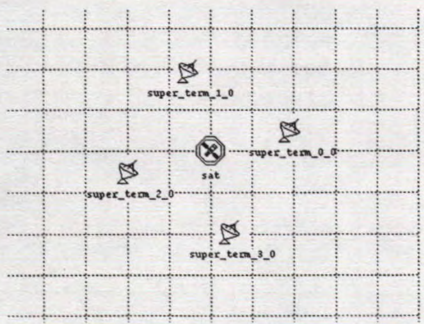
Simulation Model

- Simulation model developed in OPNET (**OP**timized **N**etwork **E**ngineering **T**ool), which permits event driven simulations.
- OPNET uses a hierarchical approach to specify a network, and has a huge list of component models which can be used as a basis

Network Model	High-level description of network topology showing the various nodes and links between nodes.
Node Model	High-level description of nodes showing packet flow between modules. Modules can be user-defined or OPNET standard (eg. transmitter, receiver, antenna).
Process Model	Detailed description of user defined modules - in the form of finite state machines using Proto-C (very similar to the C programming language).

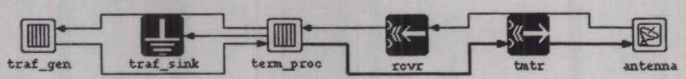
Simulation Model

- Network Model
  - Programmable number of spot beams.
  - Programmable number of terminals in a spot beam. Terminals in a spot beam are grouped into a single super-terminal, which reduces the simulation run-times.
  - Programmable number and type of users per terminal.
  - Programmable satellite altitude.



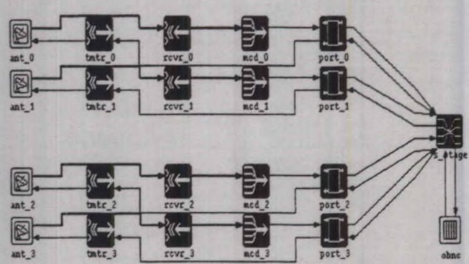
Simulation Model

- Node Models
  - Super-terminal Node
    - Traffic generator (traf_gen) generates all packets in a spot-beam.
    - Terminal processor (term_proc) contains the link layer functions of the MAC and the congestion control procedure.
    - Traffic sink (traf_sink) destroys packets at the terminal.
    - The transmitter, receiver & antenna are standard OPNET modules. They do, however, allow a user defined link performance.



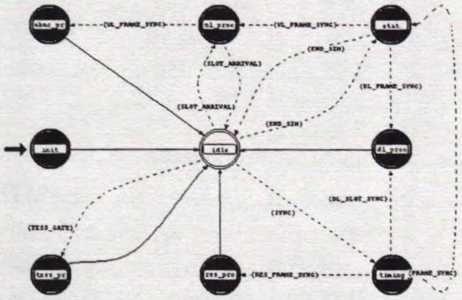
Simulation Model

- Satellite Node
  - Multicarrier demultiplexer (MCD) organizes the traffic packets into streams suitable for further processing (one MCD per uplink beam).
  - Port performs the functions of the MAC and congestion control on-board the satellite (e.g. the scheduling).
  - Switch stage routes packets from source port to destination port.
  - On-board network controller (OBNC) implements the functionality of congestion control algorithm and updates statistics.



Simulation Model

- Satellite Node (cont'd)
  - OBNC can be updated to implement Connection Admission Control (CAC) function.
- Process Models
  - user-defined processes are used in the traffic generator, terminal processor, MCD, port, switch, and OBNC. A typical example of the finite state machine for the port is shown in the figure.



Traffic Models Supported

- Constant
  - Time between packet arrivals (interarrival time) is constant.
- Poisson
  - Interarrival time is exponentially distributed.
- ON-OFF
  - Reflects a typical voice source: while ON, packets arrive at a constant rate; while OFF, no packet arrives
  - ON and OFF duration are exponentially distributed.
- Markov Modulated Poisson Process
  - Especially useful for video and aggregation of voice sources.
  - 2-MMPP: two-state model (underlaoded/overloaded)
  - Interarrival times in the two states are exponentially distributed, with rates governed by an underlying Markov chain.
  - Time in each state of the chain is exponentially distributed.

Traffic Models Supported

- Pareto Modulated Poisson Process
  - Similar to MMPP, with the duration in each state of the underlying Markov chain being Pareto distributed.
  - Exhibits self-similar behavior.
- ON-OFF WWW Model
  - Models the Web-based request traffic (browser activity).
  - ON-OFF type, with Pareto distributed OFF time and Weibull distributed ON time. Interarrival time (while in ON) is also Weibull distributed.
  - Exhibits self-similar behavior.
- Marginal Transformed Process (MTP)
  - Self-similar model, well suited to MPEG video traffic.
  - Based on matching the autocorrelation function and the marginal distribution of a real trace, to reflect both the short-range and the long-range dependence.

Traffic Models Supported

- Multifractal Model
  - Based on the view of the network with its hierarchic protocols as a cascade of processes
  - Appropriate to model the traffic in data networks (Web browsing, E-mail server, FTP etc).
  - Well suited for individual traffic sources.
  - Results suggest a very accurate matching to real traffic [1].
- Note: All models generate packet arrivals. The actual packet length distribution is a user-programmable parameter. Current choices: fixed, Pareto and histogram-based. For the latter, a histogram of the desired distribution must be specified.

[1] N. Desaulnier-Soucy, A. Iuoras, "Traffic Modeling with Universal Multifractals", submitted to Globecom'99 conference.

