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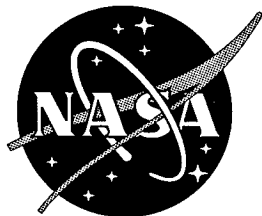
Future Benefits and Applications of Intelligent On-Board Processing to VSAT Services

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Technical Support for Defining

Advanced Satellite Systems Concepts

Final Report for Task Order 4

Future Benefits and Applications of
Intelligent On-Board Processing to VSAT Services

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Summary

Traditional VSAT service capitalizes on point-to-multipoint applications, and has proven to be very attractive from both utilitarian and economic viewpoints. Such services naturally make use of a Star network architecture, where all communications are distributed from, or collected to, a common node which is earth-based. The satellite need only be a simple repeater, with conventional CONUS-coverage C-band or Ku-band payloads meeting the requirements very well.

Future VSAT design must be low cost, flexible, highly secure, and capable of supporting new or enhanced virtual high-speed services. In addition, the future VSAT networks are expected to serve as redundant or backup to terrestrial facilities for disaster recovery and to reduce vulnerability to network failures or sabotage, which will be increasing threats in the future. Accordingly, the concept of a mesh configuration consisting of smaller and less expensive ground terminals coupled with a cost effective payload configuration offers a possible solution. This involves the combined use of higher frequency band for bandwidth, high gain multibeam antennas, and intelligent on-board processor for versatility in connecting the up and down links. The satellite architecture, the form of the on-board processing, and the economics of such a system for deployment in the year 2005 are the subjects of this study.

Important conclusions of this work are as follows:

- Three major new market applications are identified for mesh VSAT networks: (1) inter-enterprise interconnectivity; (2) image networking and distribution; and (3) LAN-WAN interconnectivity. Traffic projections for the year 2000 are made.

- Four mesh VSAT system architectues are studied. The architectures are progressively more complex designs and higher technology risks in exchange for greater satellite capacity and capability.

- Based on the network requirements and the time frame of the study, one architecture is selected for a detailed design. This architecture has fixed spot beams, on-board regeneration, and baseband switching among uplink and downlink beams on the satellite.

- The chosen design for the 2 Gb/s baseband switch is a TDM fiber optic bus. The tradeoffs in the design and implementation of the switch are described. The mass and power consumption of the switch and baseband electronics is estimated.

- A satellite design is presented for the mesh VSAT payload.

- User costs are estimated and are competitive with anticipated terrrestrial circuits. Duplex circuit costs range from $0.08 per minute for 64 kb/s circuits up to $5.06 per minute for 4 Mb/s circuits.

- The necessary technology developments are described. These technologies include multicarrier demodulators, optical bus interface devices, on-board network controller, VSAT cost reduction techniques, and rain fade sensing and mitigation techniques.

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Chapter 1

Executive Summary

This chapter is organized as follows:

1.1 Background

1.2 Statement of Work

1.3 Organization of Report

1.4 Summary of Results

1.1 Background

Traditional very small aperture terminal (VSAT) service capitalizes on point to multipoint (and vice versa) applications, and has proven to be a very attractive from both utilitarian and economic viewpoints. Such services naturally make use of a Star network architecture, where all communications are distributed from, or collect to, a common node (which is earth-based). For such the satellite need only be a simple repeater, with conventional CONUS coverage C-band or Ku-band satellites meeting requirements very well.

Higher frequency satellites have the potential of enabling the use of even smaller and less expensive earth stations than previously used. Unfortunately, in these higher frequency bands, the coverage area is segmented, a result of the necessary use of high gain multibeam antennas to aid in the overcoming of severe rain fades. Establishing a Star network in such an environment becomes difficult when the network extends over several spots. For such systems it is necessary to include some form of intelligent processing on board the satellite, in order to properly establish the required networks.

The satellite architecture, the form of the on-board processing, and the utility of such a system, for primarily point-multipoint communications (and vice-versa) is the subject of this study.

1.2 Statement of Work

Subtask 1: Identify VSAT services

The contractor shall:

- Identify the types of services which would be suitable for a VSAT service via a segmented coverage satellite network;

- Identify the approximate current volume of such traffic; and

- Forecast the traffic growth within each category.

The contractor shall assume the on-board processing is sufficient to achieve any desired connectivity and that the satellite path introduces no more than 250 ms of delay.

Subtask 2: System Architecture

The contractor shall identify and describe viable satellite architectures which can support fully connected point-point as well as point-multipoint traffic. This effort shall include delineation and description of subsystem functions within each architecture.

Subtask 3: Technology Development Plan

The contractor shall identify and describe viable architectures for the required on-board baseband switch for interconnection of the coverage segments. Also the contractor shall infer and describe technology needed to enable the said switch, including estimates of subsystem mass, subsystem power requirements, and high-level specifications (number of ports, clock speed, digital technology, etc.).

Subtask 4: Spacecraft

The contractor shall identify and describe viable satellite communication payloads, compatible with the segmented coverage VSAT application. Such description shall include:

- Payload mass,

- Payload power,

- Total spacecraft mass,

- Total satellite power, and

- Satellite costs.

The contractor shall infer from these specifications a suitable spacecraft configuration, and provide an artist's sketch of the same.

Subtask 5: User Costs

The contractor shall identify and describe a viable business venture scenario (traffic, satellites, ground segment, control) for VSAT service in a segmented coverage application. The scenario shall be of sufficient detail to obtain realistic total costs and user costs such as cents per minute or cents per packet.

Subtask 6: Critical Technologies

The contractor shall identify and describe the necessary technologies which are critical and/or enabling to the application of VSAT service in a segmented coverage environment. The contractor shall provide reasonable plans for the development of such technology, including schedules and costs.

Subtask 7: Reporting

Briefings. The contractor shall perform two briefings at the NASA Lewis Research Center:

1. Interim briefing is held approximately half way through the effort and gives the status of the effort,

2. Final briefing gives a complete description of results.

The contractor shall provide a minimum of 25 copies of viewgraph materials and one copy of transparencies.

Monthly status reports which are written shall be provided to the NASA Technical Manager.

Final Report. A draft final task report shall be provided to the NASA Technical Manager at the time of the final briefing. Following NASA review, the contractor shall make necessary changes and submit 50 copies to the NASA technical manager.

Period of Performance The contractor shall complete the technical effort and perform the final briefing within 9 months of task acceptance.

1.3 Organization of Report

Table 1-1 gives the organization of this Final Report by chapter. Chapter 2 identifies VSAT services, and Chapter 3 evaluates different system architectures. Chapter 4 describes the on-board baseband switch, and Chapter 5 describes the satellite design. Chapter 6 gives an estimate of user costs, and Chapter 7 lists the critical technologies.

There are seven appendices. Appendix A describes the hypothesized communications environment in the year 2000. Appendix B gives a review of overseas teleport projects, and Appendix C describes current VSAT systems. Appendix D discusses the problems of rain fade compensation, and Appendix E gives link budgets for the mesh VSAT system. Appendix F is a copy of the "Technology Requirements for Mesh VSAT Applications" paper presented at the 14th AIAA International Communication Satellite Systems Conference, Washington, DC, March 1992. Appendix G gives a cost comparison of the Mesh VSAT system with two other satellite system concepts, the Integrated Video and B-ISDN systems.

1.4 Summary of Results

The summary of results is organized according to the chapters of this report:

1. Identification of VSAT Services (Chapter 2)

2. System Architecture (Chapter 3)

3. On-Board Baseband Switch (Chapter 4)

4. Satellite Design (Chapter 5)

5. User Costs (Chapter 6)

Table 1–1: Organization of Report

Chapter	Contents
1.	Executive Summary
2.	Identification of VSAT Services
3.	System Architecture
4.	On-Board Baseband Switch
5.	Satellite Design
6.	User Costs
7.	Critical Technologies
A.	Communication Network and Service Environment in the Year 2000
B.	Review of Overseas Teleport Projects
C.	Current VSAT Systems
D.	Rain Fade Compensation
E.	Link Budgets
F.	AIAA Paper: Technology Requirements for Mesh VSAT Applications
G.	Cost Comparison

6. Critical Technologies (Chapter 7)

The reader is also referred to Appendix F which contains a copy of the paper "Technology Requirements for Mesh VSAT Applications", presented at *The 14th AIAA International Communication Satellite Systems Conference* in Washington, DC, March 1992.

1.4.1 Identification of VSAT Services

The current status of VSAT market applications and trends was surveyed, and future projections and forecasts were developed in the three categories shown in Table 1-2: (1) traditional services; (2) enhanced services; and (3) future services. Three major new market applications are identified for mesh VSAT networks:

Inter-enterprise interconnectivity. Future mesh VSAT market applications should stress inter enterprise interconnectivity, that is, different forms or entities whose inter communication needs will escalate in the future. Electronic data interchange, for example, allows for direct, paperless entry from one corporation to another. This will become big business in the future and is a natural application and exploitation of mesh satellite configurations with on-board processing to facilitate inter-enterprise interconnectivity. It also appears to be very competitive with terrestrial solutions that will be available.

Image networking and distribution. Another future application will be image networking and distribution. As the costs of optical scanners decrease during the 1990s and bandwidth compression or conservation techniques improve, image networking will increase greatly. The ability to scan, store on-line and make readily accessible to other network nodes/sites such items as X-rays, credit card transactions, cancelled checks, letters, and documents; will revolutionize office automation and information handling activities of organization.

LAN-WAN interconnectivity. The connection of local area networks into wide area networks will be a growth application in the 1990s. Ultimately, there will be some merging with the other two applications above.

Table 1-3 summarizes the North American Market outlook in terms of number of potential terminal sites or nodes. Sites or nodes may not necessarily be served by satellite. The table leaves blank the installed VSAT terminals for the years beyond 2000. The number of these future VSAT terminals will depend on future economics of mesh VSAT networks using advanced on-board processing techniques vis-a-vis high speed switched terrestrial services. Table 1-4 shows the changing nature of the VSAT market, by functional service class and percent of demand.

Table 1–2: Future Role of VSATs Must Consider Terrestrial Competitive Developments

Service Category	Description	Terrestrial-Based Competition
1. Traditional	Simple point-to-multipoint data distribution.	Multi-drop leased lines. Packet switched networks.
2. Enhanced (So-called third generation VSATs)	Communications plus processing and control enhancements including: – Protocol processing – Protocol compatibility – Network management – Inter-networking Business TV Some integrated applications	Continued deployment and reach of optical cable. Intelligent networks (Bellcore's IN2) ISDN
3. Future (Novel, or new at the present)	Shared use Inter-enterprise networks. Integrated Services (ISDN) Satellite–terrestrial integrated networks. Mobile VSAT Global Interconnectivity	ISDN B-ISDN PCN (Personal communications networks). Mobile and cellular

Table 1–3: North American VSAT Market Outlook

	No. of Potential Terminal Sites (1,000)					
	1990	1995	2000	2005	2010	2015
Gross Market Potential	160	400	600	1,200	2,000	4,000
Cumulative VSAT Terminals Installed (sales)	60	220	400	–	–	–

Table 1–4: Changing Nature of VSAT Market

Functional Service Class	Percent of Demand						
	1985	1990	1995	2000	2005	2010	2015
Traditional	100	70	30	20	10	0	0
Enhanced	0	30	60	50	30	20	10
Future	0	0	10	30	60	80	90

Traffic Projection for the Year 2005:

Number of Networks = 1,200

Number of terminals = 500,000 units with a breakdown as given below. (Only a small fraction of the terminals is expected to be active at the same time.)

Frequency	Terminals	Networks
C	50,000 or 10%	120
Ku	250,000 or 50%	600
Ka	200,000 or 40%	480

The distribution by terminal speeds and application for advanced VSAT satellite system in the year 2000 is given below. (Terminals may typically communicate at a rate lower than their maximum.)

Minimum user terminal speed	144 kb/s
Maximum user terminal speed	4 Mb/s
Minimum shared hub terminal speed	16 Mb/s
Maximum shared hub terminal speed	45 Mb/s

The user terminal distribution by speed class is:

144 kb/s — 384 kb/s	30%
384 kb/s — 768 kb/s	30%
768 kb/s — 2.0 Mb/s	30%
2.0 Mb/s — 4.0 Mb/s	10%

The user terminal distribution by application is:

Data only – low speed (144–256 kb/s)	20%
Med. speed data + voice (256–768 kb/s)	40%
Med. speed data + voice (0.76–2 Mb/s)	20%
High speed LAN-WAN connectivity	10%
High speed LAN-WAN + voice	10%

1.4.2 System Architecture

Four architectures as described in Table 1-5 were studied. These architectures are progressively more complex designs and higher technology risks in exchange for greater satellite capacity and capability.

Architecture 1 is best suited for a low rate demand assigned SCPC type of system where the user requirements are mostly for thin route voice traffic and low rate data.

Architecture 2 presents an improvement in the achievable VSAT transmission rates (size, and cost) and may be more suited for users with higher traffic requirements.
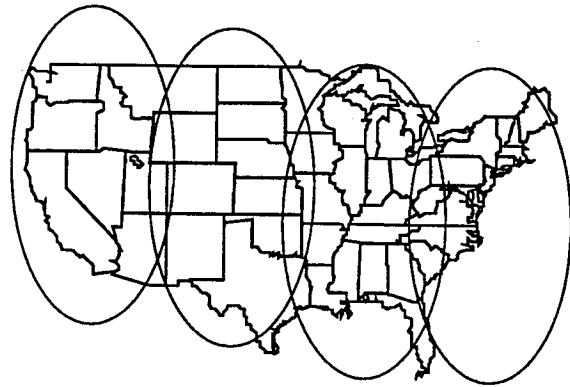
Figure 1–1: Uplink Beam Coverage
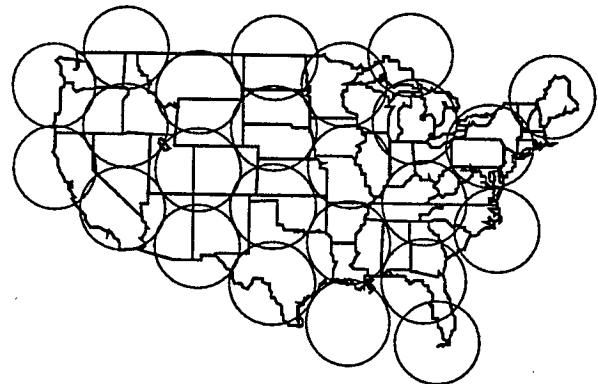
Figure 1–2: Downlink Beam Coverage

Architecture 3 offers more flexibility in accommodating a variety of traffic types and rates with reduced VSAT complexity at the expense of higher on-board complexity.

Architecture 4 gives additional improvements in capabilities and transmission rates via use of TDMA and scanning beam technologies.

Based on network requirements considerations and the time frame of the study, **Architecture 3 was selected for implementation** as the best tradeoff between capabilities and complexity. Figures 1-1 and 1-2 show the uplink and downlink beam coverages of the selected architecture. There are 4 uplink beams that provide regional coverage of an area equal in size to the CONUS, and 24 fixed downlink spot beams provide overlapping coverage of the same area.

Table 1-6 summarizes the system design parameters. The access method selected is multi-frequency TDMA (MF-TDMA) on the uplink and TDM on the downlink. The uplink transmission rate is 4 Mb/s which accommodates VSAT users with transmission requirements up

Table 1–5: Architecture 3 Was Selected for Implementation in the Year 2000

	Architecture 1	Architecture 2	Architecture 3	Architecture 4
Features:	Fixed spot beams Bent pipe IF switch FDMA SCPC access	Fixed spot beams On-board regeneration IF switch FDMA up, TDM down	Fixed spot beams On-board regeneration Baseband switch MF-TDMA, TDM	Narrow scanning beams On-board regeneration Baseband switch TDMA, TDM
Beam coverage:	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Narrow scanning beams 100 spot beam locations 10 up and 10 downlink scanning beams. CONUS coverage
Access method:	FDMA with SCPC	SCPC/FDMA or TDM/FDMA uplinks TDM downlinks	MF/TDMA via MCD's on uplinks. TDM on downlinks	TDMA up/downlinks
Connectivity:	Static IF switch Frequency-tunable transmitters and receivers.	Static IF switch Freq. tunable transmit TDM downlinks	Baseband switch	Baseband switch
Technologies:	Frequency tunable transmitters and receivers for VSAT	Frequency tunable transmitters. MCD	Baseband processor – MCD – Switch – Controller	Scanning multibeam ant. Baseband processor – MCD – Switch – Controller

to that rate. VSAT users with low throughput requirements share the low rate TDMA carriers while users with higher throughput use TDM transmissions.

The multi-frequency feature of the uplink TDMA access permits more flexible and efficient sharing of the available uplink bandwidth. With this arrangement up to 100 uplink carriers can be assigned in 500 MHz bandwidth making a total uplink throughput limit of 1.6 Gb/s. On the downlink, a single TDM carrier is received by all VSATs in each downlink beam which carries all the traffic destined to that beam. The downlink TDM carrier bit rate is 68 Mb/s so that the aggregate available downlink bit rate is approximately the same as the uplink bit rate.

Because of the power limited nature of the VSAT links, rate 1/2 convolutional coding is assumed on both uplink and downlink, with on-board FEC soft decision decoding. Both uplink and downlink transmissions are QPSK. Further differential encoding on the uplink may be used to resolve carrier phase ambiguity of the uplink bursts in the on-board receiver. Differential encoding on the downlink is not needed due to the continuous nature of the downlink transmission.

1.4.3 On-Board Baseband Switch

The chosen on-board processor design is a 1.6 Gb/s TDM optical ring which interfaces to the input and output processing units. The ring design results in a simple interface structure among the processing units. At the same time, it provides a self routing architecture with no requirement for control memory. Finally, it provides a modular design which could be utilized for redundancy considerations. The use of a bit synchronous system and differential encoding for phase ambiguity resolution on the uplink substantially simplifies the design of the on-board demodulators at the expense of negligible increase in earth station complexity.

A block diagram of the payload is shown in Figure 1-3. Four multi-carrier demods (MCDs) are used with each uplink beam to demodulate 25 carriers each. The MCD outputs comprise two-bit soft-decisions on the received channel symbols at an information bit rate of 100 Mb/s (400 Mb/s total including FEC and 2-bit quantization). The MCD outputs are processed by the input processors which perform 2-bit soft-decision FEC decoding, packet assembly, differential decoding, descrambling and deinterleaving, header error control, and buffering.

Also included in the input processor is an optical bus

Table 1–6: System Design Parameters

System Parameters	Uplink	Downlink
Number of Beams	4	24
Access Method	MF/TDMA	TDM
Modulation	D-QPSK	QPSK
Forward Error Correction	R-1/2 Convol.	R-1/2 Convol.
Burst/Transmission Rate	4 MSym/s	68 MSym/s
Bit Rate (Information)	4 Mb/s	68 Mb/s
Bit Error Rate	10^{-8}	10^{-10}
Number of Carriers per Beam	100	1
Total Number of Carriers	400	24
Beam Capacity	400 Mb/s	68 Mb/s
System Capacity	1.6 Gb/s	1.6 Gb/s

Figure 1–3: On-Board Processing Payload Features Multi-Carrier Demodulators and Fiber Optic Bus Switch

interface at the optical bus speed of 1.6 Gb/s. Twenty four output processors interface to the optical bus at the same speed and perform packet address filtering, frame buffering, bit interleaving and scrambling, and FEC encoding. Each output processor transmits a 68 Mb/s TDM stream.

Network control is provided through an autonomous network controller (ANC) which interfaces to the optic bus and sends control signals to the input and output processor units. The input processor units also send control signals to the controller. However the exchange of control information between the output processor units and the controller is strictly one way.

Preliminary estimates of mass and power requirements for the sample on-board baseband processor design are provided considering implementation in the years 1996–2000. The digital device technologies used are GaAs for high-speed processing, such as fiber optic interface processing, and high-density CMOS (HCMOS) for other processing functions. The on-board baseband processor with 1.6 Gb/s throughput is estimated to consume about 500 W power and have a mass of 58 kg using technology available in 1996.

1.4.4 Satellite Design

The approach is to evolve the existing satellite design (1990 technology base for 1995 launch) to the Mesh VSAT satellite design which assumes a year 2000 technology base for a year 2006 launch. Technology advances are assumed in the propulsion and power subsystems. Stationary plasma thrusters are used to reduce the mass of on-orbit station-keeping fuel and thus enable longer lifetimes. Lower mass batteries and solar cells allow greater payload mass.

Table 1-7 summarizes the payload electronics mass and power for the 1.6 Gb/s payload. Major components contributing to the payload mass and power are the downconverters, the upconverters, the multi-carrier demodulators (key component of the baseband processor in terms of mass and particularly power consumption), the processors, and the 30 W TWTAs.

The bus design is based on the Loral FS-1300 series which is presently in production for commercial applications such as Superbird, Intelsat-7, and N-Star. The result is a 1,727 kg dry (1,887 kg wet) satellite mass with a 310 kg M-VSAT payload (antenna plus communication electronics) and 3.6 kW end-of-life power.

The M-VSAT payload design does not occupy the to-

tal capacity of the bus. (There is 382 kg spare capacity.) Considering its use of mass and power, approximately 67% additional payload of the same type and power consumption could be carried. If the M-VSAT payload were optimized for this size bus by using the spare capacity, maximum communications capacity would increase to 2.7 Gb/s. This capacity is within that of the fiber optic bus switch.

In order to develop consistent user cost estimates, the estimated 2.7 Gb/s "full bus" M-VSAT payload will be assumed. Total spacecraft dry mass is 1,727 kg, and spacecraft power is estimated at 5.6 kW. The communications payload mass is 589 kg (50 kg antenna and 549 kg communications electronics).

1.4.5 User Costs

User costs are developed based on the schedule in Figure 1-4 for Mesh VSAT system implementation. Table 1-8 summarizes the space segment costs in 1992 dollars, and Table 1-9 gives the ground terminal costs for two sizes of terminals. The full set of assumptions for developing these costs is given in Chapter 6.

Total user costs are derived by a two step process. First the space segment and network control costs for a simplex circuit are derived. Second, the user terminal costs are added to the space/control costs to obtain the total user cost per minute of circuit use.

Table 1-10 gives the duplex circuit cost for different circuit sizes for the medium (1.8 m) and large (3 m) users. Assumed terminal use is 2 hr/day and the ground terminal capacity is shared by other users for the case of circuit sizes smaller than 4 Mb/s. A 5 minute duplex call at 128 kb/s (two-way) between two 1.8-m users would cost $0.80. A 1-hour video conference between two 3-m users at 4 Mb/s would cost $316.

1.4.6 Critical Technologies

Technology requirements are given for the mesh VSAT application in three parts: (1) satellite antenna, (2) VSAT, and (3) on-board processor technologies.

Satellite Antenna Technology

The key satellite antenna technology is the antenna system which forms the multiple beams. It may be a multi-beam or phased array design. The key design parameter is the ability to cover an area such as CONUS (5° by 3°)

Table 1–7: Payload Electronics Mass and Power Breakdown

Equipment	Mass (kg)			Power (W)			Comments
	Qty.	Unit	Total	Qty.	Unit	Total	
<u>Baseband Processor</u>							
MCDs – 4 Mb/s carriers	20	0.3	6	16	20.0	320	
Input processor	20	0.4	8	16	3.2	51	
Switch fabric & support	1	1.0	1	1	10.0	10	
Output processor	28	0.4	11	24	2.8	66	
Modulators	28	0.2	6	24	0.2	5	
Network Controller	2	0.5	1	1	12.0	12	
Timing source	3	1.0	3	1	3.0	3	3–1 redundancy
DC/DC converter	2	6.0	12	1	52.0	52	90% efficiency
Structure	1	12.0	12				
Subtotals			60			519	
Low noise amplifiers	6	0.5	3	4	1.2	5	6–4 redundancy
Receivers (28/4 GHz)	6	2.0	12	4	8.0	32	6–4 redundancy
Input demultiplexers	5	1.5	8				3 channel
Upconverter (4/20 GHz)	28	1.1	31	24	3.0	72	10–8 redundancy
TWTA/EPC (13 W, 20 GHz)	28	3.0	84	24	75.0	1,800	10–8 redundancy, 40% eff.
DC/DC convertor (TWTA, U/C)	14	0.4	6	12	16.7	200	2–1, 90% eff.
Output filter	28	0.2	6				
Master LO	2	5.0	10	1	6.0	6	2–1 redundancy
Redundancy switches			20				
Waveguide and coaxial cable			7				
Beacon transmitters	2	2.0	4	1	15.0	15	2–1 redundancy
Margin			13			129	5% margin
Totals			264			2,708	Mass (kg), Power (W)

Figure 1–4: Schedule for Mesh VSAT Satellite System Implementation

Table 1–8: Space Segment Costs, 1992 $M

Cost Category (2 satellites on orbit)	Life Cycle Cost	Annual Cost at 18%
Satellite cost (2)	560 M	
Launch Cost (2)	248 M	
TT&C Support (2)	15 M	
Launch Insurance (16%)	157 M	
Total Costs	$980 M	$192 M/yr

Table 1–9: Ground Terminal Annual Costs (1992 $)

Terminal Type and Cost	Lease Cost ($/yr)	Maintenance Cost ($/yr)	Total Cost ($/yr)
Medium (1.8 m), $45,000	9,000	4,500	13,500
Large (3 m), $55,000	11,000	5,500	16,500

with 1° or smaller beams, with good isolation between beams in order to allow frequency reuse.

VSAT Technology

The key VSAT technologies are low-cost Ka-band RF devices, such as antennas, high power amplifier, low noise amplifier, upconverter, and downconverter. Integrated outdoor RF equipment, such as that being used in the current Ku-band VSATs, is critical in reducing user equipment cost.

Other technologies are low-cost tunable transmitters and receivers to allow flexibility in assignment of TDMA/FDMA uplink and TDMA downlink carriers, a TDMA controller operating with 4 Mb/s uplinks and 68 Mb/s downlinks, and a low-cost rain-fade detection system for Ka-band in order to allow additional rain margin to be invoked. Although these technologies are currently available in VSAT and other satellite systems, further cost reduction is necessary for the mesh VSAT services to be cost competitive.

On-Board Processor Technology

The on-board baseband processor requires the use of large-scale digital integrated circuits with high component density per chip, low power consumption, high speed operation, and adequate radiation tolerance.

Critical technologies identified are as follows:

Multi-carrier demodulator (MCD) with low power consumption is the most critical technology for the realization of the on-board baseband processor. In our design for the baseband switch, it consumes about twice the power of the rest of the subsystem. Intensive development effort to reduce the MCD power requirement to the range of several watts is strongly recommended.

Bit synchronous system improves frame efficiency and simplifies on-board processor design as well as network control procedures. However, the MCD is required to measure phase errors with an accuracy of a small fraction of a symbol period. It also necessitates the user terminal to perform accurate timing correction.

Alternate techniques to implement a bit synchronous system should be investigated, and a proof-of-concept model to demonstrate its feasibility should be developed.

Multi-carrier processing devices such as a multi-carrier FEC decoder, packet assembler, differential decoder, descrambler, bit deinterleaver, and packet header error controller, are critical in reducing on-board processor mass and power and increasing reliability. These processing devices have been implemented for single carrier operation in various applications, but their multi-carrier versions will

Table 1–10: User Costs for Duplex Circuits (Shared Terminals, 2 hr/day Terminal Use)

User Size (m)	Total User Costs ($/min), Duplex Circuit for Data Rate (Mb/s)						
	0.064	0.128	0.256	0.512	1.0	2.0	4.0
1.8	0.08	0.16	0.32	0.62	1.26	2.54	5.06
3.0	0.08	0.16	0.32	0.66	1.32	2.64	5.26

require development. Some of these functions may be combined and fabricated into a single custom LSI device.

Radiation hard 16 K x 32 static RAMs or larger will help reduce parts count and increase reliability. Significantly larger memory chips are currently available for commercial applications, and their space-qualified versions are expected to available in the near future.

High-speed optical bus interface to perform optical to electronic conversion, clock synchronization, multiplexing, and serial to parallel conversions needs to be developed for space applications.

Autonomous network controller performs not only conventional monitor and control functions of on-board equipment, but also network control functions such as carrier frequency and time slot assignment for uplink and downlink, time plan change coordination, on-board buffer management, and congestion control for packet data.

A detailed investigation is needed to assess feasibility of implementing these functions on board the satellite. Also, applicability of new network control and management technology, such as expert systems and neural networks, should be investigated.

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Chapter 2

Identification of VSAT Services

The objectives of this chapter are to:

- Survey the current status of very small aperture terminal (VSAT) market applications and trends.

- Develop future projections and forecasts considering (a) traditional services, (b) enhanced services, and (c) novel applications.

- Assess how satellites will be used in the VSAT market to the year 2015.

For the purposes of this forward looking analysis, services are considered within three categories:

1. Traditional service supplies simple point to multipoint data distribution.

2. Enhanced (so-called third generation VSATs):

    - Communications plus processing and control enhancements such as protocol processing, compatibility, and network management.
    - Business TV.
    - Some integrated applications.

3. Future (novel or new at the present time):

    - Shared use inter-enterprise networks
    - Integrated services (ISDN and BISDN)
    - Satellite – terrestrial integrated networks
    - Mobile VSAT
    - Global interconnectivity

This chapter is organized as follows:

2.1 Current Status of the VSAT Market

2.1.1 VSAT Market in the United States

The current status of the United States VSAT market is best described as a special interest niche market. The market can be divided into two generic categories as described below:

i. One way broadcast distribution. This market is primarily C band and is typically represented by the distribution of training information, corporate announcements, inventory system updates and the like. This is a relatively stable segment with limited demand for additional use.

ii. Two way interactive data. This market is both C and Ku band based. However, Ku band is the growth area. The majority of recent installations have been based on interactive communication from branch locations to central site. The most typical usage is a retail chain doing "on-line" inventory management and ordering via satellite communication between point-of-sale devices and central mainframe systems.

The most common users of VSAT systems are retail firms which have national or regional branches. Indications are that the retail and service industries are the technology leaders in VSAT technology.

A common characteristic of VSAT users is that they have a need for bursty data transmissions. This is short bursts of data at random intervals from remote sites back to central locations. In addition, many require broadcast updates of files, such as price lists, from the central site to all remote sites. This type of traffic lends itself to satellite technology and is typical of many industries.

From user perception point of view, major marketing points, pro and con, for VSAT satellite services can be listed as follows:

Pro Satellite:

- Freedom from leased line networks and the associated responsibilities.

- Reduced costs. Satellite network operating costs are typically less than the cost of private networks and of dial up networks.

- Responsiveness. New sites and temporary sites can usually be supported much quicker with satellite than with leased line services.

Contra satellite:

- High capital cost and long term commitment.

- Antenna mounting problems and landlord issues.

- Weather and sun-induced outages.

- Lack of knowledge about satellite capability.

Figure 2-1 illustrates the current status of the VSAT market in the United States and names key users of VSAT networks. Tables 2-1 and 2-2 show the breakdown by frequency band and application for private VSAT networks in the United States *Satellite Communications Magazine*, July 1988.

2.1.2 What is a VSAT?

VSAT is an acronym for "Very Small Aperture Terminal". Characteristics of VSATs include:

- Broadcast data, interactive data and/or video broadcast network.

- Star Configuration-point-multipoint.

- Remote stations with small (0.6 m to 2.4 m) antennas, and other data communication equipment.

- Master earth station with large (4.5 m to 9 m) antennas, network control computer, packet switch (for mesh connected networks). Most VSAT networks today are Star configuration.

VSAT networks are distinguished from other satellite systems by the fact that the user terminals are located on the customer's premises (bypassing any local terrestrial links (tails)); and have an antenna diameter (for most locations) no larger than 1.8 m in diameter, (e. g., 0.6 m, 0.9 m, 1.2 m, 1.5 m, 1.8 m). VSAT networks can be used for (1) transmission of data – one-way and

two-way (star connectivity for host-to-remote and mesh connectivity for remote-to-remote); (2) business video broadcast; and (3) voice (but at reduced quality).

2.1.3 Third Generation VSATs

Figure 2-2 illustrates the three generations of VSAT Technology. The characteristics of the third generation VSAT are as follows:

- "Open" architecture – built around standard data communications protocols.

- Multiport/multi-protocol systems. Protocols typically supported include SNA/SDLC; X.25; 3270 Bisync; Burroughs (UNISYS) Poll/Select; DAMA/TDMA; and Slotted Aloha.

- Dynamic and flexible satellite access schemes

- Design compatible with hybrid network configurations

- Robust and flexible network management for network operations and control; network rearrangement and reconfiguration; and interface with enterprise network management.

- Approaching applications transparency.

- Achieves lower O&M costs.

Table 2-3 lists the implications of the third generation of VSATs.

Typical functional applications of corporate communications include:

Data

- Order entry
- Point of sale transactions
- Centralized inventory control
- Credit verifications/authorization
- Reservation systems
- Inquiry/response
- Automatic teller machine (ATM) transactions
- SCADA – System Control and Data Acquisition
- Host computer based CAD/CAM

Key US Users with
VSAT Networks
- **Thrifty**
- **K-Mart**
- **Service Merchandise**
- **Wal-Mart**
- **Home Depot**
- **Southland**
- **Farmer's Insurance**
- **Prudential Bache**
- **Days Inn**
- **Holiday Inn**
- **Red Roof Inns**
- **Chrysler**
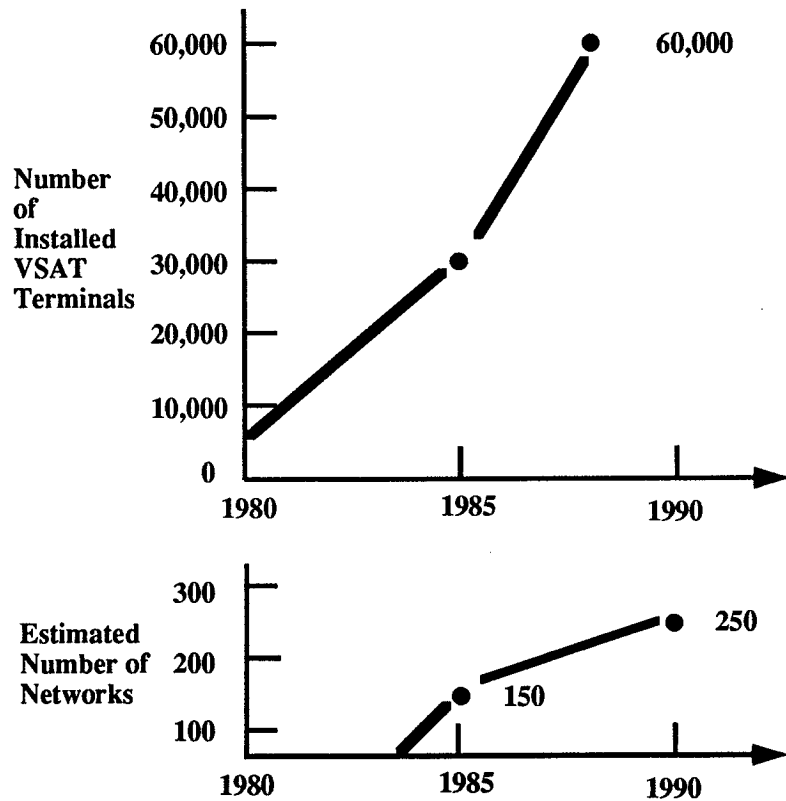
Figure 2–1: Current Status of the VSAT Market in the United States

Table 2–1: Private VSAT Networks in the United States – Breakdown by Frequency Band

Frequency Band	No. of Networks		No. of Sites	
C-Band	59	41%	8,859	30%
Ku-Band	85	59%	21,047	70%
	144		29,906	

Table 2–2: Private VSAT Networks in the United States – Breakdown by Application

Applications	No. of Networks	
Data only	63	43%
Video only	19	13%
Voice only	1	1%
Data and Video	11	8%
Data and Voice	16	11%
Video and Voice	19	13%
Data, Voice, Video	16	11%
	145	

FIRST GENERATION   **SECOND GENERATION**   **THIRD GENERATION**

| Successful Demonstration of small aperature technology | Refinement of contention access schemes | • Application to data
 • Development basic network Management | Demonstration of multi-port multi-protocol, multi-application systems | Adoption of standardized architectures, improved access and network management schemes |

Before 1980   **1980**   **1983-1984**   **1985**   **1987**

Figure 2–2: Three Generations of VSAT Technology

Table 2–3: Implications of the Third Generation VSATs

Characteristic	End User Benefit
Open, standard architecture	Investment protection Compatibility with network direction
Multi-port/Multi-protocol	Suitable for general purpose applications. Allows integration of diverse applications.
Flexible satellite access scheme	Transparent to batch or interactive traffic.
Compatible with hybrid network	Numerous implementation options. Allows network optimization.
Robust network management	Take advantage of VSAT flexibility. Save network administration costs. Improve performance.
Approaching applications transparency.	Streamlined implementation.

Other

- Compressed video

- Voice to transportable or geographically-remote sites

Table 2-4 describes the data communications environment in terms of transaction type, message length, and minimum delay requirements. Figure 2-3 illustrates how different applications tend to generate widely different data traffic.

Private business television can use VSATs to obtain a competitive edge:

- To train field sales and service employees

- To increase executive communications within the company

- To introduce new products and marketing programs

- To create multi-language television broadcasts for global multi-national corporations

Figure 2-4 illustrates how VSATs can play several principal roles. The U. S. domestic VSAT market (equipment and services combined) is estimated to represent 3% of the overall U. S. domestic market (telecommunications service revenues such as AT&T and MCI).

Figure 2-5 shows that there is a wide spectrum of options for ownership and control of VSAT networks. These options give rise to a variety of network management options:

- Remotely configured and operated

- Locally configured, remotely operated

- Monitored

- Owned and operated, stand-alone management

- Integrated with enterprise network management

Any one of these can operate with back-up or redundancy service.

Use of a shared hub offers a number of advantages:

- Easy way for user to get his "feet wet".

- Requires minimal customer involvement.

- Available with no large scale capital investment, all over the U. S.

- Sensible for almost any size customer.

- Operation/maintenance of hub equipment included.

- Does tie user into one supplier.

2.1.4 Advantages of VSAT Networks

The advantages of VSAT networks can be summarized as follows:

- A natural for broadcast applications.

- Offers a fixed cost solution under long term contract.

- Flexible/expandable network configuration.

- Cost of circuits independent of distance.

- Increased data bandwidth.

- Access to remote, transportable, mobile sites scattered anywhere in the satellite footprint.

- No interconnection by multiple carriers.

- No local loop connections required.

- Rapid network installation.

- Channel bandwidth dynamically assigned for data, voice or video.

- Hub station can perform total network management: monitor transmissions and perform remote diagnostics on user terminals.

- Hub backup provided via shared-hubs or service provider hubs.

- Ideal for disaster recovery.

- Greater security (over terrestrial leased line outages).

- Better performance availability.

Table 2–4: Data Communication Environment

Transaction Type	Message Length	Delay Requirement
Interactive (Person/computer continuous thought process)	600 to 6,000 bits	< 1 second
Inquiry/response	600 to 6,000 bits	1 to 30 seconds
Data base update	600 bits	Seconds to minutes
Short bulk data transfer	10^4 to 10^6 bits	Tens of seconds to minutes
Long bulk data transfer	10^6 to 10^8 bits	Tens of minutes to hours

TRAFFIC LEVEL
(BPS PER REMOTE IN BUSY HOUR)
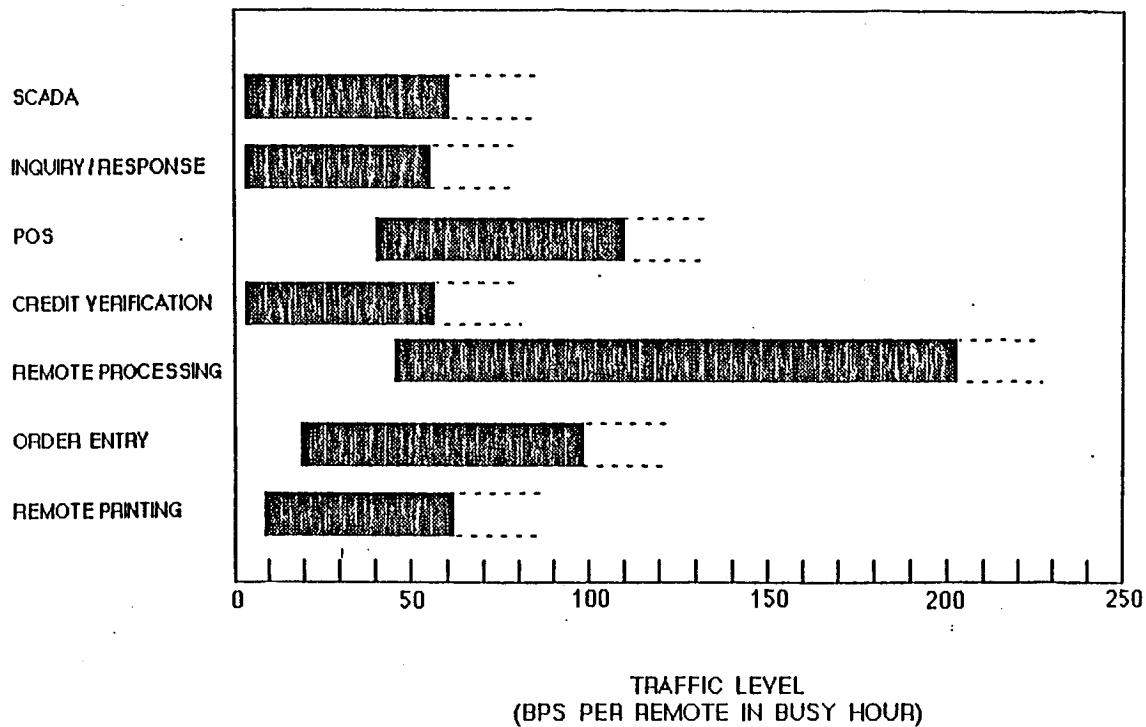
Figure 2–3: Different Applications Tend to Generate Widely Different Data Traffic
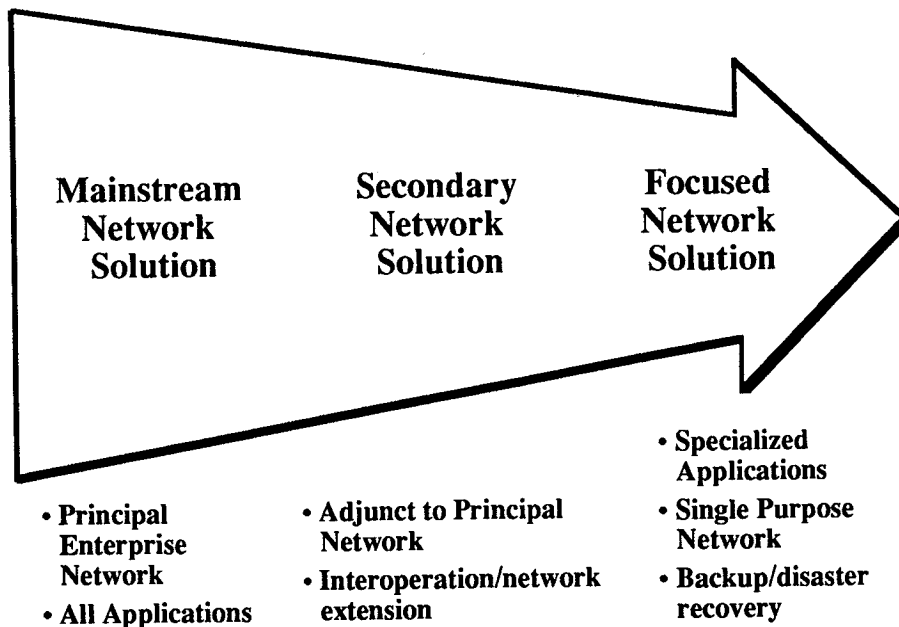
Figure 2–4: VSATs Can Play Several Principal Roles
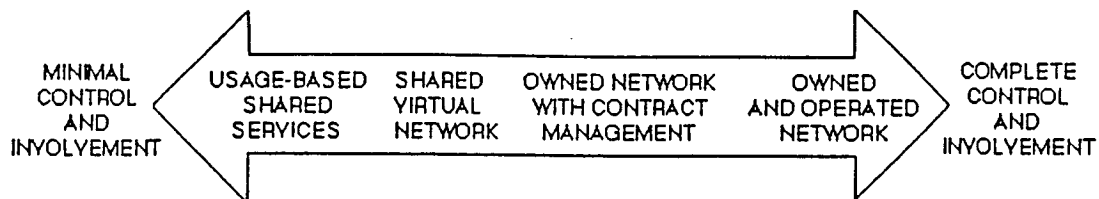
Figure 2–5: Wide Spectrum of Options for Ownership and Control of VSAT Networks

2.1.5 VSAT Case Studies

Case Study A:

- Service provider
- 50 remote sites
- Multidrop terrestrial network
- Six drops per line
- Average distance of remote from host: 850 miles
- Low line utilization
- **Chose VSAT network with shared hub**
- Payback of less than 2-1/2 years

Case Study B:

- Retailer

- 100+ sites
- Outgrowing dial-up 4800 b/s network
- Considering terrestrial 9,600 b/s multidrop network – 5 drops per line
- Average distance of remotes is 300 miles
- **Chose VSAT network with shared hub**
- Payback of 3 years
- Expect additional $1 M/year savings from communications and employee motivation, credit authorization, security monitoring, and energy management.

Case Study C:

- Manufacturer
- 20 remote sites
- Average traffic rate is 1,000 b/s per remote

- Very high utilization of 9,600 and 14,400 b/s lines
- Two drops per line
- Average distance of remotes is 300 miles
- **Stayed with terrestrial leased lines**
- VSAT network not justified because of high line utilization and low number of sites.

Case Study D:

- Hotel chain
- 100+ remote sites
- Dial-up to packet network
- Average traffic rate: 54 b/s
- VSAT network not economically justified, but
- **Chose VSAT network with private hub**
- Based decision on expected traffic increase and applications flexibility

2.1.6   Specific Industry Application Examples

It is illustrative to examine VSAT applications in a real-world context. Recent examples are highlighted here.

Corporate Systems of Amarillo, Texas is a service firm for the insurance industry. It is implementing a 120-node VSAT network to provide direct data links to a Corporate Systems claims database. The database stores property and casualty claims. The VSAT network will replace analog leased-line circuits.

The $3.5 M contract is the largest for Nova-Net Communications, Inc., of Englewood, Colorado. Corporate Systems' VSAT network will be based at a Nova-Net shared-hub facility in Houston. Nova-Net will manage the network from its Englewood Network Management Center.

Corporate Systems projects that the network will save it up to 50% on annual communications expenses compared with the analog lines while also providing reduced response times and increased throughput.

K-Mart is one of the U. S.'s largest discount department stores. After studying K Mart's data communications requirements, a financial analysis model compared satellite technology against X.25 packet switching, which K-Mart initially had favored for its wide area network.

It was discovered that over a 10-year period, satellite communications would save K Mart from $80 M to $100 M over an X.25 packet switching network. K Mart selected GTE Spacenet Corp., Fairfax, VA., to build a satellite wide area network that today links 2,200 stores and five regional offices to its Michigan headquarters.

The Ku-band VSAT network is the backbone of the $29.5 B corporation. Data processing operations center on IBM token-ring local area networks that sit at most of the K Mart stores. By 1992, LANs will be installed in every K Mart store.

Most of the LANs are equipped with two IBM Personal Computers (ATs), one Unisys Corp. U6000/31 and one U6000/61. K Mart stores with pharmacies – about half – also have an IBM Personal System/2 model 80 on the LAN.

The ATs run a point-of-sale system. The U6000/31 handles receipt of merchandise and applications such as shelf marking and sign design for the stores. The U6000/61 serves as a host, housing general-purpose applications.

If hot new merchandise – say, Teenage Mutant Ninja Turtles T-shirts – are due in the stores, the K Mart computer network would handle the rush from stock order to sell out. Headquarters would assign a certain number of T-shirts to a store, sending the data to the store via satellite. The store would download the data with its U6000/31 system, check the T-shirts in with the system when they arrived, and send an acknowledgment to the headquarters mainframe over the satellite link.

K Mart also has a series of 56 kb/s circuits between corporate locations, which let stores run credit checks on customers, for example. These lines eventually may be upgraded to 1.544 Mb/s Tls.

K Mart is exploring two-way video communications and ways to broadcast music and advertising in K Mart sites. The music and ads would be broadcast via satellite as well.

Trinity Industries is installing a $1.1 M VSAT network that will be used to transmit and receive point-to-multipoint data applications from its central data processing sites to 35 locations throughout the country. Dallas-based Trinity, which makes a variety of metal products, will use very small aperture terminals to replace terrestrial circuits. Trinity also will be the "anchor" client for a Racal-Milgo Sky-Networks shared-hub facility in Dallas.

American Airlines is installing a VSAT network to supplement, and in some places expand, communications over its SABRE computer reservation network. This is the first VSAT applications we are aware of serving the commercial airline industry. Hughes Network Systems, Inc., Germantown, MD, will operate and maintain the very small aperture terminal network.

SABRE, which is operated by American Airlines' SABRE Travel Information Network division, already has extensive backbone and packet switching facilities. The VSAT network will augment the existing network by providing inexpensive connections to some areas. These areas include those that are geographically and economically advantageous to get to by VSAT as opposed to terrestrial means. Also, VSAT looks like a much more reliable means of connectivity in small towns and on the perimeter of metropolitan areas.

The VSAT network also will serve as a backup network between the data center and American Airlines computers located at many airports around the country.

Hughes Network Systems anticipates installing a couple of thousand VSATs at airports and travel agencies. Each site will send and receive data via Ku-band satellite transmissions, also provided by Hughes. The network will operate from a shared hub facility in Los Angeles that is owned by Hughes Communications, Inc.

Hughes will provide its personal Earth Station VSAT terminals under the agreement with American Airlines who said that Hughes' ability to demonstrate "throughput and low bit-error rates" with its product was a deciding factor in awarding the deal to Hughes.

Frito-Lay is the U. S.'s largest manufacturer and marketer of salty snacks in the U. S. In a typical week, 10,000 sales people will visit 400,000 retail accounts. Over the course of a year, they will sell 4.6 billion bags of Fritos, Doritos, and other snacks. Ultimately, their efforts will bring in revenues of $5.4 B annually. The company's successful customer service and organizational strategies are built around this sales force.

Frito-Lay's data communications network is the foundation to this strategy. And the foundation to that network is Scientific-Atlanta's SkylinX.25, Frito-Lay's new VSAT network implemented in 1990. The Frito-Lay network links more than 300 remote locations throughout the United States, including manufacturing plants and distribution centers.

In late 1988, Frito-Lay began to search for a method to both simplify network operation and lower network costs. At that time, the company's existing network was based on leased telephone lines. It consisted of 70 SNAS/SDLC multidrop 9.6 kb/s analog and digital circuits, originating from the Frito-Lay data center in Dallas. Frito-Lay requirements included best price/performance, most flexibility, total end-to-end accountability, robust disaster recovery, and simplified network control. A one-year study was launched, focusing broadly on all telecommunications technologies. The conclusion: VSAT technology was the best choice.

Frito-Lay chose VSAT over AT&T's terrestrial services because of superior multi-protocol interconnectivity, the ability to configure the network without regard to geographic location, and the exciting possibilities for private business television and high-speed data broadcast. The flexibility and lower cost will enable the addition of substantial new applications on the network.

The new Frito-Lay SkylinX.25 VSAT network will include a 7-m master earth station (network hub) in Dallas, 300 1.8-m VSAT terminals, turnkey network installation, satellite transponder services, and facilities management for five years.

General Motors has recently announced plans for the world's largest private satellite network. The network will include 9,700 very small aperture terminals. It will link GM locations nationwide.

Installation of the network will begin immediately, according to Hughes Network Systems, a subsidiary of GM that will provide elements of the network. Hughes announced the plans for the network as to the 1990 International Communications Association conference. The network should be completed by the end of 1992.

Called Pulsat, the network will be used to distribute data and one-way video between GM's Detroit headquarters and its car and truck dealerships. The network will also serve GM's new Saturn Corp. and its dealers.

GM said it plans to shift data traffic from its leased-line network to the VSAT network over the next decade. GM is switching to VSAT because its current network cannot handle the data requirements GM expects for planned applications such as on-line shop manuals, electronic invoicing and pricing, and vehicle diagnostics. The VSAT network will multiply network capacity available to dealers currently using dial-up lines. Moreover, once the VSAT net has been implemented and dial-up lines have been scrapped, GM will be insulated from escalating dial-up costs.

Slow response time, as well as cost, have become

increasingly significant issues as GM saturates dial-up lines with data traffic, which is expected to increase 20% annually over the next five years.

VSATs will also provide the bandwidth necessary to accommodate this existing traffic as well as evolving high-bandwidth applications such as on-line access to repair manuals. The network will allow dealers to transmit and receive a variety of messages and request from on-site VSATs, including credit and financing inquiries, computer-aided auto maintenance, as well as on-line parts and service information. VSATs will allow dealers to conduct real-time inquiries about vehicle availability and options. Because of backups associated with batch transmissions and delays through terrestrial systems; this was not always possible the same day.

Toyota Motor Corporation is planning to add 20 very small aperture terminal links to the existing 100 connections supporting its Lexus dealerships as part of an effort to lower operating costs and increase network reliability and flexibility. The company wants to eventually establish VSAT links with an additional 1,000 Toyota dealerships.

The automaker's office in Torrance, California serves as a concentration point linking all North American dealerships and regional offices to Japan. The network dubbed Toyonet, is used to support Systems Network Architecture traffic, fax transmissions and international voice links between Japan and the U. S.

The VSAT net will enable domestic dealerships to tap into an IBM 3090 Model 400 IMS-based mainframe at the hub here. The host runs parts inventory, vehicle distribution, and financial and service history applications. Any domestic site can use the hub to access this information or to reach Tokyo.

The California site is linked to Tokyo via a 384 kb/s transpacific fiber-optic link. The fiber is backed up by a 256 kb/s satellite link. International voice, fax and data transmissions are routed to the Torrance office and then out over a T-1 line to AT&T's international gateway in the San Francisco Bay area. This network is an interesting tie-in of a domestic VSAT network with international headquarters via international leased lines.

2.1.7   Trends Based on Examples

One can glean several important developments about the trend of VSAT applications from these "real-world" examples.

1. Several years ago, it was believed that VSAT networks had to have several hundred nodes to prove cost-effective. These examples range from 35 node networks to 10,000 node networks exhibiting VSAT feasibility over a very, wide range.

2. A wide variety of bandwidths needs exist ranging from low-volume data distribution to supporting multiple applications in a real-time environment. Both fixed bandwidth and bent-mode operation may be required concurrently. [Note (5) below.]

3. VSAT networks often offer performance improvements as well as cost savings. These performance improvements are likely undervalued by the industry and possibly offer the potential for higher cost VSAT applications that yield solid performance benefits. This could prove important in justifying future MESH satellite concepts.

4. Future cost-containment seems as important as cost-savings. This may place a limit on higher cost VSAT solutions mentioned in (3) above.

5. VSAT networks are beginning to be used to interconnect remote Local Area Networks (LANs) into Wide Area Networks (WANs). LAN-WAN interconnectivity requirements will increase in number and bandwidth. Satellites must support ever increasing burst bandwidth demands for higher end applications.

6. VSAT networks are becoming an integral part of marketing distribution and support operations of the increasingly automated corporation.

7. Advanced features such as multi-protocol interconnectivity; integrated applications/services; business TV; and network configurability and reconfigurability will grow in importance. To maintain future satellite competitiveness, it would be useful to brainstorm how advanced space segment features (such as on-board processing) can be used to improve the cost-performance of advanced network features. (Having the intelligence in one place, the satellite, may prove more cost effective than having to install 1,000 smarter VSAT terminals.)

8. It is conceivable that what we are just beginning to see in linking domestic VSAT networks vis inter-

national private line with foreign operations could be the progenitor of future global MESH satellite networks interconnected with intersatellite links (ISLs) permitting direct remote VSAT in one country to another VSAT in another country. However, this is not a trend, yet, but just a prospect.

And, it will likely be determined more by management trend than technology trend. In other words, the ability to go remote to remote may be overshadowed by management centralization styles that require Remote-to-host, Host-to-Foreign Host, and then Foreign Host-to-Remote. We sense that much of the potential for the mesh satellite network concept will depend on the evolution of centrist or delegated management styles in the 21st century of multi-national enterprise. This will also apply to strictly domestic VSAT networks.

9. Future VSAT networks will have to be compatible with ISDN standards and services.

10. Today, VSAT networks compete with leased line and packet switched services. In the future, additional competition will surface in the form of terrestrial high-speed switched data services and virtual private networks (VPNs). These developments are discussed later in this report. It will be necessary to evaluate how future VSAT solutions will compete with an expanded and augmented array of terrestrial service offerings.

2.1.8   Cost and Other Issues

Table 2-5 indicates the cost sensitivity (per site) of telecommunications alternatives. Some users report U. S. leased line costs increasing at 8% per year. It's not known whether fiber plus public intelligent network provisioning will lower or allow cost containment. Internationally, leased circuit costs and prices have been decreasing and this should continue through the 1990s.

Table 2-6 lists some motivations for use of packet switching. Terrestrial-based packet switched networks are competitive with satellite-band VSAT networks.

Figure 2-6 illustrates where VSAT services fit into the continuum of terrestrial traffic. Number of remotes is plotted against the peak hour data rate (b/s).

Table 2-7 indicates how the different elements of the VSAT system are costed: either by outright purchase, lease or monthly payments. Table 2-8 gives an example cost for a VSAT network.

2.2   Future Needs

In the absence of technological development, demand will move ahead at a steady rate as the user community becomes aware of VSAT potential and the vendor sales forces reach new users.

The future needs for VSAT technology per se will depend on the evolution of todays technology and linkages to both other technologies such as cellular telephony and the emergence of new technologies, such as land mobile satellite.

Technological innovation can drive VSAT usage by making satellite service more economical, by extending the scope of service, and by introducing new services.

Basic improvements.   There are several areas where the basic satellite services can be improved to increase its marketability. These include:

- More effective power management in the satellite. The satellite cost per user channel is driven by the onboard power used. More efficient satellite transponder designs which improve effective isotropic radiated power (EIRP) would drive down user costs.

- Improved reliability. Many users avoid satellite and insist on cable because of perceived reliability problems. Of particular concern is the impact of burst error on response times.

- Improved coverage. Many firms would use satellite if they could reach all their locations using a single hub antenna. Development of onboard switching and satellite to satellite relays would allow global coverage from a single master earth station.

Global Wide Area Networking.   The Local Area Network is becoming truly wide spread and will be ubiquitous by the end of the century (...which isn't far off!). The need to link multitudes of diverse LANs into national, supernational and global LANs is already here.

- Full bandwidth wide area links, either actual or virtual, are needed. Full bandwidth refers to LAN backbone speeds 4 Mb/s, 10 Mb/s, 16 Mb/s and soon 100 Mb/s.

Table 2–5: Cost Sensitivity (per site) of Telecommunication Alternatives

	Leased Line	Packet Network	VSAT
Increased number of sites	Increase	No change	Decrease
Increased data traffic per site	No change	Increase	Decrease
Increased distance of sites	Increase	No change	No change

Table 2–6: Motivations for Use of Packet Switching

Historical Motivations	Private Networks	Public Networks
Cost Reduction	X	X
Access Central Host	X	X
Improved Network Management	X	
Widespread Access Points		X
Security	X	
Special Delay or Performance Requirements	X	
Switching Capabilities vs. Private Line	X	X
Improved Reliability	X	X

Emerging Motivations		
Integrate Heterogeneous Networking Technologies	X	X
Integrate Satellite and Terrestrial Networking	X	X
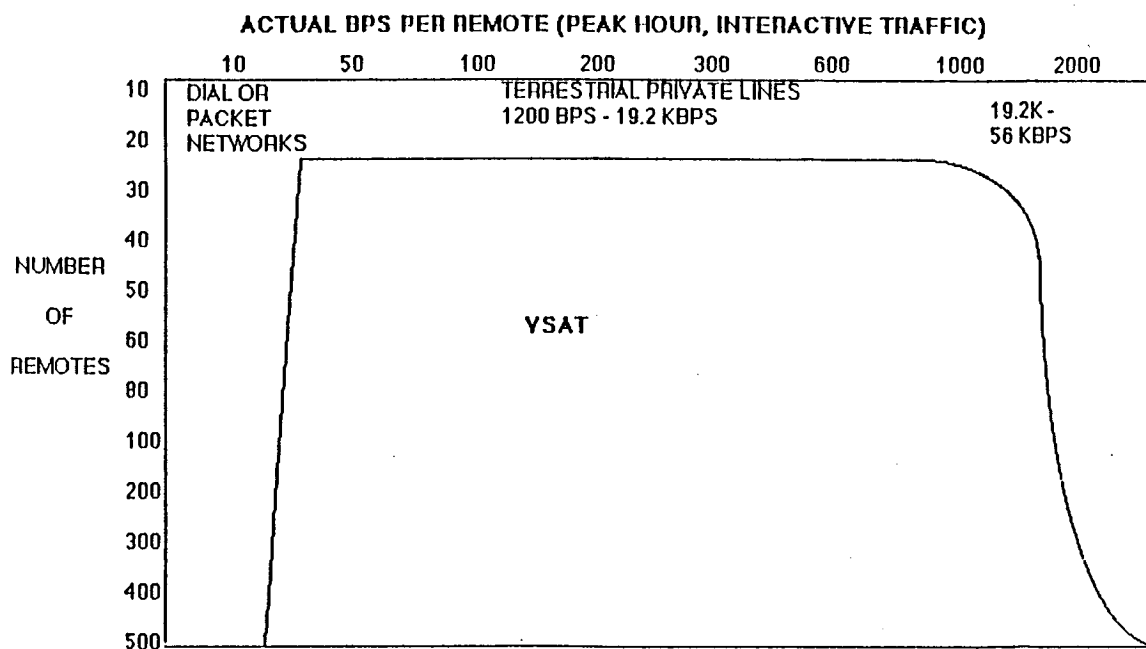
Figure 2–6: Where Do VSAT Services Fit?

Table 2–7: Elements of VSAT Cost

VSAT Hardware	Purchase or Lease
VSAT Installation	Purchase
Hub Access and Management	Monthly
Satellite Transponder	Monthly
VSAT Maintenance	Monthly
Backhaul Link (if necessary)	Monthly

Table 2–8: Example Costs for VSAT Network

Equipment Purchase Price:	
Remote — Two-way interactive terminal	$11 K
— One-way	$4 K to $5 K
— Data Broadcast	$600
Hub	$0.5 M to $1.5 M
Installation & Permits	$2 K to $6 K per site
Monthly uplinking/transponder/maintenance	$300 per site
Monthly uplinking/transponder/costs (9.6 kb/s)	$4.5 K to $6 K
Total monthly rate for C-band (1.2 kb/s data terminal)	$290 per site
56 kb/s SCPC link between 2 sites, including equipment, transponder, O&M (GTE Spacenet)	$1,950 per month plus installation

- Data base synchronization. Distributed LANs lead to distributed databases, or more precisely multiple copies of a common data base. Satellite capability to distribute multiple copies of large (multi-megabyte and gigabyte sized) data bases would fill an immediate and growing need.

- Expansion of paging and cellular telephony. There is a potential high value niche market for paging and cellular telephony unrestrained by geographic limits.

- National automatic teller and debit card access systems, using VSAT links to central data bases.

Smaller antennas, "through the window" and mobile antennas.

- Landlord, construction and zoning problems continue to impede the deployment of satellite antennas which can operate through the window, as do many microwave radio systems are needed.

- Full interactive mobile antennas are needed for paging, cellular telephony and locator services.

Global access communication. The use of fully portable, suitcase, satellite communications systems including voice, data, facsimile and video will become common.

- Initial usage has already become for voice. Prime users are currently news and media representatives.

- Future use will include; business, entertainment, legal and financial professionals.

Future Network Configurations. We envision future (2000 and beyond) VSAT user networks will evolve in three forms:

1. Conventional Star networks with remote to host or hub (Star point-to-point) will still be around by probably accounting for 20% less of the total VSAT networks;

2. Mesh networks offering switched interconnectivity among remotes will become popular for economic as well as operational reliability reasons (triangulation, backup, etc.) and will account for 40% or more of the total VSAT networks.
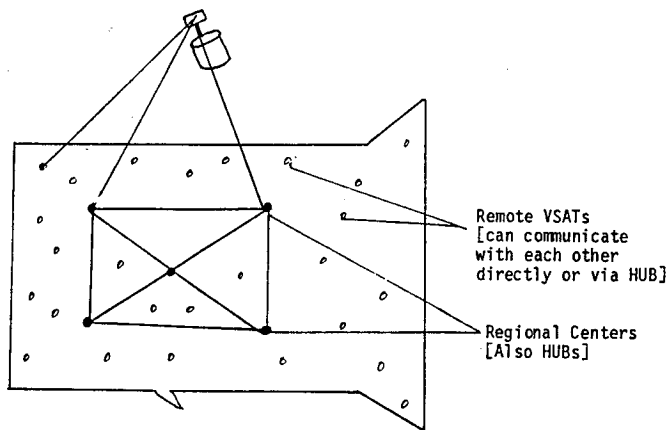
Figure 2–7: Hybrid VSAT Network

3. **Hybrid Networks.** Hybrid will refer to both Star and Mesh network configurations and also to combinations of satellite and terrestrial facilities and services. This possibility recognizes that a user may have supercenters or regional centers for global and regional processing that are interconnected by high speed switched trunks (T-3 backbone network). Each of these centers can also serve as a hub satellite station.

The advantages will be:

- Redundant media (terrestrial fiber and satellite)

- Augmented backup, disaster recovery, reliability and security

- Greater flexibility

- Cost optimization

- Mesh connectivity reduces vulnerability to net crashes, failures, sabotage which will be perceived as greater and greater threats in the future.

- Supports virtual high speed services to lower capacity VSAT nodes from any center

Figure 2-7 show a sketch of the hybrid network. Remote VSATs can communicate with each other directly or via a Hub. Such hybrid networks could represent 30% to 40% of the total networks in the early 2000's.

2.2.1 Future Novel VSAT Market Applications

We have identified three major new market applications that we believe are quite suitable to new "smart" (OBP) mesh satellite networks. These are:

1. Inter-Enterprise Interconnectivity

2. Image Networking and Distribution

3. LAN-WAN interconnectivity

All of these will have increased data distribution requirements over existing systems and can benefit from the versatility and intelligence of mesh satellites.

We highlight these three here but we call to you attention that other, more traditional, applications are discussed in Appendix A.

2.2.1.1 Inter-Enterprise Interconnectivity

Future MESH VSAT market applications should stress inter-enterprise interconnectivity, that is, different forms or entities whose inter-communication needs will escalate in the future. Electronic Data Interchange (EDI), for example, allows for direct, paperless entry from one corporation to another.

It is our understanding that a couple of auto manufactures (we believe Chrysler and GM) have been experimenting with VSAT data distribution from one company to the other. This will become big business in the future and is a natural application and exploitation of MESH satellite configurations with on-board processing to facilitate inter-enterprise interconnectivity. It also appears to us to very competitive with terrestrial solutions that will be available. MESH satellite interconnectivity will also offer more versatility and flexibility.

For example, a complete EDI order involving 50 subcontractors is sent to a company's host or regional computer center. Concurrently, EDI could segment and broadcast the 50 different orders directly to the 50 subs. This would save on communication link costs. Thus, VSAT solutions should be more flexible and cost-effective.

2.2.1.2 Image Networking and Distribution

Another future application of high interest to future satellites will be image networking and distribution. As the costs of optical scanners decrease during the 1990s

and bandwidth compression or conservation techniques improve, image networking will increase greatly.

The ability to scan, store on-line and make readily accessible to other network nodes/sites such items as X-rays, credit card transactions, cancelled checks, letters, and documents; will revolutionize office automation and information handling activities of organization.

2.2.1.3 LAN-WAN interconnectivity

The connection of local area networks into wide(r) area networks will be a growth application in the 1990s. Ultimately, there will be some merging with the other two applications above. Appendix A amply covers the development of LAN-WAN interconnection and it suffices here to point out that it is a application that should be addressed by future satellite technology. It is not clear to us at this time as to what speeds satellite can support.

It should also be understood that by year 2000, we do not expect many "-only" applications such as data-only, voice-only or image-only. This will be the era of integration, remember. ISDN will be common and B-ISDN emerging. Thus, VSAT terminals will see an application mix and not a single application as it might be used today.

2.2.2 Current and Future Trends in VSATs

Current trends in VSATs include the following:

- Custom LSI to reduce equipment prices

- Fail-safe operation with dial-up phone lines

- Multiple protocol handling

- Network management software

- Circuit switching in satellites

Future trends in VSATs include the following:

- Hopping spot beams on satellites

- Packet switching in satellite

- On-board processing

- Mesh configurations opening up remote-to-remote applications

- Mobile applications

Figure 2-8 illustrates the major environmental technology forces and the time scale over which they are operating. Figure 2-9 illustrates the major environmental international regulatory forces and the time scale over which they are operating.

2.2.3 Future User Requirements

Future user requirements for the year 2000 and beyond are as follows:

- Multiple integrated applications and services requiring internet protocols.

- Higher b/s per peak hour.

- Greater shared use and inter-enterprise interconnectivity.

- Greater image processing and networking.

- Potential for more remote to remote communications for some applications, but depends on technology development and commercial exploitation.

- Compatibility with global standards in open network environment:

  — CCITT and Regional
  — EDI (Electronic Data Interchange)
  — HDTV

- Global connectivity requirements increase.

- Data transmission speeds increase. The minimum speed for future planning beyond year 2000 should be the ISDN basic rate interface of 144 kb/s. It should be noted that 144 kb/s in 2000 is equivalent to today's 56/64 kb/s standard which, in turn, is equivalent to the 9.6 kb/s of the last decade. So, even without growth in applications, time and technology causes an upward trend in what may be considered to be the most basic speed class. Therefore, we believe the minimum VSAT terminal speeds in year 2000 will be 144 kb/s. A large class of VSAT terminals will operate in the range of 144 kb/s to 512 kb/s.

Table 2-9 illustrates how the future role of VSATs depends on terrestrial competitive developments. The terrestrial-based competition for the different VSAT service categories is listed.

1990   2000   2010

FIBER OPTICS DEPLOYMENT

HYBRID SATELLITE-TERRESTRIAL NETWORKS

WIRELESS COMMUNICATION AGE

INTEGRATED MOBILE/FSS SATELLITES
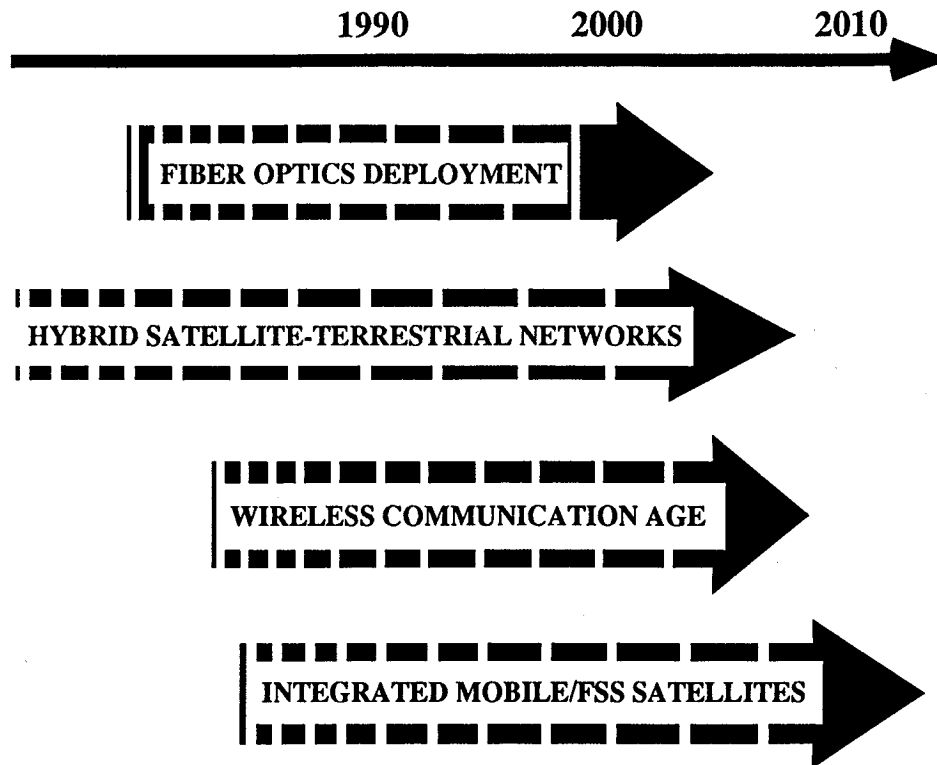
Figure 2–8: Major Environmental Technology Forces

1990   2000   2010

RESTRICTIVE USE
POLICIES REPLACED
WITH PERMISSIVE USE
ENVIRONMENT

[Examples: European Initiatives; CCITT D-1]

INCREASED INTERNATIONAL
COMPETITION DRIVES THIN
ROUTE COSTS UP

GLOBAL LIBERALIZATION AND NATIONAL
PRIVATIZATION HAVE OBJECTIVE TO IMPROVE
NATIONAL TELECOM INFRASTRUCTURE
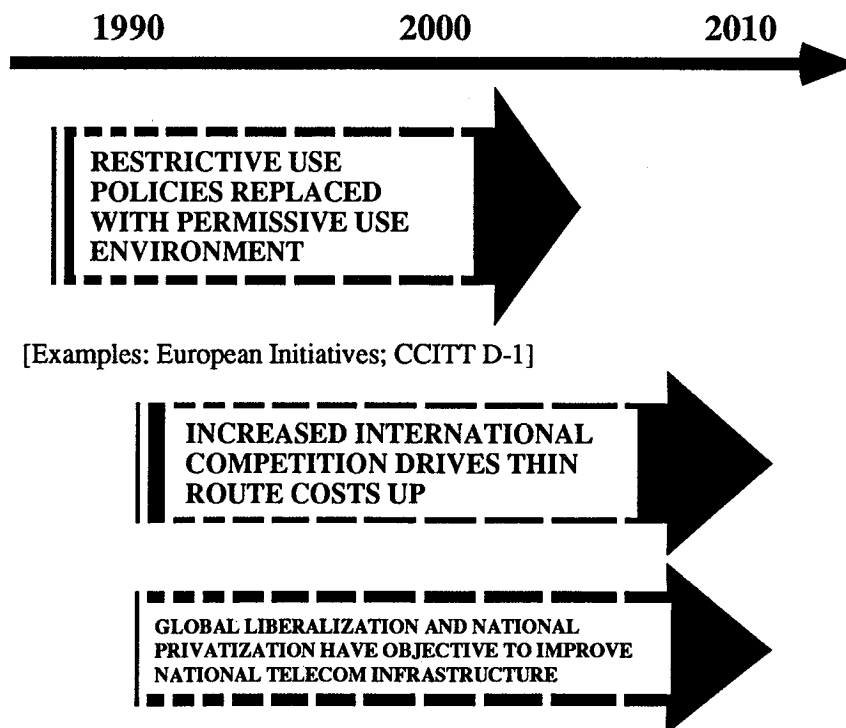
Figure 2–9: Major International Regulatory Forces

Table 2–9: Future Role of VSATs Must Consider Terrestrial Competitive Developments

Service Category	Description	Terrestrial-Based Competition
1. Traditional	Simple point-to-multipoint data distribution.	Multi-drop leased lines. Packet switched networks.
2. Enhanced (So-called third generation VSATs)	Communications plus processing and control enhancements including: – Protocol processing – Protocol compatibility – Network management – Inter-networking Business TV Some integrated applications	Continued deployment and reach of optical cable. Intelligent networks (Bellcore's IN2) ISDN
3. Future (Novel, or new at the present)	Shared use Inter-enterprise networks. Integrated Services (ISDN) Satellite–terrestrial integrated networks. Mobile VSAT Global Interconnectivity	ISDN B-ISDN PCN (Personal communications networks). Mobile and cellular

Figure 2-10 (compare with Figure 2-6), illustrates how terrestrial fiber expansion should push VSAT feasibility downwards (more remotes needed) and towards higher bit rates.

