NASA Contractor Report 189199

Applications of Satellite Technology to Broadband ISDN Networks

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March 1992

Prepared for
Lewis Research Center
Under Contract NAS3-25092

NASA
National Aeronautics and
Space Administration
Lewis Research Center
Cleveland, Ohio 44135
AC 216 433-4000

NASA Contract No. NAS3-25092
NASA Contractor Report 189199
LORAL Technical Report No. SS/L-TR00823

Technical Support for Defining
Advanced Satellite Systems Concepts

Final Report for Task Order 6

Applications of Satellite Technology to Broadband ISDN Networks

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Summary

The growing use of optical fiber between major communication centers and businesses is expected to spur the introduction of B-ISDN. Extremely wide bandwidth is available, and economics demand that the facilities be efficient and flexible in carrying a wide variety of communications in a common format. This study seeks to determine the roles that satellite technology may play in these developments. Satellites excel at providing access to remote users and point-to-multipoint services. How these advantages could best be used in the introduction and utilization of B-ISDN is the subject of this study. Important conclusions of this work are as follows:

- A number of potential B-ISDN users are identified: telemedicine, virtual offices, distance learning, and teleconferencing and messaging.

- Satellite-based networks will find applications in at least three distinct areas: (1) to bridge private service-specific networks and/or information centers – each of these networks can be looked upon as a gateway through which the end users can access the satellite; (2) to enhance the service quality of and/or to extend the service coverage for the public switched networks; and (3) to provide network diversity and backup.

- This satellite niche market could amount to a total of 60 STS3 digital lines (155 Mb/s) or a total of 9.33 Gb/s.

- Two satellite network architectures are described for the support of B-ISDN services. Each is designed to serve different types of B-ISDN traffic and user requirements.

  1. The first B-ISDN satellite architecture augments terrestrial B-ISDN networks by providing high-rate multicast and broadcast services as well as remote user access to the terrestrial network at 155 Mb/s. The system uses a nonregenerative spot beam satellite with IF switching.
  2. The second B-ISDN satellite architecture supports private B-ISDN networks and acts as the gateway to the public network. This system employs hopping-beam TDMA and baseband switching to interconnect private network earth stations and allows flexible allocation of capacity in order to statistically multiplex low rate services with high rate services.

- User costs are estimated to be \$30/min and \$20/min respectively for simplex 155-Mb/s circuits for Architectures 1 and 2.

- Needed technology developments are required in hardware and systems engineering: high speed FEC decoders, low-power high-bandwidth memory, terrestrial network interfaces, adaptive rain fade compensation techniques, B-ISDN signaling standards, fast packet switch control, traffic characterization, and performance measuring techniques.

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Chapter 1

Executive Summary

This chapter is organized as follows:

1.1 Background

The ISDN concept is to provide the user with easy access to a multiplicity of services over a single connection to the network. Voice, data, and even low rate video are simultaneously feasible in a single access with this scheme. The basic access is 144 kb/s, but greater data rates up to the primary rate of 1.544 Mb/s are possible.

In general, an end-to-end ISDN connection will involve a local and a public network. The former is intended to interconnect subscribers and the local exchange; and the latter to interconnect the local exchanges via local, national, and international trunks.

ISDN is primarily designed for local communications and flexible access to the public networks. Broadband ISDN (B-ISDN) has a greater focus on efficient and flexible use of the public network itself, but it also incorporates features that would provide greater bandwidth to the individual users. The basic access is 155 Mb/s, more than enough for digital TV and sufficient for HDTV.

The efficiency and flexibility of B-ISDN results from a quasi-packet type of communications called Asynchronous Transfer Mode (ATM). In this scheme, voice and video are broken up and packaged in 53 byte cells, carried from the source to the destination across multiple nodes and possible multiple networks, and finally reconstructed as a continuous stream at the destination. The network does not distinguish voice, video, or data cells but processes all in common high speed hardware. Efficiency results by utilizing the intermittent lulls in communications, especially data, to insert more information (additional cells). Flexibility results from using common hardware and channels to carry and process a variety of communications.

The growing use of optical fiber between major communication centers, and even to residences[1], should spur the introduction of B-ISDN. Extremely wide bandwidth is made available by these facilities, and economics would demand that these facilities be efficient and flexible in carrying a wide variety of communications in a common format such as ATM.

NASA has an interest in determining the role satellite technology might play in these developments. Satellites excel at providing access to remote users and to providing point-to-multipoint services. How these advantages could best be used in the introduction and utilization of B-ISDN is the subject of this study.

1.2 Statement of Work

Subtask 1: Potential Users of B-ISDN by Satellite

Space Systems/Loral shall identify potential users of B-ISDN satellite technology. In each case Space Systems/Loral shall cite:

1. How the user would make use of B-ISDN, in general.

2. How the satellite is expected to provide an advantage over the standard terrestrial connection – i. e.

[1] Shumate, Paul Jr.; "Cost Projections for Fiber in the Loop", IEEE LCS Magazine, Feb. 1990, pp 73-76.

cost, performance, economy of scale, flexibility, etc.

3. What B-ISDN standards, if any, would inhibit such an application, and, if so, how should they be changed or circumvented.

Space Systems/Loral shall consider, but not be limited to, the following as possible users:

1. Network providers using satellite technology to provide access to remote users and/or use the satellite system as a multicast or broadcast augmentation of the terrestrial system.
2. Stand-alone satellite networks which compete with terrestrial facilities.
3. Private corporate users who happen to use B-ISDN as an infrastructure for their networks.

Subtask 2: Estimates of Traffic

For the most promising applications of Subtask 1, Space Systems/Loral shall estimate the number of users and their traffic needs. The traffic shall be cited as to type (voice, video, data) and nature (local, long distance). These estimates are to be first order only, and not to be obtained through extensive market research efforts. The approach to meeting the requirements of this Subtask shall be approved by the NASA technical manager.

Subtask 3: Potential Satellite Architectures

Space Systems/Loral shall propose reasonable satellite system architectures which provide or interface with B-ISDN service. The architectures shall include, but not be limited to:

1. A satellite system which augments a terrestrial based network by providing dedicated multicast or broadcast and remote access service.
2. A satellite system which provides private B-ISDN based corporate networks as well as acting as the gateway to the public network for those networks.

Space Systems/Loral shall define the signaling requirements for each application and identify any compatibility issues. In particular Space Systems/Loral shall address how these systems would handle the satellite time delays in a B-ISDN compatible manner. Also, Space Systems/Loral shall address how these systems would guarantee that multiple hops would be avoided as the combined system searches for available links to route ATM cells.

The architecture description shall include a concept diagram, detailed satellite and earth station processing block diagrams, transmission system design parameters, transmission formats (frame and burst structures, frame period, multiplexing schemes, etc.), signaling channel formats and protocols, on-board control requirements, and NCS functions.

Subtask 4: Payload Design for B-ISDN Satellite

Space Systems/Loral shall develop a conceptual payload design for a B-ISDN satellite. Such description shall include the payload mass, the payload power, the total spacecraft mass, the total satellite power, and satellite costs. Space Systems/Loral shall infer from these specifications a suitable spacecraft configuration, and provide an artist's sketch of the same.

Subtask 5: User Costs

Space Systems/Loral shall identify and describe viable business venture scenarios (traffic, satellites, ground segment, control) for B-ISDN service via satellite. The scenario shall be of sufficient detail to obtain realistic total costs and user costs (cents/minute, cents/packet, other).

Subtask 6: Critical Technologies

Space Systems/Loral shall identify and describe the necessary technologies which are critical and/or enabling to the application of satellite technology to B-ISDN service. Space Systems/Loral shall provide reasonable plans for the development of such technology, including schedules and costs.

Subtask 7: Reporting

Reporting requirements include Interim and Final Briefings, Monthly Status Reports, and Final Report.

1.3 Organization of Report

Table 1-1 gives the organization of this Final Report by chapter. Chapter 2 identifies potential users of satellite B-ISDN services, and Chapter 3 provides an estimate of the traffic. Chapter 4 describes potential B-ISDN

Table 1–1: Organization of the Final Report

Chapter	Contents
1.	Executive Summary
2.	Potential Users of B-ISDN by Satellite
3.	Estimate of Traffic
4.	Potential B-ISDN Satellite Applications
5.	System Architecture Descriptions
6.	Satellite Payload Design
7.	Satellite Design
8.	User Costs
9.	Technology Development Plan
A.	Telecommunication Outages and Disasters
B.	Link Budgets
C.	Cost Comparison
D.	AIAA Paper: Satellite Delivery of B-ISDN Services

satellite applications. Chapter 5 describes the system architecture, Chapter 6 gives the payload design, and Chapter 7 gives the satellite design. Chapter 8 gives an estimate of user costs, and Chapter 9 describes the technology development plan.

There are four appendices. Appendix A gives a list of recent communication outages and disasters in the public switched network. Appendix B gives the link budgets for the B-ISDN satellite system.

Appendix C gives a cost comparison among the satellite system concepts developed under different task orders of this contract; the two B-ISDN system concepts, the Mesh VSAT system, and the Integrated Video system.

Appendix D is a copy of the paper presented on the B-ISDN satellite system at *The 14th International Communications Satellite Systems Conference*, Washington, DC, March 1992.

1.4 Summary of Results

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

1. Potential Users of B-ISDN by Satellite (Chapter 2)
2. Estimate of Traffic (Chapter 3)
3. Potential B-ISDN Satellite Applications (Chap. 4)
4. System Architecture Descriptions (Chapter 5)
5. Satellite Payload Design (Chapter 6)
6. Satellite Design (Chapter 7)
7. User Costs (Chapter 8)
8. Technology Development Plan (Chapter 9)

The reader is also referred to Appendix D which contains a copy of the paper presented on this subject.

1.4.1 Potential Users of B-ISDN by Satellite

A number of potential B-ISDN users are identified and discussed in Chapter 2. These include (1) telemedicine, (2) virtual offices, (3) distance learning, and (4) teleconferencing and messaging.

Satellite based networks have a significant advantage in providing a set of communications services of primary interest to business customers which require access to these services from distributed locations via small or medium ground terminals located as close as possible to the customer premises. The flexibility of satellite based network services and the ability to set up much quickly and in a flexible way to cover a wider remote areas than any other medium is a big advantage.

1.4.2 Estimate of Traffic

The future domestic telecommunications infrastructure will encompass several major public switched networks, a large number of private service-specific networks (e. g., the Inter-hospital network, the High

School network, the supercomputer networks, etc.), and many centralized information centers (Library of the Congress, Data Centers of Company Headquarters, major Medical Research Centers, etc.). All these networks are accessible to the general public and are fully B-ISDN compatible. For most of these terrestrial-based networks, optical fiber is the dominant technology.

Satellite-based networks will find applications in at least three distinct areas:

- Bridge private service-specific networks and/or information centers. Each of these networks can be looked upon as a gateway through which the end users can access the satellite.
- Enhance the service quality of and/or to extend the service coverage for the public switched networks.
- Provide network diversity and backup.

Four types of network applications are used to size the satellite-based B-ISDN niche market: telemedicine networks, distant learning networks, virtual office networks, and time shared networks. This satellite niche market could amount to a total of 60 STS3 digital lines (155 Mb/s) or a total of 9.33 Gb/s.

1.4.3 Potential B-ISDN Satellite Applications

The requirement for optical fiber in the terrestrial B-ISDN results from the network's high bandwidth demands. Presuming that sufficient bandwidth is available, satellites can also provide or operate within a B-ISDN. Furthermore, satellite networks offer advantages over terrestrial networks for the delivery of certain services. Two satellite network architectures are described for the support of B-ISDN services, both of which are designed to serve different types of B-ISDN traffic and user requirements.

Architecture 1: Terrestrial B-ISDN Support

The first B-ISDN satellite architecture (Figure 1-1) augments terrestrial B-ISDN networks by providing high-rate multicast and broadcast services as well as remote user access to the terrestrial network at the SDH rate of 155.52 Mb/s. These services are supported by a system in which a nonregenerative spot beam satellite is used to support transmission of B-ISDN at carrier rates of 155.52 Mb/s.

Essentially, this architecture provides 155.52 Mb/s pipes which can be used to distribute wideband signals (such as high definition video) to multiple users and to provide high rate remote access capability for point-to-point or point-to-multipoint services. It is assumed that narrow band multipoint and remote access services are provided by other systems. To provide interconnection of high rate carriers in a spot beam environment, this satellite network employs static microwave switching on-board the satellite.

A high capacity can be obtained by this network at the expense of switching flexibility. Because the system is based on SDH level routing, the network is not able to take advantage of efficiencies gained by switching at the ATM level. At the earth station, some amount of statistical multiplexing may be accomplished if the earth station includes ATM switching capabilities, but channels in this satellite network may only be accessed at the base rate of 155.52 Mb/s. Therefore, if a particular earth station wishes to seize capacity solely for a 20 Mb/s service, it will still be allocated the full 155.52 Mb/s channel capacity.

This network complements the terrestrial B-ISDN by providing backup and overload communication capacity in the event of terrestrial network failure or congestion. It also provides efficient multicast and broadcast capabilities because of its topology, especially for video services which require high bandwidth. Finally, it may also serve as an access point for remote users.

Many B-ISDN services are of the type (high bandwidth, low burstiness) most efficiently served by this network, such as:

- Supercomputer networks
- High-definition television distribution
- Cable television distribution
- Newspaper/graphics transmission
- Real-time science experiments
- High speed interconnection of LANs/WANs.

In general, users of services which require slowly varying, high bandwidth, or multicast connectivity will benefit from this architecture. Other types of B-ISDN services can also use this network, but at a lower efficiency than those previously described. Finally, because of the high basic channel capacity, earth stations which are able to statistically multiplex traffic will most efficiently use their allocated network resources.

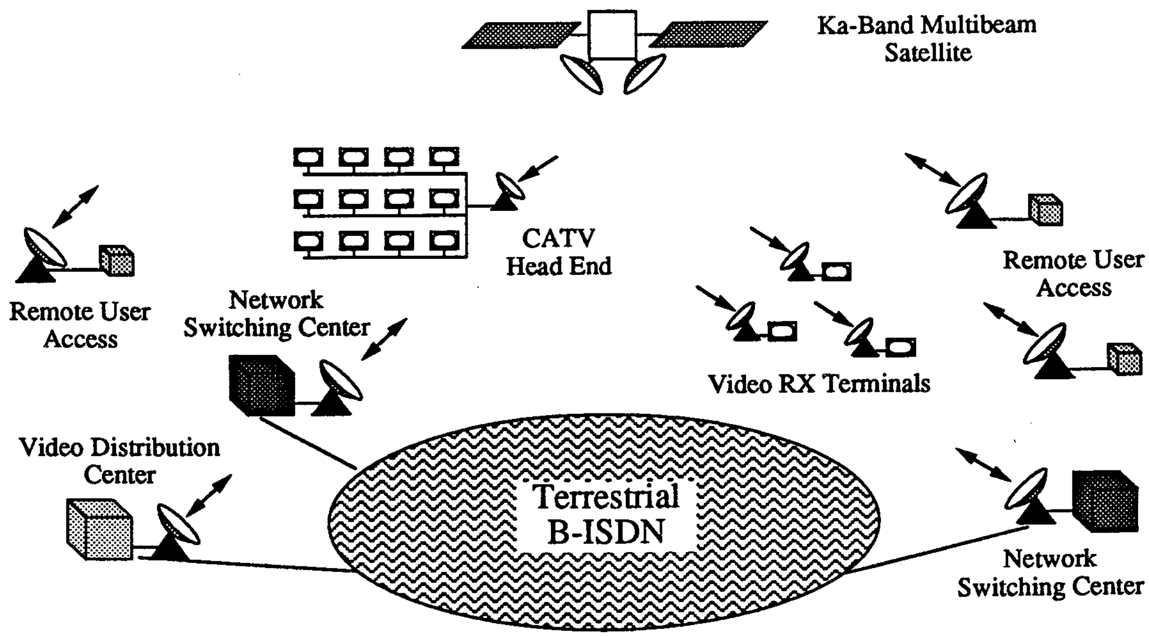

Figure 1–1: A Multicast, Broadcast, and Remote-Access B-ISDN Satellite Network

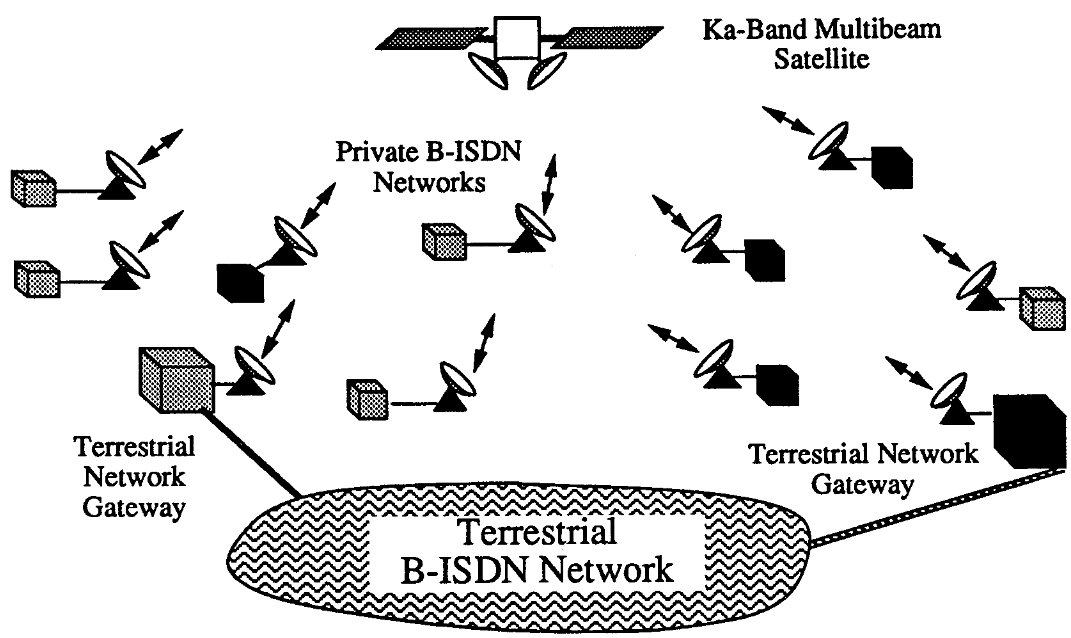

Figure 1–2: A Private-Based B-ISDN Satellite Network with Gateways to the Terrestrial Network

Architecture 2: Private Based B-ISDN

The second B-ISDN satellite architecture (Figure 1-2) supports private B-ISDN networks and acts as the gateway to the public network for these networks. This system employs hopping-beam TDMA and baseband processing to interconnect private network earth stations and allows flexible allocation of capacity to earth stations in order to statistically multiplex low rate services with high rate services.

Because of the variety of user bit rates in such a network (a mix of high and low rate bursty data) and because of the possibility of a large number of user sites or service types, a flexible, interactive network architecture was chosen. The satellite provides this flexibility via an on-board destination-directed (fast packet) switch.

This architecture employs carriers of 200 Mb/s with TDMA transmission on the uplink to allow private network earth stations to transmit ATM cells to an onboard packet switch. High speed 800 Mb/s downlink TDM carriers transport the packets to the destination earth station.

The combination of TDMA access and onboard switching allows network earth stations to efficiently support mixtures of low rate and high rate traffic. In addition, the satellite employs hopping-beam antennas on both links in order to maximize network capacity utilization and to provide sufficient antenna gains at these bit rates.

Unlike the first architecture which is designed to complement the existing B-ISDN by offering high rate transmission channels, the Architecture 2 network provides independent private B-ISDNs as well as serving as the gateway to the terrestrial B-ISDN for some users.

The system is designed to most efficiently handle the whole spectrum of B-ISDN services. It would be most effective with services which are less bandwidth consuming or bursty, such as:

- File transfers
- Facsimile
- Interactive services
- Document retrieval
- Message services
- Small computer networks.

Architecture 2 also can supply the services delivered by the first architecture quite well. Of the two architectures, it is the more capable, since it handles all types of B-ISDN services in the most efficient manner.

1.4.4 System Architecture Descriptions

Two satellite network architectures for the support of B-ISDN services will be described. The first architecture could augment terrestrial networks by providing multicast and broadcast services as well as remote user access to the terrestrial network. These services are provided by a network architecture in which a nonregenerative Ka-band spot beam satellite is used to support transmission of B-ISDN at 155.52 Mb/s.

The second architecture supports private B-ISDN networks and acts as the gateway to the public network for these networks. This network architecture is based on a Ka-band satellite system that employs hopping-beam TDMA and on-board baseband switching to interconnect private network earth stations.

Architecture 1

The antenna coverage pattern for Architecture 1 is shown in Figure 1-3. CONUS coverage is provided by using ten 1.55° spot beams for both uplink and downlink transmission.

The key requirements of the network are a large capacity coupled with a minimization of satellite power output and inexpensive earth stations. To account for the large rain fades, power control on the uplink is assumed. Various transmission parameters for this architecture are summarized in Table 1-2, based on link budget analysis.

Architecture 2

The second satellite architecture supports private B-ISDN networks and acts as the gateway to the public network for these networks. This system employs hopping-beam TDMA and baseband processing to interconnect private network earth stations, and allows flexible allocation of capacity to earth stations in order to statistically multiplex low rate services with high rate services. The satellite provides a flexible network architecture via an on-board destination-directed (fast packet) switch.

The uplink and downlink antenna coverage pattern is shown in Figure 1-4. Twelve hopping 0.4° spot beams

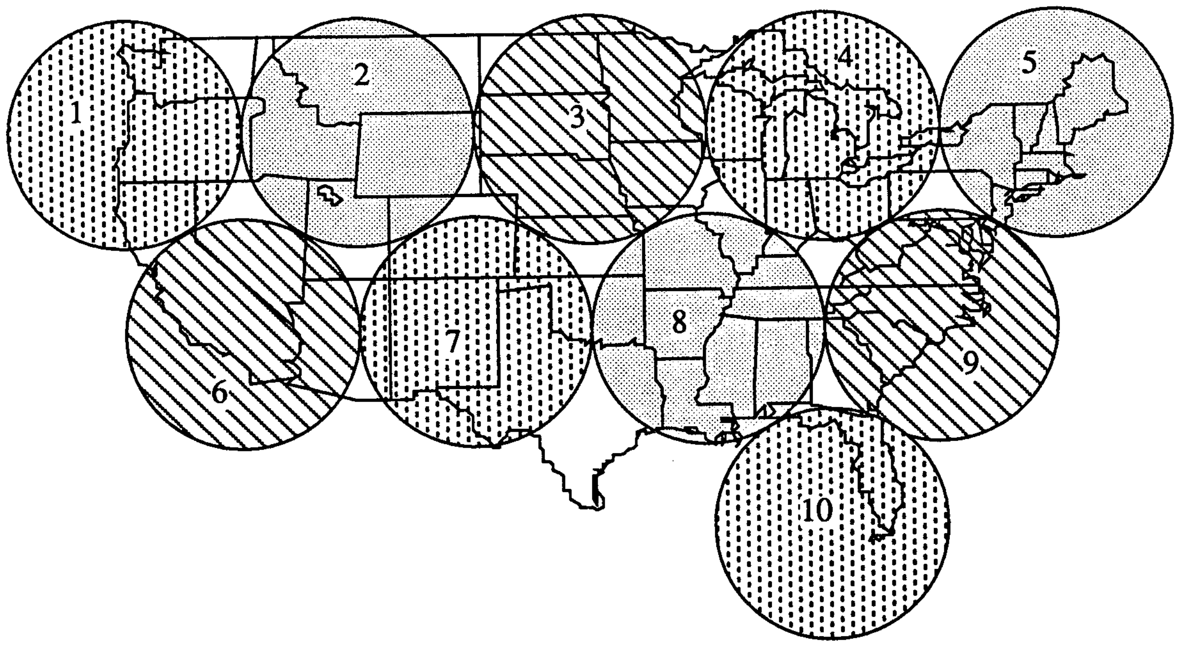

Figure 1–3: Antenna Beam Coverage for Architecture 1

Table 1–2: System Parameters for Architecture 1 Design

System Parameters	Uplink	Downlink
Frequency	30 GHz	20 GHz
Number of Beams	10	10
Access Method	FDMA	FDMA
Modulation	8-PSK	8-PSK
FEC Coding	Concat. Code RS/Trellis	Concat. Code RS/Trellis
Transmission Rate	200 Mb/s	200 Mb/s
Carrier Bit Rate (info)	155.52 Mb/s	155.52 Mb/s
No. Carriers/beam	4	4
Total No. of Carriers	40	40
Beam Capacity	622 Mb/s	622 Mb/s
Beam Bandwidth Required	400 MHz	400 MHz
Frequency Reuse Factor	3	3
System Bandwidth Req'd.	1.2 GHz	1.2 GHz
System Capacity (info)	6.2 Gb/s	6.2 Gb/s
Earth Station Diameter	3 to 4.5 m	3 to 4.5 m
Transmit Amplifier Power	30 to 140 W	32 W

are used to cover a total of 110 dwell areas. These dwell areas are divided into 12 sectors with one hopping beam covering each sector. Each sector has 7 to 10 dwells. Each beam has the same fixed capacity of 800 Mb/s.