MAC Protocol Supported

- Based on Demand (BoD), from CFDAMA family
  - CFDAMA = combined free/demand assignment multiple access.
  - Terminals request capacity from on-board scheduler.
  - Scheduler assigns capacity based on these requests and priority of traffic (with specified QoS).
  - Any capacity not assigned after servicing all requests is freely distributed across the active terminals.
  - Four types of channels (request mechanisms) available:
    - reserved capacity
    - rate based dynamic capacity
    - volume based dynamic capacity
    - free capacity
  - The mapping of services (CBR,RT-VBR, NRT-VBR,ABR, and UBR) to request mechanism is very flexible.

Congestion Control Schemes Supported

- Explicit Rate Indication for Congestion Avoidance (ERICA)
  - Terminals modulate the capacity requests based on the explicit rate (set by the switch), carried in RM cells.
  - RM cells are generated for each connection, and so the control is per connection (per VC).
- Broadcast Rate Control Allocation (BRCA)
  - Congestion is controlled per downlink destination and not per connection.
  - Congestion-related information (fair rate, rate increase / decrease, load) is broadcast to terminals in regular data cells
  - Terminals calculate the allowable cell rate based on broadcast information and modulate the capacity requests

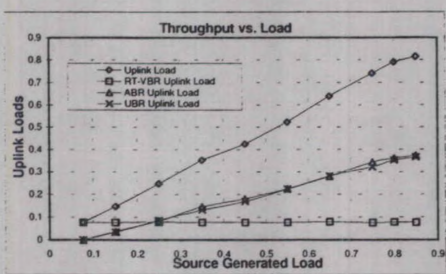
Typical Simulation Results

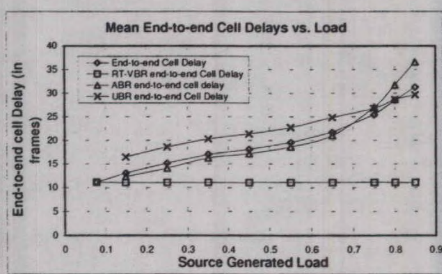
- Sample of MAC Protocol Performance
  - Based on a test a case with:
    - a single spot-beam;
    - an uplink capacity of 128 cells per frame (ATM cells considered, but cell size is user-defined);
    - 144 terminals, of four different types. The table below shows the number of terminals of each type, the type of traffic supported by each terminal, and the traffic model used for each traffic type.

Terminal Type	Number of terminals	Traffic Type Supported	Model for traffic type
1	8	RT-VBR	MMPP
2	4	RT-VBR	MMPP
		ABR	MMPP
3	4	RT-VBR	MMPP
		ABR	ON-OFF WWW
4	128	UBR	ON-OFF WWW

Typical Simulation Results

- Performance monitored in terms of UL throughput and end-to-end delay

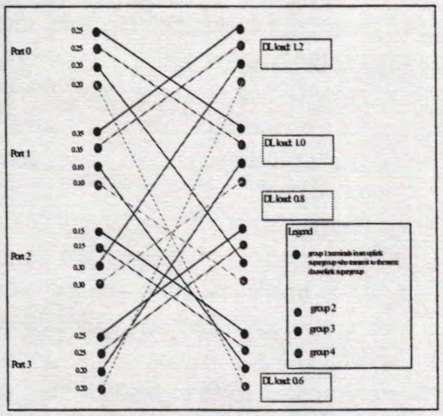




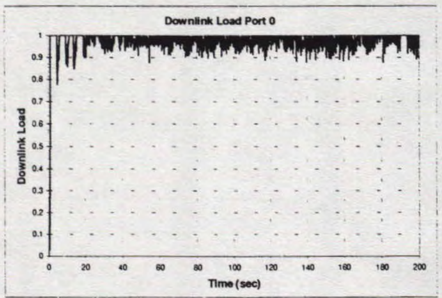
- Additional parameters that can be monitored:
  - Downlink channel utility
  - Mean end-to-end packet delay
  - Cell-delay variation
  - Transport efficiency (for various packet sizes)

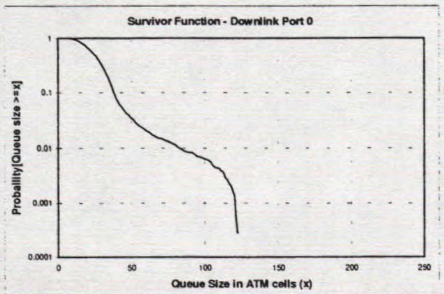
Typical Simulation Results

- Sample of Congestion Control Protocol Performance, based on:
  - 4 spot-beam architecture
  - Unbalanced loading of output ports, with the intention of intentionally congesting some ports (e.g. port 0 and port 1)
  - The load on the uplinks is evenly distributed (90% on each UL).
  - The network allows for complex traffic mixes - however worst-case scenario is typically chosen (i.e. ABR traffic only).



Typical Simulation Results





- Additional parameters that can be monitored
  - Terminal queue size and on-board downlink queue size
  - On-board queuing delay
  - Uplink throughput
  - Mean end-to-end cell/packet delay

Conclusions

- The model allows performance assessment of an integrated set of protocols and traffic models, including (in the current implementation):
  - A MAC protocol (based on CFDAMA)
  - Two congestion control protocols
  - Eight traffic models which are considered representative for multimedia traffic
  - Transmission link characteristics
- The model is robust and very flexible, allowing simulations for various traffic mixes, loading strategies, number of terminals, number of spot beams, cell payload sizes, etc.
- The model can be easily expanded to include shaping/policing mechanisms and call admission control.
- We are currently investigating the interfacing of the model with higher level terrestrial network protocols (e.g. TCP/IP).

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