2.3 Competition

The prime market for satellite services are companies with widely disbursed locations requiring data connectivity. Satellite faces competition from terrestrial media, both the emerging high speed, fiber optic based, digital services and from the traditional analog multi-drop services. These developments are discussed in Appendix A.

- The typical customer is cost driven, both in terms of capital and operating expense. Traditional analog multi-drop line are in many cases substantially cheaper than satellite. (Note that internal engineering costs and the cost of lost opportunities due to inflexibility are often ignored.)

- For some customers with high speed data needs in major business cities, high speed digital services are often more economic than satellite. The break even point for satellite needs to be brought down.

A major need is an analysis of future (2000) satellite costs vs cost/tariffs of high speed switched data service.

If ISDN interfaces remain limited (BRI and PRI) and are priced relatively high, then VSATs can offer more flexible in-between speed class offerings (say, 256 kb/s or 384 kb/s) that exploit a rigid (terrestrial) tariff structure. If terrestrial digital services offer a range of diverse speed classes, this will present more formidable competition. Then, it will be necessary for satellite to offer cost savings which is the current marketing strategy.

2.4 Satellite Usage — Traffic Forecast

2.4.1 VSAT Market in the United States

The projection for future VSAT use consists primarily of two distinct and only marginally related types of usage. The first is the number of interactive remote stations. The second is the amount of satellite capacity which will be required.

Terminals. The demand for terminals is growing steadily at a rate of almost 30% per year (source:

ACTUAL BPS PER REMOTE (PEAK HOUR, INTERACTIVE TRAFFIC)
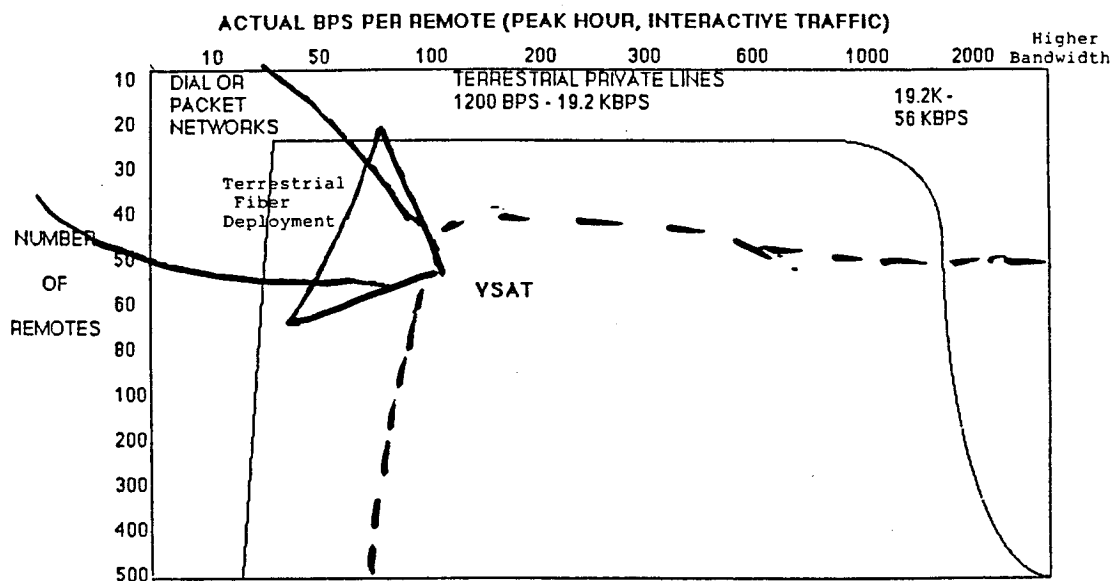
Figure 2–10: Terrestrial Fiber Should Push VSAT Feasibility Downwards and Towards Higher Bit Rates

1991 marketing plan for a major supplier). However, it must be noted that industry numbers have been skewed somewhat by sales of a few very large networks such as GMs 10,000 node network. Our sales forecast (installed terminals) reflects roughly a 30% growth through 1995 and closer to an average rate of 20% for the period 1995 to 2000.

Satellite Bandwidth. Currently there is more than enough domestic Ku band capacity to meet immediate and near-term needs. In 1993, the Telstar IV 3-satellite system will have a large supply of both C-band and Ku-band capacity.

2.4.2   Demand Projection

In trying to equate demand for terminals with demand for bandwidth, the type and nature of traffic must be considered. Unfortunately, each VSAT network is unique and there are no valid "rules of thumb". However, some rough quantitative bounding factors can be extrapolated.

- Assume that a next generation satellite (Telstar 1993) will support 18 Ku-band transponders.

- Assume that each transponder can support 10 independent clusters of VSAT terminals. (Note: a network can consist of one or more clusters). A clus-

ter consists of a shared high capacity outroute from a master hub to terminals, and a number of contention inroutes from terminals back to the master hub.

- An independent cluster can support from 400 to 800 interactive data terminals, depending on the nature of the traffic and response times required.

- Taking an arbitrary number of 600 terminals, we can then estimate that:

   — Each new network requires at least one cluster and every ten new networks require at least one new transponder.

   — Every 600 terminals require a new cluster and every 6,000 terminals require a new transponder.

   — Assume that 20% of all networks are large enough to need more than one cluster due to terminal count and/or traffic volume. Then we can estimate one new Ku-band transponder satellite for every 8 new networks or every 5,000 terminals.

- In summary, bandwidth and transponder demand are not expected to be substantial in the near term. Growth will be primarily in remote station hardware unless technological innovation makes satel-

lite more attractive or the cost trade off between terrestrial and satellite shifts.

Using this relationship, a current 60,000 terminal installed base could be supported with 12 transponders. However, these would be 100% loaded which is unusual. Assuming a 50% loading factor, current demand would have 24 transponders allocated by the industry to the VSAT market. In an potential 400,000 terminal market in the year 2000, eighty (80) transponders are implied according to the above formula. At 50% loading, 160 transponders would be made available by North American domsat suppliers but this loading factor may be reduced by then depending on industry capacity and other demand (such as for TV distribution).

After the year 2000, it is arbitrary and only speculation at this time to forecast VSAT terminal installations. This will depend on mesh satellite costs versus high speed switched terrestrial service. No future cost estimates are currently available to this forecaster. If one could assume that the future satellite solution will maintain its cost saving advantages, then the satellite market share of the gross market potential could be 3% to 4% of the total market revenues for transmission services.

Table 2-10 summarizes the North American Market outlook in terms of number of potential terminal sites or nodes. Sites or nodes may not necessarily be served by satellite. Especially after year 2000, the nodes may be interconnected by switched terrestrial services. The Gross Market Potential provides a measure of the total market potential which is always larger than industry sales or a particular market share by a sub-industry (such as the satellite portion of the total).

Table 2-10 leaves blank the installed VSAT terminals for the years beyond 2000. The number of these future VSAT terminals will depend on future economics (unknown at this time) of mesh VSAT networks using advanced on-board processing techniques vis-a-vis high speed switched terrestrial services which will be commonplace after year 2000.

Table 2-11 shows the changing nature of the VSAT market by functional service class and by percent of demand.

2.4.3 Potential System Requirements

Potential system requirements for a satellite system in the year 2010 are detailed in terms of service and application requirements, configurations, ground segment characteristics, system features, and traffic projection.

Service and Application Requirements:

- High speed data broadcasting and access (database downloading to many distributed sites).

- Image networking distribution; e.g. optically scanned images of credit card receipts and medical imaging.

- LAN-WAN connectivity at burst mode speeds from 4 Mb/s to 16 Mb/s (possibly higher by 2005).

- ISDN and Broadband-ISDN compatible; ISDN basic (2 B+D) and primary (23 B+D) access, and B-ISDN.

- Remote to remote connectivity via single-hop.

- Inter-network connectivity; OBP provided compatibility ?

- Inter-enterprise networking (different frequency bands); shared-use terminals.

- Video conferencing (time, varying, multi-point).

- High quality video broadcasting (HDTV compatible).

- Interconnection of cellular/mobile systems.

- Interconnection of transportable VSAT terminals with fixed remotes or shared hubs.

- Compatibility with (or competitive) Terrestrial networks of 2000s:

  SMDS is a fiber derived, high speed switched data service with thruput over 1.544 Mb/s and a 45 Mb/s interfaces. Access classes ARE 4, 10, 16, 25, 34 and 45 Mb/s. Access protocol is IEEE 802.6, the Distributed Queue Dual Bus (DQDB), which is the Metropolitan Area Network (MAN) Standard.

  SONET Synchronous optical network.

  Other Sonet-based digital cross-connect systems.

Table 2–10: North American VSAT Market Outlook

	No. of Potential Terminal Sites (1,000)					
	1990	1995	2000	2005	2010	2015
Gross Market Potential	160	400	600	1,200	2,000	4,000
Cumulative VSAT Terminals Installed (sales)	60	220	400	?	?	?

Table 2–11: Changing Nature of VSAT Market

Functional Service Class	Percent of Demand						
	1985	1990	1995	2000	2005	2010	2015
Traditional	100	70	30	20	10	0	0
Enhanced	0	30	60	50	30	20	10
Future	0	0	10	30	60	80	90

Configurations:

- Ku-band; compatible to existing STAR with hubs on ground,

- Ku and Ka-band; Mesh without any hubs. Use VSAT terminals.

- Equipped with terrestrial backup.

- Mobile terminal to VSAT may be desirable.

Ground Segment Characteristics:

Frequency Band	Antenna Size
Ku (VSAT)	1.2–1.8 m
Ku (Hub)	6–9 m
Ka (VSAT)	0.3–1.2 m
Ka (Hub)	4–9 m
Mobile (?)	?

System Features:

- Operate in Ku and Ka band as well as a mobile band (such as L).

- OBP frequency conversion.

- Antenna size: 0.8 m for Ku and 0.5 m for Ka-band terminals.

- Each terminal nominally operates at 1.544 Mb/s and is designed for backward compatibility; hub

stations operate at higher speeds. Possible that terminal operate at 4 Mb/s.

- New system is compatible with existing Ku-band VSAT network equipped with a ground hub on a dedicated or shared basis.

- Spacecraft will make use of dual-band multibeam antennas and OBP.

- Compatible with ISDN, (up to 23 B+D) and Broadband-ISDN (D-ISDN).

- Availability = 99.9% when possible.

- Self diagnostics with terrestrial backup.

- Transparent internetworking.

Traffic Projection for the Year 2005:

Number of Networks = 1,200
Number of terminals = 500,000 units with the following breakdown:

Frequency	Terminals	Networks
C	50,000 or 10%	120
Ku	250,000 or 50%	600
Ka	200,000 or 40%	480

The distributions by terminal speeds and applications for advanced VSAT satellite systems in the year 2005 are given below.

Basic   conditions   are   as   follows:

Minimum user terminal speed: 144 kb/s

Maximum user terminal speed: 4 Mb/s

Minimum shared hub speed: 16 Mb/s

Maximum shared hub speed: 45 Mb/s

Highest density of user terminals: 38 kb/s to 2 Mb/s

Integrated applications will be common using range of muxes. There will be no voice only or video only applications

User Terminal distribution by speed class is as follow:

144 kb/s — 384 kb/s	30%
384 kb/s — 768 kb/s	30%
768 kb/s — 2.0 Mb/s	30%
2.0 Mb/s — 4.0 Mb/s	10%

For the year 2005 where there will be an estimated 500,000 terminals, multipication of terminal speed by number of terminals and summation over the different speed classes yields a total data rate of 300 to 670 Gb/s for the satellite addressable traffic.

This number appears excessively high, but in reality only a few percent of the 500,000 terminals will be using the system at the same time. Also terminals will not always access the system at the maximum possible data rate.

Distribution by application is as follows:

Data only – low Speed (144–256 kb/s)	20%
Med. speed data + voice + V/C (256–768 kb/s) (Data and image distribution)	40%
Med. speed data + voice + V/C (0.76–2 Mb/s)	20%
High speed LAN-WAN connectivity	10%
High speed LAN-WAN + voice + V/C	10%

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Chapter 3

System Architecture

This chapter identifies and describes viable satellite system architectures which can support mesh connectivity for VSAT networks in a cost effective manner. The chapter is organized as follows:

Section 3.1 describes existing architectures for VSAT networks. Section 3.2 addresses the impact of new communication services on VSAT development and describes the user-to-VSAT network interfaces. Section 3.3 briefly summarizes future requirements for VSAT networks in terms of services and transmission rates.

Section 3.4 presents four system architecture concepts that provide full point-to-point and point-to-multipoint mesh connectivity for VSAT networks. All four architectures employ spot beam regional coverage at Ku-band and Ka-band but differ in their complexity and benefit to users. Section 3.5 addresses transition considerations from Ku-band networks to Ka-band networks and the interoperability between the two.

Most very small aperture terminal (VSAT) networks in service today have a star topology for communication between a central site (Hub) and a number of geographically scattered sites (Remotes). In such a configuration, the Hub employs a large antenna and typically controls the network. The Remotes employ low cost VSAT type antennas which are installed at the user premises. The prevalence of the star network configurations arises from two major considerations.

i. The communications requirements of the VSAT users. Most of these networks serve corporate entities whose major communications requirements is to link their branch offices with corporate headquarters, with no requirement for communication among the branches themselves.

ii. There is a limitation on VSAT-to-VSAT communication imposed by current satellite systems, specifically in the area of the communication link parameters. This limitation makes mesh connectivity through existing satellites more costly due to the increased antenna size and/or reduced satellite utilization efficiency. Hence, for mesh VSAT networks to become more economically attractive an improvement in the link parameters compared to existing systems will be required.

These factors along with the evolution in communications services, the need for higher bit rates, and the emergence of new services that require mesh connectivity, could make mesh VSAT networks more attractive from both the user requirement standpoint and the economic standpoint.

The improvement in link parameters to allow VSAT to VSAT connectivity can be achieved by increased satellite power and gain through spot beam coverage, and/or on-board regeneration and on-board forward error correction. With spot beam coverage there is usually a requirement for switching at either IF or baseband to interconnect the coverage regions. This chapter describes such architectures.

3.1 Existing VSAT Network Architectures

The discussion of this section is divided into six parts:

3.1.1 Network Topology

3.1.2 Network Types

This section first explores the features that have made VSAT networks popular today, including discussions of techniques in common use for both voice and data applications. Next, details for equipment in common use and services that are supported will be summarized and comparisons of similarities and differences will be provided. This section will also describe how this equipment might evolve for use in a mesh VSAT satellite network.

VSAT networks can be classed by network topology, modulation, multiple access techniques, error control, services provided, and protocols supported. Most VSAT networks use a star topology with a hub location controlling the network, and use random access RA-TDMA/TDM equipment. All transmissions are to the hub: remote-to-remote communications require a double hop through the hub. SCPC links are widely used for point-to-point communications and can be either dedicated or circuit switched (DAMA). SCPC equipment is used in star, mesh or partial mesh networks. Spread spectrum systems (CDMA) are used in low bit rate systems and provide multiple access to a wide bandwidth carrier by assigning a different code word to each terminal. They have found application for star networks and for data broadcast.

Existing VSAT systems can be generally placed in three groups.

i. Several systems used by large networks use a star configuration with multiple access to inbound carriers and a time division multiplex (TDM) outbound carriers. Random access to the inbound carriers typically uses a combination of slotted Aloha and time division multiple access (RA/TDMA).

ii. A second category are point to point links using single channel per carrier (SCPC). These can be either dedicated full time channels, scheduled usage, or demand assigned multiple access (DAMA).

iii. The third category are spread spectrum systems. These have been successfully used for broadcast data applications, and for data collection.

3.1.1 Network Topology

Three types of network topologies commonly encountered in satellite communications are a star, mesh, and partial mesh networks, as shown in Figure 3-1.

3.1.1.1 Star Networks

The star network configuration requires all users to communicate with the central site designated as the hub and thus has double-hop transmission between users via the hub. Typical applications, where a star topology can cost-effectively be used, are data distribution from a central location to a large number of remote sites, data collection, and data transmission between remote sites and a central data processing center. The star network allows the use of small aperture antennas in the range of 0.7 m to 2.4 m diameter at the user sites and a larger antenna, such as INTELSAT Standard A, B, or E-3, at the hub location.

For a large network, in the order of a few hundred user sites, the total equipment cost will be dominated by the remote user earth terminals. Thus, the star network is cost-effective for a large network with connectivity between remote users and a central location and is used in most VSAT applications.

If most of the traffic flow is between remote sites and a central location with some minor traffic between remote sites, a star network will be the primary candidate. Communications between remote sites will be provided by double-hop transmission through the hub location. Double-hop transmission possesses some unfavorable characteristics such as a longer transmission delay and a larger space segment capacity. The increase in transmission delay translates into an additional delay of about 600 ms for transactional data, voice call setups, and voice communications. This additional delay is relatively small for data compared with the processing times. Most users will accept double hop voice communications if there are no convenient or cost-effective alternative, nevertheless, most users do not prefer double-hop transmission.

The additional bandwidth requirement for double-hop transmission generally has an insignificant impact on the overall service cost for transactional data. However, leased line data and voice traffic require a large amount of bandwidth and its cost impact can be significant. SCPC/DAMA systems may prove to be cost effective with high line rates, or large amounts of voice traffic.

Star   Mesh   Partial Mesh
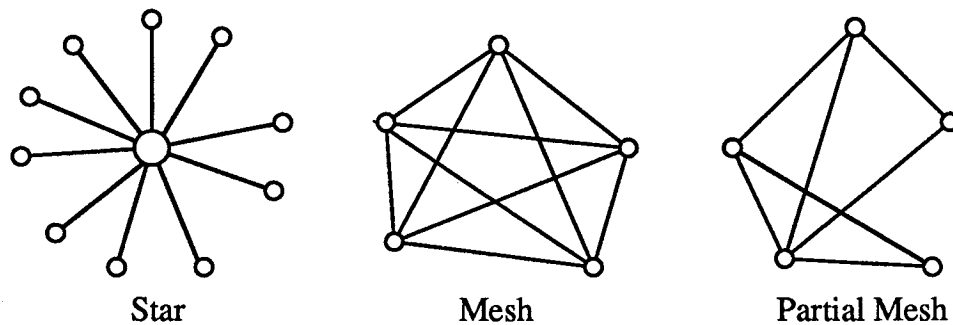
Figure 3–1: Three Types of Network Topologies Used for Satellite Communications

In the star network, the transmission direction from the hub to remote VSATs is often called "outbound" and a remote location to the hub is "inbound". The outbound transmission can be a time-division-multiplexed (TDM) carrier, i. e., one digital bit stream containing data to multiple destinations, or it can be composed of multiple carriers, each destined to a single remote station. The inbound transmission can also be time-shared by a number of VSATs on a time division multiple access (TDMA) basis or can consist of multiple carriers from different remote stations. The selection of a particular multiplexing and transmission scheme among alternatives depends on the user network requirements.

In a typical star VSAT network, inbound transmission is bandwidth limited, and outbound transmission is power limited. This implies that the transmission efficiency of the inbound carrier is not as critical as that of the outbound carrier. This fact should be taken into consideration in the architecture selection process.

3.1.1.2 Mesh Networks

Mesh networks allow users to directly communicate with other users in one-hop transmission. Typical applications include thin-route voice services to widely dispersed rural areas, where reliable, low-cost terrestrial alternatives are not available. Simultaneous interconnection among all the users requires a minimum of n(n-1)/2 full-duplex circuits, where n is the number of users. For efficient space segment utilization, demand assignment multiple access (DAMA) is often used in the mesh network.

The same earth station size is used by all the users and is larger than that in the star network, e. g. Standard F-1 (4.5 m for C-band) and Standard E-1 (3.5 m for Ku-band). This size of the earth station is not generally regarded as a VSAT class earth station. The mesh

network requires neither double-hop transmission nor a hub earth station, and hence the overall network cost is lower for a small network. For a large network, user station cost becomes dominant and may not be cost effective for many applications.

Transmission can be TDMA or single-channel-per-carrier (SCPC), where SCPC uses a pair of fixed-size carriers (e. g. 64 kb/s or companded FM) for each full-duplex circuit. Network control may be distributed as in the SPADE system or centralized as in the TDMA system and most DAMA SCPC systems currently available. The selection of TDMA or SCPC depends on the user traffic requirements, such as the number of circuits per user, network size, and traffic volume.

3.1.1.3 Partial Mesh Networks

Partial mesh networks may be regarded as mesh networks with direct connection between some user sites. Examples include a business network with communications links between remote sites and multiple data processing centers and a multi-regional network consisting of regional mesh networks with interregional communications links via gateways, e. g. the INTELSAT system. A partial mesh network can be implemented using a transmission architecture for a mesh network. In some applications, it is desirable to divide the network into star and mesh networks to optimize the overall network architecture.

3.1.2 Network Types

VSAT network architectures can also be classified in three types:

    i. Private networks

    ii. Shared networks

iii. Open networks

In a private network, space segment capacity is leased from a domestic company and is used only for the customer's traffic. Within the allocated space segment and signal radiation constraints set by the satellite provider, the customer has full control of its sites, network resource allocation, monitor/control, and network management. The customer has the flexibility of selecting the most cost-effective network configuration, access/transmission schemes, and equipment. Most domestic VSAT networks are private.

In the shared network, network resources such as the space segment, hub equipment, network operation and maintenance are shared by a number of customers, thus reducing the per-customer cost of common resources. Space segment utilization, operation/maintenance of VSAT, hub, and network control center (NCC) equipment, and billing are managed by a service provider. Individual customer subnetworks operate independently; however, interconnection among different customers is also possible.

An open network is one where users comply with established standards for network services. Examples within the INTELSAT system include IBS channels, IDR services, INTELNET I and II, VISTA and the 120 Mb/s TDMA network. Only the INTELNET services today are VSAT systems. IBS services (64 kb/s channels) may use VSAT terminals when future satellites with higher power are placed into service.

3.1.3　Access Techniques

Most VSAT network architectures currently in use are categorized by access technique into three types:

1. Random access (RA-TDMA), including Aloha, slotted Aloha (S-Aloha), and TDMA access schemes.

2. Single channel per carrier (SCPC)

3. Spread spectrum, also known as code division multiple access (CDMA).

Each technique has advantages as well as shortcomings. Figure 3-2 shows features commonly found in most current VSAT networks. Unless otherwise stated, a star network is assumed, since it allows use of VSATs with an antenna size ranging from 0.7 to 2.4 m at all sites except the hub, and most of the off-the-shelf VSAT

equipment currently available is designed for a star topology.

3.1.3.1　RA TDMA/TDM

The random access TDMA/TDM systems have been successful because of two factors:

- Most corporate systems are inherently suited to the star network configuration.

- The bursty nature of the communications allows a large number of remote terminals to efficiently share a small number of carriers.

The remote stations are designed to be inexpensive, and are usually controlled from the hub stations. The remote stations use burst modulators and continuous demodulators. The hub station has burst demodulators and continuous modulators for the outbound carriers.

In this access technique, the inbound transmission is dynamically shared by a number of VSAT stations using a combination of different time-slot access schemes. Figure 3-3 illustrates the concept. The transmission speed is typically between 56 kb/s and 128 kb/s. The inbound frame is divided into a number of fixed-size time slots, and a portion of the frame is allocated for S-Aloha transmission and the other for TDMA.

Random access uses either the Aloha or slotted Aloha technique. In Aloha, the user is free to transmit a message at any time. In S-Aloha, the user is constrained to send a message in one of a group of time slots. Both systems experience collisions when two users send packets that overlap as shown in Figure 3-4. When a collision occurs, both users must send the message again.

In some earlier experimental systems using Aloha access techniques, the terminal detected packet collision by direct loopback monitoring of the downlink signal. In most current systems, however, the VSAT is unable to receive the downlink signal. These systems rely on an acknowledgment from the hub station to indicate a successful transmission. If a collision occurs, the messages involved in the collision will not be acknowledged. If a remote station does not receive an acknowledgment after a specified waiting period, the remote station retransmits the packet at the end of a randomly selected time-out period.

A slotted-Aloha channel has a maximum theoretical throughput of 36%, however, its peak utilization is controlled to be less than 25% in practice to avoid the congestion due to retransmitted packets. S-Aloha trans-

FEATURES

• Very Small User Earth Station
• Low VSAT Equipment Cost
• Star Network with Hub
• Large Number of Users (100 - 10,000)
• Two-Way Data (Transactional)
• File Transfer
• Data Distribution/Collection
• Various Data Protocol Support
• LRE (16 kbit/s) Voice

INDOOR UNIT

INDOOR UNIT

VSAT EQUIPMENT

• 0.7 - 2.4 m Antenna Size
• SSPA
• Integrated Outdoor Equipment
• Turnkey System
• High Reliability & Non-Redundant
• Support for Data, Voice, & Video
• User Protocol Support
• Low Cost ($6K ~ $15K)

HUB EQUIPMENT

• Large Earth Station (e.g. 5 - 9 m)
• Redundant Equipment
• Inbound/Outbound Processing
• Network Control/Management
• Interface: Host, PABX, Packet
  Switch, PSTN, Leased Lines, Etc.

INDOOR UNIT

Figure 3–2: Typical Very Small Aperture Terminal (VSAT) Network Features

FRAME MARKER

FRAME

S-ALOHA

TDMA

COLLISION

TIME

RANDOM ACCESS

FIXED/DEMAND ASSIGNMENT

• Inbound Bit Rate: 56 - 128 kbit/s
• Outbound Bit Rate: 128 - 512 kbit/s
• Efficient Space Segment Utilization
• User Data Rates Up To 56 - 128 kbit/s
• Small Queuing Delay for Data
• Can Accommodate LRE Voice
• Various Data Protocol Support
• Flexible and Ease of Expansion
• Uneconomical for very low traffic volume

400 kHz
128 kb/s

1.6 MHz
512 kb/s

1 2 3 4   OB Carrier 1

time

freq

VSAT 2

VSAT 1

Inbound Carriers
TDMA Channels

Outbound Carrier
TDM Channels

Figure 3–3: Random Access Time Division Multiple Access (RA-TDMA) Concept and Features
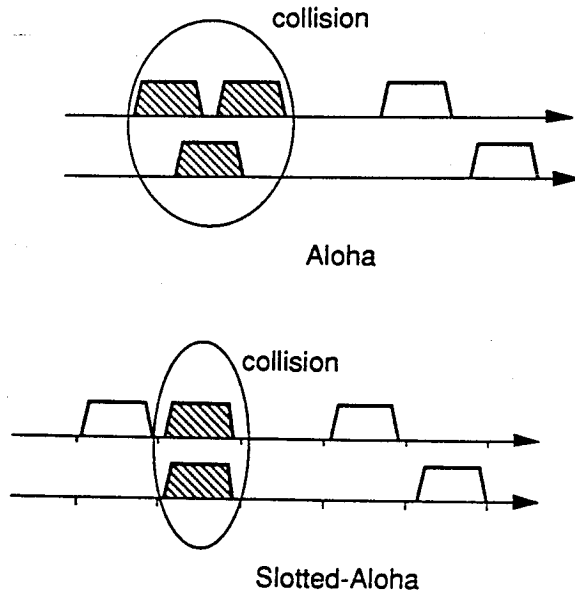
Figure 3–4: Collisions in Aloha transmission

mission, in comparison with TDMA, reduces the average queueing time in the VSAT at the expense of lower space segment utilization.

Pure-Aloha (also called simple Aloha) transmission has a maximum throughput efficiency of 18%. The difference in maximum efficiency is due to the time constraints in S-Aloha. In Aloha channels, one transmission can affect two (or more) other messages. In S-Aloha, messages are constrained to discrete slots, so one message interferes only with other messages in the same slot. S-Aloha is often used in conjunction with TDMA in systems needing the higher channel efficiency, while Aloha is used in systems where the complexity of slotted Aloha is not warranted.

Time slots in the TDMA segment are assigned to particular VSAT users for packet transmission without collision. The assignment can be fixed (leased line type services), dynamically allocated for a period of time (voice calls or file transfer), or reserved for a short time period to temporarily empty the queued packets. The TDMA segment has a larger average queueing delay, but its frame efficiency is quite high, about 75% to 85%.

The combination of S-Aloha access and TDMA provides a smaller queueing delay for transaction-oriented data, a higher frame efficiency for high volume traffic (leased lines or voice calls), and flexibility to accommodate fluctuation in traffic volume. VSAT equipment partitions the inbound carrier into two regions; one accept-

ing S-Aloha messages, and the other for TDMA messages. Although the implementation differs between manufacturers, the TDMA slots are used for queued messages and scheduled messages (e. g., stream, low rate voice), and the slotted Aloha slots are used for new messages.

The outbound transmission from the hub to VSATs is a continuous TDM carrier at a typical information bit rate of 56 kb/s to 512 kb/s. A TDM frame contains a number of data packets with destination VSAT identification codes. Each VSAT receives a broadcast outbound bit stream and extracts only the packets destined to its location. Because of this statistical multiplexing nature, the outbound frame efficiency is very high, in the range of 80% to 90%. A pair of inbound and outbound carriers can serve hundreds of VSATs for transaction oriented data, and most hub VSAT equipment has an expansion capability to accommodate multiple carriers for large networks, high traffic volumes, and/or future traffic growth.

User VSAT equipment is generally limited to one inbound and one outbound carrier operation, but offers multiple data ports to user data terminals. A high-speed user interface (56 kb/s to 128 kb/s) minimizes queueing delay at the earth station. Hub equipment includes a network control/management system to perform monitor and control of the VSAT network.

Remote terminals communicate only with the hub terminal. The system is designed to simplify the design of the remote terminal, and reduce the cost of the terminal. Remote terminals consist of an indoor unit and an outdoor unit connected by a cable carrying IF and control signals. The outdoor unit consists of the antenna, and in integrated head with the low noise receiver, up and down converters, and HPA. The integrated head is designed for the frequency band of interest. Interface to the indoor unit is at an IF frequency.

In general, several different antennas are available at each frequency band. A typical indoor unit contains a TDM demodulator and a RA-TDMA modulator, both using BPSK modulation. Baseband equipment includes an integrated system with rate 1/2 FEC (forward error correction), space communications protocol support, data equipment protocol support and physical interfaces for one or more data terminals. Several manufacturers also provide voice circuits that can interface to either a telephone set or a Private Branch Exchange (PBX).

The hub terminal provides one or more outbound carriers. The hub terminal is shared by many remote terminals. The outbound carrier is a TDM stream. The remote terminals derive timing from the outbound TDM frame. Hub terminals today are not a highly integrated as the remote units, and use off-the-shelf hardware for many components. The outdoor equipment consists of the antenna, and RF equipment in a shelter. The RF equipment consists of the LNA, HPA, and up and down converters. The indoor equipment consists of inbound carrier TDMA demodulators, and TDM modulators. Manufacturers supplying RA/TDMA-TDM systems include Hughes Network Systems (HNS), NEC, Scientific Atlanta (SA), ATT-Tridom, and Alcatel.

3.1.3.2 SCPC and SCPC/DAMA

In the traditional single channel per carrier (SCPC) system, a transponder bandwidth is divided into a number of small frequency slots, and each slot is assigned to a transmission of a single fixed-size carrier. Figure 3-5 shows the SCPC concept. Transmission can be analog using companded FM (for voice) or digital at rates from 9.6 kb/s to 64 kb/s. Both fixed and demand assignment have been used in both domestic and international systems (e. g. INTELSAT offers VISTA (FM), digital SCPC, and SPADE). These systems usually operate at 56 kb/s or 64 kb/s. SCPC access can be used successfully in star, mesh and hybrid network topologies.

Digital SCPC links continue to be of interest for connections between two corporate sites. Dedicated links are frequently connected to multiplexers that support multiple voice or data communications. Figure 3-6 shows the several options currently in service:

(a) Direct connection to a data terminal

(b) Packet switch or packet assembler/deassembler (PAD)

(c) Fixed or statistical multiplexer

(d) Digital circuit multiplication equipment (DCME) to provide eight voice channels in a 64 kb/s link

Other systems allow several voice and data channels to share the link. Fixed assignment SCPC uses dedicated links between terminal at a fixed bit rate, typically 9.6 kb/s to 128 kb/s. Higher bit rates to 1.544 Mb/s are also possible for certain applications; however, use of a lower bit rate, e. g. 2.4 kb/s, requires a special consideration on IF carrier frequency stability and has not been used in most SCPC systems.

Advantages of a fixed assignment SCPC system are simple VSAT and hub equipment (i. e., RF equipment and SCPC modems) and minimal network monitor/control functions. However, the allocation of a dedicated link to each VSAT may result in high space segment cost for low volume traffic. Expansion to a higher bit rate can easily be accommodated by changing the modem bit rate, but expansion in network size may be severely constrained by the availability of satellite bandwidth, since each additional site requires a pair of SCPC carriers (no space segment sharing). Because of the low start-up cost of hub equipment, a fixed assignment SCPC system is cost effective for a small network. The hub must provide a dedicated modem for each carrier and becomes extremely complex and high cost for a large network.

Efficient space segment utilization can be realized by use of demand assigned multiple access (DAMA), which dynamically allocates or deallocates additional SCPC carriers to a VSAT based on immediate user traffic requirements. DAMA SCPC significantly increases space segment utilization for voice traffic and has been extensively used in many satellite communications systems. However, DAMA may not be so effective for transactional data traffic because of low traffic volume due to carrier setup/teardown delay. Use of small antennas and low power SSPA equipment restricts the number of carriers to be accommodated by a user site to a few. DAMA SCPC requires a network control center to perform space segment allocation, deallocation and call processing.

Recently developed VSAT equipment frequently operates with low rate encoded voice channels ranging from 9.6 kb/s to 32 kb/s and incorporate DAMA. Hughes Network Services (HNS), for example, offers the Telephony Earth Station (TES) that is an example of this service. The HNS TES system also supports data connections. The basic card contains both a voice codec, and a data interface. Voice can be transmitted at rates from 9.6 to 32 kb/s. Data can be transmitted at rates to 64 kb/s. The card is configured by commands from the control station, to control the voice or data use, voice coding technique, type of FEC (rate 1/2 , 3/4 or no FEC) and BPSK or QPSK modulation. This system uses a control station to assign frequencies to two stations from a pool of carrier frequencies in the satellite.

- Inbound bit rate: 9.6 — 1544 kb/s
- Outbound bit rate: 9.6 — 1544 kb/s
- Some VSAT provides selectable bit rates
- Requires multiple carrier operation
- Space segment utilization can be efficient or wasteful depending on applications
- Can accommodate ADPCM/LRE voice
- Flexibility and ease of expansion
- Low equiv. cost for single-carrier leased line service
- High equiv. cost for DAMA and multiple carrier operation

Carrier Spacing: 45 kHz
16 kb/s LRPM Voice
Channels Dynamically Assigned by Master Control Station

Figure 3–5: Single Channel per Carrier (SCPC) Concept and Features

(a) Direct Connection

(b) Packet Switch

(c) Voice with Digital Circuit Multiplication

(d) Multiplexed Channels
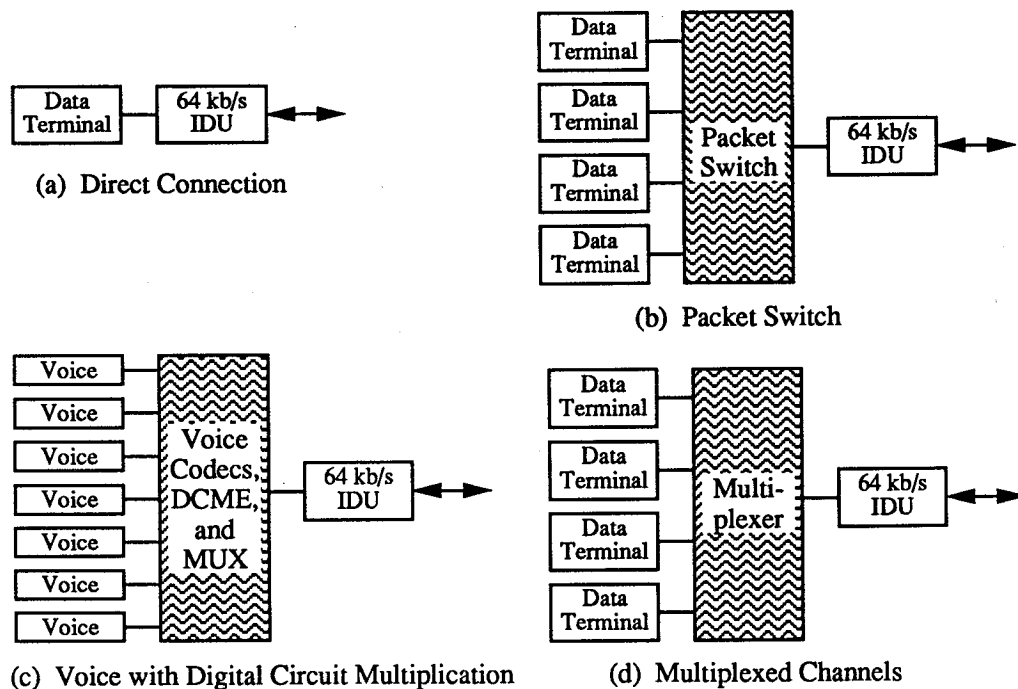
Figure 3–6: Interface Options for Digital SCPC Links

A station wanting to initiate a call uses Aloha access to send a request to the control station using a specified call request frequency. The control station then uses a common TDM channel to notify both the called and calling stations of the call request and the frequencies of the carrier pair assigned to the call. The two stations then proceed to establish a session. After the call is complete, both VSAT terminals notify the control station that the call is complete, and the carrier pair is returned to the pool.

The low channel rates and FEC allow a VSAT to support several few low-bit rate carriers. The number is determined by RF equipment constraints (small antenna size and SSPA). A larger number of channels can be provided by increasing the capacity of the RF equipment. Up to 24 channels can be mounted in a rack for a hub site, or terrestrial network access point.

NEC offers the Nextar VO (voice only) unit that is used with either in conjunction with an existing Nextar data network, or in a voice network. The associated data unit provides call establishment facilities. Nextar terminals use separate carriers for data (RA-TDMA) and VO voice channels (SCPC).

3.1.3.3 Spread Spectrum

Code division multiple access (CDMA), also referred to as spread spectrum, is another viable access scheme to implement low-cost VSAT networks. Equatorial Communications of Contel ASC has been the primary supplier of CDMA VSAT equipment.

The CDMA system, as illustrated in Figure 3-7, uses a long pseudo-noise (PN) sequence of bit patterns called chips to represent one information bit. The number of chips per bit ranges from a few tens to several thousands depending on the applications. For example, Equatorial uses an outbound bit rate of 153.6 kb/s over a 5 MHz bandwidth (32 chips per bit) and an inbound bit rate of 1.2 kb/s to 9.6 kb/s (about 500 to 4,000 chips per information bit). Multiple user access is provided by use of different PN codes and correlation receivers. In the star network, the inbound and outbound transmissions use separate transponder bandwidth, resulting in a minimum bandwidth requirement of 10 to 20 MHz for two way operation.

CDMA VSAT is characterized by ultra small antenna size (as small as 0.7-m diameter at C-band), thus a low-cost user VSAT, low bit rate operation, and resistance to RF interferences. It is cost effective for data distribution

to or data collection from a large number of VSAT stations, where VSAT equipment cost dominates the overall network cost. The interference resistance property allows the use of C-band user terminals at places where RA-TDMA or SCPC cannot be used. User data rates are generally low, and hence applications are limited to low duty-cycle data transmission. Since a wide bandwidth is required regardless the network size, this access scheme is not suited for a small VSAT network.

The strengths of CDMA are the ability to work in interference environment that would preclude other techniques, and the small size of antennas possible due to the processing gains inherent in CDMA. The weakness in the service is the limited channel bit rate (typically 1,200 b/s) that is achievable in most networks. Because of the bandwidth limitation, this system has found a few niche markets in VSAT applications, but has not become widely used.

3.1.4 Transmission and Protocols

VSAT data systems use efficient protocols for space segment operations, and support commonly used data communication protocols. RA-TDMA/TDM systems include support for several different data transmission protocols in the terminal. SCPC equipment normally provides support only for the physical layer (modulation and FEC). Higher level support such as X.25 must be provided by other equipment.

This discussion is divided into four parts:

1. Inbound and Outbound Carriers

2. Data Protocols

3. Voice Interface

4. Grade of Service

3.1.4.1 Inbound and Outbound Carriers

A VSAT network consists of an outbound carrier and a group of inbound carriers. Each inbound carrier is shared by a number of remote sites. Each VSAT is assigned one of the inbound carriers and shares the outbound carrier with all sites sharing the associated inbound carriers. A hub site can support several networks.

Figure 3-8 shows an example of the carriers for a hub site with two VSAT networks serving a single customer. The number of sites that can be served by a VSAT network is dependent on carrier bit rates, and the amount

- Inbound bit rate: 1.2 — 9.6 kb/s
- Outbound bit rate: 56 — 150 kb/s
- Continuous or Burst Mode Operation
- Very low cost VSAT (0.7 — 1.2 m)
- Occupies (2 x) 5 MHz of bandwidth
- Interference resistant
- Not suitable for voice traffic
- Various data protocol support
- Flexible and ease of expansion—limited
- Economical for low traffic volume
  with a large number of VSATs
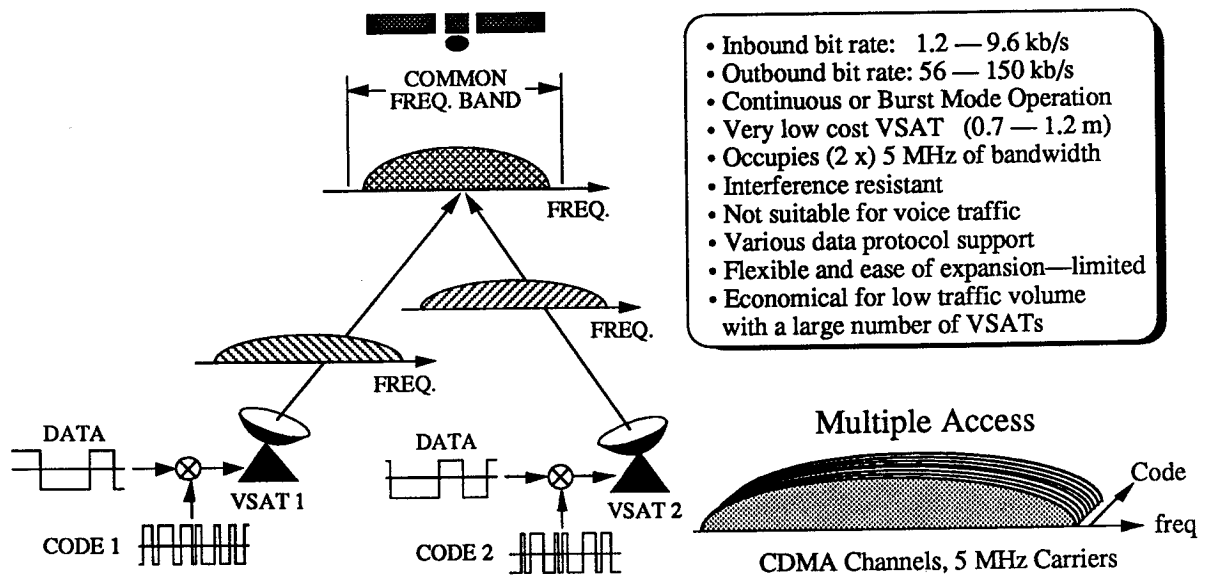
Figure 3–7: Code Division Multiple Access (CDMA) Concept and Features

of traffic to each remote site. Inbound carriers range from 32 kb/s carriers (at 100 kHz spacing) to 128 kb/s (at 400 kHz spacing). Outbound carriers range from 56 kb/s to 512 kb/s (at 1.6 MHz spacing).

Large networks are comprised of several VSAT networks. The number of outbound carriers depends on the number of terminals to be served, the traffic volume to these terminals, and the size of the outbound carriers. The optimum choice for carrier sizes depends on many factors. One factor is the space segment charges, and these are minimized when the space segment is utilization is high. Small carrier sizes are preferred when the number of sites and the aggregate data rate are both small since high rate carriers will not be efficiently loaded.

The primary performance difference between networks using low rate carriers and networks using high rate carriers is the ability to handle a high peak rate from a single site. The peak rate is determined by transactional data as well as voice and dedicated data links. In the U. S. A. the need for voice service over a VSAT link is minimal due to the excellent telephone service in this country. In other parts of the world, many locations have either little telephone service, or long waiting times for new circuits. Higher rate carriers also have larger RF requirements, and may require the expense of a larger antenna or larger SSPA.

3.1.4.2 Data Protocols

VSAT equipment manufacturers provide X.25 and SNA/SDLC support. Most offer several additional protocols, and will support others at additional cost. Most protocols were not designed to be efficient over satellite links because of the inherent delay. As a result, VSAT equipment uses efficient communication techniques for the satellite link, and terminates most user protocol transmissions at the earth station. As an example, host polls to remote sites are terminated by the hub equipment immediately unless a message from a remote site is already complete in a buffer. Similarly, equipment at the remote site frequently polls user equipment. When the user equipment responds, the message is transferred to a buffer. This message is then transferred to a hub buffer using space link protocols. The next time that the hub receives a poll message, the stored message is forwarded to the host equipment.

At the physical layer, the satellite equipment uses BPSK modulation. Remote sites use burst modulators and continuous demodulators, while hubs use burst demodulators and continuous modulators. One option is QPSK modulation that reduces the bandwidth of a channel, but this is not generally used because many satellite links are power-limited, and QPSK increases the cost of terminal equipment with no substantial increase in the number of satellite channels.

The space link protocols provide error-free delivery
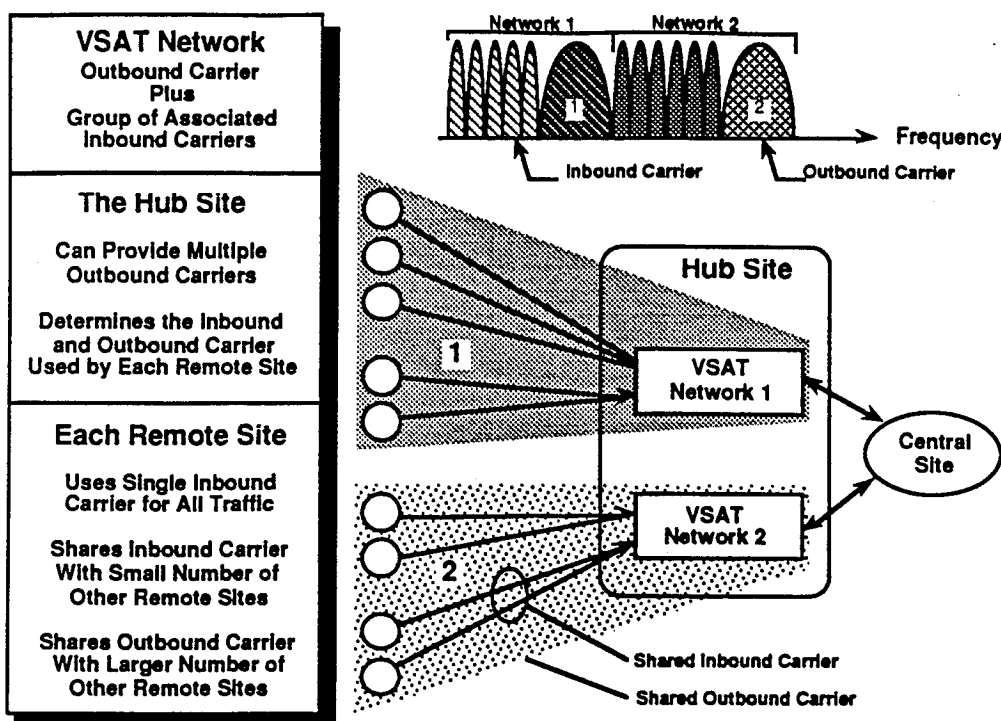
Figure 3–8: Example of Carriers for a Hub Site with Two VSAT Networks Servicing a Single Customer

of packets between the remote and hub terminals. The space link provides three functions:

i. Acknowledgment

ii. Flow control

iii. Error recovery

One key to performance at the satellite link level is the use of FEC. This greatly reduces the cost of RF equipment in the VSAT, and hence its cost. Rate 1/2 convolutional coding with Viterbi decoding is commonly used for data transmission, and specifications for bit error rate of 10^{-7} are typical.

Acknowledgment of packets is required for reliable delivery of information. Packets may be lost or corrupted for a number of reasons, e. g., packet collision from another site, or noise in the link. When a packet is corrupted, the receiving site may be unable to identify the packet. Therefore, packets received correctly are acknowledged; packets with errors are not acknowledged. A CRC (cyclic redundancy check) word is included in the packet, and checked for an error. For reliable service, the sending site is expected to repeat transmission of any packet not acknowledged after an appropriate wait time.

VSAT data systems partition the inbound carriers to random access slots (slotted Aloha) and TDMA slots. These systems have a mechanism for shifting traffic from the random access partition to the TDMA partition. The mechanism varies but the goal remains the same. In the HNS Personal Earth Station, remote sites can request a reservation slot using the random access slots. A reservation request identifies the length of a block of data to be sent. This can be either a large single block, or can be the size of queued messages waiting transfer. The space segment allocation is an assignment of a number of TDMA slots in successive frames. At the end of the assignment, these slots are returned to the pool for future assignment. Scientific Atlanta's SkylinX.25 equipment, on the other hand monitors the queue size at each remote site, and assigns TDMA slots based on the size of the queues at each site. By transmitting as much traffic as possible in TDMA slots, each system attempts to keep the random access slot utilization in an acceptable range.

Flow control is used at several points in both the remote and hub locations. Collisions in the slotted Aloha channel force additional transmissions to occur. Subsequent transmissions are scheduled at increasing wait times to smooth the channel utilization and to lower the

number of collisions. This causes an increase in the lengths of message queues. The VSAT equipment then exercises flow control back to the user data equipment to reduce the flow of new messages into the satellite system.

3.1.4.3 Voice Interface

Voice interface for most systems is analog. In star networks, the VSAT connection can be either 2-wire or 4-wire, and is 4-wire at the hub. Calls to the hub are directed either to a single line, or to a hunt group at the hub. Voice interface for mesh networks can be either 2-wire or 4-wire. Calls in these systems can be directed to either single lines, or to hunt groups.

One consequence to this interface for networks with more than a few voice channels is the number of analog to digital conversions that may be required. The largest number of voice channels will be installed in the hub site, and the hub may be located some distance from the PBX. When T1 links used to connect the hub with the corporate center, calls are digitally encoded twice once at a low rate for the satellite network, and again when the call enters and/or leaves the telephone system. This is one area where additional interfaces can be expected to evolve. VSAT audio channels with digital interfaces will minimize the quality loss due to multiple analog to digital conversions and low rate encodings.

3.1.4.4 Grade of Service

The grade of service (GOS) for voice circuits is the probability that the call will be blocked. This is a function of the amount of voice traffic being handled by a group of circuits. The grade of service at a VSAT is dependent on a number of factors. The traffic level (Erlangs) is the number of call-minutes per hour in a group of lines. Assume, for example that four VSATs with voice capability share an inbound carrier. Each VSAT handles 30 call minutes during the busy hour, or 0.5 Erlangs. The VSAT channel has to support 120 call minutes per hour, or 2 Erlangs of traffic. Two factors influencing the grade of serviced at each of the four sites are the number of voice ports installed at each VSAT, and the number of channels available in the inbound carrier.

Figure 3-9 shows grade of service as a function of traffic level (Erlangs) and number of trunks or voice channels. The grade of service is given for one through eight trunks is shown as a function of Erlangs of traffic.
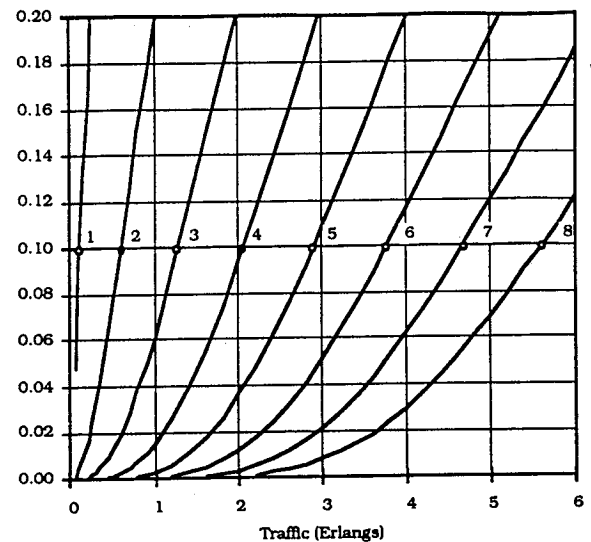
Figure 3–9: Grade of Service
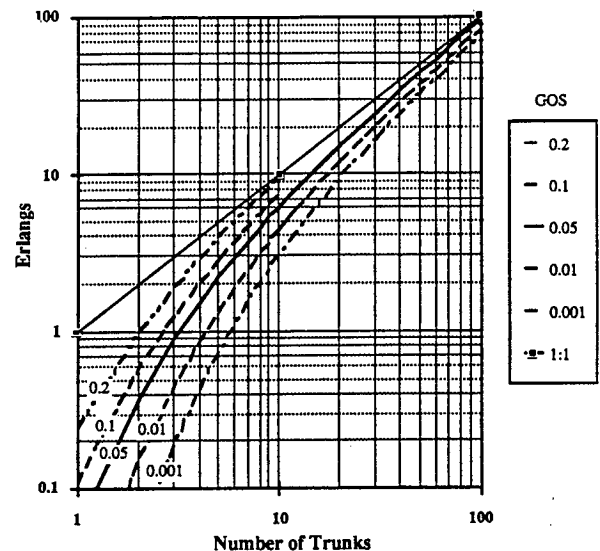
Figure 3–10: Traffic vs. No. of Trunks for GOS

The grade of service for a VSAT call is found by combining a number of blocking factors:

i. No. of lines available within the VSAT equipment

ii. No. of channels reserved in the inbound carrier

iii. No. of channels reserved in the outbound carrier

iv. No. of voice ports available to the VSAT at the hub

The total blocking factor is larger than the largest single blocking factor.

The grade of service (GOS) is particularly important for VSAT networks carrying voice over shared inbound carriers, and for VSAT networks sharing a hub. As an example, consider the case where a VSAT has a single voice card, and shares an inbound carrier with 20 other sites. Three voice channels are available in the inbound carrier. Also assume that the desired GOS is 5% (percent of calls that are blocked), which is much higher than found in most western telephone systems. For the site with only a single port, the number of Erlangs of traffic that can be supported at a GOS of 0.05 is 0.05 Erlangs (3 minutes per hour)! The three channels in the inbound carrier can support 0.9 Erlangs of traffic, or an average of 0.09 Erlangs (7 minutes) per site. When a user at a VSAT places a call and receives a busy signal, this can be caused by other users at the VSAT using the only line, or by other VSAT users sharing the inbound carrier using the channels that are available. In either case, the result is the same — a busy signal.

The situation can be improved by increasing the number of connections available at each segment of the connection. For example, installing two voice ports at the VSAT increase the connection time to 0.4 Erlangs (24 minutes). If the inbound carrier supports four voice channels, 1.6 Erlangs of traffic is supported (nearly 10 minutes per VSAT). One way to compare these options is to divide the number of Erlangs by the number of channels. This is a direct measure of the number of available call minutes per line available at any rate. The major increases are found when larger numbers of channels become available to all sites. 24 channels provides a reasonable result (19 Erlangs or 76%) and 100 channels is close to the maximum (90 Erlangs or 90%).

Figure 3-10 is another look at the grade of service as a function of traffic and voice channels (trunks). In this figure, curves are for various grades of service (GOS). The upper curve is the limit (all channels in use 100%

of the time). The central curve (0.05) is for a 5% GOS, and the lowest curve (0.001) for a 0.1% GOS.

In most VSAT terminals the number of voice circuits is limited by both equipment, and by the link parameters. Typically, the number of voice channels is between 1 and 4. Figure 3-10 shows that the number of Erlangs of traffic is much smaller than the number of channels. The GOS for a terminal with one voice channel is approximately equal to the traffic in Erlangs. If we define voice channel utilization as the traffic that can be supported divided by the number of voice circuits, the figure shows that voice channel utilization for VSAT terminals is quite low — between 5% and 30%.

Voice channel utilization becomes much better as the number of voice channels exceeds 20. This is supported by some hub sites, or at satellite network nodes with RF equipment that is no longer in the VSAT category. For 20 channels, the voice channel utilization approaches 80% for a GOS of 5%.

These same factors also apply to a group of shared data channels used for bulk transfers or database updates. Each can be viewed as a demand assigned session. As the number of connections increases, the chances of successfully establishing a session at the initial request also increase exponentially.

3.1.5 Economic Aspects of Current Systems

A number of VSAT systems have been installed with great success. These have been primarily large networks for a single customer. Customers for these networks have achieved better performance, reduced costs, and perhaps most importantly, cost containment in the future. Many attempts to install these systems in other applications have been unsuccessful for a number of economic or technical reasons.

The discussion is divided into six subsections:

1. Business Plan

2. Sharing of Facilities

3. Dedicated Hub

4. Shared Hub

5. Multiple Services in a Single Carrier

6. Multiple Services in Multiple Carriers

3.1.5.1 Business Plan

Development of a business plan includes analysis of the cash flow, rate of return on investment, and comparison of alternatives for the services provided by the network. One consideration is whether the discounted net income generated as a result of the capital expenditure is larger than expected from alternative investments. Existing terrestrial services usually have a smaller initial cost, but larger continuing costs.

For a single customer, the development of the business plan is relatively straightforward. Estimates of the number of sites to be connected, and the volume of data lead to definitions of the amount of equipment and space segment resources needed. These analyses often lead to a conclusion that one customer may not have enough traffic to justify a dedicated network, but there is a possibility that facilities shared among several customers may prove beneficial.

A business plan needs to address the number of services that can be provided by a VSAT system. Potential services include:

a. Data transactions in request/response pairs. Normally the remote terminal initiates the request, and the hub forwards the request to a central computer attached directly to the hub (or optionally is sent to another remote VSAT terminal). The central computer provides the response which is queued and then sent to the remote VSAT terminal.

b. Batch Data Transfer is normally used for either file transfer, or for remote printing. Transfers can be scheduled by either reservation modes, or stream modes (depends on manufacturer). The amount of data to be sent is known in advance, and the time can frequently be scheduled to take place during a non-peak period.

c. Stream Data. Dedicated channels that can be used for continuous rate services; e. g., 2400 b/s dedicated channel; for voice codecs; or for batch transfers. In general, the amount of data to be sent is not known in advance, but a dedicated channel is opened until released.

d. Voice. Codecs from 9.6 to 16 kb/s are common.

e. Facsimile usually uses a voice port. Most predictive codecs support facsimile data only at a reduced rate, either 1200 or 2400 b/s.

f. TV Broadcast shares the IF circuitry. Normally, the television signal modulates an FM carrier. The VSAT terminal supplies the IF signal to a separate TV demodulator and decoder for distribution of broadcast TV. If return path audio is needed, this will use the existing VSAT voice codecs.

g. Data Broadcast. Most systems for low speed data have been using CDMA (spread spectrum) modulation.

3.1.5.2 Sharing of Facilities

Sharing of facilities in a VSAT network can include sharing of both the remote and hub stations facilities. In most cases, sharing of the hub is of major concern due to the installed cost, and recurring manpower costs of operating a hub station. In some other cases, the cost of a remote site is also of enough concern to consider sharing a VSAT terminal. Sharing of these facilities complicates the analysis. When the hub is shared among several customers, the cost of terrestrial connections between the hub and company's data processing center or PBX may become important. This is often divided into two parts — the long haul, and the "last mile" costs which include connections directly to the customer's communication equipment. When the remote terminal is to be shared, the "last mile" costs may be much higher than initially expected.

One of the biggest concerns found when considering installation of a shared system is the probability that the customers needed to establish a shared system will be ready to sign contracts at the same time. The high initial costs of a VSAT system make it difficult to start at a small level, and add facilities as the business grows. The cost of the VSAT equipment needs to be added only as additional customers initiate service, but the hub, satellite, and operating costs may be the same for a small or large business.

3.1.5.3 Dedicated Hub

The cost of a dedicated hub can be divided into the RF portion, the communications equipment, and operating costs of the site, personnel, and space segment leases. The cost can be further considered as initial costs and recurring costs. In many cases, the entry level costs for a hub station exceed $1 M. This is approximately $500 K for the RF equipment, and $500 K for the communication equipment. Very large networks may require com-

munication equipment that can be 2 or 3 time the cost of the minimum equipment to initiate a network. Fortunately, once a customer has enough data traffic that requires an increase in the amount of hub equipment, the VSAT network is probably shown to be profitable.

In many enterprises, the volume of data during the peak hour may be only a few tens to a few hundred bits per second per terminal. VSAT network design effectively supports efficient transmission of this type of traffic among a large number of remote sites. A single 6 kb/s carrier can frequently support 100 or more remote sites with low traffic. Under these conditions, a large number of remote sites is needed to justify the cost. As the traffic between hub and remote becomes large, the advantages from a VSAT network become smaller, and for a small number of sites, dedicated point to point links may cost less.

A final point to consider is the location of the hub station and the customer location for services. One advantage of the remote VSAT terminal is that the antenna size is small (1.2 to 1.5 m), and can usually be mounted within a few hundred meters of the customer's building. Hub antennas, however, are much larger, typically 4.5 m or more. Within some cities, mounting an antenna close to the customer's property may be difficult. In this case, the antenna may have to be moved to a suitable location that is some distance away. Communication facilities, microwave or fiber optic cable, may then substantially increase the cost of the satellite network. This cost includes initial planning, right-of-way acquisition, cost of purchase, installation, and maintenance of the facilities. If the link between the hub station and the customer is provided by common carriers, then the monthly cost of communication facilities must be included in operating costs.

3.1.5.4 Shared Hub

One alternative to a dedicated hub station is a hub shared by a number of customers. Thus, if a VSAT network needs 150 remote sites to be economically viable, but no single customer in the area has this requirement, several customers can share the installation and operating costs of the hub site. Under favorable circumstances, this can be attractive. However, there are several cost factors in shared systems that increase the total hub cost. These include additional tail end costs, finding customers to share a site, and duplicate facilities that may be required. These same factors also apply to shared VSAT

terminals. Figure 3-11 shows an example of a shared hub network.

Tail end costs include the cost of connections between the terminals and the customer's communication equipment. These costs can frequently be minimized for a single customer. When the satellite terminals can be located physically next to the communication equipment, the primary cost is the initial installation of cables. When several customers share a terminal, there is usually an added cost of providing communication links between the satellite terminal and the individual customers. These links may be private microwave, optical communications, or facilities leased from the local telephone company. In addition, land and buildings may need to be leased. This can occur, for example, when the equipment cannot be located next to a customer site due to zoning, terrestrial interference, or line of sight limitations.

Consider the difficulty of finding customers close to the sites who will agree to sign contracts at the same time. Finding compatible customers is difficult enough, but finding ones who are willing to sign contracts at the same time is even more difficult. The network operator is then presented with a potential cash flow problem. Since revenue from a single customer may not be enough to cover expenses, there is considerable financial risk to shared facilities. The initial investment is still large, and achieving a reasonable rate of return may not be possible unless the most optimistic scenario occurs.

Another cost factor is duplicate facilities. In general, there will be separate tail end connections for each separate customer. This increases the cost of VSAT and hub equipment. This also applies to network management equipment. Two levels of network management need to be implemented — a higher level for the network operator, and a lower capability for each customer. Shared customers should exercise options that cannot affect services to other customers.

Maintaining this separation may also require additional inbound carriers, additional outbound carriers, and additional voice ports (in a mixed network). VSAT terminals belonging to one customer may only share a set of inbound carriers dedicated to that customer. This may result in low utilization of some inbound carriers, and therefore can increase both the initial cost and the recurring space segment cost. Networks providing voice circuits need an increased number of voice ports at both the VSAT and hub terminals that are shared to pre-
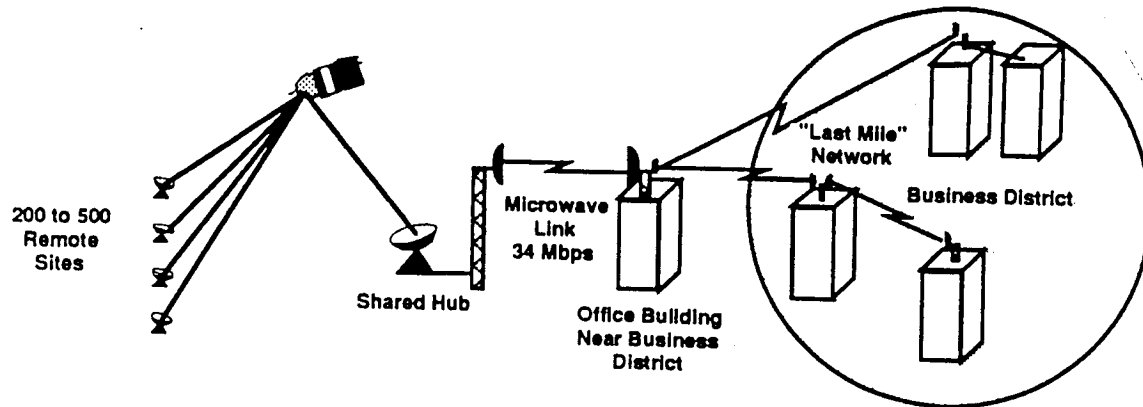
Figure 3–11: Shared Hub Network

vent traffic from one customer from affecting another.

3.1.5.5   Multiple Services in Single Carrier

Multiple services in single carrier includes two categories:

i. Star networks

ii. Point-to-point links

For star networks, the TDMA inbound carrier and TDM outbound carrier can dynamically support both transactional data and bulk data transfers. Equipment from Hughes and Scientific Atlanta (SA) allows encoded voice to be handled over these carriers. The Hughes voice codec uses RELP (Residual Excited Linear Predictor), and the SA voice codec is based on an orthogonal transform. The SA codec incorporates a special mode for facsimile, and allows higher rate transmission.

A second category is for point to point links. These links use a multiplexer and allow a number of separate channels to time share a single carrier. One example is the Republic multiplexer which allows up to 8 voice channels to be carried over a 64 kb/s or larger link. The Republic multiplexer is used with equipment from a number of manufacturers. This is often used over INTELSAT IBS (International Business Service) links. These are usually 64 kb/s links, and are often arranged through common carriers. Another is the Scientific Atlanta MCPC (multiple channels per carrier) equipment that is based on the SkylinX.25 equipment, and allows one or two voice or continuous data channels and a transactional data channel on a link between two sites.

The following list summarizes shared carrier performance for multiple services supplied via a single carrier:

a. Best feature is that time slots are very flexible, and allow higher efficiencies in each type of service within a given amount of space segment than if all facilities were provided separately

b. Very high file transfer rates are not supported since capacity is divided among other services and terminals.

c. Facsimile is limited by current voice codecs and is currently not compatible with most voice codecs. Best solution is a digital stream, but digital standard not widely accepted at this time.

d. Digital coding of voice circuits may not be compatible with other systems.

e. Limits the number of sites sharing inbound carrier. Reassignment of remote sites to carriers needed to maintain quality.

f. Inbound carrier rate limits the number of services to a single site.

g. In general, increasing the carrier rate allows more options for multiple services.

3.1.5.6   Multiple Services in Multiple Carriers

Another alternative is to use a separate carrier for separate services. The NEC equipment, for example, allows the Nextar I and Nextar VO equipment to be used together. In this case, the data channel is used to control

call setup. One advantage for multiple carriers is that the number of channels available to an individual site is determined by the total voice traffic in the network, and not on the amount of traffic in the site's inbound data carrier. Thus, a site needing three voice circuits can request them from the total network pool, and the use of voice does not impact users sharing data carriers.

One disadvantage of the use of multiple carriers for VSAT use is the cost of RF equipment. The RF amplifier and antenna size have to become larger as the number of channels increases due to the need for RF backoff to reduce intermodulation distortion. Two carriers, for example a 56 kb/s data carrier and a 16 kb/s voice carrier, require the same power as a 144 kb/s data carrier due to the need for a 3 dB input backoff for two carriers. Increasingly larger backoffs are required as the number of carriers increases.

The following list summarizes some performance aspects of multiple services supplied via multiple carriers:

a. Digital coding of voice circuits may not be compatible with other systems.

b. Facsimile is currently not compatible with low rate voice codecs. Best solution is a digital stream, but digital standard not widely accepted at this time. Facsimile needs high capacity in only one direction, so an asymmetric channel pair is beneficial.

c. Data communication protocols are not directly supported in most current systems. Networks formed by individual point to point links may need additional equipment.

d. Low utilization occurs with dedicated lines for interactive data.

e. Available VSAT transmit power or antenna size limits the number of services due to input power backoff required for multiple carrier operation.

f. Changing of bandwidth is not simple.

3.1.6 Description of Current VSAT Systems

Appendix C, "Current VSAT Systems", provides details for the carrier requirements and services provided by a number of providers of VSAT systems, such as Hughes Network Services (HNS) and Scientific Atlantic (SA). The following products are described:

1. HNS Personal Earth Station

2. HNS Telephony Earth Station

3. HNS Gemini System

4. NEC Nextar System

5. NEC Nextar VO System

6. NEC Nextar CL Clear Channel

7. SA SkylinX.25

8. Tridom Clearlink System

9. Contel ASC Equatorial Data Broadcast

These systems include RA-TDMA/TDM networks (HNS Personal Earth Station, NEC Nextar, SA SkylinX.25, Tridom Clearlink, GTE Spacenet); SCPC networks (HNS Telephony Earth Station, HNS Gemini, NEC Nextar VO and CL, Comstream Starlink); and CDMA systems (Contel ASC Equatorial).

3.2 Interfaces for Communication Services

Future VSAT networks must be able to support a wide variety of communications services, ranging from most commonly used data services, such as X.25 and X.75, SNA, datagram, and asynchronous lines to the emerging narrowband and broadband services such as ISDN voice and data (e.g. frame relay), broadband ISDN (BISDN), Switched Multimegabit Data Service (SMDS), and metropolitan area networks (MANs).

This section is divided into two parts and describes how the future VSAT network configuration can support emerging communication services.

3.2.1 "Terrestrial Broadband Services" describes the emerging terrestrial broadband services.

3.2.2 " User Interfaces for Mesh VSATs" gives possible interface configurations and procedures between user terrestrial facilities and a VSAT network.

3.2.1 Terrestrial Broadband Services

The following terrestrial broadband services are discussed:

1. BISDN (Broadband ISDN)

2. SMDS (Switched Multimegabit Data Service)

3. MAN (Metropolitan Area Networks)

4. FDDI (Fiber Distributed Data Interface)

5. SONET (Synchronous Optical Network)

3.2.1.1 BISDN

Present day telecommunications services are often provided by separate networks – voice, circuit data, packet data, telex, private line networks etc. Each network may require a dedicated physical access and a separate signaling and addressing scheme. In the past decade, there has been a recognition of the need for a more integrated approach. Along with the demand for new high-bit rate services, a potential reduction in the cost of supporting current services in a integrated way, and the availability of high speed semi- conductor and fiber optic technologies are some of the key factors in the evolution of broadband networks. From the user's point of view, there could be one virtual network providing all services whose characteristics are service independent.

This has led to the concept of Broadband Integrated Services Digital Network (BISDN). In BISDN, the applications are grouped into four classes of service called class 1, 2, 3 and 4. These four classes of services are supported using the asynchronous transport mode (ATM) protocol of the BISDN. In today's digital voice network, the transfer mode – called the synchronous transfer mode (STM) – allocates time slots within a synchronously recurring frame to a service for the duration of a call.

The structure of the ATM protocol – the way that it allocates network capacity to services – gets around the limited flexibility of STM by sharing both bandwidth and time. Instead of breaking down bandwidth into channels to carry information, ATM transfers fixed-size blocks of information, called cells, whenever a service requires bandwidth. Unlike STM, the time intervals are not fixed but vary according to the bandwidth. Each cell consists of 53 octets, broken down as a header (5 octets) and an information field (48 octets).

Each cell header contains a label field, which associates the cell with the service using the cell. The label field, in turn, contains a routing field, which is divided into two parts:

1. Virtual channel identifier (VCI)

2. Virtual path identifier (VPI)

The virtual path allows a group of virtual channels to be handled as a single entity. To meet the particular needs of each service, ATM maps the service into its cells using the protocol elements of the ATM adaptation layer. These protocol elements match the characteristics of the ATM transport layer to the service-specific transport requirements, and enable exact recovery of the original service signal.

Different adaptation layers may be used for different service requirements. BISDN supports physical interfaces at 155 and 600 Mb/s. The rate-adaptive and rate-independent nature of the ATM protocol enables network providers to carry any non-standard service data rates generated from customer premises equipment, and to transport them efficiently even though the data is almost always highly bursty in nature. At the same time, ATM will permit today's data services to work along side future multimegabit broadband applications, without rendering the user's equipment obsolete.

3.2.1.2 SMDS

Switched Multimegabit Data Service (SMDS) is a public, packet switched service that provides for the exchange of variable length data units, up to a maximum of 9,188 octets of user information per data unit. In consideration of security and privacy for subscribers, SMDS is offered by means of an access path that is dedicated to an individual subscriber. Furthermore the man switching system (MSS) validates that the source address associated with every SMDS data unit is an address that is legitimately assigned to the subscriber-network interface (SNI) from which the data unit was originated. SMDS supports source address and destination address screening features that can be used to create a logical private network. Many of the SMDS features are to be selected by the subscriber upon subscription to the SMDS and other features may be invoked individually for each SMDS data unit transferred.

SMDS uses ten digit address formatted with the same structure used for north American Numbering Plan. In addition, SMDS includes capability for group addressed data transport. Group addressed data unit transport is a feature analogous to the multi-casting feature of LANs. When CPE sends a group addressed data unit, the MSS will deliver copies of the data unit to a set of SNIs identified by the destination addresses specified by the group address.

SMDS provides for the transport of data units which can contain up to 9,188 octets of user information. Each data unit is individually addressed and transferred independently of the transfer of any other data unit. The data units carry both the source and destination address and no explicit flow control is used to control the transfer of information across the SNI. However, an implicit credit mechanism is used to enforce the access class and thus, the rate of information transfer across the SNI. Both DS3 and DS1 based access interfaces are supported. Both the ingress access class and egress access class are supported in SMDS. SMDS supports single CPE access and multiple CPE access arrangement based on the DQDB protocol. While the DS3 based access path can support both single CPE and multiple CPE access arrangements, the DS1 access path supports only the single CPE access arrangement.

3.2.1.3 MAN

The IEEE 802.6 Metropolitan Area Network (MAN) standard is based on the distributed-queue, dual-bus protocol and it can support such traffic types as data, voice, and video. The DQDB subnetwork can be used as a public network controlled by the operating companies or as a private backbone network within the customer premises. It can also serve as a LAN. The 802.6 MAN operates on a shared medium with two unidirectional bus that flow in the opposite directions. The subnetwork operates in one of two topologies: open bus or looped bus. Information is transported using fixed size data units called slots. The slot size and format align with the broadband ISDN cell size, thereby providing an easy migration path to BISDN. The payload of each 52 octet slot is called a segment.

The DQDB layer is intended support a range of services, including connectionless data transfer, connection-oriented data transfer, and isochronous data transfer. Convergence functions are defined to adapt the underlying medium access service to provide a specific service to a user. The standard specifies convergence function to support connectionless media access control data service to the logical link control sublayer and offers guidelines for the provision of an isochronous service. The connection-oriented data service is under study. The DQDB access layer is independent of the physical layer and therefore it is possible to operate the network at various data rate depending on the transmission system selected. The three transmission systems

considered are: DS3 (44.736 Mb/s), SONET STS-3c (155.52 Mb/s) and CCITT G.703. The physical layer incorporates a convergence function that provides a consistent service to the layer above it. Depending on the type of traffic, a node on the distributed-queue, dual-bus subnetwork can queue to gain access to the medium by using a distributed queue arbitrated access method or by requesting a fixed amount of bandwidth through prearbitrated access method.

The connectionless media access control service supports the transport of frames as long as 9,188 octets. This frame size can encapsulate all types of 802 LAN packets except the 18 kbyte 802.5. The connectionless media access control provides service to the logical link control sublayer (802.2 LLC). The function providing this service is called the convergence function and the connectionless media access control data is transmitted and received in queued arbitrated slots using the distributed queued arbitrated access protocol.