The key objectives of a B-ISDN satellite network are a large capacity coupled with a minimization of satellite power output and inexpensive earth stations. Because of the small dwell areas used in the uplink hopping-beams, earth stations can be kept smaller than those described in the first architecture. Uplink power control is used to combat rain fade in this architecture; the use of small spot beams and on-board regeneration on the satellite provide sufficient margin for high availability. A summary of the key transmission parameters of this satellite architecture is given in Table 1-3.

1.4.5 Satellite Payload Design

Payload implementations are developed for two candidate architectures. The first architecture is centered around four microwave switch matrices (MSMs) which provide 155.52 Mb/s pipes without on-board processing. A preliminary mass estimate for the switch matrix is 17 kg. The second payload architecture design uses an on-board, self routing switch to perform packet switching at baseband frequencies. Estimates for the mass and power requirements of the baseband processor are 98 kg and 558 W respectively.

Architecture 1 Payload Design

A block diagram of the nonregenerative satellite payload is shown in Figure 1-5. The architecture is centered around static microwave switch matrices (MSMs) which provide a space division, circuit switched architecture. Uplink carriers are switched without processing to one or more downlink carriers, depending on traffic requirements. There are 4 carriers per beam at information bit rates of 155.52 Mb/s. Each carrier group is first received and then downconverted to an intermediate frequency (between 3 and 5 GHz) before being filtered. Four 10 by 10 MSMs provide interconnectivity between any input and output beam.

This interconnectivity is not complete among all carriers but instead is such that an incoming carrier on a particular frequency can be switched to one carrier at the corresponding downlink frequency on each of the ten downlink beams. Each 10 by 10 MSM interconnects the 10 input carriers at the same intermediate frequency to 10 output carriers at the same intermediate frequency. Thus, each MSM operates at a slightly different frequency, and the system can be thought of as four independent 10 by 10 switching networks, instead of as a 40 by 40 network.

Architecture 2 Payload Design

The payload in this architecture (Figure 1-6) operates at baseband frequencies, to allow for baseband processing on the satellite. At baseband, the payload can employ packet switching for higher throughput under variable traffic conditions. Additionally, the baseband processing allows for regeneration of new carriers for the downlink, leading to separately engineered uplinks and downlinks and improved link performance.

Figure 1-7 illustrates a block diagram of the baseband processor. There are 48 uplink TDMA carriers, each with an information rate of 200 Mb/s. The input carriers are first separately demodulated, and then passed to FEC decoders, which remove the concatenated coding applied at the earth station. The data is next descrambled and deinterleaved before being reassembled into packets which are then passed to the baseband switch for routing to the correct downlink antenna beam.

The payload of this architecture is centered around an on-board self-routing packet switch. Since there are many small spot beams which require full interconnectivity and since private-based B-ISDN networks are expected to carry a wide variety of bit rates, a self-routing packet switch, in which packets consist of ATM cells, is appropriate for this architecture. After implementation considerations and preliminary mass and power estimates for candidate switches were examined, the self-routing multicast crossbar switch design (candidate ii.) was selected based on mass and power requirements and ease of implementation. The basic crossbar design is strictly non-blocking.

1.4.6 Satellite Design

The approach is to evolve the existing satellite design (1990 technology base for 1995 launch) to the B-ISDN satellite designs which assume a year 2000 technology base for a year 2006 launch. Technology advances are assumed in the propulsion and power subsystems. Ion propulsion 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.

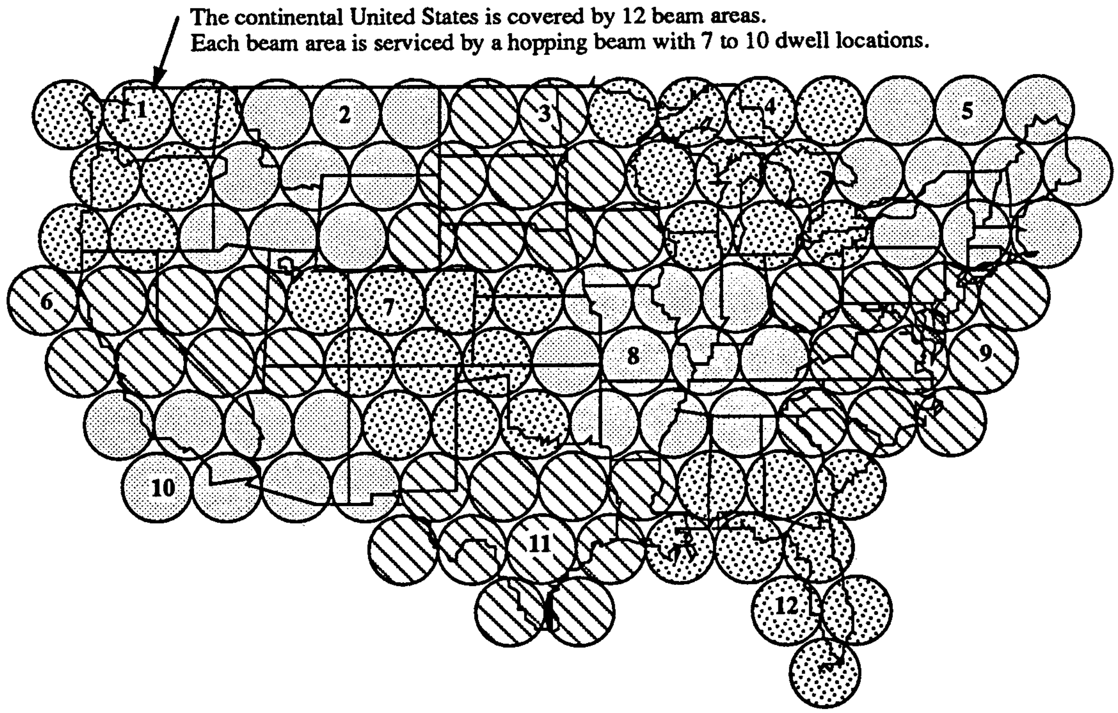

Figure 1–4: Antenna Beam Coverage for Architecture 2

Table 1–3: System Parameters for Architecture 2 Design

System Parameters	Uplink	Downlink
Frequency	30 GHz	20 GHz
Number of Beams	12 hopping	12 hopping
Number of Dwells/Beam	10	10
Access Method	TDMA	TDM
Modulation	QPSK	8-PSK
FEC Coding	Concat. Code	Concat. Code
Transmission Rate	305 Mb/s	1,030 Mb/s
Carrier Bit Rate (info)	200 Mb/s	800 Mb/s
No. Carriers/beam	4	1
Total No. of Carriers	48	12
Beam Capacity	800 Mb/s	800 Mb/s
Beam Bandwidth Required	820 MHz	460 MHz
Frequency Reuse Factor	3	3
System Bandwidth Req'd.	2.5 GHz	1.4 GHz
System Capacity (info)	9.6 Gb/s	9.6 Gb/s
Earth Station Diameter	3.0 m	3.0 m
Transmit Amplifier Power	10–40 W	40 W

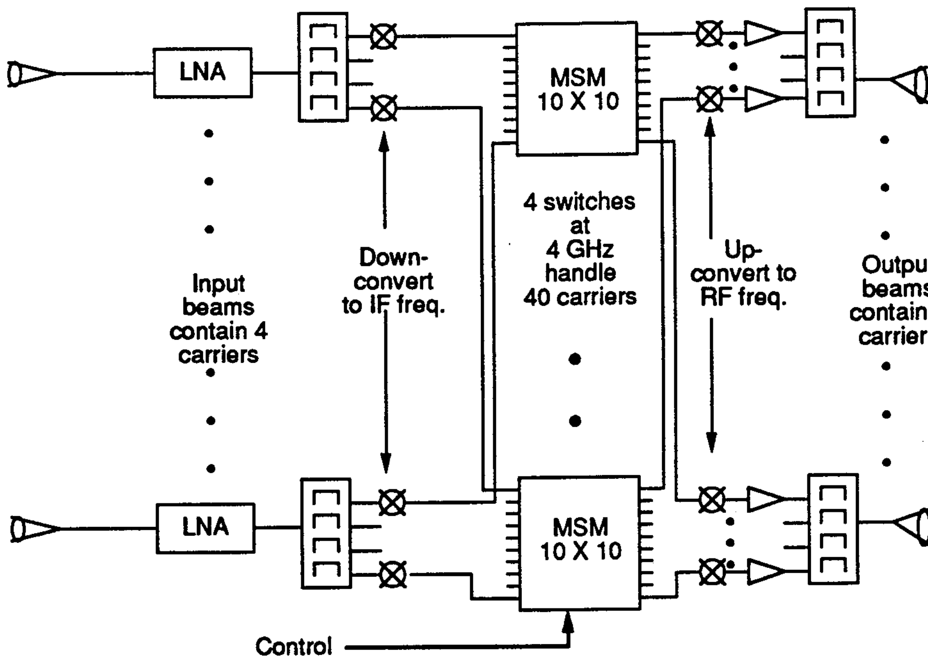

Figure 1–5: Block Diagram of Architecture 1 Payload

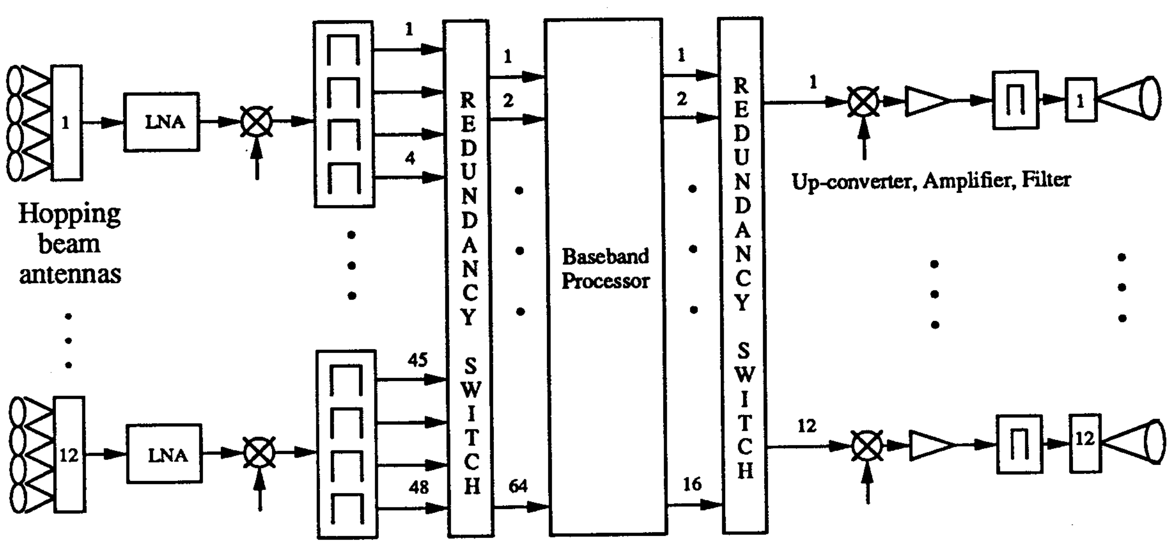

Figure 1–6: Block Diagram of Satellite Payload for Architecture 2

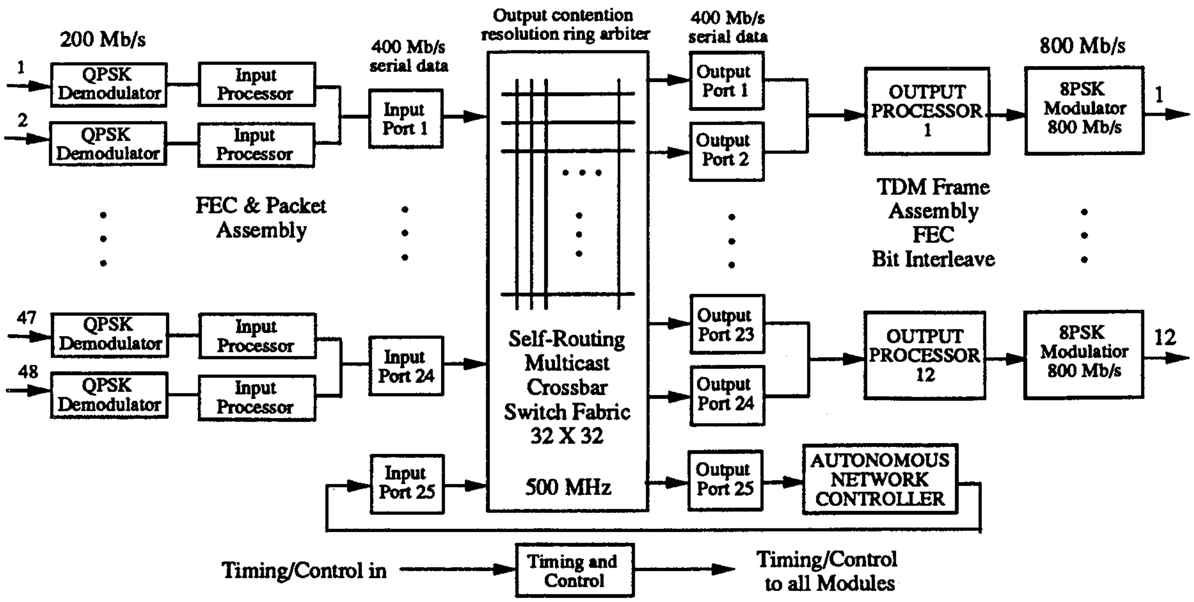

Figure 1–7: Block Diagram of Baseband Processor for Architecture 2

There are two B-ISDN satellite configurations. Architecture 1 uses a microwave switch matrix to establish connectivity between uplink and downlink beams. It is a transponder satellite which can be reconfigured to change interconnections among channels. Architecture 2 uses an on-board baseband switch that allows simultaneous interconnectivity between all uplink and downlink beams. The baseband electronics consume mass and power which are used for transponders in the Architecture 1 design. However, the Architecture 2 design has a greater communications efficiency due to its on-board processing and smaller spot beams.

Architecture 1 Satellite Design

Figure 1-8 shows the payload block diagram for Architecture 1. There are ten input beams (only one is shown) and ten output beams (only one is shown). There are four 10 x 10 microwave switch matrixes (only one is shown) to supply connectivity among the ten inputs and outputs for up to four channels per beam. There is 2-for-1 redundancy for the low noise amplifiers (LNA's) and receivers and 6-for-4 ring redundancy for the up-converters and TWTA's. The total system capacity for the Architecture 1 B-ISDN satellite is 40 channels of 156 Mb/s, or 6.2 Gb/s.

Table 1-4 summarizes the payload electronics mass and power. Major components are LNAs and downconverters, 10 x 10 MSMs, and upconverters and 32 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 1,696 kg dry (1,856 kg wet) satellite mass with a 520 kg B-ISDN payload (antenna plus communication electronics) and 5.1 kW end-of-life power.

Architecture 2 Satellite Design

Figure 1-9 shows the payload block diagram for Architecture 2. There are 12 input beams and 12 output beams. Each input beam contains four 200 Mb/s channels. The 48 input channels are demodulated and passed to 48 input processors which perform error correction and packet assembly functions. These 48 data streams are combined in pairs for the 24 input ports of the baseband switch.

The 32 x 32 crossbar switch matrix supplies connectivity among 24 input and 24 output ports. (In addition there is a 25th port for the autonomous network controller.) The 24 output ports are combined in pairs to feed 12 output processors. The 800 Mb/s downlink occupies 458 MHz bandwidth with 8-PSK modulation (712 MHz if QPSK modulation is used).

Table 1-5 summarizes the payload electronics mass and power. Major components are LNAs and downcon-

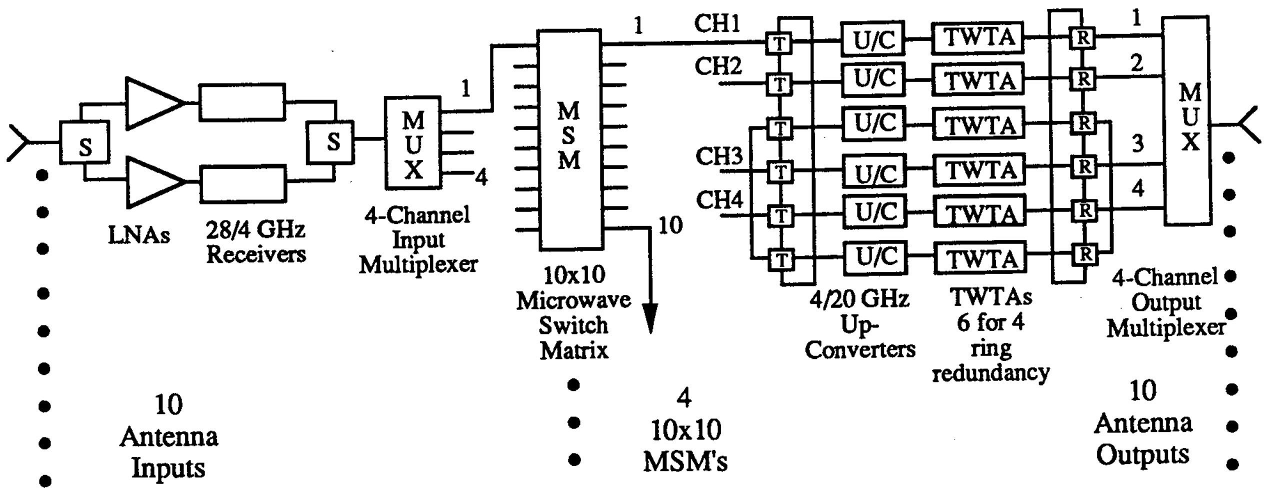

Figure 1–8: Payload Block Diagram for Architecture 1

Table 1–4: Payload Electronics Mass and Power Breakdown (Architecture 1)

	Mass (kg)			Power (W)			
Equipment	Qty.	Unit	Total	Qty.	Unit	Total	Comments
28 GHz low noise amplifier	20	0.4	8	10	1.2	12	2–1 redundancy
28/4 GHz receiver	20	2.0	40	10	7.0	70	2–1 redundancy
Input multiplexer (4 GHz)	10	2.6	26				4 channel
10x10 switch matrix	4	4.2	17				Coax. switch matrix
4/20 GHz upconverter	60	1.2	72	40	3.0	120	6–4 redundancy
32 W TWTA + EPC	60	3.5	210	40	88.9	3,556	6–4 red., 36% eff.
Output multiplexer (28 GHz)	10	2.0	20				4 channel
Master LO (upconverter)	2	5.0	10	1	6.0	6	2–1 redundancy
DC/DC converters (upconv.)	30	0.4	12	20	6.0	120	Dual outputs
S-switch (28 GHz WG)	10	0.13	1				
S-switch (4 GHz coax)	10	0.07	1				
T-switch (4 GHz coax)	60	0.12	7				
R-switch (20 GHz WG)	60	0.2	12				
Coaxial cable			3				
Waveguide			2				
Beacon transmitters	4	2.0	8	2	15.0	30	
Margin			24			196	5% mass margin
Totals			472			4,110	Mass (kg), Power (W)

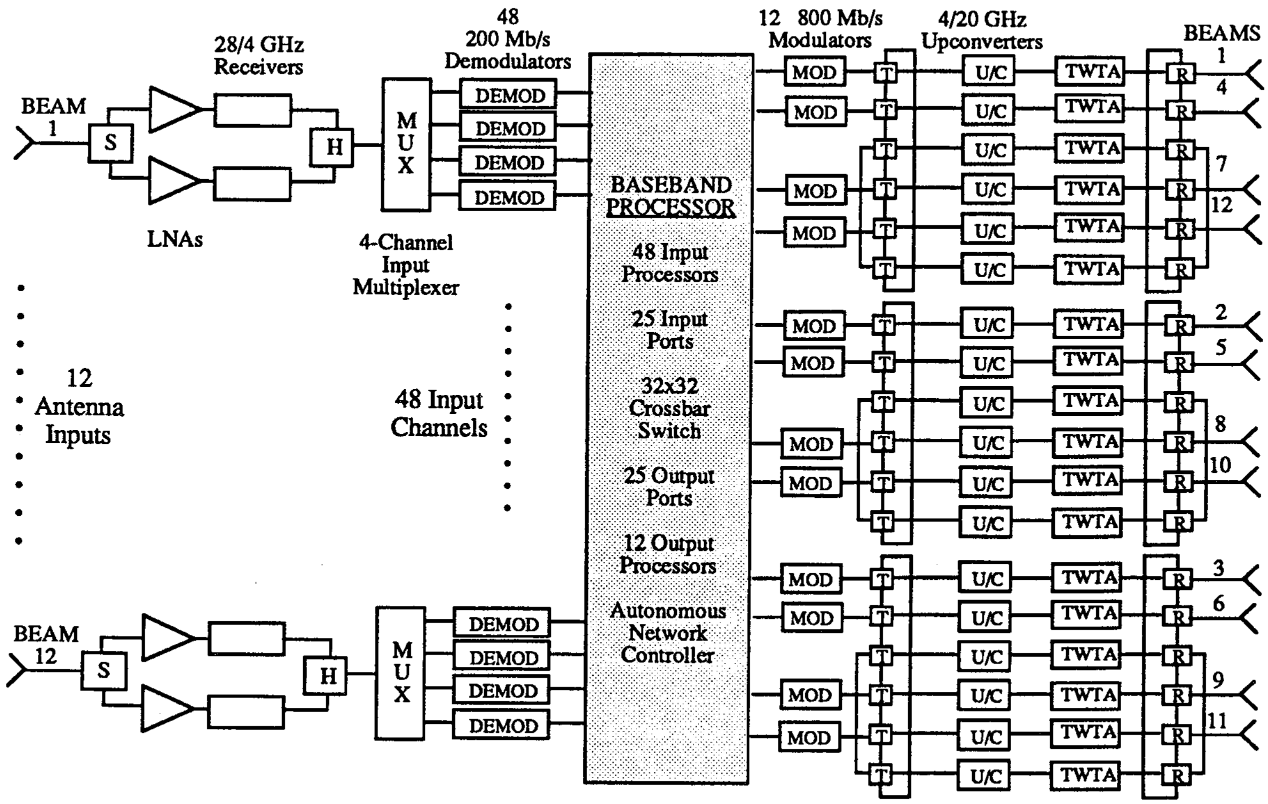

Figure 1–9: Payload Block Diagram for Architecture 2

verters, the baseband electronics, the 32 x 32 crossbar switch, and upconverters and 40 W TWTAs.