The connection oriented service supports the transport of 52 octet segments between two or more nodes sharing a virtual channel connection with no guarantee of a constant interarrival time. The connection oriented data is transmitted and received in queued arbitrated slots using the distributed queued arbitrated access protocol. This service is similar to the one offered by the BISDN.

Isochronous service interface is used by isochronous service user entities that require a constant interarrival time over an isochronous (e. g. voice) connection. Isochronous data is transmitted and received using the prearbitrated segments.

3.2.1.4 FDDI

Fiber Distributed Data Interface (FDDI) is a 100 Mb/s local area network based on dual ring optical fiber that connect stations over distances of 100 kilometers. Using optical fiber as the medium, the FDDI protocol is based on a token ring access method. The four out of five code used on the optical medium requires 125 Mbaud transmission rate. The nature of clocking, which adjusts for accumulated jitter between frames, limits frames to 4,500 octets maximum. Multiple frames may, however, be transmitted on the same access opportunity.

The entities in a station are as follows:

Station Management (SMT), which specifies the local portion of the network management applica-

tion process, including the control required for the proper internal configuration and operation of a station in and FDDI ring;

Media Access Control (MAC), which specifies the lower sublayer of the data link layer, including the access to the medium, addressing, data checking, and data framing;

Physical Layer Protocol (PHY), which specifies the upper sublayer of the physical layer, including the encode/decode, clocking and framing for transmission; and

Physical Layer Medium Dependent (PMD),
which specifies the lower sublayer of the physical layer, including power levels and characteristics of the optical transmitter and receiver, interface optical signal requirements, the connector receptacle footprint, the requirements of confirming optical fiber cable plant, the permissible bit error rates.

Two alternate forms of PMD are possible: the basic PMD and SMF-PMD which allows the use of single-mode optical fiber.

FDDI MAC provides a super set of the services required by the logical link control (802.2 LLC) protocol. Therefore, it is possible to use another appropriate LLC.

FDDI II is an upward compatible enhancement of the basic FDDI that adds a circuit switched service to the existing packet capability. Circuit switched service provides a continual connection between two or more stations. Instead of using addresses, the connection is established based upon some prior agreement, which may have been negotiated using packet messages or established by some other suitable convention known to the stations involved. This prior agreement typically takes the form of knowing the location of a time slot, or slots, that occur regularly relative to a readily recognizable timing marker. An addition sublayer, called hybrid ring control (HRC), between the MAC and PHY layers is defined in FDDI II. HRC multiplexes data between packet MAC and the isochronous MAC (I-MAC). This requires that the packet MAC be able to transmit and accept data on a noncontinuous basic because packet data are interleaved with isochronous data.

Four kinds of traffic may coexist in a FDDI II ring.

1. Once wideband channel's are allocated, the isochronous traffic within them has the highest priority.

2. Second highest priority is given to synchronous packet traffic where predictable units of data are to be delivered at regular intervals. These data may be transmitted following the capture of either a restricted or nonrestricted token.

3. Third highest priority is given to asynchronous traffic operating in restricted token mode. Such traffic may be transmitted upon the capture of either a restricted or a nonrestricted token. Restricted token mode operation allows stations to vie for available asynchronous bandwidth on as dialog basis.

4. Lowest priority is given to asynchronous traffic that may be transmitted only by capturing a nonrestricted token.

This mode of operation allows stations to vie for the available asynchronous bandwidth on a single frame basis.

3.2.1.5 SONET

The Synchronous Optical Network (SONET) standard, a new synchronous digital hierarchy standard for fiber-optic network, is the world's first fiber optic telecommunications network standard. SONET makes it possible to integrate the transmission, switching, and access portions of the network by using fiber at all network interconnection points. This capability will provide transport for broadband services. The SONET standard, which defines standard data rates, frame format, and the first optical signal parameters, was completed in 1988 by the T1 committee for ANSI. The CCITT has adopted an equivalent international standards, specifying the synchronous digital hierarchy (SDH).

SONET defines standard interconnect rates of up to 2.488 Gb/s, using a basic building block called the synchronous transport signal level 1 (STS-1). The STS-1 frame format, which is really an abstraction of a 125 μs period of a serial transmission, is organized into a 9-row by 90-column byte matrix. The byte from row one, column one, is transmitted first followed by row one, column two and so on, from left to right and from top to bottom. This format results in a serial transmission rate of 51.84 Mb/s.

The frame format consists of two sections: the transport overhead and the synchronous payload envelope. The transport overhead, which occupies the first three columns of the matrix, contains section overhead and

line overhead and performs the functions needed to transmit the payload envelope over a fiber system. The transport overhead also includes an STS-1 synchronous payload pointer as part of the line overhead, which indicates the start of the STS-1 synchronous payload envelope. The STS-1 synchronous payload envelope, which occupies the remaining 87 columns of the frame, consists of path overhead and a payload. The path overhead, which is nine bytes long, is allocated to support transport of the payload from the point where the payload is assembled to the point where it is disassembled. The payload is the information being carried in the remainder of the synchronous payload envelope. The payload, which has a maximum capacity of 49.536 Mb/s, could consists of DS-3 signal at 44.746 Mb/s, for instance, or 28 each DS-1, each at 1.54 Mb/s. Several STS can be combined for the transport of payloads that have bandwidth requirements greater than 50 Mb/s. This process of combining STS-1 payload envelopes is referred to as concatenation, and the concatenation of N STS-1s is denoted STS-Nc.

The synchronous payload envelope can be divided into virtual tributaries (VTs) to allow the transport and management of subrate payloads, such as today's DS-1 at 1.544 Mb/s. VTs come in four sizes: VT1.5, VT2, VT3, and VT6, which have payload capacities of about 1.5 Mb/s, 2 Mb/s, 3 Mb/s, and 6 Mb/s, respectively. An STS-1 synchronous payload envelope can accommodate up to 28 VT1.5, or 21 VT2, or 14 VT3s, or 7 VT6s, or combinations of these VT sizes. Each VT is divided into two parts: the VT payload pointer and envelope. The VT payload pointer indicates the start of the VT synchronous payload envelope, which like the STS-1 synchronous payload envelope, consists of path overheads and payload.

Higher transmission rates are achieved by synchronously byte interleaving N STS-1 to form an STS-N; N currently can be any of 1, 3, 6, 12, 18, 24, 36, or 48. Prior to interleaving, the STS-1s are frame aligned so that the transport overhead of each STS-1 can be combined for use as STS-N transport overhead. When the STS-N signal is transmitted, the resulting optical signal is called optical carrier, or OC-N.

3.2.2 User Interfaces for Mesh VSATs

Broadband services, such as described above, typically operate at a speed of 100 Mb/s, or higher. However, this is a user interface rate to a public or private network,

and actual user information rates may be significantly smaller (a few hundred b/s to 4 Mb/s), in most applications. Higher information rates (e.g. 10's or 100's of Mb/s) are primarily limited to large data processing centers communicating with remote branch offices, corporate headquarters of large companies, trunking between communications centers, or high-speed image or video transmission. Thus, although bit rates of terrestrial interfaces are high, user information rates will be often well within the speeds supported by future VSAT networks.

As current terrestrial voice and data communications networks make a gradual transition into more flexible and integrated digital networks, a future VSAT network must be capable of supporting emerging communications services, such as basic and primary rate ISDN, SMDS, FDDI, ATM, and SONET, and a wide variety of signaling and communications protocols for voice, data, and video. Figure 3-12 shows such an advanced VSAT configuration. Figure 3-13 depicts a protocol interface configuration for a VSAT network using the OSI model.

Terrestrial protocols are terminated at the VSAT, and flexible and efficient satellite protocols are used for the space segment to minimize the impact of satellite delay and to accommodate special satellite access, signaling, and control mechanisms. For on-board processing satellites, different protocols may be used for uplink and downlink communications. Detailed descriptions of terrestrial/satellite interface configurations are presented for the following communications services:

1. X.25

2. X.75

3. ISDN (Integrated Service Digital Network)

4. FDDI (Fiber Distributed Data Interface)

5. SMDS (Switched Mulitmegabit Data Service)

6. BISDN (Broadband ISDN)

7. SONET (Synchronous Optical Network)

3.2.2.1 X.25

CCITT Recommendation X.25 comprises three levels of protocols. It gives access to the virtual call and permanent virtual circuit services. It allows multiplexing, on the same physical circuit, of connections between
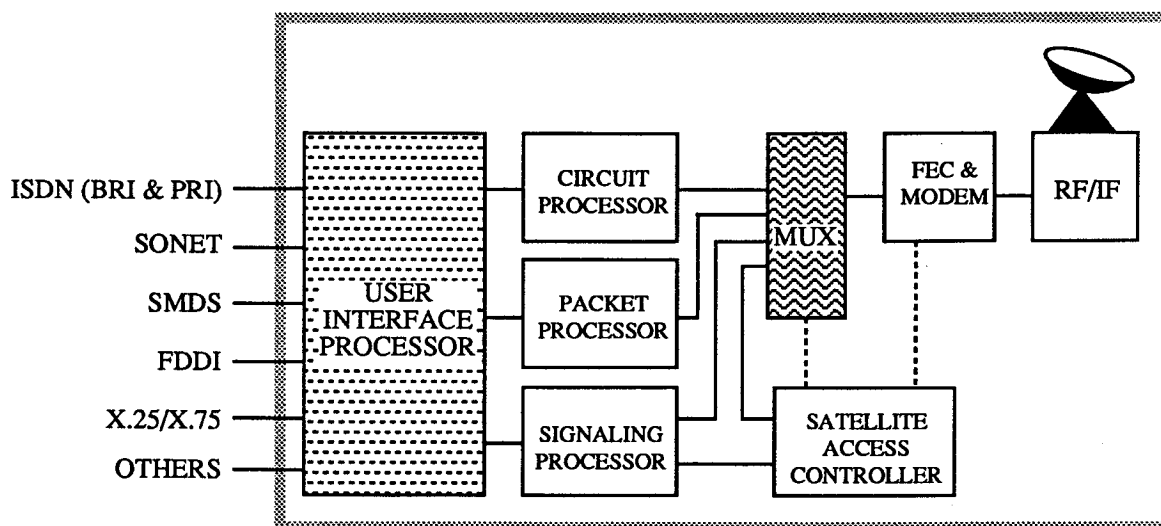
Figure 3–12: Future VSAT Configurations Must Support Emerging Communication Services
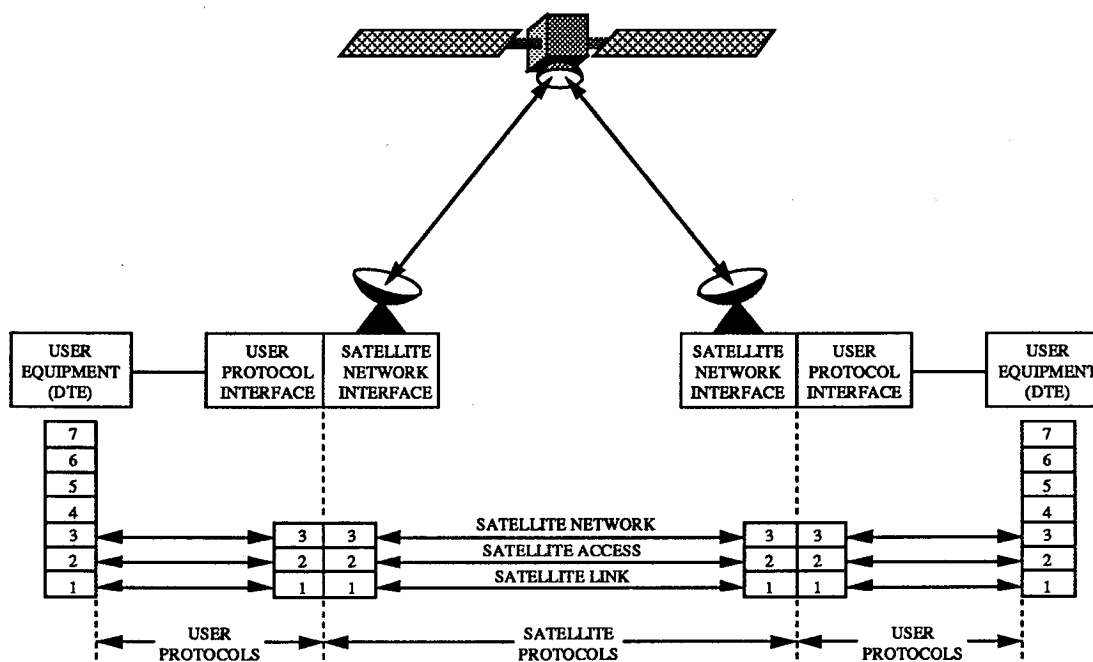
Figure 3–13: Protocol Interface Configuration for VSAT Network (OSI Model)

DTE and a number of other DTEs on the network. Each of these logical connections makes use of a virtual circuit defined at the packet level of X.25 interface. All the exchanges across the three levels of the DTE/DCE interface have only local significance. Figure 3-14 shows the X.25 interface between the DTE and the VSAT. In this environment, the VSAT acts as a DCE.

The DTE interfaces to the VSAT at the physical level using X.21*bis* which is equivalent RS-232-C. If high speed transmission facility is used then the physical level interface may be based on V.35.

The second level of the protocol called the link level procedure is based on LAPB. The link level procedure supports the reliable transfer of frames across the physical link. The reliable data transfer is achieved by supporting error control by retransmission, synchronization, and flow control.

The packet level specifies a virtual circuit service. The virtual circuit service consists of virtual call and permanent virtual circuit facilities. A virtual call is a temporary association between two DTEs and initiated by a DTE by sending a call request packet to the network on free logical channel. A permanent virtual circuit is a permanent association between two DTEs and no call set-up or clearing action is needed; thus the permanent virtual circuit is similar to a point-to-point private line.

The DTE/DCE interface is asymmetric in that only selected layer 3 protocol information is transferred end-to-end between DTEs. Much of the information such as flow control and acknowledgment, usually have only local significance. Recommendation X.25 specifies a default maximum packet size of 128 bytes but other packet sizes are negotiable between the DTE and the network. The packet layer supports features such as multiplexing, flow control, packet sequences, reset and restart, interrupt, call progress and user facilities. Some of the user facilities are optional.

Multiplexing feature allows the DTE to establish up to 4,095 simultaneous virtual circuits with other DTEs over a single physical DTE/DCE link. A DTE can have as many permanent virtual circuits and/or virtual calls active at the same time. These calls will be to a number of other DTEs in the network and the packets associated with these calls all share the same physical link and error control procedures of level 2. It is important for the network not to accept packets from a source at a rate higher than the destination. To achieve this each logical channel implements a flow control scheme by employing a window mechanism. The flow control scheme is available to the DTE as well as to the DCE, so that a subscriber can control the rate at which it receives data.

An interrupt facility allows two DTEs communicating via a virtual circuit to exchange short pieces of information in interrupt packets. They can therefore be employed to resolve conditions where neither end process can accept data and the logical channel flows have ceased. The interrupt packet bypasses the flow control procedures used for data packets and is delivered to the destination DTE at a higher priority than data packets in transit.

Recommendation X.25 provides the capability to identify a contiguous sequence of packets, which is called a complete packet sequence. This feature allows higher layer messages to be segmented to conform to network packet size restrictions. In the event that the two ends of an association can only resolve their problems by clearing the flow in a logical channel, X.25 provides the facility of resetting virtual calls and permanent virtual circuits. The reset operation clears the logical channel of all data packets and reinitializes the flow control. A restart facility clears all virtual calls and resets permanent virtual circuits associated with a particular DTE. The network itself will, in the event of internal problem, reset calls and restart DTEs.

3.2.2.2 X.75

Recommendation X.75 specifies an internetworking interface between signal terminating equipment (STE). The interworking arrangement is based on the concept of the virtual circuit. The model is based on the idea of building up an internetworking connection by concatenating a series of intra-network and gateway to gateway virtual circuits. Recommendation X.75 is practically identical with X.25. The only important difference is the presence of a network utilities field. Figure 3-15 shows the X.75 support at the VSAT earth station.

At the link level, X.75 defines both a single link procedure (SLP) and a multilink procedure (MLP) that allows the interface to operate over multiple lines and achieve greater reliability and throughput. The SLP is defined to be LAP-B. When multiple links exist between STEs, each link is governed the SLP LAPB. When multiple links are used, the set of links is used as a pooled resource for transmitting packets, regardless of virtual circuit number. When a packet is presented to MLP for transmission, any available link may be chosen. To keep track of packets, a special MLP frame is
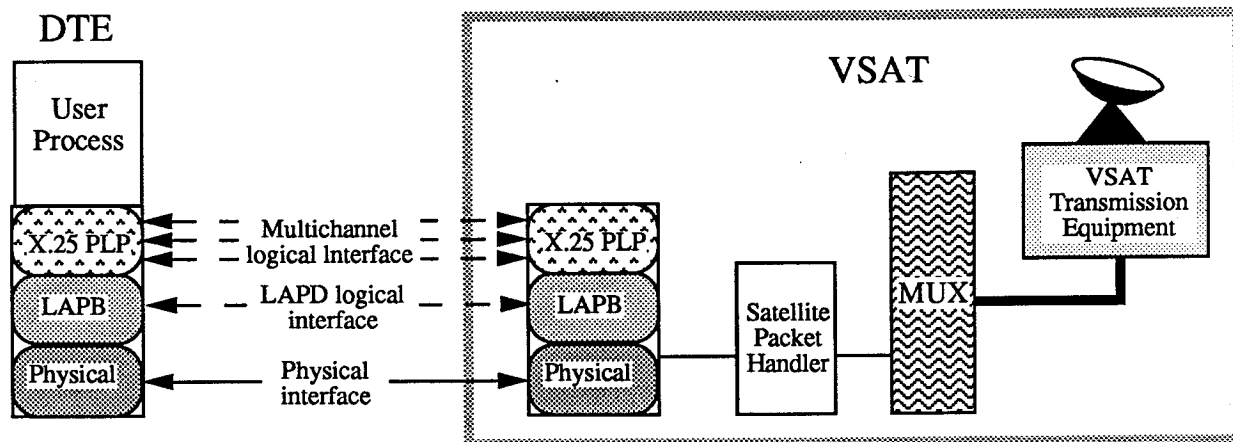
Figure 3–14: X.25 Interface Between Data Terminal Equipment (DTE) and VSAT
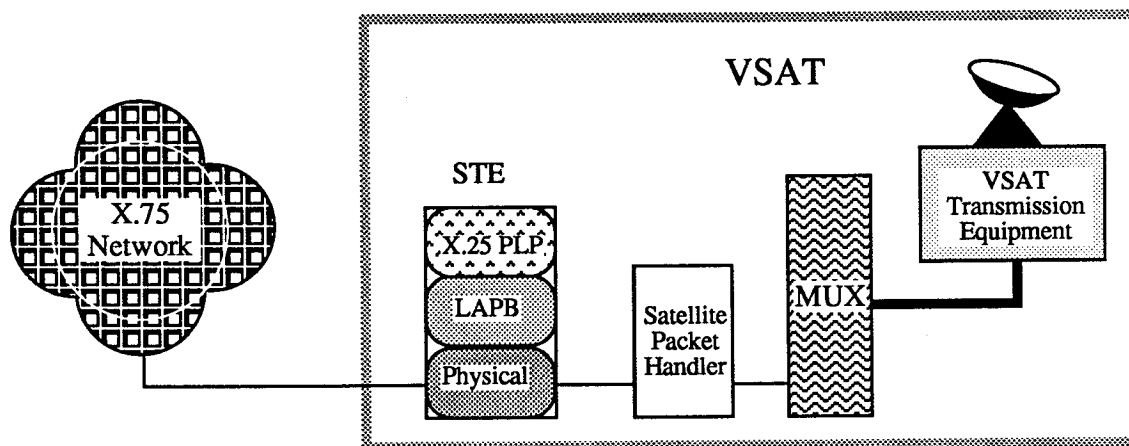
Figure 3–15: X.75 Network Interface to VSAT

defined, which consists of the packet and a two octet multilink control (MLC) field. The MLC contains a 12-bit sequence number which is unique across all links. Once an MLP frame is formed it is assigned to a particular link, and further encapsulated in an SLP frame. The SLP frame includes, the usual sequence number unique to that link.

There are two main reasons for using MLP sequence number. First, frames sent out over different links may arrive in a different order from that in which they were first formed by the sending MLP. The destination MLP will buffer incoming frames and reorder them according to MLP sequence number. Second, if repeated attempts to transmit a frame over one link fails, the STE will send the frame over one or more other links. Then, the MLP sequence number is used for duplicate detection.

3.2.2.3 ISDN

The objective of narrowband ISDN is to provided end-to-end digital connectivity to support a wide range of services by a limited set of standards multipurpose user-network interfaces. Two CCITT ISDN user-network interfaces are used for connection to end-user devices. They are the Basic Rate Interface (BRI), 2B+D, and the Primary Rate Interface (PRI), 23B+D/30B+D. The PRI offers an economic alternative for connecting digital PBXs, host computer, LANs and other devices to the network. The BRI brings CENTREX and PBX customers integrated voice and data capabilities as well as advanced voice features. Figure 3-16 shows the ISDN user interface to the VSAT network.

The physical layer is based on Recommendation I.430/I.431. Recommendation I.430 specifies the physical and electrical characteristics of the basic interface to insure digital transmission over passive bus wiring. These specifications include transmission line code, interface frame format, impedance characteristics of the cable driver/receiver, and plug and jack specification. D-channel contention resolution is required because the channel can be accessed by multiple terminals simultaneously. The basic rate interface supports two 64 kb/s circuit switched B channels to carry voice, data and one 16 kb/s packet switched D channel to carry signaling messages and other packet data. The protocol used on the B channel is application dependent.

Recommendation I.431 specifies the physical layer of the primary rate interface. Frame formats and bit rates of the primary rate interface is based on the pri-

mary digital hierarchy of existing trunk transmission systems. Recommendation I.431 defines two primary rate interfaces operating at 1.544 and 2.048 Mb/s rates. The North American PRI consists of 23 B channels and a D channel all operating at 64 kb/s. The frame format is similar to the DS1 format (30 B + D).

At the network node (VSAT), the integrated channelized access is separated into components either physically or logically, depending on the implementation, and diverted to their appropriate functions. Recommendation Q.921 and Q.931 specify the ISDN user-network interface signaling protocols. Although different physical layer protocols is defined at the physical layer, the same layer 2 and 3 protocols apply for the basic and primary rate interfaces. The D channel signaling is used to obtain a B channel for voice or data transfer. As shown in Figure 3-17, the D channel signaling is used to get a B channel which is then used for information transfer.

The data link layer protocol used in D channel is called LAPD. This belongs to the family of data link layer protocols based on HDLC procedures defined by international Standards Organization (ISO). Recommendation Q.921 specifies layer 2 functions such as link establishment/release, error control, sequence control, and frame synchronization. In addition, ISDN LAPD protocol supports multiple layer 3 entities and multiple terminal equipments on one interface using octets of addressing via Data Link Connection Identifiers (DLCIs). To differentiate between different logical link connections, the address field is divided into two subfields: the service access point identifier (SAPI) and terminal end point identifier (TEI). LAPD supports multiple frame operation with modulo 128 for point-to-point information transfer associated with most call control. Unacknowledged information procedures in LAPD handle broadcast information transfer for initial call setup to a passive bus from the network.

Currently, there are four values of SAPI defined for use and the rest are reserved:

i. SAPI = 0 used for signaling,

ii. SAPI = 1 reserved for packet communications using Q.931 call control procedures,

iii. SAPI = 16 used for packet communications conforming to X.25 level 3 procedures,

iv. SAPI = 63 used for layer 2 management procedures.
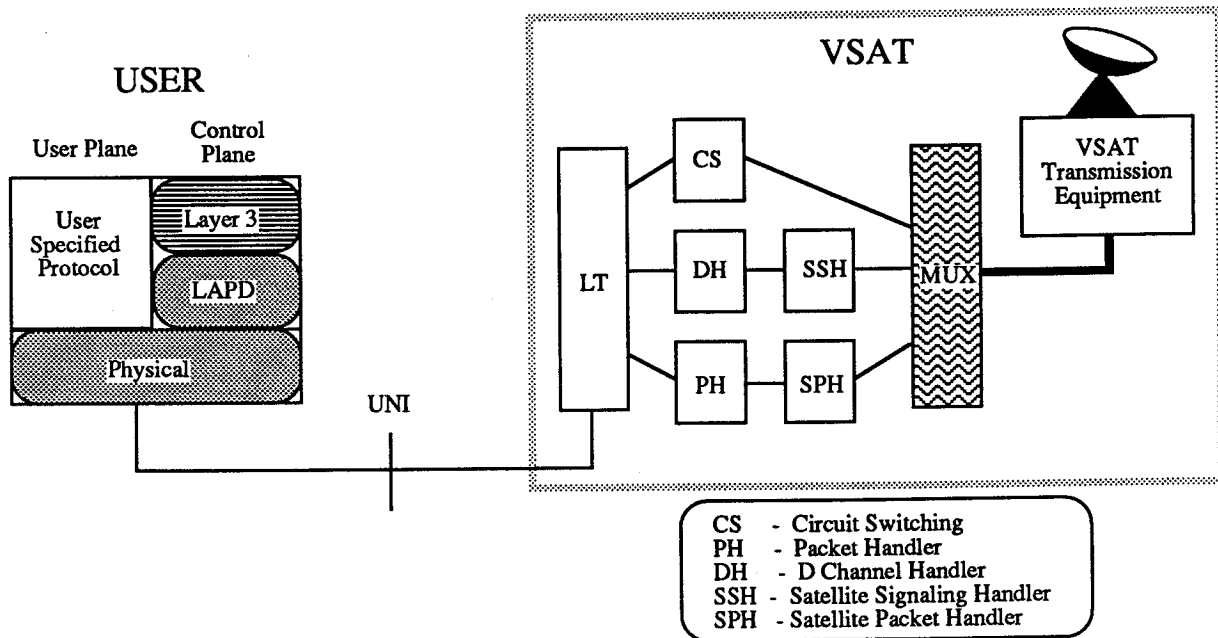
Figure 3–16: ISDN User Interface to VSAT Network

Thus, in most implementations, for D channel X.25 information transfer, X.25 layer 3 procedures are indicated at the data link layer by a SAPI value of 16. Those X.25 frames are routed based on recognition of this layer 2 SAPI to an X.25 packet handling function.

Recommendation Q.931 specifies the network layer protocol used for call control. It defines the protocol for establishing, maintaining, and clearing network connection such as:

• Circuit switched connection using B channel,

• Packet switched connection using either B or D channel,

• User-to-user signaling connection using the D channel.

The Q.931 message format consists of two main parts, (1) the common part which is common to all the messages, and (2) the message-specific part. The message specific part is composed of a number of information elements that are either mandatory or optional for a particular message.

The four common information elements that appear in each layer 3 message in the same order are: protocol discriminator, length of call reference value, call reference value, and message type information element. The call control messages are grouped into four types and the message types and the messages are listed below:

i. Call Establishment Message: ALERTING, CALL PROCEEDING, CONNECT, CONNECT ACKNOWLEDGE, PROGRESS, SETUP, SETUP ACKNOWLEDGE.

ii. Call Information Phase Message: SUSPENDING, SUSPEND ACKNOWLEDGE, SUSPEND REJECT, RESUME, RESUME ACKNOWLEDGE, RESUME REJECT, USER INFORMATION.

iii. Call Clearing Message: DISCONNECT, RELEASE, RELEASE COMPLETE, RESTART, RESTART ACKNOWLEDGE.

iv. Miscellaneous Messages: CONGESTION CONTROL, FACILITY, INFORMATION, NOTIFY, STATUS, STATUS INQUIRY.

Recommendation Q.932 contains generic procedures for the control of ISDN supplementary services. Supplementary services provide additional capabilities to be used in conjunction with telecommunications services. Supplementary services cannot be offered to a customer on a stand alone basis.

Figure 3-17 shows the support of circuit mode bearer service in a VSAT environment. The terminal uses the Q.931 call control messages to get a B channel from the VSAT network. This signaling information is passed on to the satellite network signaling system. The VSAT

network based on the information contained in the signaling messages obtains a suitable channel in the satellite network. This channel is connected to the selected B channel at the VSAT earth station and an end-to-end circuit switched path is established. The terminal can use this circuit switched path to transfer information. The protocol used is application specific.

Figure 3-18 shows the support of X.25 service using B channel in ISDN. As in the previous case, the D channel is used to obtain a B channel. The Q.931 control messages are terminated by the VSAT network. The VSAT earth station is assumed to support a Packet Handler function. This Packet Handler acts as an X.25 DCE. The intra-network packet protocol support is vendor specific. This is represented by the satellite packet handler function (SPH).

Once the B channel is assigned to the terminal, the terminal uses the X.25 protocol to connect to the Packet Handler in the VSAT. The protocols are similar to the one explained under X.25 support. The terminal uses the X.25 in-band call setup procedures to setup a logical channel to the end user. At the end of data transfer the terminal releases the logical channel, again by using the in-band X.25 call release procedures.

After this event, the B channel is released using the D channel Q.931 call control messages. This assumes that the terminal is an ISDN TE1. If the terminal is not an ISDN Terminal Type 1, a Terminal Adaptor (TA) is used to convert the attached terminal to an ISDN TE1.

Figure 3-19 shows the X.25 support using D channel. The X.25 packet are carried in LAPD frames instead of LAPB frames as in X.25 support using B channel. The X.25 packet are carried in LAPD frames using SAPI=16. The signaling (Q.931) messages are carried in LAPD frames using SAPI=0.

The X.25 Packet Level protocol uses the X.25 packet level in-band call setup messages to establish a virtual circuit to the destination terminal. The VSAT earth station D-channel handler, uses the SAPI value of 16 to collect the X.25 data packets and forwards them to the satellite packet handler. Figure 3-19 also shows the a Packet Handler, that support X.25 service over a B-channel.

3.2.2.4 FDDI

Figure 3-20 shows the FDDI (Fiber Distributed Data Interface) support in VSAT environment. Fiber Distributed Data Interface (FDDI) is a 100 Mb/s local area network. Using optical fiber as the medium, the FDDI protocol is based on a token ring access method. The protocol architecture for FDDI support at the VSAT is as shown in the figure.

The physical layer consists of two sublayers called the Physical Layer Medium Dependent (PMD) and Physical Layer Protocol (PHY). PMD specifies the lower sublayer of the physical layer. The functions supported by the PMD include power levels and characteristics of the optical transmitter and receiver, interface optical signal requirements, the connector receptacle footprint, the requirements of confirming optical cable fiber cable plant and the permissible bit error rates. There are two alternative versions of the PMD, one of which allows the use of single-mode optical fiber.

The VSAT earth station must support the PHY which forms the upper sublayer of the physical layer. The function supported include encode/decode, clocking and framing for transmission. The VSAT interfaces to the users using a pair of counter rotating rings. PHY simultaneously receives and transmits. The transmitter accepts symbols from MAC, converts these to five-bit code groups, and transmits the encoded serial data stream on the medium. The receiver recovers the encoded serial data stream from the medium, establishes symbol boundaries based on the recognition of a start delimiter, and forwards decoded symbols to the MAC. Addition symbols (QUIET, IDLE, and HALT) are interpreted by the PHY and used to support SMT functions. PHY also provides the bit clocks for each station. PHY provides an elasticity buffer which is always inserted between the receiver and transmitter. The receiver employs a variable frequency clock, using standard techniques such as a phase-locked loop oscillator, to recover the clock of the previous transmitting station from the received data. The transmitter, by contrast, uses a local fixed frequency clock. The transmitter clock has been chosen with .005% stability.

FDDI MAC forms the lower sublayer of the data link layer. FDDI MAC supports a superset of the services required by the Logical Link Control (LLC). The MAC layer schedules and performs all data transfer on the ring. Each station on the ring repeats the frame it has received from its upstream neighbor to its downstream neighbor. If the destination address of the frame matches that MACs address and there is no error indicated, then the frame is copied into the local buffer with MAC notifying LLC (or SMT) of the frames arrival. If a MAC has a frame from LLC to transmit, it may do so
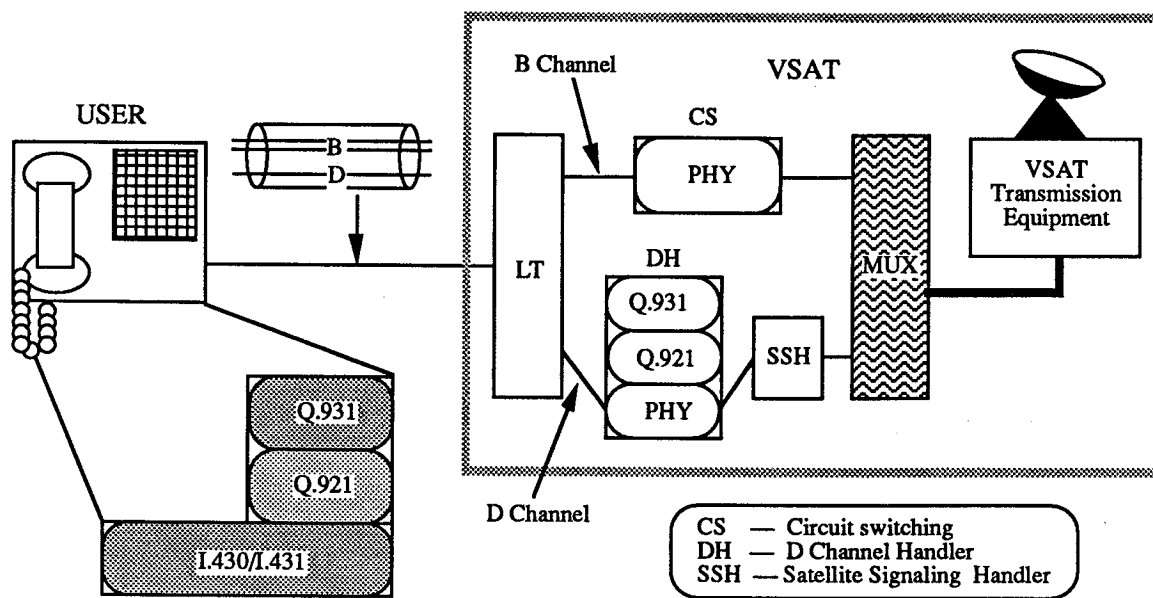
Figure 3–17: ISDN Circuit Mode Bearer Service in a VSAT Environment
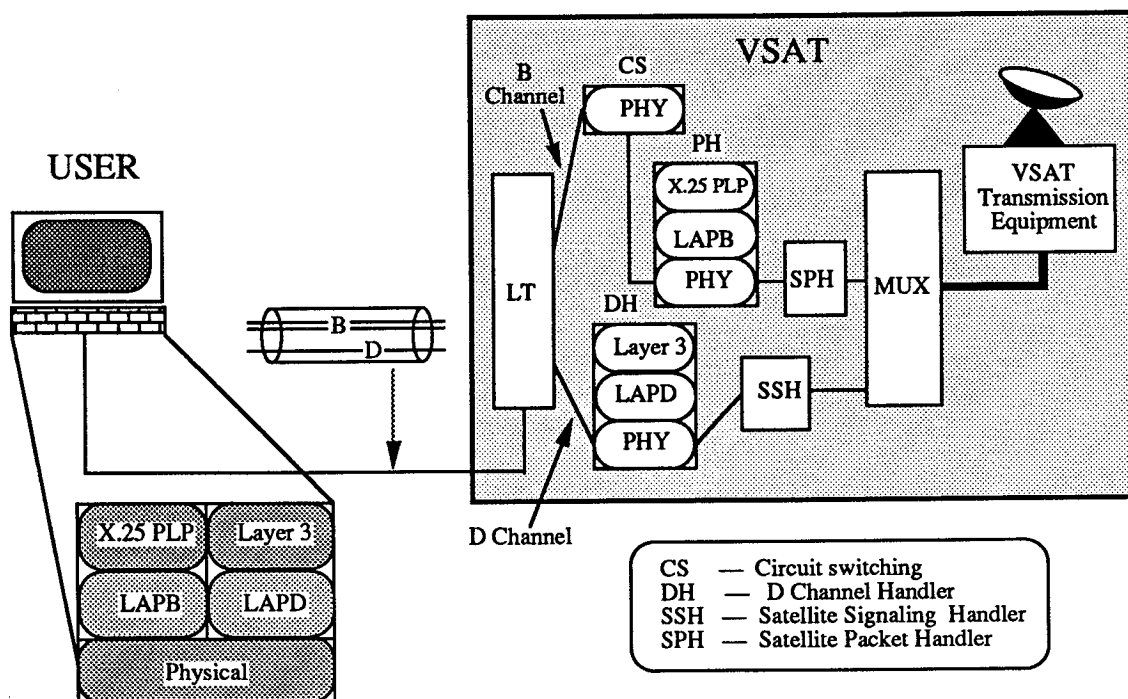
Figure 3–18: ISDN Packet Switched Service (X.25) Using the B-Channel
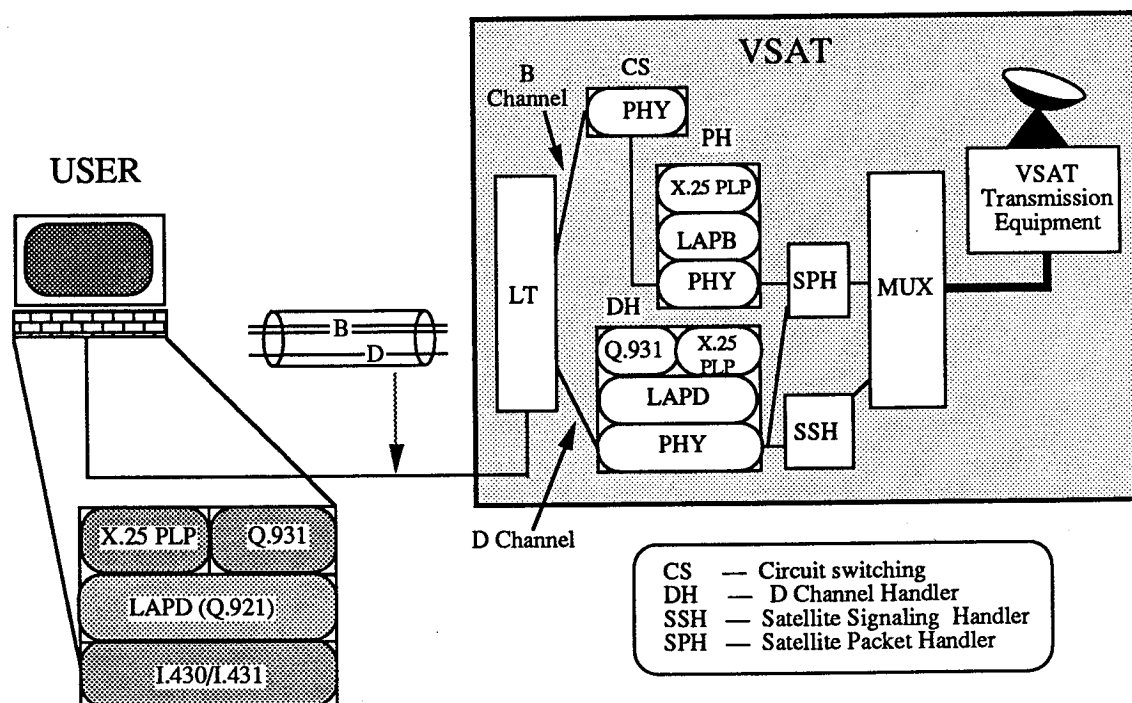
Figure 3–19: ISDN Packet Switched Service (X.25) Using the D-Channel
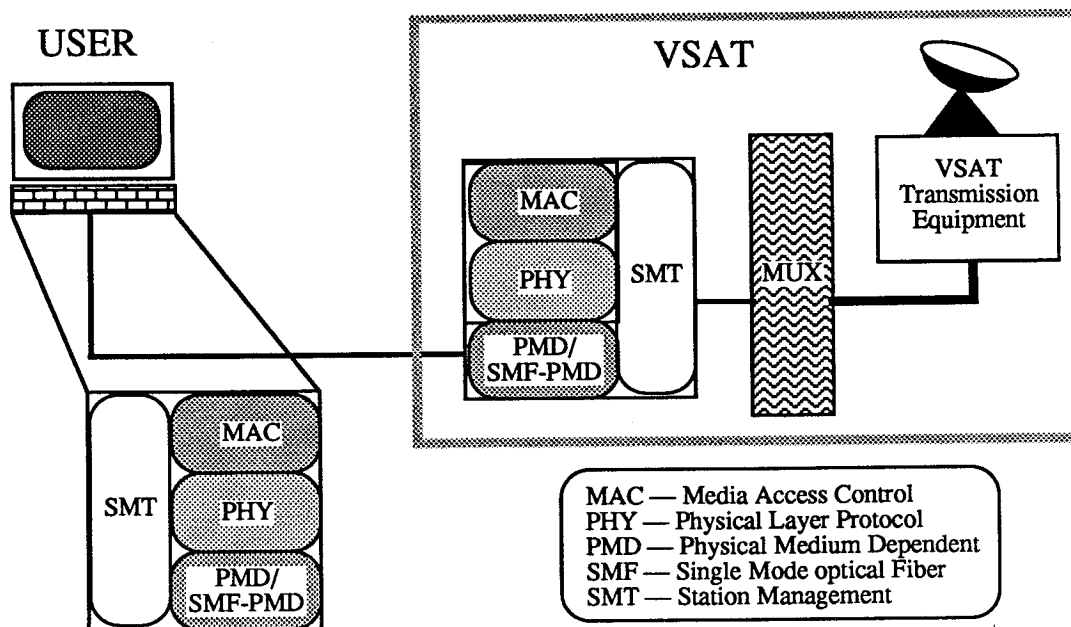
Figure 3–20: Fiber Distributed Data Interface (FDDI) Support in a VSAT Environment

only after a token has been captured. The FDDI MAC uses a Timed Token Rotation (TTR) protocol to control access to the medium. Two classes of services are defined.

i. Synchronous service allows user of a token whenever MAC has synchronous frames queued for transmission.

ii. Asynchronous service allows use of token only when the time since a token last was received has not exceeded the established Target Token Rotation Time (TTRT).

Station Management (SMT) is the local portion of the network management application process, including the control required for proper operation of an FDDI station in an FDDI ring. SMT monitors activity an exercises overall control of station activity. These function include control and management within the station for such purposes as initialization, activation, performance monitoring, maintenance, and error control. In addition, SMT communicates with other SMT entities on the network for the purpose of controlling network operation. The SMT Connection Management (CMT) function establishes the physical connections between adjacent stations. Once a physical connection is established, SMY creates a logical configuration within the station by activating the appropriate paths between the PHY and MAC entities within that station. The VSAT earth station has to provide all the above function to support FDDI. Once the LLC frame is received at the VSAT earth station it can be carried internally using intra-network protocols.

3.2.2.5 SMDS

SMDS (Switched Multimegabit Data Service) is a high-speed, connectionless, public, packet switched data service that will extend Local Area Network performance beyond the subscribers premises, across a wide area. SMDS interface protocol is a connectionless protocol based on the Distributed-Queue, Dual-bus (DQDB) medium access control (MAC) protocol as defined in the IEEE 802.6 standard. Figure 3-21 shows the SMDS architecture at the VSAT earth station to support SMDS services.

At the physical layer both DS3 and DS1 based access interfaces are supported. SMDS supports single CPE access and multiple CPE access arrangement based on the DQDB protocol. While the DS3 based access

path can support both single CPE and multiple CPE access arrangements, the DS1 access path supports only the single CPE access arrangement. The access DQDB to a network supporting SMDS (VSAT earth station) is based on the open bus topology.

The VSAT earth station should support the SMDS interface protocol (SIP). SIP is a connectionless protocol based on the distributed Queue dual bus MAN MAC protocol. The SIP consists of three protocol layers whose functions include addressing, framing, error detection, and physical transport.

SIP level 3 contains the appropriate SMDS addressing information for the data unit passed from the level 3 user, as well as a means to detect lost SIP level 2 PDU. SIP level 2 functions include bit error detection and framing for a SIP level 3 PDU through the use of fixed length slots. Level 2 also includes segmentation and reassembly functions on the variable length level 3 PDU. The SIP level 1 provides physical layer functions, e. g. bit level transmission across the physical facilities.

A SIP level 3 PDU is formed by adding a level 3 header and trailer to the user data unit. The user data unit can be up to 9,188 octets. The header is 43 octets long and consists of 10 fields. The trailer is 4 octets long and is made up of 3 fields. Once a level 3 PDU is received the VSAT earth station SMDS interface performs validation procedures including checking whether the various fields of the header and trailer are valid.

A SIP level 2 PDU consists of a 44 octets data unit, 7 octets level 2 header and a 2 octets trailer. The SIP level 2 takes a level 3 PDU and segments the level 3 PDU and prepend header and append trailer to each segment to form one or more level 2 PDUs for transmission. Each level 2 PDU shall have 44 octet segment unit field to carry the segmented L3_PDU information. However, the lat L2_PDU may only be partially filled since the L3_PDU may not contain an integral number of 44 octet segments. If the last L2_PDU contains less than 44 octets of the level 3 data unit, it shall be padded to 44 octets using zeros. The header of the L2_PDU shall include a segment type field, a MID field, network control information, and access control field. The trailer shall include a payload length field and a payload CRC. The segment type field issued to indicate if an L2_PDU is a single, beginning, continuation, or end segment (SSM, BOM, COM, or EOM). The MID field is used to identify the L3_PDU to which the L2_PDU belongs, except in the case where only one L2_PDU is needed to transmit a full L3_PDU. Therefore, in cases
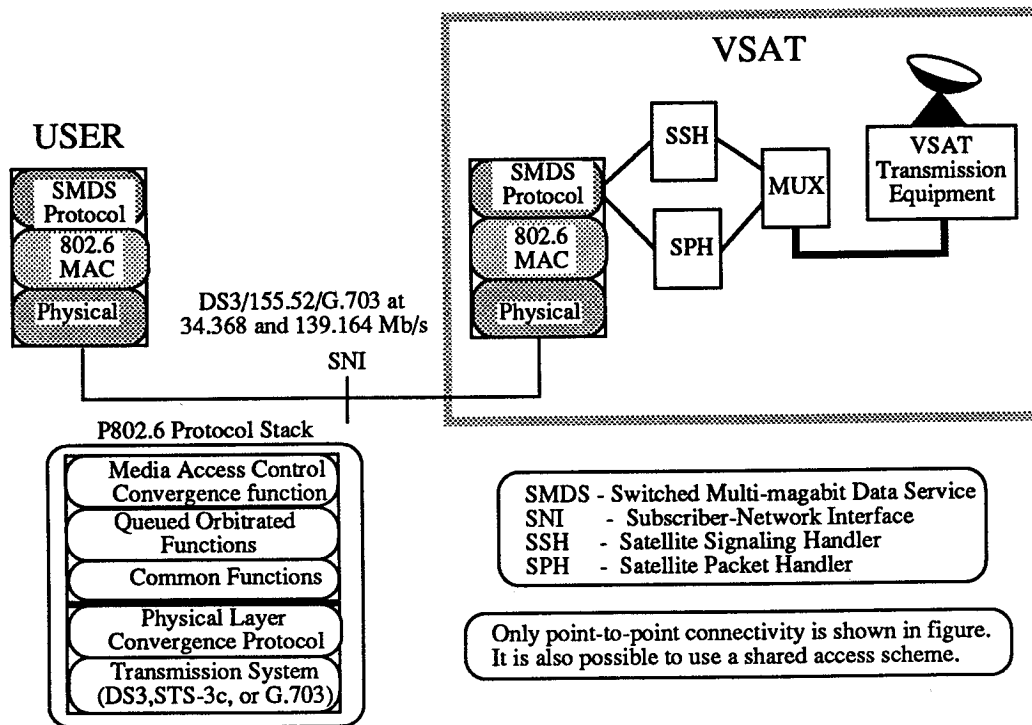
Figure 3–21: Switched Multimegabit Data Service (SMDS) Interface

where more than one L2_PDU is required to transfer an L3_PDU, the transmitting Level 2 entity assigns an MID to each L3_PDU. An L3_PDU's MID shall be unique among L3_PDUs being simultaneously transmitted in a given direction on the access DQDB.

The SIP level 1 is divided into two parts, the physical convergence protocol (PLCP) and the transmission system sublayer. The transmission system sublayer defines the characteristics and the method of attachment to the transmission link. The transmission system sublayer is defined as a DS3 interface and a DS1 interface. The PLCP adapts the service of the transmission system sublayer into generic physical layer service. The PLCP defines a method of mapping the SIP level 1 control information and L2_PDUs into a format that is suitable for the transmission system sublayer.

3.2.2.6 BISDN

The protocol architecture to support BISDN (Broadband ISDN) at the VSAT earth station is presented in Figure 3-22. The BISDN protocol layers consists of a service independent core layer called the ATM layer, which performs cell transfer and switching for various B-ISDN services and service dependent ATM adapta-

tion (AAL) layer. The AAL layer performs cell assembly/disassembly along with service dependent functions. The VSAT earth station supports only one AAL layer which is related to the signaling function.

An ATM transport consists of two layers: the ATM layer and the Physical Layer. The physical layer consists of two sublayers: physical medium sublayer and transmission convergence sublayer. The physical medium sublayer supports a symmetric 155.52 and 622.08 Mb/s, and the physical layer interface can be based on Synchronous Digital Hierarchy (SDH) or cell based.

The functions supported by this layer are the generation and reception of waveforms suitable for the medium, and the insertion and extraction of bit timing information. The transmission Convergence Sublayer supports functions such as:

- Cell delineation to identify the cell boundary according to the cell self-delineating mechanism.

- Cell rate decoupling is related to the insertion and suppression of idle cells to adapt the rate of valid cells to the payload capacity of the transmission system.
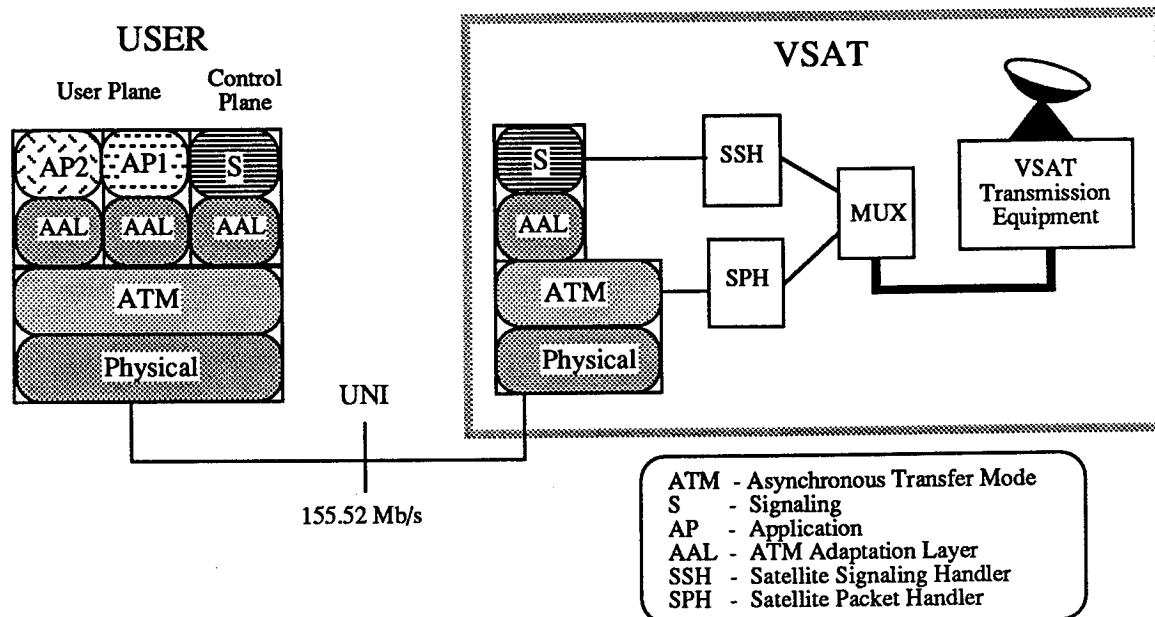
Figure 3–22: Broadband ISDN Interface Using ATM

- HEC sequence generation and cell header verification.

- Transmission frame generation and recovery.

- Transmission frame adaptation adapts the cell flow into the payload structure of a transmission frame (a cell equivalent or an SDH envelope), and extracts the cell flow out of a transmission frame.

ATM (Asynchronous Transfer Mode) is a connection oriented technique, and the ATM layer is physical medium independent. The ATM layer supports the concept of Virtual Paths and Virtual Channels. The Virtual paths and virtual channels are identified using virtual path identifier (VPI) and virtual channel identifier (VCI) respectively. The ATM layer transports information using fixed size cells of 53 octets out of which 5 octets are used for ATM cell header. The contents of the cell header supports ATM layer function only. The cell header represents the functions supported by the ATM layer. A virtual connection is identified by cell header field and the attributes of the connection are negotiated using the signaling protocol. The ATM layers supports the following functions:

- Cell multiplexing/demultiplexing;

- Cell Switching and VPI/VCI translation,

- Cell header generation/extraction (without the HEC),

- Generic flow control,

- Quality of Service.

In addition, the VSAT earth station should also support BISDN signaling capabilities. These functions are for further study by the CCITT.

3.2.2.7 SONET

Figure 3-23 shows the SONET interface at the VSAT earth station. In the approach shown in the figure, the virtual tributaries are demultiplexed and them mapped on to the appropriate services within the VSAT mesh network. Another approach is to map the incoming virtual tributaries on to the appropriate outgoing SONET frames. In this case the VSAT mesh network provides an end-to-end circuit mode service.

3.3 Network Requirements for Mesh VSAT Networks

Chapter 3 of this report presented a comprehensive examination of the current status and future outlook of VSAT market applications. Based on this information,
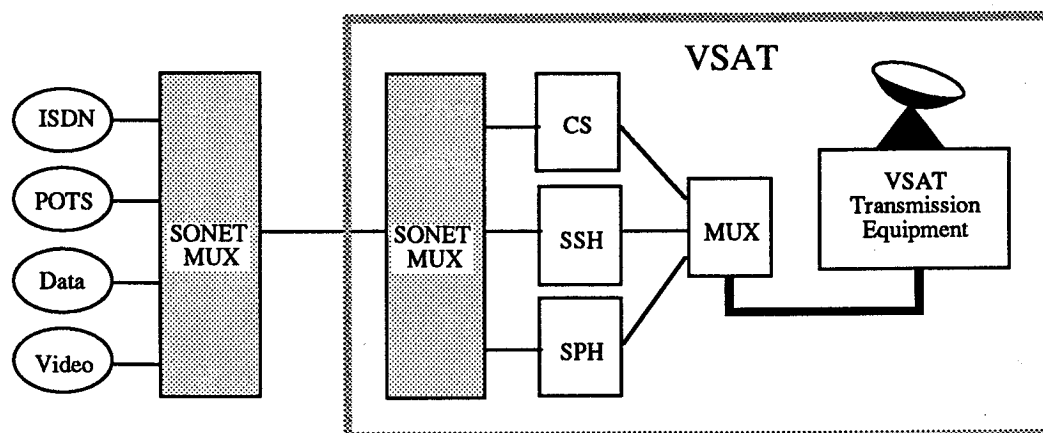
Figure 3–23: SONET Interface at the Earth Station

the network requirements for a mesh VSAT system in the year 2010 can be summarized in three categories: traffic projections, service requirements, and general network requirements.

3.3.1 Traffic Projections

Traffic projections for year 2010 in the U. S. show that the expected number of VSAT terminals at Ku-band is around 250,000. The projected number of Ka-band VSAT terminals in the same time frame is slightly less, at about 200,000 terminals. Of the all the VSAT terminals, 30% will have transmission requirements from 16 to 384 kb/s, another 30% from 384 to 768 kb/s, another 30% from 768 kb/s to 2 Mb/s, and the remaining 10% from 2 Mb/s to 4 Mb/s.

3.3.2 Service Requirements

VSAT service requirements include voice services, data access and distribution, image networking and distribution, LAN–WAN connectivity, ISDN and BISDN services, video conferencing, and video distribution. These services have widely differing characteristics as to data rate, performance requirements, utilization factors, type of switching, etc. Therefore, it is important for an advanced VSAT system design to be flexible enough to accommodate a wide variety in service characteristics.

3.3.3 General Network Requirements

General network requirements are for a full mesh point-to-point and point-to-multipoint systems at Ku-band and Ka-band. Data rates range from 16 kb/s to 4.096 Mb/s with VSAT size ideally as small as possible but not to exceed 2.4 m diameter. Traffic type could be either circuit switched or packet switched and the system should be flexible enough to accommodate both types in an economical manner.

With these general network requirements in mind, the next section presents alternate satellite architectures that would be suitable for advanced mesh VSAT networks.

3.4 Satellite Architectures

Suitable satellite architectures for mesh VSAT networks will very likely employ a spot beam coverage pattern to achieve the high uplink gain and downlink EIRP required for mesh connectivity between small aperture terminals. In this section, four different architectures that employ spot beam coverage are presented and described. The four architectures differ in their complexity and their flexibility to accommodate various user requirements.

Architecture 1 is a fixed multibeam architecture with bent pipe connectivity between uplink and downlink beams established through a reconfigurable static IF switch.

Architecture 2 adds on-board regeneration and forward error correction (FEC) functions to Architec-

ture 1 to improve the communication link performance, but does not include any on-board processing of the baseband signals.

Architecture 3 employs the same fixed spot beam coverage pattern as Architectures 1 and 2, but includes on-board baseband processing functions such as switching, retiming, and multiplexing. This results in more complexity on-board the satellite but offers added flexibility and improvement in link performance.

Architecture 4 represents a departure from the fixed beam coverage patterns of Architectures 1–3 in that it uses very narrow hopping beam coverage which results in higher gains at the expense of TDMA operation at the earth stations.

3.4.1 Architecture 1

Architecture 1 is a fixed multibeam system very similar to the one suggested by Stanford Telecom [1]. It provides CONUS size regional coverage through 4 elliptical shaped uplink beams (Figure 3-24) and 24 downlink spot beams (Figure 3-25). (The use of more uplink beams could decrease required VSAT size and/or transmit power, but there would be greater complexity in the frequency reuse plan and IF switch.)

3.4.1.1 Beam Coverage

Both the uplink and downlink beams are positioned in a fixed overlapping pattern that covers the entire region. The downlink beams may be shaped differently and have varying coverage patterns per beam to optimize the coverage, however for simplicity it is assumed the beams are circular in shape.

Isolation between the four uplink beams is maintained through spatial separation and cross polarization so that adjacent uplink beams will have alternate vertical and horizontal polarization. This should provide on the order of 30 dB of isolation among the uplink beams. On the downlink, isolation is maintained through a combination of spatial separation, cross polarization, and frequency division.

Like all architectures considered in this study, Architecture 1 is described for both Ku-band and Ka-band coverage, however the Ka-band system generally results in a higher system capacity due to the wider bandwidth available at Ka-band. Uplink beams at Ka-band
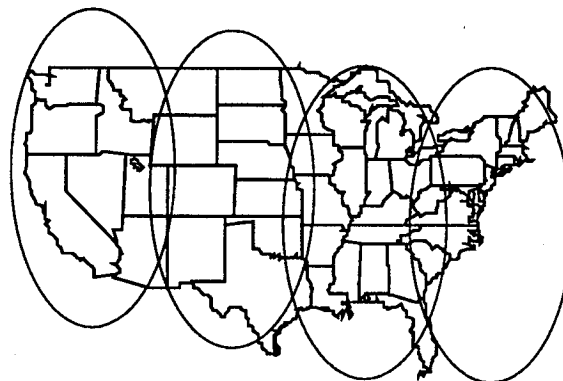
Figure 3–24: Uplink Beam Coverage
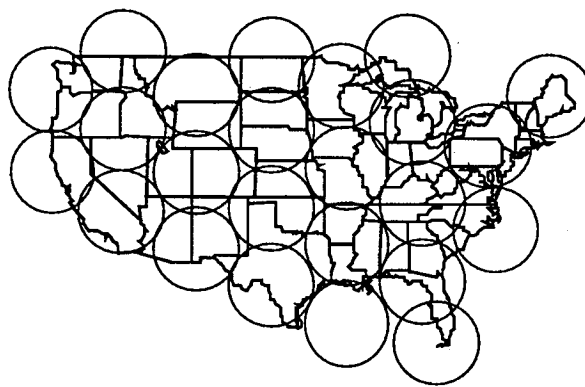
Figure 3–25: Downlink Beam Coverage

are allocated 1 GHz of bandwidth each. Hence the total system capacity is 4 GHz on the uplink. Due to the number of downlink spot beams, frequency division has to be used among adjacent beams that have the same polarization. Therefore, each of the downlink beams at Ka-band is allocated only a fraction of the available 1 GHz bandwidth.

In a worst case scenario, a downlink spot beam would have six adjacent neighbors three of which would have the same polarity, and hence only 250 MHz of bandwidth can be used by each beam. Assuming 250 MHz is allocated for each downlink beam, the total downlink capacity would be 6 GHz which is 50% more than the uplink capacity. This feature is utilized to provide flexible allocation of spacecraft resource to meet traffic demands. At Ku-band on the other hand, the bandwidth allocation per uplink beam is limited to the available 500 MHz, for a total uplink bandwidth capacity of 2 GHz. Downlink beams are allocated up to 125 MHz each in a worst case scenario, with a total downlink bandwidth capacity of 3 GHz.

3.4.1.2 Connectivity Between Beams

Connectivity between uplink and downlink beams is maintained by a static IF switch configuration which allows a flexible allocation of bandwidth for a given uplink-to-downlink connection up to the downlink beam bandwidth capacity. This allocation is done in increments of 20 MHz at Ka-band and 10 MHz at Ku-band. For each uplink beam, there will be 24 fixed allocations each corresponding to one of the downlink beams. For each downlink beam, there will be at least 4 fixed allocations corresponding to each one of the four uplink beams. Assuming a total useful bandwidth capacity of 960 MHz per beam at Ka-band and 480 MHz per beam at Ku-band, this fixed allocation utilizes half the available bandwidth for each system. The other half is flexibly allocated among those spot beams with higher traffic requirements and the allocation can be changed as the traffic requirements change.

Because uplink-to-downlink connectivity is implemented through frequency channelization, stations that wish to simultaneously communicate with several other stations in different downlink beams will have to transmit multiple carriers, with at least one carrier for each downlink beam to which there is traffic. This is particularly unsuitable for broadcast mode (point-to-multipoint) transmissions since a station may have to duplicate its transmission on up to 24 carriers, hence requiring more equipment and utilizing more bandwidth.

One possible method for meeting the requirements for point-to-multipoint transmission is to designate one (or possibly more) of the frequency slots on each of the uplink beams for broadcast transmissions. The four broadcast slots will have the same center frequency and bandwidth, and will be shared in FDMA mode by all stations transmitting in broadcast mode. A combiner on-board the satellite is used to mix the four signals from the uplink beams and route them to a frequency slot in each of the downlink beams. This way the number of fixed-allocation uplink slots increases to 25 and the number of fixed-allocation downlink slots increases to 5. Such an arrangement guarantees most efficient use of the bandwidth resource and simple implementation on-board the satellite.

3.4.1.3 Block Diagram

A functional block diagram of Architecture 1 is shown in Figure 3-26. It consists of the receive antenna, LNA and downconverter, input demultiplexer, a reconfig-urable static IF switch, output multiplexers, up convertor and SSPA's, and downlink spot beam antennas. The IF switch acts as a space switch connecting uplink channels from the four uplink beams with downlink channels in the 24 downlink beams. Some of the interconnections are reconfigurable through ground command while others are fixed to connect each uplink to every one of the downlink beams. For the case where the allocated downlink capacity is 50% greater than the downlink capacity, a simple switch implementation can utilize a number of smaller 4x6 switches arranged in parallel, with inputs and outputs routed from and to the desired beams.

3.4.1.4 Access Scheme

Since this architecture involves a frequency translation receiver which does not include any on-board processing functions, a station which has traffic for a number of downlink beams will have to access each beam at a different frequency. Satellite channel access can be either through frequency division multiple access (FDMA), time division multiple access (TDMA), or multi-frequency time division multiple access (MF/TDMA).

With MF/TDMA, a station wishing to communicate with several downlink beams hops its transmission in TDMA mode among the frequencies associated with the downlink beams. A central controller will have to coordinate the TDMA time slot assignments on both the transmit and receive sides to ensure that no time slot overlap occurs at either side. Further, MF/TDMA transmission requires VSAT's to transmit bursts which are at a transmission rate that is higher than their actual traffic requirements. This may place undue requirements on the VSAT size, transmit power levels, or satellite antenna gain. For this same reason, TDMA also becomes unsuitable in this particular case.

The remaining transmission access method, FDMA, is more suited for this architecture. In FDMA, a VSAT uses frequency synthesized oscillators to transmit a continuous carrier at the uplink frequency which corresponds to the desired destination beam. SCPC is a form of FDMA where carriers are generally at a low basic rate (e.g. 64 kb/s) and carry a single channel. Each carrier will be active for the duration of a call and the actual transmission frequency could be demand assigned. For voice traffic, voice activation can be used to better utilize the transponder bandwidth.
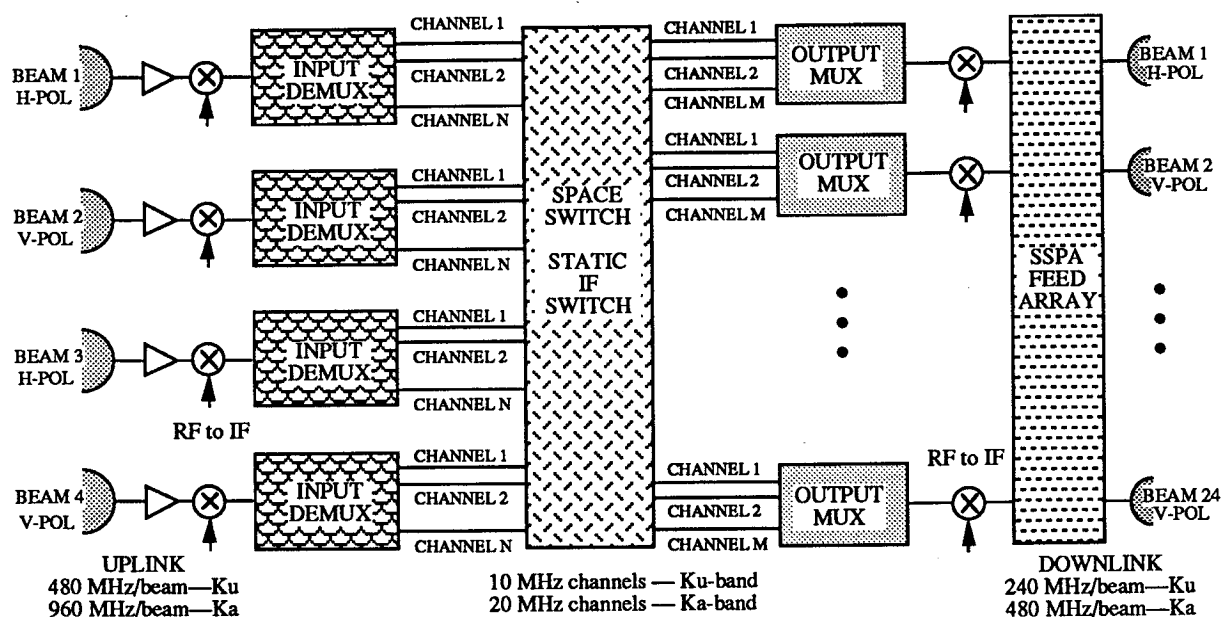
Figure 3–26: Architecture 1 Uses Static IF Switch to Establish Connectivity

In FDMA mode, a carrier transmitting to several stations in the same downlink beam or several channels to the same station can use a TDM carrier on which it multiplexes all its transmissions. However, it is more likely that the station will have traffic requirements to several beams simultaneously, in which case it has to transmit multiple carriers. For this reason, single channel per carrier (SCPC) FDMA seems to be the preferred channel access method.

3.4.2 Architecture 2

Architecture 2 is very similar to Architecture 1 in that it employs the same fixed multibeam coverage shown in Figures 3-24 and 3-25. It also uses a reconfigurable static IF switch to achieve uplink to downlink beam connectivity through frequency channelization. It differs from Architecture 1 in that it includes an on-board regeneration package and on-board FEC to improve the link parameters compared to a bent pipe system. It does not include, however, any baseband processing functions such as baseband switching or retiming, although it does provide rate conversion between the uplink FDMA carriers and downlink TDM carriers through multi-carrier demodulation.

A functional block diagram of Architecture 2 is shown in Figure 3-27. A multi-carrier demodulator unit

is assigned to each of the uplink frequency channels in the four uplink beams. The MCD unit also includes a shared soft decision FEC decoder. The MCD/FEC unit output TDM stream is FEC encoded and modulated by the on-board modulator units on a QPSK carrier at IF. The IF TDM carriers are then switched by the reconfigurable IF switch matrix, which is identical to the one in Architecture 1, to the downlink frequency slots. Hence, earth stations in the downlink beams receive a single TDM carrier in each frequency slot.

The use of on-board regeneration in Architecture 2 provides for some improvement in the link performance compared to a bent pipe receiver. This improvement could be two fold, in the form of an increase in the overall link performance due to the separation of uplink noise from the downlink noise, and in the form of better rain margins and hence availability since uplink fades are not reflected on the downlink as downlink fades. On-board regeneration also provides for optimizing the uplink transmissions and the downlink transmission independently. This includes using different FEC rates and possibly modulation formats on the uplink and the downlink to achieve the best overall link performance.

Due to the fact that an IF switch is still utilized, this architecture does not have the flexibility that an architecture with on-board baseband switching can provide. Uplink access still has to be in FDMA mode and a sta-
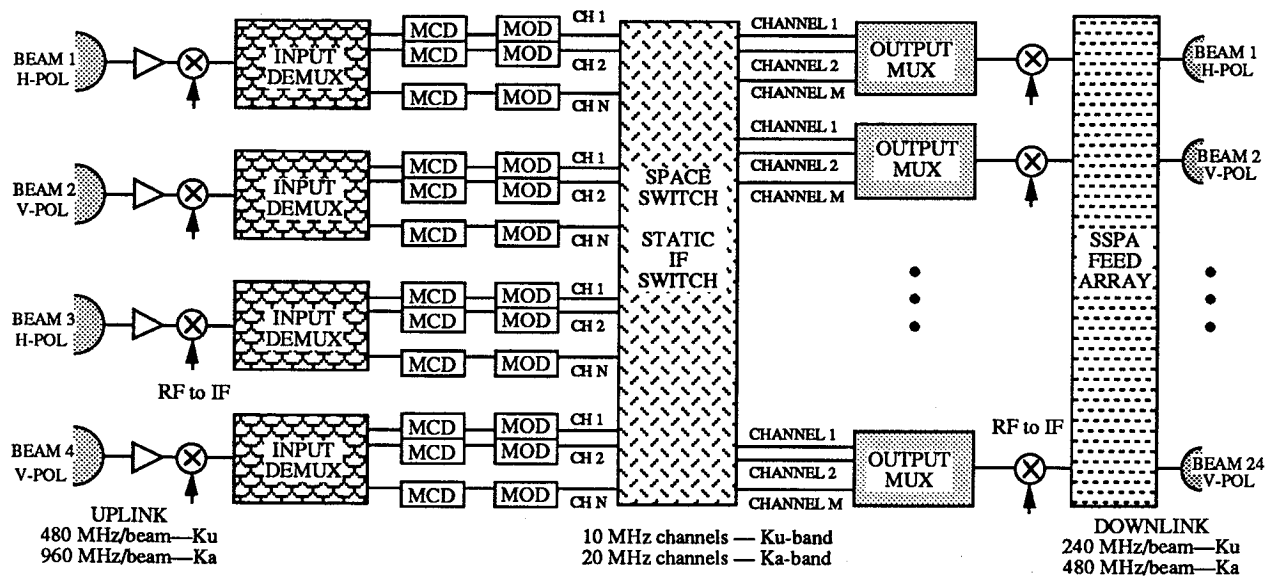
Figure 3–27: Architecture 2 Adds On-Board Regeneration

tion with simultaneous traffic requirements for several downlink beams will have to transmit at different carrier frequencies. Stations receiving traffic from different uplink beams will also have to do so at different carrier frequencies although the number of downlink carriers is substantially reduced by using the TDM downlinks.

Finally, the improvement in link performance due to on-board regeneration allows higher transmission rates on the uplink compared to Architecture 1. Hence, uplink access can be either SCPC/FDMA or TDM/FDMA. Multi-frequency TDMA can also be used although the practical limit imposed on the TDMA carrier rates may limit the usefulness of this access method. In either case, a demand assigned system remains the best approach.

3.4.3   Architecture 3

This architecture also employs the same beam coverage pattern used with Architectures 1 and 2 as shown in Figures 3-24 and 3-25. This architecture could allow 8 uplink beams in order to decrease required VSAT size and/or transmit power. This gives increased complexity on the satellite, but could be accommodated by the on-board baseband processor.

Architecture 3 differs from the previous two architectures in that it employs an on-board baseband processor which performs on-board regeneration, including FEC, switching, and rate conversion. The use of on-board baseband processing and switching allows increased interconnection flexibility, and allows earth stations in any uplink beam to communicate with earth stations in any downlink beam while transmitting and receiving only a single carrier. A functional block diagram of Architecture 3 is shown in Figure 3-28.

The use of a baseband switch also allows for a more efficient implementation of multicast functions. The earth station access method can now be MF/TDMA where a group of VSAT's in the same uplink beam with low traffic requirements can share the use of a low bit rate (e. g. 4 Gb/s) TDMA carrier. VSAT's with higher traffic requirements can transmit their multiplexed traffic on a single TDM carrier of the same rate as the TDMA carriers.

In addition to the improvement in link parameters due to on-board regeneration, this architecture provides single carrier transmission for all VSAT's up to an aggregate rate equal to the TDMA carrier rates. An earth station with traffic to several destination stations in a number of downlink beams can multiplex its traffic on a single carrier. The on-board baseband processor demodulates and demultiplexes the traffic and switches it to its downlink destinations. Downlink traffic to each beam is multiplexed on a single TDM carrier which is received by all stations in that particular beam.
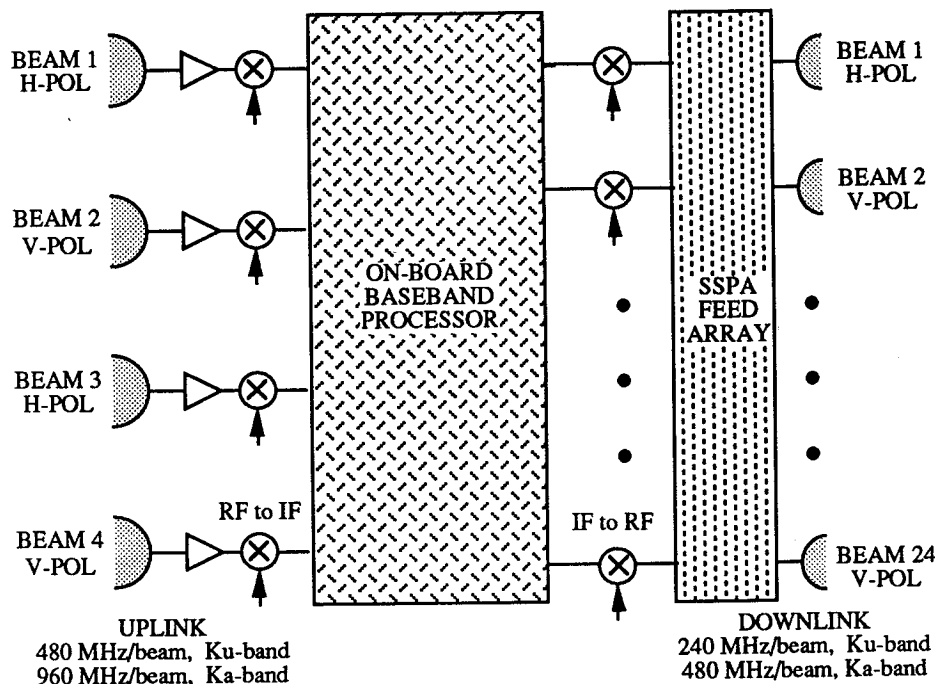
Figure 3–28: Architecture 3 Uses On-board Regeneration and Baseband Switching

Another enhancement to the previous architectures that this architecture provides is the ability to accommodate low duty cycle packet switched traffic, such as is normally the case with connectionless packet traffic.

3.4.4   Architecture 4

Architecture 4 employs narrow hopping beams on the uplink and downlink to achieve even higher satellite receiver gains and transmit power. Figure 3-30 shows the functional block diagram.

The beam coverage for Architecture 4 consists of 100 narrow spot beams covering the continental United States (Figure 3-29). There are 10 uplink scanning beams and 10 downlink scanning beams, each with 10 dwell positions for a total of 100 positions.

Due to the high gain and transmit power that result from the narrow spot beam coverage, VSAT transmission rates can approach tens of Mb/s. However due to the hopping beam nature of the coverage, VSAT's must transmit in TDMA mode during beam dwell time. The on-board processor routes the traffic to its destination downbeams and multiplexes it on downlink TDM carriers which are received in burst mode by the destination stations. Beam dwell times on both the uplink
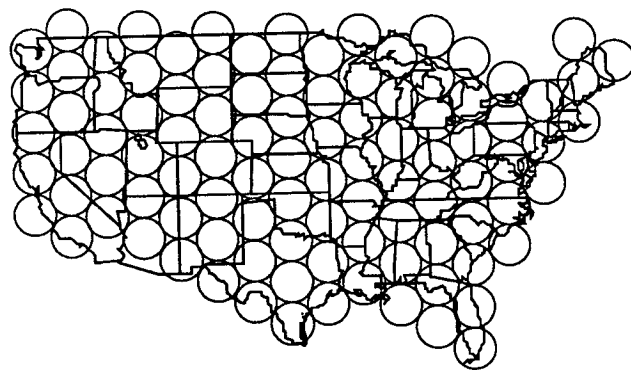
Figure 3–29: Architecture 4 Beam Coverage

and downlink can be adjusted to accommodate the variations in traffic requirements among different spot coverage regions.

A variation on this architecture which eliminates the requirement for TDMA transmission on the uplink is to use the uplink coverage pattern for the other three architectures. The achievable uplink transmission rates will then lower, however some of the complexities associated with TDMA transmission can be eliminated.
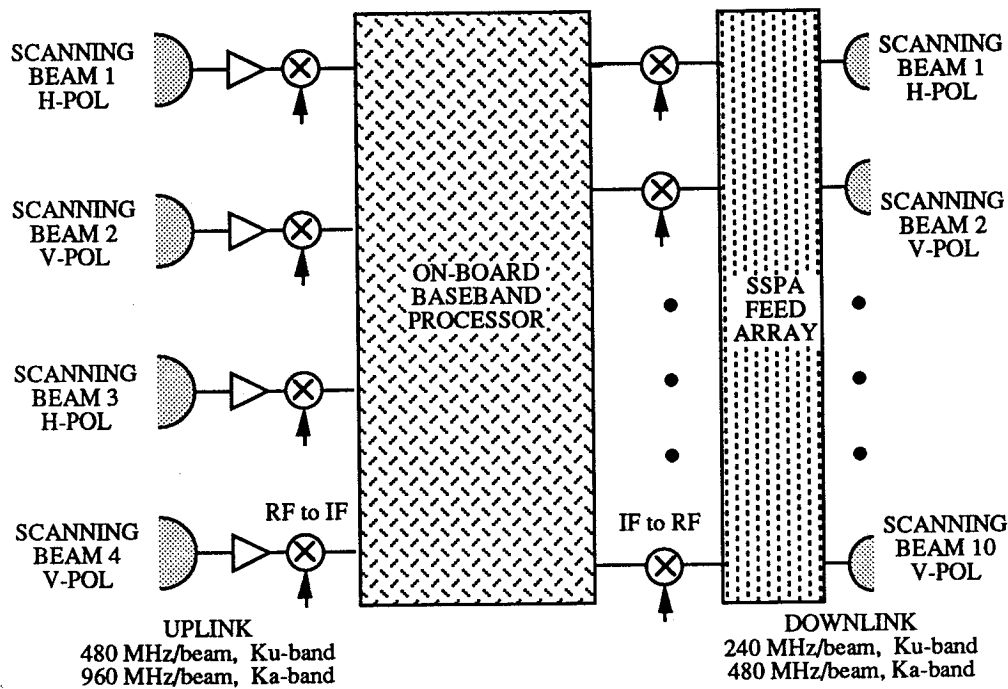
Figure 3–30: Architecture 4 Uses On-board Regeneration, Baseband Switching, and Scanning Beams

Table 3–1: Summary of Architectures

	Architecture 1	Architecture 2	Architecture 3	Architecture 4
Features:	Fixed spot beams Bent pipe IF switch FDMA SCPC access	Fixed spot beams On-board regeneration IF switch FDMA up, TDM down	Fixed spot beams On-board regeneration Baseband switch MF-TDMA, TDM	Narrow scanning beams On-board regeneration Baseband switch TDMA, TDM
Beam coverage:	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Narrow scanning beams 100 spot beam locations 10 up and 10 downlink scanning beams. CONUS coverage

Access method:	FDMA with SCPC	SCPC/FDMA or
		  TDM/FDMA uplinks
		TDM downlinks
			MF/TDMA via MCD's
			  on uplinks.
			TDM on downlinks
				TDMA up/downlinks

Connectivity:	Static IF switch
	Frequency-tunable
	  transmitters and
	  receivers.
		Static IF switch
		Freq. tunable transmit
		TDM downlinks
			Baseband switch	Baseband switch

Technologies:	Frequency tunable
	  transmitters and
	  receivers for VSAT
		Frequency tunable
		  transmitters.
		MCD
			Baseband processor
			– MCD
			– Switch
			– Controller
				Scanning multibeam ant.
				Baseband processor
				– MCD
				– Switch
				– Controller

3.4.5 Choice of Architecture for Further Study

All four architectures presented above allow single hop connections among VSAT's due to the improvements in link parameters gained through spot beam coverage. The capability and flexibility offered by these architectures, however, vary substantially as they differ in complexity.

Table 3-1 presents a comparison of the four architectures. These architectures are progressively more complex designs and higher technology risks in exchange for greater satellite capacity and capability.

Architecture 1 is best suited for a low rate demand assigned SCPC type of system where the user requirements are mostly for thin route voice traffic and low rate data.

Architecture 2 presents an improvement in the achievable VSAT transmission rates (size, and cost) and may be more suited for users with higher traffic requirements.

Architecture 3 offers more flexibility in accommodating a variety of traffic types and rates with reduced VSAT complexity at the expense of higher on-board complexity.

Architecture 4
offers additional improvements in VSAT capabilities and transmission rates through sophisticated on-board processing functions and scanning beam technology.

Based on network requirements considerations and the time frame of the study, Architecture 3 presents the best tradeoff between capabilities and complexity. A detailed examination of the on-board processing functions for this architecture and a high level design of a baseband processor for this architecture is given in Chapter 4 of this report.

3.5 Transition Considerations

The architectures described above are applicable to both Ku-band and Ka-band. However Ka-band operation offers particular advantages in terms of the available bandwidth and antenna size. Since most existing VSAT systems operate at Ku-band, the transition to Ka-band VSAT networks or combined Ku- and Ka-band networks becomes an important consideration in the design of an advanced mesh VSAT network. One transition approach which is applicable to existing Ku-band systems with increasing traffic requirements is to switch to a Ka-band system by replacing the RF portion of the VSAT, but use the existing reflector and baseband equipment. This could be performed for all sites in a VSAT network or only at selected sites which have higher traffic requirements.

This transition phase approaches completion as new Ka-band sites get added to the network and older Ku-band sites replaced. Since most existing Ku-band VSAT networks are of the star topology, Ku band sites will be able to communicate with their Ka-band counterparts through a central hub which employs either dual antennas (separate satellites) or one antenna with both transmission types (same satellite). The new Ka-band sites can communicate among themselves in a single hop. An enhancement to this approach is to use on-board cross strapping through an on-board switch, which eliminates the double hop requirement between the two types of sites.

Chapter 4

On-Board Baseband Switch

The advanced system architectures described in the previous chapter identified the requirement for an on-board baseband switch to interconnect the uplink and downlink coverage regions and to switch the uplink traffic to its downlink destination coverage regions.

In this chapter, several viable architectures for the on-board baseband switch are identified and described. The subsystem functions that are examined include carrier demodulation, TDMA/TDM synchronization, FEC decoding, descrambling, packet assembly, traffic channel demultiplexing, switching and routing, traffic channel assembly and multiplexing, TDM formatting, FEC encoding, and downlink signal remodulation. Also included is a description of network control functions such as monitoring and control of the on-board processor, channel request processing, allocation of time or frequency slots to user terminals, and congestion control for fast packet switching.

This chapter is organized as follows:

4.1 On-Board Processor Configuration

4.2 Design Considerations

4.3 Baseband Switch Structures

4.4 Baseband Switch Design

4.5 Technology Assessment

4.1 On-Board Processor Configuration

The on-board baseband processor function is to efficiently interconnect traffic on the uplink beams to its downlink destination beams. In this context, the basic functions performed by the on-board processor include:

- Multiplexing and demodulation on uplink carriers,

- Processing of the demodulated data,

- Switching baseband data to its destination ports,

- Processing of the switched data for remodulation on downlink carriers, and

- Remodulating and multiplexing to the downlink carriers.

- Autonomous network control including monitor and control of the processor subsystems, and processing channel request followed by allocation of time or frequency slots to user terminals.

For fast packet switched systems, a congestion control function is implemented in the on-board processor autonomous network controller.

Figure 4-1 shows a functional block diagram of the on-board baseband processor configuration. This block diagram includes demodulator, input processor, baseband switch, output processor, downlink remodulation, and autonomous network control subsystem. The on-board baseband processor interconnects "M" uplink beams to "N" downlink beams. For each uplink and downlink beam there could be a number of these functional blocks which all feed to the baseband processor.

4.2 Design Considerations

The design considerations associated with the on-board processor (OBP) are now examined:

1. Multi-Carrier Demodulator

2. Bit Synchronous System

3. Phase Ambiguity Resolution

4. Multicarrier Input Processing

5. Point-to-Multipoint Connections
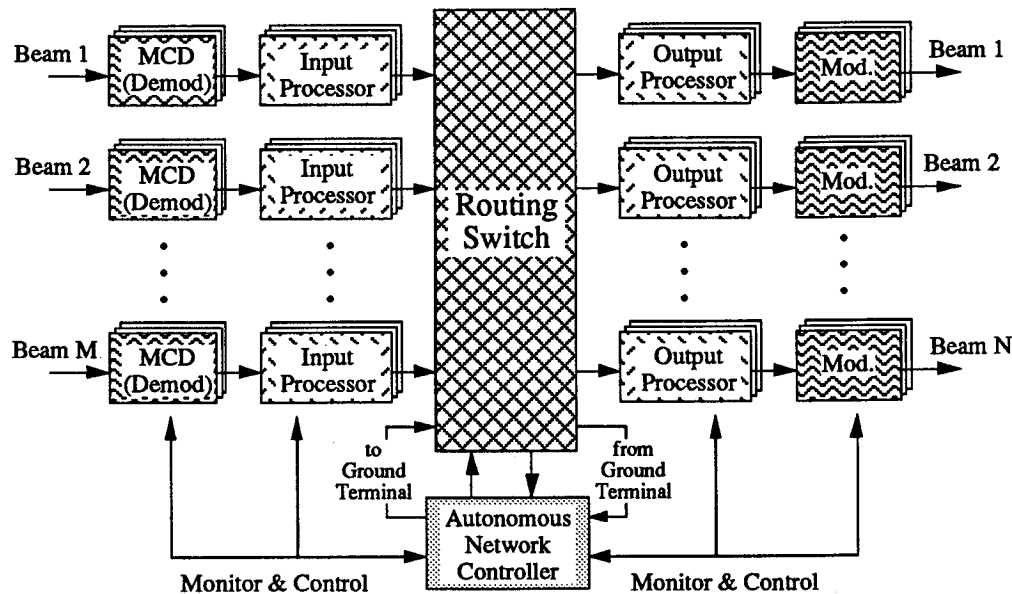
Figure 4–1: On-Board Baseband Processor Configuration

4.2.1   Multi-Carrier Demodulator

The multicarrier demodulator (MCD) design considerations include implementation technology, input carrier bit rate, and timing and synchronization issues.

The technologies include digital signal processing technology which is the most promising and is currently being investigated by TRW for NASA, acousto-optic signal processing currently being investigated by Westinghouse for NASA, and surface acoustic wave (SAW) signal processing.

The carrier bit rate issues include whether or not the MCD can operate with multiple bit rate carriers or whether it should operate with the same bit rate carriers, and also the reconfigurability of the MCD with changing carrier bit rates. For fairly high bit rate carriers as in Architecture 4, dedicated demods can be used instead of the MCD's which are needed for narrow band carriers.

R&D activities in the area of MCD's are currently being conducted by NASA, INTELSAT, and the European Space Agency (ESA) as well as many private laboratories.

4.2.2   Bit Synchronous System

Another consideration in the design of the on-board processor is whether to implement bit synchronous operation or to use asynchronous user clocks. In a bit synchronous system, all user clocks are synchronized to the on-board clock so there is no need to perform bit timing

recovery on board the satellite. Bit synchronous operation is illustrated in Figure 4-2.

The advantage of a bit synchronous system is that it does not require timing adjustments for each carrier or burst at the satellite. Hence, it eliminates the need for uplink frame synchronization at the satellite. For TDMA systems, a higher TDMA frame efficiency is achieved due to the fact that no timing synchronization preamble pattern is required. By using a fixed time slot size, simpler TDMA slot assignment is achieved. Hence, a potentially simpler MCD design can be done.

The disadvantage of such a system is that timing phase data storage is needed for individual carriers or TDMA bursts. In order to synchronize all uplink transmissions, uplink bit clock error measurements are needed on-board the satellite. Further, user terminals need to achieve precision transmit timing control in order to achieve and maintain bit synchronous operation. This kind of system also poses some specific design problems for random access schemes where the identity of the transmit station is not known until its transmission is correctly received.

To achieve bit timing synchronization, two basic approaches can be used:

- Open loop synchronization

- Closed loop synchronization

In open loop synchronization, user terminal timing is obtained through combining a received reference clock
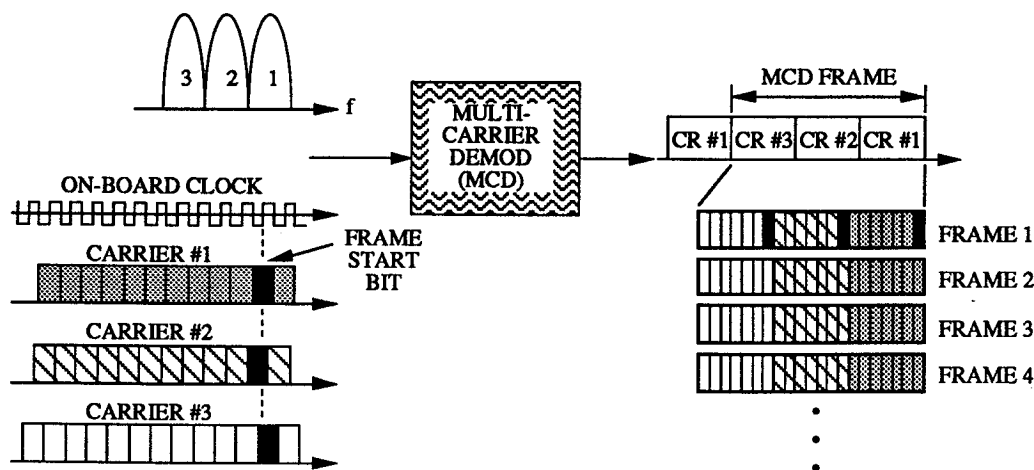
Figure 4–2: Bit Synchronous System Allows a Simpler MCD Design

signal with satellite position information used for terminal delay calibration.

Closed loop synchronization uses on-board phase error measurements which are used to send bit timing correction information to user terminals. This approach is preferred since it does not require precise satellite position ranging and terminal delay calibration, nor does it require special monitor and control equipment at the earth station. A closed loop bit timing synchronization system is shown in Figure 4-3 along with the pertinent parameter values.

4.2.3 Phase Ambiguity Resolution

A bit synchronous system provides proper bit timing on board the satellite for the demodulation process. However there is a need to also perform carrier phase synchronization for proper demodulation.

Carrier phase estimation can be performed over a preamble pattern which includes a unique word detection and phase ambiguity resolution algorithm. Alternatively, one can use differential coherent modulation which does not require an absolute carrier phase reference for demodulation but only estimates the phase change between one symbol and the next. This is shown in Figure 4-4a. Although this is feasible, it is not as power efficient.

Another approach is to use differentially encoded coherent modulation which will resolve four fold phase ambiguity. With a rotationally invariant FEC code which is insensitive to four fold phase ambiguity, the differential encoder can be placed on the outside of the FEC-modulator combination. This arrangement, shown

in Figure 4-4b, provides the best performance since it only degrades the decoded bit error rate by a factor of two.

A third alternative is to place the differential encoder after the FEC encoder and use hard decision FEC decoding at the receiver as shown in Figure 4-4c. This results in higher performance loss due to the hard decisions that are made prior to decoding and to the doubling in channel error rate which may result in more than a doubling in the decoded bit error rate.

4.2.4 Multicarrier Input Processing

Input processing of the signal to the baseband switch involves performing the following:

- Bit timing adjustment

- TDMA or TDM burst or frame timing generation and synchronization (unique word detection),

- Descrambling

- Forward error correction decoding

- Channel or message demultiplexing from the TDMA burst or TDM carrier

Of these functions, bit timing adjustment and burst and frame timing generation are not required if a bit synchronous system is used.

A typical multicarrier input processing block is shown in Figure 4-5. In a general implementation, a shared processing unit processes the input data from the

On-Board Clock (Δfs/fs)	2E-9
Doppler Shift (Δfd/fd)	7.8E-9 (±0.1° in inclination & drift)
User Terminal Clock (Δfe/fe)	1E-8 (locked to the receive clock)
Phase Correction Period	500 ms
Phase Meas./Corr. Resolution	1/20 clock period
Phase Error Due to Doppler	8-ns over 500 ms
Total Phase Error	58 ns (at 2 MHz or 12%)
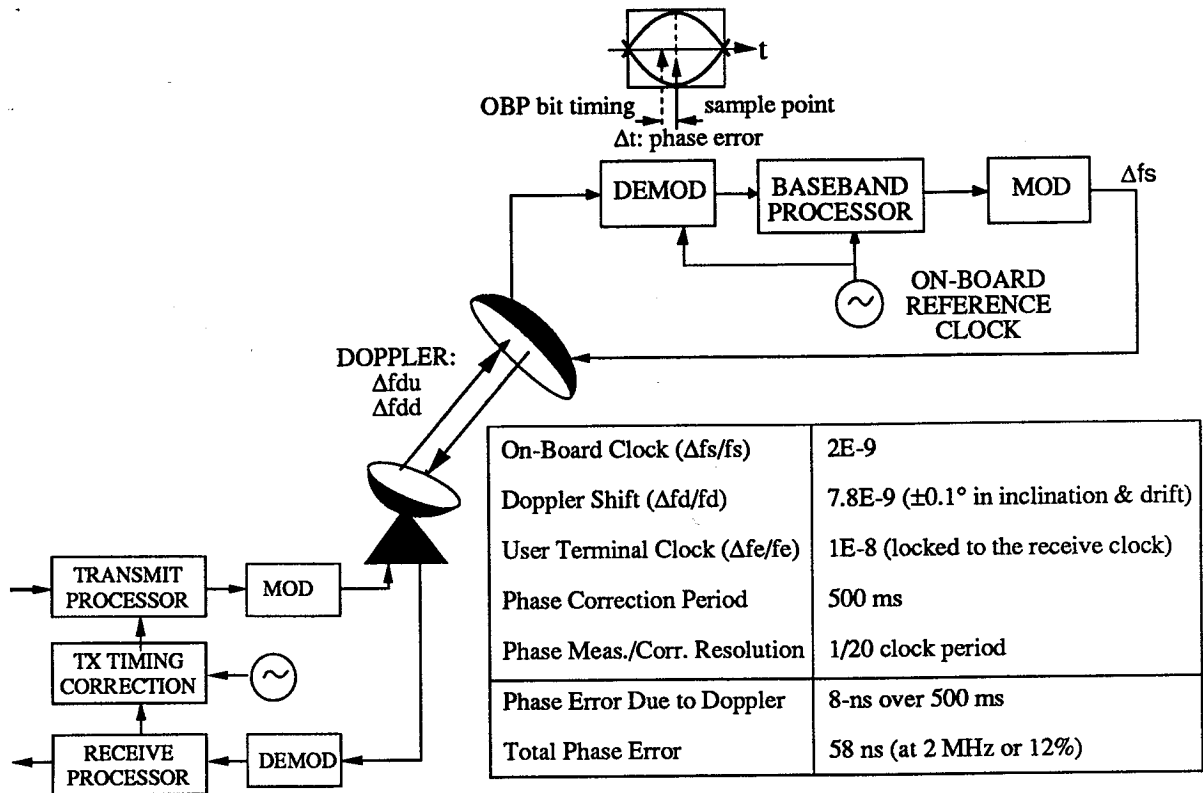
Figure 4–3: Closed Loop Bit Timing Synchronization System Uses On-board Phase Error Measurements

a. Differential Coherent Modulation

b. Differential Encoding, Coherent Modulation — Configuration 1

c. Differential Encoding, Coherent Modulation — Configuration 2
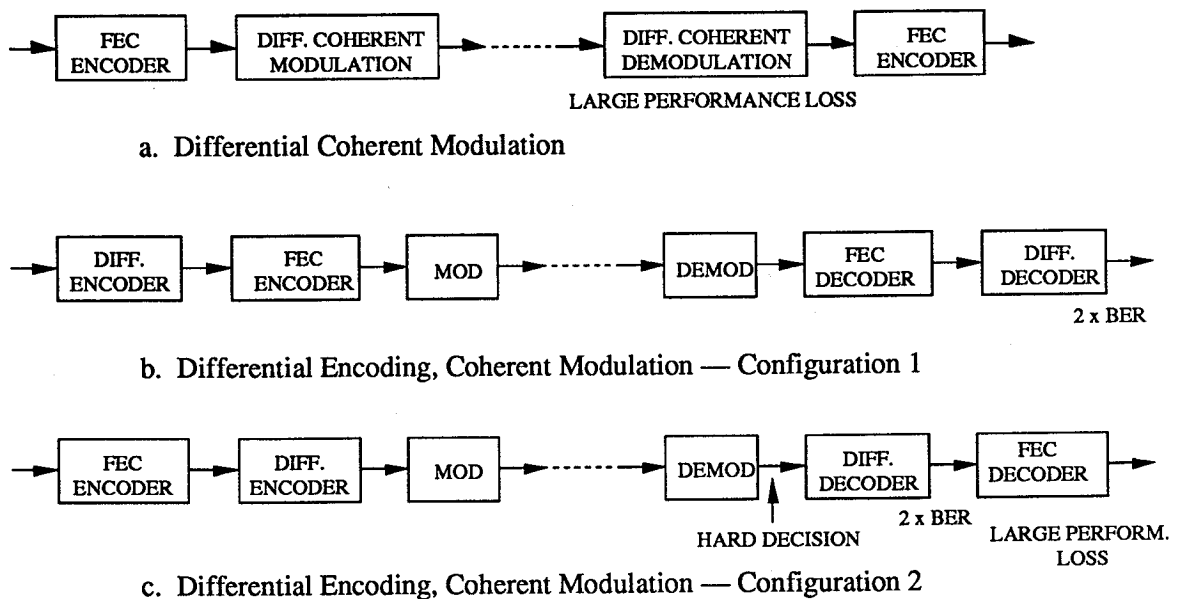
Figure 4–4: Alternate Approaches to Phase Ambiguity Resolution
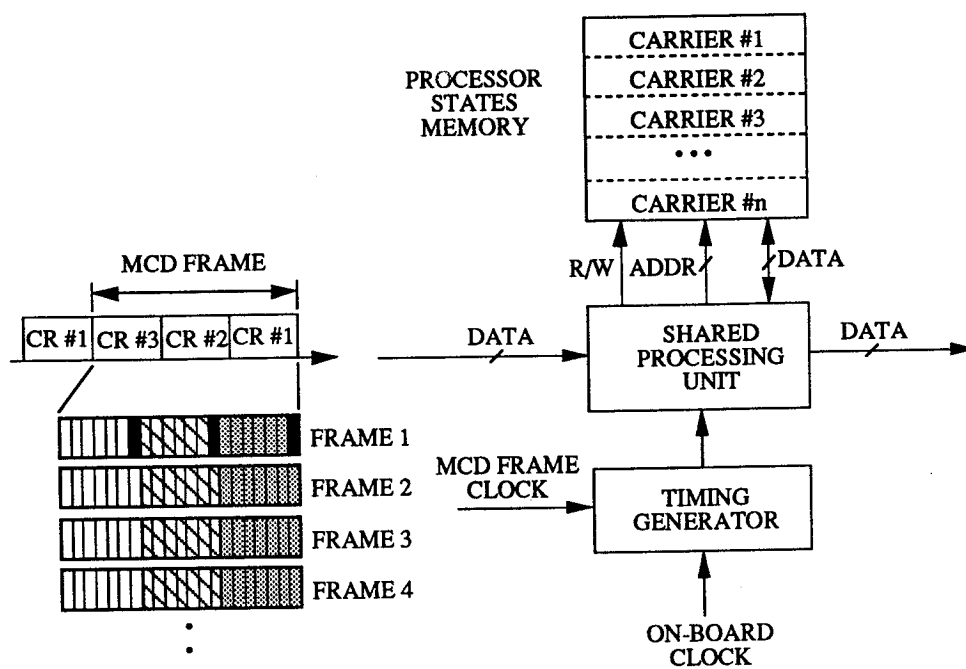
Figure 4–5: Typical Multicarrier Input Processing Block

MCD and performs the processing functions by utilizing on-board memory which is accessed at the on-board clock and MCD frame clock.

4.2.5 Point-to-Multipoint Connections

The requirement to accommodate point to multipoint connections can be achieved through two basic approaches:

- Multiple copy transmission

- On-board multipoint routing

Multiple copy transmission consists of establishing multiple single destination connections to each VSAT which is part of a multidestination group. This simplifies the on-board processor and/or network control designs but is an inefficient utilization of uplink capacity. On-board multipoint routing, on the other hand, consists of a single transmission which is routed to multiple destinations, thus providing a very efficient utilization of critical uplink capacity.

The on-board multipoint routing is based on packet headers or multipoint call setup protocols between the on-board processor and the originating VSAT. In order to accommodate this capability, multipoint signalling must be used between VSATs. This approach translates to larger overhead, a requirement for special on-board

processing switch structure, and use of multipoint protocols between VSATs.

4.3 Baseband Switch Structures

There are in general two types of baseband switching architectures to consider with the advanced VSAT network system:

- Circuit switching

- Fast packet switching

In circuit switching, uplink-to-downlink connections are established by mapping time slots in uplink beams and carrier to time slots on downlink destination beams and carriers. This mapping is maintained until a controller deallocates the assigned slots. In fast packet switching on the other hand, data is packetized and tagged with a routing header which indicates the packet destination, then switched on a packet by packet basis to the destination beams and carriers according to the header information.

Both circuit and fast packet switching architectures offer particular advantages and disadvantages. Selection of a preferred method depends on the particular system architecture being considered, including number of input and output ports, traffic capacity, and traffic

characteristics such as circuit or packet switched traffic. Comparisons between the two methods include bandwidth utilization efficiency, flexibility, autonomous operation, and congestion control.

While circuit switching architectures provide more efficient bandwidth utilization for circuit switched traffic, they are highly inefficient for packet switched traffic. Circuit switches also lack flexibility when it comes to traffic reconfiguration .

Fast packet switching on the other hand can accommodate circuit switched traffic albeit less efficiently due to the additional overhead of the packet routing headers. However, fast packet switching is preferred for packet switched traffic and for circuit switched traffic with frequent channel reconfiguration.

The discussion of switch structure is divided into six parts:

1. Common Memory Switch

2. Distributed Output Memory Switch

3. Time-Space-Time Switch

4. Fiber Optic Bus Switch

5. Sorted Banyan Network Switch

6. Other Switch Structures

4.3.1   Common Memory Switch

In the common memory switch (also known as a T-stage switch) structure, all users share the same on-board memory in alternating read/write cycles. A block diagram of this structure is shown in Figure 4-6. The common memory switch architecture can be used for both on-board circuit switching and on-board fast packet switching. However, on-board circuit switching will require different control functions and may result in different requirements on the common memory size and access speed.

In a common memory baseband switch architecture, data from the various input processors are multiplexed to form one high speed TDM stream. The multiplexer provides the rate conversion function by controlling the rate at which data from different inputs access the switch. The TDM stream is then written into a common memory area in the baseband switch one data word at a time, while at the same time it is read out of the common memory in the same manner. The switching function

is implemented by controlling the address of the memory reads and writes by using separate on-board control memory. The high speed TDM output of the switch is then demultiplexed among the output processors for the destination downlink carriers or beams.

There are several methods of performing the common memory read/write operation.

i. The common memory can be partitioned into separate areas corresponding to the destination output lines. Arriving packets (or channel packets) are sorted according to their destination and sequentially written to the corresponding memory areas. The output lines sequentially read from the corresponding memory areas. This method does not require any control memory.

ii. The incoming packets can be written sequentially into a unified memory area and their addresses can be written into separate control memories which are dedicated to each of the output lines. Packets are read out of memory using the first address in the control memory of each output line. This method utilizes the data memory in a ping-pong manner.

iii. In-place memory techniques can be used where incoming packets are written to the most recently read memory space in common memory, thus reducing the buffering requirements by half. The in-place memory technique requires more sophisticated control and the use of ping-pong control memory.

A major design issue in a common memory switch implementation is the memory access speed which should be very fast to accommodate the high aggregate data rate of the switched traffic. For example, a common memory switch with a capacity of 1.6 Gb/s and a 64-bit wide data bus would require a memory access speed less than 40 ns. The available memory access speed usually places the upper design limit on the switch capacity.

Another design issue is the size of the common memory, which has to be at least large enough to buffer a full TDM frame of data if in-place techniques are used and two frames if a ping-pong technique is used. The size and speed of control memory is also an issue although it usually is less than that of the data memory.
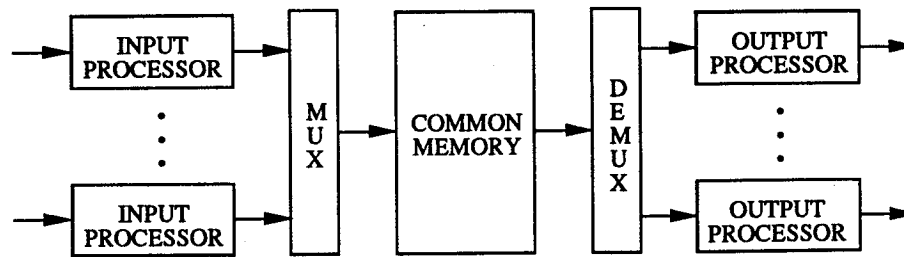
Figure 4-6: Common Memory Baseband Switch Structure

4.3.2 Distributed Output Memory Switch

In a distributed output memory switch structure, shown in Figure 4-7, data from the input processors is multiplexed onto a high speed TDM bus. The data on the bus includes an address field which specifies the destination output line. The address field is processed by address filters on each output line which enable a memory write to the destination output memory from the data bus. The downlink carriers are formed by reading the associated output memories for each carrier.

The design issues involved with the distributed output memory switch include the size and speed of the bus, fault tolerant bus design, the output memory size and memory access time. In addition, careful bus design is essential to avoid signal interference among the bus lines. As an example, with a 64-bit wide bus operating at 25 MHz, the maximum available switch capacity is 1.6 Gb/s. For higher capacities, bus speed and memory access time requirements can be relaxed by using a bit-slice approach which uses a number of bus switches of the above structure which are operated in parallel.

4.3.3 Time-Space-Time Switch

The Time-Space-Time (TST) switch is also known as a distributed input/output memory switch. In this type of baseband switch architecture, data from each input line is written into its own input memory. A baseband switch matrix is used to route data read from input memories to be written to output memories for each of the output lines. This type of baseband switch structure is shown in Figure 4-8. The input memory has to be programmable to perform time slot interchange, which is necessary to eliminate contention between two or more input memories for the same output memory. Also, the space switch should be of the non-blocking type.

The TST switch is mostly suitable for circuit switched traffic which is slowly varying in nature. For packet switched traffic, the update requirements of the memory map which is used to reorder the incoming packets in input memories, and the real time (i. e. on a frame-by-frame basis) calculation of the space switch states become prohibitively complex even for a small number of input/output lines.

A major design issue in this approach is the size of the input/output memory which has to accommodate at least one frame of data for each of the input/output lines. If ping-pong data memories are used, the data memory requirement will be for two frames of data for each line. If in-place memory techniques are used then only one frame of data needs to be buffered in the data memories, however the control memories will have to operate in a ping-pong manner. This is usually an attractive tradeoff since control memory requirements are less than those of the data memories.

Another design issue is the switch control, which includes the path search (calculation of switch state) for the space switch, update of the memory map, and performing the switchover to the new state in response to traffic variations. The complexity of these control functions increases dramatically with the number of input/output lines, and hence can only be performed if the traffic is slowly varying, such as for voice traffic. An example design shows a thoughput of 8 Gb/s for a 16 x 16 switch operating at 500 MHz.

4.3.4 Fiber Optic Bus Switch

The fiber optic bus switch is a shared media switch design similar to the distributed memory switch structure with the TDM bus replaced by a high speed fiber optic ring structure. The fiber optic ring topology eliminates some of the restrictions imposed by interference considerations on the shared medium speed. This topology also provides a modular design which can embody
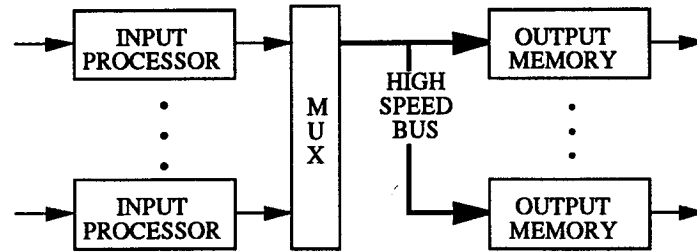
Figure 4–7: Distributed Output Memory Baseband Switch Structure
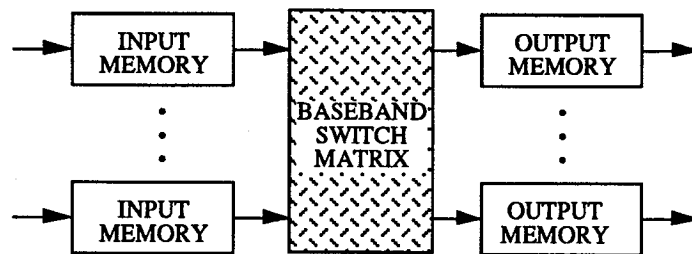
Figure 4–8: Time-Space-Time Baseband Switch Structure

a fault tolerant structure and achieve a high throughput. The fiber optic ring switch structure is shown in Figure 4-9.

Like the distributed output memory switch, this design can accommodate both circuit switching and fast packet switching. The major design issues in this structure are the speed of the optic ring, the incorporation of fault tolerant design, and space qualification of the fiber optic ring topology.

As discussed later, this design is selected for the baseband switch on-board the satellite. A sample baseband switch design that uses this structure and accommodates both circuit switched and packet switched traffic as well as multicast traffic is given in Section 4.4.

4.3.5   Sorted Banyan Network Switch

The Batcher-Banyan switch architecture is a space division type which, unlike the shared memory and shared medium types, offers a high degree of parallelism in processing and switching the incoming data as well as the ability to distribute switch control among the switching fabric. It uses a Batcher sorting network that arranges the arriving packets in descending order according to their output destinations for forwarding to

a Banyan switch network. The sorting operation renders the switch internally non-blocking and identifies output conflicts at the input to the Banyan network for resolution. Both the sorting network and switching networks are very modular in nature and can be implemented in electronics, optoelectronics, or optics. Figure 4-10 shows the Batcher-Banyan switch structure.

Because of its distributed control nature and its variable throughput characteristics, this switch structure is inherently suited for packet switched traffic. A major design issue in this type of switch architecture is the resolution of output blocking which occurs when multiple packets are routed to the same output line at the same time. There are two basic approaches to the resolution of output blocking in the switch. The first is to use a trap network after the sorting network which would extract packets on the list with the same destination and present them to the switch at a later time. The other is to use multiple Banyan networks either in parallel or in tandem to increase packet thoughput.

Other design issues include fault tolerance which can be achieved by using redundant input/output processors and redundant Batcher-Banyan network or network elements. Multi-cast routing is also another design issue.
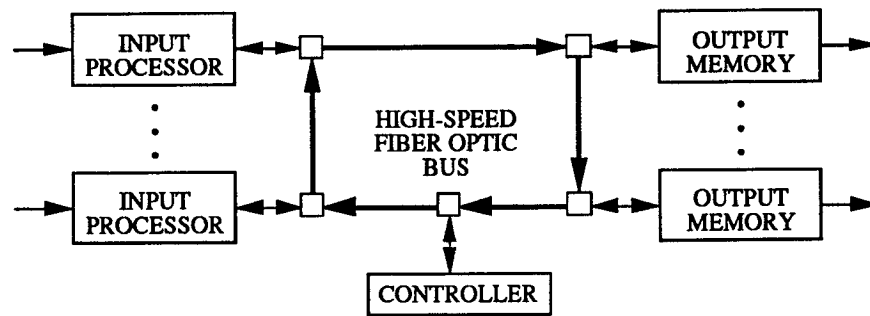
Figure 4–9: Fiber Optic Bus Switch Structure
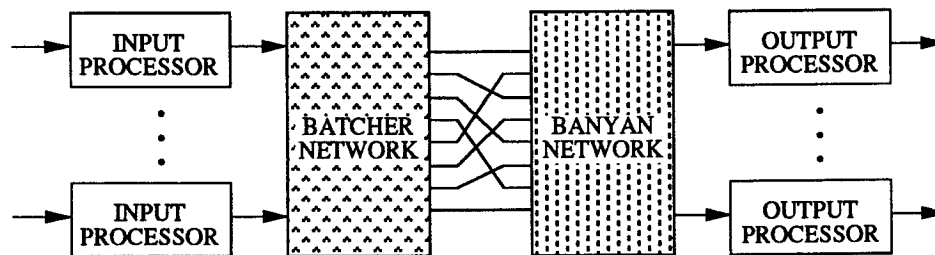
Figure 4–10: Sorted-Banyan Baseband Switch Structure

4.3.6 Other Switch Structures

In addition to the above switch structures, there are several other switch structures that have been identified. Some of these structures constitute variations on one of the above structures.

One structure is the double Banyan network, also known as the Benes interconnection network, which consists of a Banyan network followed by its mirror image. This arrangement results in an internally non-blocking switch structure, provided that global control is used. By global control means that a controller has to have knowledge of all the packet destinations to assign non-blocking paths through the switch.

Another structure is the input ring reservation with internally non-blocking switching fabric (as in Batcher-Banyan). The input ring reservation structure, where by packets reserve output ports before being routed through the switch, eliminates output contention problems. An enhancement to this structure is the addition of an output multicast ring network to accommodate point-to-multipoint packets.

Point-to-multipoint routing can also be accommodated by using a multicast switch fabric. In a multicast switch fabric, the basic switch elements have the ability to either route incoming packets or to duplicate them.

This approach becomes a self routing multicast switch.

Other approaches include the knockout switch and various buffered self-routing switching fabrics.

4.4 Baseband Switch Design

The baseband switch architectures discussed in the previous section all offer certain advantages and disadvantages and are suited for some applications better than others. In this section, a high-level sample baseband switch design is introduced which meets the set of requirements most likely to be encountered in an advanced mesh VSAT system. The discussion is divided into four parts:

1. System Design Parameters

2. Network Requirements

3. Switch Design

4. On Board Processor Design

4.4.1 System Design Parameters

The selected VSAT system design is Architecture 3. Table 4-1 summarizes the system design parameters.

Table 4–1: System Design Parameters

System Parameters	Uplink	Downlink
Number of Beams	4	24
Access Method	MF/TDMA	TDM
Modulation	D-QPSK	QPSK
Forward Error Correction	R-1/2 Convol.	R-1/2 Convol.
Burst/Transmission Rate	4 MSym/s	68 MSym/s
Bit Rate (Information)	4 Mb/s	68 Mb/s
Bit Error Rate	10^{-8}	10^{-10}
Number of Carriers per Beam	100	1
Total Number of Carriers	400	24
Beam Capacity	400 Mb/s	68 Mb/s
System Capacity	1.6 Gb/s	1.6 Gb/s

There are 4 uplink beams that provide regional coverage of an area equal in size to the CONUS, and 24 fixed downlink spot beams provide overlapping coverage of the same area.

The access method selected is multi-frequency TDMA (MF-TDMA) on the uplink and TDM on the downlink. The uplink transmission rate is 4 Mb/s which accommodates VSAT users with transmission requirements up to that rate. VSAT users with low throughput requirements share the low rate TDMA carriers while users with higher throughput use TDM transmissions.

The multi-frequency feature of the uplink TDMA access permits more flexible and efficient sharing of the available uplink bandwidth. With this arrangement up to 100 uplink carriers can be assigned in 500 MHz bandwidth making a total uplink throughput limit of 1.6 Gb/s. On the downlink, a single TDM carrier is received by all VSATs in each downlink beam which carries all the traffic destined to that beam. The downlink TDM carrier bit rate is 68 Mb/s so that the aggregate available downlink bit rate is approximately the same as the uplink bit rate.

Because of the power limited nature of the VSAT links, rate 1/2 convolutional coding is assumed on both uplink and downlink, with on-board FEC soft decision decoding. Both uplink and downlink transmissions are QPSK. Further differential encoding on the uplink may be used to resolve carrier phase ambiguity of the uplink bursts in the on-board receiver. Differential encoding on the downlink is not needed due to the continuous nature of the downlink transmission.

4.4.2 Network Requirements

The proposed sample design provides service to the type of traffic which will be encountered in an advanced VSAT system. Requirements are to accommodate the following traffic characteristics:

- Circuit switched traffic such as will be generated by voice traffic and long data traffic has rates up to 4 Mb/s.

- Packet switched traffic can have high or low duty cycles.

- Packet switched traffic of the connectionless type (datagram traffic) is likely to be encountered.

- System design should be flexible enough to accommodate such wide variety of traffic types.

- Multipoint connections such as video teleconferences are also essential.

- Autonomous operation of multiple user networks is desired.

4.4.3 Switch Design

Based on the above system design parameters and network requirements, a sample baseband processor design was chosen that provides modularity, flexibility to interconnect different traffic types, and ability to provide multicast connections. A fiber optic ring design with distributed output memories was chosen as the best match to these requirements. In order to simplify the

on-board processor hardware, a bit synchronous system is assumed.

The switch structure is inherently a self routing packet switched structure. However, circuit switched traffic can also be accommodated by packetizing and appending routing headers. These packets will have a fixed length data and header fields.

The TDMA (TDM) frame structure used for uplink access (Figure 4-11) has a 15 ms frame with 60 time slots (64 kb/s TDMA channels). Each time slot contains 1024 bits, with a 64-bit header and 960-bit information field. A 1024 bit scrambler pattern is used for each of the 64 kb/s TDMA channels. The resulting frame efficiency is 94%.

The downlink has a 15 ms TDM frame which consists of 1,000 TDM channels, each channel having the same number of bits and the same format as the uplink TDMA channels (Figure 4-11).

These TDMA and TDM frame structures accommodate circuit switched traffic at integer multiples of 64 kb/s. Lower bit rate traffic can be multiplexed in 64 kb/s channels or can be transmitted with a loss in efficiency at the 64 kb/s rate. The use of fixed length traffic packets (satellite virtual packets) results in simple uplink time slot allocation and eliminates the need for coordinated time plans.

4.4.4 On-Board Processor Design

The chosen on-board processor design is a 1.6 Gb/s TDM optical ring which interfaces to the input and output processing units. The ring design results in a simple interface structure among the processing units. At the same time, it provides a self routing architecture with no requirement for control memory. Finally, it provides a modular design which could be utilized for redundancy considerations. The use of a bit synchronous system and differential encoding for phase ambiguity resolution on the uplink substantially simplifies the design of the on-board demodulators at the expense of negligible increase in earth station complexity.

4.4.4.1 Block Diagram of Processor

A block diagram of the on-board processor is shown in Figure 4-12. Four multi-carrier demods (MCDs) are used with each uplink beam to demodulate 25 carriers each. The MCD outputs comprise two-bit soft-decisions on the received channel symbols at an information bit rate of 100 Mb/s (400 Mb/s total including FEC and 2-bit quantization). The MCD outputs are processed by the input processors which perform 2-bit soft-decision FEC decoding, packet assembly, differential decoding, descrambling and deinterleaving, header error control, and buffering.

Also included in the input processor is an optical bus interface at the optical bus speed of 1.6 Gb/s. Twenty four output processors interface to the optical bus at the same speed and perform packet address filtering, frame buffering, bit interleaving and scrambling, and FEC encoding. Each output processor transmits a 68 Mb/s TDM stream.

Network control is provided through an autonomous network controller (ANC) which interfaces to the optic bus and sends control signals to the input and output processor units. The input processor units also send control signals to the controller. However the exchange of control information between the output processor units and the controller is strictly one way.

Finally, redundant MCD units, input and output processing units, and a redundant ANC are provided for fault tolerant operation. Switchover to the redundant units is accomplished via two redundancy switches at the input to the MCD units and the output of the downlink modulator units.

4.4.4.2 High Speed Optical Bus

The structure of the high speed optical bus is shown in Figure 4-13 along with the TDM frame structure used on the bus. The 250 μs TDM frame consists of a control field "C" for use by the autonomous network controller (ANC), and 16 packet fields for use by the input processor units (IP). The control field is one packet long while the IP field is 25 packets long corresponding to one packet from each uplink carrier assigned to the input processor. Note that there is no contention provided that the optical bus bandwidth is greater than the uplink (input) bandwidth.

The input processor and ANC interface to the bus via an optical receiver and optical driver. The output processor interface is an optical receiver which allows the processor to receive all the information on the bus but process only that information destined to it. A status bus is provided separately at very low speed. Alternately, the status bus can be integrated into the high speed TDM bus. Optical switches at interface points allow bypass or connection of any processing units and network control units for redundancy operation.
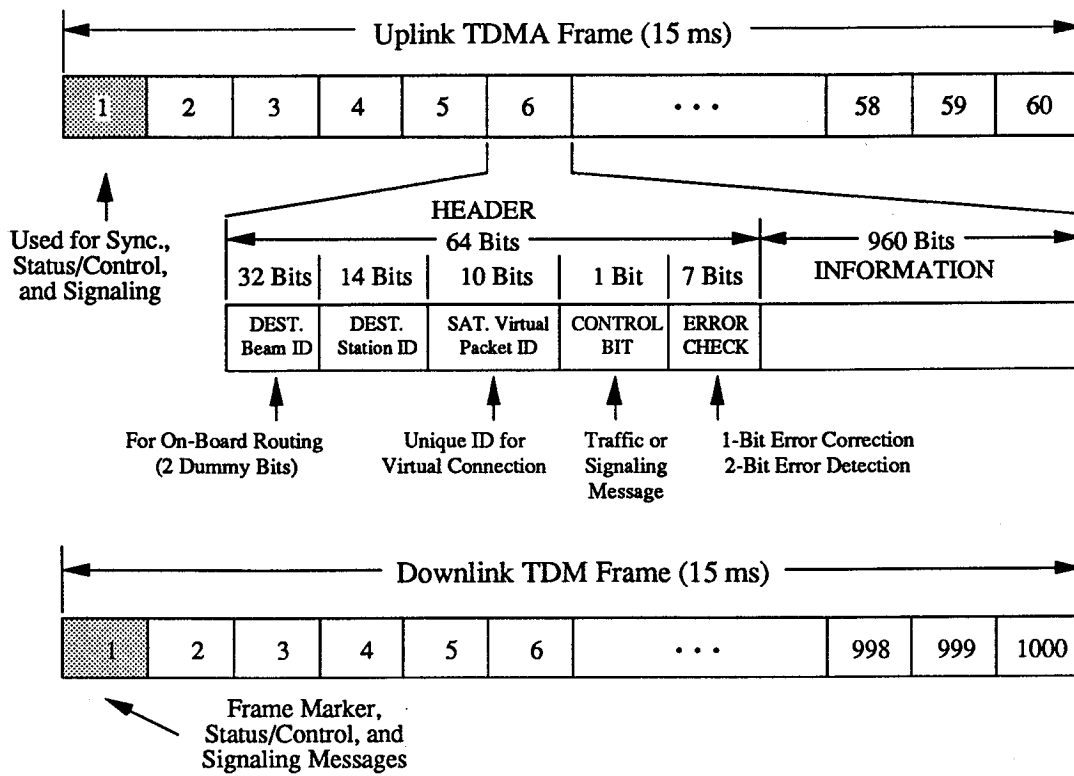
Figure 4–11: Uplink and Downlink Frame Structures
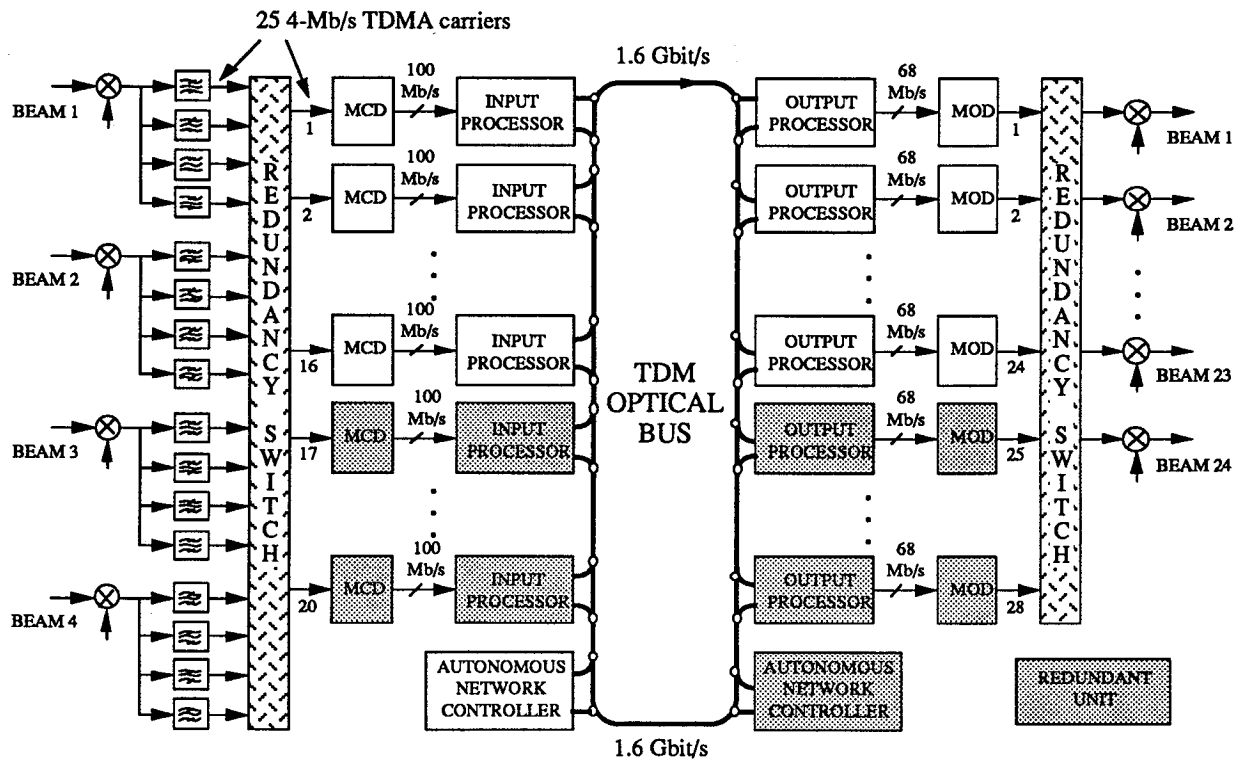
Figure 4–12: On-Board Processor Block Diagram
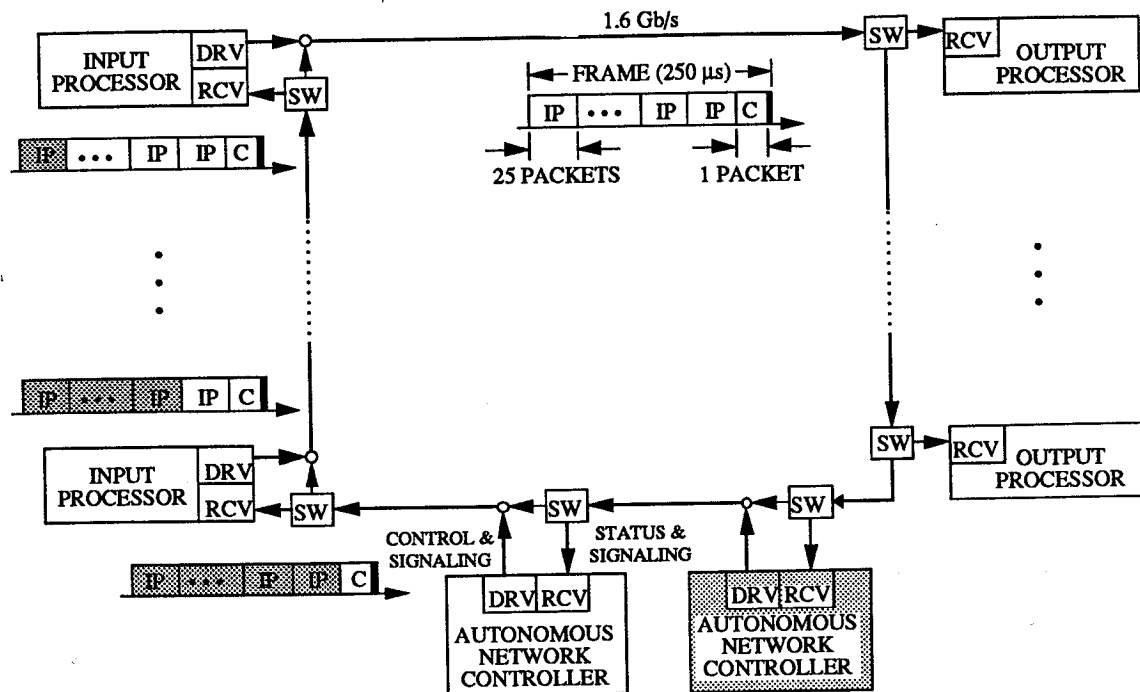
Figure 4–13: High Speed Optical Bus

4.4.4.3 Input Processor

A block diagram of the input processor is shown in Figure 4-14. The input processor performs a number of operations on the data from the MCD.

- TDMA or TDM burst or frame synchronization

- Phase ambiguity resolution

- Forward error correction decoding

- Descrambling

- Packet assembly for fast packet switch with MCD

- Traffic channel demultiplexing

4.4.4.4 Output Processor

A block diagram of the output processor is shown in Figure 4-15. The functions performed by the output processor are as follows:

- Traffic channel assembly and multiplexing

- TDM formatting

- Scrambling

- Forward error correction encoding

4.5 Technology Assessment

This section addresses digital device technologies for on-board applications and presents mass and power estimates for the sample on-board baseband processor design described in the previous section.

4.5.1 Digital Device Technology

The on-board baseband processor requires the use of large-scale digital integrated circuits (ICs). These ICs must have high component density per chip, low power consumption, and high speed operation, while maintaining reasonable tolerance for radiation hits.

Candidate device technologies for on-board applications include ECL, GaAs, CMOS, and BiCMOS. ECL and GaAs are much faster than CMOS and require a larger current drive. CMOS ICs, on the other hand, consume less power, dissipate less heat, and pack more gates than ECL and GaAs. BiCMOS technology attempts to trade off the lower power dissipation of CMOS with the higher speed of bipolar chips. It does this at the cost of an increased number of mask levels during the production cycle.

The performance trends in digital semicustom chips in terms of speed, gate density and power dissipation

Figure 4–14: Input Processor Block Diagram

Figure 4–15: Output Processor Block Diagram

are illustrated in Figure 4-16 [E. Meyer, "BiCMOS, ECL and GaAs Chips Fight for Sockets in 1990", *Computer Design*, January 1990, pp. 39-43] and Figure 4-17 ["Special Report: This Time GaAs is for Real", *Electronics*, June 1988, pp. 65-72].

In addition to keeping pace with the need for increased density and speed and lower power dissipation, these ICs must be radiation-hardened to withstand the harsh radiation conditions [typically, a total dosage of 10^5 rad (Si) over a 10-year span] in the space environment which can cause premature failure.

Additionally, one has to protect ICs against single-event upsets (SEUs) caused by alpha particles emitted by radioactive contaminants within the device package and by secondary cosmic rays. SEUs do not require threshold accumulation of a total dose before the damage becomes unacceptable.

Because of large gate density, the effect of radiation is especially sensitive to memory chips. Typical radiation tolerance values for these devices are 10^5 to 10^6 rads for radiation hard CMOS and 10^9 to 10^{10} rads for GaAs, and their SEUs are typically 10^{-7} to 10^{-9} error/bit/day. The impact of SEUs is less significant for self-routing packet switches, since no control memories are used for the switching function.

4.5.2 Mass and Power Estimates for Design

Preliminary estimates of mass and power requirements for the sample on-board baseband processor design are provided considering implementation in the years 1996–2000. The digital device technologies used are GaAs for high-speed processing, such as fiber optic interface processing, and high-density CMOS (HCMOS) for other processing functions.

Table 4-2 summarizes the performance of the most promising technologies. The GaAs device currently offers 0.1 mW of power/gate, 50,000 usable gate density, and speeds up to 5 Gb/s. Radiation hard HCMOS, on the other hand, offers 12 μW/MHz of power/gate, 50,000 usable gate density, and a speed of up to 400 Mb/s. It is envisaged that both the power consumption and gate density of these devices will further improve in the coming years. A 50% reduction in power/gate for CMOS and GaAs device technologies is assumed by the 1996–2000 time frame.

Most processing functions required in the sample design can be implemented with currently available technology and are regarded as low risk. The processing

units identified for new development (and assumed to be developed for the purpose of this mass and power estimate) are as follows:

- Low power MCD for 25 each 4 Mb/s carriers

- 100 Mb/s, single chip, multicarrier decoder (1 W)

- 16 K x 32 static RAM (SRAM)

Extensive development efforts are currently taking place on MCDs by a number of R&D organizations worldwide, and it is expected that a 25-carrier MCD with power consumption of about 20 W (using 20 LSI/ASIC devices) may be realized in the 1996–2000 time frame.

A high speed programmable Viterbi decoder operating at above 100 Mb/s has been implemented by COMSAT Laboratories using custom add-compare-select logic. Although it currently requires several chips to implement the desired function, its single chip fabrication with power consumption of 1 W is well within the technology forecast.

Radiation hard memory technology is also expected to improve significantly in the coming years, by increasing its current size of 8 K x 8 or 16 K x 4 to 16 K x 32 or larger. The sample design conservatively assumes the availability of 16 K x 32 SRAMs. The use of larger capacity memory chips, such as 16 K x 64, will further reduce the estimated parts count and improve reliability.

Based on the above technology assumptions, the parts counts, power consumption, and mass requirements are estimated in Table 4-3. The sample design includes 20 MCD/Input Processor units (16 active and 4 backup), 28 Output Processor/Modulator units (24 active and 4 backup), and fully-redundant autonomous network controller (ANC). According to the table, the on-board baseband processor will consume about 500 W power and have a mass of 58 kg using technology available in the years between 1996 and 2000.

The sample design assumes extensive use of ASIC devices as identified in Table 4-4. The table indicates the types of processing elements, clock speeds, device technology, and the estimates of the numbers of gates required.

A further reduction in parts count may be achieved by combining certain processing functions into a single ASIC device. For example, the descrambler, bit deinterleaver, and header FEC codec functions in the input processor may be fabricated on a single CMOS ASIC
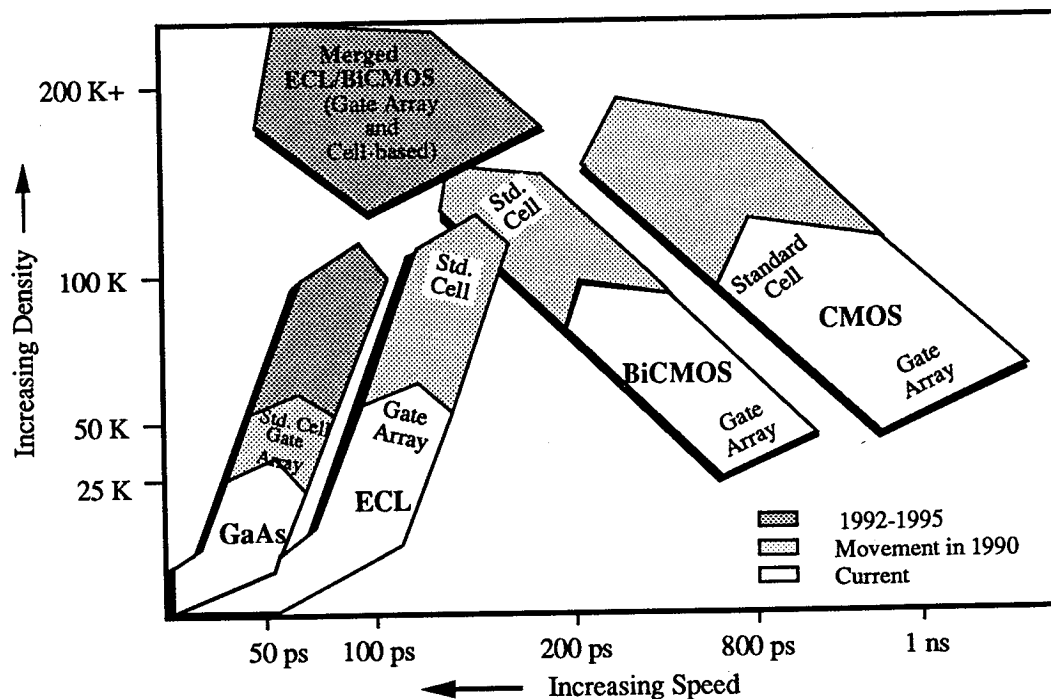
Figure 4–16: Density and Speed Performance Trends in Digital Semiconductor Chips
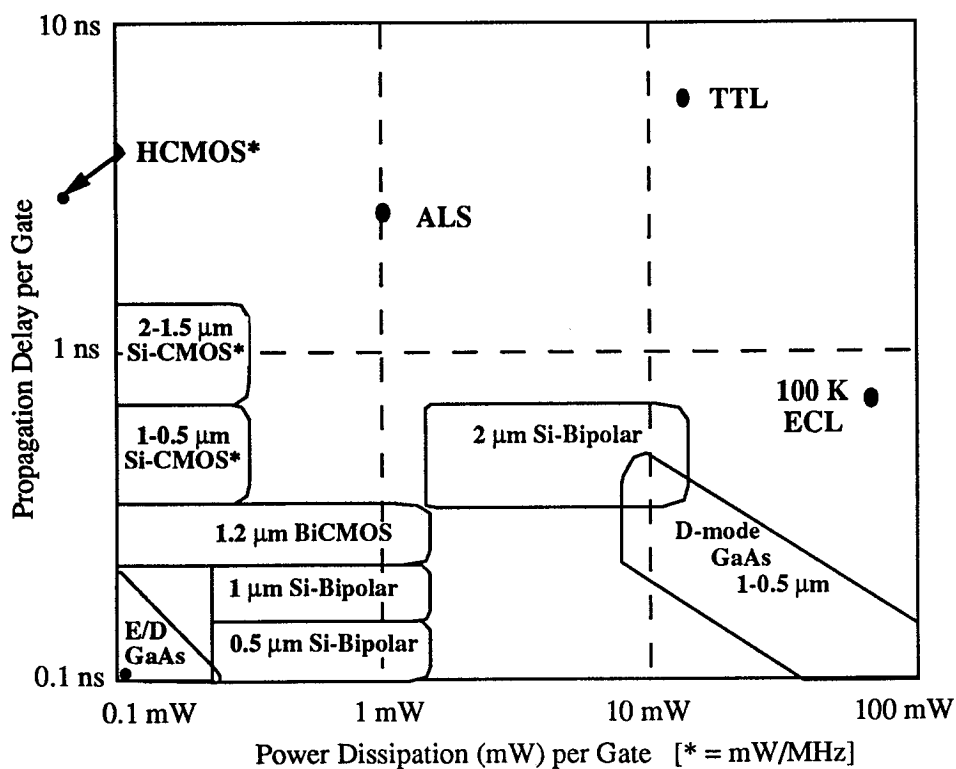
Figure 4–17: Propagation Delay and Power Dissipation Performance of Various Digital Technologies

Table 4–2: Performance of Promising Technologies

Technology	Power per Gate	Density (Usable Gates)	Speed
GaAs	0.1 mW	50,000	1–5 Gb/s
HCMOS (rad hard)	12 μW/MHz	50,000	400 Mb/s
ECL/TTL mix	0.5–1 mW	10,000	650 Mb/s

Table 4–3: Mass and Power Estimates (Year 1996-2000)

Component	No. Active Units	No. Redundant Units	Parts Count	Power (W)	Mass (kg)
Multi-carrier demodulator	16	4	400	320.0	6.7
Input processor	16	4	480	50.4	8.0
Output processor	24	4	616	66.2	10.3
Modulator	24	4	28	3.6	4.2
Autonomous network controller	1	1	66	12.2	1.1
Timing source	1	2	3	3.0	3.0
Power supply (90% eff.)				50.6	12.0
Structure					13.0
Totals				506.0	58.3

device of 11,000 gates. Similarly, combined fabrication into a single chip is possible for the elastic buffer, P/S converter, multiplexer, frame synchronizer, clock recovery, and timing generator functions (19,000 gate GaAs), the scrambler, FEC encoder, and bit interleaver functions (8,000 gate CMOS), and the S/P converter, frame synchronizer, clock recovery, and timing generator functions (13,500 gate GaAs).

4.5.3 Critical Technology

Critical technologies identified are as follows:

1. Multicarrier Demodulator

2. Bit Synchronous System

3. Multicarrier FEC decoder

4. High Speed Optical Bus Interface

5. Autonomous Network Controller

The most critical technology for the realization of the on-board baseband processor is the development of a low-power consumption multicarrier demodulator. In our sample design for the baseband switch, it consumes about twice the power of the rest of the subsystem. Intensive development effort to reduce the MCD power requirement to the range of several watts is strongly recommended.

A bit synchronous system improves frame efficiency and simplifies on-board processor design as well as network control procedures. However, the MCD is required to measure a phase error with an accuracy of a small fraction of a symbol period. It also necessitates the user terminal to perform accurate timing correction. Alternate techniques to implement a bit synchronous system should be investigated, and a proof-of-concept model to demonstrate its feasibility should be developed.

Other less critical technology areas include a high-speed multicarrier decoder, a high-speed optical bus interface, and an autonomous network controller. Further study and hardware development are recommended.

Table 4–4: Potential Processing Elements for ASIC Implementation

Component	Element	Clock Speed (MHz)	Technology	Number of Gates
Input Processor	FEC Decoder	100	CMOS	50,000
	Packet assembly control	13	CMOS	2,000
	Differential decoder	13	CMOS	500
	Descrambler	13	CMOS	500
	Bit deinterleaver	13	CMOS	7,000
	Header FEC codec	13	CMOS	3,000
	Elastic buffer	200	GaAs	5,000
	8-bit P/S converter	1,600	GaAs	1,000
	Multiplexer	1,600	GaAs	1,000
	Frame synchronizer	1,600	GaAs	5,000
	Clock recovery	1,600	GaAs	2,000
	Timing generator	1,600	GaAs	5,000
Output Processor	Scrambler/FEC encoder	68	CMOS	1,000
	Bit interleaver	1	CMOS	7,000
	Address filter	25	CMOS	2,000
	64-bit S/P converter	1,600	GaAs	1,500
	Frame synchronizer	1,600	GaAs	5,000
	Clock recovery	1,600	GaAs	2,000
	Timing generator	1,600	GaAs	5,000

Chapter 5

Satellite Design

This chapter describes the satellite design needed to accommodate the Mesh VSAT (M-VSAT) payload. The resultant satellite's mass, power, and configuration are given. The chapter is organized as follows:

5.1 Introduction

5.2 Mesh VSAT Satellite Design

5.3 Discussion of Design

5.1 Introduction

The satellite design approach is given, the mass and power allocations are described, and the features of the satellite bus are summarized.

5.1.1 Satellite Design

The approach is to evolve the existing satellite design (1990 technology base for 1995 launch) to the Mesh VSAT satellite design which assumes a year 2000 technology base for a year 2005 launch.

Table 5-1 compares the Mesh VSAT satellite design with those of three communications satellites currently being produced by Space Systems/Loral (formerly known as Ford Aerospace).

Superbird is a Japanese domestic communications satellite with X, Ku, and Ka-band transponders. Intelsat-7 is the next generation of international communications satellites and has C and Ku-band transponders. N-Star is a communications satellite being built for the Japanese telephone company NTT. These satellites are currently under production with launches scheduled in the 1992 to 1995 time frame.

In contrast, the Mesh VSAT satellite uses an on-board baseband switch that allows simultaneous interconnectivity between its 4 uplink and 24 downlink beams. NASA's ACTS satellite, planned for launch in 1993,

will demonstrate the first generation of on-board switching. The combination of narrow spot beams and on-board switch to interconnect the beams according to traffic demands enables increased communications efficiency and thus increased capacity from the payload.

The payload mass fraction (ratio of the mass of the antenna plus communications electronics to the total satellite wet mass) is 20% for Superbird, 22% for Intelsat 7, and 27% for N-Star versus 33% for the Mesh VSAT satellite design.

The improvement is due to technology advances in the propulsion and power subsystems. Ion propulsion is used to reduce the mass of on-orbit station-keeping fuel and thus enable longer lifetimes. Use of lower mass density batteries and solar cells also allow greater payload mass.

5.1.2 Satellite Mass and Power Allocations

The Mesh VSAT satellite design with 3,548 kg launch mass and 3.6 kW power is summarized in Table 5-1. Table 5-2 summarizes the satellite characteristics. An Atlas 2AS launch from the Eastern Test Range (ETR), i. e. Cape Kennedy, is assumed. Launching from the more equatorial site of French Guinea by the Ariane would reduce the satellite wet mass by 200 kg.

The Mesh VSAT payload design does not occupy the total capacity of the bus, as shown by the 382 kg spare capacity in Table 5-1. Considering its use of mass and power, approximately 67% additional payload of the same type and power consumption could be carried. If the Mesh VSAT payload were optimized for this size bus (by using the additional 382 kg), maximum capacity would increase to 2.7 Gb/s. As will be discussed later, this could be accomplished by the use of additional uplink and downlink beams with more TWTAs.

Table 5–1: Comparison of Mesh VSAT Satellite with Current Communication Satellites

Satellite Name	Superbird 2	Intelsat 7	N-Star	Mesh VSAT
Launch Year (first)	1992	1993	1995	2006
Launch Vehicle	Ariane 3	Atlas 2AS	Ariane 44P	Atlas 2AS
Lifetime (yr)	10	11	10 (12)	15
Number of satellites	2	5	2	–
Total Bandwidth (GHz)	1.8	2.4	2.6	1.6
Max. Capacity (Gb/s)	–	–	–	1.6
DC Power, end of life (kW)	3.55	3.53	4.1	3.6
RF Transmit Power (W)	885	929	1,050	720
Battery Capacity (W-hr)	3,964	3,972	4,592	4,700
Satellite Subsystem Mass (kg)				
Structure	208	209	200	210
Propulsion	91	108	112	221*
Power	174	180	188	110
Solar array	116	120	130	104
Attitude control	86	93	56	60
Spacecraft control electronics	–	80	74	60
TT&C	38	15	17	20
Thermal	93	94	103	120
Integration, elect. & mech.	114	105	131	130
Antenna	52	103	155	46
Communication electronics	246	320	370	264
Spare capacity	–	–	–	382†
Dry Mass of Satellite (kg)	1,218	1,427	1,536	1,727
On-orbit Fuel (kg)	273	454	422	160*
Wet Mass of Satellite (kg)	1,491	1,881	1,958	1,887
Orbit-raising Fuel (kg)	1,030	1,710	1,571	1,661
Launch Mass (kg)	2,521	3,591†	3,529	3,548‡

* Use of ion propulsion increases propulsion mass and decreases on-orbit fuel mass.
   (Superbird, Intelsat, and N-Star use bipropellant for on-orbit and orbit-raising fuel.)
† Mesh VSAT payload does not occupy the total satellite capacity.
‡ An equatorial launch (Ariane) would save 200 kg launch mass.

Table 5–2: Characteristics of Satellite to Supply Mesh VSAT Service

Manufacturer & model:	LORAL FS-1300
Baseline satellite name:	M-VSAT Satellite
Lifetime:	15 yr
On-board switching:	Baseband switch interconnects channels.
Launch vehicle:	Atlas IIAS
Launch year:	2006
Frequency band and bandwidth:	Ka-band, 1,600 MHz
– receive:	27.5–30.0 GHz
– transmit:	18.3–20.2 GHz
Antenna	
– type:	Offset parabolic
– number:	2
– size:	0.6 m receive, 1.1 m transmit
– mass:	46 kg
– coverage (Ka-band):	4 fixed uplink and 24 fixed downlink beams cover CONUS
Communications electronics	
– number of receivers:	4 at Ka-band.
– TWTAs:	24 @ 30 W
– mass:	264 kg
– dc power:	2,708 W
Spacecraft	
– size (stowed):	2.5 m x 1.88 m x 2.64 m
– mass, BOL:	1,887 kg (includes 382 kg spare capacity)
– power (EOL) at summer solstice:	3,576 W
– primary power:	Solar cells (thin silicon)
– batteries:	4 NiH, 220 Ah (total)
– attitude and station keeping:	3-axis stab, stationary plasma thrusters
– attitude pointing accuracy:	$\pm 0.05°$
– apogee motor:	Liquid propulsion
– stationkeeping & attitude control:	Ion propulsion motor

5.1.3 Summary of Satellite Design Features

The key features of the satellite design from the standpoint of the satellite bus are as follows:

Higher power is able to be supplied from the same size bus due to advanced battery and solar cell designs which have improved performance per unit mass.

Advanced nickel hydrogen batteries (NiH) are used which are based on estimates of battery performance and technology readiness dates by NASA/JPL [G. Halpert and A. Attia, *Advanced Electrochemical Concepts for NASA Applications*, Proc. 24th IECE Conference, Aug. 1989, Vol. 3, Editor W. D. Jackson]. JPL concluded that advanced NiH batteries will be available in the year 2000 with 75 Wh/kg specific energy, compared to the capability of 1990 NiH batteries which provide 45 Wh/kg specific energy. We adopt a figure of 33 W/kg (which combines 75 Wh/kg for batteries plus packaging and power conditioning overhead) to estimate the total power subsystem mass for our year 2006 satellites, based on their end-of-life DC power.

Thin silicon solar cells are used for the satellite designs. The assumed total array specific power is 35 W/kg (ratio of dc power to solar array mass). Thin silicon cells on a four panel, two wing configuration provide 5 kW power. This is the same configuration being qualified by Loral for Intelsat 7.

The Intelsat 7 design uses 8 mil (0.20 mm) thick cells. The assumption is made that by the year 2006, a 20% reduction in cell thickness can be made with the consequent 10% improvement in total array specific power since cell mass is 50% of array mass. An additional 5% radiation degradation is assumed for the extra 4 years of life. A specific power improvement of 10% over Intelsat 7 is achieved.

Thermal radiators are required to dissipate the higher power from the satellite. Of the 3.7 kW dc power, 0.7 kW is radiated away in rf power, leaving approximately 3.0 kW to be disposed of by the thermal subsystem.

Use of stationary plasma thrusters for east-west station keeping reduces the combined propulsion system plus on-orbit fuel mass. It becomes increasingly attractive as satellite lifetime is extended.

Orbit raising fuel has a higher specific thrust (320 vs. 310 ISP) and thus allows 50 kg more launch mass.

Use of Ka-band gives increased spectrum availability for communications, and a resultant higher communications capacity.