The baseband processor has 132 kg mass and 606 W power consumption. It contains the hardware required to demodulate the RF signal to baseband, recover the information bits, switch the contents of the individual input data channels to the correct outputs, assemble the output data streams, and modulate the information onto the downlink channel carriers. Use of MMIC components is assumed for electronic components where appropriate.

The basis for the bus is 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. The existing satellite design (1990 technology) has been upgraded to incorporate hypothesized year 2000 technology improvements. The result is a 1,613 kg dry (1,773 kg wet) satellite mass with a 433 kg payload (antenna plus communication electronics) and 3.5 kW end-of-life power.

Comparison of Satellite Designs

In spite of the addition of a 132 kg, 606 W baseband processor, the Architecture 2 satellite design achieves 50% more throughput capacity compared with the Architecture 1 "bent pipe" design with less mass and power consumption. In addition, the Architecture 2 design is more flexible in accommodating user traffic and has greater rain margin.

Architecture 2 achieves its better performance due to the combination of a number of factors:

- There is a 3 dB performance advantage with regeneration on the satellite.
- Uplink and downlink performance can be separately optimized according to available bandwidth, modulation and coding, and rain margin.
- Use of smaller, scanning spot beams becomes possible as a method to allocate capacity across the coverage area.

The end result is that 26-W TWTA's could be used on the satellite to deliver 800 Mb/s channels rather than

Table 1–5: Payload Electronics Mass and Power Breakdown (Architecture 2)

	Mass (kg)			Power (W)			
Equipment	Qty.	Unit	Total	Qty.	Unit	Total	Comments
Low noise amplifiers	24	0.4	10	12	1.2	14	2–1 redundancy
Receivers (28/4 GHz)	24	1.8	43	12	7.0	84	2–1 redundancy
Input demultiplexers	12	2.6	31				4 channel
Baseband Processor							
Demodulators	60	0.3	18	48	0.5	24	5–4 redundancy
Input processor	60	0.6	36	48	4.4	211	5–4 redundancy
Input port	32	0.6	19	25	3.6	90	Extra ports used for control
Switch fabric/support	1	3.0	3	1	36.0	36	2–1 redundancy
Output port	32	0.6	19	25	2.5	63	
Output processor	16	1.2	19	12	6.6	79	
Modulators	16	1.0	16	12	1.0	12	
DC/DC converter	2	1.0	2	1	91.0	91	85% efficiency
Subtotals			132			606	
Autonomous Network Controller	2	1.5	3	1	15.0	15	2–1 redundancy
Upconverter (4/20 GHz)	24	1.2	29	12	4.0	48	8–4 redundancy
TWTA/EPC (40 W)	24	4.5	108	12	125.0	1,500	8–4 redundancy, 32% eff.
Master LO	2	5.0	10	1	6.0	6	2–1 redundancy
DC/DC convertor (upconverter)	12	0.4	5	6	7.0	42	2–1 redundancy
Redundancy switches			26				
Waveguide and coaxial cable			7				
Beacon transmitters	4	2.0	8	2	15.0	30	2–1 redundancy
Subtotals			412			2,345	
Margin			21			117	5% margin
Totals			433			2,462	Mass (kg), Power (W)

the 32 W TWTA's required with Architecture 1 for 155 Mb/s channels. In fact, 40-W TWTA's are used to improve link performance by reducing required co-channel interference to -16 dB (versus -20 dB for Architecture 1) and increasing downlink rain margin to 5.6 dB which is 99.5% availability in Rain Region E.

Thus it is not surprising that many more channels (48 versus 30) can be carried on the Architecture 2 satellite design, in spite of the mass and power of the required baseband electronics. The capacity limitation is available downlink bandwidth, even when 8PSK modulation is used.

1.4.7 User Costs

User costs are developed based on the schedule in Figure 1-10 for B-ISDN system implementation. Table 1-6 summarizes the space segment costs in 1992 dollars, and Table 1-7 gives the ground terminal costs for two sizes of terminals. The full set of assumptions for developing these costs is given in Chapter 8.

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 1-8 gives the simplex circuit costs for the two B-ISDN architectures, for different hours of terminal use per day. System utilization is assumed to be 15% for architecture 1 and 20% for architecture 2. A duplex connection at 155 Mb/s costs \$60/min for Architecture 1 versus \$38/min for Architecture 2. For large circuit sizes, the total user cost is dominated by the space segment costs.

Chapter 8 presents more cost data, and Appendix C presents a cost comparison of the B-ISDN systems with the Mesh VSAT and Integrated Video satellite system concepts. The B-ISDN systems have significantly

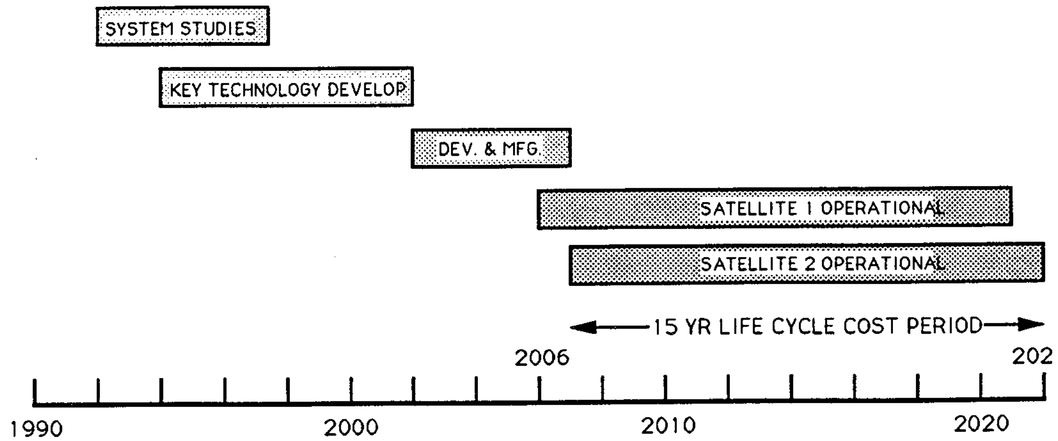

Figure 1–10: Schedule for B-ISDN Satellite System Implementation

Table 1–6: Space Segment Costs, 1992 $M (2 satellites, 15 yr life beginning 2006)

Cost Category (2 satellites on orbit)	Architecture 1 Life Cycle Cost	Architecture 1 Annual Cost at 18%	Architecture 2 Life Cycle Cost	Architecture 2 Annual Cost at 18%
Satellite cost (2)	443 M		663 M	
Launch Cost (2)	248 M		248 M	
TT&C Support (2)	15 M		15 M	
Launch Insurance (16%)	134 M		176 M	
Total Costs	$840 M	$164 M/yr	$1,102 M	$216 M/yr

Table 1–7: User Terminal Annual Costs

Terminal Type & Cost	Annual Terminal Cost (1992 $) Lease Cost ($/yr)	Maintenance Cost ($/yr)	Total Cost ($/yr)
Architecture 1, $100,000	20,000	10,000	30,000
Architecture 2, $80,000	16,000	8,000	24,000

lower user costs due to the higher capacity of the satellite.

1.4.8 Technology Development

Critical technology developments are identified in two areas: hardware and systems engineering.

Hardware Developments:

High-speed FEC decoders with low power dissipation. The FEC codes for the B-ISDN payload were chosen for superior BER performance and bandwidth efficiency by concatenating several coding systems. The power consumption of the resulting codecs must be low and the actual codec performance at these B-ISDN rates must be verified.

Low power, high bandwidth memory and logical components. High speed, low-power memory components are required for the buffering needed in the input and output ports of the multicast crossbar switch. In addition, high speed logic components will be required for the input ports, the switch fabric and the output ports.

Terrestrial network interfaces for improved forward error correction of B-ISDN ATM headers, and network congestion control

Systems Engineering Developments:

Adaptive rain fade compensation techniques should be developed to combat rain fade by the increase of the satellite EIRP in the affected area, the use of ground station diversity, and/or the decrease in communications capacity.

B-ISDN signaling standards. A number of services envisaged for B-ISDN are multipoint or multicast in nature and satellite networks are ideally suited for providing these services. Currently, the ISDN signaling standards are specified for point-to-point connections only. It is therefore highly desirable if B-ISDN signaling standards can be extended to cover multipoint/multicast applications.

Fast packet switch control and design issues. Congestion is a difficult problem associated with the control and management of the satellite capacity. The problem is not unique to satellite communications and in fact, it has been studied extensively for terrestrial ATM networks. However, some of the techniques proposed for terrestrial networks are ineffective to cope with long propagation delay in the satcom environment. To alleviate the delay impact on the classical congestion control methods, the predictive techniques using neural network formulation may be useful. A congestion control procedure must be devised as a part of the overall network control, including packet queue monitoring and buffer management by the onboard processor and user earth station, call admission control at the user and network levels and satellite capacity allocation procedures.

Traffic characterization and quality of service maintenance techniques. Since the effectiveness of the satellite B-ISDN system design is closely related to the traffic pattern described by its burstiness, destinations (i. e., the amount of broadcast, multicast and point-to-point traffic), bit rates and the quality of service (QOS), techniques should be developed to characterize these system parameters.

Performance measuring techniques. In order to comply with the "service on demand" requirements, fast and accurate techniques are needed to measure the quality of service in conjunction with the service provided.

Table 1–8: Total (Space plus Ground) Cost for 155 Mb/s Simplex Circuit

System Utilization (%)	Ground Terminal Use (hr/day)	Architecture 1 Costs, $/min Space/ Control Cost ($/min)	User Terminal Cost ($/min)	Total User Cost ($/min)
15%	1	29.79	+ 2.00	= 31.79
	2	29.79	1.00	30.79
	4	29.79	0.50	30.29
	8	29.79	0.25	30.04
		Architecture 2 Costs, $/min		
20%	1	18.72	+ 1.60	= 20.32
	2	18.72	0.80	19.52
	4	18.72	0.40	19.12
	8	18.72	0.20	18.92

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Chapter 2

Potential Users of B-ISDN by Satellite

Significant changes are currently taking place regarding both the telecommunications infrastructure and the services that it provides. The rapid deployment of fiber optic lines is generating vast increases in the available bandwidth in the network. A whole host of new services are being developed and proposed to take advantage of this expanding resource. With reference to the (now mostly standardized) Integrated Services Digital Network (ISDN), this new high-bandwidth network has been termed Broadband ISDN (B-ISDN). The role that satellites play in the telecommunications network will change as the network changes, and satellite networks will need to target certain types of users and services in order to remain competitive with terrestrial networks.

Users' requirements have evolved over the last decade from the need for relatively stable and simple voice connectivity to include such advanced capabilities as interactive imaging, full-motion video conferencing, multimedia file transfer, and LAN-to-LAN connectivity. When effectively networked, these capabilities can enhance productivity and decision making, accelerate the movement of information, and remove distance as a barrier to communications within and between companies, as well as across nations.

While today's network could technically provide new high-bandwidth services, it can not do so cost effectively because of the rigid way in which it subdivides and allocates network capacity to services. But B-ISDN, which will give the switched telecommunications network the flexibility to handle advance broadband services, uses a new protocol called Asynchronous Transfer Mode (ATM). The ATM protocol, which has been agreed upon internationally, will position the network provider to meet rising customer demand for switched high-bandwidth services.

When the capacity available to the ISDN user is increased substantially, the range of services that it can support also increases substantially. CCITT classifies the services that could be provided by a B-ISDN into interactive services and distribution services. Interactive services are those in which there is a two-way exchange of information between two subscribers or between a subscriber and a service provider. These include conversational services, messaging services, and retrieval services. Distribution services are those in which the information transfer is primarily one way, from service provider to B-ISDN subscriber. These include broadcast services, for which the user has no control over presentation of information, and cyclical services, which allow the user a measure of presentation control.

This chapter identifies a number of applications that can be supported by B-ISDN. Example applications such as telemedicine and tele-education that use multimedia as well as various broadband services are presented. A possible migration strategy to support broadband applications based on the SONET standard is discussed. Finally, the issues in integrating various applications and the advantages of supporting integrated services via satellite system are presented.

The chapter is organized as follows:

2.1 Broadband ISDN

The broadband Integrated Services Digital Network (B-ISDN) is commonly viewed as the next major step in the evolution of the switched telephone network. It is based on an infrastructure consisting of high bandwidth transmission systems and high speed switching based on industry standard networking protocols. The central concept in B-ISDN is that it can support a wide variety of services ranging from voice to data and, ultimately, the distribution of high quality entertainment video signals. In addition, B-ISDN is expected to support multimedia services such as conferencing, which consists of voice, data, and video.

2.1.1 Broadband ISDN Environment

The infrastructure envisioned by B-ISDN moves us from a service-dependent environment to a demand environment where users can get virtually any service, on demand, from public switched network based on B-ISDN. In an ATM-based B-ISDN networking environment, if user wants voice, data, and full motion video delivered in a integrated fashion, it can be accomplished. Multimedia information transfer will be seamless any where and any time. This simplification means that communications services can be built without having to worry about which network will deliver the services. This results in supporting a richer set of services.

Network simplification, as envisioned by B-ISDN, will be achieved as B-ISDN product replace the traditional wire center by B-ISDN switch center. This B-ISDN switching center will replace multitude of low-bandwidth copper interfaces with few high capacity transmission systems. It may also eliminate many network elements – such as main distribution frames, cross-connects, and stand alone multiplexers – by integrating their functions into a minimal number of products. With this simplified infrastructure, network providers will not only be able to save in capital expenses but also be able to cut operating expenses by 20 to 30 percent through the resulting simplification of operations tasks.

Cost savings and expense reduction are undoubtedly important. But beyond these benefits are the order of magnitude improvements in network performance, bandwidth capacity, and faster service provisioning that B-ISDN makes possible. The ultimate benefit is accomplished by removing the complexity that had impeded service growth.

Changing user needs and accelerating demand for greater networking capabilities are providing the telecommunications industry with compelling reasons to transform today's networks. The challenge facing the industry – a challenge that stands in front of tremendous market opportunity – is to evolve the existing voice-optimized, public switched telecommunications network into a multimedia, variable bandwidth, broadband network to which all users have immediate global access.

2.1.2 User Requirements and B-ISDN

Users' requirements have evolved over the last decade from the need for relatively stable and simple voice connectivity to include such advanced capabilities as interactive imaging, full-motion video conferencing, multimedia file transfer, and LAN-to-LAN connectivity. When effectively networked, these capabilities can enhance productivity and decision making, accelerate the movement of information, and remove distance as a barrier to communications within and between companies, as well as across nations.

The network infrastructure articulated in the B-ISDN vision is considerably different from the one that exists today. The ATM based B-ISDN infrastructure will:

- Offer megabits of bandwidth on demand;
- Switch all types of traffic-from POTS to new multimedia broadband services;
- Simplify the network, by reducing the number of physical interfaces and network elements;
- Give all businesses – including large, small, and branch offices – access to the full range of advanced broadband services;
- Be based on open architecture, standard protocols, and multivendor connectivity;
- Ensure modular, seamless evolution path.

2.1.3 Need for Broadband

To a large extent, demand for higher network bandwidth comes from the growing penetration and power of desktop computers. Since 1983, more than 113 million desktop and transportable personal computers (PCs) have been sold worldwide, and it is estimated that another 107 million will be sold within the next four years. It is these PCs – which now offer end users such advanced capabilities as color, audio, and full motion graphics and video – that have changed the networking needs of business. The centralized computing environment of yesterday has been replaced by distributed computing and database islands.

Increasingly, these islands are being linked at single sites by local area networks (LANs), representing a growing marketplace need for high speed interconnection. Five years ago, less than 10% of all PCs were connected to LANs. This year, the percentage will increase to almost 30%, and by 1993, more than 40% of all PCs will be connected by LANs.

The success in connecting LANs to other LANs, however, has been less than perfect. Although reliable and widely available, today's public data networks are generally limited to transmission rates of 56 kb/s – too slow to be an attractive option for interconnecting LANs that themselves operate at between 4 to 100 Mb/s. While some businesses have chosen to use private dedicated networks to interconnect these LANs across their multisite organizations, private lines can be difficult to reconfigure and are not well suited for intercompany and intra-enterprise communications.

Further evidence of user need can be seen in the emerging use of imaging as a form of information handling, the growing using of video conferencing, and the increased importance of telecommunications in education and healthcare. Many hospitals, for example, are experimenting with communications systems that combine voice, X-ray images, and text to improve timely communication of radiological images and diagnostic reports to physicians treating hospital patients. These systems today, however, generally operate within single hospitals, with few connections to other hospitals, clinics, or physicians' private offices.

2.1.4 ATM-Broadband Network Protocol

B-ISDN, which will give the switched telecommunications network the flexibility to handle advance broadband services, uses a new protocol called Asynchronous Transfer Mode (ATM). The ATM protocol, which has been agreed upon internationally, will position the network provider to meet rising customer demand for switched high-bandwidth services. Increasingly, the telecommunications network, will be required to provide large amounts of bandwidth rapidly for variable durations. It will also have to support services reliably regardless of whether they use variable or constant bandwidths, need single or parallel point-to-point connections or require in-band procedures to route connections across the network and to support end-to-end information transfer.

For example, the transfer of data between two supercomputers – a very low distribution, low interaction application – needs very high bandwidth from the telecommunications network. In contrast, another application environment that links an advertising or publishing firm with its suppliers such as graphic designers, type setters, color separators, and printers, requires the network to support a high degree of distribution and user interaction, as well as offer high bandwidth.

While today's network could technically provide new high-bandwidth services, it can not do so cost effectively because of the rigid way in which it subdivides and allocates network capacity to services. This method of allocating capacity to transfer blocks of information across the network – called the transfer mode – follows a set of rules and concepts for dealing with bandwidth and time.

In today's digital voice network, the transfer mode – called synchronous transfer mode (STM) – fixes the movement of information blocks to time, at regular intervals (bytes/125 microseconds). Specifically, STM allocates time slots within a synchronously recurring frame to a service for the duration of the call. Multiplexing and switching equipment divide the available network capacity into hierarchy of fixed size channels. Each STM channel is identified by the position of its time slots with in the frame.

STM works best when the network is handling a single service, such as the continuous bit-rate requirements of voice, or a limited mix of services at fixed channel rates. In the future, however, a dynamically changing mix of services will require a much broader range of bandwidth and a switching capability for both continuous traffic and non-continuous traffic

To be effective, the interconnection of LANs that use such standards as Ethernet, 100-Mb/s Fiber Distributed Data Interface (FDDI), and IEEE 802.6 will require much more bandwidth than is commonly used today. Future systems will likely be called upon to provide transport between ultra high speed supercomputer interfaces, such as those that meet the ANSI's High Performance Parallel Interface (HPPI) standard at rates of

800 Mb/s and 1.6 Gb/s.

While STM could provide most of these services, the network provider would have to supply and tariff for facilities that are dedicated 100% of the time for the full bandwidth needed by each service, even if users require the peak bandwidth for only a fraction of the time. To assign such bandwidth full time, the network would operate at low efficiency and the cost to users would be prohibitive.

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 header (5 octets) and an information field (48 octets). Each cell header contains a label field, which associates the cell with the service using that cell – much like the time-slot position for channel identification in STM networks. The label field, in turn, contains a routing field, which is divided into two parts: the virtual channel identifier (VCI), which associates each particular cell with a virtual channel; and the virtual path identifier (VPI), which allows groups of virtual channels to be handled as a single entity.

The cell header does not contain any information that is specific to a particular service or service class. As a result, the network provider can use a common transport mechanism for any type of service. The service specific data, called the payload, is contained in the ATM cell's information field. When required for a particular service, the information field also contains service adaptation fields. With ATM, the routing information resides in the cell header. Instead of counting bytes coming into a switch and matching them to indexing tables as in STM, the ATM switch extracts the cell header and reads its VCI to index a routing table in the switch. The routing table then tells the switch where to direct the cell.

To meet the particular needs of each service, ATM maps the service into its cells using protocol elements of the ATM adaptation layer. These protocol elements match the transport characteristics of the ATM transport layer to the service-specific transport requirements, and enable exact recovery of the original service signal. Different ATM adaptation layers may be used for different service requirements.

2.1.5 ATM Network Components

To implement an ATM network, network providers typically have to deal with three groups of network components:

- Transport network, based on Synchronous Digital Hierarchy (SDH);
- Central office and tandem ATM switching equipment; and
- Terminals, terminal adaptors, and remote ATM cell multiplexers at or near subscriber location.

The first group of ATM network components, the transport network, includes statistical multiplexers that enable large number of subscriber links to be concentrated into one or more high speed links.

2.1.5.1 ATM Switches

In large ATM networks, the second group of network components – ATM switches – includes both central office and tandem switches. Central office ATM switches provide both signal routing and service-related functions such as call signaling and setup, traffic screening, and billing – functionality similar to that of a conventional digital switch.

However, because of the ATM protocol, the switch will be able to work independently of the channel rates and, consequently, will have the flexibility to handle very high speed, high bandwidth services entering the ATM network at a wide range of bit rates. This capability has been impractical with STM.

Because ATM tandem switches are required to provide only automatic signal routing, their functionality can be less than that of the central office ATM switch. The cell routing switch core of the ATM switches has three fundamental functional parts:

i. a switchable path, to carry the actual ATM traffic;

ii. buffers, to hold ATM cells temporarily to avoid collisions between cells headed for the same internal output port; and

iii. header decoding and path steering logic circuits.

2.1.5.2 Terminal Equipment

The third group of ATM network components, terminal equipment, could include a multifunction workstation connected to a user network interface that employs one ATM protocol for all communications – from signaling to voice, data, image, and motion video communications. Today's terminal equipment at a multifunction workstation could be connected to the user network interface through an ATM terminal adaptor. Although one typical implementation would be connection of a high-speed LAN to other LANS over the ATM network, the structure of ATM provides flexibility in offering transport services to non-typical application environment, which features a myriad of terminals operating at unpredictable rates.

2.1.5.3 Unique Benefits

The absence in ATM of the rigid bit-rate hierarchy of STM systems will enable future services to use the bit rate that is most suitable to the service. Because the ATM protocol functions independently of transmission, the network provider can assign the ATM services to a higher rate facility without having to alter any ATM network components to make the network run faster. All that happens is that more cells per unit of time are processed. The rate-adaptive and rate-independent nature of the ATM protocol enables network provider to carry any non-standard service data rates generated from the 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 multi-megabit broadband applications, without rendering the user's equipment obsolete. In addition, ATM offers service developer much greater freedom from the current rigid dictates of an inflexible network, and gives the network providers the means to reach new markets quickly and cost effectively.

In addition to supporting new services, B-ISDN can reduce the cost of operating the network. This is accomplished by integrating switching, signaling, and transport facilities both at the access network and with in the backbone network. This integration enables the B-ISDN network operators to handle special services in a more standardized switching techniques. This reduces the need to build service specific transmission and switching systems to support broad mix of services, and it can effectively integrate network signaling with user information to reduce cost further. The major benefit of B-ISDN is the reduction in cost in managing and operating a single network to support multiple application.

2.2 Potential Users

The potential users of B-ISDN by satellite may include all segments of society. While B-ISDN was previously thought to be a future residential offering, most industry observers now agree that B-ISDN access will be limited to business applications for the foreseeable future. It is the unanimous position of the Regional Bell Operating Companies and Bell Communications Research that fiber in the loop will not be deployed until the technology is at, or below cost parity with today's copper system for the delivery of Plain Old telephony according to a December 1990 Bellcore Technical Advisory. On the other hand, the interexchange carriers have already deployed fiber and are in the process of experimenting with broadband technology. Therefore, a unique opportunity exists for satellite systems to support services not only in the local loop, but also to provide special networks to support B-ISDN services in a wider context.