Multiple beam antennas are used rather than direct radiating phased arrays (or phased array feeds) on account of the multiple, simultaneous beams formed by each antenna.

A design alternative would use phased arrays with scanning spot beams. Separate beam forming networks would be required for each of the 4 uplink or 24 downlink beams. This could be feasible for the relatively simple uplink antenna.

5.2 Mesh VSAT Satellite Design

This section describes the satellite design which is summarized in Table 5-2. This section is divided into four parts:

1. Antenna Coverage and Size

2. Payload Block Diagram

3. Payload Electronics Mass and Power

4. Satellite Characteristics

5.2.1 Antenna Coverage and Size

Figures 5-1 and 5-2 show the uplink and downlink antenna coverages. Separate multiple beam antennas supply 4 fixed elliptical beams for uplink coverage and 24 fixed beams of $1.0°$ diameter for downlink coverage of the Continental United States (CONUS).

There are two Ka-band multiple beam antennas:

• Receive (30 GHz) – 0.6 m, 18 kg mass.

• Transmit (20 GHz) – 1.1 m, 28 kg mass.

Each uplink beam uses 400 MHz of the frequency band, with 800 MHz total required with 2-times frequency reuse for the 4 uplink beams. Polarization reuse could also be used if additional isolation between beams (decrease in C/I due to co-channel interference) is desired. (Caution is required with polarization reuse at Ka-band, particularly on uplinks, due to the depolarization effects of rain drops.)
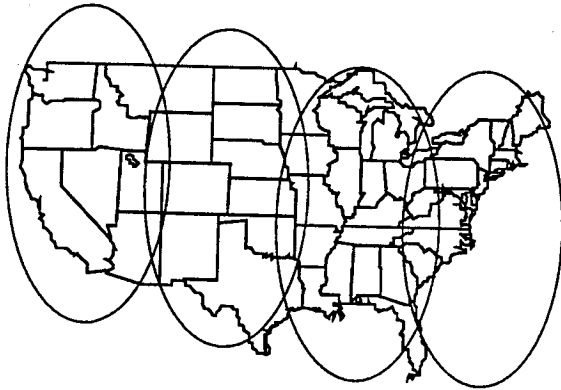
Figure 5–1: Uplink Beam Coverage
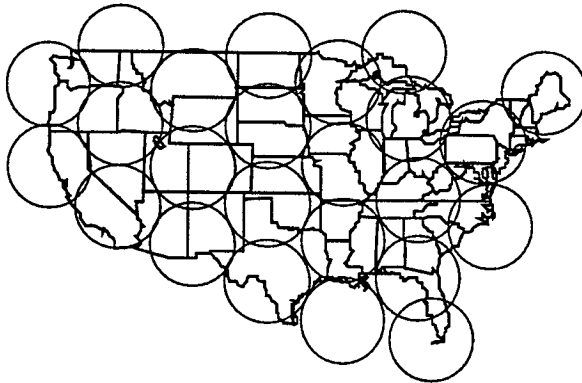
Figure 5–2: Downlink Beam Coverage

For the downlink, there are seven different beam frequencies, arranged in hexagonal groups of seven beams. Each beam uses 68 MHz of the frequency band, giving a total usage of 476 MHz. The frequency band is reused approximately 4 times over CONUS. Again polarization reuse could be used if additional isolation between signals in different beams is required.

5.2.2 Payload Block Diagram

Figure 5-3 shows the payload schematic. There are 4 input beams in one group with the LNAs and downconverters having 6-for-4 redundancy. Each input beam contains 4 channels of 100 Mb/s, each channel containing 25 4-Mb/s carriers. The channels are separated by the input mux and passed to a multi-carrier demodulator (MCD). The MCDs have 5-for-4 redundancy. There are up to 100 4-Mb/s carriers in each of the 4 beams, giving a maximum uplink capacity of 1.60 Gb/s.

The baseband switch is serviced by 20 input and 28

output processors. The input processors have 5-for-4 redundancy, and the output processors have 7-for-6 redundancy. The switch fabric is a TDM fiber optic bus with 2 Gb/s capacity. There are 24 active output processors, each producing a 68-Mb/s data stream. The maximum downlink capacity is 1.632 Mb/s.

The output beams are also in seven groups of four, and the upconverters and TWTAs have 7-for-6 redundancy. There are 28 modulators, 28 upconverters, and 28 30-W TWTAs, only 24 of which are active at one time.

5.2.3 Payload Electronics Mass and Power

Table 5-4 summarizes the payload electronics mass and power. The baseband processor estimates come from the discussion in Chapter 4 as summarized in Table 4-3. Major components contributing to the payload mass and power are as follows:

LNAs and downconverters have 6-for-4 redundancy. There are a total of 6 LNAs and 6 downconverters, with 4 of each active at one time.

MCDs (multi-channel demodulators) are the key component of the baseband processor in terms of mass and particularly power consumption. Each MCD handles 25 4-Mb/s carriers for a total capacity of 100 Mb/s.

TDM Fiber-Optic Bus switch supplies the simultaneous connectivity between 4 (active) inputs and 24 (active) outputs. The fiber optic bus can allow up to 32 inputs and 32 outputs. Maximum capacity can be up to 3 Gb/s with GaAs device technology in the input and output processors.

Upconverters and TWTAs have 7-for-6 ring redundancy. There are a total of 28 upconverters and 28 TWTAs, with a maximum of 24 active at one time.

Also included in the mass and power tabulations of Table 5-4 are the coaxial and waveguide interconnections and the beacon transmitters for earth terminal pointing and rain fade detection. There is a provision for 5% payload mass and power margin.

The major payload items in terms of contribution to mass and power consumption are the 30 W TWTAs. Current technology is exemplified by the 29 W Superbird TWTA/EPC which has a mass of 3.5 kg and power
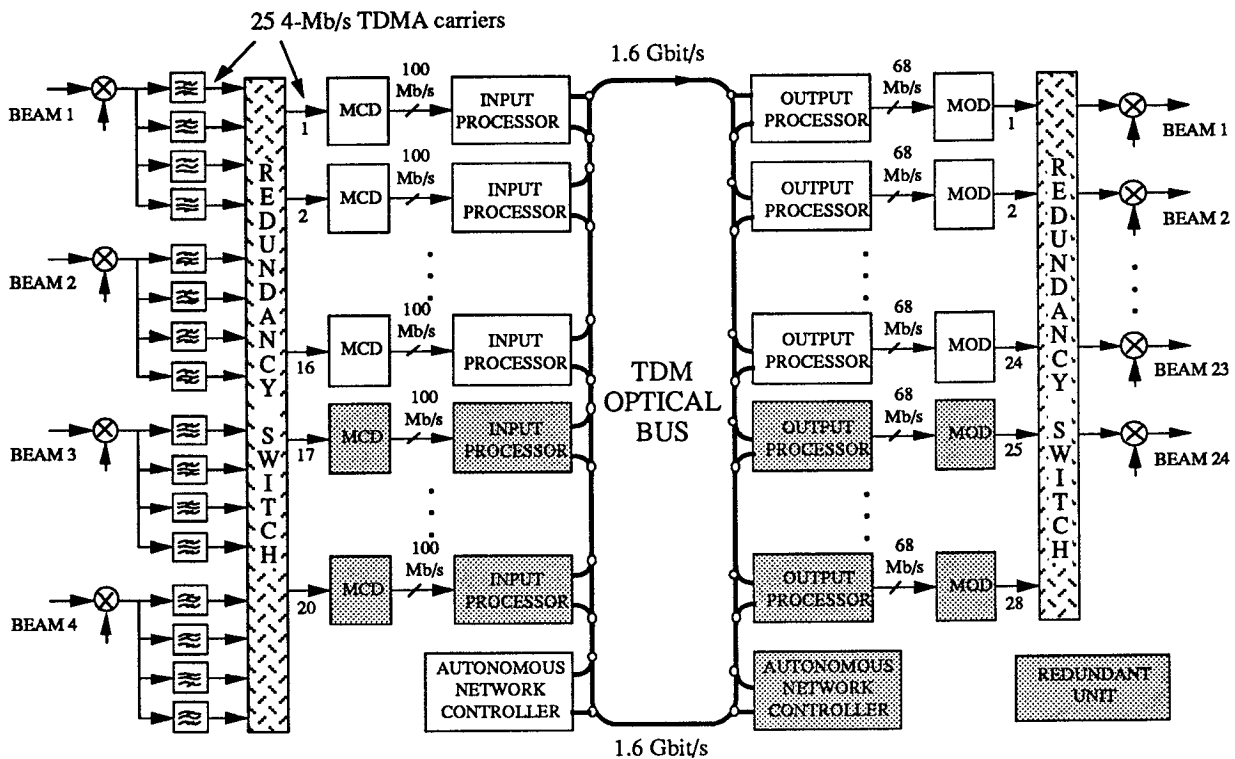
Figure 5–3: Payload Schematic

efficiency of 30%. The assumption is made that another 10 years of development (year 2000 technology) will achieve a 30 W TWTA with 3.0 kg mass and 36% dc-to-rf efficiency (40% tube efficiency and 90% dc-to-dc efficiency). Use of MMIC components is assumed for electronic components where appropriate.

5.2.4   Satellite Characteristics

The bus design is based on the Loral FS-1300 series which has a 1,900 kg wet, beginning-of-life (BOL) mass capability and is presently in production for commercial applications such as Superbird, Intelsat-7, and N-Star. Table 5-2 gives the satellite characteristics, and Table 5-3 gives the power budget.

The existing satellite design (1990 technology) has been upgraded to incorporate hypothesized year 2000 technology improvements. The result is a 1,727 kg dry (1,887 kg wet) satellite mass with a 310 kg M-VSAT payload (antenna plus communication electronics) and 3.6 kW end-of-life power. (Since the M-VSAT payload does not fill the satellite to capacity, there is a provision for 382 kg of spare capacity in Table 5-1 which summarizes the mass budget by satellite subsystem. Figure 5-4 shows the satellite on-orbit configuration.

Table 5–3: Power Budget

Component	Power (W)	
LNAs, Receivers	37	
Transmitters	2,000	
Baseband electronics	519	
Other/Margin	152	
Total Payload	2,708	2,708
TT&C	30	
Attitude control	135	
Propulsion	12	
Power subsystem	52	
Thermal subsystem	163	
Control electronics	80	
Harness loss	44	
Total Bus	516	516
Battery charging		352
Total Satellite		3,576

CONUS

Ka BAND FIXED BEAMS,
4 BEAMS RECEIVE
24 BEAMS TRANSMIT

0.6 M RECEIVE ANTENNA

1.1 M TRANSMIT ANTENNA

NiH_2 220 Ah BATTERY (4 ea)

3 AXIS STABILIZED,
STATIONERY PLASMA
THRUSTERS

3600 W, THIN SILICON CELLS
SOLAR ARRAY PANELS

Figure 5–4: Mesh VSAT Satellite On-Orbit Configuration

Table 5–4: Payload Electronics Mass and Power Breakdown

Equipment	Mass (kg) Qty.	Unit	Total	Power (W) Qty.	Unit	Total	Comments
Baseband Processor							
MCDs – 4 Mb/s carriers	20	0.3	6	16	20.0	320	
Input processor	20	0.4	8	16	3.2	51	
Switch fabric & support	1	1.0	1	1	10.0	10	
Output processor	28	0.4	11	24	2.8	66	
Modulators	28	0.2	6	24	0.2	5	
Network Controller	2	0.5	1	1	12.0	12	
Timing source	3	1.0	3	1	3.0	3	3–1 redundancy
DC/DC converter	2	6.0	12	1	52.0	52	90% efficiency
Structure	1	12.0	12				
Subtotals			60			519	
Low noise amplifiers	6	0.5	3	4	1.2	5	6–4 redundancy
Receivers (28/4 GHz)	6	2.0	12	4	8.0	32	6–4 redundancy
Input demultiplexers	5	1.5	8				3 channel
Upconverter (4/20 GHz)	28	1.1	31	24	3.0	72	10–8 redundancy
TWTA/EPC (30 W, 20 GHz)	28	3.0	84	24	75.0	1,800	10–8 redundancy, 40% eff.
DC/DC convertor (TWTA, U/C)	14	0.4	6	12	16.7	200	2–1, 90% eff.
Output filter	28	0.2	6				
Master LO	2	5.0	10	1	6.0	6	2–1 redundancy
Redundancy switches			20				
Waveguide and coaxial cable			7				
Beacon transmitters	2	2.0	4	1	15.0	15	2–1 redundancy
Margin			13			129	5% margin
Totals			264			2,708	Mass (kg), Power (W)

5.3 Discussion of Design

The M-VSAT payload design does not occupy the total capacity of the bus (382 kg spare capacity entry in Table 5-1). Considering its use of mass and power, approximately 67% additional payload of the same type and power consumption could be carried. If the M-VSAT payload were optimized for this size bus by using the spare 382 kg, maximum capacity would increase to 2.7 Gb/s. This capacity is within that of the fiber optic bus switch.

The number of uplink beams could be increased to 8, doubling the number of MCDs and uplink capacity to 3.2 Gb/s (not all would be used at once). The resultant smaller beam size would increase uplink link budget performance by 3 dB (see link budgets in Appendix E), allowing smaller VSAT size or power to be used.

The number of downlink beams could be increased from 24 to 28, and the number of active 68-Mb/s trans-

mit channels from 24 to 40. Some of the 28 downlink beams would have two channels, implemented by use of OMJs on the antenna ports.

In order to develop consistent user cost estimates in Chapter 6, the estimated 2.7 Gb/s "full bus" M-VSAT payload will be assumed. Total spacecraft dry mass is 1,727 kg, and spacecraft power is estimated at 5.6 kW. The power and solar array subsystem masses (Table 5-1) would be 184 kg and 174 kg respectively. The communications payload mass is 589 kg (50 kg antenna and 549 kg communications electronics).

Chapter 6

User Costs

This chapter defines the overall system cost scenario; estimates the costs of the space segment, network control, and user ground terminals; and determines the composite pro rata user costs associated with various Mesh VSAT communication services and capacity utilization. The chapter is organized as follows:

6.1 Cost Guidelines

6.2 Space Segment Costs

6.3 Ground Terminal Costs

6.4 Network Control Costs

6.5 Utilization Factors

6.6 Composite Costs

6.7 Discussion

6.1 Cost Guidelines

Cost guidelines are discussed in this section.

6.1.1 Key Technology Development Costs

The Mesh VSAT (M-VSAT) satellite incorporates advanced communications techniques including full demodulation, processing, switching and remodulation in the satellite. This is a major change from current transponder methods and significant R&D development will be required to assume satisfactory performance with high reliability.

The R&D effort would be incurred in the 1994 to 2002 time period, assuming space segment hardware contract in year 2002 with first launch in year 2006. The costing estimates assume that such developments would be separately funded by NASA R&D programs.

6.1.2 Space Segment Cost Guidelines

The key elements of the space segment would consist of the following:

- Development and manufacture of two satellites with contract award in year 2002.

- Launch of two satellites in 2006.

- TT&C control of satellites over a 15 year period.

- Each satellite has a 15-year on-orbit life.

6.1.3 User Terminal Cost Guidelines

The costs associated with the user terminals would include the terminal lease and associated repairs and maintenance costs over a 15 year period. It is assumed that a terminal may be upgraded during the 15 year operations period but that a full replacement terminal would not be required. No salvage value of the terminal equipment is assumed at the end of the 15 year period.

It is postulated that the various Ka-band terminals would be manufactured in large quantities in support of this as well as other programs. The quantities would be 4 units for the network control terminals (5 m) and thousands of M-VSAT user terminals (1.8 m and 3 m).

The costs associated with acquisition of land and/or buildings for the terminal site and the costs associated with the terminal operations room or with operations personnel are not included.

6.1.4 Network Control Center Cost Guidelines

It is postulated that a single communications control center, located within CONUS, would be used to control access to the M-VSAT communications subsystem.
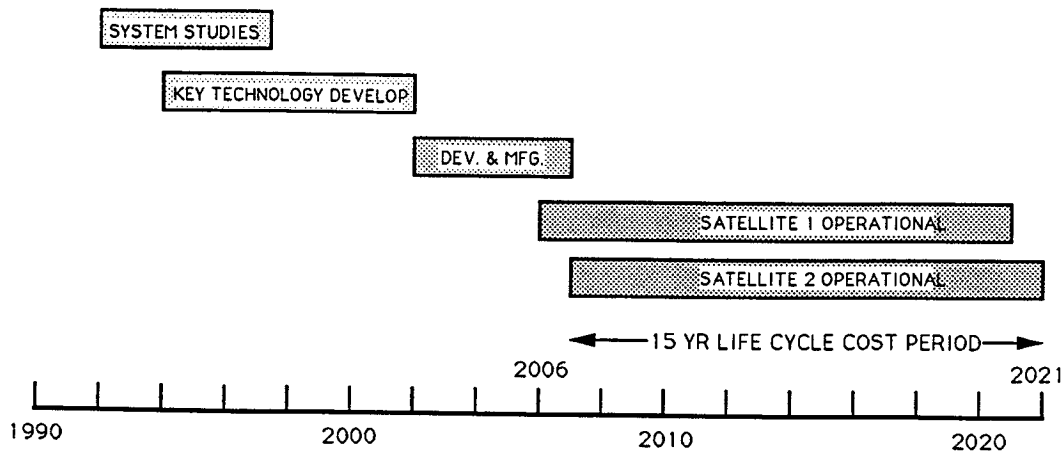
Figure 6–1: Schedule for Mesh VSAT Satellite System Implementation

The antenna system would operate at Ka-band. For improved performance and availability during severe rainfall periods, three separate terminals would be located several kilometers apart to provide site diversity.

6.1.5   System Utilization Cost Guidelines

The degree of composite users utilization of available system capacity over time has a very significant impact on allocation of space segment costs per unit of information transmittal. The model for capacity usage is postulated as follows:

- The theoretical maximum capacity is 2.72 Gb/s for a single satellite (downlink limited).

- The system achieves 15% utilization.

6.1.6   Program Schedule

A summary of schedule planning for system implementation is shown in Figure 6-1. The plan calls for manufacturing to begin in 2002 with two launches in 2006.

6.2   Space Segment Costs

For this study the space segment costs comprise the total of development and manufacture of two satellites, launch of two satellites, insurance, and TT&C support. The space segment cost discussion is divided into five parts; (1) satellite costs, (2) launch costs, (3) insurance cost, (4) TT&C costs, and (5) total space segment costs.

Table 6–1: Satellite Launch Cost ($M, 1992)

Category	Cost
Hardware	$85 M
Launch Support	12 M
Integration	12 M
Other	15 M
Total (1 sat.)	$124 M

6.2.1   Satellite Costs

Satellite costs are extrapolations from those for the current communications satellite programs of Space Systems/Loral, according to subsystem mass. Cost categories include bus subsystems, communications payload, integration and assembly, ground equipment, and program management.

Table 6-2 summarizes these costs which include a 10% fee to the satellite manufacturer. A commercial program is assumed. A government (NASA) satellite program would have 40% higher nonrecurring costs and 15% higher recurring costs due to additional testing, monitoring, and paperwork requirements.

A payload complexity factor of $100 M is added to the satellite cost in Table 6-2. This is a contingency to adjust for the difficulty of the cost model in accommodating advanced technology that is smaller and more complex than current technology.

6.2.2   Launch Costs

The expected launch vehicle for year 2006 launch of the M-VSAT satellites would be the Atlas IIAS which

Table 6–2: Cost for Development and Manufacture of Two Satellites

| Cost Category | Costs, $M (1992) | | |
	Non-Recurring	Recurring (2 sats.)	Total
Satellite Bus	72.7	114.2	186.9
Communications Payload	14.1	62.5	76.6
Integration & Assembly	6.5	15.7	22.2
Ground Equipment	15.1	–	15.1
Program Management	33.6	74.7	108.3
Cost Subtotal	142.0	266.1	408.1
Payload Complexity Factor	50.0	50.0	100.0
Fee at 10%	19.2	31.6	50.8
Total Cost	211.2	348.7	559.9

has planned capacity of 3,600 kg to geosynchronous transfer orbit (GTO). The price per launch, assuming two launches, is given in Table 6-1. The launch support costs include mission operations and TT&C support for the launch.

6.2.3 Insurance Costs

A launch insurance rate of 16% of the total launch value is assumed. It is expected that the rate will be in the range of 15% to 20% of costs insured and would be dependent upon the maturity and launch success record of the Atlas IIAS launch vehicles.

6.2.4 TT&C Costs

The costs of TT&C associated with the initial launch are included in the launch cost segment. It is expected that standard TT&C hardware would be used and that no unique TT&C facility would be required. It is estimated that TT&C services could be obtained at a yearly cost of $1 M for two satellites.

6.2.5 Total Space Segment Costs

A summary of annual program costs for the M-VSAT satellites is given in Table 6-3. The annual cost based on an 18% rate of return is also given. The life cycle cost is $490 M per satellite or $96 M per satellite per year over a 15 year period beginning in the year 2006.

The maximum single satellite capacity is 680 4-Mb/s circuits, for a total capacity of 2.72 Gb/s. The system is downlink limited.

6.3 Ground Terminal Costs

Several Ka-band ground terminal configurations are used, ranging in size from 1.8 and 3 m for user terminals to 5 m for the large network control terminals. The total ground terminal costs include initial terminal acquisition (or annual lease cost), maintenance and repair costs, and periodic upgrade and maintenance costs. Additional costs include installation and checkout, on-site costs, and operator personnel costs.

6.3.1 User Terminal Costs

The user terminal sizes are 1.8 and 3 m with respective transmit powers of 15 W and 35 W at Ka-band. Uplink data rate is 4 Mb/s. Appendix E gives link budget calculations for the 4 uplink beam case; it is assumed that the 8 uplink beam case is implemented, which results in a 3-dB reduction in user terminal transmit power.

The user terminal costs are estimated in Table 6-4. D-QPSK and a rate 1/2 Viterbi code are used for the 4 Mb/s uplinks, and the transmitter and receiver are tunable to different frequency bands. The TDM 68-Mb/s downlinks use QPSK modulation and rate 1/2 Viterbi coding.

Manufacturing quantity is assumed to be 6,000 for the 1.8-m user terminals and 2,000 for the larger 3-m user terminals. The two satellite system has 1,360 4 Mb/s circuits. The assumed ratio of user terminals to circuits is 6-to-1.

Users in high rainfall regions or with high availability requirements may elect larger diameter antennas or

Table 6–3: Space Segment Costs, 1992 $M (2 satellites, 15 yr life beginning 2006)

Cost Category (2 satellites on orbit)	Life Cycle Cost	Annual Cost at 18%
Satellite cost (2)	560 M	
Launch Cost (2)	248 M	
TT&C Support (2)	15 M	
Launch Insurance (16%)	157 M	
Total Costs	$980 M	$192 M/yr

higher power amplifiers than users of the same communications services in low rainfall regions.

Significant items contributing to user terminal costs are the high power amplifiers and modems. Table 6-4 estimates user costs for 1.8 and 3 m terminals. The 1.8-m 4-Mb/s terminal has a lower cost because of its smaller size, lower transmit power, and greater production quantity which allows a reduction in non-recurring cost allocation and increased manufacturing efficiencies. However, many of the components are common between the different terminal sizes, with resultant sharing in non-recurring costs.

6.3.2   Network Control Terminal Costs

The network control terminal cost breakdown is given in Table 6-4. Although of larger size than the user terminals, many of its components such as modems and codecs are the same as in the smaller user terminals.

6.3.3   Terminal Sharing Concepts

The advent of wideband local area networks will make it possible for multiple users to share a common user terminal providing that available capacity is not exceeded. For example multiple buildings at a university or multiple companies in a town could share a common terminal, thus reducing the cost per user by increasing the utilization of the terminal.

Sharing can become very favorable statistically. For example, 62 64-kb/s users can simultaneously share a 4-Mb/s ground terminal. There is even more to be gained from terminal sharing if links are asymmetric, i. e. users are either transmitting or receiving but not both equally at the same time. Then a mostly "receiving" user can use the terminal at the same time as a mostly "transmit" user.

6.3.4   Terminal Lease Fees

The initial capital expenditures may be reduced by leasing of terminals. Table 6-5 estimates terminal costs and gives the yearly lease fee assuming 20% of the terminal acquisition cost per year over 15 years for debt servicing and profit. This is equivalent to 18% return on investment for the leasing company. An additional yearly cost for maintenance and periodic upgrade of terminal subsystems typically equals 10% of the initial acquisition cost, with no value included for operating personnel.

Table 6-6 gives the terminal cost per minute of operation, assuming different amounts of usage per working day. (We postulate five working days per week and 250 working days per year). Costs range from a few cents per minute (for use 24 hours per day) to a dollar per minute (for use 1 hour per day). It is clear that the amount of utilization has a large effect on prorata terminal costs, and thus schemes which share a terminal among users are economically attractive. (Note that the MF/TDMA access scheme ensures that the space segment usage is shared among users.)

6.4   Network Control Costs

The regular on-orbit housekeeping functions for monitoring and care of M-VSAT satellite subsystems are achieved by the TT&C subsystem with costs defined as part of the space segment.

The communications access control to the satellite is performed by a single communications network control center located within CONUS. Users would request data channels and capacity through this facility. The cost for development and construction of this control center is estimated to be $100 M stated in 1992 dollars. This is equivalent to a cost of $20 M/yr for 15 years at 18% rate of return. The control center facility is forecast

Table 6–4: Ground Terminal Costs (1992 $M)

Terminal Parameters	Medium User Terminal	Large User Terminal	Network Control Terminal
Size	1.8 m	3 m	5 m
Transmit Power	15 W	35 W	50 W
Total Number of Terminals	6,000	2,000	4
Data Rate: Uplink	4 Mb/s	4 Mb/s	4 Mb/s
Downlink	68 Mb/s	68 Mb/s	68 Mb/s
Access Scheme: Uplink	MF/TDMA	MF/TDMA	MF/TDMA
Downlink	TDM	TDM	TDM
Modulation, Uplink	D-QPSK	D-QPSK	D-QPSK
Downlink	QPSK	QPSK	QPSK
Coding (up/down)	Viterbi	Viterbi	Viterbi
Availability (Region E)	98%	99.5%	99.8%
Non-recurring Costs			
Management and system design	$2,000	$3,000	$20,000
Equipment design	$4,000	$5,000	$50,000
Recurring Costs			
Production management	$1,000	$2,000	$20,000
Antenna subsystem	$6,000	$8,000	$20,000
Electronics, antenna mounted	$12,000	$15,000	$25,000
Electronics, control room	$13,000	$13,000	$30,000
Integration hardware	$3,000	$4,000	$7,000
Assembly and test	$4,000	$5,000	$8,000
Total Costs	$45,000	$55,000	$180,000

Table 6–5: Ground Terminal Annual Costs (1992 $)

Terminal Type and Cost	Lease Cost ($/yr)	Maintenance Cost ($/yr)	Total Cost ($/yr)
Medium (1.8 m), $45,000	9,000	4,500	13,500
Large (3 m), $55,000	11,000	5,500	16,500

Table 6–6: Ground Terminal Costs per Minute vs. Number of Hours Utilized per Working Day

Terminal Type	Annual Cost ($/yr)	Terminal Cost, $/minute of Use Number of hours utilized per working day					
		1	2	4	8	12	24
Medium (1.8 m)	13,500	0.90	0.45	0.23	0.11	0.08	0.04
Large (3 m)	16,500	1.10	0.55	0.28	0.14	0.09	0.05

to have yearly maintenance and operating costs of about $4 M based upon a level of 10 people (see Table 6-7).

6.5 Capacity Utilization

The theoretical "maximum capacity" of a single satellite is 2.72 Gb/s of simplex circuits (maximum downlink capacity). This consists of 680 4-Mb/s circuits. However, average capacity utilization will be considerably less due to a number of factors.

- Varying distribution of users among a discrete number of satellite antenna coverage beams.

- Inefficient allocation of channels among a discrete number of 100-Mb/s MCDs.

- Inefficient allocation of capacity within channels for TDMA sharing of uplink channels.

- The average utilization is reduced from peak use because of daily and hourly variations in user communication needs.

- Capacity is reduced by the frame efficiency (estimated at 90%), and uplink TDMA efficiency for users sharing 4-Mb/s uplinks.

The average utilization of capacity is estimated to be 15% of the peak utilization. For example, use of the full satellite capacity 5.2 hours per day, 250 days per year, equals 15% average utilization.

6.6 Composite Costs

Total user costs are derived by a two step process. First the space segment and network control costs for a simplex circuit are derived. Second, the user terminal costs are added to the space/control costs to obtain the total user cost per minute of circuit use.

6.6.1 Space/Control Costs for Simplex Circuit

Table 6-7 gives the total yearly costs for the space segment and network control for two satellites, assuming a 15 year life starting in the year 2006. The annual cost is $216 M for 5.4 Gb/s maximum capacity (2 satellites). Additional costs are incurred for the user ground terminal.

Table 6-8 gives the space/control cost per simplex circuit minute. At 15% utilization, the cost is $507 per

Table 6–7: Space Segment and Control Costs

	Annual Cost
Space Segment Charges	$192 M
Network Control Center Charges:	
Development and Manufacture	$20 M
Operations (15 yr)	$4 M
Total Yearly Charges ($ 1992)	$216 M

Table 6–8: Space/Control Costs vs. Circuit Size

Circuit Size	Simplex Circuit Cost (15% System Utilization)
64 kb/s	$0.032/min
128 kb/s	$0.065/min
256 kb/s	$0.13/min
512 kb/s	$0.26/min
1 Mb/s	$0.52/min
2 Mb/s	$1.04/min
4 Mb/s	$2.08/min

minute per Gb/s simplex circuit capacity. The M-VSAT system (2 satellites) has 1,360 4-Mb/s circuits. However, TDMA can be used on the uplink to allow a number of smaller users to share a single circuit in time. Thus Table 6-8 gives simplex circuit costs for 64 kb/s, 128 kb/s, 256 kb/s, 512 kb/s, 1 Mb/s, 2 Mb/s, and 4 Mb/s circuits. Circuit costs are given for a 15% system utilization.

6.6.2 Total User Costs per Circuit Minute

Tables 6-9 and 6-10 give total costs for the 1.8 m and 3 m terminal users respectively. The space/control segment cost is added to the ground terminal cost in order to obtain the total user cost. Each table gives results for unshared ground terminal use (user bears full per-minute cost of terminal) and shared ground terminal use (user only pays for portion of 4-Mb/s ground terminal capacity used). The true user cost will lie somewhere between these two extremes for users with terminals that can be shared.

Total user costs are given for different data rates and hours/day use of the ground terminal. The tables give the simplex (one-way) circuit cost plus one ground terminal cost. A duplex circuit (two-way) and two ground

Table 6–9: Total Cost for 1.8-m Terminal User (Simplex Circuit)

Terminal Use (hr/day)	User Cost ($/min), (Unshared Terminal) for Data Rate (Mb/s)						
	0.064	0.128	0.256	0.512	1.0	2.0	4.0
1	0.93	0.97	1.03	1.16	1.43	1.95	2.98
2	0.48	0.52	0.58	0.71	0.98	1.50	2.53
4	0.26	0.30	0.33	0.49	0.76	1.28	2.31
8	0.14	0.18	0.24	0.37	0.64	1.16	2.19

Terminal Use (hr/day)	User Cost ($/min), (Shared Terminal) for Data Rate (Mb/s)						
	0.064	0.128	0.256	0.512	1.0	2.0	4.0
1	0.05	0.09	0.19	0.37	0.73	1.49	2.98
2	0.04	0.08	0.16	0.31	0.63	1.27	2.53
4	0.04	0.07	0.15	0.29	0.58	1.16	2.31
8	0.03	0.07	0.14	0.27	0.55	1.10	2.19

Table 6–10: Total Cost for 3-m Terminal User (Simplex Circuit)

Terminal Use (hr/day)	Total User Cost ($/min), (Unshared Terminal) for Data Rate (Mb/s)						
	0.064	0.128	0.256	0.512	1.0	2.0	4.0
1	1.13	1.17	1.23	1.36	1.63	2.15	3.18
2	0.58	0.62	0.68	0.81	1.08	1.60	2.63
4	0.31	0.35	0.41	0.54	0.81	1.33	2.36
8	0.17	0.21	0.27	0.40	0.67	1.19	2.22

Terminal Use (hr/day)	Total User Cost ($/min), (Shared Terminal) for Data Rate (Mb/s)						
	0.064	0.128	0.256	0.512	1.0	2.0	4.0
1	0.05	0.10	0.20	0.40	0.80	1.59	3.18
2	0.04	0.08	0.16	0.33	0.66	1.32	2.63
4	0.04	0.08	0.15	0.30	0.59	1.18	2.36
8	0.03	0.07	0.14	0.28	0.56	1.11	2.22

terminals would cost double the value in these tables.

There are several points that can be made regarding these tables:

- Tabulated total cost is the sum of the space segment/control cost (Table 6-8) and the ground terminal cost (Table 6-6) for the unshared terminal case (top). Depending on circuit size and ground terminal cost and usage, the space or ground costs can dominate.

- The shared terminal case costs (bottom of tables) are dominated by the space/control costs, with much less dependence on terminal use (hr/day).

- User costs are a strong function of selected data rate for the larger size circuits where the space segment costs are larger than the ground terminal costs. This is also true if the terminal utilization is high (many hours per day).

- If terminal utilization is low and the terminal is unshared, the total user cost changes very little with data rate. This is because the ground terminal costs are much larger than the space segment costs.

- The establishment of a duplex circuit will double the simplex circuit cost shown in the tables.

- The costs will vary directly according to changes in the overall system utilization factor which is assumed to be 15% in these tables. Thus there will incentives for the system operator to sell off-peak capacity at lower rates in order to increase utilization.

It must be emphasized that the user is only charged for the communications capacity used, i. e. the actual bits transmitted. Circuit establishment and disconnection, or reconfiguration to a new size can be accomplished in a few seconds.

The circuit costs of Tables 6-9 and 6-10 can be divided by the circuit size to obtain a cost to transmit a given amount of information (one-way transmission or simplex circuit). The below tabulation gives the cost and time to transmit 1 Gb of information. System utilization is assumed to be 15%, transmission rate is 4 Mb/s, and terminal use is assumed to be 8 hours per day. The full cost for use of one ground terminal is included.

User Type	Terminal Size	1 Gb Transmit Cost	1 Gb Transmit Time
Medium	1.8 m	$9.13	250 sec
Large	3.0 m	$9.25	250 sec

As a point of reference, this report contains about 1 Mb of text and graphic information. A digitized TV picture (1 frame) could contain 100 Mb; thus 1 Gb is equivalent to 10 color video pictures (uncompressed). A 5 minute "videophone" call at 128 kb/s (two-way) would take 0.08 Gb and cost $0.70. However, a 1-hour duplex connection between two locations at 4 Mb/s would take 29 Gb and cost $263.

6.7 Discussion

Table 6-11 gives the duplex circuit cost for different circuit sizes for the medium (1.8 m) and large (3 m) users. Assumed terminal use is 2 hr/day and the ground terminal capacity is shared by other users for the case of circuit sizes smaller than 4 Mb/s.

A 5 minute "videophone" duplex call at 128 kb/s (two-way) between two 1.8-m users would cost $0.80.

A 1-hour video conference between two 3-m users at 4 Mb/s would cost $316 (requires 4 simplex half circuits where a half circuit is from the ground to the satellite or vice versa). A 1-hour video conference between three locations for large users at 4 Mb/s would cost $710 (requires 9 simplex half circuits). However, 1-hour video conference between four locations for large users at 4 Mb/s would cost $1,262 (requires 16 simplex half circuits).

Table 6–11: User Costs for Duplex Circuits (Shared Terminals, 2 hr/day Terminal Use)

User Size (m)	Total User Costs ($/min), Duplex Circuit for Data Rate (Mb/s)						
	0.064	0.128	0.256	0.512	1.0	2.0	4.0
1.8	0.08	0.16	0.32	0.62	1.26	2.54	5.06
3.0	0.08	0.16	0.32	0.66	1.32	2.64	5.26

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Chapter 7

Critical Technologies

This chapter identifies and describes the necessary technologies which are critical or enabling to the application of Mesh VSAT services. Also provided are plans for the development of such technology, with the assumption that VSAT operations begin in the year 2006. This chapter is organized as follows:

7.1 Identification of Technologies

7.2 Technology Development Plan

7.3 Technology Development Costs

7.1 Identification of Technologies

Technology requirements are given for the mesh VSAT application in four parts: (1) satellite antenna, (2) VSAT, (3) on-board processor technologies, (4) systems engineering developments.

7.1.1 Satellite Antenna Technology

The key satellite antenna technology is the antenna system which forms the multiple beams. It may be a multi-beam or phased array design. The key design parameter is the ability to cover an area such as CONUS ($5°$ by $3°$) with $0.5°$ or smaller beams, with good isolation between beams in order to allow frequency reuse.

7.1.2 VSAT Technology

The key VSAT technologies are low-cost Ka-band RF devices, such as antennas with diameters of 0.8 m to 2.4 m, a 10-W SSPA, a low noise amplifier, an upconverter, and a downconverter. Integrated outdoor RF equipment, such as that being used in the current Ku-band VSATs, is critical in reducing user equipment cost.

Other technologies are low-cost tunable transmitters and receivers to allow flexibility in assignment of TDMA/FDMA uplink and TDMA downlink carriers, a TDMA controller operating with 4 Mb/s uplinks and 70 Mb/s downlinks, and a low-cost rain-fade detection system for Ka-band in order to allow additional rain margin to be invoked. Although these technologies are currently available in VSAT and other satellite systems, further cost reduction is necessary for the mesh VSAT services to be cost competitive.

7.1.3 On-Board Processor Technology

The on-board baseband processor requires the use of large-scale digital integrated circuits with high component density per chip, low power consumption, high speed operation, and adequate radiation tolerance. (See discussion in Chapter 4.)

Critical technologies identified are as follows:

Multi-carrier demodulator (MCD) with low power consumption is the most critical technology for the realization of the on-board baseband processor. In our design for the baseband switch, it consumes about twice the power of the rest of the subsystem. Intensive development effort to reduce the MCD power requirement to the range of several watts is strongly recommended.

Bit synchronous system improves frame efficiency and simplifies on-board processor design as well as network control procedures. However, the MCD is required to measure phase errors with an accuracy of a small fraction of a symbol period. It also necessitates the user terminal to perform accurate timing correction.

Alternate techniques to implement a bit synchronous system should be investigated, and a proof-of-concept model to demonstrate its feasibility should be developed.

Multi-carrier processing devices such as a multi-carrier FEC decoder, packet assembler, differential decoder, descrambler, bit deinterleaver, and packet header error controller, are critical in reducing onboard processor mass and power and increasing reliability. These processing devices have been implemented for single carrier operation in various applications, but their multi-carrier versions will require development. Some of these functions may be combined and fabricated into a single custom LSI device.

Radiation hard 16 K x 32 static RAMs or larger will help reduce parts count and increase reliability. Significantly larger memory chips are currently available for commercial applications, and their space-qualified versions are expected to available in the near future.

High-speed optical bus interface to perform optical to electronic conversion, clock synchronization, multiplexing, and serial to parallel conversions needs to be developed for space applications.

Autonomous network controller performs not only conventional monitor and control functions of on-board equipment, but also network control functions such as carrier frequency and time slot assignment for uplink and downlink, time plan change coordination, on-board buffer management, and congestion control for packet data.

A detailed investigation is needed to assess feasibility of implementing these functions on board the satellite. Also, applicability of new network control and management technology, such as expert systems and neural networks, should be investigated.

7.1.4   Systems Engineering Development

Design of the signaling packet for transmit acquisition. To determine the exact format and size of the signaling packet assuming that the guard time between TDMA frames is 60 μs and the timing acquisition window is 170 μs.

On-board network controller with a flexible strategy. The network controller must be fast and flexible enough in changing multipoint connections, service quality, and channel bandwidth.

Rain fade mitigation techniques.
Effective techniques must be developed to combat excessive propagation loss by a combination of resource allocation methods through an increase of EIRP, a decrease of information bit rate, and/or the inclusion of a special FEC codec in the affected transmission channel.

A tradeoff must be made as to where (satellite, user terminal, or network control center) hardware and software is placed to give rain fade protection. (See discussion in Appendix D.)

7.2   Technology Development Plan

The Technology Development plan as part of the Mesh VSAT Satellite Program is given in Table 7-1. The following steps are assumed:

* The procurement cycle of Mesh VSAT satellites will begin in the third quarter of 1999 by issuing a draft satellite specification to the Industry for comments.

* The issuance of RFP in 2000.

* The selection of spacecraft contractors in 2001.

* The launch of the first satellite with the commencement of VSAT network operation by early 2006. (See schedule in Figure 6-1, Chapter 6.)

7.3   Technology Development Costs

Table 7-2 gives a list of critical technology together with the estimated cost of development.

Table 7–1: Technology Development Plan for Mesh VSAT System

Item	Start	Finish
Integrated Specifications	3/95	1/96
Services		
Traffic		
Performance		
Quality of Service		
Draft System Engineering Specifications	3/95	1/96
Space segment		
Ground segment		
Network management & control		
Critical Technology Development		
Satellite antennas	1/96	9/98
VSAT hardware	1/96	9/98
On-board processor	9/96	1/99
Systems engineering	9/96	1/99
Final Systems Engineering Specifications		6/99
Issuance of Draft Procurement Specification		9/99
Receive Comments from Industry		1/00
Issuance of Draft Procurement Specification		9/00
Procurement Cycle	1/01	9/01
Launch and Begin Operations		1/06

Table 7–2: Critical Technology Development Cost Estimates

Item	Cost ($M)
VSAT Hardware	
Low cost Ka-band antenna (1 – 2 m)	—
10 W SSPA, Ka-band	$4
Ka-band integrated RF equipment	$1
VLSI TDMA controller (4 Mb/s transmit, 68 Mb/s receive)	$3
VLSI burst modem	$2
User interface processors	$2
Total	$10 M
On-Board Processor	
Multi-carrier demultiplexer demodulator	$4
Multicarrier processors (FEC decoder, packet processor, etc.)	$2
Modulator	$2
Rad-hard memory device (use commercially available device)	—
Self-routing baseband switch	$2
High-speed optical bus interface	$2
On-board network controller	$2
Other (test bed facility, etc.)	$2
Total	$16 M
Systems Engineering	
Systems architecture definition	$2
Rain fade mitigation techniques (other program such as ACTS)	—
Space segment specification	$3
Ground segment specification	$3
Total	$10 M

APPENDIX A

<u>Communication Network and Service Environment -- Looking Toward 2000</u>

The potential for VSAT applications after the year 2000 will depend on the suitability of satellites in the communication network environment of that time period. A statement on that environment is a critical part of a business plan for VSAT services in 2000-2005. Herein, we take a look at the evolving network and applications environment. We try to bridge the year 2000 with today by considering how we expect network services and applications and to evolve over the 1990s. This grounding provides reasonableness to the futuristic view. The shortcoming is that it will mask truly unique and novel applications that may emerge. However, this can be handled separately.

It is important that network planners and business planners leap ahead 10 years and appreciate how different networks and services will be in 2000 and beyond. For example:

●   High speed switched services, not available today, will become widespread in the early 2000s;

●   minimal average terminal speeds will be higher;

●   services will be more diverse and sophisticated;

●   connectivity requirements will vary among user applications.

Also, there are unknowns. We don't know, for example, whether hubbing--a key concept in networking today--will be as important in the future distributed switching environments.

Changing Service and Communication Patterns - Public Network Services

Traditionally, the communication services offered by common carriers have been divided into voice, record, data, video, private lines, and packet switched public services. An exceptionally important changing communication pattern is the movement of bulk traffic over wide bandwidth circuits (such as IBS or T-1 ckts). This is beginning to have demonstrable effects on voice and data circuits both for domestic and international usage.

In past years, data communication over public networks has evolved from leased lines and switched connections on the analog telephone network, through the implementation of point-to-point and point-to- multipoint digital data networks, into the establishment of dedicated data networks based on circuit and packet-switched techniques. The last techniques have an increasing attraction for a significant portion of data applications.

Current telecommunication services are often provided by separate networks--voice, circuit-data, packet-data, telex, private-line networks, etc. Each network may require a dedicated physical access and a separate signaling and addressing scheme. In the last ten years, there has been a recognition of the need for a more integrated approach. From a user's viewpoint, there could be one virtual network providing all services via an access interface whose characteristics are service independent. This recognition has led to a worldwide vision called the Integrated Services Digital Network (ISDN).

A migration of digital communication services is now expected toward the telephony IDN that progressively will incorporate a wide range of new and established services, thus evolving into the Integrated Services Digital Network (ISDN). What we end up with is a common digital communication facility providing for a variety of either point-to-point or switched services via intelligent, digital switches or switching processors, themselves interconnectd by a separate common channel signaling system.

The advent of widespread digital transmission technologies, from 64 kbit/s to 1.544 Mbit/s and higher rates, and the introduction of digital Cross-connect Systems (DACS) are key elements in the rapid evolution of new telecommunications services. These digital technologies, being offered to customers in the form of new services, provide the ISDN capabilities for integration of voice, data, and video services, customer control of channel provisioning, and network management information for customer dedicated digital networks.

In the ten years from 1980 to 1990, the service environment dramatically shifted from a rather simple service structure of analog- based, voice-grade leased lines, packet switched networks and low-speed data services (DATEL) to a relatively rich variety of services as shown in Table 1. Service specific or dedicated networks (i.e., packet- switched) will be supplanted by integrated service or digital backbone networks, whereas the public switched telephone network which was traditionally inadequate for data services, will become a vital component

TABLE 1

CHANGING SERVICES ENVIRONMENT

1980	1985	1990
MTS	MTS	MTS
Private Voice-Grade Leased Circuits	Private Voice-Grade Leased Circuits	Private Voice-Grade Leased Circuits
DATEL or Data Over Voice	DATEL	?
	Dedicated Packet-Switched Services	Integrated Packet-Switched Services
	Wideband Leased Circuits (INTELSAT IBS)	Wideband Leased Circuits (Satellite & Cable)
		Switched Data Services (Public switched network-based)
		Switched Multi-Megabit Data Service (SMDS)
		Software Defined Network (SDN) Services
		Metropolitan Area Network Services (MAN)
		Integrated Services Digital Networks (ISDN)
		Broadband ISDN
		AT&T's Universal Information Services (UIS) Concept

of the provisioning of domestic and international data services, as it becomes digital and integrated. The competition between private networks and public network services will remain vigorous as the public network increases in both intelligence and bandwidth.

Of course, country networks will differ widely with respect to the sophistication of network plant and services. Nonetheless, the more advanced developing countries (sometimes referred to as 'newly industrialized countries') will have extensive digital plants by the mid-to-late 1990's in principal cities.

Carriers around the world are planning to introduce new services that will influence the shape and features (and their timing) of international private business networks and the choice between private and public. As an example, New York Telephone has introduced new services based on shared private-line concepts, tentatively named Intellihub and Vanguard. In the 1990s, the RBOC's (Regional Bell Operating Companies) and PTT's will be capable of offering enhanced networks based on Signaling System No. 7.

High Speed Public Network Services

In this study, we are especially interested in the evolving higher speed public network services. These include the:

- Metropolitan Area Network
- Switched Multi-Megabit Data Service
- ISDN, and,
- Broadband ISDN

Metropolitan Area Networks

Metropolitan Area Networks proclaim to be a natural evolution of Local Area Networks (LAN's), which have been around several years. The MAN tries to extend the scope of the LAN in geographic coverage beyond customer premises and in functionality beyond data only. The range covers about a 200 km diameter. At the same time there is an increase in bandwidth from the 1 to 10 Mb/s range of LAN's to the 50 to 150 Mb/s range. Just like the LAN uses a distributed architecture, starting with a bus topology (Ethernet) later extended to ring topologies, so have the MAN proposals started with the assumption of a distributed bus or ring topology. Later it was recognized that the determining characteristic of a LAN is not its topology or access control but rather the fact that it is a data network controlled by the owner/user. If we apply this insight to the MAN concept, we have to realize that in contrast to LAN's (which have always been private) MAN's may be either private or public networks. For the moment, these are discussed in the context of public network services. However, their role in private metropolitan "ring" networks should not be missed.

MAN Standards

Drafting of metropolitan area network standards has been worked on for
several years within the purview of the standardizing body for local area
networks, IEEE Project 802. Within IEEE Project 802, the concept of a
metropolitan area network does not extend to all the computer and voice
traffic of a city. Rather, it is an overlay on existing communication
facilities that can interconnect corporate locations scattered throughout
a city and its suburbs with an efficient private network. The packet
capability of the metropolitan area network is better adapted to file
transfer or interactive applications than circuit-switched connections
with fixed bandwidth. Connection of the internal voice networks in a
corporation's various buildings is also a priority item for the network,
simply because of the large voice volume. Voice interconnection between
the corporation's buildings still represents more bits per second than
data, by a margin of 4-to-1 or more, save in rare cases. Consequently,
voice has received much more attention in the MAN committee's work than
it has in the LAN standards.

In the time since the committee began studying fiber optic
implementations in 1984, participation by the telephone industry has
increased to the point where a very large fraction of the world's
industry is participating.

> Participants include:
> AT&T
> Bell Communications Research
> All 7 Bell Operating Companies
> Telecom Australia
> British Telecom
> Nippon Telephone and Telegraph
> Bell Northern
> L.M. Ericsson
> Hewlitt-Packard
> Data General
> Prime/Computervision

Among the activities being pursued in the MAN area are field trials in
Australia and the publication of a specification for a metropolitan data
service (SMD) by Bell Communications Research.

The most recent MAN standard proposal likely to gain acceptance is based
on a protocol and architecture known as DBDQ for Duplex Bus Distributed
Queueing, which originally appeared under the name of QPSX. The fast
packet protocol uses a fixed length cell, where the header carries "busy"
and "reservation request" fields. A distributed architecture is assumed
with each station being connected to two unidirectional buses which
operate in opposite directions. An ingenious reservation/busy scheme
gives each station the equivalent of having knowledge of everybody's
current queue, operating in essence as if there were a single distributed
queue. The data rates will be established at 45 Mb/s (because of the
Common Carrier DS-3 offerings) and 150 Mb/s to be optimally compatible
with the upcoming Broadband ISDN standard.

The system being standardized in 802.6 is based on a proposal submitted by Telecom Australia and its subsidiary QPSX Communications. Originally known as QPSX for Queued Packet and Synchronous Exchange, the protocol's name was changed to Distributed Queue Dual Bus (DQDB) to distinguish it from the development company. This proposal is quite distinct from any other standard. It involves a dual loop of the medium (nominally optical fiber but not necessarily so) arranged as a physical ring but operated as a logical bus.

Switched Multi-Megabit Data Service

Data communications is a broad and complex arena consisting of public and private networks, medium- and high-speed applications, and connection-oriented and connectionless modes of transfer.

In response to this need, Bellcore has proposed Switched Multi-megabit Data Services (SMDS) as a standard public connectionless packet-switched data service. In proposing SMDS, there was a strong intent to integrate with the customer's existing environment and add value to it. The public service should require as little change to the customer's network as possible, both in terms of hardware and software. To achieve this goal, SMDS has been architected to be capable of appearing as a "subnetwork" in the customer's overall network configuration. The customer's internetworking protocol and transport protocol can run over the network supporting SMDS, be it the popular TCP/IP protocol suite, Digital Equipment Corporation's DECnet/DNA, Xerox's XNS, Unisys' BNA, the evolving Open Systems Interconnection (OSI) standards suite, or others.

The interface to the network will require some addition to the customer's environment in order to meet the standard public network interface. This is viewed as a plug-in, with associated "driver" software, that would be inserted into a customer's gateway, bridge, host or workstation. This scenario is commonly used today for gaining access to LAN's, leased lines or X.25 packet networks.

Availability of Metropolitan/Area Network Technology

The Regional Bell Operating Companies have a strong desire to offer a high-speed data service in the near-term timeframe. An objective of 1990-91 had been established for general availability of SMDS. At the same time, a top priority is to ensure that the service migrates smoothly to the Broadband ISDN network that is anticipated for deployment beyond 1995. The strategy that has evolved is to offer SMDS on an adjunct data fabric in the near term, which will ultimately be augmented or replaced by a full Broadband fabric. The near-term fabric can be based on the rapidly evolving Metropolitan Area Network (MAN) technology.

MAN technology is a next generation outgrowth of LAN technology. Two important advances occurred in LAN technology that enabled their high-speed backbones to extend beyond a local area to span a large, metropolitan area. First, LAN's began using fiber optics as the means for transmission. And second, new Medium Access Control (MAC) protocols

evolved which can operate in the presence of increased propogation delays incurred when a backbone is extended over a large geographic area. Thus MAN technologies are viewed as a potential basis for systems used by the Regional Companies to provide SMDS. It is believed that systems based on MAN technology can be readied for field deployment to meet the 1990-91 timeframe objective for standard service.

In order to provide a standard service across all Regional Companies and in order to bring about CPE interfaces that can terminate the network access link, one standard Subscriber-Network Interface (SNI) needs to be agreed upon. To help achieve this end, Bellcore has proposed an SMDS Interface Protocol (SIP) at Levels 1, 2 and 3. Level 1 is compatible with the DS3 transmission rate so that the Regional Companies can use existing fiber transmission systems to provide access to customers. Levels 2 and 3 are the equivalent of 2 and 3 DS3s. SMDS will operate at speeds up to 155 Mbps which corresponds to the OC-3 level of the SONET standard.

Synergy with ISDN

The relation betwen MAN and ISDN is a complementary one in several ways. ISDN provides the best wide-area extension to the MAN capabilities. The isochronous MAN channels will map directly to ISDN B channels; the non-isochronous data packets can be mapped to D channels, but with a considerable speed degradation. Possibly new frame relay capabilities in ISDN will provide better long-distance service for data. However, it is in the more advanced area of broadband ISDN that the synergy between ISDN and metropolitan networks will be most valuable. The 802.6 standard is being set to the broadband ISDN speed of 155 megabits per second on each fiber, to keep link speed compatibility. In addition, the time slotting that the MAN has adopted to provide fixed-bandwidth services imposes a structure on the MAN that is very compatible with broadband ISDN switching technology.

As a result, AT&T has proposed using this switching technology to interconnect DQDB buses, in effect forming a MAN hierarchy. A project authorization to do this, in addition to the authorization for the basic MAN standard, has been approved by the IEEE. By analogy to the inter-LAN bridges now in use, it is regarded architecturally as a multiport bridge.

Integrated Services Digital Network (ISDN)

Certainly, a major public network trend to consider is the evolution of Integrated Services Digital Networks (ISDN).

Two CCITT ISDN user-network interfaces are used for connection to end-user devices. They are the Basic Rate Interface (BRI) operating at 144 Kbps and the Primary Rate Interface (PRI) at 1.544 Mbps for North America and 2.048 Mbps in Europe.

We note that the higher-speed carrier services which business use, such as DSI (1.544 megabits per second, a.k.a. Tl) are not readily available "on demand," i.e., as dial-up public services. Thus, bulk capacity or wideband digital leased circuits will continue to be a viable market for some years to some--likely until Broadband-ISDN emerged in the latter 1990s.

Sophisticated uses of "POTS" (Plain Old Telephone Services) often demand costly customer premises communications equipment (e.g., multiplexers and modems) and leased lines. ISDN, by contrast, puts more intelligence into the network, and, therefore, only needs a single user interface per user location. Its services are on demand, in terms of where connections are made, traffic types, and bandwidth a location.

ISDN is still an emerging technology in an ocean of POTS. We have "islands of ISDN" from the local exchange carriers (LECs), offering ISDN in specific metropolitan areas. We have "backbones of ISDN," long-haul offerings from the interexchange carriers IXCs). And some corporations and campuses have begun to install private campus and wide area ISDN networks. But ISDN is far from everywhere--and few, if any, applications have been demonstrated for which ISDN is essential. An exception is switched video conferencing.

ISDN is simply integrated digital services over a network or connected networks.

Services refers to the type of traffic flowing over the network, such as voice ("Good morning"), data (such as X.25 packets), video signals, image (electronic copies of medical X-rays), etc.

Digital means this information travels the network in "digitized" format.

Integrated means that all the various types of traffic can flow through a common interface--such as an ISDN line from the local telephone company's central office to your building. If you have an ISDN connection in your office, that one outlet might let you talk on the phone, use your terminal to send electronic mail, do video conferencing, and receive a fax. The traffic for all these **services** is turned into **digital** form and **integrated** into the single shared **network**.

The network can be private or public and refers to the line and associated communications switches that you plug your computers, LANs, PBXs, phones, and other business equipment into. Within buildings and campuses, these networks are usually wires and cables owned by the organization. To connect geographically separate sites, an organization either buys long-distance facilities of its own, such as microwave or satellite links-or purchases BRI or PRI services from a carrier.

A public ISDN network should be viewed as part of the public telecommunication network (PTN) infrastructure rather than a particular public switched service. [Viewed in this way, separate systems could obtain dedicatd circuits from carriers for connection into a worldwide private ISDN network. However, they would be barred from interconnecting to a PSN service also provided over the ISDN PTN infrastructure.]

ISDN circuits consist of some number of "B" channels, each providing 64 kilobits per second for user traffic, and a "D" channel, used for control signaling within the ISDN network. The ISDN Basic Rate Interface (BRI) provides two B channels plus the D channel. Basic ISDN can be run over the standard telephone twisted pair wiring found in most buildings and in many homes.

In North America, Primary Rate ISDN (PRI) consists of 23 "B" channels plus the D channel, for a total of 1.554 megabits. This is the same speed as "T1"--but they use the bandwidths differently, so you can't necessarily plug the two together.

Primary ISDN is what IXC (Interexchange carriers) tend to offer between their central offices and to corporate sites.

In the U.S., Basic Rate access ISDN is offered most frequently as part of the new Centrex Service by the local exchange carrier (LECs), however, some LECs started unbundling BRI and offer it even in single line quantities.

The PRI offers an economic alternative for connecting digital PBX's, host computers, LAN's and other devices to the network. The BRI brings CENTREX and PBX customers integrated voice and data capabilities as well as advanced voice features. BRI and PRI are standard interfaces, and offer customers the benefit of multi-vendor compatibility.

In spite of ISDN being defined as a network access method, implementation architectures must be network-wide. That is, the end systems, private networks, exchange carrier networks and interexchange carrier networks must work in harmony following the ISDN standards in order to provide end-to-end services.

User Benefits of ISDN

Users stand to benefit from ISDN services in a variety of ways. These include:

- End-to-end digital connectivity will eliminate the need for modems and similar data communication devices. Eliminating the need for analog conversion provides for virtually error-free transmission.

- Integrated access eliminates the need for different kinds of wire, cable, and connectors. Existing pair and four-wire circuits with standard interfaced plugs can be used.

- With standard interfaces, ISDN provides plug-in capability which allows configuration flexibility with easier moves and changes.

- Higher speed transmission (and eventually broadband capability using fiber optics) will allow for a wide variety of work station devices and high volume applications such as file transfer, data base updates, graphics design, and full motion video.

- The separate D Channel signaling concept opens up a wide variety of capabilities that will allow the customer to directly interact with the network for better control and management.

- Standardized terminal adaptor products will interface existing terminals, PC's, telephones and other devices to the ISDN network thus protecting the customer's investment in this installed equipment.

- Service related and software defined products available in or through the network lets users take advantage of new services and functions without expensive application design and development or changeovers and upgrades.

- Ease of line reestablishment -
  The ISDN data terminal user will have the same ability that voice users have today for overcoming line outages, namely, redial. If a line being used for data goes bad, the user will be able to reestablish the line by redialing.

- Increased line speed -
  The ISDN Basic Rate Interface provides a 64 Kbps switched connection. This is faster than current analog switched connections, thus enabling a terminal user to enjoy higher throughput and shorter response times.

- Single wiring scheme--The enterprise will be able to wire its building with a single media i.e., twisted pair cable, and not have to support separate cable media for its voice and data systems as is the case today.

  A single wiring media also will provide financial benefits since a single scheme should cost less to install and be easier to maintain.

- Integration of voice and data in an establishment. This includes: The sharing of primary trunks by voice and data calls, thus reducing the total number of trunks needed by an establishment.

- Access to enhanced services for both voice and data devices. An example is a "call forwarding" feature provided by a local switch can be used by either a voice or data device.

- Extension of voice network functions like Call Detail Recording to data devices so as to allow enterprise network administrators to more accurately track the cost of data connections and to provide information on the frequency and duration of access to Host systems.

  This information could then be used to predict when and where network bottlenecks may occur.

- The extension of data network management capabilities to include voice as well as data devices. This will allow a network administrator to get an accurate reasonably up-to-date (daily, weekly, etc.) picture of location of his equipment in the combined voice/data network, as existing equipment gets relocated or additional equipment gets installed.

- A possible reduction in the number of host access ports needed for data devices. This could be done if use is made of a switch's contention mechanism.

ISDN Will Improve Enterprise-Wide Connectivity

ISDN will provide enterprises with new ways to increase their network connectivity.

In the case of inter-establishment connectivity, ISDN will provide the enterprise and its data users with the following benefits:

1. Access to a number of services through a standard interface.

2. Ability to mix terminal equipment from a number of vendors rather than being limited to a single vendor.

3. Access to remote applications or data bases by means of dialed connections.

An example of inter-establishment connectivity is shown in Figure 1 and is discussed below.

A Local Area Network (LAN) that provides connectivity between workstations and hosts/servers within an establishment could be connected, via a LAN/ISDN gateway to an ISDN network. Such a gateway connection would provide inter-establishment connectivity as follows:

- LAN's located in different establishments could be connected by ISDN channels. The bandwidth of these channels can be chosen to accommodate the traffic flowing between the LAN's. ISDN networks can supply channels having various transmission speeds, including:
  Single B-Channels of 64 Kbps, or
  Multiple HO-Channels of 384 Kbps, or
  A single H10-Channel of 1472 Kbps, or
  A single H11-Channel of 1536 Kbps.

FIGURE 1. INTER ESTABLISHMENT
CONNECTIVITY

FIGURE 2. INTRA ESTABLISHMENT
CONNECTIVITY
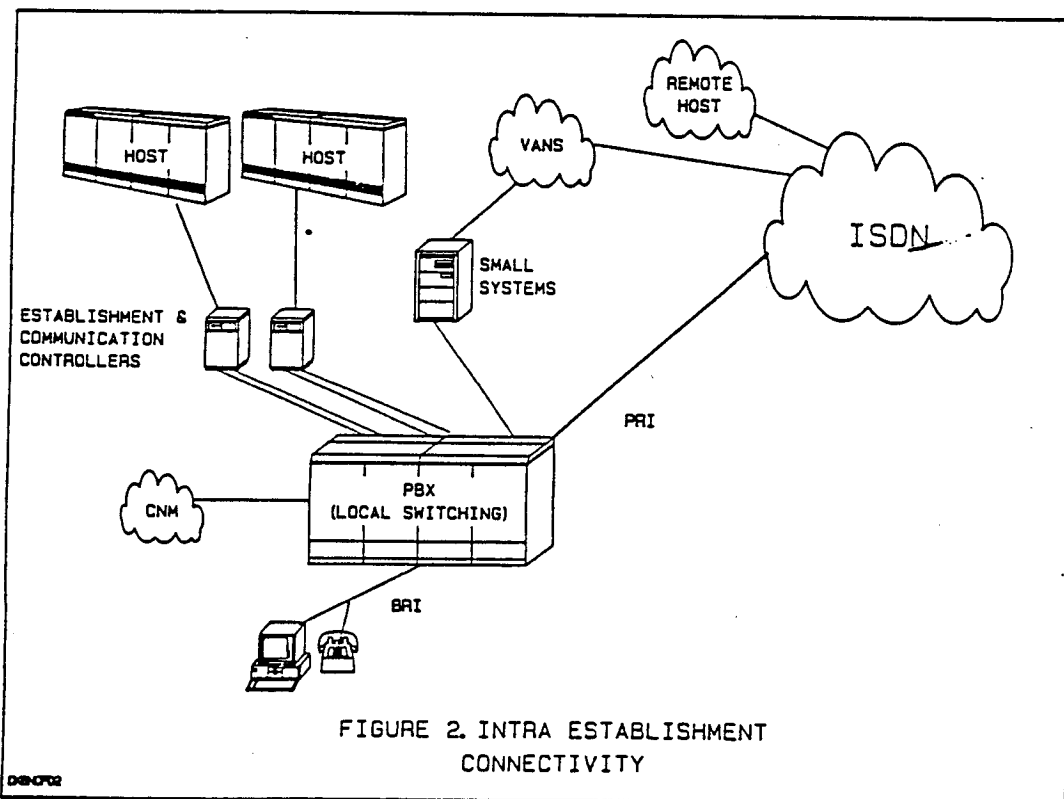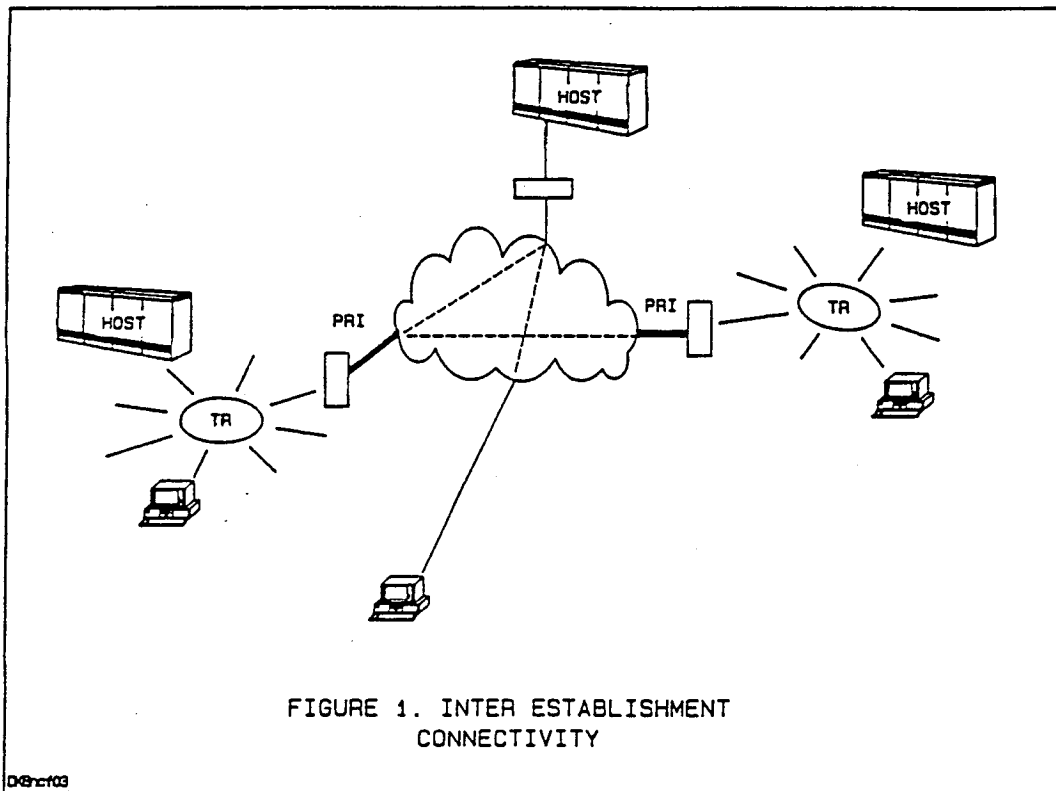
BRI – Basic Rate Interface   CNM – Communication Network Management
PRI – Primary Rate Interface   VANs – Value Added Networks
TR – Token Ring

- The interconnected LAN's could be any of the IEEE 802 types of LAN i.e., token ring; token bus or contention bus.

- Workstations and Hosts that are directly attached to the ISDN network could be linked to Workstations and Hosts/Servers that are attached to the LAN's. The LAN/ISDN Gateways could be designed to make such connections "transparent" in the sense that the ISDN-attached workstation, when contacting a LAN-attached Host/Server, performs procedures that are similar to those that it performs when contacting an ISDN-attached host. (Similarly, a LAN-attached workstation, when contacting a Host/Server in a remote establishment, could perform similar procedures to those that it performs when contacting a local, LAN-attached, Host/Server.)

- A LAN is a "broadcast channel" on which virtual circuits can be established between pairs of stations. In order to direct data packets to the proper target station on a LAN, each packet includes a "Destination Address" as well as a "Source Address". These two addresses form part of the information required to identify a logical circuit.

ISDN Networks provide logical circuits over either circuit-switched or packet-switched connections. The ISDN connections are established by means of call set-up procedures prior to the transmission of user data. During the call set-up procedure, a calling ISDN station can supply information about itself (such as its "Calling Party Number") as well as information about the target station (e.g., "Called Party Number").

The LAN/ISDN gateway could provide a mapping function that converts ISDN addresses into LAN addresses, and vice versa.

Even if public ISDN services do not materialize in the near term, private ISDN networks will likely emerge. As facilities for Integrated Services Digital Networks become available, it should be possible to implement ISDN based private networks, or private ISDN's which realize to the fullest extent users' networking requirements, while maximizing the efficiency and cost effectiveness with which both user-provided and carrier-provided facilities are employed. In a private ISDN, a user will be able to exercise supplementary services such as call forwarding, call transfer, and camp-on to any target address within the network. Data communication services, including access to remote directories, databases and servers, will be available across the network. In addition, transport and control mechanisms for wideband services such as video teleconferencing and highspeed facsimile and graphics will be available throughout the network. Finally, the user will be able to take advantage of extensive network management services, including route selection and optimization, bandwidth management and failure isolation.

While ISDN planning and early implementation has taken some 1 to 12 years from its inception to the reality, Broadband ISDN which will build on the base, is likely to cut this interval to no more than 4 to 5 years. Given that no technology changes can justify a complete retrofit replacement of the existing public network, (now valued in trillions of dollars), these new technologies will be introduced alongside those existing and currently deployed.

Broadband Services

The term Broadband is being applied to services which operate in the range above several Megabits/sec (Mb/s). We think that typical offerings will be at the 45 Mb/s rate or its European counterpart of 34 Mb/s, at the 100 Mb/s range as proposed for Metropolitan Area Networks, or in the neighborhood of 150 Mb/s as envisioned for Broadband ISDN.

The efforts to extend the Integrated Services Digital Network into the broadband range were originally directed at providing digital video service and hence targeted at a circuit-switched rate of about 150 Mb/s, which would suffice to carry the current video signals uncompressed and allow for later extension to compressed high definition video signals. More recently it was realized, that a lot of the profitable broadband service opportunities might actually be in data networking, which is much better served by packet-switched offerings. Hence one has arrived at a fast packet switched standard proposal which now goes by the name of Asynchronous Transfer Mode (ATM). ATM assumes fixed size cells with a descriptive header ("label multiplexing"). The ATM cell consists of 5 bytes of header and 48 bytes of information.

New Broadband Standards

Recently, several standards for new broadband services have appeared. First, the ANSI proposal for a Fiber-Distributed Data Interface (FDDI) standard appeared, for a private Metropolitan Area Network (MAN) data services at a 100 Mb/s rate. Second, in the international arena, a CCITT working group has been working on a Broadband-ISDN access interface standard that would offer services up to video rates of about 150 Mb/s. Third, the IEEE 802 committee has been working on a public network MAN standard that would include voice and data and operate at or above 45 Mb/s.

For several reasons, standardization for the broadband ISDN will be much more complex and difficult as it was the case for the 64 kbit/s ISDN:

- First, for the ISDN at 64 kbit/s we had to enhance the digital telephone network in other words, an existing network has to be upgraded in some parts only; for broadband ISDN, some parts of the ISDN network will have to be entirely replaced by new technologies (optical fibers in local networks, in loops, new switching technologies like ATM, "fast packet switching", which are still under development.

- Second, in the ISDN we have only two predetermined bitrate--this is 64 kbit/s and 1.544 Mbps; bitrates for the broadband ISDN may, vary from 64 kbit/s to 140 Mbit/s or even more.

- Third, there exists a divergence between at least the United States and Europe as to which services or applications should be taken into account for standardization of the broadband ISDN. This divergence already came up in the ISDN standardization, but for the broadband ISDN it can certainly be foreseen as well.

In the United States the stress is on more pragmatism: "Let us first have the broadband capabilities---services and applications will come later, from conventional telphone-type to video and HDTV services". In a deregulated environment like the United States, people are more application-minded; customers will decide which services and applications they wish to make use of via the broadband access, but this implies that they all have to be defined, standardized, and offered by the same service provider.

In Europe (at least in some large countries), where PTT's are the traditional network and service providers, the situation is opposite: for PTT's having been the exclusive, unchallenged service providers over many years, it is simply unbelievable that their position would not remain the same with broadband ISDN. Consequently, they attempt to define and standardize broadband services (which, of course, they then intend offering to customers), an attempt which is almost impossible to resolve at this point in time. What would e.g., be the bitrate for a standardized videotelephone service while bitrates from 64 kbit/s to 140 Mbit/s are under discussion? Upgraded video services and HDTV are for many PTT's long-term developments and for legal reasons will soon not be allowed to carry such signals in their broadband networks, whereas in the United States these video services are seen as short-term opportunity which is one of the driving forces towards the broadband ISDN.

Despite all these problems some first steps have been made in the standardization of broadband ISDN. There is a first conceptual Recommendation (I.121, Broadband aspects of ISDN) which will serve as a working basis for the forthcoming study period. Two broadband accesses (user/network interfaces) at 150 and 600 Mbit/s are foreseen; a wide range of services and applications accessing the broadband ISDN via these interfaces are listed for further study. As technology progresses rapidly, timing similar to the standardization of the 64 kbit/s ISDN might also be forecasted for the standardization of broadband ISDN.

FDDI

The ANSI standard proposal for a Fiber-Distributed Data Interface (FDDI) assumes an optical fiber ring operating in a variable length packet mode at 100 Mb/s. Actually, the architecture proposes two counter-rotating rings which provide a self-healing property in case the ring breaks by bridging both rings into one ring at the two ends of the broken rings.

FDDI is fast becoming a reality in the market place, and interfaces will soon be offered by many computer manufacturers or data networking equipment suppliers. We will see a similar evolution as with LAN's, with

private broadband networks being put together. Unfortunately, FDDI is incompatible with the evolving Broadband ISDN standard which is based on the ATM protocol. The development of sophisticated bridges and inter-networking protocols (IPs) will provide future compatibility. In the 1990s, we will see Eternets (10Mb), Token Rings (16 Mb) and FDDI 100 Mb) networks that require interconnect. For these applications SMDS could act as a transparent bridge or routed (TCP/IP, ISO/IP) interconnect. since SMDS is considered to be the first service to fall under the generic title of Broadband ISDN, SMDS would provide a bridge between FDDI and B-ISDN.

Broadband Service Opportunities

In the business market segment LAN's are expected to continue growing at a rate of between 30-35% annually. The emergence of initial FDDI chips demonstrates the need to interconnect the multitude of LAN's within a customer's data network. The B-ISDN network can extend this data network by interconnecting LAN's from different locations into high-speed Metropolitan Area Networks (MAN's) and Wide Area Networks (WAN's). In addition to providing LAN interconnect, the MAN's and WAN's can also provide LAN-like services such as remote access to disk servers and backend networks for host-to-host computer connectivity, but over larger distances. B-ISDN will also offer a consistent numbering and addressing plan across the geographically distributed data network.

Table 2 indicates potential broadband service opportunities.

TABLE 2

POTENTIAL BROADBAND SERVICE AND NETWORK EVOLUTION

	BUSINESS	RESIDENCE
Near Term (Early 1990s)	LAN Interconnections (Intra-business connectivity)	Broadcast Video
Mid Term (Mid 1990s)	Increasing MAN deployment ISDN interworking (Multi-media communications & inter-business connectivity)	Multi-cast Video ISDN interworking (Increased control & quality)
Long Term (After 2000)	Full broadband switching (Business to residence services)	Full broadband switching (Information & merchandising)

Broadband Service Examples

A representative service for many business applications is multi-media desktop teleconferencing, in which a Broadband Terminal would provide the capabilities for audio, facsimile, still-image, graphics, and full-motion video communications. Each terminal would have both display (or hardcopy output), and input (or origination) capabilities for some or all of these media. A single terminal might be equipped for a subset of the media, or it might be fully configured, much as today's personal computers are configurable for a variety of user needs.