In our view the following industries are either already using or planning to use broadband technology. For them the transition from present day broadband technologies to industry standard B-ISDN will be easy and will be a natural evolution. The industries that are involved in one form or another in broadband technology are:

- Advertising
- Aerospace
- Architecture firms/heavy construction contractors
- Automobile manufacturers
- Cable TV
- Colleges and Universities
- Commercial real estate management/realty
- Computer and office equipment manufacturers
- Federal Reserve Banks
- Financial services/banking
- Heavy electrical equipment

- Industrial supply firms (with catalog sales)
- Insurance
- Internal Revenue Service
- Legal services
- Major research institutions
- Meteorology/weather services
- Military logistic commands
- Municipal court systems
- Oil exploration
- Petrochemicals
- Primary and secondary schools
- Printing and publishing
- Private hospitals and associated medical services
- Public safety and police
- Public utilities
- Retail trade
- Telephone common carriers
- Travel agencies/reservation networks
- TV broadcast networks
- Video pre and post production services.

In general, it is believed the industries listed above will use a public switched broadband network and services to meet their requirement.

2.3 Broadband Services

When the capacity available to the ISDN user is increased substantially, the range of services that it can support also increases substantially. CCITT classifies the services that could be provided by a B-ISDN into two categories:

1. Interactive services which have two way exchange of information, and
2. Distribution services which are primarily one way.

2.3.1 Interactive Services

Interactive services are those in which there is a two-way exchange of information (other than control signaling information) between two subscribers or between a subscriber and a service provider. These include conversational services, messaging services, and retrieval services.

2.3.1.1 Conversational Services

Conversational services provide the means for bidirectional dialogue communication with bidirectional, real-time (not store-and-forward), end-to-end information transfer between two users or between a user and a service-provider host. These services support the general transfer of data specific to a given user application. That is, the information is generated by and exchanged between users; it is not "public" information.

This category encompasses a wide range of applications and data types. These are moving pictures (video), data, and document. In the long term, perhaps the most important of these services is *video telephony*. Video telephony simply means that the telephone instrument includes a video transmit and receive/display capability so that dial-up calls include both voice and live picture. The first use of this service is likely to be the office environment. It can be used in any situation where the visual component of a call is advantageous, including sales, consulting, instruction, negotiation, and the discussion of visual information, such as reports, charts, advertising layouts, and so on. As the cost of videophone terminals declines, it is likely that this will be a popular residential service as well.

Another video conversational service is *videoconference*. The simplest form of this service is a point-to-point capability, which can be used to connect conference rooms. This differs from videophone in the nature of the equipment used. Accordingly, the service must specify the interface and protocols to be used to assure compatible equipment between conference rooms. A point-to-point videoconference would specify additional features such as facsimile and document transfer and the use of special equipment such as electronic blackboards.

A different sort of videoconference is a multipoint service. This would allow participants to tie together single videophones in a conference connection, without leaving their workplaces, using a video conference server with in the network. Such a system would support a small number of simultaneous users. Either one participant would appear on all screens at a time, as managed by the video conference server, or a split screen technique could be used.

A third variant of video conversational service is *video surveillance*. This is not a distribution service, because the information delivery is limited to a specific, intended subscriber. This form of service can be unidirectional; if the information is simple video images generated by a fixed camera, then the information flow is only from video source to subscriber. A reverse flow would come into play if the user had control over the camera (change orientation, zoom, etc.).

Video/audio information transmission service is a final example. This is essentially the same capability as video telephony. The difference is that a higher quality image may be required. For example, computer animation that represents a detailed engineering design may require much higher resolution than ordinary human-to-human conversation.

Representative file sizes without further processing for the transmission of normal images and data files are given below:

- Color television picture: 4 to 6 Mb
- High definition television picture: 16 to 24 Mb
- A4 facsimile:
  - 1 to 4 Mb (black and white)
  - 9 to 16 Mb (halftone)
  - 30 to 60 Mb (color)
- Newspaper page: 200 to 600 Mb
- High def. computer graphics: 20 to 100 Mb
- Large data file: 100's Mb

The use of signal processing techniques on the data bit rates of images can be reduced by a factor of 3 to 15. Although this is usually accompanied by a deterioration in picture quality, it is not necessarily detectable. Data reduction saves transmission capacity, however, at the cost of more complex terminal equipment.

Video telephony offers practically all the elements of communication that are available in normal face-to-face conversation, including gestures, facial expression, and posture, which, through the ability to transmit moving images, will add to the advantages of improved speech transmission quality. Apart from actually showing objects and texts when explaining things, one is able to draw sketches, show scenes, and transmit electronic video recordings and pictures.

The variety of video telephony uses covers a wide range of commercial and private activities. It can be used to assist in coordination processes where the emphasis is visual, i. e., on designs, as in the fashion-oriented textile and leather goods industries; to help mail-order companies and travel agents produce their catalogs and prospectuses; to provide support for difficult planning jobs and in consulting work and sales negotiations; and to aid complex learning processes. Video telephony will be of particular benefit to people with hearing difficulties, too.

Video telephony is aligning itself on the standards established for television, e. g., on the 5 MHz standard. A transmission rate of 140 Mb/s is emerging as the possible standard for the subscriber area. This rate permits using less expensive terminals and offers a more favorable basis for high definition television than other alternatives (70, 34 Mb/s), although these are also being discussed. As a supplement to video telephony, a memory-based "picture mail" service is imaginable, permitting the exchange of film and pictures, with a verbal and textual accompaniment, via an electronic mailbox. A special low-cost form of video telephony, known as semivideo telephony, requires only one broadband channel in the user's direction. There would be no problem changing over to full video telephony at a later date, as this would only require installing the missing network and terminal components.

Video conferences can take the place of numerous meetings to which people now have to travel from different places, although in many cases personal contact will still be essential in the future. Video conferences will not only save time and traveling costs, but also improve and speed up the information, coordination, and decision-making process by allowing people to convene more frequently and with greater flexibility, and by allowing experts to be consulted at short notice. Video conferencing is especially suitable in the case of regular, routine meetings at which the participants know each other personally.

Where video conferences between studios are concerned (studio conferencing), it would seem practical to aim for full television picture quality as a longer-term objective. This would allow the same technology to be used, in part at least, for both video telephony and video conferencing. Conferences may also be supported with high-quality document, text, and data transmissions. Apart from private video conference studios for industrial, commercial, and administrative use, there will be public studios (for international and intercontinental conferences as well) that the network operators, as well as hotel chains and airport authorities, will offer to users who have not yet installed their own facilities, or to occasional users and travelers.

Once video telephony has been introduced, setting up workstation conferences will shorten and simplify the whole process of convening for a video conference. Without leaving his own workstation, each participant will simply link up with his video partners when required. The participants will appear on the workstation screens either individually or in groups.

2.3.1.2 Conversational Service Applications

High-speed document traffic is an important office application. An electronic document can contain images, text, and data as well as commentaries in digitized speech form. Using and transmitting electronic documents should cut down on paper documentation. Already, some higher grade video terminals are in operation and are called bit map terminals, which use screens that contain between 3 and 5 million dots for displaying documents. A bit rate of at least 2 Mb/s is required for the exchange of documents between workstations, between workstation terminals and archives, and for exchanging drawings between design centers.

The ability to send out fully assembled pages of newsprint as facsimiles, or to transmit printing-plate data, will enable the larger publishing houses to keep their off-premises printers supplied from a centralized editorial office. The result will not only be more up-to-the-minute information because of the longer deadlines, but faster and cheaper newspaper distribution as well. To ensure the quality needed for printing, roughly 100 to 600 Mb of data will need to be sent for a typical page of newsprint. Where necessary, this could be reduced by a factor of 15 through data compression that uses suitable supplementary equipment. At the receiving end, the pages of newsprint will be fed out directly onto film, photographic paper, or printing plates for printing in either black and white or color. A bit rate of 2 Mb/s (for compressed data) and more (for uncompressed data) is desirable for achieving acceptable transmission times.

Apart from the transmission of A4 color documents (color facsimile), other applications for high-speed document traffic will arise from the growing need to remotely copy and print out large volumes of information: fax mail, textfax mail, and text mail in bulk traffic for closed user groups or for the public electronic mail service. High-speed transmissions can help when sizable quantities of documents, such as letters, reports, lists, drawings, and the like, are needed elsewhere in a hurry. The facsimile equipment of the future will handle this, while offering the requisite high quality, as will the use of high-definition laser printers with current operating speeds of up to 200 pages a minute. The same applies to the direct high-speed transmission of results from super-large computers to the printers or plotters of the computing center's customers (remote printing). Transmission rates of 2 Mb/s and more will still be required for this, despite the use of redundancy reducing techniques.

Applications for *high speed data traffic* could also increase as more efficient networks, computers, memories, and output devices become available. The possibilities range from computer networking serving the most varied purposes to the coupling of in-house high-speed networks (local area networks).

Future computer networking on the basis of fast and reliable data transmission (with a transmission rate of up to 2 or 34 or even 140 Mb/s) offers a number of operational and economic advantages:

- To cope with occasional peaks in the load, it is possible to use computers operated by the same institution at different localities. With this type of load sharing, on-site processing capacity need only be designed for handling the basic load, not the peaks.

- To provide the high level of safety concerning failures required by industry, banks, insurance companies, and public authorities, there must be at least two identical systems (even if, as far as requirements are concerned, just one would suffice), and they should be set up as far apart as possible. An efficient mutual backup system can be established by operating the two systems in parallel, or at least by relocating and continually updating the safeguarded programs and databases. The standby system could occasionally be used for other tasks if there is no great demand for real-time response.

- Compared to centralized databases, distributed databases in many cases will offer organizational advantages for the collection, storage, and interrogation of data. To ensure that the data in noncentralized databases are current and mutually consistent, database extracts will have to be transmitted between the relevant locations.

- In a few years' time, when artificial intelligence has become more widespread in its application, it will be possible for complex problem-solving and decision-making tasks to be supported by expert systems with the aid of functional interworking between procedure and knowledge banks. Examples include medical diagnostics, mineral resource exploration, and technical fault detection (using, among others, techniques based on image analysis).

There is also a need for high-speed data transmission for file transfers in connection with mass booking, the remote loading of programs and changed databases, and the remote diagnosis of computers and comparable technical systems. Being able to transmit scientific and technical measurements, radar information, etc. quickly and directly will obviate the costly and time-consuming task of data buffering and make it easier to process the data and to carry out any control measures that may be necessary.

The coupling of private automatic branch exchanges (PABXs) or local area networks (LANs) via in-house and public networks is likely to increase in significance. And no matter what the distance between the distributed networks, after they have been coupled in this way, the communication facilities offered to the workstation users should be as good as those available via the autonomous networks. LANs with an overall bit rate of 10 Mb/s are already in wide use, and LANs operating at 100 Mb/s and above are currently being developed. For interworking between the various intercoupled high-speed networks, a data transmission speed of 2 Mb/s and more – predominantly via dedicated links – will initially be required, and at some time in the future, 140 Mb/s will be required.

The next type of conversational service is for data. In this context, data signify arbitrary information whose structure is not visible to B-ISDN. Examples of applications that would use this service are the following:

- File transfer in a distributed architecture of computer and storage.
- Large-volume (load sharing, back-up systems, decentralized databases, etc.).
- Program downloading.
- Computer-aided design and manufacturing (CAD/CAM).
- Connection of local area networks (LANs) at different locations.

Finally, there is the conversational transfer of documents. This could include very high resolution facsimile or the transfer of mixed documents that might include text, facsimile images, voice annotation, and/or a video component. Two types of applications are likely here: a document transfer service for the exchange of documents between users at workstations; and a document storage system, based on the document transfer service, which provides document servers for the filing, update, and access of documents by a community of users.

2.3.1.3 Messaging Services

Messaging services offer user-to-user communication between individual users via storage units with store-and-forward, mailbox and/or message handling (e.g., information editing, processing, and conversion) functions. In contrast to conversational services, messaging services are not in real time. Hence, they place lesser demands on the network and do not require that both users be available at the same time. Analogous narrowband services are X.400 and teletex.

One new form of messaging service that could be supported by ISDN is *video mail*, analogous to today's electronic mail (text/graphic mail) and voice mail. Just as electronic mail replaces the mailing of a letter, so video mail replaces mailing a video cassette. This may become one of the most powerful and useful forms of message communication. Similarly, a document mail service allows the transmission of mixed documents containing text, graphics, voice, and/or video components.

2.3.1.4 Retrieval Services

Retrieval services provide the user with the capability to retrieve information stored in information centers that are, in general, available for public use. This information is sent to the user on demand only. The information can be retrieved on an individual basis; that is, the time at which an information sequence is to start is under the control of the user.

An analogous narrowband service is *videotex.* This is an interactive system designed to service both home and business needs. It is a general-purpose database retrieval system that can use the public switched telephone network or an interactive metropolitan cable TV system. The videotex provider maintains a variety of databases on a central computer. Some of these are public databases provided by the videotex system. Others are vendor-supplied services, such as a stock market advisory. Information is provided in the form of pages of text and simple graphics.

Broadband videotex is an enhancement of the existing videotex system. The user would be able to select sound passages, high-resolution images of television standard, and short video scenes, in addition to the current text and simplified graphics. Examples of broadband videotex services are as follows:

- Retrieval of encyclopedia entries
- Results of quality tests on consumer goods
- Computer supported audio visual entries
- Electronic mail order catalogs and travel brochures that have the option of placing a direct order or making a direct booking.

Another retrieval service is *video retrieval.* With this service, a user could order full-length films or videos from a film/video library facility. Since the provider may have to satisfy many requests, bandwidth considerations dictate that only a small number of different video transmissions can be supported at any one time. A realistic service would offer perhaps 500 movies/videos for each two-hour period. Using a 50-Mb/s video channel, this would require a manageable 26-Gb/s transmission capacity from video suppliers to distribution points. The user would be informed by the provider at what time the film will be available to be viewed or transmitted to the subscriber's video recorder.

Because of the growing need for information in all areas and the growing volume of information available on paper, film, disks, cassettes, and electronic data carriers, many people will welcome the opportunity to retrieve the information they require immediately and selectively. Retrieval services help to solve this problem, while at the same time bring additional information within reach that would otherwise be difficult or impossible to obtain.

Film retrieval will allow quite lengthy feature films, documentaries, and instructional films to be selected from "videotheques" and film libraries with videotex support. Depending on the availability of suitable playing equipment and broadband channels, the films will then be transmitted automatically and copied onto the users' preprogrammed video recorders when required, or at some other time (copying on demand).

Broadband videotex will not only allow text and graphics to be called up from a computer center as in the case of the videotex service, but will also include sound, images, and short film sequences as well. Examples of broadband videotex applications (where it is desirable or even essential to add speech and music, images, or film scenes of television quality) include encyclopedia entries, the results of quality texts on consumer goods, instructions, film accompaniments to periodicals and books, computer-supported audiovisual lessons, and electronic mail-order catalogs and travel brochures, with the option of placing a direct order or making a direct booking.

The sound, image, and film information will be transmitted to the user via switched broadband channels from an image/film base controlled by the videotex computer center. The narrowband information (which includes, among other things, pages of text and graphics information for the user, as well as user requests transmitted to the videotex center) will be sent on the customary videotex channels. The introduction of broadband videotex will be favored by the development of erase-and-record video disks for the image/film base and of TV-image memories for the user terminal equipment.

Besides film retrieval and broadband videotex, there are other types of information retrieval, a particular feature of which are more stringent demands on picture quality (relative to today's television standards). In this connection, the main emphasis over the next few years will be on local or in-house applications, whereas later, as the networks become available, there will be an increase in retrieval from remote archives and computers. This will also give smaller users (attorneys' and engineers' offices, etc.) access to the central services that will at first only be available to large users.

Document retrieval from electronic archives and registries will probably become an important application in the office sector. The required A4 documents or drawings can be requested via a narrowband channel, transmitted in a fraction of a second on a broadband channel (2 Mb/s or more), and displayed in the correct format at a high-definition video workstation where, if necessary, it can be processed and restored.

Initial experiments are currently being conducted using digital optical disk storages, although the disks can only be used once for writing the processed data of the documents being filed. Each disk can store approximately 50,000 A4 pages after the data have been compressed. The access times are in the order of 0.1 s or less, which is essential for fast searches through stored documents. Over the next few years, further improvements can be expected in the areas of storage volume, access time, and read-out rate, as well as from the development of erasable and rewriteable disks.

High-definition image retrieval will form the basis for the interactive composition of newspapers, periodicals, books, advertising material, and television programs in editorial offices or studios and for digital processing that will permit image evaluation, enhancement, and synthesis in the fields of meteorology, cartography, astronomy, and space travel, in industry and administrative sector, for military applications, and also for medicine.

The scope of local or remote applications ranges from electronic editing techniques to replace the old "cut-and-paste" method of producing newsprint, to digital imaging systems that give doctors useful internal diagnostic information: ultrasonic scanning, nuclear medicine, computer tomography, digital subtraction angiography, and, as the latest addition, nuclear magnetic resonance imaging. What is called picture archiving and communication systems (PACS) is currently being developed to increase efficiency, especially with regard to noncentralized retrieval, and to picture transportation and archiving. To begin with, these will require a data transmission rate of 34 Mb/s, as well as extensive storage systems with a capacity of up to 1,000 Gbytes as a prerequisite for short response times.

There are applications for *graphics, text, and data retrieval* in the area of noncentralized information generation and processing: computer-aided design (CAD) and computer-aided manufacturing (CAM) in electronics, in vehicle and aircraft construction, and in connection with other engineering activities, as well as work processing and software engineering and programming, and documentation, and telesoftware retrieval.

Numerous instances of problem solving in high technology would be inconceivable without computer-aided methods such as CAD, including simulation, evaluation, and optimization procedures. The terminals, equipped with high definition screens (up to 3,000by4,000 dots), are connected using private or/and public networks to efficient central computers, via which the required graphics are called up, modified by means of a light pen or similar device, and immediately fed out again in modified form after being processed in the central computer. Interactive CAD processing requires a transmission rate of up to 2 Mb/s and above.

2.3.2 Distribution Services

Distribution services are those in which the information transfer is primarily one way, from service provider to B-ISDN subscriber. These include broadcast services, for which the user has no control over the presentation of the information, and cyclical services, which allow the user some measure of presentation control.

2.3.2.1 Distribution Services Without User Presentation Control

Services in this category are also referred to as broadcast services. They provide a continuous flow of information, which is distributed from a central source to an unlimited number of authorized receivers connected to the network. Each user can access this flow of information but has no control over it. In particular the user cannot control the starting time or order of the presentation of the broadcasted information. All users simply tap into the information flow.

The most common example of this service is broadcast television. Currently, broadcast television is available from network broadcast via radio waves and through cable television distribution systems. With the capacities planned for B-ISDN, this service can be integrated with the other telecommunications services. In addition, higher resolutions can now be achieved and it is anticipated that these higher-quality services will also be available via B-ISDN.

An example of a nonvideo service is an electronic newspaper broadcast service. This would permit the transmission of facsimile images of newspaper pages to subscribers who had paid for the service.

2.3.2.2 Distribution Services With User Presentation Control

Services in this class also distribute information from a central source to a large number of users. However, the information is provided as a sequence of information entities (e. g., frames) with cyclical repetition. Here, the user has the ability of individual access to the cyclical distributed information and can control start and order of presentation. Due to the cyclical repetition, the information entities, selected by the user, will always be presented from the beginning.

An analogous narrowband service is *teletext*. Teletext is a simple, one-way system that uses unallocated portions of the bandwidth of a broadcast television signal. At the transmission end, a fixed set of pages of text is sent repeatedly in round-robin fashion. The receiver consists of a special decoder and storage unit, a keypad for user entry, and an ordinary television set.

Teletext is oriented primarily to the home market, with different sets of pages offered on different channels. Examples of information presented by such a system are stock market reports, weather reports, news, leisure information, and recipes.

With Broadband ISDN (B-ISDN), an enhancement to teletext known as cabletext can be provided. Whereas teletext uses only a small portion of an analog television channel, cabletext would use a full digital broadband channel for cyclical transmission of pages of text, images, and possibly video and audio passages. As an electronic newspaper that uses public networks, or as an in-house information system for trade fairs, hotels, and hospitals, cabletext will provide low-cost access to timely and frequently-requested information. A typical system might allow access to 10,000 pages with a cycle time of 1 second.

The main developments where *television* is concerned consist of an expanded range of available programs and information, pay television, and in the medium term, new television standards. All of these aim at satisfying existing requirements.

The expanded range of programs and information consists of not only programs that can be received directly (including satellite broadcasts), retransmitted programs, and delayed transmissions from both home and abroad, local studio broadcasts, and the "open channel" for everyone, but also periodically transmitted information presented in the form of distributed cable newspapers with pages of text, moving messages, and pictures ("cable images for all"), although there is no "page turning" function available to the users. The B-ISDN, with its wide range of options made possible by centralized switching, will one day give users "live" participation in telefacilities such as trips around town or a visit to the zoo, theater, or museum. And there will also be applications for special users (closed-circuit television): city television using television screens set up in public places, services for doctors' practices or hospitals, hotels, discotheques, and cinemas, or business in-hours information systems.

The United States and various other countries already have pay television. "Pay-per-channel" is the most common method of charging for the service. The "pay-per-view" method, where a charge can be made for each broadcast or according to how long the service is used, is currently of little but growing significance, and requires more expensive charge-collection facilities than the pay-per-channel method.

The purpose of new television standards is to improve picture and sound quality. The most important developments and efforts at standardization currently in progress are being directed at improvements within the scope of existing standards, multiplexed analogue components (MAC) techniques, and high-definition television (HDTV).

There are a number of possible approaches that would lead to compatible improvements within the scope of existing television standards. These range from the use of digital technology in the studio sector to large-scale integrated digital television receivers with an integral image memory. The advantages of this memory include reduced noise and flickering and functions such as picture freeze. The proposed MAC techniques, on the other hand, although providing better picture quality than today's standards, as well as allowing additional sound and data signals to be transmitted, are not compatible with present day standards for television signals.

HDTV is the long-term solution; apart from its applications in the professional sector, it will put the quality of television reception on a totally new plane. A number of different concepts are currently being discussed, all of them based on roughly twice the number of lines provided for by present day standards, and including the possibility, at some time in the future, of presenting nonflickering images on large, flat screens (1 x 2 m, for instance), or via large-image projectors.

HDTV requires a baseband signal of between 20 and 30 MHz. The corresponding digital value is around

600 Mb/s. Taking the use of reduction techniques into account, it can be assumed that perhaps a 140 Mb/s transmission channel will one day be sufficient for the HDTV signal. The most suitable transportation paths for HDTV productions are further-developed versions of today's video cassettes, video disks, broadcast satellites, and in particular, the broadband ISDN. Apart from its use in cinema film production and marketing, HDTV is not a project for the immediate future, although it could become a reality in Japan in the early 1990s. One thing that is absolutely essential for its introduction is the availability of low-cost terminals.

The *distribution of other information* via broadband channels comprises facsimile newspapers or tele-newspapers, text information services for business user groups (e. g., detailed commercial information transmitted in coded form for further use in conjunction with personal computers), as well as data distribution services for regularly updating programs and databases in similar subsystems in a large computer network.

2.3.3 Example Integrated Applications

A number of example B-ISDN applications that make use of various B-ISDN services are identified and presented in this section. Examples include (1) telemedicine, (2) virtual internal department, (3) distance learning, and (4) teleconferencing and messaging.