Applications for multi-media teleconferencing include research and development collaborations, staff or project meetings, educational programs, presentations, etc. In a day's work an engineer could use the broadband teleconferencing capabilities of the terminal for reviewing drafts of a memo with management and co-workers, sometimes using full-motion video to simulate face-to-face meetings, but more often relying on the audio channel for voice communications, the still-imaging capability for exchanging illustrations, figures, tables, or charts, and graphics for annotations, sketches, etc. The output of graphics applications, such as CAD/CAE, can be displayed immediately on all the participant's terminals.

During an afternoon, the engineer might use the graphics capability to monitor the progress of a large, complex simulation. The engineer might also use the terminal to review a multi-media course covering operation, maintenance, and repair of a large refinery or plant for which she or he has responsibility. Several times during the review, the display is 'frozen' to allow annotations to be added, so that the training department can clarify and correct the course material. The BN provides a multi-media mail service, so the annotated materials are accessible to the course developers at any time. In order to prepare a report, the engineer might access remote multi-media databases, using both specific queries and general browsing services to gather some or all of the necessary information.

These applications generalize to many professions beyond engineering, such as the technicians who use the multi-media course for training and references, architects and designers who use the graphics capabilities instead of producing and displaying actual models, or real-estate agents, who use electronic listings (with data describing the land, home, or other buildings, still images of the lot and house or building, and full-motion recorded walk-throughs of properties.

SONET - Synchronous Optical Network Standard

The SONET (Synchronous Optical Network) transmission standard proposal provides a framing and multi-plexing strategy for 155 Mb/s, 620 Mb/s, and 2.4 Gb/s communications links using optical fiber. The SONET format is suitable for connections from a network element to other network elements and for connections to subscriber's equipment. Thus a single, extensible transmission format provides a potential infrastructure for local, regional, national, and worldwide BN's.

The SONET transmission standard proposal provides a physical layer protocol for Broadband Networks. The 155 Mb/s interface provides adequate bandwidth for several NTSC-quality channels (compressed) or a single uncompressed NTSC channel, with spare capacity for data transmission, audio, and signaling information.

Technology

Recent advances in optics, electronics, and high-speed packet switching systems will impact the national and international telecommunication networks. It is likely that the future networks will also include transport of image and high bandwidth data in addition to the familiar integrated voice and data services. The combination of technologies of fiber optics and wideband digital switching will revolutionize the way in which networks are designed and operated.

Technology advances in optical systems, VLSI, broadband switching and distributed processing are strongly influencing the network evolution. Leading-edge fiber optic and VLSI technologies are particularly influential in determining potential capabilities in the broadband arena, particularly broadband ISDN. Cost advances in single mode fiber have made fiber deployment a reality. That is, costs per meter have decreased from about 1 dollar in 1982 to about 23 cents in 1987, and projected to drop about 4 cents by 1993. Similar cost advances in LED and laser technologies, and more powerful VLSI are further stimulating inexpensive transport. The availability of economical fiber and broadband switch technology in the 1990's will make broadband ISDN a reality. VLSI technology is presently available to make high speed broadband circuit and packet switching technically feasible with expected economic feasibility in the 1990's. Of particular interest is the Batcher-banyan switching network combination which provides a fast packet or cell routing/switching capability. Projections indicate 150 Mb/s switching capabilities.

Over the next decade transmission technology and products will continue to play a key role in the evolution of common-carrier and private networks.

Lightwave Communication Developments

The economics of lightwave transmission, compared to other forms of information transport such as radio and copper based carrier, will continue to make it the technology-of-choice over the foreseeable future for national systems. Lightwave systems will eventually offer multigigabit throughput, but a major product development thrust for the next few years will be aimed at providing economical access to the bandwidth available from today's technology. SONET, now adopted as an international standard, will play an important role in achieving multivendor optical product compatibility.

Lightwave system capacity has doubled almost every 18 months since the first commercial product was installed in the beginning of this decade. From an initial rate of 45 Mb/s (672 channels) we have today 1.13 Gb/s

(16,128 channels) lightwave equipment field trialed and providing service.

Present direct modulation techniques employed to produce optical signals is expected to be augmented in the mid 90's with coherent technologies. Improvements in optical devices and electronics over the next five years will move the bandwidth frontier for direct modulation from today's 2 Gb/s level to about 4-6 Gb/s. Dramatic increases in system performance, required to take advantage of the 50,000 Gb/s capacity inherent in single mode fiber, will require coherent modulation. Practical systems utilizing these new techniques will be offered in the 1993-95 time period.

With this explosion of system bandwidth has come a dramatic fall in transport costs. Compared to a 90 Mb/s product selling in 1981, the electronics expenses for a 1.13 Gb/s system are one tenth of the earlier equipment on a per circuit basis. Fiber cable prices have similar history. Multimode in 1988 was priced at $1.00 per meter, now an equivalent sells for less than $.20. Single mode optical cable, priced at over $2.00 in 1982, cost less than multimode today. Fiber optic undersea cable systems such as TAT-8 and -9, HAW4/TPC3 PTAT bring lightwave technology developments to international undersea cable.

The Evolving Role of Satellites

The application of satellite links in the provision of telecommunications services has been an evolutionary one. In addition to the continuing usage for the transmission of international switched message services on a global basis, the domestic telephony and TV, recent applications have augmented both the types of services available and their points of access. As one example, the usage of satellite facilities for video-conferencing represents a service wherein the natural point-to-multipoint capabilities of satellites are exploited. Increasingly, the location of small earth stations (IBS, VSAT's) relatively nearer to ultimate users than previously possible has become a reality in many countries. In this respect, INTELSAT has now approved access of its satellites by standardized earth stations having a wide range of capabilities. Furthermore, the existing INTELSAT Standard A and C earth station specifications have been modified to accommodate antenna diameters approximately one-half of those originally required. Inasmuch as many of these applications are congruent with anticipated ISDN services, it would appear, for reasons of economy, that they should be compatible with and integrated into the ISDN.

Although satellite systems can provide diversified services, dissimilar services presently require interconnection to different terrestrial transmission networks at earth stations. The demand for service flexibility requires a satellite communications carrier to look beyond its earth stations to the overall communications network for a solution to the varied end-to-end services which are demanded by today's customers.

Computers are being directly connected via satellite around the world without the network management problems inherent with circuits routed through several countries speaking different languages. This simplification in network architecture can significantly reduce the maintenance support requirements within data processing centers. A single computer can broadcast data via satellite to many locations concurrently in a single transmission. Files can be updated concurrently worldwide, a critical requirement of many businesses. These features appear necessary to meet the global nature of ISDN.

The success of a global ISDN network depends on the interconnectibility of both multiple carriers and mutliple transmission media. For instance, host computers in different countries made by different manufacturers and connected to an optical fiber local area network, on the one hand, and a microwave radio local area network, on the other, must be able to communicate efficiently through OSI via intercontinental satellite systems or cable systems to meet the ISDN global standard requirements. The increased bandwidth and quality that are expected to be available in the fiber optic cable media must be complemented by the mobility, connectivity, flexibility, and geographical independence which satellite systems provide.

By the year 2000 all of the satellites currently in geosynchronous orbit will have died; taking their place, literally, will be a new breed operating in the C, Ku and Ka-Bands (some in all three). These new birds will be much more powerful typically, with transponders providing more than 50 db EIRP. This increased power will have the beneficial effect of both reducing the cost and increasing the performance of the ground segment; thus one can expect to see Ku-band earth stations with half meter dishes delivering T-1 speeds at costs under $5,000. Ka-band may offer even greater economics.

Integration in both terminal design and componentry will also contribute to price performance, with a rationalization of the functions of switching (both packet and circuit), up and down conversion, modem, codec and data interface units (including protocol conversion).

The new satellites will offer greater coverage of the earth than is presently available. Switched beams will be provided, as will on-board processing. We should also see the fairly prolific use of phased array antennas, some of which will be electronically steerable, a quality which is particularly useful for mobile applications. Finally, we will see some crosslinks between satellites allowing truly "live" broadcasts of events of global interest such as the Olympics or the America's Cup.

Digital Cross-Connect Systems

Digital Cross-connect Systems will quickly emerge from their present role as a facility management tool to more of a call processing and service providing vehicle. These changes, combined with the introduction of broadband termination and switching capabilities in traditional narrowband CO switches, will make the distinction between switching and transmission much less clear.

Since the first DCS introduction in 1981, the role and functional capabilities of automated cross-connect systems has changed. Originally planned as primarily a digital test access tool for DS1 network facilities, DCS's have emerged as network management products providing remotely controlled cross-connects for all levels in the digital hierarchy, and serving as facility and service performance monitors. Today they are used for trunk restoral, traffic segregation, grooming/filling, and narrowband customer control.

New DCS equipment in the next few years will offer DS3/DS1 interfaces and direct optical terminations, DS1/DS0 and substrate switching, extensive performance maintenance and monitoring features, and sophisticated network and customer control capabilities. As compared to today's products, advances in VLSI and packaging technologies will bring dramatic reductions in size, price and energy consumption.

But, perhaps the most important change in DCS's is how they will be used not only to provide network management, but to serve as gateways to future network offerings. One example is high capacity virtual networking.

With the introduction of call processing and signaling protocol conversion features in cross-connect products, exchange and interexchange carriers will be able to offer high capacity (DS1 and DS3) virtual private network services. These software defined customer controlled networks will be constructed with DCS's that can terminate ISDN primary rate (23B+D) customer access lines, perform D-channel to CCS SS7 processing, and establish DS1 and DS3 links under Intelligent Network control. These changes to cross-connect system - which are really just patterned after CO and tandem circuit switch capabilities - will occur over the next three to five years, and will allow DCS service control to be decentralized.

Today DCS's are normally considered as "transmission" products - not part of the circuit switching equipment family - primarily because they have been viewed as replacements for transmission equipment such as cross-connect patch panels and back-to-back channel banks. But, the distinction between DCS's and circuit switches will become less clear as cross-connects assume software controlled call processing capabilities, and switches are modified to offer broadband services. Applications will determine the difference between these two technologies. Cross-connect systems will be employed to establish connections requiring long holding times and needing very limited switch processing; high capacity VPN's, network restoration and facility hubbing are examples. Circuit switches, regardless of their bandwidth routing capabilities, will be used where powerful call processing capabilities are required; POTS, Centrex, and perhaps a practical version of Picturephone[TM].

Network Architecture of the 1990's

The architecture of the Network of the 1990's is being driven by a number of user and carrier needs. The end-users of information age services must be able to respond rapidly to change in their competitive market-

place. They will have a wide range of communication needs and a strong desire to control the mix of services to address their needs. The network supplier of these services in turn must be able to satisfy the demand for services rapidly, economically and efficiently in a manner that provides each customer with services tailored to meet specialized needs and the ability to control them. Current service introduction cycles and procedures of 3 to 5 year periods are not satisfactory for the carriers to satisfy their customers' demands. To meet the needs of their customers, the 1990's network architecture must allow for:

- ease of service introduction, including a wide spectrum of user bandwidths and features,

- carrier service programmability/service creation capabilities

- customer control and management of network services.

Use of standard interfaces will allow end-users to easily attach to carrier networks and receive compatible services, and allow these networks to be built from equipment provided by the widest range of vendors.

Intelligent network concepts which support customer control, centralized call disposition information, and network flexibility are key elements in the Network of the Nineties. These concepts are becoming a reality today with the introduction of out-of-band Common Channel Signaling capabilities and information/logic stored in centralized databases external to network switches.

A large number of new applications, in high speed data and video, are putting a great deal of pressure on the carrier network in terms of requiring ubiquitous connectivity and customer control of the services. Customers desire an integrated approach to managing and controlling their voice, data or video services. This desire is coming about from the merging of technologies, the desire to reduce costs and the potential for new services, such as in multi-media voice and data or voice and video.

As shown in Figure 3, the trends toward increased bandwidth and intelligence in the network.

FIGURE 3

NETWORK TREND: INCREASED INTELLIGENCE AND BANDWIDTH

INCREASE NETWORK INTELLIGENCE
-->

	INFORMATION TRANSPORT	INFORMATION SERVICES	INFORMATION CONTENT OR SOURCE
V O I C E	PRESENT		
D A T A	POSITION		
V I D E O			

(left axis, read bottom-to-top) INCREASE NETWORK BANDWIDTH

A-23
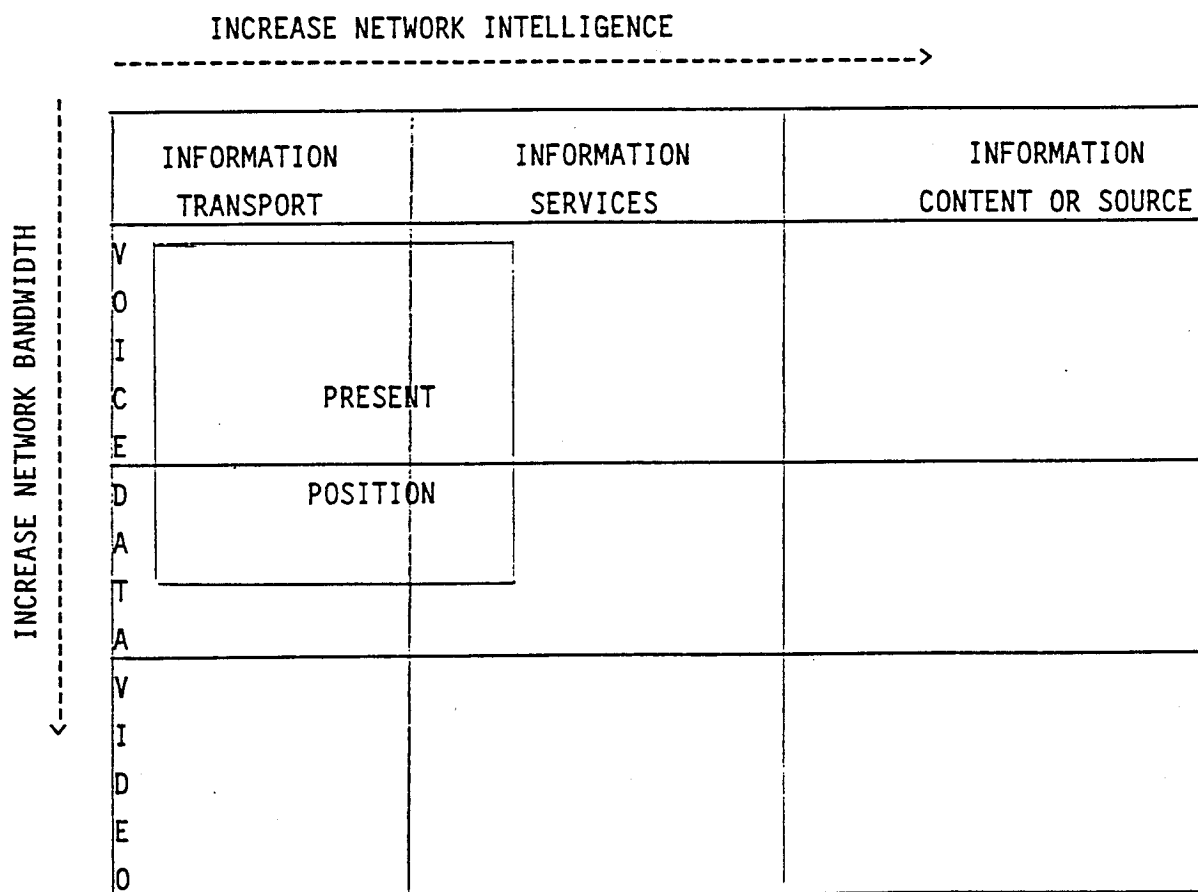
Changing Service and Communications Patterns--Private Network Applications

Private Networking

Most large multi-location enterprises presently employ private networks to meet their needs for inter-location communications. Their objectives include maximizing communication efficiency and flexibility or minimizing overall communications cost. Additionally, private network facilities are normally interconnected with the public network for so-called "off-net" communications, such as calling from a station within the private network to one outside it.

Private networks have evolved over the past few years to the point where they can provide a variety of sophisticated network resource management functions for their users. These may be realized through the use of user-provided equipment such as stored-program-controlled PBX's, intelligent add-drop multiplexers (ADMS), data communication controllers, and so-called transmission resource managers (TRM's), together with some mechanism for control of communication between these devices. Alternatively, they may be carrier-provided services relying on the capabilities of the carrier's stored-program-controlled switching equipment, network control facilities, and common channel signaling system; this case has sometimes been referred to using the term "software-defined network" or "virtual private networks" (VPN). VPN's are carrier solutions to retain or get back the private network users.

Logical Networks

Four types of logical networks may be defined within the technical network architecture of the enterprise. These are:

1. Transactional networks, which are used to capture and process data generated within the business of the organization. These networks are usually mature and relatively stable. They typically use either asynchronous devices or synchronous IBM 3270 terminals, or their equivalents, and are attached to a single host processor.

2. Factory automation networks, which are found in manufacturing organizations. These are process control networks, generally highly decentralized, with a dedicated process control minicomputer for overall process management.

3. Information service networks, which is similar to an older idea, that of decision support networks. Here, the personal computer has emerged as the workstation of choice for the environment. This network is a growing priority to most organizations concerned with strategic uses of technology by end users.

4. Messaging networks, including electronic mail, facsimile, telephone, telex, and increasingly, electronic data interchange between corporations. Most of an enterprise's resources are dedicated to supporting this type of network.

Manufacturing users generally employ all four types of logical networks. Financial institutions employ all but the factory automation network.

Network Architectures

Three basic network architectures may be defined: switched private line networks, dedicated private line networks, and virtual private networks. Each of these basic network types, in turn, have multiple configurations.

Switched Private Line Networks

Switched private line networks allow large business customers to connect their geographically dispersed locations via tandem switching nodes. In general, switched private line networks serve voice and voice band data traffic. In a switched private line network, customer locations are connected to the nearest tandem switch via dedicated private line facilities. Dedicated private line facilities are also utilized to interconnect the tandem switched.

Switched private network tandems can be located in a serving office, or on a customer's premises. In a serving office base network, the customer's access lines, which generally originate from a Private Branch Exchange (PBX) or key set, are terminated on a shared central office switch. This central office switch can be shared with other private network customers, or with other services. As a private network tandem, the central office switch receives dialed digits from the PBX, then performs private network digit analysis, screening, and routing for the switched private network call. The central office switch either completes the call directly to the destination, or routes the call to a far end central office switch for completion. AT&T's Common Control Switching Arrangement (CCSA) and Enhanced Private Switched Communications Service (EPCS) are examples (1980s) of serving office based switched private networks. In a customer premises based network, Private Branch Exchanges (PBX's) serve as customer dedicated network tandems. (The PBX's also serve as intra-premises switches.) As a tandem switch, the PBX receives dialed digits from either directly terminated stations or subtending PBX's. The PBX tandem then performs private network digit analysis, screening and routing for the switched private network call. The tandem either routes the call directly to the terminating PBX/station, or directs the call to a far end tandem for subsequent routing and completion. AT&T' Electronic Tandem Network (ETN) was an example of a premises based private switched network.

Dedicated Private Line Networks

Dedicated private line networks allow large business customers to connect their geographically dispersed locations on a point-to-point basis. While switched private line networks are primarily voice and voice band data oriented, dedicated private line networks may be voice or data oriented.

Dedicated private network facilities can be analog or digital but are usually the latter today. Dedicated private network facilities provide the underlying point-to-point digital transmission at rates of up to 45 Mb. U.S. users currently have multiple T-1 carriers in their network and will upgrade to T-3 or DS-3 (45 Mbps) rates by 1992 for, at least, their domestic backbones.

Virtual Private Networks

As noted above, most private networks have either premise-based switches dedicated to a single location or have centrally located switches shared by several locations. These private networks have dedicated access lines from premises equipment to the nearest switch and customer dedicated trunks between switches. The customer purchases or leases the equipment and trunks at a fixed cost that is independent of usage.

There are several reasons why customers are using these private networks. First, these networks allow customers to transmit and control information at a lower cost. In addition, customers can control the types of calls made by various sets of callers and change these calling privileges. Customers can define a uniform numbering plan that allows callers from different network locations to dial the same seven-digit number to reach a specific on-network station. Finally, many private networks provide customers with information for allocating internal costs and for engineering, administering and operating their network.

Problems

From the customers' perspective, the above private network services were not satisfying all their telecommunications needs. First, since it is expensive to include corporate locations with long access lines or trunks to the private network switches, this limits the number of locations that can use the features and functions of the private network. In addition, some of the hardware-based private networks cannot be changed easily to respond to varying traffic demands or to improve the feature capabilities. Another deficiency is that the price performance of the private networks has not been stable or predictable over the years. Also, many of these networks do not have centralized monitoring and control capabilities. As a result, many customers began looking for alternative solutions to satisfy their telecommunications needs. Finally, users are beginning to question the cost of "techies" and other labor costs which are becoming the major cost of private networks.

In response, carriers created an alternative that combines the benefits of their public network facilities with the features of a private network. One of the first offerings was AT&T's Software Defined Network (SDN) that allowed the creation of virtual private networks (VPN's). SDN serves businesses with multi-location telecommunications needs by combining voice and data transport on the AT&T Network with call processing capabilities that enable customers to develop and manage a corporate telecommunications network. SDN offers customers shorter access lines and consistent capabilities at all locations.

AT&T has filed a tariff for its Virtual Telecommunications Network Service (VTNS). DuPont was an early purchaser. MCI (VNET) and U.S. SPRINT soon followed SDN with virtual network alternatives.

These network services have been well received in the domestic marketplace and have yielded both improved quality and lower costs and are expected to appeal to some categories of users for international communications.

Combination Hybrid Networks

Virtual network services will likely be combined with private lines to optimize customer networks.*

Many, if not most, large multi-location customers employ all of the above services in their corporate networks as well as public services. For example, users may combine public, common-carrier based services such as WATS with Virtual Network Services (VNS), and VANS and backbone private leased lines (56 KB to 4.5 Mbps). UNISYS, for example, will supplement their T-1 based ETGN with SDN service to tie more than 100 locations to their T-1 backbone network. Thus, future VSAT applications will not be standalone but part of a bigger hybrid network. This implies interconnectivity requirements.

Private Network Deployment in the United States

A private network may be defined generically as the use of dedicated facilities, either publicly provisioned or privately constructed, for the transmission of voice, video or data traffic over an integrated system not accessible to the general public. The number of private systems in the United States has been growing at a rapid rate in recent years. In the U.S., capacity on these private networks now exceeds that available from common carriers. It has been estimated that 1987 investment levels in private information networks exceeded $16 billion -- more than the sum of the capital programs of all the Bell Operating Companies combined.

Large corporate entities such as General Motors, J. C. Penney, McDonnell-Douglas and Southland Corporation has all developed or are in the process of developing large-scale private networks. Over time, as these private networks develop and proliferate, there will be an ever-diminishing share of total telecommunications traffic traversing the public switched network. This trend toward private network development has already reached large-scale proportions. Recently, the Bell Operating Companies and GTE estimated that the monetary value of telecommunications traffic traversing dedicated facilities that was capable of being carried over the public switched network was equivalent to some $3.8 billion in switched access revenues. This trend is expected to continue and perhaps even accelerate over the ensuing years.

*See: Luczak, M. Tapping the Hidden Savings in Virtual Networks, Telecomunications, March 1991, pp 45-48.

The business users that have constructed their own private networks to date tend to be rather large corporate entities. This does not suggest, however, that smaller firms and perhaps someday even residential customers will not make use of private networks. There is increasing evidence to suggest that potential resale opportunities on these private networks will position them to compete effectively with the users' other capital investment projects. In addition, so-called metropolitan area networks (MAN's) are springing up in the larger cities around the country. Two of the more active developers of MAN's in the U.S. are Merrill-Lynch Teleport of New York and Institutional Communications Company (ICI) of Washington, D.C. These MAN's generally deploy fiber optic rings around downtown city cores and generally serve large business customers requiring sophisticated voice, data and video transmission with direct connect service to the IXC's as well as to one another. MAN's may also be interconnected through the use of various radio and waveguide technologies. Once connected to these large business locations, the MAN's may span out some 5,000 radial feet to connect smaller users within that defined geographic boundary, using the original location as a facility hub or switching point. These MAN's tend to propogate themselves due to economies of scale that serve to reduce operating costs continuously as a function of both the number of subscribing customers and traffic volumes. These MAN's are being deployed in New York, Orlando, Miami, Chicago, Washington, D.C., Dallas, Minneapolis and elsewhere. These activities suggest that private network deployment is well underway in the United States. It should be noted however, that the use of the word "private" here is somewhat misleading. Resale opportunities on private networks and MAN's themselves represent competitive alternatives to the public switched network.

Data and Digital Voice Traffic Will Grow in the 1990's

During the 1990's, the amount of data imaging and digital voice traffic is expected to increase significantly. This growth will in turn cause a growth in the customer's digital networks. From the customer's perspective, it is not necessarily operationally, nor economically efficient to maintain multiple independent telecommunications networks. Integrated voice/data (IVD) networks and integrated service (ISDN) networks are the trend. Facsimile, videoconferencing and electronic mail are other applications that are being implemented (integrated) over digital networks.

Figure 4 shows the diverse applications of a global business network. Some nodes (e.g., CAD/CAM) will have higher speed requirements than other nodes.

Over the next 10-15 years there will be an ever-increasing thirst for information, not only in the office and the factory, but also in the home. In the factory there will be increased use of CAD/CAM for design and manufacturing and more importantly large corporations will get involved in CAD/CAM networking, in many cases on a global scale.

FIGURE 4

DIVERSE APPLICATIONS IN THE GLOBAL BUSINESS NETWORK
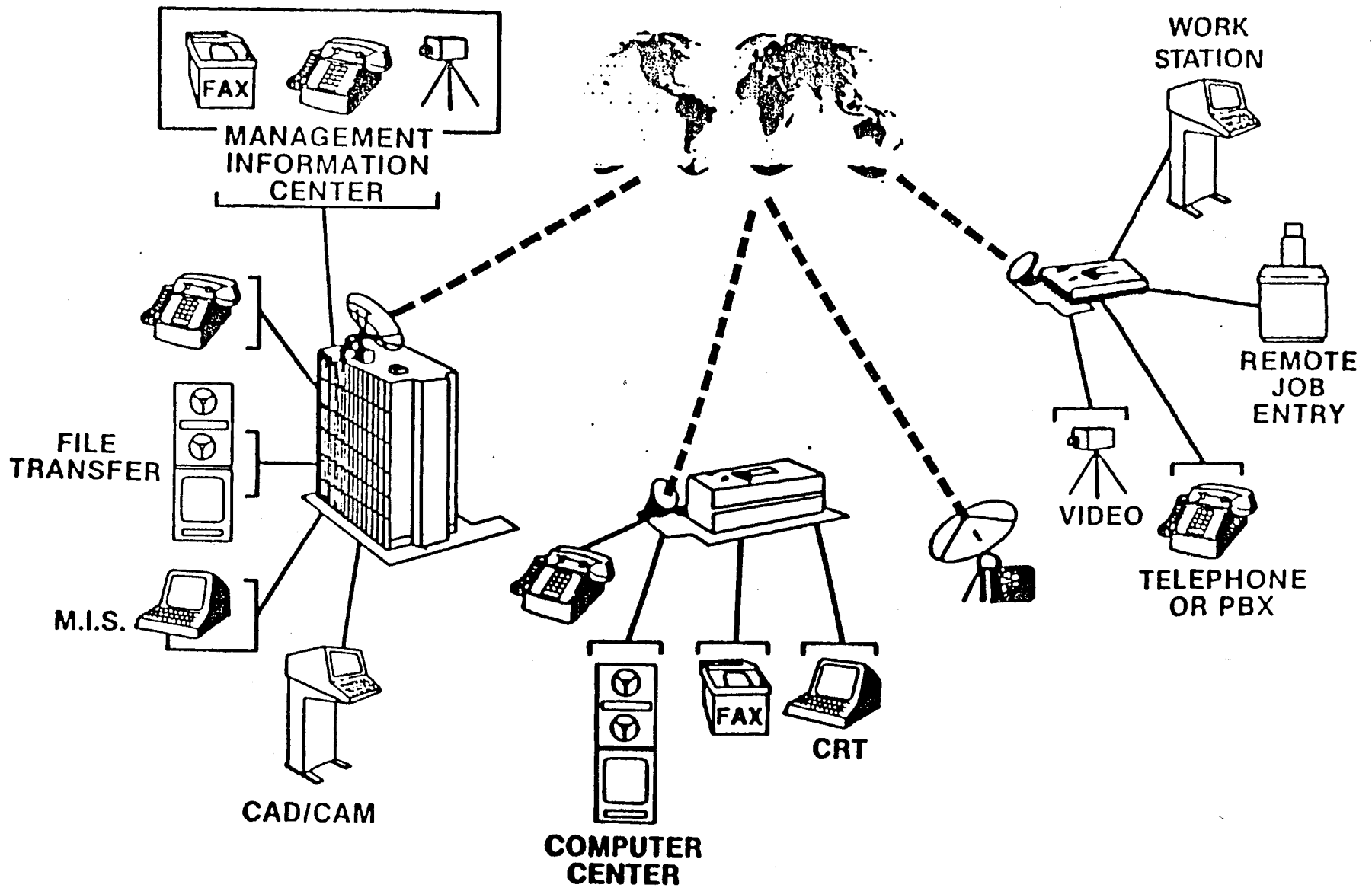
Artificial intelligence is already becoming a useful addition to the collection of available business tools and will see rapid and expansive growth. Artificial intelligence will not only be used in robotics, but in many other applications, such as telecommunications network management, where already some progress has been made in reducing the number of messages which a network operator has to interpret.

Remote work centers have been discussed for many years, but we can now observe many actual examples of working applications. For example, much of the word processing for New York City is actually performed in Jamaica, where there is a highly literate pool of low cost labor available to perform this task. Airline tickets are being sent to several countries in the Caribbean for data entry. These applications are supported by 64Kb or 128Kb IBS circuits.

There are already 14 million personal computers in the U.S.; this number is expected to increase to over 50 million by the year 2000. These personal computers will become for all intents and purposes ubiquitous, as new generations become computer literate in school and as useful applications continue to be created. These personal computers will not only perform locally, but will be used as terminal devices to access the thousands of public databases that will be available on a pay-per-use basis.

As the year 2000 approaches there will continue to be a strong market demand to reduce cost. In many cases, competition and increasing volume of product sold will enable this to happen. Improved error performance is and will continue to be an important requirement.

Ubiquitous availability of access will be demanded, meaning that individuals will want access to databases whether they are at the desk, at home or in motion. Many applications will require that higher and higher transfer speeds be available. Integrity and reliability will be expected to a degree that they will be taken for granted in much the same way that a local telephone call is today.

As we move into a workstation environment on a worldwide basis, adequate measurements of workstation effectiveness; of effective communications (as opposed to only telecommunications); and of the organization's connectivity infrastructure are needed for business management to ensure that the networks are meeting the requirements defined to support the business systems architecture. Few systems provide these types of measurements today. There will be a firm requirement for adequate network management and control systems.

In the future, satellite service providers must do three things:

1. Promote VSAT-type services;

2. Provide high bandwidth services at good price; and,

3. Provide a cheap service for batch data and videoconferencing applications.

Many users believe the only competitive answer to fiber cable is VSAT or customer premise type services. This would also give them the end-to-end performance they wanted. Users often point out the incompatibility (and silliness) of leasing a high speed, high quality digital circuit to, say, a major city of a country only to have the signal quality degraded to unusable levels over the last mile (or last twenty miles and even a few blocks in New York City and London).

Consider the case of VSAT service to Mexico presently quite popular among U.S. and non-U.S. users which include:

- Ford
- American Express
- UNISYS
- NCR

- Reuters
- Thomson Consumer
- Volkswagen

Presently, some nine (9) satellites from three (3) system operators are known to be authorized to provide digital business services to U.S., non-U.S. and Mexican users. Six of these are provided by GTE Spacenet; two by the Mexican Morelos system; and, one by INTELSAT. Carriers such as OTI offer services using more than one satellite system [OTI uses the Morelos and INTELSAT satellites. Figure 5 depicts OTI's transborder VSAT service to Mexico using the Morelos satellite.] These services are delivered directly to customer premises via VSAT terminals.

Liberalization trends will cause European VSAT applications to take off. This would stimulate international VSAT between the U.S. and Europe.

Generally, users do not find satellite delay a factor in batch data or videoconferencing applications and, if cheap, they would entertain stripping out these applications. This is more prevalent among U.S. users who demonstrate today some contrary notions to the integrated service or multi-media trend. It does not appear to be of interest to Japanese users who are excited about multi-media networks.

The high bandwidth service idea requires further research. Users want to move increasingly large amounts of data quickly and reliably. In some cases, they want a lot of bandwidth point-to-point. Some want this in burst mode for LAN- to-LAN interconnection. Some want 10 Mbps Ethernet bridging and 4 or 16 Mbps token ring bridging. This could be a good service idea but requires further user requirements analysis and service definition to fully assess its potential for satellite.

Teleport/MAN Interconnection

One area we feel INTELSAT should be looking at is the global interconnection of Metropolitan Area Networks (MAN's) served by or co-located with international teleports. [The concept is depicted in Figure 6. The concept drawing is oversimplified insofar as a single satellite cannot serve the three separated locations shown.] This concept exploits the conjunction of increased high speed data requirements; metropolitan and wide area networks; and international teleports. MarTech has recently completed a study that foresees a
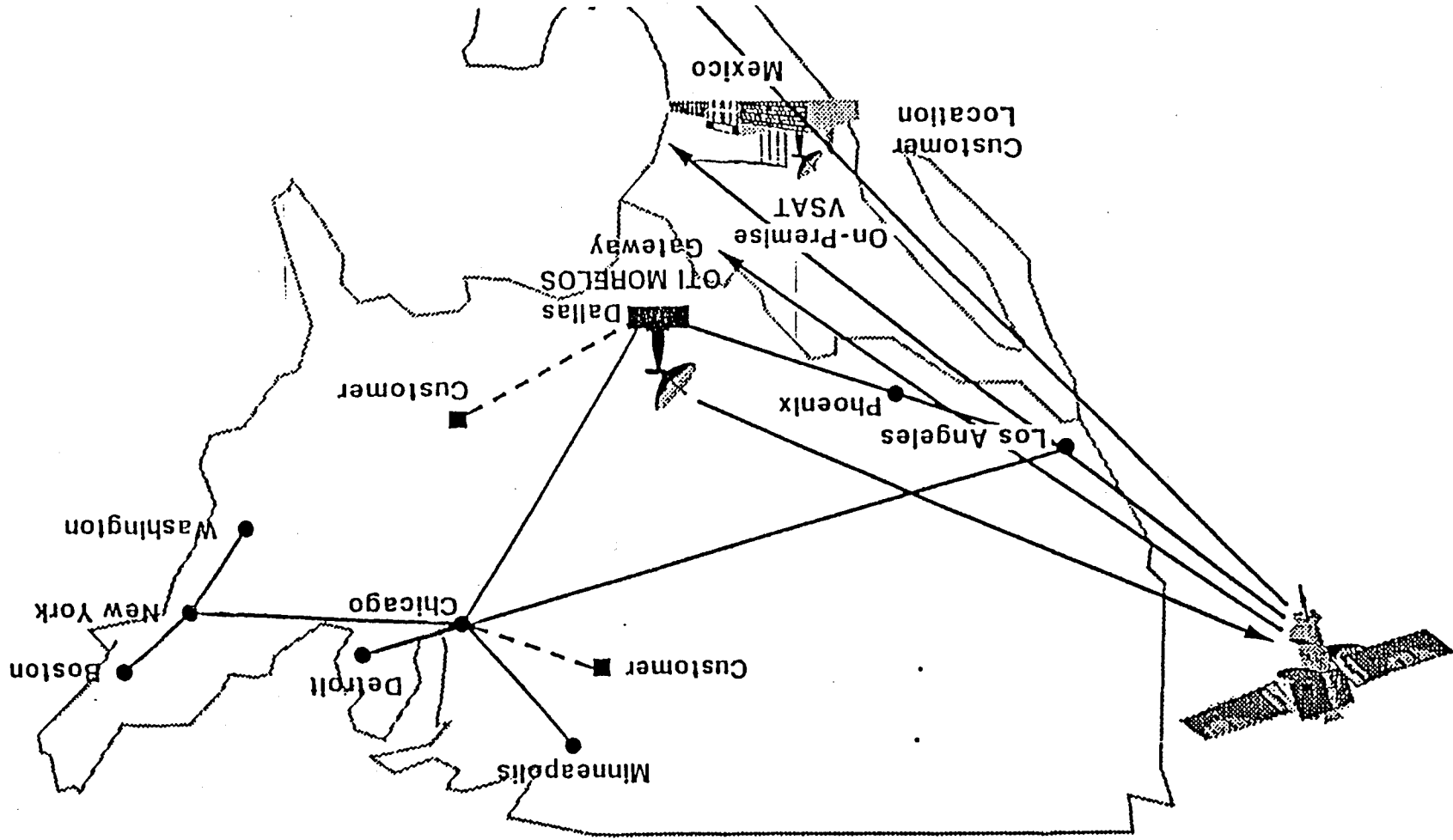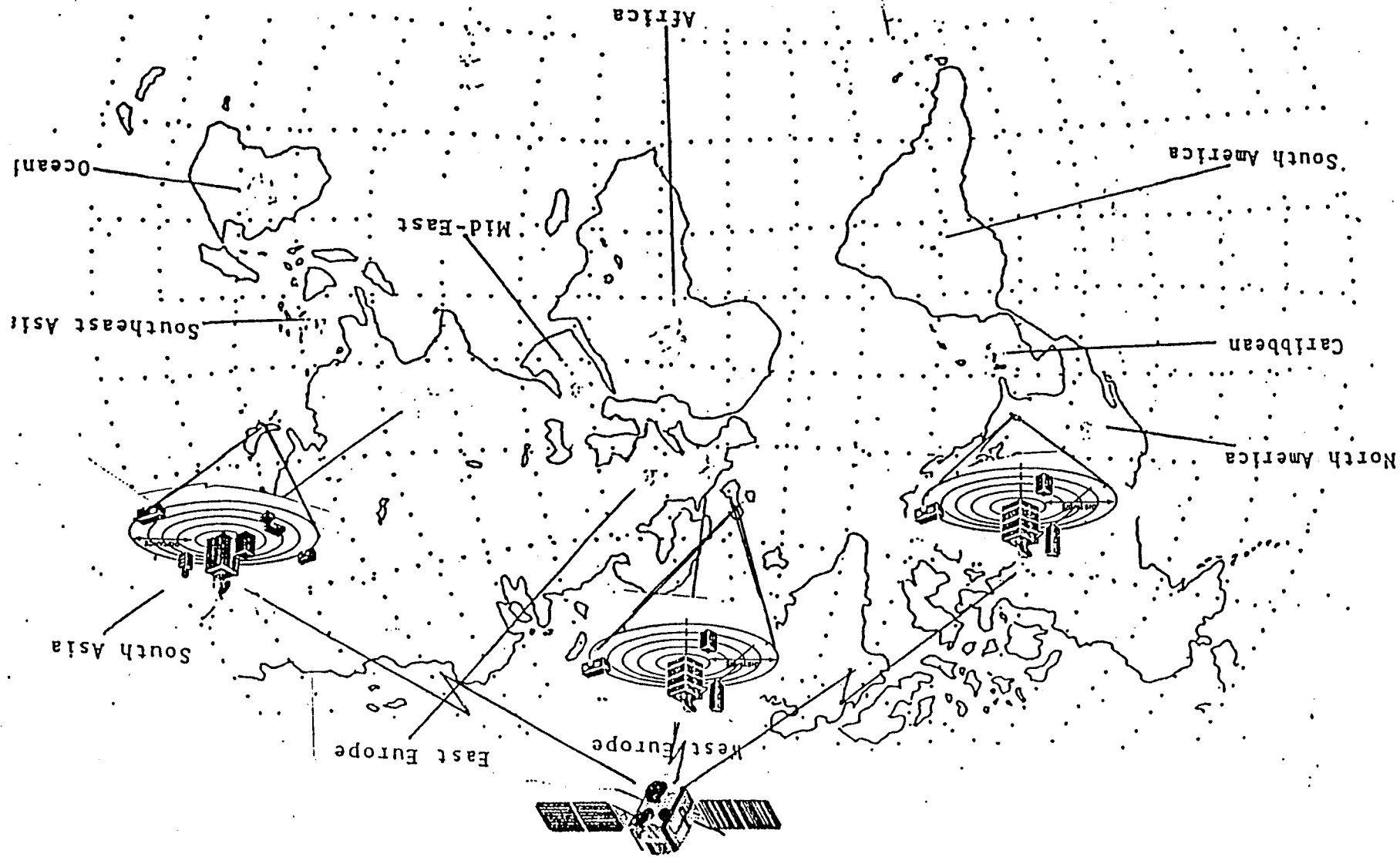
FIGURE 6

growing role for international teleports interconnected by a global satellite system.* Attached as an Appendix is a description of worldwide teleport development.

Growth in High Speed Data Applications

The demand for high speed switched data connectivity is experiencing tremendous growth and within the world of connectivity solutions, the LAN is experiencing the fastest growth patterns.

Today's business data market is beginning to demand broadband network connectivity and broadband services. Data processors ranging from workstations to supercomputers are doubling their processing power each year. Local Area Networks (LAN's) already link small communities to these devices over limited distances at multi-megabit per second speeds. Higher bandwidth LAN's running at speeds of 100 Mbps or more, such as those based on the FDDI (Fiber Distributed Data Interface) standard, will soon be available. The next challenge will be to network hundreds and thousands of these systems together over larger distances (e.g., Metropolitan Areas, the nation and international networks).

There are over 30 million PC's installed worldwide today. We estimate that roughly 12 percent are interconnected to LAN's, by 1992, almost 60 percent of the world's 55-60 million PC's will be connected to LAN's.

As LAN's, hosts and workstations become deployed locally, there is a natural need to interconnect "islands" of high-speed computing capability. At first this was done with low-speed links, and as a result many of the applications which ran locally could not be extended well to multiple locations. More recently, T-1 networking has enabled customers to interconnect their resources at high enough speeds to begin to create a geographically distributed, high-speed environment. However, the resulting networks are still primarily private, and the desire to increase the transmission rate at interconnection points will not abate as LAN technology advances. Thus, there is a need for an economical high-speed data service which will meet the customer's existing and evolving Customer Premises Equipment (CPE) environment and provide high performance, high reliability interconnection. While carriers ready their services, private networks will employ their own high bandwidth facilities.

LAN's and MAN's

Users are increasingly linking dispersed LAN's into wider area Metropolitan Area Networks (MAN's).

*"Market Outlook For International Wideband Circuits" by MarTech
   Strategies, Inc. 1989

The types of traffic that MAN's will generate include:

        LAN interconnection
        CAD and graphical images
        Bulk data transfer
        Digital voice
        Medical images
        Compressed video
        Interactive database access

The LAN traffic feeding into the MAN will consist of today's interactive and file transfer applications, but in addition it will include high-resolution graphics or imaging. The graphics will generate considerable loads on the system. Present CAD screens use approximately a million pixels (1000 x 1000 points) in color, requiring a megabyte of data to refresh them. In the future the screens will be 2000 x 2000 points with up to three bytes per pixel, a twelve-fold increase. In addition to the images, the files that describe the items being designed often require megabytes of transfer capacity between locations, for example, between engineering and production departments of manufacturing corporations.

Video for conferencing and instructional purposes can be compressed to a few megabits per second without serious loss of quality. While this is a small volume application now, it can be expected to grow considerably in the next decade or two. Of the types of usage listed above, only interactive terminal traffic is served fully by existing facilities. Digital voice, as in PBX-to-PBX traffic, can be handled by leased T1 circuits, but the modularity is fixed at 24 voice calls, and the flexibility is very limited.

Metropolitan area networks suitable for both voice and data are now appearing as a challenge to the traditional star topology of the telephone system. Designed for a metropolitan scale, these networks will provide high-speed services that have previously been available only on much smaller local networks.

The new metropolitan network technology has evolved from local area networks, making use of existing and planned fiber optic links in the telephone industry to provide high-speed backbone.

A schematic view of a metropolitan network interconnecting a corporation's plants and offices is shown in Figure 7. While the cable topology of the network is a ring, the wiring geometry approximates multiple stars. This permits network maintenance and system management to be handled from normally attended telephone offices.

With local area networks, computers share a high-speed transmission facility that none of them uses a large percentage of the time. When they need high performance, they are able to obtain it, for purposes of file transfer, bit-map CAD graphics, and the like. For most computer applications, this situation is clearly preferable to a full-time connection with limited bandwidth. As a result, local area networks have increasingly become the norm for computer interconnection within

FIGURE   7

METROPOLITAN AREA NETWORK DEPLOYMENT

TRAFFIC
LOCATION

DISTANCE

LOCAL
DISTRIBUTION
NETWORK

WORLD

IXC

INTEREXCHANGE
CARRIER
POINT OF
PRESENCE

TRAFFIC
LOCATION

TARGET
MARKET
AREA
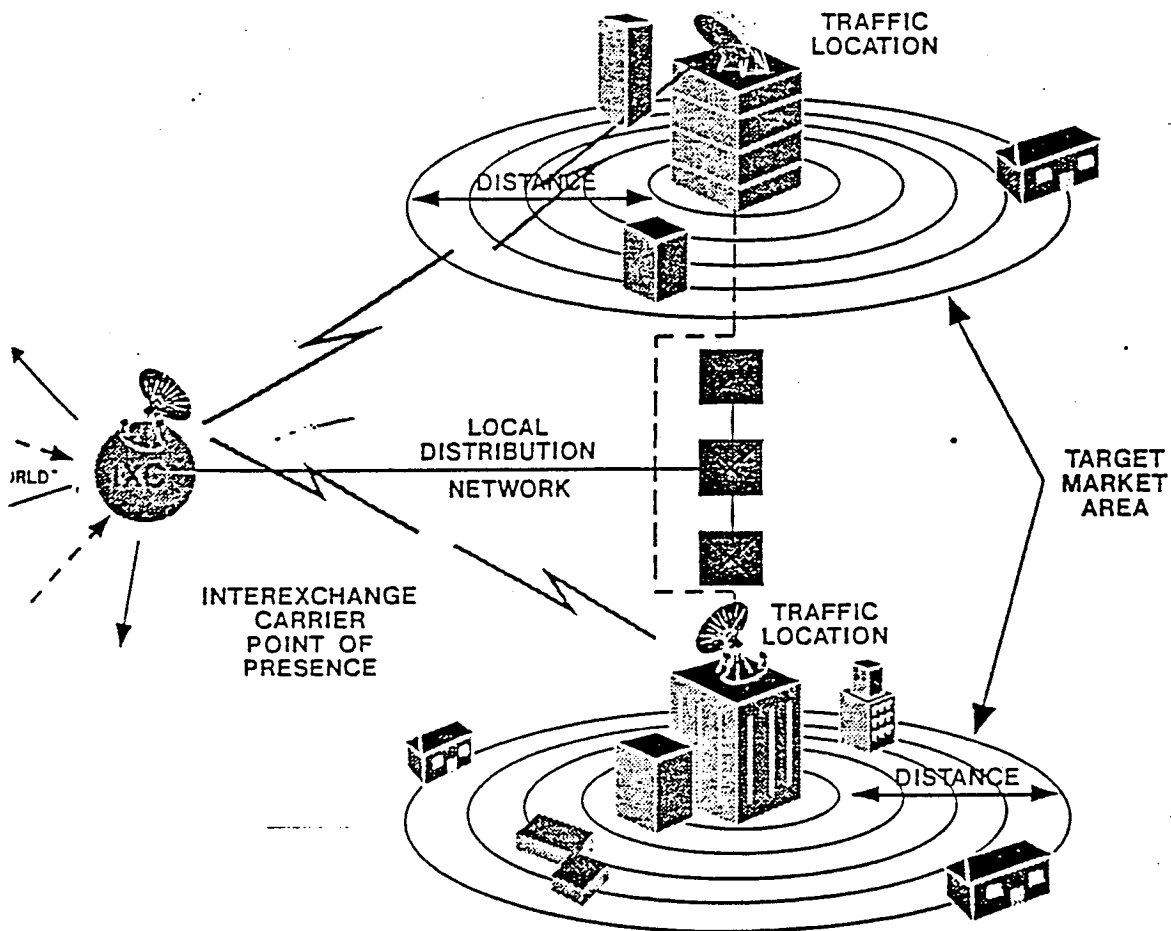
DISTANCE

buildings or adjacent clusters of buildings. Local area networks, however, have been optimized only for distances up to several kilometers, and therefore will not work with the same capacity over long distances. This is where metropolitan area networks come in. Wide area networks are still in province of telephone-based technology or earth satellites, but local area networks are expanding to serve areas the size of a city and its suburbs. Metropolitan area networks represent local network technology re-optimized for these longer distances.

The international network architecture of the 1990's Multi National Enterprise will include a framework for global connectivity at all levels from local area networks (LAN's), to wide area networks (WAN's) to worldwide or global networks, the ultimate earth-bound WAN or Global WAN (see Figure 8). Figure 9 shows a simple connectivity structure linking customers and suppliers to the domestic enterprise with no international connections. This should be contrasted with the complexity of the global connectivity requirement of the Multi National Enterprise. Two main support systems are show in Figure 10:

1.   Customer Sales/Service/Support; and,

2.   Inter-Enterprise Management

We have seen in the VSAT network examples that VSAT networks today have played a vital role in providing these support systems.

As a result of the development of information services, gobalization and high-technology, business activities have become more sophisticated, and consequently data processing and telecommunications needs have increased both in demand and complexity. This, in turn, has placed a higher premium on quality of service and network performance expectations and standards.

As corporations extend their electronic products and services to their customers via telecommunications, the ability to link business goals and objectives into the dynamics and complexity of data and voice communications technology has become a differentiating factor in the marketplace. To the telecommunications service provider, planner, and customer alike, this increasing need for business relevant connectivity presents a significant challenge to the industry. When business planners analyze their requirements over the next 10 years, connectivity becomes a critical success factor within their information technology plan. A reflected on the earlier Figure 1, this connectivity need spans: various logical networks; broad geographic coverage and inter-enterprise networks.

The Role Of International Teleports

In 1983, Staten Island, once a swampland, was developed by a regional development bureau into a center of information-age business opportunities to serve the New York and New Jersey regions. The antenna site of about 50,000 square meters and the Teleport Center in a large park make up the cornerstone of New York Teleport. To redevelop the port

FIGURE 8

MultiNational Enterprise Increases Global Connectivity
Requirements Across Diverse Logical Networks and Wider Area
Geographic Spans!

Four Types of Logical Networks

- Transactional Networks

- Factory Automation Networks

- Messaging Networks

- Information Services Networks

Across various
Logical Networks

MultiNational
Enterprise

GLOBAL CONNECTIVITY
Interconnection of
- Communication
  facilities, and
- private & public
  network resources

Information
Resources
(data bases,
host computers,
etc.)

GEOGRAPHICALLY

GLOBAL NETWORK

WAN

LAN

GLOBAL WAN

- diverse devices
- increased competition within each sphere
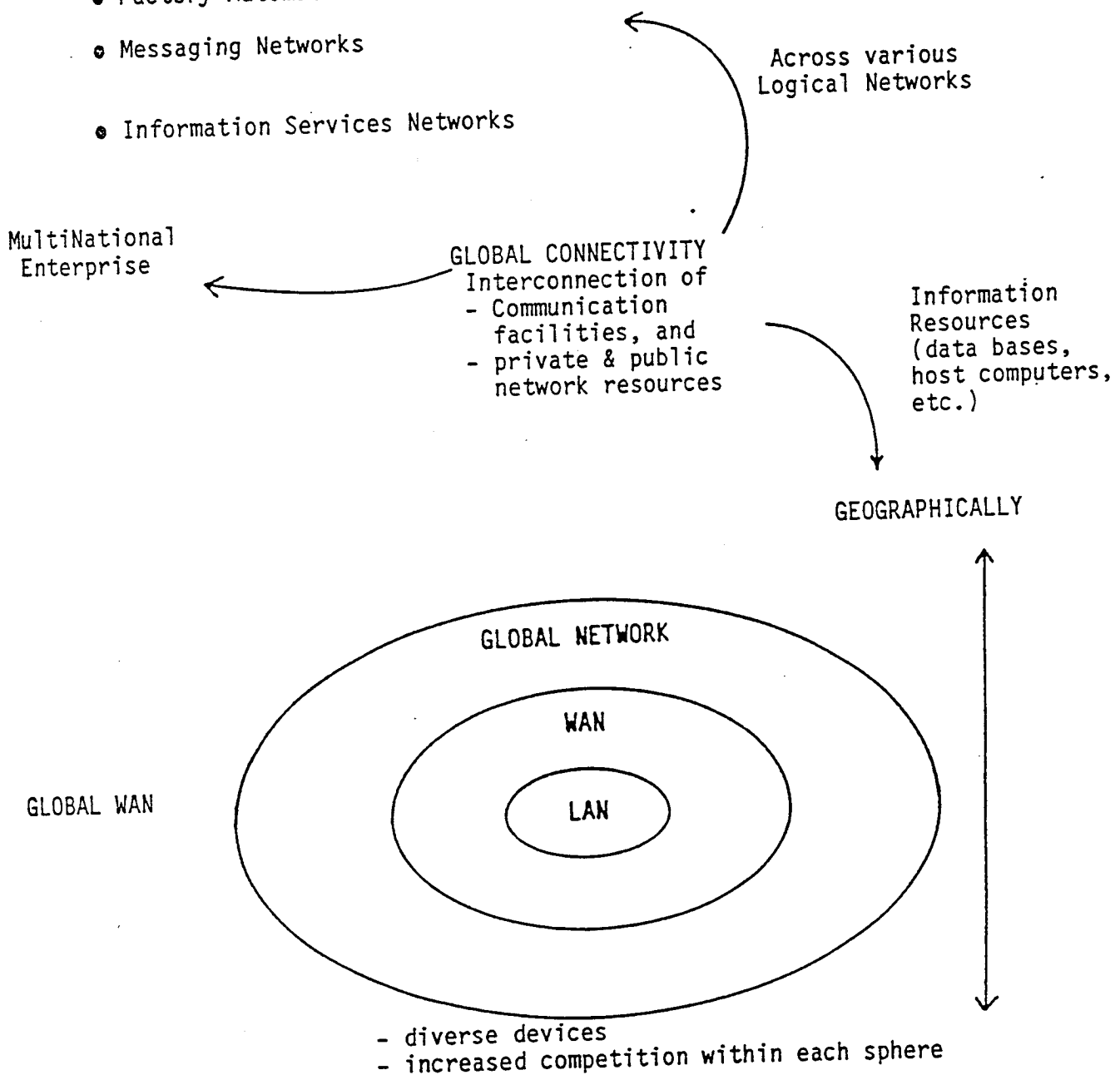
FIGURE 9

CONNECTIVITY: SINGLE COUNTRY BASIS

CUSTOMERS

ENTERPRISE
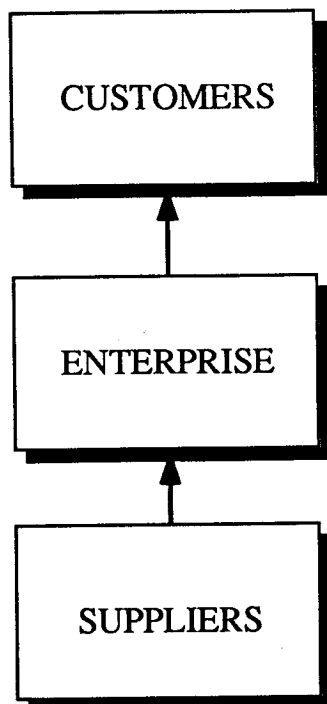
SUPPLIERS

This diagram of a <u>single enterprise</u> integrating its suppliers and serving customers in a <u>single country</u> is shown in stark contrast to a multi-national enterprise (next figure) whose supplier and customers are globally distributed. The connectivity needs of the latter are much more diverse and complex.

FIGURE 10
GLOBAL CONNECTIVITY: MULTI-COUNTRY BASIS

GLOBAL CUSTOMER BASE

COUNTRY A	COUNTRY B	COUNTRY C	COUNTRY D	COUNTRY N

MULTI NATIONAL ENTERPRISE PLANTS, FACTORIES AND OPERATIONS

COUNTRY A		COUNTRY G		COUNTRY X

INTERNATIONAL ORGANIZATION
- STRATEGIC ALLIANCES
- JOINT VENTURE
- DISTRIBUTION ARRANGEMENTS

GLOBALLY DISTRIBUTED SUPPLIERS

COUNTRY B	COUNTRY D	COUNTRY Y

CUSTOMER SALES/SERVICE/SUPPORT

INTER-ENTERPRISE MANAGEMENT

areas of New York and New Jersey, the Port Authority of New York and New Jersey constructed the world's first intelligent office park/ telecommunications center. The organization and operation of the communications facilities were carried out by Teleport Communications Corporation, a private/public partnership established through a joint investment by Merrill Lynch & Co., Inc. and the Western Union Telegraph Company.

The earth station facility, which employs Teleport Communications Corporation's antenna designed for public use, is the hub for image transmissions, telephone services and data communications throughout the U.S.A., for data communications of the finance and information industries in Manhattan through IBS of COMSAT, and for transmissions to national TV networks by privately-owned TV stations such as those owned by Catholic churches. All communications and signals are directly sent to the facility in Manhattan, 11 miles away from the earth station facility, through a regional, 150 mile fiber optic network.

We believe that the combination of urban Metropolitan Area Networks (Man's) with International Teleports and their interconnections could be a major structural change in global communications and an opportunity for Mesh-type satellite networks.

Many countries are now installing or planning new multi-purpose urban gateway earth stations or teleports in or near major cities. These will be in use very shortly in a number of countries to provide new services to their subscribers. The international teleport made its appearance in 1985.

A review of overseas teleport projects indicates that certain common threads exist among them. See Appendix A. For example, there is a growing awareness that conventional telecommunication facilities are not sufficient to meet future business information needs. There is also a growing recognition that future economic development will be significantly tied to the quality of information services. Industry officials (and analysts) think that both teleports and fiber optics (for both domestic and international interconnection) are the necessary tools to facilitate information service development and its commercial benefits, both directly and indirectly.

Most overseas projects try to capture the benefits of having an advanced information industry. For example, the British, the Dutch, and the Japanese indicate clearly that the teleport concept by its nature must not only welcome but also succeed in encouraging foreign participation. Otherwise, the goals of the information service industry, by their nature, cannot be met.

The Japanese in particular have devoted considerable effort toward defining specific information systems that they want to see developed. They have also defined how tools like the teleport concept can be most effectively applied in developing these systems and integrating the benefits into all Japanes commercial sectors. They have explored highly detailed planning considerations. One example is the discussion of whether to locate public and private research institutes of such promising industries as biotechnology within teleport industrial parks.

As far as the conventional and future telecommunications structure is concerned, most of the overseas international teleport projects are viewed as part of the large integrated network infrastructure. Teleports are primarily well suited to provide information, private lease, and specialized services, all of which promote national trade, technological and commercial interests. As a result, greater liberalization of entry should gain a powerful constituency in many of these industrialized countries.

APPENDIX B

REVIEW OF OVERSEAS TELEPORT PROJECTS

Rotterdam Teleport

The Rotterdam Teleport is a joint venture of the Port of Rotterdam and the Netherlands PTT Telecom. Rotterdam Teleport is staffed by experts in logistics, port operations, information technology, telecommunications and electronic data interchange. In addition it can call on the expertise of the Port Management and PTT Telecom.

The mission of Rotterdam Teleport is:
To promote the use of telematics in port and port-related industries,
To develop applications in telematics which underpin the logistics
Functions of the port,
To expand and promote the 'Teleport' Rotterdam.

The Rotterdam Teleport operates in close cooperation with the transportation industry and its communication functions and applications are, correspondingly, oriented to this industry. For example, the TELEGATE service has been developed to offer universal access to transportation information systems and communication services. TELEGATE subscribers will have at their fingertips a simple and universal method of accessing numerous databases of interest to the port and transport sectors.

The TELEGATE service has a central server in Rotterdam operating as a switch with conversion facilities. (Note Figure B-I)
TELEGATE can be used by anyone who has:
- an ASCII-terminal or PC with modem, or
- a videotex terminal (Prestel) with modem, or
- a telex terminal.
No additional facilities are needed.

TELEGATE can be accessed worldwide by means of:
- the public X.25 data system
- the public telephone network
- the public telex network.

On request the TELEGATE server collects information from several databases in various host computers. For demonstration purposes, the server is now linked to:
- **Ship arrivals and departures**
    This is a closed system run by the Rotterdam Port Authority, containing the latest information on all seagoing vessels in the port, including nationality, time and data of arrival, berth, agency and so on.
- **Port Guide**
    This is the signposting system of the Port of Rotterdam as stored in Viditel, the public videotex service in the Netherlands. By means of the guide, you can find the number of any company in the port's signposting system.

B-1

FIGURE B-1

TELEGATE
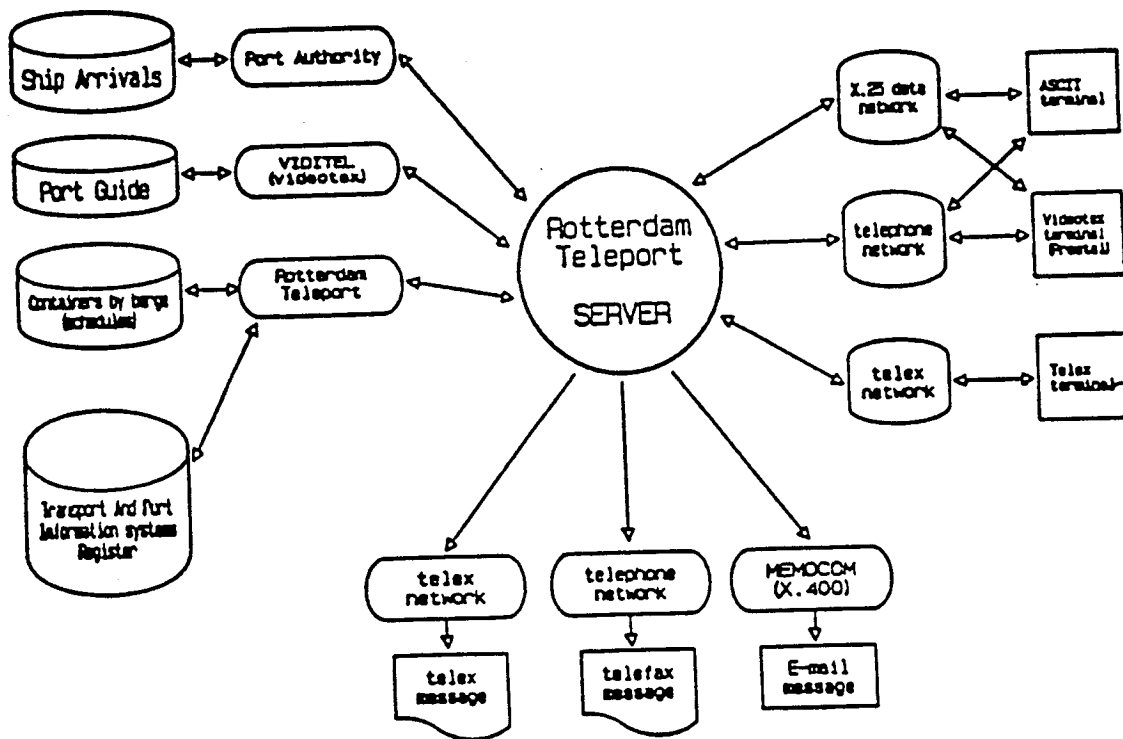
- Container Barge Schedules·
   This is a closed system developed by Rotterdam Teleport, containing information on the sailing times of the scheduled container services on the Rhine as well as the inland barge carriers and terminals concerned.

TELEGATE also provides access to Rotterdam Teleport's special service called TAPIR, which stands for Transport and Port Information systems Register. It contains information about a large number of information systems for the transport sector all over the world.

TELEGATE also has a message-sending facility. Messages can be sent by:
- telex
- telefax
- electronic mail (Dailcom).

Over the coming years this concept will grow into an operational service with an increasing number of facilities. More protocols will be added to the list of access options and more databases and information systems will be accessible through TELEGATE.

MediaPark Cologne - The Media and Communications City

Cologne is the leading media and communications city in the western area of the Federal Republic of Germany. The city is noted for Germany's largest radio and television services, important publishing houses with publications ranging from daily newspapers and technical journals to art and literature. The City now has started the project "MediaPark Cologne" to strengthen its position as the foremost Media and Communications City in the West of the Federal Republic of Germany.

Cologne is the fourth-largest city in West Germany, (City-Population: 970,000; 500,000 jobs) with a workforce of about 40,000 engaged in all areas of communications. The Cologne Teleport is an integral part of the larger MediaPark concept which will be built on a large inner city site of 200,000 m² near the Rhine, the Cathedral, Broadcasting Centers and the Central Business District. The MediaPark is an innovative development project to promote the acceptance and growth of new media production techniques and promote the use of new information and communication technology and data processing in the media, in the service and administrative sectors and also in industry. Specialized service agencies take on new activities (computer graphics for TV productions, sound-effects, equipment leasing, video-text production, etc.), and produce programs (software) in the overlapping areas between computer, information and communications technology.

A range of inter-connecting facilities and network will provide links for the various media agencies working in the Cologne MediaPark. There will be
- Small to medium-sized video and television production studios with ancillary facilities such as sound-studio, cutting-rooms,

offices, dressing-rooms, equipment for electronic process of materials;
- Radio studios and local broadcasting facilities;
- HD-TV (High Definition TV) studios for productions employing future-oriented technical standards;
- Equipment and studios for computer-animation;
- Electronic archives for film and television productions, either as excerpt facilities or for documentary purposes;
- A Media Service Center where publishers, editorial staff and agencies may enjoy extensive common technical office and news facilities;
- A graphics and allied-trades center equipped with the latest technology;
- Computer type-setting center, data transfer facilities and access to data banks and information centers.

It is the intention of the MediaPark Cologne planners to concentrate on sectors which will grow in importance in the future: software production, development of user-friendly equipment and a future-oriented infrastructure.

The big users form the base for this development in Cologne, (Insurance Companies, Banks, Public Institutions, University, Technical High Schools, Industry, Manufacturers, Research and Training Establishments, and numerous highly-specialized advisory and development organizations, software producers, publishers and the German Post Office, the Trade and Exhibition Center and the municipal authorities.

The MediaPark will be equipped with
- Connections to the fiber-optic network of the German Post office;
- A satellite link to facilitate fast and efficient transmission all over the world;
- A highly efficient communications infrastructure within the MediaPark via early connection to the wide-band network ISDN,
- Efficient connections with other telecommunications centers in the Cologne City area.

Organizations which would benefit from such an infrastructure are:
- A "Telecommunications Service Center" which could take over control and supervisory tasks for other companies;
- Video-conference facilities operated either privately or by the Post Office;
- Mailbox centers as a service for the whole business area of Cologne which would enable optimal use of computers at the work-place as information centers within the German Post Office network;
- TV screen-text agencies and user-centers providing access to the medium for other companies; for advertising purposes, as an internal information system or for communications within a closed group;

- Data banks as specialist·centers or internal information centers with computing capacity connected to information networks and programming services, and requiring maintenance as well as access to information. Resources for information systems are, for example, the archives of media organizations, development sections of large industrial concerns, libraries and museums.

THE-ILE-DE-FRANCE TELEPORT

As a public entity, the Ile-de-France Region is in charge of the economic, social, urban and scientific development of an area that has undoubted assets in European and international competition. The Ile-de-France consists of 10 million inhabitants, 22% of the French working population, more than 120,000 businesses, nearly 80% of company head offices, 30% of the manpower in electronics manufacturing, 30% of service industry jobs, 60% of research workers and 5,000 data processing banks.

It is believed that the Ile-de-France Teleport will stimulate various key sectors in this regional development plan. It therefore will consist of four complementary Telepark units, each of which will combine the most advanced equipment and communication services contributing to the dominant activity of the sector concerned.

In the Defense area: tertiary and finance sectors;
in the Charles de Gaulle Airport area with extension to Garonor and Paris Nord II: aeronautics (freight and transport);
on the Saclay plateau with extensions towards Massy and Saint Quentin en Yvelines; research and innovation; and,
at Marne la Vallée: media, image and tourism.

These Teleparks will be connected by "electronic highways" into Wide Area Networks (WAN's).

It is also believed that the Teleport will enable, the Ile-de-France to meet successfully European and international competition.

It will encourage the international flow of information, with economies in transmission costs.

Thus, by sharing equipment available at the Teleport, small and medium-size firms and industries will have access at worlwide level to facilities hitherto enjoyed only by larger industrial organizations.

Already today, Ile-de-France has established in infrastructure interfaces with "Long Distance" networks are now under operation and sophisticated, high capacity distribution networks are being developed.

The keypoint of the redeployment of the economic activities of the Ile-de-France, Marne-la-Vallée forms part of the service sector axis; La

Defensé, Bercy, and plays a full part in the urban, social and economic modernizations of the east of Paris.

Marne-la-Vallée is a true place of choice for regional economic development and for the siting of large-scale projects exemplified by the major audio-visual pole at Bry-sur-Marne, Euro Disneyland, the Cité Descartes and the future teleport.

The Cité Descartes, a genuine scientific and technological pole to the east of Paris, will cover 130 hectares and house high added-value companies, research and training centers, higher education centers oriented to data processing or town planning and transport.

A technolopolis of the future, the Cité Descartes will accommodate the future Ile-de-France teleport concerning the media and imaging services (image banks, videos, etc.).

Marne-la-Vallée will thus meet the current national and international communications needs of the European scale companies that are present on the site.

Teleport Developments in Japan

Japan's economy accounts for more than 10% of the world's total economic activity, and its role in the international community has been one of increasing importance.

Japan is committed to creating information cities of the future, all with integral domestic and international teleport capabilities. Teleports have been constructed or under development in Nagoya, Yokohama, Tokyo and Osaka. Some of these are reviewed here.

NAGOYA CITY

The Nagoya region has contributed to Japan's rapid economic growth as one of its main industrial production bases. With its sophisticated industries and future-oriented technology, the Nagoya region is expected to make its contribution to the international community as an "international leader of industrial technology".

The Nagoya Teleport, the sophisticated telecommunications heart of the entire region, is seen to be of fundamental importance to this prospect.

The Nagoya region, with Nagoya City as its center, spans an area with a radius of about 50 km. With its population of more than 8.1 million and advanced integration of such diverse industries as automobile manufacturing, aerospace, electro-mechanics, textile and garment manufacturing, ceramics, clay and stoneware, the Nagoya region ranks with the Tokyo and Kansai areas as one of the largest metropolitan centers in Japan.

Nagoya City, Japan's fourth largest city after Tokyo, Yokohama and Osaka, is the hub of the Nagoya region. The city, with a population of 2.15 million, fulfills the administrative, managerial, financial and distributive functions of the region.

Nagoya port, an international shipping center and Japan's second largest port in terms of cargo value, supports the industrial and economic activities of the Nagoya region.

The Nagoya region is located virtually in the center of the Japanese archipelago, between the Tokyo and Kansai regions, and forms the nucleus of Japan's main transportation systems - the Tomei, Meishin and Chuo Expressways and the New Tokaido Rail Line.

Teleport: City Center and Seafront Bases

The Nagoya Teleport complex will consist of two main facilities; the City district based in Sasashima - this site, adjacent to Nagoya Station, is the center of the Nagoya region and its extensive transportation network - and the Seafront district on the Kinjo Pier, the center of the Nagoya Port.

At the Kinjo Pier site earth stations for international and domestic satellite communications will be set-up and directly connected to the Sasashima area by optical fiber networks. (See Figure B-2)

In each area, a telecom-center providing information management, processing and telecommunication services will be constructed. See Figure B-3.

The core of the Sasashima area, the telcom-center, will be an international business data base for the 21st century. It will provide sophisticated information management and processing capabilities to businesses dealing in finance, securities, insurance, software, design and other information related activities.

Primarily through the telecom-centers at the Sasashima and Kinjo Pier sites, high quality telecommunication services will be provided through fiber optic networks within the two areas.

Service to the adjacent areas will also be provided in the city center area, linking central business functions to the Nagoya Port Seafront district, integrating trade, distribution and production functions.

By providing satellite communications services throughout the Nagoya region, a more active international development of business activities carried out by its sophisticated industrial base will be achieved.

By means of a communication satellite, Nagoya Teleport will allow businesses located in the Nagoya region to have access to a world-wide information network instantly, and to profit from advances in modern telecommunications.

NAGOYA TELEPORT COMPLEX

名古屋都心・主要地域
Nagoya City Central District

笹島地区 Sasashima Area

テレセンター
Telecom-center

海外・国内
Overseas-Domestic

光ファイバー幹線
Optical Fiber Cable

Telecom-center
テレセンター

地球局
Earth Stations

インテリジェントビル
Intelligent Office

金城ふ頭 Kinjo Pier

名古屋港臨海部
Nagoya Port Seafront District

岐阜県
Gifu Pref.

岐阜 Gifu

愛知県
Aichi Pref.

豊田
Toyota

四日市
Yokkaichi

名古屋
Nagoya

津
Tsu

三重県
Mie Pref.

豊橋
Toyohashi

静岡県
Shizuoka Pref.