2.3.3.1 Telemedicine and B-ISDN

Telemedicine network is being studied as a vehicle for providing health care services to remotely located and under privileged segments of the society. The population in the rural areas have long been plagued by a shortage of health care providers and a disparity in terms of access to quality health care resources compared to urban areas. In 1980, the Army, Navy, and Air Force joined other federally sponsored studies of health care delivery in an effort to improve medical services to personal on small bases and ships at sea. The main interest was in the field of teleradiology, where prompt interpretation of radiographic images in necessary for providing timely treatment. The Army envisioned that the successful development of a teleradiology system would not only serve military personnel during peace time, but also provide a knowledge base upon which to build filmless radiology systems that would improve medical care under combat conditions. In addition to its use in teleradiology, a high-bandwidth telemedicine network is useful in the field of pathology.

The medical industry can benefit from the development of new network services such as image transport at variable bit rates, image processing, image consultation, and image network management. Image acquisition, image storage, image display and processing, and image transport represent four major categories of medical imaging technology. In many medical institutions, the digital images are stored on magnetic tapes for archival purposes. Using radiographic film as a means of diagnosis and moving this film from one physician to another for consultation is expensive, cumbersome, and inefficient. Digital radiology has so far been identified as a major application needing broadband communication capabilities. This is only a small part of the total amount of image information in the over all area of radiology. Developments in digitization techniques, storage technologies, and broadband communications technologies may lead to filmless radiology. A broadband network will allow the sharing of specialists' expertise by many remotely located patients irrespective of distance.

To support such a service, the network should be able to provide an image transport communication time of the order of 1 to 2 seconds per image. To meet the real time image transport requirement calls for an adequate channel bandwidth. The emerging broadband network will be able to provide this type of bandwidth on demand based on customer needs. In addition, all medical communications such as integrated customer records and multimedia voice, data, image, and video can also be supported by the broadband network based on B-ISDN protocols.

The broadband network for telemedicine will provide a range of medical communication for a number of communities of interest in the medical field. These communities of interest include referring physicians, radiologists, pathologists, surgeons, the medical facility, research faculties, insurance and legal personnel. The following service scenarios identify the requirements for broadband communications to support telemedicine:

- A referring physician needs to transfer a patient's examination record file, containing high-quality images and other pertinent records, from a centralized image database to his work station.
- A referring physician needs to consult with specialist using a common image database but having

incompatible terminal.

- A real-time consultation session takes place among three experts – a referring physician, a radiologist, and a surgeon. During this consultation session, a reference to a common image and an area pointed to by one expert must be viewed simultaneously by all the consultants.
- A medical researcher needs to access and track a patient's record from a centralized database to study the impact of a particular course of treatment over a period of time.
- A complicated surgical operation performed by a specialist must be transmitted to three neighboring hospitals and a research facility.

These limited scenarios highlights the need for a broadband based flexible interactive communication capability. One of the salient features of this type of communication is the need for multipoint and broadcast communication capability.

The B-ISDN architecture has the capability to support wide range of interactive, multimedia, and variable bandwidth communications services. The users should be able to access bandwidth on demand which may range from few bits to multiple megabits. The following are some of the medical communications services that can be support using B-ISDN:

- File transfer – direct: machine-to-machine communication, prompted in real time or preprogrammed.
- File transfer – indirect: machine-to-machine communication with format conversion by network
- Image consultation – direct: multiparty image communication service with compatible terminals.
- Image consultation – indirect: multiparty image communication service with incompatible terminals
- Image processing: image compression and 3-D image formulation
- Image broadcast: image broadcast to multiple institution for training/education.

The majority of services in telemedicine requires multipoint and broadcast capability as well as multimedia support. B-ISDN based on ATM concept provides an ideal means to support such an on demand, variable bandwidth service. The ATM virtual channel concept allows multiple closed user groups to be formed to meet the requirements of the application. In addition, the complex and costly equipment may be shared among a number of locations. This calls for a communications networks that is flexible. As the majority of communication in telemedicine requires multipoint and broadcast capability, a satellite based B-ISDN network will better support these capabilities than its terrestrial counterpart.

2.3.3.2 Virtual Internal Department

During the next decade, image intensive applications are expected to achieve substantial growth, which in turn drive an increasing demand for high-speed data transmission. Multimedia applications are likely to increase in importance for a variety of corporate automation applications, all of which will be widely deployed only if productivity is measurably improved. As oil prices increase, the motivation to use communication instead of transportation increases. Distance education and training are expected to increase in cost effectiveness. In addition, corporate growth rates are often greatest in the smaller branch offices. Indeed, a reasonable case exist that 80% to 90% of smaller branch offices have the greatest unmet corporate communications needs.

Increasingly, large corporations are moving to bring their vendors and strategic partners onto their network as Virtual Internal Departments (VIDs) to improve business efficiency. For example, auto manufacturers want to have their major component vendors "on-line" to accomplish a variety of functions such as placement of orders for just-in-time delivery, or down-loading Computer-Aided Design (CAD) files to a machine shop that can directly drive their computer-controlled machines.

As large corporations bring vendors "on-line", these smaller business establishments become virtual establishments of the corporate enterprise. In turn, these smaller businesses become, from the communications point of view, virtually indistinguishable from the smaller branch offices of the corporate enterprise itself. The most significant improvement resulting from this approach is the measure of response time or performance in milliseconds. Ultimately, many businesses would benefit if their customers had access to multimedia documents such as catalogs. For example, semiconductor manufacturers would benefit by having their data books and application notes available on-line to customers. It becomes apparent that the distinction between commercial and consumer applications of distance shopping will eventually become insignificant. The notion of VIDs will then extend to the residence.

The Home Information Professional (HIP) market also appears to be growing. Many of these HIPs are employees of large corporate enterprises. Many are single parents who can obviate the need for child-care services by providing a variety of interactive voice, data, and image services. The homes of these HIPs become VIDs of the corporate enterprise. As this phenomenon spreads, the residence/small business markets and the medium/large business markets become increasingly inseparable.

2.3.3.3 Tele-Education (Distance Learning)

A significant potential overlap between business and residential markets will emerge in the next few years as multimedia education and training applications become increasingly commonplace. These applications are currently being developed for use on LANs, and use digital compressed video and digital audio for the sight and sound portions of the multimedia experience. Annual public and private spending on elementary and secondary education in the U. S. is $189.1 billion. Annual spending by employer on formal and informal training of employees is $210 billion. Both business and non-business institutions are beginning to pursue distance learning to improve cost effectiveness and productivity. In addition major computer companies are aggressively pursuing the education and training market.

The trend is clear, that an increasing number of organizations, school districts, corporations, and government institutions are deploying computer and video networks to enhance the education and training. The national Foundation for the Improvement of Education (NFIE) has published a booklet, "Images of Potential – Learning Tomorrow", that describes a future in which communications, video, and computers provide multimedia learning and teaching opportunities for students, teachers, and parents.

2.3.3.4 Teleconferencing and Messaging

The most exciting possibilities are in the new or extended services that will link human working communities together and with information processing resources. In some countries, simple real-time video telephone service, both desktop and in conference rooms, is seen as a major attraction for business users. In addition more sophisticated conferencing possibilities are on the horizon. But the potential of non-real time communications is some times overlooked. Integrating and going far beyond today's electronic and voice mail systems, electronic messaging in the future will use a single subscriber identifier for all media. The user at a terminal may see a common message listing, similar to today's electronic mail listing, with indications of the media used as well as the originator and time of arrival.

Future multimedia messages may range from voice, graphics, hand drawing, messages with high resolution animated graphics, full color pictures, high quality audio, frequent annotation of one medium by another, and moving picture sequences. Multimedia messages can be created, sent, retrieved, forwarded, and stored with simple commands. Messaging will be closely coupled with real-time communications. For personal communication, users may feel more comfortable with video messaging than they have in the past trials of real time videophone. A video message can be edited by the sender until it is satisfactory, can be accompanied by high fidelity audio, and can include attachments in other media, such as documents and drawings. Company officers may broadcast messages to groups of employes. international banks might use video messaging to help overcome the time-zone problem, and soldiers and college students might send video messages to their families at home.

Personalized real-time multimedia communications is also going to become prominent. Desktop teleconferencing describes a group meeting conducted through desktop communication terminals. The terminals are increasingly coming to be seen as powerful work stations, with the participants sharing computer supported applications as well as interpersonal communications media.

These advances in technology will result in the integration of a wide range of communications facilities and the support of, in effect, universal communications with the following key characteristics:

- Worldwide exchange between any two subscribers in any medium or combination of media.
- Retrieval and sharing of massive amounts of information from multiple sources, in multiple media, among people in a shared electronic environment.

- Distribution, including switched distribution, of a wide variety of cultural, entertainment, and educational materials to home or office, virtually on demand.

2.4 Network Strategies for Broadband Services

In the past, the public telecommunications network has evolved to primarily serve relatively low-bandwidth requirements of the plain old telephones (POTs). Dealing with diversity in a network that was designed for homogeneity is slow, costly, and inefficient. Consequently, special services not falling within the performance envelope of voice have been forced of the network onto customized overlay networks. Overlay networks, however, limit service flexibility and are unable to exploit the strengths of the public network, such as a distributed networking architecture, inherent real-time call-based switching, economies of scale, unsurpassed quality of service, survivability, and a simple user interface.

2.4.1 SONET Based Networking

To support new broadband as well as old services, network architecture based on Synchronous Optical Network (SONET) standard have been developed. SONET defines standard interconnect rates of up to 2.488 gigabit per second, using a basic building block called the synchronous transport signal level 1 (STS-1). The frame format consists of two sections: the transport overhead and the synchronous payload envelope. The transport overhead consists of section and line overheads along with the STS-1 pointer which indicates the start of the STS-1 synchronous payload envelope. The synchronous payload envelope can be divided into virtual tributaries (VTs) to allow the transport and management of subrate payloads, such as, DS-1.

The SONET standard provides a number of important characteristics.

Payload capacity beyond 50 Mb/s allows the ability to support higher bandwidth applications.

Synchronous multiplexing provides network equipment with simplified access to the multiplexed channels, paving the way for cost effective, integrated interfaces on various network elements. In current transport network, asynchronous multiplex formats are used in a way that the signal must be completely demultiplexed before switching – a step that adds significant cost to the overall network.

Payload transparency refers to SONET's ability to transport payloads without regard to their exact structure. The interface between a payload and the SONET network is defined by a SONET standard mapping into the appropriate payload envelope.

Flexible bandwidth allocation means that bandwidth requirement of new services are not restricted to the STS-1 or VT capacities. Through process of STS-1 and VT concatenation, the network provider can offer services at n x STS-1.

Ability to transport existing digital hierarchy signals – SONET can provide efficient transport for the existing digital hierarchy as well as broadband channels.

Timing transparency takes into account the fact that the overall SONET network will not be entirely synchronous. Using the payload pointer, SONET can transport between synchronous islands the payloads carried within the payload envelope, and can do so free of error. When a payload envelope generated in one synchronous island crosses into another synchronous island, it will have a slightly different frame rate than the frame in which it is carried. This difference causes the position of the payload envelope within the frame to shift periodically. The payload pointer is designed to gracefully track shifts of the payload envelope within the frame.

The services and applications identified in sections above can be supported by a SONET based network. The SONET based network supports various bandwidth requirements in a an integrated way. This integration takes place at the physical layer, in that a single access segment from the customer premises is capable of supporting various applications with varying bandwidth requirements. One strategy would be to deploy access nodes directly in the customer's location. This allows the network provider to move the line cards that support different service to be moved closer to the customer to provide better service quality. In addition, it shortens the subscriber loop. This strategy is based on the STM transfer mode where channels are allocated for the duration of the service.

An alternate strategy is to use the B-ISDN based the transfer mode of ATM. This allows integration at the service level in that all the services are carried using an integrated approach.

2.5 Satellite System and B-ISDN

On 8 May 1989, disaster struck Illinois Bell on Mother's Day, the busiest telephone calling day of the year. Fire in its Hinsdale central office wiped out local service to 35,000 customers and closed down 118,000 interoffice and interexchange trunks that served Chicago high-tech industries in the western suburbs. Service was restored to 12,000 subscribers by May 11, but other services could not be restored for weeks. In November 1988, a construction crew digging in a New Jersey railyard accidentally knocked out AT&T's largest Eastern Seaboard route – a 1.7 Gb/s fiber optic trunk.

Even though these disasters made headlines, every year hundreds of local cable cuts and dozens of central office failures occur (see listing in Appendix A). Therefore, disaster can hit anywhere, at anytime. The impact of such failures has increased dramatically over the last decade as telecommunications networks have evolved from low capacity T1 meshes to today's high capacity fiber networks. At the same time, the increasing use of telecommunications network for vital business transactions – such as electronic funds transfer, order processing, customer service, and inventory control – makes survivability planning more important than ever before. Because of the serious impact that service disruptions can have on telecommunications users, most network providers are seeking to evolve their network to become more survivable – that is, to make them self-monitoring, self-diagnosing, and self-healing so that traffic is automatically routed around cable cuts or switch failures without loss of connections or data. This issue of survivability will become much more important when B-ISDN is used to carry various types of traffic using a single integrated network.

In an information-based society, all segments of society have to have access to the information infrastructure to enjoy opportunities that otherwise would be available to only a few. For example, most current users of high-bandwidth services are concentrated in large centers, downtown business districts, and suburban office parks, where their needs are served by specialized overlay networks. However, many potential users – regional offices, small businesses, schools, medical facilities, and residential customers – are widely dispersed and have no access to these overlay networks. To become full participants in the emerging information-based economy and social structure, these users need a public switched network that can support all of their information needs. In addition, multipoint and broadcast services are going to play an important part in supporting future B-ISDN services.

Therefore, network providers will have strong incentive to use satellite systems not only as a back up to provide network survivability but also as a vehicle to provide B-ISDN services to remote users. In addition, satellite systems provide multipoint and broadcast capabilities in a natural way than the terrestrial network systems.

2.6 Benefits of Integrated Services Environment

The primary motivation for evolving towards broadband technology include a demand for new high bit-rate services, and a potential reduction in the cost of supporting current services on the public telephone system. To handle such future information needs, the network requires both several orders of magnitude increase in individual switch and total network throughput. Also, the ability to support large dynamic range of signal bandwidths. The high bandwidth traffics are dominated by video.

An integrated services network based on broadband technology can provide a range of benefits to both network providers and end users. An integrated services network provides a wide range of flexibility in provisioning services. It enhances the ability of network provider to support existing services, combine these services in new ways to provide new services, and respond quickly to new service needs. B-ISDN networks are also robust in several other dimensions important to service flexibility. These networks can, with appropriate packetization and protocol techniques, be designed to offer graceful overload performance; for example, by trading off voice quality for throughput. This allows a network provider to offer more services, by letting the customer define their own service levels and priorities. The network provider can, if desired, support multiple grades of services in very adaptive ways.

The logical connectivity of B-ISDN networks can also extend the range of services supported by network providers. These networks can facilitate services which require multiple connections, or connectivity to multipoints, to support a single user application. Integrated networking can also provide wide range of pricing flexibility for service providers, e. g., billing for logical connectivity, information moved, priority treatment etc., to stimulate new applications.

Broadband packet technology can provide more efficient transport of virtually any type of information – voice, data, image, or signaling. For example, when used with packetized voice where the compression ratio of 5:1, with respect to 64 kb/s voice, this compression is effectively carried across the whole network, not just on transmission facilities. It provides a natural and automatic way to take advantage of and non-coincidence in use of virtual circuits on the network link.

A significant benefit is obtained in the area of operations and administration. The network integration afforded by common packet format across services eliminates the need for operational and administrative support of multiple networks. Furthermore, the fact that resources are dedicated logically rather than physically has several advantages. One is that resources can be managed in the aggregate rather than individually. Provisioning of individual connections or virtual circuits is also a logical process, amenable to software control, rather than requiring direct physical connections. For the end user, integrated packet switching provides benefits in the areas of service integration, enhanced customer control, and new applications.

B-ISDN extends the concepts of integrated access and the end user has the ability to statistically multiplex all services together, and to reuse the access capacity without the need for reconfiguration of access channels. In addition, customer information can be compressed if desired, with any access integration or compression benefits extended into the network. The end user has the ability to exert more control over their services. Users can take advantage of the graceful overload characteristics to choose their own level of service on the critical access link. The logical aspects of virtual circuits allows more control over their networking needs.

The end-user's ability to dynamically access bandwidth, up to the limit of the access link, provides for low latency, high throughput applications. The range of end-user applications that can be supported is extended. The combination of dynamic bandwidth and the logical nature of circuits can also allow new multimedia and/or multipoint services. While the specific applications for multimedia applications may rely on layers 4 to 7 of the OSI model, integrated packet switching allows multiple virtual circuits to be economically provided. Because of the logical nature of connections, it becomes economically feasible to establish connections to many different points.

2.7 Issues in Integrating Services

ATM technology provides a cell based integrated transport network for all services. The cell based technology offers a number of advantages but it has certain limitation in supporting certain services. Some of these issues are presented below.

2.7.1 Packetized Voice

The ATM approach provides a flexible way to dynamically allocate bandwidth and to support various services in an integrated fashion. In such an integrated network user information including voice is packetized and carried as a fixed size cell. By sending voice packets only during talkspurts, integrated switching offers a natural way to multiplex voice calls with other traffic. Another advantage is that call blocking can be a function of the required average bandwidth rather than the required peak bandwidth. In addition integrated network based on packet concept is capable of supporting point-to-multipoint connections and priority traffic.

However, packet voice is not without difficulties. Some of these issues are addressed here. The packet nature of the network has certain effect on speech quality. An ATM network introduces a variable delay due to cell assembly or queueing and also cell loss due to congestion and misdelivery of cell due to error in header are some of the drawbacks of ATM for speech compared to the Synchronous Transfer Mode networks. In addition speech coding is used to compress speech and this may degrade quality of service through coding distortion.

Speech coding technique is an important area for voice traffic in an integrated services environment. A variable rate coding is capable of encoding bursty speech signal or can be used to control the bit rate to meet the quality requested by the user. This feature gives speech coding techniques a rate independent capability in ATM networks. For low bit rate coding algorithm such as ADPCM, a variable coding capability can be realized by changing the number of bits used for coding signals. For example, the 24 and 40 kb/s ADPCM standardized by CCITT provides variable rate coding with three bit and five bit quantization, respectively. In a integrated services environment using satellite as a medium, this issue of coding needs to be looked into and researched to find a suitable coding technique which is flexible as well as efficient for an integrated services environment.

The missing cell recovery is another important issue for speech in an integrated services environment. In an ATM based network, when the network enters a congested state, the network discards cells to avoid further degradation of the network performance. Cell loss can also take place due to error in the header of the cell. In an ATM network, the network is capable of detecting and correcting a single bit error in the header. In any case, loss of cells can degrade speech quality. In low bit coding schemes, the degradation caused by cell loss is greater than that for PCM encoding. To minimize degradation in speech quality caused by cell loss, powerful low bit rate coding techniques need to be developed.

The quality of the reconstructed output speech that has experienced cell loss is a function of the contents of the missing cells. There are a number of ways to recover from the loss cell effect. In the substitution technique, the lost cell is replaced by another signal. In the sample interpolation technique the missing samples are replaced by an interpolated sample based on the arrived signals. In the embedded coding scheme with Least Significant Bit dropping, a codeword is divided into two segments one containing the most significant bits and the other the least significant bits. These segments are assembled into separate cells. In the event of network congestion, the cell containing least significant cells are dropped. What scheme among these are better suited in an integrated services satellite environment needs further investigation and research. The guiding principle would be to select a technique that will provide smooth and graceful degradation of speech quality as well as a variable bit rate speech coding.

Conversational speech is not continuous and rarely uses both directions of transmission simultaneously. Digital speech interpolation takes advantage of inactive periods in a conversation to insert other traffic. Because speech activity occupies, on the average, about 40% of the total time in a conversation. DSI raises the capacity by a factor of 2.5. To take advantage of this concept requires prompt recognition of the presence of speech to avoid front-end clipping (chopping of words beginning). To reduce front-end clipping of a speech burst, a fixed delay can be added to account for the processing time in the speech detector. To eliminate another distortion, called tail-end clipping, the speech detector may extend the effective burst length by about 16 ms. For satellite environment other techniques may need to be explored.

For an integrated network based on the ATM concept, cells experience variable delay within the network. While delay variation are acceptable in the case of digital data, they are troublesome for cnoversational speech. Therefore the delay of voice packets must be equalized, especially for interactive voice traffic. One of the techniques is to use a time stamp function. The time stamp function records the cumulative variable delays that the packet experiences traversing the network. Each node adds the amount of time it took to serve the packet to the time stamp before forwarding the packet. By the time it reaches the terminating edge, the value in the time stamp field will have indicated the total queueing delay in the network. The packet is then delayed before playout so that the end-to-end delay is equal to the value of the "build-out" delay, which is the maximum accepted network delay. The value of the build-out delay is a tradeoff between accepting excessively large delays and forcing a higher number of lost packets.

Another function which helps to detect lost packets is the concept of sequence number. In addition, the destination can use this information in conjunction with the time stamp to remove variability in delay between talk spurts. Another issue here is the range of sequence number. Determination of optimal sequence number requires an in depth analysis.

Background noise and build-out procedures are other issues that need to be addressed in an integrated services environment in order to obtain better quality of service for speech. Background noise refers to the action to be taken in the event a voice packet is missing. In the background noise technique, a certain level of background noise is played out instead of a missing packet. In the build-out procedure, those packets that experience more than the defined build-out time are dropped and a background noise packet takes the dropped packet's place. The value of the build-out time should be chosen to improve speech quality.

Delay variability complicates the speech reconstruction process and it is therefore undesirable. Delay variability can be minimized by applying some form of dynamic priority queueing discipline. Under the first come first served queueing discipline, some packets experience long transit delays while other packets experience much shorter delay. In order to control variability of queueing delays to a greater degree, the queueing discipline must be capable of giving preference to those packets that are determined to be urgent, where urgency depends on factors such as packet's present position, route, age, and expiration time. Such queueing discipline necessarily involves time varying priorities. Effectiveness of such schemes in reducing the delay variability and their demand on resources needs further investigation in an integrated services environment.

2.7.2 Packetized Video

A video encoder in a ATM environment must assemble its coded information into discrete cells that are independently transported by the network. The video decoder must then extract the information out of these cells at the correct pace and reconstruct the desired pictures and timing. These operations are vulnerable to packetization defects (packetization delay, cell loss, and cell delay jitter) occurring in an integrated networking environment. On the other hand, video coding can benefit from the packet technique, by using variable bit rate coding techniques to optimize performance or by exploiting the bandwidth flexibility to offer user selectable picture quality.

Compared to 64 kb/s telephony, video services are more prone to cell loss. Because of the high bit rate involved, cell loss occurs more frequently for video services. The shorter primary frame length of telephony service allows an integer number of primary frames to fit within one cell. If a cell is lost, an audible click may occur, but frame alignment of subsequent primary frames are not affected. For video services, the primary frame is a video frame of 40 ms. Therefore a primary frame is transmitted using a number of cells. If a cell is lost in the middle of a primary frame, the phase alignment is lost for the rest of the frame. Depending on the synchronization scheme used, a cell loss may thus corrupt a large part of a frame. For the DPCM coding algorithm discussed by CCITT, cell loss will indeed result in loss of the rest of the video frame if no action is taken. These kinds of errors can be compared to service interruptions, and should occur less often to meet a better video quality of service.

It is clear that cell loss may significantly affect the quality of high bit rate services and it is a function of the service and the coding method used. If ATM based integrated services network is to meet present quality of service, a cell loss rate of 10^{-11} may be required. This figure is very demanding in terms of queue lengths in the network and for dejittering buffer at the decoder. Therefore it is necessary to include appropriate functions in the video terminals themselves.