浜松
Hamamatsu
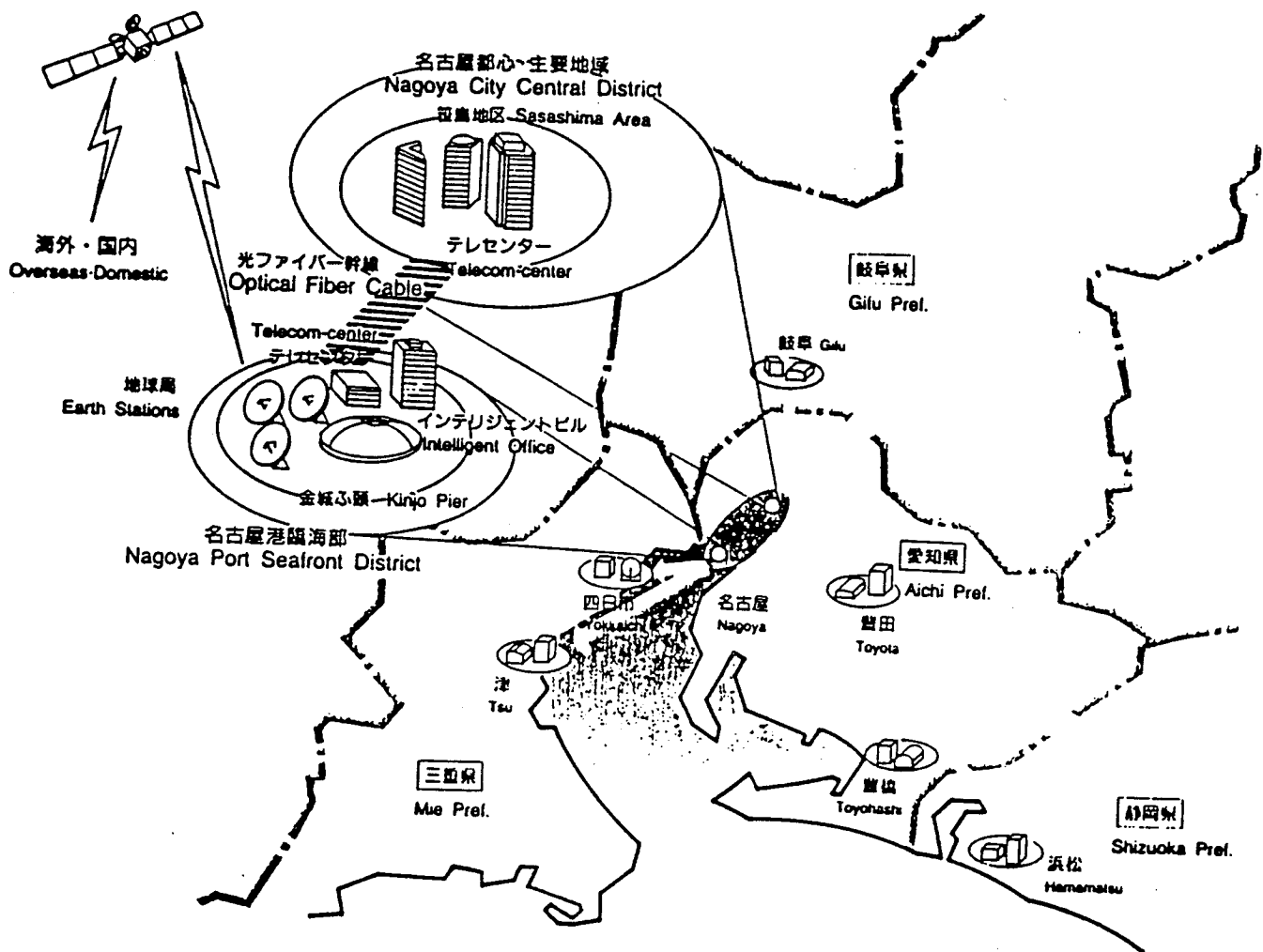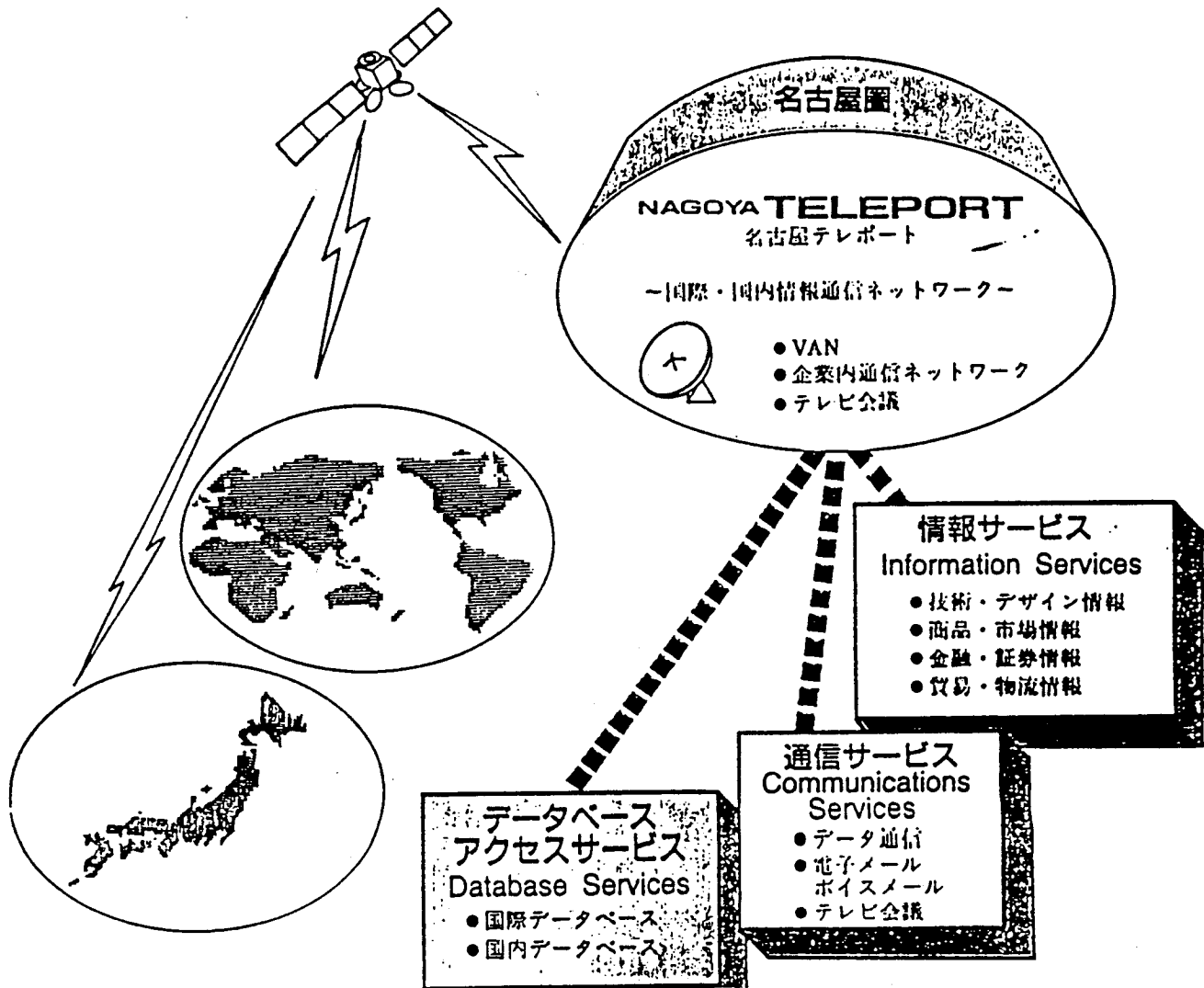
Coping not only with today's need for telecommunication services but also those of the coming 21st century, Nagoya Teleport will be the nerve center from which the Nagoya region collects, processes and distributes financial and securities related information as well as design and technological data for research and development in the hi-tech fields.

It will also be the center for communication, management and information processing to support the establishment of an international trade network, gathering international market data, and the creation of a comprehensive international distribution center for land, sea and air.

In order to realize this aim, it will join an information network of the major cities of the world, where similar teleports are being planned or built, and will stimulate further international telecommunications.

YOKOHAMA, THE INFORMATION CITY OF THE FUTURE

Yokohama is situated virtually in the center of the Japanese archipelago that extends nearly 3,000 kilometers (1,864 miles) from the northern tip of Hokkaido to the southern island of Okinawa. Located 30 kilometers from Tokyo, Yokohama possesses a thriving economic base that makes it an intrinsic part of the National Capital Region. In this region live 30% of Japan's total population and almost 35% of the total work force.

With the opening of Yokohama's port in 1859, Japan ended its 250 years of isolation from the rest of the world. Yokohama became one of the nation's most vibrant gateways to foreign cultures and to modern civilizations. Its importance to the economy of Japan grew as the nation developed domestic industries and increased its trade with other nations.

The total population of Yokohama City is second only to Tokyo; 3,049,782 (as of October 1986). The average age is a youthful 33.4. There is a comparatively high percentage of university graduates, specialists, and professionals involved in advanced technology.

Even as it has developed into an international trade port, Yokohama City has built up considerable economic strength by encouraging various types of industries to establish themselves in the city. Many of them are oriented toward research and development, particularly the advanced technology industries such as electronics. Sony Corporation and Du Pont Japan have their research centers in Yokohama, and Nissan maintains both a research center and a factory.

In fact, most government and private research institutes in Japan are found in Tokyo, Tsukuba Science City and Kanagawa Prefecture. Yokohama boasts of a respectable number of them; 150.

Additionally, industries involved in urban life or culture such as the fashion industry, are increasing in number in response to the diversified needs of consumers.

Yokohama Minato Mirai 21 Teleport

The Minato Mirai 21 (MM21) Teleport is an integral part of the Minato Mirai 21 core city development aimed at transforming Yokohama into the information city of the future.

The MM21 Teleport under these conditions of city development will possess the functions of a communications center meeting the diverse needs of a society highly directed towards advanced information. To bring off this transformation, a sophisticated information media will be created and data collecting, processing, transmitting functions and an information-directed environment will be created for the project area.

In this respect, the overall development of MM21 will depend heavily on the important role of the MM21 Teleport. Their interaction and joint development will make the MM21 Teleport a vital part of the new metropolis and a highly efficient information center.

*A large-scale optical fiber network installed in underground conduit and a satellite communications earth station established in the zone will serve as the backbone of the MM21 Teleport.

*By utilizing localized networks, commercial and institutional tenants of "smart" building complexes will have access to sophisticated communications services such as the interactive Visual Information System and the high-speed digital network.

*Low-costing telecommunication services will become possible as a result of an international digital circuit that will link major cities overseas with the international communications satellite.

The MM21 Communications Center and Network

In addition to the establishment of large-scale fiber optic networks and a satellite communications earth station, the plan of the MM21 Teleport calls for building a "communications center" to serve as a strategic information center for generating and processing data and adopting the "Interactive Visual Information System" the "Public Facility Information and Control System" and the "MM21 Database System" to create data and establish an environment directed at advanced information.

The fiber optic network will be constructed within the zone around the Teleport. This local network will be linked to various points in Japan by domestic communication satellites and trunk fiber optic networks. The accompanying system diagram shows such links to the Tokyo, Yokohama and 'other' domestic cities.

The zone will be linked to various points in the world through international communication satellites and submarine fiber optic cables. The system will permit the real-time exchange of information with points in Japan and overseas.

SYSTEM IMAGE

International Communications Satellite

Domestic Communications Satellites

Overseas

Other Domestic Cities

Submarine optical fiber cable

Core areas of Yokohama City

Tokyo Metropolitan Center
(Companies, etc.)

Operation Center
(Gateway)
(Switch)

Communications Center

International Convention Center

ISDN Exchange

Optical fiber cables

Satellite Communications Earth Station

"Smart" building complex

The following are examples of the communications networks that will be offered:

- **Database Service System**
  A comprehensive database service center will be established to provide reports written in Japan and in other countries about topics that include the economy, industry, and scientific developments.

  A consulting service will be available for those who wish to utilize overseas databases.

- **Interactive Visual Information System**
  This system will reproduce motion pictures, photographs and illustrations on videotex and provide information on subjects such as entertainment, shopping, news and the stock market.

- **Public Facility Information and Control System**
  This system will help ensure greater safety and efficiency in building maintenance and service.

Figure B-5 depicts the functions of the MM21 communication and information center.

The interactive visual information system will use a wideband fiber optic network that links the visual information center with the MM21 and nearby commercial, cultural and public facilities. The system disseminates city, fashion, product and other information in different modes that combine stills, motion pictures and sound which reach viewers on visual terminal screens.

As the system will link up MM21 with existing city centers, the formation of a visual information network will promote the flow of advanced information. In this manner, the aims of the MM21 project--the harmonious union of city centers and the strengthening of their capabilities and functions--will be materialized.

The Super Videotex, a high-tech system with search functions, will be incorporated to satisfy the quantitative and qualitative information needs of a society oriented towards sophisticated information. Users of this interactive visual information system can retrieve "necessary information when necessary" by conversing with a base computer hooked up to a wideband circuit. The system offers a wide variety of information services that freely combine still images (characters, maps, photos and others), motion pictures and voice information.

The ISDN will be adopted at an early stage. Active response will be made to cope with individual communication needs surfacing as a result of the inherent character of the MM21 project and the nature of the companies settling there.

In addition to the ISDN, three other local network services will be established in this area:

FUNCTIONAL IMAGE

Information communications science hall
Citizen's cultural exchange center
International industrial cooperation center
Software stall
Seminar house
Computer graphics center
Hall

General services
Common use open studio

Information service
International communications service center
Common use information service center
Public information center

Information communications service
CATV center
CATV software distribution center
Computer security center
Interactive Visual Information System Center
Public Facility Information and
Control System Center
Data base center
ISDN Exchange

People-oriented
exchanges

Information

Advanced Long-Distance Communications Network Service

A company located in the MM21 zone derives the benefit of access to low-cost, highspeed digital circuit services that link the earth station of the communications satellite or the international gateway station to buildings occupied by users of long-distance communications services.

Inter-Building Communications Network Service

The MM21 communications network will link up of "smart" buildings within the zone, that will make possible diffusion of the LAN, expansion of the shared tenant service system and centralization of the building management network.

Advanced Inter-Zone Communications Network Service

These systems, such as sound and digital transmission systems, TV conference and motion picture transmission systems, will be adopted and can be made available for use--in addition to possible common use--linking the MM21 area where company headquarters and branches will be located with the areas where many of their closely associated institutions are located.

INTERNATIONAL GATEWAY

One of the most important functions of the MM21 Teleport Project is an access to long-distance communications media, especially international communication. To establish this function, a city-type earth station is required to provide regional service. At the same time, a national-level international operation center (gateway switch) is also required to provide all kinds of international communication services including the increasingly-important optical fiber communication. As a result, it was recently decided that an international operation center would be established in Yokohama by IDC (International Digital Communications Co., Ltd.), a secondary international carrier established after the liberalization of telecommunications in 1985. The construction of the center is under way toward the opening in May, 1989.

This center will serve as an international communication service base covering the entire area of Japan and as the point where telephone charges are first counted inside Japan in the case of IDC-provided international telephone lines. Therefore, the installation of the center in Yokohama will enable users not only inside the MM21 Teleport Zone but also throughout Yokohama to utilize international telephone lines at lower costs than before.

Tokyo Waterfront Subcenter Project

Tokyo, as with other large cities of the world, are facing the pressures of change from greater internationalization, informationalization and increasing service orientation.

The construction of the Waterfront Subcenter is a positive response to the requirements of such an age, and will provide a futuristic city in the heart of the coastal district of Tokyo.

Located in this subcenter will be Tokyo Teleport, with the most advanced telecommunications functions to date, and Tokyo International Convention Park, with its international-scale exhibition hall.

A number of "intelligent" buildings will be built facing the promenade extending from Telecom Center, the symbol of Teleport. Serving as an information center and banking center of the world, these dynamic business quarters will be pulsating with the non-stop flow of up-to-the-minute information. This 24-hour city will have a working population of about 70,000.

Like projects in Yokohama and Nagoya, there will be fiber optic LAN/WAN and trunk networks for local and domestic communications and access to international services.

Appendix C

Current VSAT Systems

This appendix provides somes detail for the carrier requirements and services provided by a number of manufacturers of VSAT systems. These systems include RA-TDMA/TDM networks, SCPC network equipment, voice options or network equipment, and spread spectrum equipment.

1. HNS Personal Earth Station

2. HNS Telephony Earth Station

3. HNS Gemini System

4. NEC Nextar System

5. NEC Nextar VO System

6. NEC Nextar CL Clear Channel

7. SA SkylinX.25

8. Tridom Clearlink System

9. Contel ASC Equatorial Data Broadcast

C.1   HNS Personal Earth Station

The Hughes Network Services (HNS) Personal Earth Station (PES) is the equipment used in more than 50 networks world wide. These systems are used for reservation systems, central data processing for nationwide locations, and transaction applications. The network topology is a star network communicating with ISBN (Integrated Satellite Business Network) equipment at the hub.

The PES equipment consists of an indoor unit with three plug-in slots, and interfacility cable, and the outdoor unit consisting of the antenna, low noise receiver, SSPA, and up and down converters. The card slots can hold either data cards or voice port cards and are connected through a high speed bus. Each data card incorporates the equipment interface, support for one protocol and network level communications to the hub. Each separate data communication protocol at a site requires a separate data card.

Voice cards for the PES equipment require two slots for a 16 kb/s RELP codec. Therefore, the minimum installation can hold one data card (required) and one voice channel. If additional channels are needed, an expansion chassis can be added which provides an additional 15 slots.

The IF interface frequency for the PES is 1 GHz, and uses one of two integrated RF assemblies for C or Ku-band operation. These integrated units contain the up and down converters, the low noise receiver, and the SSPA. NEC is the manufacturer of these assemblies, and they can be mounted on several different antennas. Ku band antennas range from 1.2 to 1.8 m. C-band antennas are usually 1.8 or 2.4 m, although larger antenna can also be used. The HNS equipment uses 128 kb/s inbound carriers, and 512 kb/s outbound carriers, with options for 64 kb/s inbound carriers and 128 kb/s outbound carriers. Inbound carriers employ burst modulators at the VSAT and burst demodulators at the hub. Outbound carriers employ continuous modulators at the hub and continuous demodulators at the remote. This reduces the cost of the VSAT equipment.

The ISBN interfaces to the RF equipment at a 70 MHz IF. Standard RF equipment from a number of different manufacturers are used depending on the frequency, satellite and the number of channels. The ISBN equipment uses a LAN to connect the outputs of the demodulators to data and voice interfaces, and to the network control and monitor equipment. The same LAN connects the data and voice interfaces to the continuous modulator for the outbound carrier. The data ports

consist of separate functions for data processing, and for terrestrial line interface. Voice ports have two channels, and provide a four wire E&M interface for each channel.

A block diagram showing hub equipment modules in shown in Figure C-1. The network control computer monitors traffic, controls the network configuration, and captures billing information.

C.2   HNS Telephony Earth Station

The Telephony Earth Station (TES) equipment is used in a thin-route mesh satellite network. This system uses a single card with DSP (digital signal processing) and VLSI technologies. The TES card is programmed from a network management node for the desired operating mode. The system uses digital SCPC transmission for all services. Circuits are demand assigned for each call by the network management node. The TES card provides the following interfaces:

a. User interface is either data (RS-232D) or voice (4 wire).

b. Speech coding is 9.6 or 16 kb/s RELP or 32 kb/s ADPCM (CCITT), and includes voice activation of the carrier and echo cancellation

c. Data communications are synchronous from 4.8 kb/s to 56 kb/s, and asynchronous from 300 b/s to 19.2 kb/s.

d. Modulation is either BPSK (below 32 kb/s) or QPSK (32 kb/s and above). FEC is either rate 3/4 or rate 1/2 convolutional coding with Viterbi decoding.

e. Carrier frequency synthesis is 70 ± 18 MHz, with a 2.5 kHz step size.

A mounting box for remote sites holds up to 4 TES cards. A rack-mounted unit for high traffic nodes holds 24 TES cards. Each mounting unit has an IF combiner and interfaces to the RF unit. The power required in the RF unit is a function of the number of channels and the satellite transmission parameters.

Call setup is performed by communications from remote nodes to the network control node. Two or more designated channels are used for call setup. Communications to the network control node use Aloha access, and communications outbound from the control node use TDM. Call channels are set up using a dialog from the originating node to the network control system (NCS). The originating node sends a call request to the NCS. The NCS then assigns a pair of channels from a pool to the caller and called nodes. After an initial check of the link, the two nodes participate in the session. At the completion of the call the calling node sends a clear indication to the called node who responds with a clear confirmation. The two nodes then independently send call complete messages to the NCS using a control channel.

The TES system can be used for several applications:

a. A thin route voice system to a number of sites.

b. Extend terrestrial connections to a number of remote sites. A large station is installed at a corporate headquarters, or a regional telephone center.

c. Use for demand-assigned data networks.

C.3   HNS Gemini

The Gemini system is a digital SCPC data system that can be used either in a star network or in point to point networks. There are two major parts to a network: (1) the data channels, and (2) a low rate Monitor and Control channels used to monitor network health and central control. A remote site consists of the outdoor unit, the indoor unit and the interfacility link. Each channel also contains a separate Monitor and Control channel that can provide status, or receive control commands from the hub that are time multiplexed with the data channel. Each Gemini terminal is capable of operating in the following rates.

Single 56 kb/s: One 56 kb/s data channel and one 1 kb/s M&C channel

Dual 56 kb/s: Two 56 kb/s data channels and one 2 kb/s M&C channel

Single 112 kb/s: One 112 kb/s data channel and one 2 kb/s M&C channel

Single 38 kb/s: One 384 kb/s data channel and one 2 kb/s M&C channel

Single 512 kb/s: One 512 kb/s data channel and one 2 kb/s M&C channel
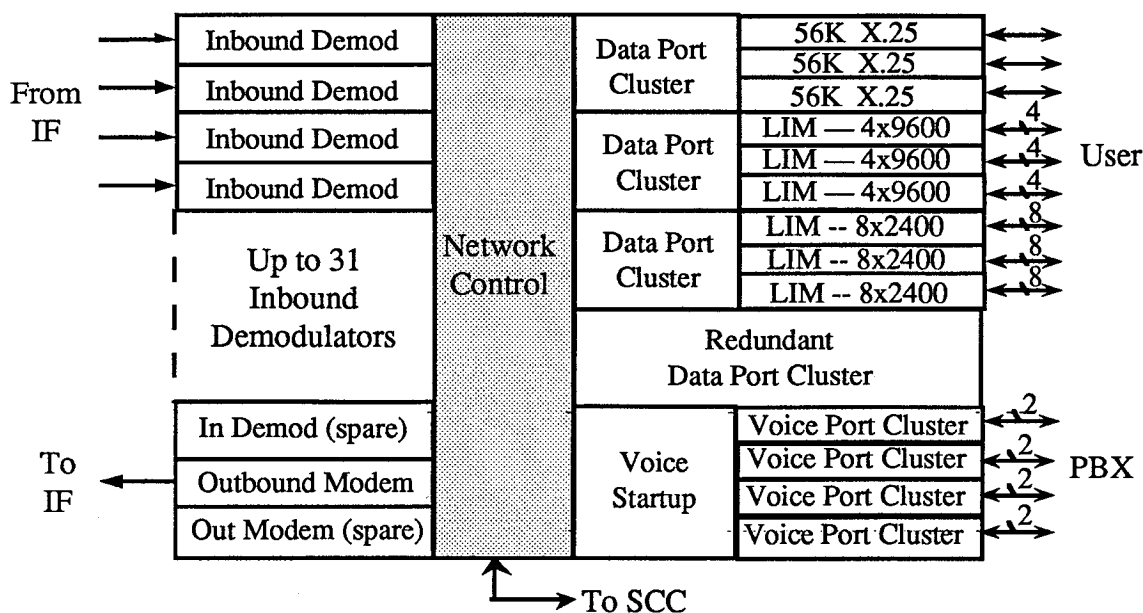
Figure C–1: Integrated Satellite Business Network (ISBN) Equipment

When the Gemini equipment is used in a star network, the channel units are mounted in a channel unit rack. Each channel unit can contain up to 16 channel units. Each channel unit operates at 112 kb/s using pre-assigned frequencies to each remote site.

The M&C function at the hub constantly collects status information from each Gemini channel unit. This is stored and displayed in a microcomputer. Modulation for 56 kb/s channels is BPSK, rate 1/2 coding. Modulation for 112 kb/s and higher rates is QPSK. The IF interface is either at 70 or 140 MHz.

C.4   NEC Nextar

NEXTAR I systems use a proprietary access technique called Adaptive Assignment Time Division Multiple Access (AA/TDMA). The AA/TDMA technique sends outbound data packets to all receiving sites. If the address of the packet matches that of the receiving site, the site accepts that packet. If the packet is addressed to a different site, the receiving site discards that packet. Inbound packets are sent in a burst mode, each satellite channel shared by many remote VSATs.

An AA/TDMA node processor integrated with each

VSAT dynamically adapts to traffic variations. The systems support X.25, SNA/SDLC, Bisync, Burroughs Poll Select (PBS) and asynchronous protocols. The NEXTAR I system transmits data at up to 56 kb/s inbound and outbound using a R 1/2 forward error correction technique.

The NEXTAR I system's primary application is in interactive computer to terminal networks for transaction processing, data exchange, and inquiry response in the retail, financial, and transportation industries.

VSAT Equipment consists of an ODU (outdoor unit) and an IDU (indoor unit) and cables. The primary application is interactive data with optional video reception. Voice capabilities are added as an option.

The antenna is composed of the dish, feed horn, and mount for roof, ground, or wall. Ku-band applications normally use a 1.2 to 2.4 m antenna. C-band applications typically use a 2.4 m antenna. Larger sizes are available for regions in heavy rainfall or weak satellite signals. The outdoor unit is mounted at the focal point of the antenna to eliminate signal loss between the feed horn and the RF equipment. The weather proof unit includes a

high-power converter, low noise receiver, and the coaxial cable interfacility link IF interface. NEC supplies the outdoor unit to Hughes Network Systems for the Personal Earth Station.

The indoor unit comprises a modem and a baseband processor (BBP). The BBP supports a maximum of 16 ports at combined data rates up to 56 kb/s. X.25, SNA/SDLC, Bisync, Burroughs Poll Select, and asynchronous protocols are supported. Interfaces supported are RS-232C and V.35.

Hub Equipment. The central hub earth station consists of outdoor and indoor equipment. Outdoor equipment consists of an antenna ranging from 4.5 to 11 m in diameter and RF equipment. The RF equipment includes an antenna feed and redundant low noise converters. An equipment shelter located near the antenna includes redundant up and down converters, redundant high power amplifiers, and monitor and control equipment. NEC claims operation with 45 mph winds gusting to 60 mph, and a survival wind velocity of 125 mph.

The indoor equipment, shown in Figure C-2, includes a modem, satellite access controllers (SACs), and the Satellite Network Control Processor (SNCP). The SAC and the SNCP can be connected over a terrestrial link at speeds from 4.8 kb/s to 56 kb/s. Each 56 kb/s satellite channel requires an IF divider/combiner equipment, a BPSK modem, and a satellite access controller. Each SAC supports a single outbound 56 kb/s TDM satellite channel and up to three 56 kb/s inbound AA/TDMA channels. SACs also perform flow control and packet routing and provide the interface to the customer's front end processor. Modems and SAC can be configured for 1- to-N redundancy.

The SNCP provides network management and maintenance functions, consisting of automatic network configuration, traffic throughput, alarm processing, and system diagnostics. Implementation is on a minicomputer which depends on the network size and complexity. The SNCP can be located remotely at the user's data center if desired.

C.5   NEC Nextar VO

The Nextar VO is a SCPC/DAMA system, and can be used alone, or in conjunction with Nextar data terminals to provide voice capabilities to a site. The unit uses a 16 kb/s voice coding rate and a carrier rate of 19.2 kb/s. The voice interface is analog, either two wire FXS (Foreign Exchange Subscriber), two wire FSO (Foreign Exchange Office), or four wire E&M Interface.

Multiple voice channels to a site require a voice card for each channel and a multi-port controller.

In the voice only network, the system uses a common signalling channel to a DAMA controller to establish a call connection. All voice channels monitor this channel when idle, and respond to call requests. In an integrated voice and data network, the Nextar data system provides connections to the DAMA controller which is located at the hub.

C.6   NEC Nextar CL Clear Channel

The NEXTAR CL Clear Channel systems uses SCPC (single channel per carrier) satellite access methods, and transmits at speeds from 9.6 kb/s to 2.048 Mb/s depending on the modem used. This is not a continuous range, however; data rates must be specified at time of order. Options include analog video reception, digitized voice capability, and data encryption using the Data Encryption Standard (DES) algorithm.

The NEXTAR CL VSAT includes an antenna, an outdoor unit, an interfacility link link (IFL), and an indoor unit (IDU). An optional Remote Monitoring and Control (RMAC) system is available.

VSAT Equipment. Antennas used in the NEXTAR CL VSAT range from 1.2 to 4.5 m in diameter. Larger sizes are used for higher data rates, to improve performance in regions with heavy rainfall or weak satellite signals, or where the VSAT is configured as a central hub. Mounts are available for roof, ground, or wall mounting.

The ODU is mounted at the antenna's focal point. It is composed of a high power converter and a low noise amplifier in a weather-proof housing.

The NEXTAR CL IDU offers user-selectable R=1/2 and R=3/4 forward error correction, and data rates from 9.6 kb/s to 2.048 Mb/s. Operation is single channel per carrier operation without any

FEP   Front End Processor
SW   Redundancy Switch
SAC   Satellite Access Controller
RFT   RF Terminal
ODU   Outdoor Unit
IDU   Indoor Unit
DTE   Data Terminal Equipment
SNCP Satellite Network
      Control Processor
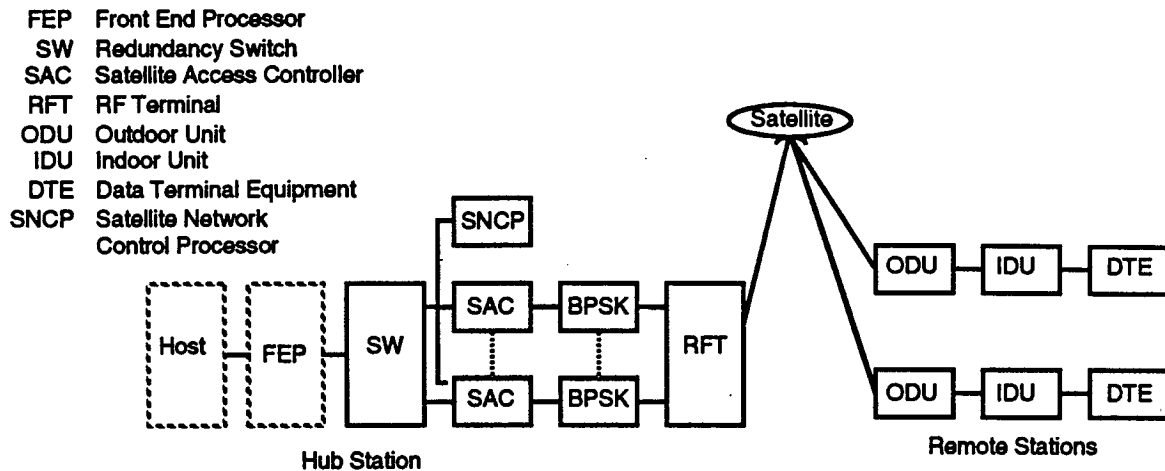
Figure C–2: NEC Hub Equipment

protocol conversion. In the event of an alarm, the IDU can call the RMAC controller.

Remote Monitoring and Control System
(RMAC). An optional Remote Monitoring and Control (RMAC) system allows centralized control of a NEXTAR CL network. This allows a central operator to configure, monitor, and control a network using the public telephone network. The operator can send commands, and can monitor status and alarm information. Among parameters that the operator can monitor are the satellite link error rate, power levels, and data rates. The RMAC system is based on an IBM-compatible NEC APC IV computer using a menu-driven interface.

C.7   SA SkylinX.25

Scientific Atlanta (SA) supports satellite-delivered data services based on the use of the SkylinX.25 VSAT equipment. SA based the design of their equipment on the specifications for X.25 packet networks. SA's protocol architecture is shown in Figure C-3. Multiple protocols and transmission rates are supported. SA's satellite services include shared hub networks, 56 and 64 kb/s point-to-point service, broadcast T1 service, and secure video broadcasting.

By basing its networks on the X.25 packet-switching protocol, Scientific-Atlanta can integrate its network products into hybrid networks, and use VSATs to back up terrestrial networks. Scientific Atlanta's satellite access method provides dynamic switching between TDMA and slotted Aloha. Switching occurs at a predetermined traffic level and avoids problems created by contention for available channels as traffic load increases.

The system is designed for a 1 GHz IF interface, and has provisions for attaching a B-MAC integrated receiver decoder, a T-1 data broadcast unit, or an audio receiver. Two system options support operation in the C or Ku-band frequencies. Other options that will not be covered here allow a node to incorporate a video uplink or wide-band data link. These options fall outside the VSAT definition and will not be discussed further. Data transmission uses BPSK modulation and Rate 1/2 convolutional coding and Viterbi decoding.

VSAT equipment consists of an indoor unit, outdoor unit, and interfacility link cable. Each node can support four data ports. Each port can support a different protocol, and can be configured as asynchronous or synchronous at rates to 19.2 kb/s. Each port can support up to 4 multidropped devices on each port. Each port also has a DMA (direct memory access) controller to maintain performance as the load at the site increases.

Optional equipment, offered in international markets, includes a voice codec that can be plugged into one of the data port slots. This voice codec operates at rates from 9.6 to 16 kb/s. The voice

Application					Application
Presentation					Presentation
Session					Session
Transport	Network		Network		Transport
	Site Recovery		Site Recovery		
Network	Broadcast		Broadcast		Network
Link	Link	Link	Link	Link	Link
Physical	Physical	Physical	Physical	Physical	Physical
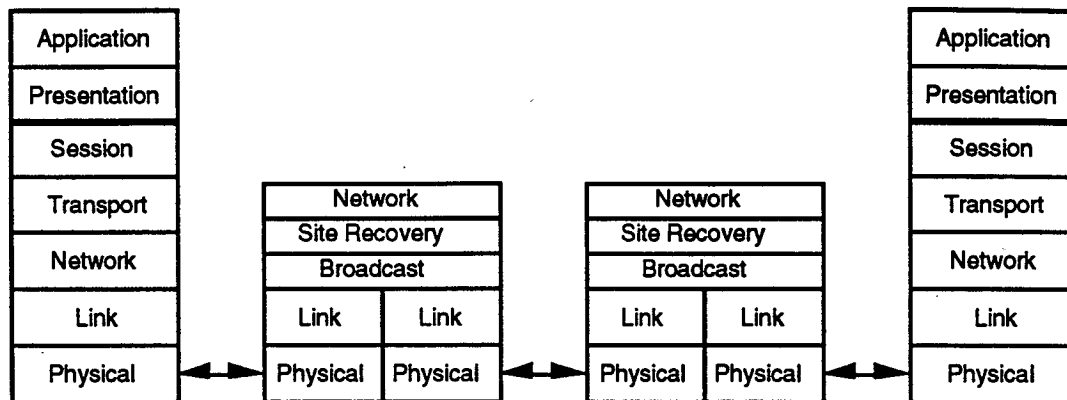
Figure C–3: Scientific Atlanta VSAT Protocol Architecture

codec uses an orthogonal transform for compression. One capability unique to the SA terminal is the ability to handle a facsimile connection, at rates to 4.8 kb/s. The codec recognizes the presence of data, and shifts to a mode optimized for data from the facsimile modem.

Hub equipment primary components are the RF equipment, burst demodulators and continuous modulators, and a combined packet switch and network control system. The SA Series 3000 packet switch is the focal point for all network traffic. Customer traffic enters the packet switch on host lines and is packetized into a common X.25 format. An optional PAD function is available that communicates in the host's native protocol. Traffic is routed to the appropriate outbound carrier, or from the appropriate receiver.

The packet switches run the network control system software. This software provides data network management features including the master and remote stations, the terrestrial connections (including dial backup), and some local customer equipment functions. An IBM PC is used for the human interface.

Several features of the SA VSAT system support high throughputs. These include link enhancement features to reduce X.25 supervisory traffic without sacrificing end-to-end reliability. Selective reject ARQ reduces the number of packets that are re-transmitted due to uncorrected errors.

C.8 Tridom Clearlink System

The network is organized into transmission "clusters", with each cluster consisting of a single 512 kb/s outbound channel received by all VSATs and up to fifty 32K or 64 kb/s inbound channels. Each 32 kb/s Aloha channel may have 25 to 1,000 sites assigned, depending on traffic volume. Installation of an option card allows more than one protocol to be supported at a site.

One of the options is a communications mode known to the financial services industry as "hoot and holler". This mode supports voice transmission from a central site with occasional return transmission from branch offices. Branch sites can call in questions. These questions are later broadcast along with the answers from the central site.

The system was originally designed for Direct Broadcast Satellite service and uses a standard 950 to 1450 MHz IF signal. The signal can therefore piggyback full transponder, full-motion video signal from the hub to VSAT.

The Clearlink network is designed to fully support OSI standards. The network implements the three bottom layers of the OSI model (physical, data link, and network) while the upper four layers — transport, session, presentation and application – are supported by the end system computers that connect to the OSI network as shown in Figure C-4. In the satellite access

link layer, the network supports a wide range of access options: Aloha, slotted Aloha, Fixed Assignment TDMA, Combined Access TDMA, and proprietary Demand Controlled TDMA.

A focal point of the network is a Host Interface installed at the customer host computer. The network hub connects to the host interface over terrestrial line with rates from 9.6 to 56 kb/s. The Clearlink system provides end-to-end protection for the customer's data through a host interface at the customer's host site, which performs the necessary protocol conversions and processing. Thus, traffic enters the Clearlink network with its error correction protocol at the host site, rather than being transmitted to the master earth station before entering the network.

System backup uses a $1,200 option card that dials through the DDD network to the customer's next nearest site in the event of a system outage. The card provides a high speed synchronous modem that can command use of one of the customer's existing lines, eliminating the expense of leasing a dedicated backup line. Clearlink data is encrypted, and can be received only by authorized stations.

VSAT Equipment. The indoor unit provides three serial ports, and fits on a desktop in an office environment. Each serial interface is capable of handling a separate protocol, and may be configured as RS-232, V.35 or RS-422. The remote terminal processor performs protocol conversion, and formats the data for the 32 kb/s inbound channel. Additional ports are added by installing the Modem Sharing Option or Multi-port Interface cards. Broadcast ports to receive data from the host site for unique user applications or stock tickers are supported by the broadcast Interface card. The outdoor unit consists of a 1.2 or 1.8 m diameter antenna with feed, the antenna mount, and the transmit/receive module. The antenna requires no AC power, and uses DC power provided by the indoor unit. The non-penetrating mount continues to function in winds to 90 mph and survives winds up to 120 mph.

Hub Equipment. The hub operates at Ku band with an antenna typically 4.5 to 7.1 m in diameter. The hub system consists of the burst demodulators, burst modulators, a high-speed OSI packet switch, and the Network Control Computer. The high speed packet switch is connected to Host Interfaces located near the customer's host computers. The Network Control Computer uses a Stratus fault tolerant computer, and stores and manages all network information. All data between the hub switch and Host Interfaces is addressed to a particular location, and cannot be decoded by other systems.

C.9 Contel ASC Equatorial Data Broadcast

Equatorial data broadcast is a one-way digital service used to transmit data from a central location to multiple remote locations. The system is based on the EDB-1000 Master Station, and succeeds the C-100 and K-100 series. Compatibility with the older C-100 and K-100 stations is retained. The Master station antenna are usually 7 to 9 m in diameter.

C-100 Series Micro Earth Station and **K-100 Satellite Data Receiver.** Point-to-multipoint, one-way network service is based on the C-100, a receive-only earth station receiving data at 4 GHz. Data rates up to 19.2 kb/s are supported. Available antenna diameters are 0.6, 0.75, and 1.2 m.

C-120 Series Micro Earth Station.
Private Newswire service uses the C-120 series earth station, an enhanced version of the C-100 station. The C-120 includes an additional programmable microprocessor interface board providing data buffering. Based on information contained in the data stream, the C-120 provides selective data routing or filtering, data reformatting, and special protocol conversions. For private newswire service the user site must have a C-120, an IBM PC or compatible, two disk drives, 320 K bytes of memory, a 1.2 kb/s Hayes-compatible modem, and PCC/Systems cc:Mail software.

EDB-1000 Micro Earth Station is the current offering for data reception. Users can establish virtual circuits between any Master Station port and any physical Micro Earth Station port.

Application
Presentation
Session
Transport
Network
Link
Physical

Remote
User

Network	TP4
	IP
Link	TLCP
Physical	Burst Mod CW Demod

Indoor
Unit

IP	IP
TLCP	X.25 L2 LapB
Burst Demod CW Mod	RS-422

Hub Switch

TP4	Network
IP	
X.25 L2 LapB	Link
RS-422	Physical

Host
Interface

Application
Presentation
Session
Transport
Network
Link
Physical

Central
Host
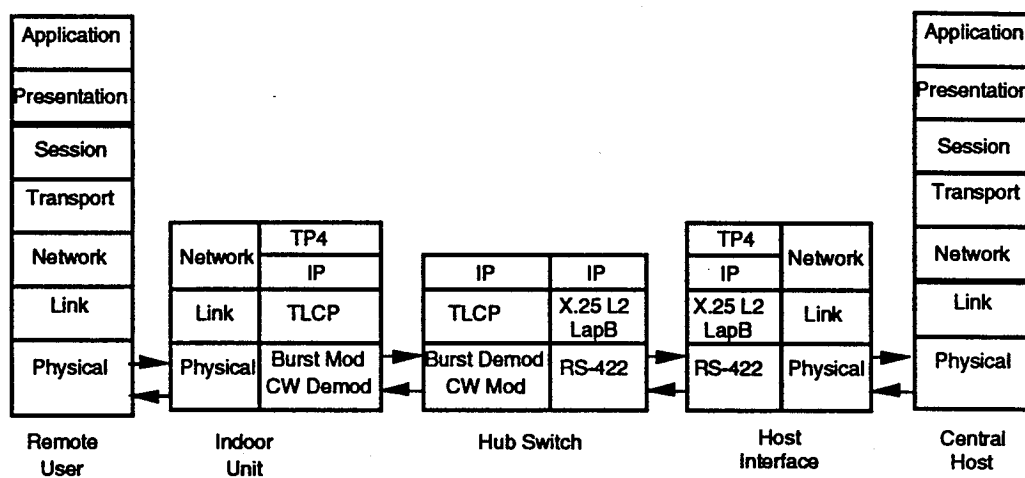
Figure C–4: ATT-Tridom Protocol Architecture

Appendix D

Rain Fade Compensation

The problem of rain fade compensation is very serious at Ka-band for users who demand high availability. Standard analysis based upon annualized statistics may not be appropriate for users in areas with a "rainy season". An additional 5 to 10 dB margin may be required to achieve 98% "worst month" availability, equivalent to 15 hours per month outage. The problem becomes how to dynamically supply additional margin on a user-by-user basis.

This appendix is organized as follows:

1. Rain Fade at Ka-Band

2. Link Availability Requirements

3. ACTS Fade Compensation

4. PASS Fade Compensation

5. Recommended Alternatives

6. Required Technology Developments

D.1   Rain Fade at Ka-Band

D.1.1   Rain Climate Regions

The continental United States (CONUS) is divided into rain rate climate regions as shown in Figure D-1 (*NASA Propagation Effects Handbook for System Design*, ORI TR-1679). Regions are designated by letters B, C, D, E, F with further subdivision of D into D_1, D_2, D_3, and B into B_1 and B_2. Heaviest rainfall and most attenuation occurs in Regions E, D_3, and D_2.

The satellite elevation angle as viewed from the ground terminal also affects the amount of rain attenuation on account of the longer atmospheric path length. Table D-1 gives satellite elevation angles for the eight rainfall regions and three satellite locations. The 120° W satellite location is less desirable for servicing

Table D-1: Satellite Elevation Angles

| Rainfall Region | Minimum Satellite Elevation in degrees | | |
| | Satellite long. (W) | | |
	70°	95°	120°
E	43	45	28
D3	40	43	27
D2	36	35	20
D1	24	32	18
B2	22	32	18
B1	17	28	33
C	15	28	33
F	24	36	37

users in the heavy rainfall regions (E, D3, and D2) due to the lower elevation angle which results in longer atmospheric path length and more attenuation. In general, elevation angles remain relatively high for the highest rainfall regions (E and D3) due to their lower latitudes.

D.1.2   Availability — Annual Average

Table D-2 presents the rain attenuation data for Ka-band as a function of desired annual availability and rainfall region. The data of Table D-1 is used to obtain the worst case elevation angle (in parentheses under E, D3 etc.) for each rainfall region in Table D-2. For example, if the desired availability is 99.5%, the Ka-band downlinks and uplinks must have 5.7 dB and 11.6 dB rain margins respectively to service Rain Region E.

Figures D-2 and D-3 illustrate the rain attenuation for the downlink and uplink respectively for five locations in the continental United States for a satellite located at 95° W. The percentage of the year that a given attenuation is exceeded for a particular location
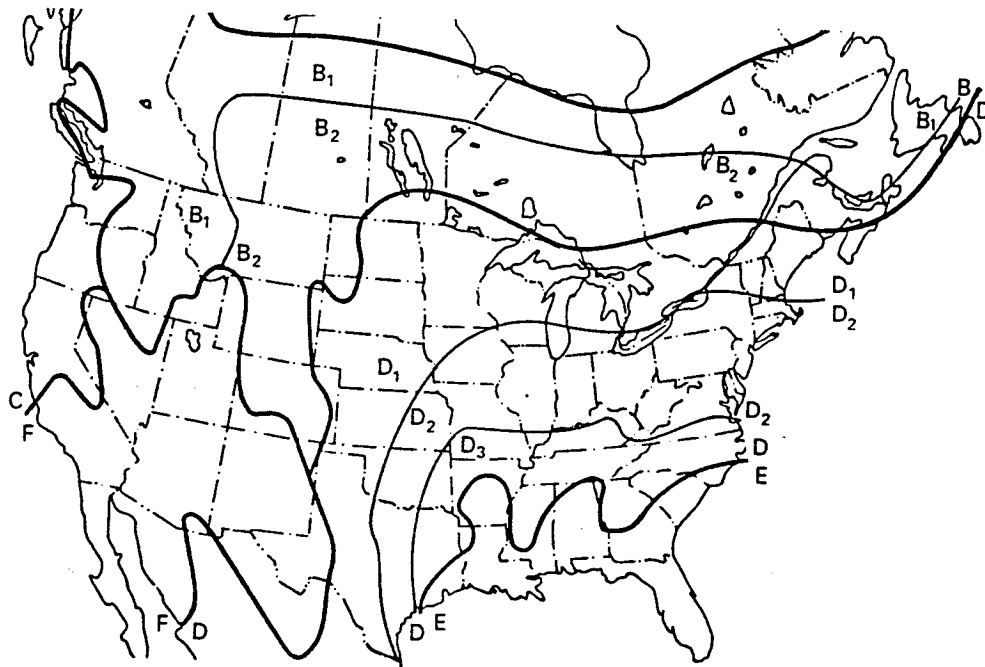
Figure D–1: Rain Rate Climate Regions for the Continental United States

was computed (M. K. Sue, "PASS Rain Attenuation Compensation Techniques and an Assessment of Service Availability", JPL Satcom Quarterly, April 1991) using a rain model developed by R. M. Manning ("A Unified Statistical Rain Attenuation Model for Communication Link Fade Predictions ... ", MSAT-X Quarterly, no. 25, JPL 410-13-25, October 1990). These figures show that 99.8% of the year, the rain attenuation will not exceed 20–30 dB; and 98% of the year, the rain attenuation will not exceed 3 dB.

D.1.3   Availability — Worst Month

B. K. Levitt ("The Effectiveness of PASS Rain Compensation Techniques Based on Worst Month Statistics", NASA/Jet Propulsion Laboratory, Satcom Quarterly, No. 1, April 1991) extends the availability analysis to the worst month — what happens to required margins when the user asks for 98% availability (15 hr/month outage) for the worst month? During the rainy season in a particular user terminal location, the performance can be seriously degraded.

Figure D–4 shows the comparison between worst-month and annualized average uplink outage probability as a function of nominal clear-sky link margin for a Ka-band user terminal in Portland, Maine (average annual rainfall of 43.5 inches). A 98% worst-month

availability, or 2% (2×10^{0}) link outage probability as shown in Figure D–4, which corresponds to 15 hours per month outage, requires a margin of 8 dB versus the 3 dB margin for the annualized average. The difference in margin between worst month and annual average increases rapidly for lower outage probabilities.

D.2   Link Availability Requirements

Different users will have different availability requirements, ranging from "no outages", to "reduced quality and service", to "wait until conditions improve". Thus it seems that the satellite link supplier needs to have a strategy to supply high grade service during rain fades. This will involve a mechanism to implement the following, according to individual user preference:

- Sensing of poor link quality and termination of connection before failure.

- Graceful degradation of the link quality, such as by reducing the data rate.

- Increasing link margin to allow communications through the increased atmospheric attenuation. This could involve such steps as increased transmit power, increased bandwidth, and invocation of forward error correction coding.
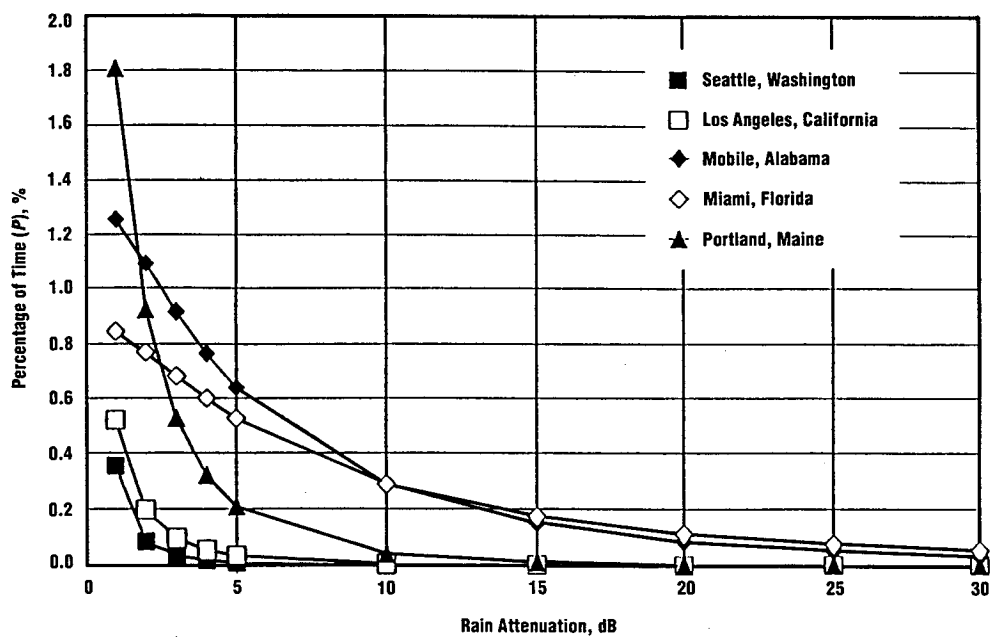
Figure D–2: Rain Attenuation for 20 GHz Downlink at Five Locations (Satellite at 95° W)
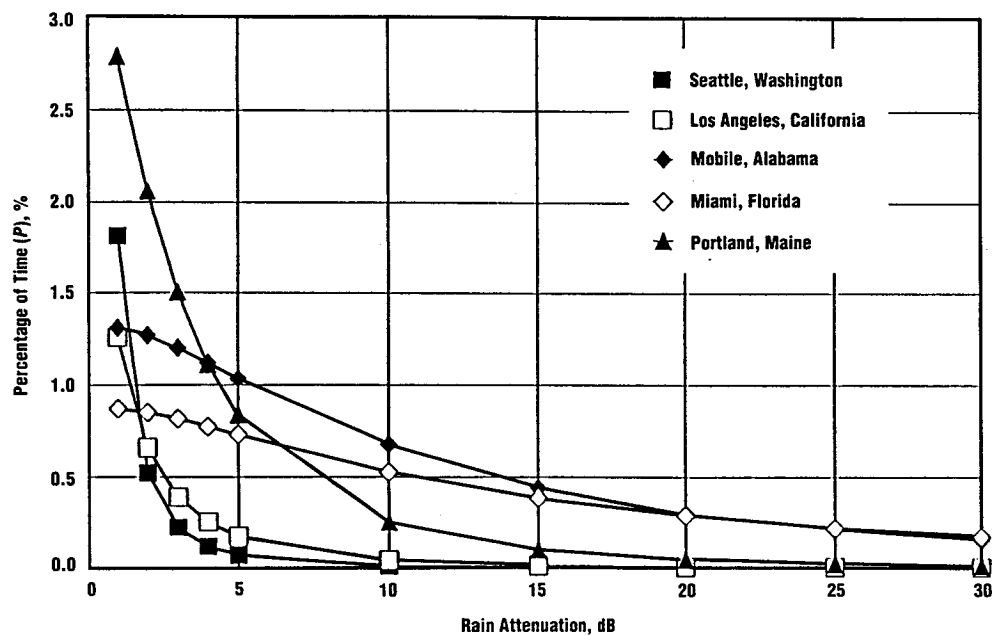
Figure D–3: Rain Attenuation for 30 GHz Uplink at Five Locations (Satellite at 95° W)

Table D–2: Ka-Band Rain Attenuation (dB) by Rain Region Versus Availability

Annual Availability (%)	Outage (hr/yr)	Ka-band Downlink: Frequency = 19.7 GHz Worst Case Attenuation (dB) CONUS Rainfall Region (elevation angle)							
		E (45°)	D3 (40°)	D2 (35°)	D1 (30°)	B2 (30°)	B1 (30°)	C (25°)	F (35°)
99.99	0.9	55.2	39.0	30.9	23.3	15.7	10.9	21.3	14.9
99.98	1.8	43.7	29.6	21.8	15.4	10.3	7.4	13.6	9.5
99.95	4.4	29.1	19.6	13.7	8.8	5.6	3.9	7.3	4.9
99.9	8.8	19.5	13.3	8.5	5.5	3.3	2.3	4.8	2.8
99.8	17.5	11.7	8.6	5.3	3.2	1.8	1.3	2.9	1.5
99.5	43.8	5.7	4.5	2.6	1.4	.8	.5	1.3	.5
99.0	87.7	3.1	2.5	1.3	.7	.4	.3	.7	.2
98.0	175.3	1.4	.9	.5	.3	.1	.1	.3	.0

Annual Availability (%)	Outage (hr/yr)	Ka-band Uplink: Frequency = 29.5 GHz Worst Case Attenuation (dB) CONUS Rainfall Region							
		E	D3	D2	D1	B2	B1	C	F
99.99	0.9	97.1	70.0	57.0	43.9	30.3	21.6	40.7	28.8
99.98	1.8	78.0	54.5	41.1	29.7	20.3	14.9	26.6	18.7
99.95	4.4	53.1	36.9	25.7	17.4	11.4	8.2	15.8	10.1
99.9	8.8	36.6	25.7	16.8	11.2	6.3	4.9	9.9	6.0
99.8	17.5	22.6	17.1	10.7	6.7	4.0	2.9	6.1	3.3
99.5	43.8	11.6	9.2	5.5	3.2	1.8	1.2	2.9	1.2
99.0	87.7	6.5	5.4	2.9	1.6	.9	.6	1.5	.5
98.0	175.3	3.1	2.2	1.3	.7	.4	.2	.7	.1

D.3 ACTS Fade Compensation

The NASA/LeRC Advanced Communications Technology Satellite (ACTS) uses fade compensation techniques to supply up to 10 dB link margin. In the OSBS/TDMA mode (on-board stored baseband switch), the link is designed for a 5-dB clear weather margin.

Terminals experiencing fade can be dynamically provided a further 10-dB fade protection. This is provided by a combination of 4 times reduction in data rate and use of rate 1/2 coding. The satellite TWTAs are always operated at high power (46 W) in the OSBS mode.

ACTS is currently scheduled for launch in early 1993, and operational experience will be gained with rain fade compensation at Ka-band. (Reference: NASA, Lewis Research Center, "NASA's ACTS: an Overview of the Satellite ... ", F. M. Naderi and S. J. Campanella, March 1988.)

D.3.1 Dynamic Compensation Technique

Beacon signals are transmitted by ACTS at approximately 20.2 and 27.5 GHz for uplink and downlink fade monitoring. The signals are continually received and processed at each ground terminal for fade detection. Once the received beacon power drops below a certain threshold, the affected terminal sends a request over ACTS to the network master control station (MCS) for additional fade protection.

The MCS takes two actions:

● MCS sends a command over ACTS to the terminal instructing it to invoke coding – uplink coding, downlink coding, or both. The MCS also instructs the ACTS baseband processor to enable the on-board decoder and/or encoder for processing of the signal from/to the affected terminal. The rate 1/2 code provides a 4-dB performance gain.
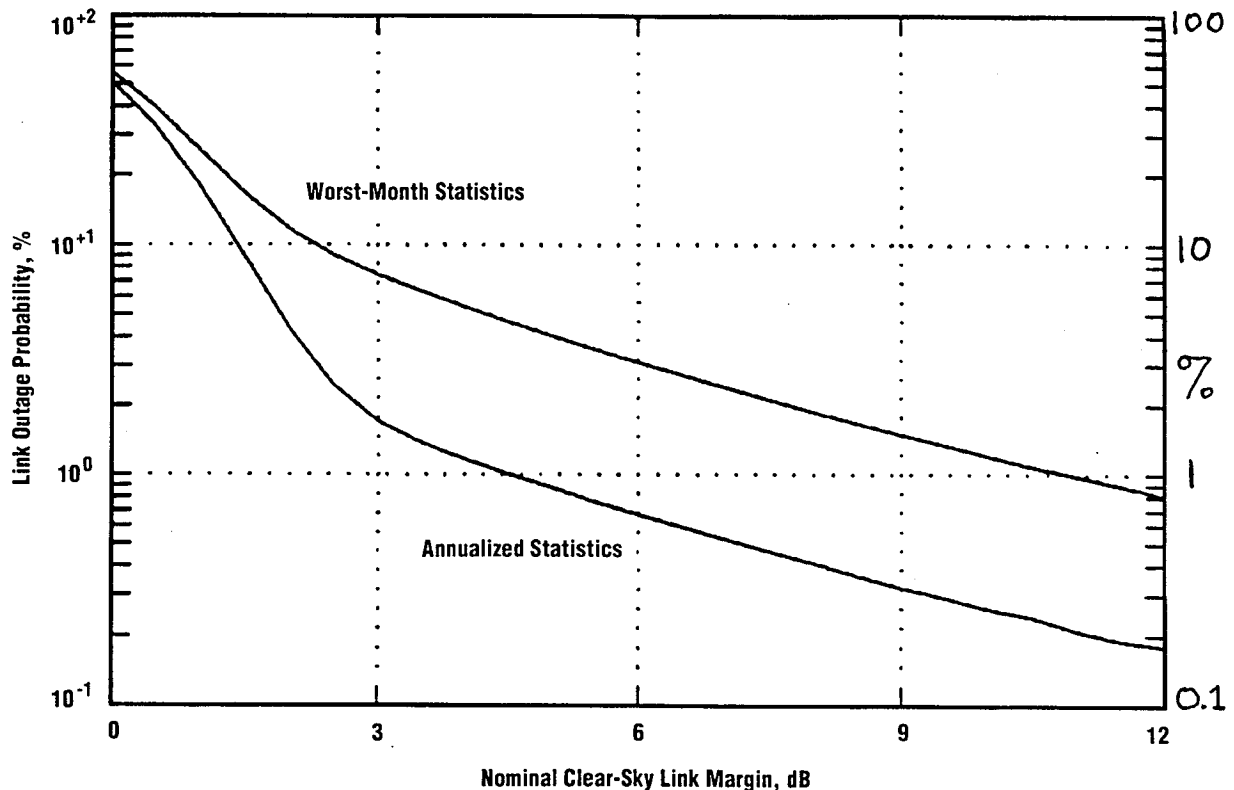
Figure D–4: Comparison Between Worst-Month and Annualized Average Outage Probability (30 GHz Uplink)

- If the fade is on the uplink, the MCS instructs the affected terminal to reduce its uplink data rate by a factor of 4. If the fade is on the downlink, the MCS commands the satellite to reduce its downlink rate by a factor of 4 when transmitting to that specific ground terminal. The rate reduction provides an additional margin of 6 dB, for a total of 10 dB.

Rate reduction and coding are invoked together. The combination of reducing the information data rate by a factor of 4 and invoking rate 1/2 coding (which doubles the transmitted data rate) results in a transmission burst rate that is one half of normal.

It should be noted that while the transmission burst rate is reduced, the actual information rate remains unchanged during fading, thus making the whole operation transparent to the user. This is possible by giving the rain-faded user more transmission time since ACTS is a TDMA system with scanning spot beams and variable dwell times. Of course the total satellite capacity is reduced by a factor of 4 times that percent of the users experiencing rain fades.

D.3.2 Baseband Processor

The baseband processor is shown in Figure D–5. It has the following major elements — modems, codecs, input/output memories, a routing switch, and a central processor. At any instant in time, on each of the two uplink hopping beams, the baseband processor can receive data on either one 110-Mb/s channel or on two FDM 27.5-Mb/s channels. The maximum baseband processor throughput is 110 Mb/s per beam, for a total maximum of 220 Mb/s.

The ground terminals experiencing fade reduce their rate by a factor of 4 and also invoke rate 1/2 coding. This combination results in a burst rate that is one half of the burst rate during normal operation. To accommodate reduced burst rates during fade intervals, the baseband processor modems are dual rate. The 110-Mb/s demodulator can also accept 55-MS/s bursts and the 27.5-Mb/s demodulator can also process 13.75-MS/s bursts. The ACTS transmission burst plan is summarized in Table D–3. The modulators and demodulators are based on a serial implementation of MSK, referred to as SMSK. The theoretical performance of SMSK is identical to that of MSK. However, at high data rates,
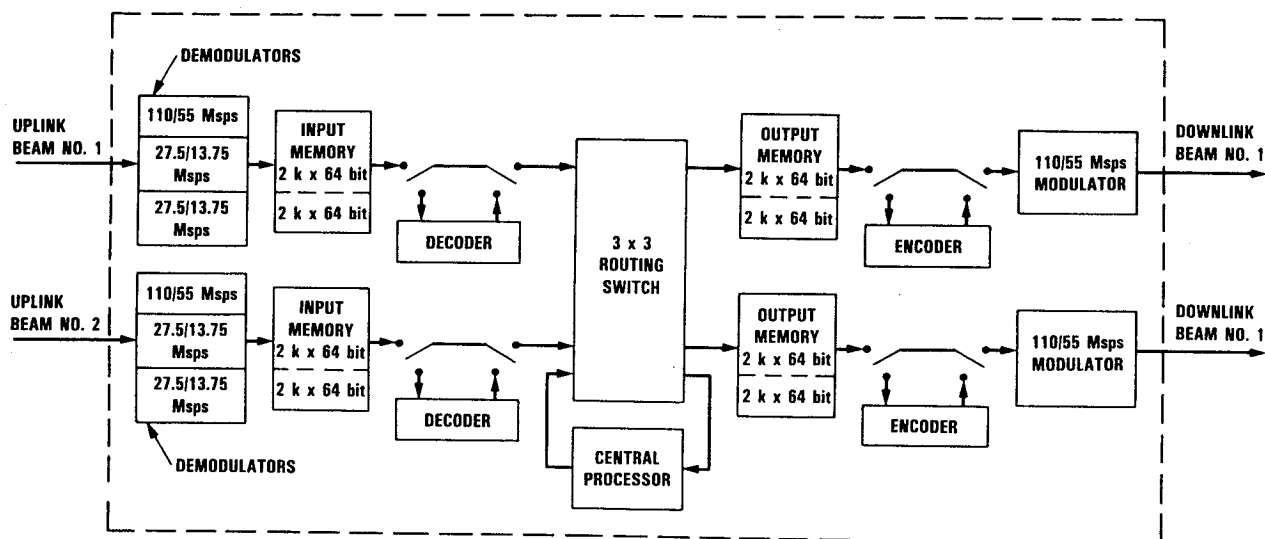
Figure D–5: Block Diagram of the Baseband Processor for the Advanced Communications Technology Satellite

Table D–3: ACTS Burst Rate Summary

| | Modes of Operation | | | |
| | Uncoded (Mb/s) | | Coded, R 1/2 (MS/s) | |
	Uplink	Downlink	Uplink	Downlink
Baseband Processor:				
Single Channel TDMA	110.0	110	55.00	55
Two Channel TDMA	27.5	110	13.75	55

SMSK has simpler implementation.

The IF input to the demodulators is at approximately 3 GHz. Once demodulated, the baseband output is routed to the input memory. In the OSBS/TDMA mode, capacity allocation to requesting ground terminals is made in increments of 64-kb/s channels. Within the 1-ms TDMA frame interval, each channel transmits 64 bits. Since the highest transmission rate is 110 Mb/s (actually 110.592), a maximum of 1,728 64-bit words can be transmitted in one frame. Some of this data is reserved for preambles and control channels. To be able to store data received during each frame interval, the input and output memories in the baseband processor are sized for 2,000 64-bit words.

Adaptive forward error correction (FEC) is selectively applied by the baseband processor under the direction of the ground master control station (MCS). ACTS uses a constraint length 5, rate 1/2 convolutional encoder and a maximum likelihood convolutional decoder (MCD) with 2-bit soft decision and a path memory length of 28. The MCD implementation is on a single chip. When decoding is necessary, the output of the input memory is routed through a parallel-to-serial converter to the MCD (Figure D–5).

The decoding throughput per beam is 6.8 Mb/s or approximately 100 64-bit words during each frame period. But each frame, even after the preambles and other words are stripped, may contain over 1,000 words, far exceeding the capacity of the decoder. The sizing of the decoder is based on an assumption that only a small percentage of all terminals will experience fading at the same time.

Table D–4 summarizes the ACTS baseband processor mass and power. Mass is 58 kg (128 lb) and power consumption is 211 W. This is based upon early 1980's technology and could be considerably reduced with todays technology. Total throughput for the baseband processor is 220 Mb/s.

Table D–4: ACTS Baseband Processor Parameters

Item	Mass (kg)	Power (W)
Modem	15.3	45.0
I/O Memory	25.8	103.5
Processor	14.7	35.4
Cables	2.4	0.0
Totals	58.2	210.9

D.4 PASS Fade Compensation

The NASA/JPL Personal Access Satellite System (PASS) proposes to use fade compensation techniques to supply up to 6 dB link margin. The forward service from a large fixed supplier terminal uses uplink power control and then data rate reduction to close the link. The return link from the small user terminal uses only data rate reduction to compensate for rain attenuation.

The data rate is reduced by successive factors of two from 4.8 kb/s, to 2.4 kb/s, to 1.2 kb/s for a total of 6 dB fade compensation margin. This results in a reduction of service quality or even termination of certain services during severe rain events. (Reference: NASA/Jet Propulsion Laboratory, Satcom Quarterly, No. 1, April 1991.)

D.5 Recommended Approach

A VSAT system may support a number of users with differing data rate requirements from 144 kb/s to 4 Mb/s. Depending on user location and requirements — particularly desired availability, data rate, and cost of ground terminal — different rain fade compensation techniques are recommended.

The available methods of supplying fade compensation are as follows:

Uplink power control is possible for users willing to spend more money on their ground terminal.

Downlink power control by   increasing satellite power may be possible as a general solution to providing slightly higher downlink rain margins for high rainfall regions. For example, 3 dB higher EIRP (either by increased transmit power or a higher gain transmit antenna) could be provided to the Southeast (see Figure D–1) to compensate for the higher rainfall. In fact, EIRP could

be adjusted over CONUS to equalize the expected annual availability.

Satellite G/T could be increased for users in high rainfall regions to supply more uplink rain margin. This would require a larger satellite receive antenna. A multiple beam antenna could use single horns for high rain regions and multiple horns, a three-horn cluster for example, for the remainder of CONUS. There are practical difficulties with this approach.

Coding or increased coding could be switched on to compensate for detected fading. Coding can be applied individually to uplinks and downlinks with an on-board processing satellite.

Reduced transmit data rates could be successively invoked to combat fading. Quality (total information transfer rate) could be maintained by allocation of more time slots for transmission. This would result in reduced satellite capacity and hence increased communications costs to overcome rain fading.

Users would pay more for this service, which would be invoked only when needed (i. e. rain) and desired by the user for the particular communications.

Transmit data rate reduction can be applied to both uplinks and downlinks. Only TDM or TDMA links have the option of maintaining information transfer rate by allocating more time slots for the transmission to compensate for transmit data rate reduction.

Fade compensation techniques are discussed for three classes of users:

1. Small users are in the 144 kb/s data rate category and desire low-cost ground terminals. Cost of communications is most important.

2. Medium users require data rates up to 1 Mb/s and can afford more expensive ground terminals. The option of higher availability is important.

3. Large users have up to 4 Mb/s data rate and are able to spend a relatively large amount on the ground terminal due to high utilization and/or importance of communications. There may be a desire for higher availabilities in so far as practical.

D.5.1   Small User Fade Compensation

These users cannot afford the complexity of fade sensing via beacon monitoring and multiple rate modems. The recommended approach is to allow 3 dB increase in ground terminal transmit power (uplink) for small users in high rainfall regions, together with increased satellite EIRP (downlink) to the high rainfall regions (i. e. the Southeast). Small users elsewhere in the country would have no additional fade compensation.

D.5.2   Medium User Fade Compensation

Medium users will have beacon-monitoring fade detection systems. They may be able to increase transmit power. Medium users have up to 1 Mb/s data rates within the 4 Mb/s TDMA burst rate. They can drop back in data rate by a factor of 4 while increasing time slot usage by a factor of 4.

The recommended approach is 3 dB increase in ground terminal power for the uplink, plus data rate reductions of up to 4 times (4 Mb/s, to 2 Mb/s, to 1 Mb/s) on both uplinks and downlinks for an additional 6 dB fade margin with no loss in link quality.

A case example is given of a medium user with an FDM/TDMA uplink and TDM downlink. Table D–6 summarizes system design parameters. The uplink and downlink burst rates are 4 Mb/s and 52 Mb/s respectively. The satellite covers CONUS on uplinks and downlinks with 28 beams of 0.87° diameter.

Medium user link parameters are given in Table D–5. Uplink and downlink rain margins correspond to 98% annual availability in Region E or 99.5% annual availability in Region D1 (see Table D–2).

D.5.2.1   Uplink Fade Compensation

Table D–7 summarizes the rain fade compensation strategy for uplinks. The medium user is assumed to require a 1 Mb/s information transfer rate which is implemented using a 4 Mb/s burst uplink. The underlined values in the table represent the preferred steps to obtain increasing margin. The 1 Mb/s information transfer rate is maintained as the burst rate drops back to 1 Mb/s, giving 6 dB fade margin. Further fade margin up to 12 dB is achieved by simultaneous reduction in burst rate and information transfer rate in steps down to 256 kb/s.

The medium user VSAT must have a variable rate modem (4 Mb/s to 256 kb/s) in order to obtain these

Table D–5: Medium User Link Parameters

Parameters	Downlink
Carrier frequency	20 GHz
Satellite transmit power	15 W
Satellite beam size	0.87°
VSAT diameter	1.8 m
VSAT system temperature	470 K
Burst data rate	52 Mb/s
Modulation	BPSK
Coding rate (block)	0.616
Rain margin	1.4 dB
Design margin	3.0 dB

Parameters	Uplink
Carrier frequency	30 GHz
VSAT diameter	1.8 m
VSAT transmit power	3 W
Satellite beam size	0.87°
Burst data rate	4 Mb/s
Modulation	D-QPSK
Coding rate (Viterbi)	1/2
Rain margin	3.0 dB
Design margin	3.0 dB

uplink fade margins. Further fade margin, without affecting the data rate, is achieved by increasing VSAT transmit power from the nominal 3 W to 6 W (+3 dB) or to 12 W (+6 dB). The result is a 12 dB total fade margin (no reduction in information transfer rate) or up to 18 dB margin with 4 times reduction in information transfer rate. The 12 dB margin gives 99.5% annual availability (44 hr/yr outage) in Region E, or 99% worst month availability (8 hr/month) for the example in Figure D–4.

There is a corresponding variable rate demodulator on the satellite. The first thought is to have reprogrammable multichannel demodulators (MCD) which can be changed in data rate from, for example, 25 each 4 Mb/s channels to 100 each 1 Mb/s channels. However, this leads to quantization losses if MCD capacity cannot be filled. A better solution is an internally reprogrammable demodulator such that part can be 4 Mb/s channels and another part 1 Mb/s channels, with the partitions changing according to user requests.

Another item required in the VSAT is different transmit filters corresponding to the variable data rates (bandwidths) being transmitted — 4 MHz to 256 kHz. These could be switched in are required, according to

Table D–6: Case Example of Medium User: System Design Parameters

System Parameters	Uplink	Downlink
Number of Beams	28	28
Access Method	MF/TDMA	TDM
Modulation	D-QPSK	BPSK
Forward Error Correction	R-1/2 Convol.	R-1/2 Convol.
Burst/Transmission Rate	4 MSym/s	52 MSym/s
Bit Rate (Information)	4 Mb/s	52 Mb/s
Avg. No. Carriers per Beam	18	1.4
Total Number of Carriers	504	40
Beam Capacity	24-160 Mb/s	52–156 Mb/s
System Capacity	2 Gb/s	2 Gb/s

Table D–7: Uplink Fade Compensation Alternatives for Medium User

Information Transfer Rate	Additional Uplink Fade Margin				
	Uplink Burst Rate				
	4 Mb/s	2 Mb/s	1 Mb/s	512 kb/s	256 kb/s
1.0 Mb/s*	0 dB*	3 dB	6 dB	–†	–†
512 kb/s	0 dB	3 dB	6 dB	9 dB	–†
256 kb/s	0 dB	3 dB	6 dB	9 dB	12 dB

* Unfaded link condition — 1 Mb/s data rate with 4 Mb/s burst rate.
† Cannot transfer information faster than the burst rate.

data rate in use. In theory this would allow other uplink transmission(s) in the unused bandwidth. However, this could result in an imbalance between uplink and downlink capacity, since the satellite does not have excess power to allow more downlink transmissions.

D.5.2.2 Downlink Fade Compensation

Table D–8 gives the downlink fade compensation alternatives for the medium user. The downlink burst rate is normally 52 Mb/s, but can be altered for the user experiencing rain fading. Fortunately, the magnitude of the downlink rain fading is around half the number of dB's required for the uplink, and 18 dB uplink margin is equivalent in terms of availability to 9 dB downlink fade margin. As shown in the table, the downlink burst rate for the faded user is decreased by a factor of 8 to achieve 9 dB fade margin.

The requirement on the satellite modulator is that it reduce data rate by a factor of 8. The first thought is to have programmable modulators on the satellite that

can be reprogrammed. However, this leads to quantization problems as discussed for the MCDs on the uplinks. A better solution is to intersperse data rates within the downlink burst according to user time slot. For example, the downlink burst would be at the nominal 52 Mb/s for unfaded users (the first 500 time slots in the 15-ms downlink TDM frame), but would drop to 13 Mb/s for the faded users (the next 260 time slots).

The VSAT demodulator would need to be able to lock up on and detect the lower rate part of the downlink burst.

D.5.3 Large User Fade Compensation

Large users will have beacon-monitoring fade detection systems. Large users already have a data transfer rate equal to the uplink burst rate (4 Mb/s) and thus can only drop back in information transfer rate to improve link margin. They may be able to increase transmit power.

The recommended approach is a 3 dB or 6 dB increase in ground terminal power for the uplink, plus data

Table D–8: Downlink Fade Compensation Alternatives for Medium User

Information Transfer Rate	Additional Downlink Fade Margin			
	Downlink Burst Rate			
	52 Mb/s	26 Mb/s	13 Mb/s	6.5 Mb/s
1.0 Mb/s*	0 dB*	3 dB	6 dB	9 dB

* Unfaded link — 1 Mb/s data rate with 52 Mb/s burst rate.

rate reductions of up to 32 times (4 Mb/s, to 2 Mb/s, to 1 Mb/s, to 512 kb/s, to 256 kb/s, to 128 kb/s) on both uplinks and downlinks for a further 15 dB fade margin.

sensitivity and reaction time of the compensation system.

D.6   Technology Developments

A number of technology developments are required in order to provide rain fade compensation at Ka-band. The experience gained with the NASA ACTS satellite (1993 launch) will indicate further technology requirements.

Fade monitor beacon systems that are low cost and suitable for VSATs should be developed. Distinction should be able to be made between rain fade and other problems such as mispointing. Tradeoffs should be done between what is on the satellite and what is on the ground, and where the sensing of the fade is accomplished. Rain fade sensing and compensation systems should not have a significant price impact on VSATs estimated to be in the $20,000 to $50,000 price range.

Network Control Software that coordinates rain fade compensation requests over the spatial distribution of users must be developed.

Variable rate modulators for ground terminals ranging from 64 kb/s to 1 Mb/s, and from 128 kb/s to 4 Mb/s by powers of two are required.

Programmable MCDs (multiple carrier demodulators) on the satellite should be able to be partitioned "on the fly" such that part of their capacity is at one data rate and other parts are at different data rates.

ACTS Experiments should be carried out to better estimate minimum clear weather margins required for operation with various rain fade compensation techniques. The margin must be adequate to allow the rain fade to be reliably sensed within the

Appendix E

Link Budgets

This appendix gives the link budgets used for the satellite design summarized in Table 4-1 and shown in Figure 4-12. The Mesh VSAT satellite uses on-board regeneration and switching. Link budgets are given for uplinks and downlinks, for 1.8 m and 3 m user terminals. The larger terminal is required if the user is located in a "severe" rain region (Regions D-3 or E) and/or the user needs high availability.

There are six link budget calculation tables:

Fig. E-1: Uplink Budget: 1.8 m diameter VSAT, 4 Mb/s, 98% Availability in Region E

Fig. E-2: Uplink Budget: 1.8 m diameter VSAT, 4 Mb/s, 99% Availability in Region E

Fig. E-3: Uplink Budget: 3 m diameter VSAT, 4 Mb/s, 99% Availability in Region E

Fig. E-4: Uplink Budget: 3 m diameter VSAT, 4 Mb/s, 99.5% Availability in Region E

Fig. E-5: Downlink Budget: 1.8 m diameter VSAT, 99% Availability in Region E

Fig. E-6: Downlink Budget: 3 m diameter VSAT, 99.5%+ Availability in Region E

Parameter	Link Analysis Value Units		Link Data Value Units		Remarks
Carrier Frequency			29.75	GHz	Uplink, VSAT to S/C
VSAT Transmit Power	14.17	dBW	**26.1**	**W**	
Line Loss	1.00	dB			
VSAT Antenna Gain	52.77	dBi			
VSAT Antenna Diameter			**1.80**	**m**	70.9 in
Antenna Efficiency			60	%	
EIRP	65.93	dBW			
Free Space Loss	213.52	dB			
Range			38,000	km	
VSAT Pointing Loss	1.00	dB			
Atmosphere Loss	0.60	dB			
Rain Margin	**3.10**	**dB**	**98.00**	**%**	**Availability in Rain Region E**
Net Path Loss	218.22	dB			
S/C Antenna EOC Gain	32.61	dBi			**4 beams cover CONUS**
S/C Antenna Diameter			0.29	m	11.4 in
Antenna Efficiency			60	%	
Line Loss	1.00	dB			
System Temp. @ Rcvr. Input	26.80	dB-K	479	K	
S/C Antenna Temp.			280	K	
Receive Line Temp.			130	K	
S/C Receiver Temp.			230	K	Noise Figure = 2.5 dB
Effective G/T	4.80	dB/K			
Received Carrier Level			-120.67	dBW	Flux = -101.4 dBW/m^2
Boltzmann's Constant	-228.60	dBW/Hz-K			
Received C/No	81.12	dB-Hz			
Data Rate	66.02	dB-Hz	**4.00**	**Mb/s**	
Interference Degradation	1.80	dB			C/I = 16.0 dB
Modem Implementation Loss	1.50	dB			
Coding Gain	5.50	dB			**Viterbi coding, R=1/2 soft decision**
Available Eb/No	17.30	dB			
Required Eb/No	14.30	dB	**1E-08**	**BER**	**D-QPSK**
Margin	3.00	dB			

UPLINK (COMSAT)	**98.00 %**	**Availability,**		**175 hr/yr outage**
	4.000 Mb/s	**Data rate**		
VSAT parameters:	**1.80 m**	**VSAT diameter**		
	26.1 W	**VSAT transmit power**		

Figure E–1: Uplink Budget: 1.8 m diameter VSAT, 4 Mb/s, 98% Availability in Region E

Parameter	Link Analysis Value Units		Link Data Value Units		Remarks
Carrier Frequency			29.75	GHz	Uplink, VSAT to S/C
VSAT Transmit Power	17.57	dBW	**57.1**	**W**	
Line Loss	1.00	dB			
VSAT Antenna Gain	52.77	dBi			
VSAT Antenna Diameter			**1.80**	**m**	70.9 in
Antenna Efficiency			60	%	
EIRP	69.33	dBW			
Free Space Loss	213.52	dB			
Range			38,000	km	
VSAT Pointing Loss	1.00	dB			
Atmosphere Loss	0.60	dB			
Rain Margin	**6.50**	**dB**	**99.00**	**%**	**Availability in Rain Region E**
Net Path Loss	221.62	dB			
S/C Antenna EOC Gain	32.61	dBi			**4 beams cover CONUS**
S/C Antenna Diameter			0.29	m	11.4 in
Antenna Efficiency			60	%	
Line Loss	1.00	dB			
System Temp. @ Rcvr. Input	26.80	dB-K	479	K	
S/C Antenna Temp.			280	K	
Receive Line Temp.			130	K	
S/C Receiver Temp.			230	K	Noise Figure = 2.5 dB
Effective G/T	4.80	dB/K			
Received Carrier Level			-120.67	dBW	Flux = -101.4 dBW/m^2
Boltzmann's Constant	-228.60	dBW/Hz-K			
Received C/No	81.12	dB-Hz			
Data Rate	66.02	dB-Hz	**4.00**	**Mb/s**	
Interference Degradation	1.80	dB			C/I = 16.0 dB
Modem Implementation Loss	1.50	dB			
Coding Gain	5.50	dB			**Viterbi coding, R=1/2 soft decision**
Available Eb/No	17.30	dB			
Required Eb/No	14.30	dB	**1E-08**	**BER**	**D-QPSK**
Margin	3.00	dB			

UPLINK (COMSAT)	**99.00 %**	**Availability,**	**88 hr/yr outage**
	4.000 Mb/s	**Data rate**	
VSAT parameters:	**1.80 m**	**VSAT diameter**	
	57.1 W	**VSAT transmit power**	

Figure E–2: Uplink Budget: 1.8 m diameter VSAT, 4 Mb/s, 99% Availability in Region E

Parameter	Link Analysis Value Units	Link Data Value Units	Remarks
Carrier Frequency		29.75 GHz	Uplink, VSAT to S/C
VSAT Transmit Power	13.14 dBW	**20.6 W**	
Line Loss	1.00 dB		
VSAT Antenna Gain	57.20 dBi		
VSAT Antenna Diameter		**3.00 m**	118.1 in
Antenna Efficiency		60 %	
EIRP	69.34 dBW		
Free Space Loss	213.52 dB		
Range		38,000 km	
VSAT Pointing Loss	1.00 dB		
Atmosphere Loss	0.60 dB		
Rain Margin	**6.50 dB**	**99.00 %**	**Availability in Rain Region E**
Net Path Loss	221.62 dB		
S/C Antenna EOC Gain	32.61 dBi		**4 beams cover CONUS**
S/C Antenna Diameter		0.29 m	11.4 in
Antenna Efficiency		60 %	
Line Loss	1.00 dB		
System Temp. @ Rcvr. Input	26.80 dB-K	479 K	
S/C Antenna Temp.		280 K	
Receive Line Temp.		130 K	
S/C Receiver Temp.		230 K	Noise Figure = 2.5 dB
Effective G/T	4.80 dB/K		
Received Carrier Level		-120.66 dBW	Flux = -101.3 dBW/m^2
Boltzmann's Constant	-228.60 dBW/Hz-K		
Received C/No	81.13 dB-Hz		
Data Rate	66.02 dB-Hz	**4.00 Mb/s**	
Interference Degradation	1.80 dB		C/I = 16.0 dB
Modem Implementation Loss	1.50 dB		
Coding Gain	5.50 dB		**Viterbi coding, R=1/2 soft decision**
Available Eb/No	17.31 dB		
Required Eb/No	14.30 dB	**1E-08 BER**	**D-QPSK**
Margin	3.01 dB		

UPLINK (COMSAT)	99.00 %	Availability,	88 hr/yr outage
	4.000 Mb/s	Data rate	
VSAT parameters:	3.00 m	VSAT diameter	
	20.6 W	VSAT transmit power	

Figure E–3: Uplink Budget: 3 m diameter VSAT, 4 Mb/s, 99% Availability in Region E

Parameter	Link Analysis Value Units		Link Data Value Units		Remarks
Carrier Frequency			29.75	GHz	**Uplink, VSAT to S/C**
VSAT Transmit Power	18.23	dBW	**66.5**	**W**	
Line Loss	1.00	dB			
VSAT Antenna Gain	57.20	dBi			
VSAT Antenna Diameter			**3.00**	**m**	118.1 in
Antenna Efficiency			60	%	
EIRP	74.43	dBW			
Free Space Loss	213.52	dB			
Range			38,000	km	
VSAT Pointing Loss	1.00	dB			
Atmosphere Loss	0.60	dB			
Rain Margin	**11.60**	**dB**	**99.50**	**%**	**Availability in Rain Region E**
Net Path Loss	226.72	dB			
S/C Antenna EOC Gain	32.61	dBi			**4 beams cover CONUS**
S/C Antenna Diameter			0.29	m	11.4 in
Antenna Efficiency			60	%	
Line Loss	1.00	dB			
System Temp. @ Rcvr. Input	26.80	dB-K	479	K	
S/C Antenna Temp.			280	K	
Receive Line Temp.			130	K	
S/C Receiver Temp.			230	K	Noise Figure = 2.5 dB
Effective G/T	4.80	dB/K			
Received Carrier Level			-120.67	dBW	Flux = -101.4 dBW/m^2
Boltzmann's Constant	-228.60	dBW/Hz-K			
Received C/No	81.12	dB-Hz			
Data Rate	66.02	dB-Hz	**4.00**	**Mb/s**	
Interference Degradation	1.80	dB			C/I = 16.0 dB
Modem Implementation Loss	1.50	dB			
Coding Gain	5.50	dB			**Viterbi coding, R=1/2 soft decision**
Available Eb/No	17.30	dB			
Required Eb/No	14.30	dB	**1E-08**	**BER**	**D-QPSK**
Margin	3.00	dB			

UPLINK (COMSAT)	**99.50 %**	**Availability,**		**44 hr/yr outage**
	4.000 Mb/s	**Data rate**		
VSAT parameters:	**3.00 m**	**VSAT diameter**		
	66.5 W	**VSAT transmit power**		

Figure E–4: Uplink Budget: 3 m diameter VSAT, 4 Mb/s, 99.5% Availability in Region E

Parameter	Link Analysis Value Units	Link Data Value Units	Remarks
Carrier Frequency		19.95 GHz	**Downlink, S/C to VSAT**
S/C Transmit Power	14.77 dBW	**30.0 W**	Power per channel
Line Loss	1.00 dB		
S/C Antenna EOC Gain	40.40 dBi		**1.0 deg. beam (24 over CONUS)**
S/C Antenna Diameter		1.06 m	41.7 in
Antenna Efficiency		60 %	
EIRP	54.17 dBW		
Free Space Loss	210.04 dB		
Range		38,000 km	
VSAT Pointing Loss	0.50 dB		
Atmosphere Loss	0.40 dB		
Rain Margin	**3.10 dB**	**99.00 %**	**Availability in Rain Region E**
Net Path Loss	214.04 dB		
VSAT Antenna Gain	49.30 dBi		
VSAT Diameter		**1.80 m**	70.9 in
Antenna Efficiency		60 %	
Line Loss	1.00 dB		
System Temp. @ Rcvr. Input	25.04 dB-K	319 K	
VSAT Antenna Temp.		100 K	
Receive Line Temp.		290 K	
VSAT Receiver Temp.		180 K	Noise Figure = 2.1 dB
Effective G/T	23.26 dB/K		
Received Carrier Level		-111.58 dBW	Flux = -112.4 dBW/m^2
Boltzmann's Constant	-228.60 dBW/Hz-K		
Received C/No	91.98 dB-Hz		
Data Rate	78.33 dB-Hz	68.00 Mb/s	
Interference Degradation	1.80 dB		C/I = 16.0 dB
Modem Implementation Loss	1.50 dB		
Coding Gain	5.70 dB		**Viterbi coding, R=1/2 soft decision**
Available Eb/No	16.05 dB		
Required Eb/No	13.06 dB	**1E-10 BER**	**QPSK**
Margin	**2.99 dB**		

DOWNLINK (COMSAT)	**99.00 %**	**Availability,**	**88 hr/yr outage**
	68 Mb/s	**Data rate**	
	30.00 W	**S/C power per channel**	
	720 W	**Total S/C RF transmit power (24 channels)**	
VSAT parameters:	**1.80 m**	**VSAT diameter**	

Figure E–5: Downlink Budget: 1.8 m diameter VSAT, 99% Availability in Region E

Parameter	Link Analysis Value Units	Link Data Value Units	Remarks
Carrier Frequency		19.95 GHz	**Downlink, S/C to VSAT**
S/C Transmit Power	14.77 dBW	**30.0 W**	Power per channel
Line Loss	1.00 dB		
S/C Antenna EOC Gain	40.40 dBi		**1.0 deg. beam (24 over CONUS)**
S/C Antenna Diameter		1.06 m	41.7 in
Antenna Efficiency		60 %	
EIRP	54.17 dBW		
Free Space Loss	210.04 dB		
Range		38,000 km	
VSAT Pointing Loss	0.50 dB		
Atmosphere Loss	0.40 dB		
Rain Margin	**5.70 dB**	**99.50 %**	**Availability in Rain Region E**
Net Path Loss	216.64 dB		
VSAT Antenna Gain	53.73 dBi		
VSAT Diameter		**3.00 m**	118.1 in
Antenna Efficiency		60 %	
Line Loss	1.00 dB		
System Temp. @ Rcvr. Input	25.04 dB-K	319 K	
VSAT Antenna Temp.		100 K	
Receive Line Temp.		290 K	
VSAT Receiver Temp.		180 K	Noise Figure = 2.1 dB
Effective G/T	27.69 dB/K		
Received Carrier Level		-109.74 dBW	Flux = -115.0 dBW/m^2
Boltzmann's Constant	-228.60 dBW/Hz-K		
Received C/No	93.82 dB-Hz		
Data Rate	78.33 dB-Hz	68.00 Mb/s	
Interference Degradation	1.80 dB		C/I = 16.0 dB
Modem Implementation Loss	1.50 dB		
Coding Gain	5.70 dB		**Viterbi coding, R=1/2 soft decision**
Available Eb/No	17.89 dB		
Required Eb/No	13.06 dB	**1E-10 BER**	QPSK
Margin	**4.83 dB**		

DOWNLINK (COMSAT)	**99.50 %**	**Availability,**	**44 hr/yr outage**
	68 Mb/s	**Data rate**	
	30.00 W	**S/C power per channel**	
	720 W	**Total S/C RF transmit power (24 channels)**	
VSAT parameters:	**3.00 m**	**VSAT diameter**	

Figure E–6: Downlink Budget: 3 m diameter VSAT, 99.5%+ Availability in Region E

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Appendix F

Technology Requirements for Mesh VSAT Applications[†]

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Abstract

This paper first examines the trends and the roles of VSAT services in the year 2010 time frame based on an overall network and service model for that period. An estimate of the VSAT traffic is then made and the service and general network requirements are identified.

In order to accommodate these traffic needs, four satellite VSAT architectures based on the use of fixed or scanning multibeam antennas in conjunction with IF switching or on-board regeneration and baseband processing are suggested. The performance of each of these architectures is assessed and the key enabling technologies are identified.

1 Introduction

Traditional VSAT service capitalizes on point-to-multipoint applications, and has proven to be very attractive from both utilitarian and economic viewpoints. Such services naturally make use of a Star network architecture, where all communications are distributed from, or collected to, a common earth-based node. The satellite can be a simple repeater, with conventional C or Ku-band, CONUS-coverage payloads meeting the requirements very well.

Future VSAT design must be low cost, flexible, highly secure, and capable of supporting new or enhanced virtual high-speed services. In addition, future VSAT networks are expected to serve as redundant or backup to terrestrial facilities for disaster recovery and to reduce vulnerability to network failures or sabotage, which will be increasing threats in the future.

Accordingly, the concept of a mesh configuration consisting of smaller and less expensive ground terminals coupled with a cost effective payload offers a possible solution. This involves the combined use of higher frequency band for bandwidth, multibeam antennas for stronger signal amplification, and intelligent on-board processor for versatility in the establishment of the transmission links.

2 Network and Service Environment, Year 2000 and Beyond

The potential of VSAT applications into the 21st century will depend on the suitability of satellites in the communications network and service environment of that time period. Based on the projected user's needs, some general network and service features emerge:

- High speed switched services, not available today, will become widespread in the early 2000;

- Minimum average terminal speeds will be higher;

- Services will be more diverse and sophisticated;

- Connectivity needs will vary with user applications.

2.1 VSAT Trends

A common characteristic of VSAT users is that they have a need for bursty data transmissions. These are short bursts of data transmitted at random intervals from remote sites back to central locations. In addition, many require broadcast updates of files from the central site to all remote locations. This type of traffic lends itself to satellite technology and is typical of many industries.

Specifically, the current VSAT niche market can be divided into two generic categories:

1. One way broadcast distribution. This market is typically represented by the distribution of training information, corporation announcements, inventory updates, etc. This is a relatively stable segment with limited demand for additional use.

2. Two way interactive data. This market covers interactive communications from branch locations to the central site. The typical usage is a retail chain doing "on-line" inventory management and ordering via satellite between point-of-sale devices and central mainframe.

The future VSAT services will be influenced by the evolution of the current satellite technology and other emerging technologies such as mobile communications and fiber optics. Through technological innovation, satellite VSAT services can be made more versatile and economical. Some desirable features/capabilities for the future VSAT network are as follows:

a. Must be economically feasible for a wide range of network sizes varying from 50 to 10,000 nodes.

b. Support a wide variety of bandwidth needs, ranging from low volume data distribution to multiple applications in a real-time environment.

c. Offer performance improvements as well as cost savings.

d. Future cost containment is as important as cost savings.

e. Must support the ever increasing burst bandwidth demands for higher end applications because LAN-WAN interconnectivity requirements will increase in number and in bandwidth.

f. Will be used as an integral part of marketing distribution and support operations of increasingly automated corporation.

g. Capable of handling multi-protocol interconnectivity, integrated applications and services, business TV, and network reconfigurability.

h. Must be compatible with ISDN standards and services.

i. Must be cost competitive with the evolving expanded and augmented array of terrestrial services including the leased line and high speed switched data services.

j. Must offer the availability required by user. Must gracefully degrade service quality in times of link stress.

2.2 Traffic Projections

An estimate of the VSAT traffic in the Year 2010 time frame is made based on three service categories:

Traditional. This service offers simple point to multipoint data distribution.

Enhanced. This service category handles communications plus processing and control enhancements such as protocol processing and compatibility, network management, business TV, and some integrated service applications.

Future. This service category includes shared-use inter-enterprise networks to allow electronic data interchange for direct paperless entry from one corporation to another; image networking and distribution to revolutionize the office automation and information handling activities; ISDN, satellite-terrestrial integrated networks, mobile VSAT, and global interconnectivity.

Traffic projections for year 2010 in the U. S. show that the expected number of VSAT terminals at Ku-band is around

250,000. The projected number of Ka-band VSAT terminals in the same time frame is slightly less, at about 200,000 terminals. Of the all the VSAT terminals, 30% will have transmission requirements from 16 to 384 kb/s, another 30% from 384 to 768 kb/s, another 30% from 768 kb/s to 2 Mb/s, and the remaining 10% from 2 Mb/s to 4 Mb/s.

2.3 Service Requirements

VSAT service requirements include voice services, data access and distribution, image networking and distribution, LAN–WAN connectivity, ISDN and BISDN services, video conferencing, and video distribution. These services have widely differing characteristics as to data rate, performance requirements, utilization factors, type of switching, etc. Therefore, it is important for an advanced VSAT system design to be flexible enough to accommodate a wide variety in service characteristics.

2.4 General Network Requirements

General network requirements are for a full mesh point-to-point and point-to-multipoint systems at Ku-band and Ka-band. Data rates range from 16 kb/s to 4.096 Mb/s with VSAT size ideally as small as possible but not to exceed 2.4 m diameter. Traffic type could be either circuit switched or packet switched and the system should be flexible enough to accommodate both types in an economical manner.

With these general network requirements in mind, the next section presents alternate satellite architectures that would be suitable for advanced mesh VSAT networks.

3 Satellite Architectures

Suitable satellite architectures for mesh VSAT networks will very likely employ a spot beam coverage pattern to achieve the high uplink gain and downlink EIRP required for mesh connectivity between small aperture terminals. In this section, four different architectures that employ spot beam coverage are presented and described. The four architectures differ in their complexity and their flexibility to accommodate various user requirements.

Architecture 1 is a fixed multibeam architecture with bent pipe connectivity between uplink and downlink beams established through a reconfigurable static IF switch similar to the one studied by Bruno and Welti[†].

Architecture 2 adds on-board regeneration and forward error correction functions to Architecture 1 to improve the communication link performance, but does not include any on-board processing of baseband signals.

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† R. Bruno and G. Welti, "A Satellite System Concept for Fully-Meshed VSAT Networks", Stanford Telecom Report, June 1990.
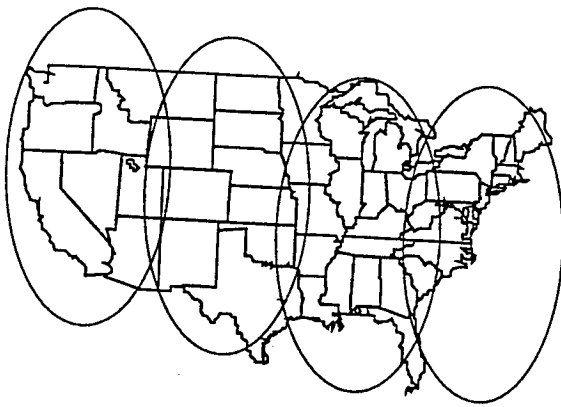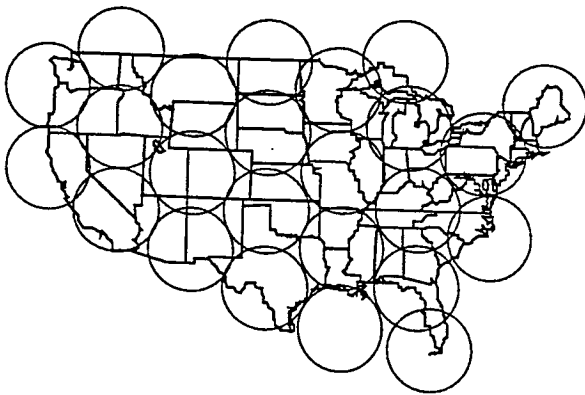
Figure 1: Uplink Beam Coverage

Figure 2: Downlink Beam Coverage

Architecture 3 employs the same fixed spot beam coverage pattern as Architectures 1 and 2, but includes on-board baseband processing functions such as switching, retiming, and multiplexing. This results in more complexity on-board the satellite but offers added flexibility and improvement in link performance.

Architecture 4 represents a departure from the fixed beam coverage patterns of the other architectures by using very narrow hopping beam coverage which results in higher gains at the expense of TDMA operation at the earth stations.

3.1 Architecture 1

Architecture 1 provides CONUS regional coverage via 4 elliptical uplink and 24 downlink spot beams (Figures 1 and 2).

Connectivity between uplink and downlink beams is maintained by a static IF switch configuration which allows a flexible allocation of bandwidth for a given uplink-to-downlink connection up to the downlink beam bandwidth capacity. This allocation is done in increments of 20 MHz at Ka-band. For each uplink beam, there will be 24 fixed allocations each corresponding to one of the downlink beams.

For each downlink beam, there will be at least 4 fixed allocations corresponding to each one of the four uplink beams. Assuming a total useful bandwidth capacity of 960 MHz per beam at Ka-band, this fixed allocation utilizes half the available bandwidth for each system. The other half is flexibly allocated among those spot beams with higher traffic requirements and the allocation can be changed as the traffic requirements change.

Because uplink-to-downlink connectivity is implemented through frequency channelization, stations that wish to simultaneously communicate with several other stations in different downlink beams will have to transmit multiple carriers, with at least one carrier for each downlink beam to which there is traffic. This is particularly unsuitable for broadcast mode (point-to-multipoint) transmissions since a station may have to duplicate its transmission on up to 24 carriers, hence requiring more equipment and utilizing more bandwidth.

A functional block diagram of Architecture 1 is shown in Figure 3. It consists of the receive antenna, LNA and downconverter, input demultiplexer, a reconfigurable static IF switch, output multiplexers, up convertor and SSPA's, and downlink spot beam antennas. The IF switch acts as a space switch connecting uplink channels from the four uplink beams with downlink channels in the 24 downlink beams. Some of the interconnections are reconfigurable through ground command while others are fixed to connect each uplink to every one of the downlink beams.

Since this architecture involves a frequency translation receiver which does not include any on-board processing functions, a station which has traffic for a number of downlink beams will have to access each beam at a different frequency. Satellite channel access can be either through frequency division multiple access (FDMA), time division multiple access (TDMA), or multi-frequency time division multiple access (MF/TDMA).

FDMA access is more suited for this architecture. The VSAT uses frequency synthesized oscillators to transmit a continuous carrier at the uplink frequency which corresponds to the desired destination beam. SCPC is a form of FDMA where carriers are generally at a low basic rate (e.g. 64 kb/s) and carry a single channel. Each carrier will be active for the duration of a call and the actual transmission frequency could be demand assigned. It is likely that the station will have traffic requirements to several beams simultaneously, in which case it has to transmit multiple carriers. For this reason, single channel per carrier (SCPC) FDMA seems to be the preferred channel access method.

3.2 Architecture 2

Architecture 2 uses the same fixed multibeam coverage and a reconfigurable static IF switch to achieve uplink to downlink beam connectivity through frequency channelization. However, it differs from Architecture 1 by including an on-board regeneration package and on-board forward error
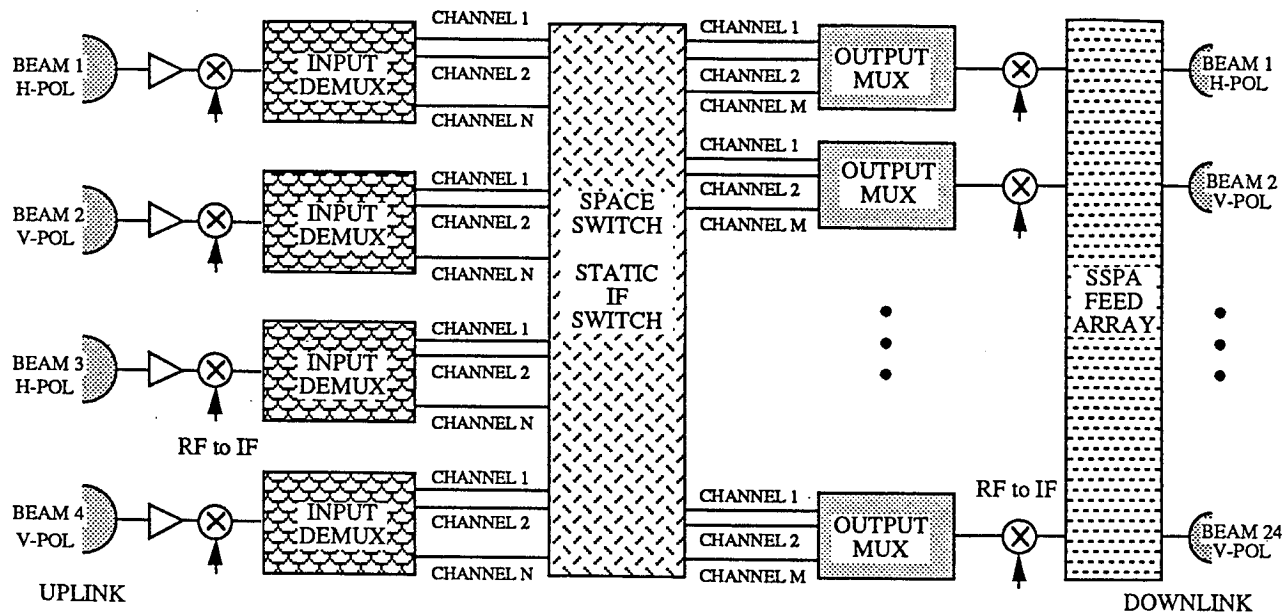
Figure 3: Architecture 1 Uses Static IF Switch to Establish Connectivity

correction (FEC) to improve the link parameters. It does not include baseband switching or retiming, although it does provide rate conversion between the uplink FDMA carriers and downlink TDM carriers through multi-carrier demodulation.

A functional block diagram of Architecture 2 is shown in Figure 4. A multi-carrier demodulator unit is assigned to each of the uplink frequency channels in the four uplink beams. The MCD unit also includes a shared soft decision FEC decoder. The MCD/FEC unit output TDM stream is FEC encoded and modulated by the on-board modulator units on a QPSK carrier at IF. The IF TDM carriers are then switched by the reconfigurable IF switch matrix, which is identical to the one in Architecture 1, to the downlink frequency slots. Hence, earth stations in the downlink beams receive a single TDM carrier in each frequency slot.

The use of on-board regeneration in Architecture 2 provides for some improvement in the link performance compared to a bent pipe receiver. This improvement could be two fold, in the form of an increase in the overall link performance due to the separation of uplink noise from the downlink noise, and in the form of better rain margins and hence availability since uplink fades are not reflected on the downlink as downlink fades. On-board regeneration also allows the independent optimization of the uplink and downlink transmissions. This includes using different FEC rates and possibly modulation formats on the uplink and the downlink to achieve the best overall link performance.

Due to the fact that an IF switch is still utilized, this architecture does not have all the flexibility that an architecture with on-board baseband switching can provide. Uplink access still has to be in FDMA mode and a station with simultaneous traffic requirements for several downlink beams will have to transmit at different carrier frequencies. Stations receiving traffic from different uplink beams will also have to do so at different carrier frequencies although

the number of downlink carriers is substantially reduced by using the TDM downlinks.

Finally, the improvement in link performance due to on-board regeneration allows higher transmission rates on the uplink compared to Architecture 1. Hence, uplink access can be either SCPC/FDMA or TDM/FDMA. Multi-frequency TDMA can also be used although the practical limit imposed on the TDMA carrier rates may limit the usefulness of this access method. In either case, a demand assigned system remains the best approach.

3.3 Architecture 3

This architecture also employs the same beam coverage pattern used with Architectures 1 and 2. However, it differs from the previous two architectures by employing an on-board baseband processor which performs on-board regeneration, including FEC, switching, and rate conversion. The use of on-board baseband processing and switching increases interconnection flexibility, and allows earth stations in any uplink beam to communicate with earth stations in any downlink beam while transmitting and receiving only a single carrier. A functional block diagram of Architecture 3 is shown in Figure 5.

The use of a baseband switch also allows for a more efficient implementation of multicast functions. The earth station access method can now be MF/TDMA where a group of VSAT's in the same uplink beam with low traffic requirements can share the use of a low bit rate (e. g. 4 Gb/s) TDMA carrier. VSAT's with higher traffic requirements can transmit their multiplexed traffic on a single TDM carrier of the same rate as the TDMA carriers.

In addition to the improvement in link parameters due to on-board regeneration, this architecture provides single carrier transmission for all VSAT's up to an aggregate rate equal to the TDMA carrier rates. An earth station with traf-
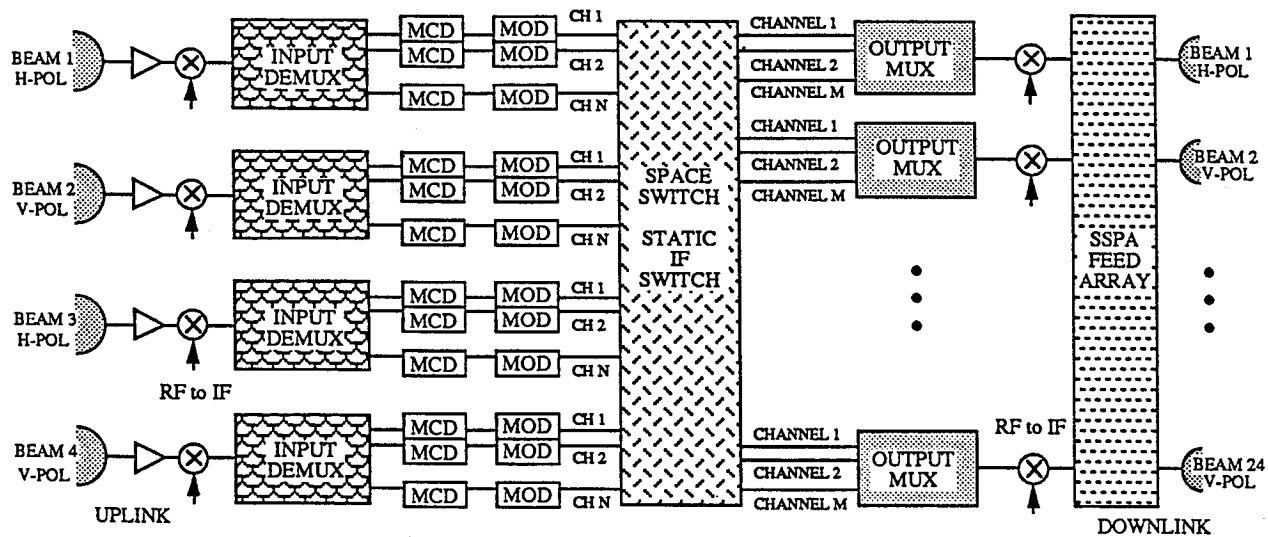
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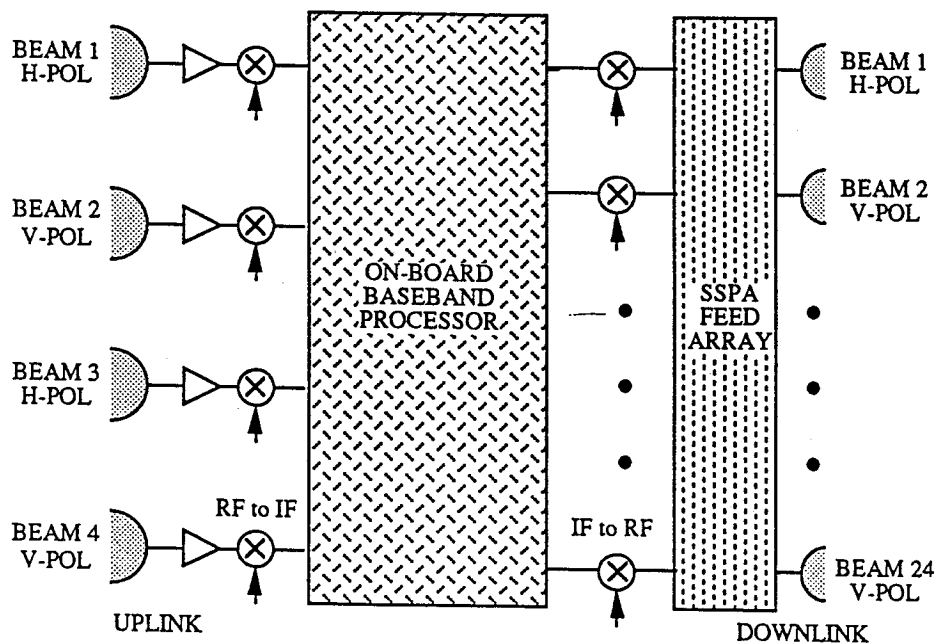Figure 4: Architecture 2 Adds On-Board Regeneration

Figure 5: Architecture 3 Uses On-board Regeneration and Baseband Switching

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fic to several destination stations in a number of downlink beams can multiplex its traffic on a single carrier. The on-board baseband processor demodulates, demultiplexes, and switches the traffic to its downlink destinations. Downlink traffic to each beam is multiplexed on a single TDM carrier which is received by all stations in that particular beam.

Another enhancement that this architecture provides is the ability to accommodate low duty cycle packet switched traffic, such as is normally the case with connectionless packet traffic.

3.4 Architecture 4

Architecture 4 employs narrow hopping beams on the uplink and downlink to achieve even higher satellite receiver gains and transmit power. The beam coverage for Architecture 4 consists of 100 narrow spot beams covering the continental United States. There are 10 uplink scanning beams and 10 downlink scanning beams, each with 10 dwell positions for a total of 100 positions.

Due to the high gain and transmit power that result from the narrow spot beam coverage, VSAT transmission rates can approach tens of Mb/s. However due to the hopping beam nature of the coverage, VSAT's must transmit in TDMA mode during beam dwell time. The on-board processor routes the traffic to its destination downbeams and multiplexes it on downlink TDM carriers which are received in burst mode by the destination stations. Beam dwell times on both the uplink and downlink can be adjusted to accommodate the variations in traffic requirements among different spot coverage regions.

A variation on this architecture which eliminates the requirement for TDMA transmission on the uplink is to use the uplink coverage pattern for the other three architectures. The achievable uplink transmission rates will then lower. However some of the complexities associated with TDMA transmission can be eliminated.

3.5 Summary of Architectures

All four architectures presented above allow single hop connections among VSAT's due to the improvements in link parameters gained through spot beam coverage. The capability and flexibility offered by these architectures, however, vary substantially as they differ in complexity.

Table 1 presents a comparison of the four architectures. These architectures are progressively more complex designs and higher technology risks in exchange for greater satellite capacity and capability.

Architecture 1 is best suited for a low rate, demand assigned, SCPC type of system where the user requirements are mostly for thin route voice traffic and low rate data.

Architecture 2 presents an improvement in the achievable VSAT transmission rates (size, and cost) and may be more suited for users with higher traffic requirements.

Architecture 3 offers more flexibility in accommodating a variety of traffic types and rates with reduced VSAT complexity at the expense of higher on-board complexity.

Architecture 4 offers additional improvements in VSAT capabilities and transmission rates through sophisticated on-board processing functions and scanning beam technology.

Considering the year 2000 time frame, Architectures 3 and 4 present the best opportunity for significantly enhancing satellite throughput and hence reducing communication costs while allowing users flexibility in mesh VSAT connections.

4 On-Board Processor Design

As a vehicle for the identification and discussion of critical technologies, an example design is given for the on-board baseband processor. Architecture 3 is chosen since it offers a good balance in flexibility, technology risk, and user needs in the year 2000 time frame.

The on-board processor, shown in Figure 6, must efficiently interconnect traffic on the uplink beams to the downlink destination beams. The basic functions performed by the on-board processor include:

- Demultiplexing and demodulating uplink carriers,

- Processing of the demodulated data,

- Switching baseband data to its destination ports,

- Processing of the switched data for remodulation on downlink carriers, and

- Remodulating and multiplexing downlink carriers.

- Network control including monitoring and controlling the processor subsystems, processing channel requests, and allocating time or frequency slots to user terminals.

On-board baseband processor components include demodulators, input processors, routing switch, output processors, modulators, and autonomous network controller.

4.1 System Design Parameters

The Architecture 3 VSAT system design parameters are summarized in Table 2. There are 4 uplink beams that provide regional coverage of an area equal in size to the CONUS, and 24 fixed downlink spot beams provide overlapping coverage of the same area.

The access method is multi-frequency TDMA (MF-TDMA) on the uplink and TDM on the downlink. The maximum uplink transmission rate is 4 Mb/s. VSAT users with lower throughput requirements can share the low rate

Table 1: Summary of Architectures

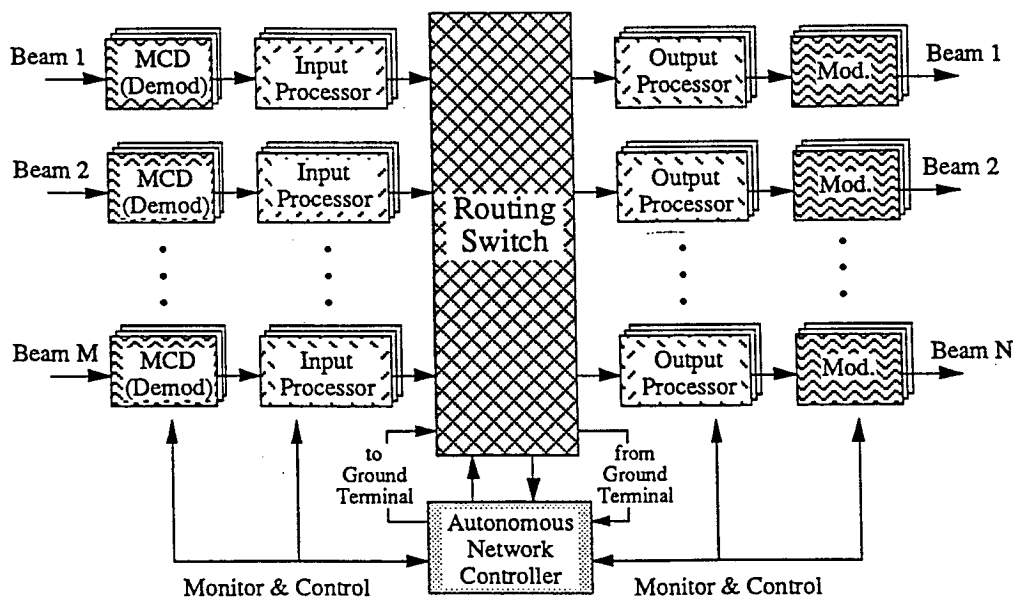|	Architecture 1	Architecture 2	Architecture 3	Architecture 4
Features:	Fixed spot beams Bent pipe IF switch FDMA SCPC access	Fixed spot beams On-board regeneration IF switch FDMA up, TDM down	Fixed spot beams On-board regeneration Baseband switch MF-TDMA, TDM	Narrow scanning beams On-board regeneration Baseband switch TDMA, TDM
Beam coverage:	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Fixed spot beams 4 elliptical, uplink 24 spots, downlink CONUS coverage	Narrow scanning beams 100 spot beam locations 10 up and 10 downlink scanning beams. CONUS coverage

Access method:	FDMA with SCPC	SCPC/FDMA or
		   TDM/FDMA uplinks
		TDM downlinks
			MF/TDMA via MCD's
			   on uplinks.
			TDM on downlinks
				TDMA up/downlinks

Connectivity:	Static IF switch
	Frequency-tunable
	   transmitters and
	   receivers.
		Static IF switch
		Freq. tunable transmit
		TDM downlinks
			Baseband switch	Baseband switch

Technologies:	Frequency tunable
	   transmitters and
	   receivers for VSAT
		Frequency tunable
		   transmitters.
		MCD
			Baseband processor
			– MCD
			– Switch
			– Controller
				Scanning multibeam ant.
				Baseband processor
				– MCD
				– Switch
				– Controller

Figure 6: On-Board Baseband Processor Configuration

Table 2: System Design Parameters

System Parameters	Uplink	Downlink
Number of Beams	4	24
Access Method	MF/TDMA	TDM
Modulation	D-QPSK	QPSK
Forward Error Corr.	R-1/2 conv.	R-1/2 conv.
Burst/Transmit Rate	4 MSym/s	68 MSym/s
Bit Rate (info)	4 Mb/s	68 Mb/s
No. Carriers/beam	100	1
Total No. of Carriers	400	24
Beam Capacity	400 Mb/s	68 Mb/s
System Capacity	1.6 Gb/s	1.6 Gb/s

TDMA carriers while users with higher throughput can use full 4 Mb/s TDM transmissions.

The multi-frequency feature of the uplink TDMA access permits more flexible and efficient sharing of the available uplink bandwidth. With this arrangement up to 100 uplink carriers can be assigned in 500 MHz bandwidth making a total uplink throughput limit of 1.6 Gb/s. On the downlink, a single TDM carrier is received by all VSATs in each downlink beam which carries all the traffic destined to that beam. The downlink TDM carrier bit rate is 68 Mb/s so that the aggregate available downlink bit rate is approximately the same as the uplink bit rate.

Because of the power limited nature of the VSAT links, rate 1/2 convolutional coding is assumed on both uplink and downlink, with on board, forward error correction, soft-decision decoding. Both uplink and downlink transmissions are QPSK. Further differential encoding on the uplink may be used to resolve carrier phase ambiguity of the uplink bursts in the on-board receiver. Differential encoding on the downlink is not needed due to the continuous nature of the downlink transmission.

4.2 Network Requirements

The system design must service the type of traffic which will be encountered in an advanced VSAT system. Requirements are to accommodate the following traffic characteristics:

- Circuit switched traffic generated by voice traffic or long data traffic with rates up to 4 Mb/s;

- Packet switched traffic with high or low duty cycles;

- Packet switched traffic of the connectionless type (datagram traffic);

- System design should be flexible enough to accommodate a wide variety of traffic types;

- Multipoint connections such as video teleconferences;

- Autonomous operation of multiple user networks.

4.3 Transmission Signal Format

The TDMA (TDM) frame structure used for uplink access has a 15 ms frame with 60 time slots (64 kb/s TDMA channels) as shown in Figure 7. Each time slot contains 1024 bits, with a 64-bit header and 960-bit information field. A 1024 bit scrambler pattern is used for each of the 64 kb/s TDMA channels. The resulting frame efficiency is 94%.

The downlink has a 15 ms TDM frame which consists of 1,000 TDM channels, each channel having the same number of bits and the same format as the uplink TDMA channels.

These TDMA and TDM frame structures accommodate circuit switched traffic at integer multiples of 64 kb/s. Lower bit rate traffic can be multiplexed in 64 kb/s channels or can be transmitted with a loss in efficiency at the 64 kb/s rate. The use of fixed length traffic packets (satellite virtual packets) results in simple uplink time slot allocation and eliminates the need for coordinated time plans.

4.4 On-Board Baseband Processor Elements

A detailed block diagram of the on-board processor is shown in Figure 8. A discussion of the processor components follows: (1) baseband routing switch, (2) input and output processors, (3) demodulators and modulators, and (4) network controller. Finally, (5) an estimate of processor mass and power consumption is given.

4.4.1 Baseband Routing Switch

The baseband routing switch is a fiber optic bus design consisting of a 1.6 Gb/s TDM optical ring which interfaces to the input and output processing units. The ring design results in a simple interface structure among the processing units. At the same time, it provides a self routing architecture with no requirement for control memory.

The bus uses a 250 μs TDM frame structure consisting of a control field for use by the autonomous network controller and 16 packet fields for use by the input processor. The control field is one packet long while the input processor field is 25 packets long corresponding to one packet from each uplink carrier assigned to the input processor. There is no contention provided that the optical bus bandwidth is greater than the uplink (input) bandwidth.

The input processor and autonomous network controller interface to the bus via an optical receiver and optical driver. The output processors interface is simply an optical receiver which allows the processor to receive all the information on the bus but process only that information destined to it. Optical switches at the interface points allow bypass or connection of any of the processing units and network control units for redundancy operation.
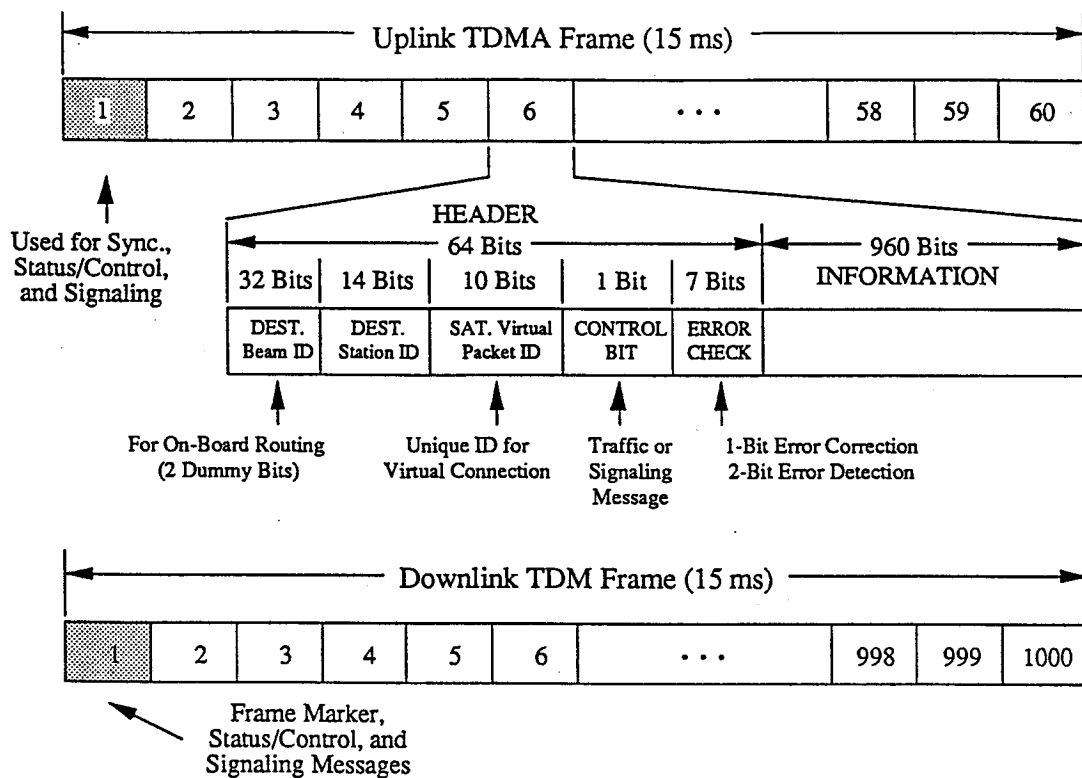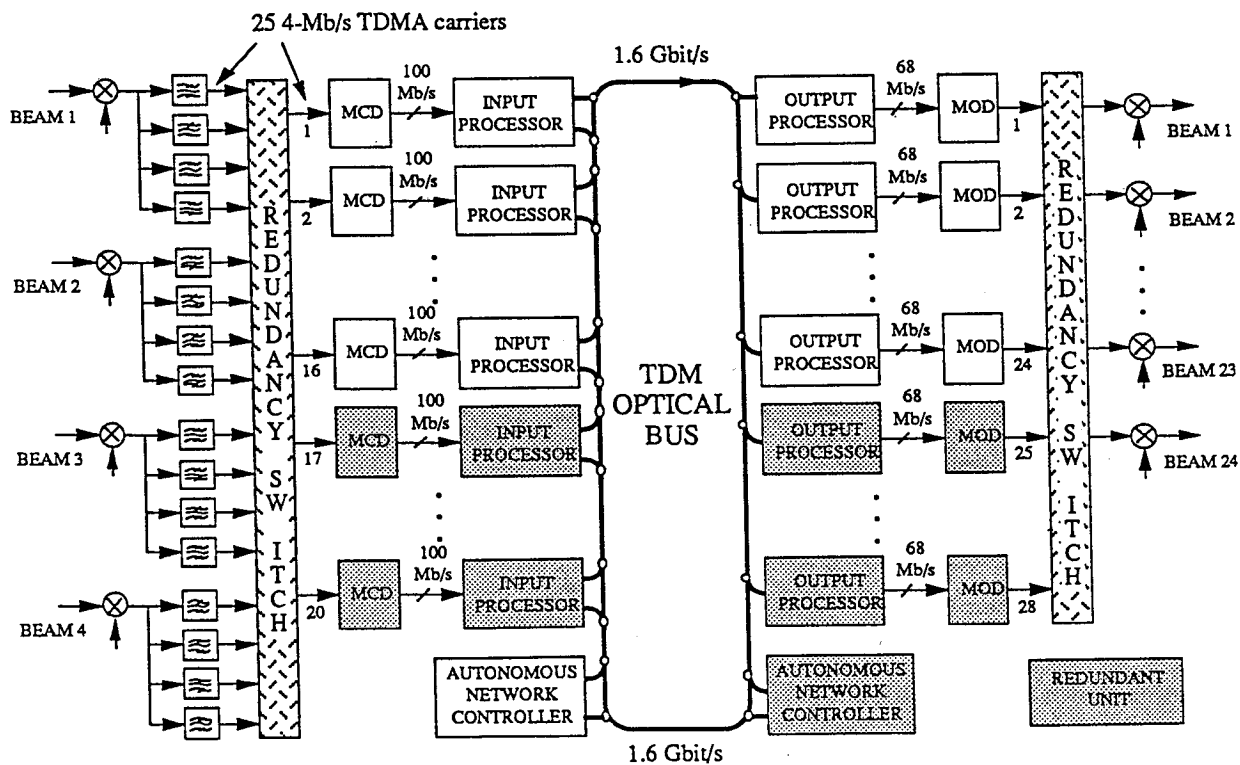
Figure 7: Uplink and Downlink Frame Structures

Figure 8: On-Board Processor Block Diagram

4.4.2 Input and Output Processors

The input processor processes the multi-carrier demodulator outputs by performing 2-bit soft-decision forward error correction decoding, packet assembly, differential decoding, descrambling and deinterleaving, header error control, and buffering. Also included in the input processor is an optical bus interface at the optical bus speed of 1.6 Gb/s. The input processor operations on the data from the MCD include TDMA or TDM burst or frame synchronization, phase ambiguity resolution, forward error correction decoding, descrambling, packet assembly for fast packet switch with MCD, and traffic channel demultiplexing.

Twenty four output processors interface to the optical bus at the same speed and perform packet address filtering, frame buffering, bit interleaving and scrambling, and FEC encoding. Each output processor transmits a 68 Mb/s TDM stream. The functions performed by the output processor are traffic channel assembly and multiplexing, TDM formatting, scrambling, and forward error correction encoding.

4.4.3 Multi-Carrier Demodulators

The use of a bit synchronous system and differential encoding for phase ambiguity resolution on the uplink substantially simplifies the design of the on-board demodulators at the expense of a negligible increase in earth station complexity.

Four multi-carrier demodulators (MCDs) are used with each uplink beam to demodulate 25 4-Mb/s carriers each. The MCD outputs comprise two-bit soft-decisions on the received channel symbols at an information bit rate of 100 Mb/s (400 Mb/s total including FEC and 2-bit quantization). The MCD outputs are then processed by the input processors.

The carrier bit rate issues include whether or not the MCD can operate with multiple bit rate carriers or whether it should operate with the same bit rate carriers, and also the reconfigurability of the MCD with changing carrier bit rates.

Whether to use a bit synchronous system or asynchronous user clocks is a key decision affecting MCD hardware complexity. In a bit synchronous system, all user clocks are synchronized to the on-board clock with an accuracy of a fraction of a symbol period, so there is no need to perform bit timing recovery on board the satellite.

The advantage of a bit synchronous system is that it does not require timing adjustments for each carrier or burst at the satellite. Hence, it eliminates the need for uplink frame synchronization at the satellite. For TDMA systems, a higher TDMA frame efficiency is achieved due to the fact that no timing synchronization preamble pattern is required. By using a fixed time slot size, simpler TDMA slot assignment is achieved. Hence, the MCD design is potentially simpler.

The disadvantage of such a system is that timing phase data storage is needed for individual carriers or TDMA bursts. In order to synchronize all uplink transmissions, uplink bit clock error measurements are needed on-board the satellite. Further, user terminals need to achieve precision transmit timing control in order to achieve and maintain bit synchronous operation.

4.4.4 Autonomous Network Controller

Network control is provided through an autonomous network controller that interfaces to the optic bus and sends control signals to the input and output processor units. The input processor units also send control signals to the controller. However the exchange of control information between the output processor units and the controller is strictly one way.

4.4.5 Mass and Power Estimates

Estimates of mass and power requirements for the on-board baseband processor design are made for implementation in 1996. The digital device technologies used are GaAs for high-speed processing, such as fiber optic interface processing, and high-density CMOS (HCMOS) for other processing functions.

The GaAs device currently offers 0.1 mW of power/gate, 50,000 usable gate density, and speeds up to 5 Gb/s. Radiation hard HCMOS, on the other hand, offers 12 μW/MHz of power/gate, 50,000 usable gate density, and a speed of up to 400 Mb/s. It is assumed that both the power consumption and gate density of these devices will further improve with a 50% reduction in power/gate by 1996.

Most processing functions can be implemented with currently available technology and are regarded as low risk. The processing units identified for new development and assumed to be developed for the purpose of this mass and power estimate are as follows: (1) low-power MCD for 25 each 4 Mb/s carriers; (2) 100-Mb/s multicarrier decoder on a single chip with 1 W power consumption; and (3) 16 K x 32 static RAM (SRAM).

Extensive development efforts are currently taking place on MCDs by a number of organizations worldwide, and it is assumed that a 25-carrier MCD with power consumption of about 20 W (using 20 LSI/ASIC devices) can be realized in the 1996 time frame.

A high speed programmable Viterbi decoder operating at above 100 Mb/s has been implemented by COMSAT Laboratories using custom add-compare-select logic. Although it currently requires several chips to implement the desired function, its single chip fabrication with power consumption of 1 W is well within the technology forecast.

Radiation hard memory technology is also expected to improve significantly in the coming years, by increasing its current size of 8 K x 8 or 16 K x 4 to 16 K x 32 or larger. The sample design conservatively assumes the availability of 16 K x 32 SRAMs. The use of larger capacity memory

chips, such as 16 K x 64, will further reduce the estimated parts count and improve reliability.

Based on the above technology assumptions, the parts counts, power consumption, and mass requirements are estimated. The sample design includes 20 MCD/input processor units (16 active and 4 backup), 28 output processor/modulator units (24 active and 4 backup), and a fully redundant autonomous network controller.

The on-board baseband processor is estimated to consume 620 W power and to have a mass of 75 kg, using technology available in 1996.

5 Technology Requirements

Technology requirements are given for the mesh VSAT application in three parts: (1) satellite antenna, (2) VSAT, and (3) on-board processor technologies.

5.1 Satellite Antenna Technology

The key satellite antenna technology is the antenna system which forms the multiple beams. It may be a multibeam or phased array design. The key design parameter is the ability to cover an area such as CONUS (5° by 3°) with 0.5° or smaller beams, with good isolation between beams in order to allow frequency reuse.

5.2 VSAT Technology

The key VSAT technologies are low-cost Ka-band RF devices, such as antennas with diameters of 0.8 m to 2.4 m, a 10-W SSPA, a low noise amplifier, an upconverter, and a downconverter. Integrated outdoor RF equipment, such as that being used in the current Ku-band VSATs, is critical in reducing user equipment cost.

Other technologies are low-cost tunable transmitters and receivers to allow flexibility in assignment of TDMA/FDMA uplink and TDMA downlink carriers, a TDMA controller operating with 4 Mb/s uplinks and 70 Mb/s downlinks, and a low-cost rain-fade detection system for Ka-band in order to allow additional rain margin to be invoked. Although these technologies are currently available in VSAT and other satellite systems, further cost reduction is necessary for the mesh VSAT services to be cost competitive.

5.3 On-Board Processor Technology

The on-board baseband processor requires the use of large-scale digital integrated circuits with high component density per chip, low power consumption, high speed operation, and adequate radiation tolerance.

Critical technologies identified are as follows:

Multi-carrier demodulator (MCD) with low power consumption is the most critical technology for the real-ization of the on-board baseband processor. In our design for the baseband switch, it consumes about twice the power of the rest of the subsystem. Intensive development effort to reduce the MCD power requirement to the range of several watts is strongly recommended.

Bit synchronous system improves frame efficiency and simplifies on-board processor design as well as network control procedures. However, the MCD is required to measure phase errors with an accuracy of a small fraction of a symbol period. It also necessitates the user terminal to perform accurate timing correction.

Alternate techniques to implement a bit synchronous system should be investigated, and a proof-of-concept model to demonstrate its feasibility should be developed.

Multi-carrier processing devices such as a multi-carrier FEC decoder, packet assembler, differential decoder, descrambler, bit deinterleaver, and packet header error controller, are critical in reducing on-board processor mass and power and increasing reliability. These processing devices have been implemented for single carrier operation in various applications, but their multicarrier versions will require development. Some of these functions may be combined and fabricated into a single custom LSI device.

Radiation hard 16 K x 32 static RAMs or larger will help reduce parts count and increase reliability. Significantly larger memory chips are currently available for commercial applications, and their space-qualified versions are expected to available in the near future.

High-speed optical bus interface to perform optical to electronic conversion, clock synchronization, multiplexing, and serial to parallel conversions needs to be developed for space applications.

Autonomous network controller performs not only conventional monitor and control functions of on-board equipment, but also network control functions such as carrier frequency and time slot assignment for uplink and downlink, time plan change coordination, on-board buffer management, and congestion control for packet data.

A detailed investigation is needed to assess feasibility of implementing these functions on board the satellite. Also, applicability of new network control and management technology, such as expert systems and neural networks, should be investigated.

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Appendix G

Cost Comparison

This appendix presents a cost comparison of three satellite system concepts developed under NASA Contract No. NAS3-25092.

Task 4: Mesh VSAT satellite system

Task 5: Integrated Video satellite system

Task 6: B-ISDN satellite system (2 concepts)

Cost assumptions, comparison tables, and cost conclusions are given. The comparison shows that the B-ISDN system has lower user costs, primarily due to its higher capacity.

G.1   Cost Assumptions and Methodology

Costing assumptions were reasonably constant over the three studies with satellite wet mass being very similar, but there being differences in end-of-life power. The following is a list of these assumptions and differences for the three concepts.

All Concepts:

- Commercial system costing (versus NASA or DoD program).
- Launch on Atlas IIAS; launch insurance at 16%.
- User costs in $/min, 1992 $; 18% return on investment.
- Develop and manufacture two satellites with contract award in 2002 and launch in 2006.
- 15-yr on-orbit life.
- Satellite design uses year 2000 technology: ion thrusters for on-orbit station keeping; advanced NiH batteries; and thin silicon solar cells.
- Satellite wet mass 1,770 kg to 1,890 kg; power 3.5 kW to 5.6 kW.
- Payloads use baseband processing and switching except B-ISDN Architecture 1.
- Ground terminal use ranges from 1 to 8 hr/day; 250 days per year.
- System utilization is assumed to be 15% for all systems except the B-ISDN Architecture 2 which has 20% utilization.

Mesh VSAT Satellite:

- Uses multi-carrier demodulators and baseband switching.

B-ISDN Satellite:

- IF Switching and no on-board processing for Architecture 1.
- Demodulation and baseband switching for Architecture 2.
- Smaller (0.4°), scanning spot beams used for Architecture 2.
- System utilization is assumed higher (20% versus 15%) for Architecture 2.

Integrated Video Satellite:

- Uses multi-carrier demodulators and baseband switching.

User costs per minute are derived from the annualized costs for the ground terminal and the space segment (satellite plus network control) costs. The user cost per minute is based on (1) the number of minutes per year utilization of the ground terminal, and (2) the proportional use of the space segment capacity by the single user. This is expressed by the formula on the "Cost Formulas" table (Table G-7).

G.2   Comparison Tables

There are eight tables which present a side-by-side comparison of the mesh VSAT, B-ISDN (2 concepts), and integrated video satellite system design concepts.

Table G-1: "Comparison of System Designs" summarizes the satellite, ground terminal, and system parameters. Note that the satellite mass is approximately the same (same launch vehicle, Atlas 2AS), but there is a 4 times difference in circuit capacity among the different concepts. The B-ISDN Architecture 2 has 0.4° spot beams versus 0.9° or larger spot beams for the other concepts.

Table G-2: "Downlink Performance Comparison" gives parameters from the downlink link budget calculations. Note the higher EIRP for the B-ISDN Architecture 2, and the use of concatenated codes with 11 dB coding gain for the two B-ISDN concepts.

Table G-3: "Uplink Performance Comparison" gives parameters from the uplink link budget calculations. Large VSATs are required for the higher data rates of the B-ISDN systems.

Table G-4: "Space plus Network Control Costs" summarize space segment costs and network control center costs, and adds them together. For comparison purposes, the bottom of the table gives the estimated total ground terminal cost based on number of ground terminals (see Table G-1) and cost of a single ground terminal (see Table G-6). The B-ISDN systems have lower total ground terminal costs

Table G-5: "Space plus Network Control Costs per Minute" is based on the data in the previous table, the total satellite capacity, and the assumed overall satellite utilization.

For example, consider the Mesh VSAT system with $216 M annual space plus NCC cost. The number of equivalent "full capacity" minutes use per year is the number of minutes in a year (525,960) times the satellite utilization (15%) or 78,894 min/yr. Dividing $216 M by this number gives $2,738/min for use of the full capacity (5.4 Gb/s). The cost per Gb/s is $507/min ($2,738/5.4), and the cost per Gb transmitted is $8.45 ($507/60, since there are 60 seconds per minute).

Table G-6: "Ground Terminal Cost Comparison" is given for the different size terminals used in the different systems. The B-ISDN terminals are more expensive due to higher data rates.

Capital costs are amortized over 15 years at 18% interest and added to O&M costs in order to obtain the annual ground terminal cost. The cost per minute operation of the ground terminal is the annual cost divided by the number of minutes used per year.

For example, the 1.8 m Mesh VSAT terminal has an annual cost of $13,500. Operation for 1 hr/day, 250 working days per year, is 15,000 minutes per year. Thus the effective ground terminal cost per minute is $0.90/min ($13,500/15,000).

Table G-7: "Cost Formulas and Values for 4 Satellite System Concepts" are given. The formula at the bottom is used to determine user cost per minute. The user $/min is composed of two terms: (1) the ground terminal cost per minute (discussed above under Table G-6), and (2) the user's pro rata share of the space segment plus NCC cost (given in Table G-4). The formulas and data in this table is used to produce the total user costs given in Table G-8.

The "minutes use per year" is for the individual user. For example, operation for 1 hr/day, 250 working days per year, is 15,000 minutes use per year.

The "User annual traffic" is the number of bits transmitted in one year. For example, 15,000 minutes per year at 4 Mb/s would be 3.6×10^{12} bits in one year.

The "Total annual traffic" for the entire system equals the system utilization, times the system capacity in bits per second, times the number of seconds in a year. For example, the Mesh VSAT system utilization is 15% and capacity is 5.4 Gb/s. Since there are 3.16×10^7 seconds per year, "Total annual traffic" is 2.56×10^{16} bits or 26 Pb.

Table G-8: "Comparison of User Costs" gives the cost per minute for different circuit sizes, for shared ground terminal use. The formulas and data from Table G-8 are used to produce the total user costs in this table.

Consider for example the Mesh VSAT system. The $4.62 cost/min is for a duplex circuit at 4 Mb/s (costs for two ground terminals plus two simplex circuits). The $9.13 cost to transmit 1 Gb is for two ground terminals and one simplex 4 Mb/s circuit (it would take 250 seconds or 4.2 minutes of terminal time).

The cost per minute for a duplex circuit include use of two ground terminals plus two simplex circuits at the designated rate. The assumed terminal use per year is 4 hours per day, 250 working days per year (1,000 hours or 60,000 minutes per year). For circuits of size smaller than nominal (i. e., less than 4 Mb/s for the Mesh VSAT system), it is assumed that the ground terminal capacity and cost are shared among multiple users. For example, two 2-Mb/s users are sharing the costs of the 4-Mb/s Mesh VSAT ground terminals.

G.3 Cost Conclusions and Drivers

It is clear from Table G-8 that the B-ISDN system, Architecture 2 in particular, has approximately 4 times lower cost than the Mesh VSAT or Integrated Video systems. One reason is the 1.33 times higher system utilization (20% versus 15%) which is justified by the argument that it is easier to share capacity with B-ISDN. However, the main reason is the much higher system capacity due to the use of small spot beams (0.4° versus 1°). This conserves satellite downlink power and allows more capacity from the same mass satellite.

A number of cost conclusions can be drawn:

- Utilization assumptions are a key cost driver.

- Sharing of circuit capacity can have a large effect on effective rates. Some concepts such as B-ISDN have greater potential for circuit sharing.

- TDMA (hopping spot beam) has better potential for making capacity available to users.

- Spot beam size is the key cost driver. Limit on spot beam size is imposed by antenna size and baseband switch size. Switch architecture to accommodate 100 inputs and 100 outputs is difficult.

- Ground terminal costs are not significant except for the smallest circuits or else when the terminal is used a small number of hours per year.

- B-ISDN performs well due to its large circuit size and small spot beams.

System cost drivers can be summarized as follows:

Costs:

- Space segment costs (only pay for capacity used).
- Ground terminal costs (share fixed yearly cost among many users).

System Utilization:

- Assumed to be 15% to 20%.

System Capacity:

- Improved by increases in spacecraft payload to orbit.
- Better bus performance for payload mass and available power.
- Payload limited by available downlink transmit power.
- Use of smaller spot beams (larger antenna and/or higher frequency) conserves downlink power and allows more capacity in same mass.
- Switch imposes connectivity limit on number of spot beams.
- Use of TDMA on downlink can lessen connectivity problem.

Table G–1: Comparison of System Designs

	Mesh VSAT	B-ISDN Arch. 1	B-ISDN Arch. 2	Integrated Video
Satellite Parameters				
Mass, wet	1,890 kg	1,860 kg	1,770 kg	1,890 kg
DC power, end-of-life	5.6 kW	5.1 kW	3.5 kW	4.3 kW
RF transmit power	1,200 W	1,280 W	480 W	640 W
Baseband switch type	FO bus	IF	Crossbar	FO bus
Baseband processor power	870 W	—	606 W	874 W
Uplink spot beam size	2°x 4°	1.6°	0.4°	0.9°
Receive antenna size	0.6 m	1.4 m	1.8 m	0.8 m
Downlink spot beam size	1°	1.6°	0.4°	0.9°
Transmit antenna size	1.1 m	2.2 m	2.7 m	1.2 m
Transmit power/channel	30 W	32 W	40 W	13 W
Channel size (space-earth)	68 Mb/s	155 Mb/s	800 Mb/s	54 Mb/s
Ground Terminal Parameters				
Number of terminals	8,000	500	2,000	10,000
Terminal size (m)	1.8 & 3 m	3.1 m	3.0 m	1.2, 1.8, 3 m
Transmit power/channel	20 to 60 W	140 W	40 W	4 to 20 W
Channel size (earth-space)	4 Mb/s	155 Mb/s	200 Mb/s	2 or 6 Mb/s
System Parameters				
Simplex circuit capacity	5.3 Gb/s	12.4 Gb/s	19.2 Gb/s	5.3 Gb/s
Utilization	15 %	15%	20%	15%

Table G–2: Downlink Performance Comparison

	Mesh VSAT	B-ISDN Arch. 1	B-ISDN Arch. 2	Integrated Video
Transmit power/channel	30 W	32 W	40 W	13 W
EIRP (edge of coverage)	40.4 dBW	50.5 dBW	63.3 dBW	51.6 dBW
Data rate	68 Mb/s	155 Mb/s	800 Mb/s	54 Mb/s
Required bit error rate	10(-10)	10(-10)	10(-10)	10(-6)
Modulation	QPSK	8PSK	8PSK	BPSK
Coding type	Viterbi	Concat.	Concat.	Viterbi
Code rate	0.50	0.78	0.78	0.50
Coding gain	5.7 dB	11.2 dB	11.2 dB	5.3 dB
Assumed C/I	16 dB	20 dB	16 dB	16 dB
Interference degradation	1.8 dB	2.0 dB	4.0 dB	1.1 dB
Modem loss	1.5 dB	2.5 dB	2.5 dB	1.0 dB
Required Eb/No	13.1 dB	16.7 dB	16.7 dB	10.5 dB
Req'd. C/No – Data rate	13.7 dB-Hz	10.5 dB-Hz	15.0 dB-Hz	10.3 dB-Hz
Rain margin (dB)	3.1 dB	1.4 dB	5.7 dB	1.4 - 5.7 dB
Availability, Region E	99%	98%	99.5%	98 to 99.5%

Table G–3: Uplink Performance Comparison

	Mesh VSAT	B-ISDN Arch. 1	B-ISDN Arch. 2	Integrated Video
VSAT diameter	1.8 & 3 m	3.1 m	3 m	1.2, 1.8, 3 m
Transmit power/channel	26 W	140 W	8-18 W	4 - 12 W
EIRP	52.8 dBW	77.5 dBW	65.1+ dBW	53.7+ dBW
Data rate	4 Mb/s	155 Mb/s	200 Mb/s	2 - 6 Mb/s
Required bit error rate	10(-8)	10(-10)	10(-10)	10(-6)
Modulation	D-QPSK	8PSK	QPSK	D-QPSK
Coding type	Viterbi	Concat.	Block	Viterbi
Code rate	0.50	0.78	0.75	0.50
Coding gain	5.5 dB	—	6.0 dB	5.3 dB
Assumed C/I	16 dB	END-	20 dB	16 dB
Interference degradation	1.8 dB	-TO-	1.0 dB	1.1 dB
Modem loss	1.5 dB	-END	2.0 dB	1.0 dB
Required Eb/No	14.3 dB	LINK	13.1 dB	13.2 dB
Req'd. C/No – Data rate	15.1 dB-Hz	—	13.1 dB-Hz	14.8 dB-Hz
Rain margin (dB)	3.1 dB	3.1 dB	3.1 - 6.5 dB	3 - 12 dB
Availability, Region E	98%	98%	98 to 99%	98 to 99.5%

Table G–4: Space plus Network Control Costs

Space Segment Costs	Mesh VSAT	B-ISDN Arch. 1	B-ISDN Arch. 2	Integrated Video
Satellites (2)	$ 560 M	$ 443 M	$ 663 M	$ 560 M
Launches (2)	$ 248 M	$ 248 M	$ 248 M	$ 248 M
TT&C support (2)	$ 15 M	$ 15 M	$ 15 M	$ 15 M
Launch insurance (16%)	$ 157 M	$ 134 M	$ 176 M	$ 157 M
	$ 980 M	$ 840 M	$ 1,102 M	$ 980 M
Annual cost (15 yr @ 18%)	$ 192 M	$ 164 M	$ 216 M	$ 192 M
Network Control Costs				
NCC capital cost	$ 100 M	$ 100 M	$ 100 M	$ 100 M
NCC annual cost	$ 20 M	$ 20 M	$ 20 M	$ 20 M
O & M annual cost	$ 4 M	$ 4 M	$ 8 M	$ 4 M
	$ 24 M	$ 24 M	$ 28 M	$ 24 M
Space plus NCC Cost				
Total annual cost	$ 216 M	$ 188 M	$ 244 M	$ 216 M
Ground Terminal Costs				
Total terminal capital cost	$ 380 M	$ 50 M	$ 160 M	$ 400 M
Total terminal annual cost	$ 114 M	$ 15 M	$ 48 M	$ 120 M

Table G–5: Space plus Network Control Costs per Minute

	Mesh VSAT	B-ISDN Arch. 1	B-ISDN Arch. 2	Integrated Video
Space plus NCC Cost				
Total annual cost (2)	$216 M	$ 188 M	$ 244 M	$ 216 M
Satellite Capacity (2)	5.4 Gb/s	12.4 Gb/s	19.2 Gb/s	5.3 Gb/s
Satellite Utilization	15%	15%	20%	15%
Cost per Gb/s per minute of use (simplex circuit)	$507/min	$192/min	$121/min	$517/min
Cost per Gb transmitted	$8.45	$3.20	$2.02	$8.62

Table G–6: Ground Terminal Cost Comparison

	Mesh VSAT	B-ISDN Arch. 1	B-ISDN Arch. 2	Integrated Video
1.2 m Terminal				
Capital cost	—	—	—	$35,000
Annual cost (plus O&M)				$10,500
Cost per minute operation				
• 1 hr/day				$0.70/min
• 8 hr/day				$0.09/min
1.8 m Terminal				
Capital cost	$45,000	—	—	$45,000
Annual cost (plus O&M)	$13,500			$13,500
Cost per minute operation				
• 1 hr/day	$0.90/min			$0.90/min
• 8 hr/day	$0.11/min			$0.11/min
3 m Terminal				
Capital cost	$55,000	$100,000	$80,000	$55,000
Annual cost (plus O&M)	$16,500	$ 30,000	$24,000	$16,500
Cost per minute operation				
• 1 hr/day	$1.10/min	$2.00/min	$1.60/min	$1.10/min
• 8 hr/day	$0.14/min	$0.25/min	$0.20/min	$0.14/min

Table G–7: Cost Formulas and Values for 4 Satellite System Concepts

	Mesh VSAT	B-ISDN Arch. 1	B-ISDN Arch. 2	Integrated Video	
Circuit size	4 Mb/s	155 Mb/s	155 Mb/s	2 Mb/s	6 Mb/s
Ground terminal size	1.8 m	3.1 m	3.0 m	1.2 m	1.8 m
Ground terminal annual $	$13,500	$30,000	$24,000	$10,500	$13,500
Space segment annual $	$216 M	$188 M	$244 M	$216 M	
System utilization	15%	15%	20%	15%	
System capacity (2 sats)	5.4 Gb/s	12.4 Gb/s	19.2 Gb/s	5.3 Gb/s	
Total annual traffic*	26 Pb	59 Pb	121 Pb	25 Pb	

* 1 Pb = 10(+15) bits

$$\text{\$/min} = \frac{\text{Ground terminal annual \$}}{\text{minutes use per year}} + \frac{\text{Space segment annual \$}}{\text{minutes use per year}} \times \frac{\text{User annual traffic}}{\text{Total annual traffic}}$$

Total annual traffic = System utilization x System Capacity x seconds/year

Table G–8: Comparison of User Costs

	Mesh VSAT	B-ISDN Arch. 1	B-ISDN Arch. 2	Integrated Video	
Circuit size	4 Mb/s	155 Mb/s	155 Mb/s	2 Mb/s	6 Mb/s
Cost/min, duplex circuit*	$4.62	$60.58	$38.24	$2.46	$6.78
Cost per Gbit transmit †	$9.13	$3.42	$2.18	$10.25	$9.42
Cost/min, duplex circuit‡					
128 kb/s	$0.14	$0.05	$0.03	$0.15	$0.14
512 kb/s	$0.58	$0.20	$0.13	$0.62	$0.57
2 Mb/s	$2.32	$0.80	$0.51	$2.46	$2.26
4 Mb/s	$4.62	$1.60	$1.02	—	$4.52
6 Mb/s	—	$2.35	$1.53	—	$6.78

* Duplex circuit includes 2 terminals and two-way circuit,
† Simplex circuit includes 2 terminals and one-way circuit.
‡ Assumes use of 4 hour per day, 250 days per year; and
   sharing of terminals by multiple circuits where possible.

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13. ABSTRACT (Maximum 200 words)

The trends and roles of VSAT services in the year 2010 time frame are examined based on an overall network and service model for that period. An estimate of the VSAT traffic is then made and the service and general network requirements are identified. In order to accommodate these traffic needs, four satellite VSAT architectures based on the use of fixed or scanning multibeam antennas in conjunction with IF switching or onboard regeneration and baseband processing are suggested. The performance of each of these architectures is assessed and the key enabling technologies are identified.

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