The first function is the detection of cell loss. This can be achieved by numbering cells. A sequence length of 4 has been suggested in the literature, but further study and research is required to select an optimum sequence number space. As cell losses may occur due to error bursts, the cell numbers must be protected against bit error to prevent error multiplication. Also cell loss detection need to be done prior to the extraction of synchronization information ahead of the dejittering function.

Variable bit rate coding offers a higher efficiency, as network resources can be statistically shared by numerous sources. For a video source, a variable bit rate can be achieved by adapting the generated bit rate to the local and temporal image complexity, while pursuing a constant image quality. Using variable bit rate coding, a nearly constant and subjectively better image can be achieved. Besides achieving a better subjective image quality, the average bandwidth is significantly reduced, depending on the application.

Another issue in video as an integrated service is the concept of video coding. The technique of layered video coding is the division of a video service into a number of complementary components, referred to as layers. Some of these layers contain hierarchical information such as a low resolution, a medium resolution and a high resolution video component. The layered coding concept allows tailoring a video service to the individual and instantaneous needs of the subscribers. The layered coding concept offers an intrinsic compatibility between a wide range of video services. Another advantage of layered coding schemes is the error concealing capabilities.

A layered coding model classifies the image components according to their relative importance. Loss of information in the higher resolution will only slightly influence the image quality, while loss of information in the lower resolution layers severely reduces image quality. The separate coding of the different resolution layers thus results in a redistribution of the errors generated by cell losses. Small errors occur regularly, while the rate of occurrence of severe error is greatly reduced. This rate can be further reduced by applying forward error correction to the low resolution layer.

There are a number of advantages to be gained by transmitting video services in an integrated services environment.

i. The first advantage of video packet coding is that improved and consistent picture quality is obtained using a variable bit rate.

ii. The second advantage is multimedia integration.

iii. The third merit is improved transmission efficiency using channel sharing among multiple video sources.

2.7.3 Packetized Data

At present most of the data traffic is carried by packet switched network based X.25 protocols. These protocols were designed to operate using an analog transmission medium. Data traffic is mostly bursty with a very high ratio of peak to average. Hence, they are well suited for the packet mode of transfer. In addition, packet data transmission requires a high degree of error free transmission but can tolerate variable delay. In this sense, these characteristics are just the opposite of that needed for voice traffic, which can tolerate error but is very sensitive to variable delay. In general, data traffic requires high capacity for a short duration as indicated by the burstiness.

2.8 Integrated Services via Satellite

Satellite based networks have a significant advantage in providing a set of communications services of primary interest to business customers which require access to these services from distributed locations via small/medium ground terminals located as close as possible to the customer premises. The flexibility of satellite based network services and the ability to set up much quickly and in a flexible way to cover a wider remote areas than any other medium is a big advantage. The Business satellite networks such as IBS and SMS provides a means for supporting services such as audio and video conferencing, electronic mail, remote printing, computer-to-computer data transfer, fast facsimile, and telex in a flexible way on an international basis. Some of the main features of these International Business Satellite services are:

- Fully digital transmission
- Wide range of customer bit rates
- Variety of circuit provision modes
- Transparency to the type of services carried
- Point-to-multipoint transmission capability
- Use of both small dish earth stations at customer premises and the ability to accommodate new users easily through the rapid installation of earth stations.

The intrinsic flexibility of the satellite as a transmission system can be made available to the integrated telecommunications services, provided the performance parameters are tuned to the application to be supported.

Advances in satellite technology, such as more sophisticated coverage and the use of higher frequency band will make available to users distributed small dish earth terminals for integrated services. Architecturally, it may be possible to provide network functions in the earth stations and thereby to make them part of the network node. Also there is the possibility of providing the switching capability in the satellite and thereby making the satellite a real switchboard in the sky.

Future developments in satellite technology need to focus on changes to system design parameters to make satellite a viable transmission medium for the integrated services of future. In the area of transmission quality, clear indications of what will be required are emerging. However, this is an area where satellites cannot adapt without limit. On the question of delay there is even less room to move but those possibilities that do exist, such as double hop, must be carefully examined. In the area which relate to transparency (modification of frame format, use of forward error correction etc.) the inherent technical constraints on satellite systems are fewer and it is here that maximum scope exist for satellite technology to realign with the direction of broadband ISDN.

The broadcast capability of satellites is well suited for providing cost-effective video services to a wide range of applications, including video teleconference, distribution of video programs to local broadcast stations and cable TV operators, live video broadcast of emergency news, religious programs, and sports events. The use of video transmission is expected to grow significantly as new video services such as high definition television (HDTV), extended quality television (EQTV), video telephony, and videotex services become available in the near future. Also, standardization of coding algorithms for video teleconference and digital television, along with high-speed digital transmission using ISDN, will increase the demand for digital video services.

Chapter 3

Estimate of Traffic

This chapter defines the central concept of B-ISDN, and describes the evolution of the public and private switched telephone networks from the current "service-dependent" environment to the "service-on-demand" environment of the 21st century. In addition, it delineates the satellite-based B-ISDN services and identifies its niche market and potential users. The issues pertaining to compatibility and interoperability between the satellite and terrestrial based networks were also addressed.

The "demand" feature of the future B-ISDN multimedia (voice, data and video) services places a great emphasis on the user's ability to vary the service quality, bandwidth and connectivity while the call is in progress. Although satellite-based networks would be well suited for some of the multimedia applications because of the inherent bandwidth flexibility and broadcast capabilities, the extent of the U. S. domestic satellite-based B-ISDN service demand has not been quantified. Therefore, one of the objectives in this study is to establish a first-order estimate of the traffic requirements around the year 2010 time frame.

The traffic model used in this study assumes that the majority of the total market (i. e., both terrestrial and satellite) will be served by the backbone terrestrial-based networks. Four types of B-ISDN services which are particularly suited for satellite-based network applications are then identified for further demand analysis. The year 2010 traffic needs are determined in two steps. First, the total market for each application will be estimated and subsequently, a subjective approach is used to size the satellite niche market for each application.

This chapter is organized as follows:

3.1 Traffic Model

3.2 Capacity Requirements

3.1 Traffic Model

It is envisioned that the future domestic telecommunications infrastructure will encompass several major public switched networks, a large number of private service-specific networks (e. g., the Inter-hospital network, the High School network, the supercomputer networks, etc.), and many centralized information centers (Library of the Congress, Data Centers of Company Headquarters, major Medical Research Centers, etc.). All these networks are accessible to the general public and are fully B-ISDN compatible. For most of these terrestrial-based networks, optical fiber is the dominant technology.

It is anticipated that satellite-based networks will find applications in at least three distinct areas:

- Bridge private service-specific networks and/or information centers. Here, each of these networks can be looked upon as a gateway through which the end users can access the satellite;
- Enhance the service quality of and/or to extend the service coverage for the public switched networks; and
- Provide network diversity and backup.

Specifically, the following four types of network applications are used to size the satellite-based B-ISDN niche market:

1. Telemedicine Networks
2. Distant Learning Networks
3. Virtual Office Networks
4. Time Shared Networks

This satellite niche market could amount to a total of 60 STS3 digital lines (155 Mb/s) or a total of 9.33 Gb/s as summarized in Table 3-1.

Table 3–1: Capacity Requirements (155 Mb/s Circuits) for Satellite-Based B-ISDNs, Year 2010

Type	Application	Each	Total
1.	Telemedicine:		16
	a. Distant Diagnostics Network	6	
	b. Inter-Hospital Network	10	
2.	Distant Learning:		31
	a. R&D Network	25	
	b. High School Network	6	
3.	Electronic Offices:		9
	a. Virtual Business Network	9	
4.	Time-Shared Network:		4
	a. Restoration Network	4	
	b. CAD/CAM Network	4	
	c. Financial Network	4	
	d. Supercomputer Network Extension	4	
	Grand Total		60

3.2 Capacity Requirements

The approach taken to establish a first-order estimate of the domestic traffic demand over the satellite-based B-ISDN follows a heuristic process.

- First, the total B-ISDN traffic for each of the above four applications was estimated using certain readily available parameters. For example, the population of medical specialists and, in particular, that of the radiologists is used to project the traffic demand for a Distant Diagnostics network.
- Depending on the relative merits in the delivery of services through the use of the satellite versus the terrestrial-based network facilities, a portion of this total traffic is designated as "satellite-based".
- The sum of these four separate "satellite-based" traffic represents a first-order projection of the satellite-based B-ISDN traffic demand.

Clearly, this estimate could be judged as too conservative since it is only derived from four specific applications. However, this conservatism is deemed to be acceptable for the purpose of this study.

3.2.1 Tele-Medicine

One basis for the telemedicine estimates is the number of practicing doctors. According to the *Statistical Abstract of the United States*, there were 700,000 physicians in 1990. At a conservative annual growth rate of 3%, the projected number of physicians in the U. S. by 2010 will be 1.2 million. Most of these physician will operate in major medical centers which are interconnected electronically.

Distant Diagnostics Network. The forecast indicates that there will be 1.2 M doctors in the U. S. by 2010. Out of this total, there will be 24,000 radiologists and 64,000 specialists. If 1% of the 664,000 physicians use a T1 line for an average of one hour per day, this will require 600 T1 (or 6 STS3) lines, assuming a 12-hour day. Note that the line rate for one T1 is 1.544 Mb/s and that for one STS3 is 155.52 Mb/s. Synchronous Transport Signal (STS) or Optical Carrier (OS) line rates have been standardized within the B-ISDN operation.

Inter-Hospital Network [2]. There will be 30 Inter-Hospital networks serving 200 major medical centers by 2010. Satellite B-ISDN will be used to bridge these networks using a minimum of 155 Mb/s (one STS3 or one OC3) line for an average of 4 hours a day. This will require 10 STS3 lines, assuming a 12-hour day.

3.2.2 Distant Learning

Basis for future distant learning traffic is found in estimates of R&D networks and numbers of high school age population.

The R&D Network will serve major research universities, the U. S. government executive departments and its Independent establishments, corporations, and quasi-official agencies. There were 2,129 universities in 1989, 13 departments and 69 independent establishments within the U. S. government in 1991 [Ref 1, p. 111 & p. 278].

The 14 to 17 year age group is projected to reach a peak of 15.2 M in year 2000, but will decline to 14.7 M by 2010 [Ref. 1, p. 207].

R&D Network. There will be 50 University and Research Labs networks by 2010. Satellite B-ISDN will be used to bridge them using STS3 lines for an average of 2 hours a day. In addition, 400 end users of these networks will use the satellite network to obtain access to centralized information centers for an average of 0.5 hours a day. This will require 25 STS3 lines, assuming a 12-hour day.

High School Network. The 14 to 17 age group will be 14,746,000 by year 2010. There will be 7,400 schools if the average school enrollment is about 2,000 students each. It is further assumed that on the average a group of 100 schools will form an information center for distant learning purposes resulting in 74 High School Learning centers. This will require 6 STS3 lines if each center uses an average of one hour a day, assuming a 12-hour day.

3.2.3 Electronic Offices

[Reference 1, pp. 242-244.] Small business accounts for 99% of the 19 million non-farm businesses in the United States in 1991. Sole proprietorships make up 13.2 million of these small businesses, while 1.8 million are partnerships and 4 million corporations. Small businesses employ 55% of the private work force, making 44% of all sales in America, and produce 38% of the nation's gross national product. During the first six months of 1987, the most recent period for which statistics are available, small business income was $320.1 B, up 12.9% from the same period of 1986.

Small businesses are twice as likely as large firms to produce innovations relative to the number of persons they employ, and they have created more than half of the new products and service innovations developed since World War II. Among the fastest growing small businesses today are eating and drinking establishments, trucking firms, doctor's offices, computer and data services, and amusements and recreation services.

The standards used by the U. S. Small Business Administration to determine whether a business is small vary from industry to industry and are relative within an industry. In manufacturing, a firm with 500 to 1,500 employees is classified as small business. In construction, this classification applies to companies with gross annual receipts between $7 M and $14.7 M. A company in the service and retail industry with gross annual receipts between $2.5 M to $14 M is considered a small business. A wholesaler with as many as 100 employees also will be classified as a small business. Thus a steel mill with 1,200 employees is considered to be small business right along with a mom and pop candy store.

The Fortune Service 500 consists of eight different lists: the 100 largest diversified service companies, the 100 largest banks, the 50 largest diversified financial companies, the 50 largest retailers, the 50 largest life insurers, the 50 largest utilities, and the 50 largest transportation companies. They are ranked according to sales or assets depending on the industry.

It was estimated that 714,000 out of the 19 million businesses, are the potential candidates for electronics offices with the following assumptions:

- 10% of 4 million corporations
- 3% of 1.8 million partnerships, and
- 2% of 13.2 million sole proprietorship.

With a projected annual growth rate of 6%, by the year 2010 there will be 2.16 M corporations in the U. S. with yearly sales exceeding $5 M. Assuming that 1% of these corporations require B-ISDN services at T1 rate for an average of 0.5 hours per day, this results in 900 T1 or 9 STS3 lines over a 12-hour day [(21,600 x 0.5)/12 = 900].

3.2.4 Time Shared Network

Appendix A provides a record of Communication Outages and Disaster Recovery from 1975 to 1991. From this record it is clear that a stand alone disaster recovery network can not be self sufficient as the demand is infrequent and highly unpredictable. However, it is believed that a time-shared network with a throughput of four STS3 lines providing services in restoration, CAD/CAM, Financial, and supercomputer network extension could be viable [2].

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[1] J. W. Wright, Editor, "The Universal Almanac, 1992", Andrews and McMeel, Kansas City, Missouri 64112.

[2] *Satellite Week*, Warren Publishing Company, Inc., 22 January 1990.

Chapter 4

Potential B-ISDN Satellite Applications

Broadband ISDN (B-ISDN) is intended to provide efficient digital transmission of a wide variety of services at high bit rates. An example topology is illustrated in Figure 4-1 [1]. B-ISDN differs from narrowband ISDN (N-ISDN) in essentially three aspects [1]:

- Terrestrial B-ISDNs use optical-fiber media, while N-ISDN is designed for copper media,
- B-ISDN is based on packet switching, as opposed to the primarily circuit switched (except for frame relay) N-ISDN,
- B-ISDN does not require predetermined bit rates, while N-ISDN connection bit rates are preassigned.

In the coming years, new and currently available high bandwidth services are expected to take advantage of the large information capacity that B-ISDN offers.

Two types of networks are planned for support of B-ISDN:

- Asynchronous Transfer Mode (ATM) networks
- Synchronous Digital Hierarchy (SDH) networks

ATM networks support B-ISDN by providing transport of ATM cells. At the physical layer, ATM networks can in turn be supported by SDH networks or can rely on a pure ATM architecture with a cell-based physical layer. The SDH-based physical layer is expected to be the dominant architecture and is the one emphasized in this report. In addition to support of B-ISDN, SDH is designed to support circuit switched services through the multiplexing of virtual tributaries. Because of the B-ISDN focus of this study, SDH support of these switched services is not considered.

Support of B-ISDN at both the ATM and the SDH levels will be common to future B-ISDN networks and both are addressed in this report. Satellite support of B-ISDN at the ATM layer inherently assumes that the underlying SDH is terminated at the interface to the satellite network. In addition, support of B-ISDN at the SDH layer is also considered. This scenario assumes that the satellite network processes only the SDH overheads and transparently passes the ATM cells contained in the payload.

In the following sections, and in Figure 4-1, we refer to ATM networks as being part of an SDH frame network (i. e. not "pure ATM"), and we refer to SDH networks as networks in which all of the traffic consists of ATM packets (not virtual tributaries). Routing in the SDH network is based on fields within the SDH frame overhead, while routing in the ATM network is performed on the basis of VPI/VCI numbers.

The requirement for optical fiber in the terrestrial B-ISDN results from the network's high bandwidth demands. Presuming that sufficient bandwidth is available, satellites can also provide or operate within a B-ISDN. Furthermore, satellite networks offer advantages over terrestrial networks for the delivery of certain services. This section describes two such satellite network architectures for the support of B-ISDN services, both of which are designed to serve different types of B-ISDN traffic and user requirements. The following subsections highlight service requirements for a satellite B-ISDN and describe the two architectures which meet these requirements.

This chapter is organized as follows:

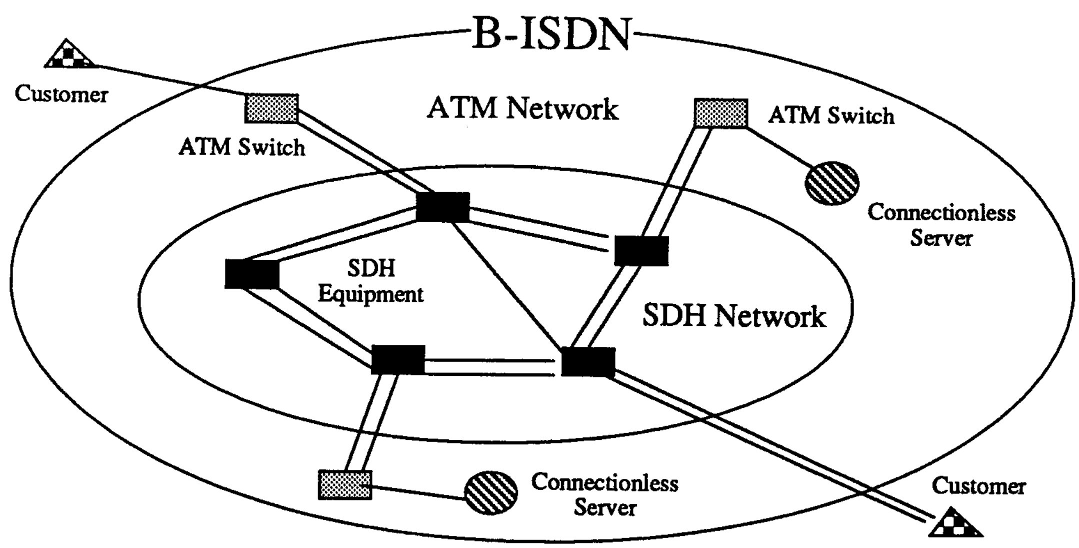

Figure 4–1: An Example Topology of a Broadband ISDN

4.1 General B-ISDN Service Requirements

Broadband ISDNs are, by definition, characterized by a large system capacity, a minimum number of physical interfaces and network elements, an open architecture consisting of standard protocols and multivendor connectivity, and a modular, seamless evolution path. Because of the network's flexibility, B-ISDN is anticipated to be the foundation of future high data rate networks. Many of the potential users and services of B-ISDN have been described in Chapter 2. These services are diverse and cover a wide range of burstiness and bandwidth requirements.

In particular, satellites are expected to contribute to or provide B-ISDNs in the future. In comparison with terrestrial networks, satellite networks hold a number of advantages. Foremost, a satellite network can provide variable, high speed capacity over its coverage area, which allows for simple and direct user interconnection across many thousands of square miles. Satellite networks could reach many places where terrestrial B-ISDNs are not deployed. In addition, the satellite's star network topology easily lends itself to broadcast and multicast capabilities, which are expected to be heavily utilized by certain services. Satellite B-ISDNs will also provide backup communication services for overloaded or damaged terrestrial B-ISDNs. For some applications that require small capacity or quick response, terrestrial B-ISDNs will have an edge over satellites. However, satellite networks should be able to competitively provide most B-ISDN services.

The B-ISDN concept is to efficiently handle a wide variety of services with different transmission requirements or characteristics. In doing so, different parts of a B-ISDN may handle different types of traffic. For example, a certain portion of the network may require a large capacity at the expense of a great amount of flexibility, and vice versa. As a network, the B-ISDN is expected to accommodate many diverse types of services.

In this chapter, two different types of satellite network architectures are explored.

- The first architecture is based on Synchronous Digital Hierarchy (SDH) traffic, and is intended to provide high bandwidth trunks between network nodes.

- The second architecture, based on termination of SDH and transport of Asynchronous Transfer Mode (ATM) traffic, is more general and provides packet switching and statistical multiplexing in order to achieve greater flexibility between user nodes.

The applicability of these types of networks is described below.

4.2 Architecture 1: Terrestrial B-ISDN Support

4.2.1 System Concept

The first satellite architecture (see Figure 4-2) augments terrestrial B-ISDN networks by providing high-rate multicast and broadcast services as well as remote user access to the terrestrial network at the SDH rate of 155.52 Mb/s. These services are supported by a system in which a nonregenerative spot beam satellite is used to support transmission of B-ISDN at carrier rates of 155.52 Mb/s.

Essentially, this architecture provides 155.52 Mb/s pipes which can be used to distribute wideband signals (such as high definition video) to multiple users and to provide high rate remote access capability for point-to-point or point-to-multipoint services. It is assumed that narrowband multipoint and remote access services are provided by other systems. To provide interconnection of high rate carriers in a spot beam environment, this satellite network employs static microwave switching on-board the satellite.

A high capacity can be obtained by this network at the expense of switching flexibility. Because the system is based on SDH level routing, the network is not able to take advantage of efficiencies gained by switching at the ATM level. At the earth station, some amount of statistical multiplexing may be accomplished if the earth station includes ATM switching capabilities, but channels in this satellite network may only be accessed at the base rate of 155.52 Mb/s. Therefore, if a particular earth station wishes to seize capacity solely for a 20 Mb/s service, it will still be allocated the full 155.52 Mb/s channel capacity.

4.2.2 Types of Services Supported

This network complements the terrestrial B-ISDN by providing backup and overload communication capacity in the event of terrestrial network failure or congestion. It also provides efficient multicast and broadcast capabilities because of its topology, especially for video services which require high bandwidth. Finally, it may also serve as an access point for remote users.

Many B-ISDN services are of the type (high bandwidth, low burstiness) most efficiently served by this network, such as:

- Supercomputer networks
- High-definition television distribution
- Cable television distribution
- Newspaper/graphics transmission
- Real-time science experiments
- High speed interconnection of LANs/WANs.

In general, users of services which require slowly varying, high bandwidth, or multicast connectivity will benefit from this architecture. Other types of B-ISDN services can also use this network, but at a lower efficiency than those previously described. Finally, because of the high basic channel capacity, earth stations which are able to statistically multiplex traffic will most efficiently use their allocated network resources.

4.3 Arch. 2: Private Based B-ISDN

4.3.1 System Concept

The second satellite architecture (see Figure 4-3) supports private B-ISDN networks and acts as the gateway to the public network for these networks. This system employs hopping-beam TDMA and baseband processing to interconnect private network earth stations and allows flexible allocation of capacity to earth stations in order to statistically multiplex low rate services with high rate services.

Because of the variety of user bit rates in such a network (a mix of high and low rate bursty data) and because of the possibility of a large number of user sites or service types, a flexible, interactive network architecture was chosen. The satellite provides this flexibility via an on-board destination-directed (fast packet) switch.

This architecture employs carriers of 200 Mb/s with TDMA transmission on the uplink to allow private network earth stations to transmit ATM cells to an onboard packet switch. High speed 800 Mb/s downlink TDM carriers transport the packets to the destination earth station.

The combination of TDMA access and onboard switching allows network earth stations to efficiently support mixtures of low rate and high rate traffic. In addition, the satellite employs hopping-beam antennas on both links in order to maximize network capacity utilization and to provide sufficient antenna gains at these bit rates.

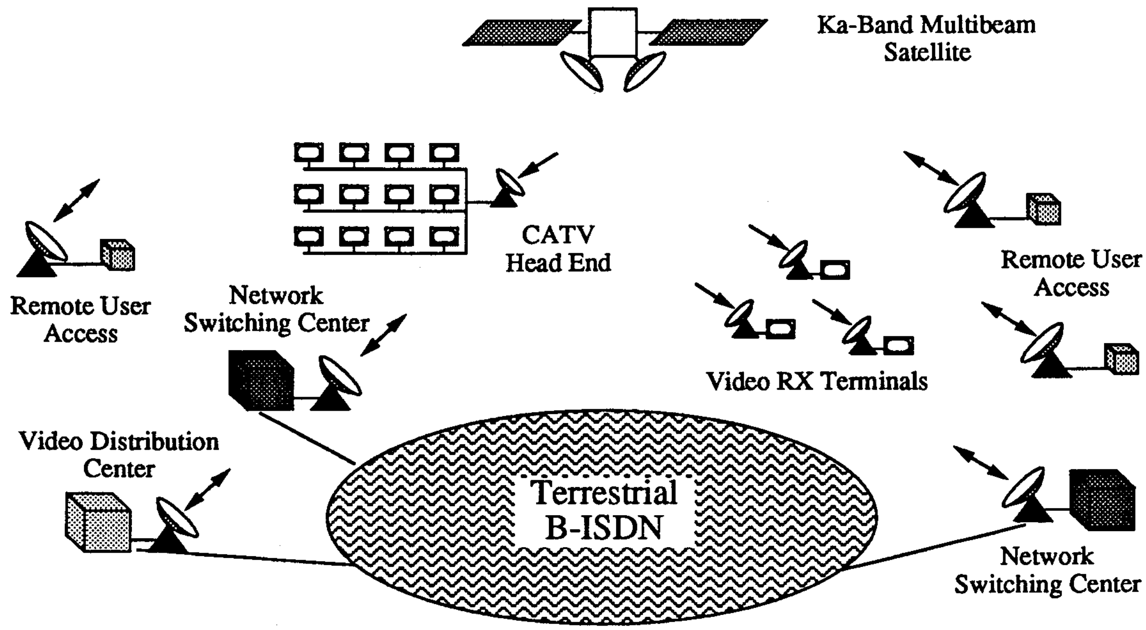

Figure 4–2: A Multicast, Broadcast, and Remote-Access B-ISDN Satellite Network

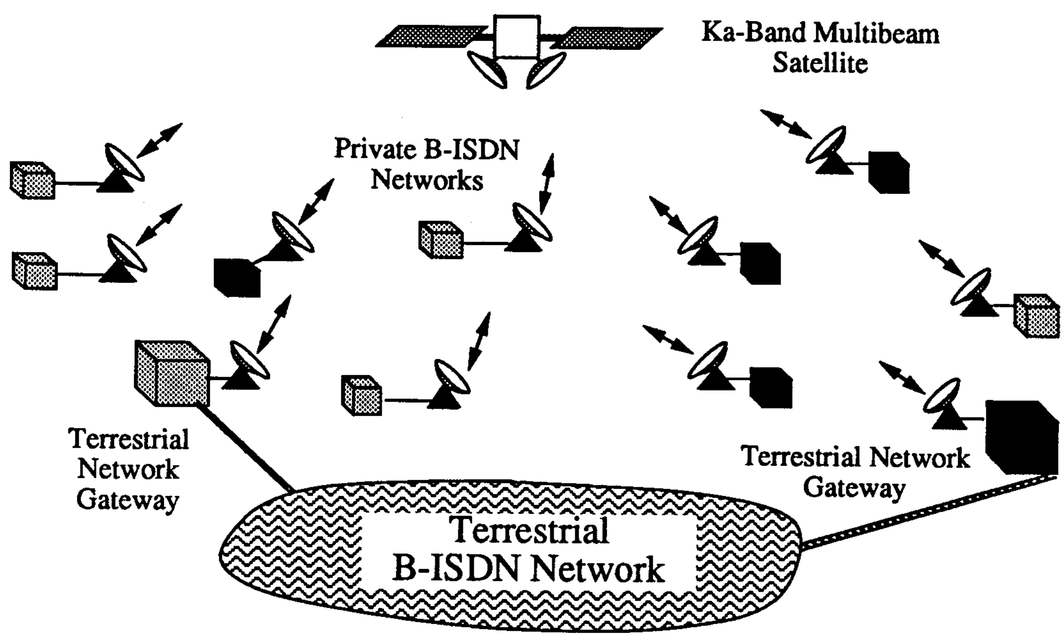

Figure 4–3: A Private-Based B-ISDN Satellite Network with Gateways to the Terrestrial Network

4.3.2 Types of Services Supported

Unlike the first architecture which is designed to complement the existing B-ISDN by offering high rate transmission channels, the Architecture 2 network provides independent private B-ISDNs as well as serving as the gateway to the terrestrial B-ISDN for some users.

The system is designed to most efficiently handle the whole spectrum of B-ISDN services. It would be most effective with services which are less bandwidth consuming or bursty, such as:

- File transfers
- Facsimile
- Interactive services
- Document retrieval
- Message services
- Small computer networks.

It is important to emphasize that this architecture also delivers the services mentioned in the first architecture quite well. Of the two architectures, this is the more capable, since it must handle all types of B-ISDN services in the most efficient manner.

References

[1] D. Delisle and L. Pelamourgues, "B-ISDN and How It Works", *IEEE Spectrum*, pp. 39-42, August 1991.

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Chapter 5

System Architecture Description

This chapter describes two satellite system architectures to provide B-ISDN service. It is organized as follows:

5.1 General Network Architecture Requirements

5.2 Arch. 1: Terrestrial B-ISDN Augmentation

5.3 Arch. 2: Private Based B-ISDN

A number of basic assumptions were considered in developing the network architectures. The assumptions included the following considerations:

- A target for the network system capacity was between 1 and 10 Gb/s.
- The total number of users was assumed to be on the order of 100 for the first architecture and 1,000 for the second architecture.
- Complete continental U. S. (CONUS) coverage was desired.
- Expected B-ISDN transmission rates for the network ranged from a few Mb/s to 155.52 Mb/s.
- User terminals between 2 m and 6 m, with amplifiers ranging up to 200 W, were considered.

Additional assumptions (e.g. link availability) are described in more detail within the appropriate sections.

5.1 General Network Architecture Requirements

5.1.1 Frequency Band Selection

One of the key considerations in defining the network architectures is bandwidth availability. Because of the high bandwidth requirements for B-ISDN services, Ka-band was chosen for the satellite networks. Current frequency allocations as defined by CCIR are given in [2]. Only portions of the Ka-band not shared by other types of satellite services on a primary basis were considered for use. Sharing with terrestrial fixed and terrestrial mobile services was not expected to be a problem. Bands that are allocated to fixed satellite services on a primary basis and to mobile satellite services on a secondary basis were also considered readily usable.

Figure 5-1 (bottom) shows the current uplink frequency allocations in the range from 27.5 to 30.0 GHz. In this range, bandwidth is allocated to be shared among a variety of non-government services. The band from 27.5 to 29.5 GHz is allocated to fixed satellite earth-to-space services on a primary basis, along with fixed and mobile terrestrial services. The band from 29.5 to 30.0 GHz is allocated to fixed satellite earth-to-space services on a co-primary basis and shared with mobile satellite earth-to-space services in ITU Region 2 which includes North America (WARC 1992). This study, which was completed before WARC 1992, assumed that 2.5 GHz of bandwidth, in the band from 27.5 to 30 GHz, is available on the uplink.

Figure 5-1 (top) shows the current downlink frequency allocations in the range from 17.7 to 20.2 GHz. In this range, bandwidth is allocated to be shared among a variety of non-government services, including fixed satellite space-to-earth services. The band from 17.7 to 19.7 GHz is allocated to fixed satellite space-to-earth services on a primary basis, along with terrestrial fixed and mobile services. However, some portions of this band are reserved for special types of fixed satellite space-to-earth services. Of the total allocation between 17.7 and 19.7 GHz, only the portions from 18.3 to 18.6 GHz and from 18.8 to 19.7 GHz have been considered for use. The band from 19.7 to 20.2 GHz is

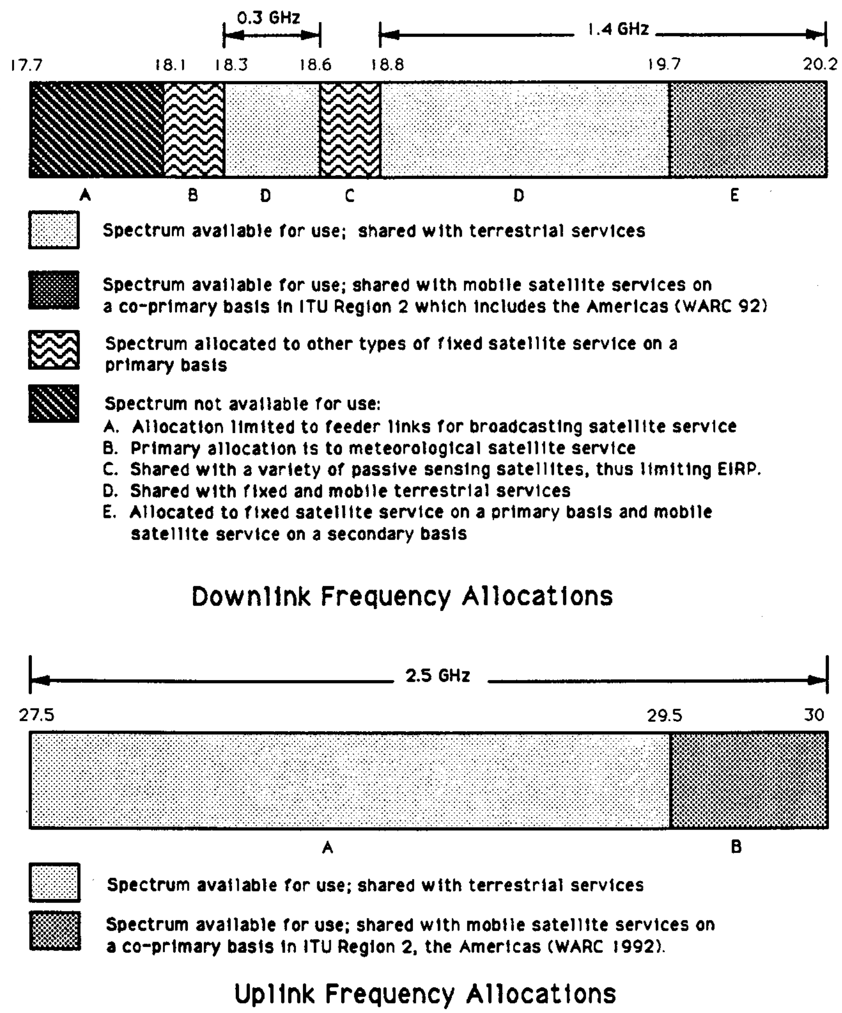

Figure 5–1: Ka-band Frequency Allocations for Region 2 which Includes the Americas (WARC 1992)

allocated to fixed satellite space-to-earth services on a co-primary basis and shared with mobile satellite space-to-earth services (WARC 1992 agreement for ITU Region 2 which includes North America). This study was completed before WARC 1992 and assumed that 1.7 GHz of bandwidth, including the bands from 18.3 to 18.6 GHz and from 18.8 to 20.2 GHz, is available on the downlink.

Although the Ka-band provides sufficient bandwidth, its use has some disadvantages. Rain fades at these frequencies are large, especially on the uplink, which force systems to incorporate either large clear-sky margins or uplink power control. Also, at Ka-band frequencies, significant depolarization occurs during rain, so that cross-polarization isolation degrades rapidly. Consequently, in the following architectures, cross-polarization is only used to add to other isolation techniques, such as frequency and spatial isolation.

5.1.2 General Signaling Issues

Currently, B-ISDN signaling requirements are not fully defined. It is likely that many aspects of B-ISDN signaling will adopt N-ISDN requirements for the short term but evolve towards some different set of target goals for the long term. This section discusses envisioned short term requirements and elaborates on potential long term requirements that need to be met in order to most efficiently use satellites for B-ISDN.

First, the issue of metasignaling, or how the network initiates signaling connections, must be addressed. There are a number of possible alternatives for establishing the signaling channel. The network may have the signaling channel available and open at all times. For example, a separate TDMA channel may be open for each earth station to transmit a message every frame. This approach may be the easiest to implement, but will waste capacity when no signaling is necessary.

Metasignaling provisions could also be incorporated in the satellite link, via a random access strategy. For example, a random access window may be left at the end of a TDMA frame for signaling messages. This method requires more complicated processing on the satellite. Alternatively, signaling for the satellite network may be initiated through a terrestrial connection to the earth station. This approach, however, may present problems for remote users. The appropriate selection of a metasignaling strategy will depend on the overall topology and attributes of the network.

The network is responsible for two types of B-ISDN management:

- Connection management
- Virtual traffic management

These functions are located mainly at the network control station (NCS) located in one of the beams, but are also included in the earth stations and in the on-board processor. For the first architecture, connection management is minimal beyond establishing free carriers for the connection and reconfiguring the on-board switch matrix, as described below. For the second architecture, connection management involves establishing the routing needed to transport ATM cells from earth station to earth station through the on-board switch. This is accomplished by mapping VPI/VCIs into satellite virtual packet (SVP) addresses that are used for routing within the satellite network. Different SVP addresses are used to identify particular switch outputs and destination earth stations within the satellite network.

Virtual traffic management consists of properly allocating network resources to accommodate dynamically varying virtual traffic within these connections. For example, uplink and downlink bandwidth must be managed to adapt to changing traffic patterns. This function is not critical in the first architecture, where capacity for a connection is not variable. For the second architecture, the uplink TDMA burst time plans must be adapted to provide each earth station with adequate capacity. For the downlink, capacity will be dynamically allocated within the TDM frame on a frame-by-frame basis based on outbound buffer status on board the satellite. Coordination of the hopping beam dwell times with the TDMA and TDM burst time plans must also be accomplished.

In providing this management, two types of B-ISDN signaling protocols, network and access, will be present.

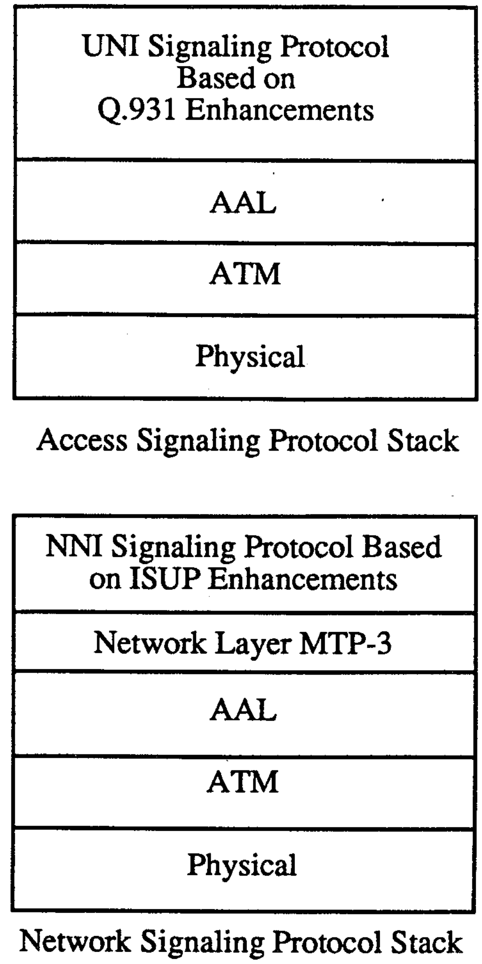

Figure 5–2: Protocol Stack for B-ISDN Signaling

These signaling messages are most often initiated by a user requesting a connection in the network. Access signaling refers to signaling for the user-network interface (UNI), and network signaling applies to network node interface (NNI) signaling. For example, in ISDN, Q.931 is the access signaling protocol and Signaling System No. 7 (SS7) is the network signaling protocol. Presently (Release 1+ for B-ISDN from CCITT), the signaling for B-ISDN is based at the higher OSI levels on enhanced Q.931 at the UNI and on enhanced SS7 ISDN User Part (B-ISUP) at the NNI. Both of these protocols are layered on an ATM-based network (see Figure 5-2). Message routing within ATM is based on the use of Virtual Path Identifier/ Virtual Channel Identifier (VPI/VCI) assignments. Consequently, the satellite network may need to interpret both SS7 and Q.931 signaling messages in establishing a connection over the satellite link, or else such signaling messages must be translated by the earth station.

Networks may be specified in terms of the type of routing provided as either (internal and external) datagram or virtual-circuit oriented. Internal orientation refers to how the network handles the traffic without regard to the outside network. This routing can be performed either as datagram or virtual circuit. External orientation refers to how the network presents the traffic to the outside network. For example, a network may be internal-datagram/external-virtual-circuit, in which packets are routed as datagrams within the network, but are presented to the outside network properly sequenced as if they were routed on a virtual circuit basis. For both signaling and traffic handling, both architectures presented in this section are external-virtual-circuit, internal-virtual-circuit. Although the second architecture employs a fast packet switch for routing, the internal network performs logically as a virtual-circuit network. In that network, routing for ATM cells is still performed on the basis of VPI/VCI number, but is simplified for the on-board packet switch in order to reduce complexity and avoid retranslation of the VPI/VCI numbers at the on-board switch.

5.1.2.1 Handling of B-ISDN Protocols

Protocols defined for B-ISDN are largely independent of the transmission medium, with a few exceptions. However, the satellite system must comply with basic requirements in order to effectively support B-ISDN services. These requirements vary depending on the level of integration of the satellite system with B-ISDN networks and the type of architecture chosen. The basic B-ISDN requirements for the satellite system, as they apply to protocols, are discussed in this section.

The essential processing functions needed for the earth station supporting a SDH interface are frame synchronization, bit parity check and generation, scrambling and descrambling, and header processing. Additional processing functions may be necessary for the purpose of switching or statistical multiplexing at the earth station. Architectures that provide transmission facilities only will not require SDH protocol termination, provided that signaling information from the SDH layer need not be accessed. If an earth station provides ATM switching or cross-connect (switching based on VPI only), both the ATM and the SDH protocol layers must be terminated. Earth stations supporting switching functions will require VPI/VCI processing and translation, cell header generation/extraction, generic flow control, cell multiplexing and demultiplexing, cell sequence integrity, and provisions for quality-of-service (QOS). In general, no ATM Adaptation Layer (AAL) processing is needed at the earth station.

Two areas in which the propagation time in the satellite network must be considered are error control and call set-up signaling. For example, many standardized data communications protocols employ a Go-Back-N error recovery mechanism for missing packets. Such a method, which is suitable for terrestrial applications, performs very poorly at high speeds on satellite links. Although timing parameters may be adjusted on some protocols, it may be necessary to implement protocol conversion functions or other interworking strategies for transit through the satellite network. As for call set-up signaling, many network elements outside of the satellite network may operate timers constraining the response time for an acknowledgment of a signaling message. Appropriate timer values must be chosen to take into account the delay encountered on the satellite network.

5.1.2.2 Multicast Traffic

The subject of B-ISDN multicast traffic has not yet been addressed by specific CCITT Recommendations, since a priority has been placed on the development of standards for point-to-point connections. Recommendations will be forthcoming once the standards for point-to-point traffic are more finalized. The particular type of multicast signaling method chosen will have a large impact on satellite network efficiency.

In general, multicast capability can be added in two basic ways. First, multicast traffic may be replicated at the transmitting earth station and broadcast on many different carriers on the uplink. This method would be inflexible and bandwidth inefficient. A better method would be to allow the on-board processor to route data from one input carrier to several output carriers. This method, chosen for the selected architectures, allows for a more flexible connection pattern and uses the uplink capacity more efficiently. Consequently, multicast switch configuration patterns will be used to route traffic to more than one output carrier.

Because B-ISDN multicast traffic has not yet been addressed by CCITT, it is difficult to specify particular requirements for satellite networks which use packet routing. A number of options, described below (see Figure 5-3), exist for addressing and replicating multicast

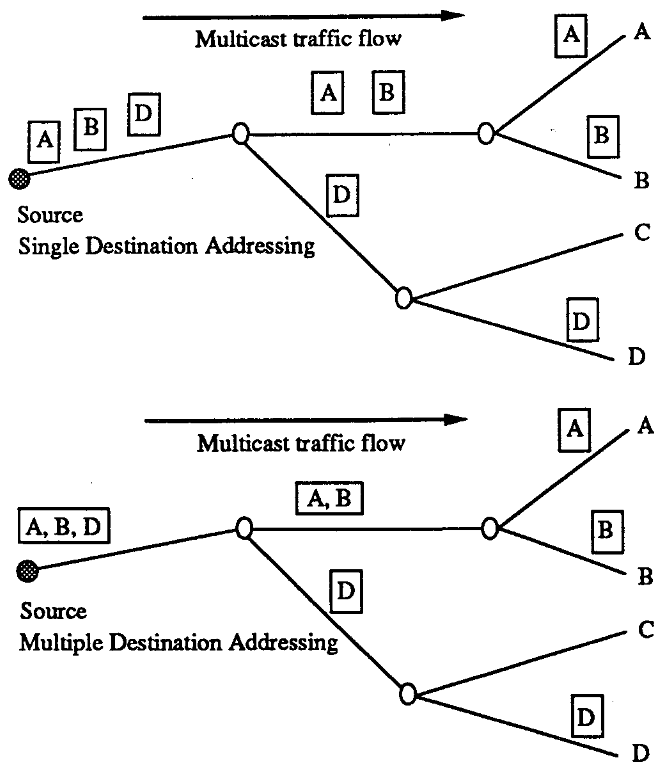

Figure 5–3: Point-to-Multipoint Signaling Methods

packets.

First, and most straightforward, packets with multiple destinations may be replicated at the origin and transmitted one-by-one. This method corresponds to Figure 5-3 (top). This approach would be simplest to implement because it reduces multicast traffic to a collection of point-to-point connections, which the network is designed to handle. A major drawback, however, would be the large bandwidth inefficiency incurred. This type of routing would essentially eliminate the inherent multicast advantage of the satellite, since there may be a large waste of bandwidth caused by traffic duplication before uplink transmission.

Multiple destination addressing, in which the multicast traffic is addressed to several destinations, is another approach. This strategy, which can be used with call-setup messages and traffic, requires that packets be replicated only at switching nodes at which the packets must be routed to more than one output line, as illustrated in Figure 5-3 (bottom). This scheme is more bandwidth efficient, but calls for increased processing demands on each switching node and probably an increase in signaling overhead as well, in order to accommodate larger address fields. The extra processing demands at each switch would consist of message replication and address set reduction on the remaining messages. It is possible that very large address fields would be required to accommodate a complicated broadcast pattern.

A more efficient method would be to replicate call setup messages at the origin, but to use multiple destination for information messages. Switching nodes would treat the first such packet as a point-to-point request and assign it a virtual path. Then, if a subsequent call-setup message with the same ID requested a path to another destination already covered by an outbound connection, that particular call-request would be grouped by the switch with the first. Effectively, this means setting up group membership via a separate signaling packet for each destination. In this way, although the duplication of signaling packets at the origin is bandwidth-inefficient, it results in easier call-setup processing. Then, when traffic flows, it is only duplicated at nodes where needed. The replication of call-setup packets will not significantly affect the traffic load. This approach is a combination of Figure 5-3 (top) for the call setup messages and Figure 5-3 (bottom) for the traffic packets, with a single address used for the multicast messages.

Finally, this group association may be performed in advance. Multicast traffic may be assigned a group address which is forwarded to a dynamic database at each switch node ahead of the traffic. The traffic with that particular ID is then switched according to the forwarded address fields. This approach does not require complex header addressing, but instead rests on the reliable updating and distribution of database information of user group membership should changes in the connection pattern occur. In a large network, global knowledge of network topology may not be easy to maintain.

5.1.2.3 Avoidance of Multiple Hops

The possibility of multiple hops in a satellite link must be accounted for as well. Such a delay would have a negative impact on certain services, such as video conferencing or voice communication. Presently, in the ISDN, SS7 possesses a satellite indicator (SI) field, but Q.931 does not. Therefore, multiple hop avoidance must be handled differently depending on the location of the satellite link in the path. The satellite link may be present at the UNI or the NNI. For calls originating through a satellite access, the originating network node, aware of the source of the call, must populate the SI field of the SS7 messages translated from the received Q.931 messages. For calls between network nodes, the existence of the satellite link is conveyed by the SI field capability. Since this SI field must be examined and modified as necessary, the processing loads on each node will increase. Furthermore, multiple satellite hops may be unavoidable for cases in which a given destination may only be accessed via two satellite links. Depending on the quality-of-service specified, the terminating exchange may or may not need to drop the call in this case.

One possible method of avoiding multiple hops would be to perform destination address screening at the initial point of call establishment, and to use a satellite indicator field to inform switching nodes that one link of the call is required to use a satellite link and that further satellite routing is to be avoided. The specified satellite switch must, however, be allowed to route messages with the SI set. This approach would naturally increase the a priori processing demands and setup time delay.

5.1.2.4 Link Propagation Delay Accommodation

One minor drawback of using a ground-based network control station (NCS) for capacity management is the additional delay necessary during call setup. For example, although non-signaling traffic will experience only one satellite hop, there may be two hops in either direction for a signaling message that is processed by the NCS on its way through the network. For services that require rapid call-setup, such a delay may be unacceptable. Furthermore, as mentioned above in Section 5.1.2.1, switching nodes upstream of the satellite link will not know that the call setup is traveling over a satellite link, and timers waiting for connection confirmation may expire.

One possible solution to this problem is to send a signaling packet upstream from the satellite that alerts the switching nodes (and originating user) that the signaling will take longer than expected, thereby forcing an enlargement of the signaling window. Another solution that would limit the number of call-setup hops to two would be to exclude the NCS from call-setup processing, although this would place a larger burden on the earth stations and would also be less flexible in terms of capacity assignment.

In any case, the end-to-end attributes for a proposed B-ISDN service must be flexibly specified to accommodate the transport delays of satellite links. This is not so much a design issue of satellite networks as it is of B-ISDN protocols themselves. If the eventual standards do not account for satellite transmission delays, modifications will need to be made by the satellite network for interworking, which would generally imply the termination of certain protocols at the network boundary. This would include parameters such as forward and backward window sizes, retransmission timers, etc., which also bear on quality-of-service (QOS). Within the context of the B-ISDN these parameters are defined as ATM Adaptation Layer (AAL) attributes and are transported end-to-end. Identification of the necessary interworking could be accomplished based on signaling information provided in call-setup messages (such as ISUP in SS7).

5.2 Arch. 1: Terrestrial B-ISDN Augmentation

The first satellite architecture augments terrestrial B-ISDN networks by providing high-rate multicast and broadcast services as well as remote user access to the terrestrial network at the SDH rate of 155.52 Mb/s. These services are supported by a system in which a nonregenerative spot beam satellite is used to provide transmission of B-ISDN at carrier rates of 155.52 Mb/s. Essentially, this architecture consists of 155.52 Mb/s pipes which can be used to distribute wideband signals to multiple users and to provide high rate remote access capability for point-to-point or point-to-multipoint services.

5.2.1 Transmission System Design Parameters

5.2.1.1 Coding and Modulation

To provide bit error performance comparable to that expected from fiber optic systems while keeping earth station costs to a minimum, a high performance modulation/coding scheme is required. At bit error rates on the order of 10^{-12}, concatenated coding systems offer relatively large coding gains. Recently, concatenated coding schemes that utilize Reed-Solomon outer codes and trellis inner codes in conjunction with higher order modulation schemes have been shown to offer high levels of coding gain with good bandwidth efficiency.

One such modulation/coding scheme described [Ref. 3] uses rate 2/3 trellis coded octal-PSK modulation concatenated with a (255,223) Reed-Solomon outer code. Extrapolation of the results presented in [3] show that this scheme could provide a bit error rate of 10^{-12} at an Eb/No of approximately 5.5 dB. This represents a coding gain of over 8 dB compared to uncoded BPSK or QPSK. Use of this code gives a transmission rate of 272 Mb/s or 91 MSymbols/s. Nyquist filtering with a 33% roll off gives a signal bandwidth of 120 MHz. It is therefore assumed that a channel spacing of 125 MHz should be adequate and that up to 13 channels can be accommodated by the available Ka-band bandwidth.

5.2.1.2 Antenna Coverage

The antenna coverage pattern for Architecture 1 is shown in Figure 5-4. CONUS coverage is provided by using ten 1.55° spot beams for both uplink and downlink transmission.

The downlink beams are divided into three groups (the three patterns illustrated in Figure 5-4) so that no two members of the same group are adjacent. The available Ka-band bandwidth is divided into three blocks and one block is assigned to each of the beam groups. In this architecture only 12 of the 13 available channels are utilized. Beam groups A, B, and C are assigned 4 channels each. The coverage is symmetric for the uplink and the downlink. A different combination of channel allocations could be used to meet projected traffic requirements provided that the number of channels allocated to the three groups does not exceed the available bandwidth and that required satellite transmit power is available.

As mentioned above in ¶5.1.1, because of Ka-band carrier depolarization during rain, orthogonal polarizations are not used to provide isolation within a single beam. However, adjacent beams of the same group are cross-polarized to augment isolation.

5.2.1.3 Link Budgets and Rain Fade Mitigation

The key requirements of the above network are a large capacity coupled with a minimization of satellite power output and inexpensive earth stations. To account for the large rain fades, power control on the uplink is assumed. Various transmission parameters for this architecture are summarized in Table 5-1, based on link budget analysis. Sample link budgets are given in Appendix B. The link budgets assume the following:

i. Earth station antenna sizes and transmit power are 3 m to 4.5 m and 30 W to 140 W, with power control during uplink rain.

ii. Rain margins can be sufficient for 99.8% availability in U. S. Rain Region D2 and 99.5% availability in Rain Region E, Antenna and amplifier sizes can be varied to provide different levels of availability in different regions.

iii. 8-PSK modulation and a concatenated code are used as described in ¶5.2.1.1.

iv. Satellite amplifier outputs are 32 W peak power per carrier.

5.2.2 Earth Station Diagram

The satellite network will interconnect network nodes via a SDH interface at 155.52 Mb/s. At the earth station, only the SDH section overhead is processed to perform management functions on the connection; the SDH line and path overheads and the payload are passed transparently to the destination earth station. A functional block diagram of an earth station providing SDH transmission capabilities is shown in Figure 5-5. Doppler buffers are used to account for clock differences that result from satellite motion. Beyond the interface, all outbound data is processed through a doppler buffer, a scrambler to smooth out spectral peaks in the data, a FEC encoder, and a 8PSK modulator. It then is transmitted to the satellite through the terminal's RF equipment. From the satellite to the earth station, the coded signal is first demodulated using soft decisions for better error performance and then decoded and descrambled. After the data passes through the doppler buffer, the SDH section overhead is again processed before the data leaves the interface.

The signaling units are shown connected to the RF equipment. This signaling may interface with the terrestrial network as well, as discussed above in ¶5.1.2.

5.2.3 Network Control Station

In addition to the traffic earth stations, there will be a network control station (NCS) in one of the beams which coordinates the allocation of channels to earth stations and controls the on-board microwave switch matrix (MSM) via an uplink command channel. Out-of-band signaling channels will be used to provide signaling between traffic stations and the network control

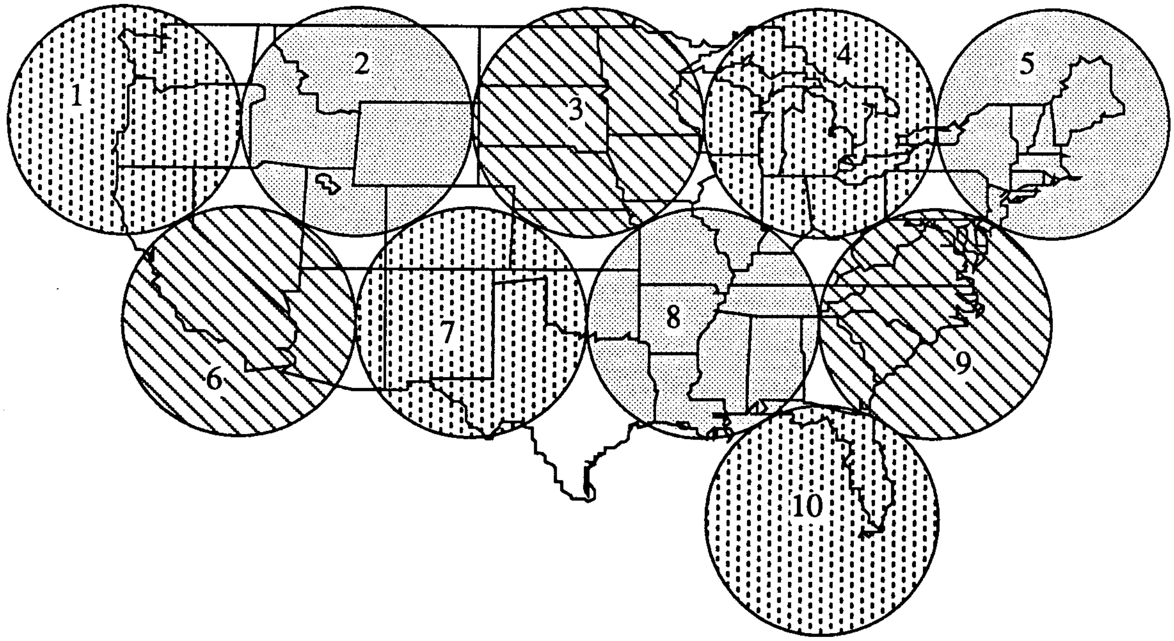

Figure 5–4: Antenna Beam Coverage for Architecture 1

Table 5–1: System Parameters for Architecture 1 Design

System Parameters	Uplink	Downlink
Frequency	30 GHz	20 GHz
Number of Beams	10	10
Access Method	FDMA	FDMA
Modulation	8-PSK	8-PSK
FEC Coding	Concat. Code RS/Trellis	Concat. Code RS/Trellis
Transmission Rate	200 Mb/s	200 Mb/s
Carrier Bit Rate (info)	155.52 Mb/s	155.52 Mb/s
No. Carriers/beam	4	4
Total No. of Carriers	40	40
Beam Capacity	622 Mb/s	622 Mb/s
Beam Bandwidth Required	400 MHz	400 MHz
Frequency Reuse Factor	3	3
System Bandwidth Req'd.	1.2 GHz	1.2 GHz
System Capacity (info)	6.2 Gb/s	6.2 Gb/s
Earth Station Diameter	3 to 4.5 m	3 to 4.5 m
Transmit Amplifier Power	30 to 140 W	32 W

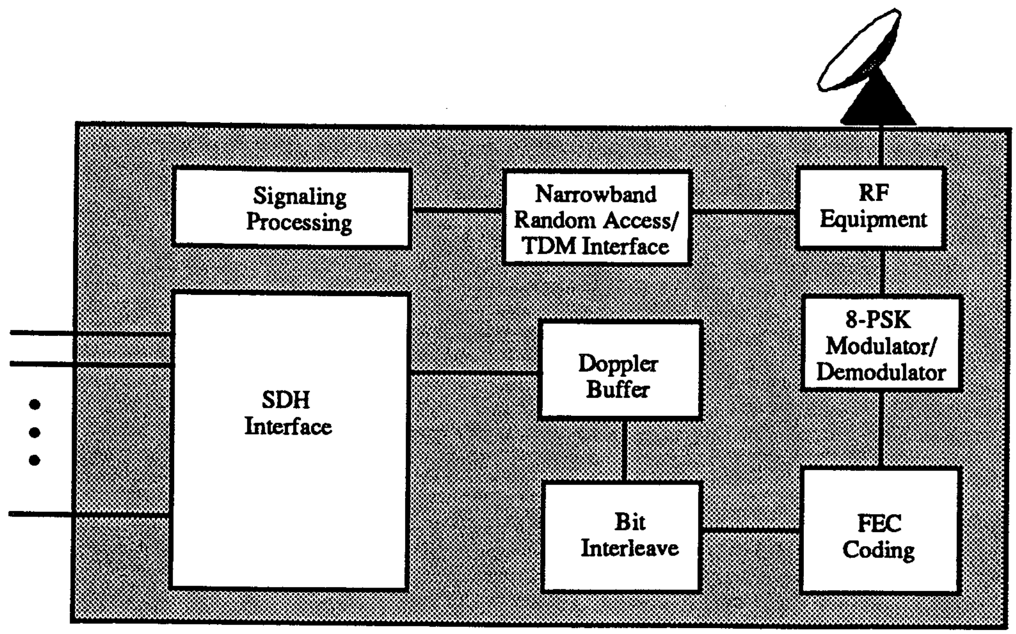

Figure 5–5: Earth Station Block Diagram for Architecture 1

station. The signaling channels, which will not require a high bandwidth, could be accommodated by terrestrial links or by out-of-band signaling over the satellite. This signaling will be used to establish 155.52 Mb/s transparent connections between user earth stations. Users will access the system by requesting 155.52 Mb/s connections to another terminal. If the required bandwidth is available the NCS will send the appropriate frequency assignments to the traffic stations and will configure the MSM.

5.2.4 Signaling Network

In this architecture, no B-ISDN signaling information will be passed to either the network control station (NCS), the satellite, or the earth stations. As a result, B-ISDN protocols need not be terminated. There will be internal signaling requirements, however, in the allocation of capacity and the on-board configuration of the switch matrix.

The satellite architecture's internal signaling network may be provided either through a terrestrial network or through an out-of-band signaling network on the satellite. Using the terrestrial network for the satellite signaling has advantages and disadvantages. Among the benefits are quicker response times for the messages and avoidance of added complexity on-board the satellite. A drawback is that all users must ensure that they have an appropriate connection (such as an ISDN interface). If all users are expected to have appropriate terrestrial signaling connections, it will probably be advantageous to bypass the satellite network for signaling connections between the earth stations and the NCS. It will be necessary, however, to maintain a channel between the satellite and the NCS for configuration and maintenance signaling.

If a satellite supported signaling network is desired, one possible approach would be to use random access channels within each spot beam. These random access channels would not require significant bandwidth and could occupy a small slice of spectrum adjacent to the uplink carriers in that beam. On the satellite, separate narrowband filters would be appended to each filter bank, and the ten (due to ten beams) narrowband channels would be multiplexed together. As a result, since frequencies are reused, there would be some overlap as, for example, all channels from beams using similar uplink frequencies are multiplexed together. However, since there is not expected to be significant amounts of signaling, this should not be a problem, and would in effect amount to increasing the number of beams served by each random access channel. This multiplexed channel would then be relayed on the downlink to the NCS. A return TDM signaling channel from the network control station could then be routed to each earth station via a downlink narrowband channel, from which each earth station could extract its own packets.

After channel set-up the satellite essentially would function as a transparent medium, much the same as with an optical fiber between a user and the network, or between network nodes. Links need to be engineered to provide comparable bit error performance to that of fiber. For point-to-point service between network nodes, the same type of call setup is envisioned, except that the underlying internal signaling protocol may be different.

5.3 Arch. 2: Private Based B-ISDN

The second satellite architecture supports private B-ISDN networks and acts as the gateway to the public network for these networks. This system employs hopping-beam TDMA and baseband processing to interconnect private network earth stations, and allows flexible allocation of capacity to earth stations in order to statistically multiplex low rate services with high rate services. The satellite provides a flexible network architecture via an on-board destination-directed (fast packet) switch.

5.3.1 Transmission System Design Parameters

5.3.1.1 Coding and Modulation

Both the uplink and downlink employ concatenated coding schemes as in the first architecture. On the uplinks, each carrier has an information rate of 200 Mb/s. Use of an inner rate 3/4 convolutional code concatenated with a (255, 223) Reed-Solomon outer code and QPSK transmission results in a transmission rate of 305 Mb/s and a modulation rate of 152.5 Msymbols/s for each carrier. Assuming Nyquist filtering with 33% roll off gives a total carrier bandwidth of 203 MHz. Since each beam contains four carriers, each beam requires an allocation of approximately 820 MHz. Extrapolation of the results presented in [4] show that a rate 1/2 convolutional code concatenated with a (255,223) Reed-Solomon code will provide a bit error rate of 10^{-12} at an Eb/No of 3.2 dB. Furthermore, rate 1/2 convolutional codes are shown in [4] to provide approximately 1 dB more coding gain than rate 3/4 convolutional codes. It is therefore assumed that a concatenated coding scheme using a rate 3/4 convolutional code and a (255,223) Reed-Solomon code could provide a bit error rate of 10^{-12} at an Eb/No of less than 4.5 dB.

On the downlink, a modulation/coding scheme similar to that described for the first architecture uses rate 8/9 trellis coded octal-PSK modulation concatenated with a (255,223) Reed-Solomon outer code [3]. Extrapolation of the results presented in [3] show that this scheme could provide a bit error rate of 10^{-12} at an Eb/No of 5.7 dB. This represents a coding gain of over 8 dB compared to uncoded BPSK or QPSK. Use of this code with the 800 Mb/s carriers results in a transmission rate of 1,030 Mb/s or 343 Msymbols/s. Nyquist filtering with a 33 percent roll off gives a signal bandwidth of 456 MHz. It is therefore assumed that a channel spacing of 500 MHz should be adequate and that up to 3 channels can be accommodated by the available Ka-band bandwidth and an appropriate frequency reuse pattern.

The above coding and modulation presume that such codes can efficiently operate at high bit rates, which has yet to be determined. However, it is expected that these codes or codes similar in performance at high rates will be available within the decade. The inclusion of low power decoders is most critical for the uplinks, because of a limitation on satellite power.

5.3.1.2 Antenna Coverage

The uplink and downlink antenna coverage pattern is shown in Figure 5-6. Twelve hopping 0.4° spot beams are used to cover a total of 110 dwell areas. These dwell areas are divided into 12 sectors with one hopping beam covering each sector. Each sector has 7 to 10 dwells. The sectors are divided into three groups with each group operating on the same frequency. No two members of the same group are adjacent. In addition, hopping-beam dwell patterns are coordinated to maximize isolation. Consequently, the available Ka-band bandwidth is divided into three blocks, one for each group. Each beam has the same fixed capacity of 800 Mb/s. As mentioned above in ¶5.1.1, Ka-band carrier depolarization during rain hinders the use of orthogonal polarization for isolation within a beam. However, adjacent beams of the same group are cross-polarized to augment isolation.

5.3.1.3 Acquisition

Earth stations which have already been assigned time slots in a carrier may request a change in their allotment through the use of signaling SVPs, routed to the network control station. Earth stations which do not have time

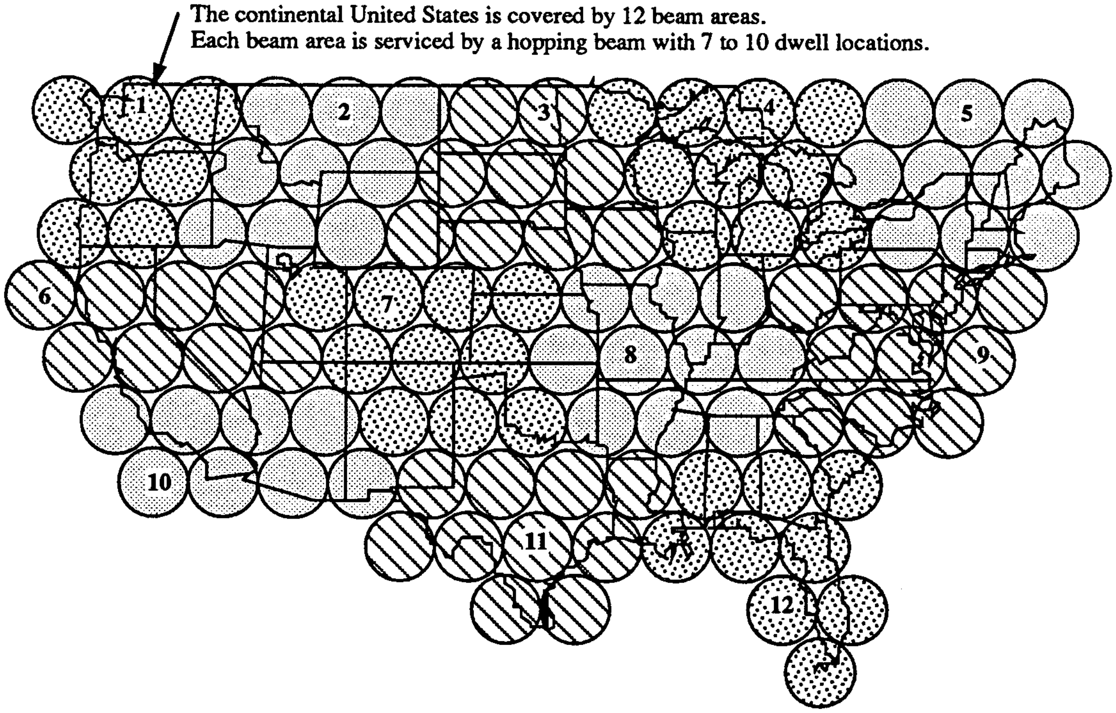

Figure 5–6: Antenna Beam Coverage for Architecture 2

slots allocated to them but which desire carrier access must acquire synchronization. Within a TDMA carrier burst time plan, an acquisition window may be included during which earth stations could transmit access messages. This window could be either random access or coordinated access. Random access allows an earth station to attempt to signal the NCS within any frame. Coordinated access allows the earth station to attempt to signal the NCS only within a frame assigned to it during the reference burst on the downlink. The use of coordinated access allows for smaller acquisition windows, but may cause acquisition times to grow as earth stations wait for their turn.

An acquisition window may be placed in each uplink dwell or may be outside of the normal traffic dwells. In any case, earth stations which wish to transmit during this window must synchronize to and receive the downlink reference burst in order to obtain an estimate of the required transmit timing.

5.3.1.4 Synchronization

The uplink and downlink bursts require extra overhead for preambles and guard times. Examples of burst time plans will be presented in Chapter 6 in more detail (see Figure 6-4). For a particular burst on the uplink, the data must be preceded by a guard time, a carrier and bit timing recovery sequence, and a unique word. There must be a guard time between bursts from stations within a particular dwell, as well as the guard times between dwells.

On the downlink, each reference burst requires a dwell area guard time, carrier bit and timing recovery, and a unique word, in order for stations to acquire the reference burst. Within each dwell burst also, the carrier requires synchronization overhead. However, once the earth station has acquired the dwell burst, it does not need additional synchronization overhead for user bursts.

5.3.1.5 Link Budgets and Rain Fade Mitigation

Again, the key objectives of a B-ISDN satellite network are a large capacity coupled with a minimization of satellite power output and inexpensive earth stations. Because of the small dwell areas used in the uplink hopping-beams, earth stations can be kept smaller than those described in the first architecture. Uplink power control is used to combat rain fade in this architecture; the use of small spot beams and on-board regeneration on the satellite provide sufficient margin for high availability. A summary of the key transmission parameters of this satellite architecture is given in Table 5-2. The link budgets assume the following:

i. Earth station antenna size and transmit power are respectively 3.0 m and 10 W, with power control up to 40 W.

ii. Rain margins are sufficient for 99.5% availability in Rain Region E and for 99.8% in Rain Region D2. Antenna and amplifier sizes could be varied to provide different levels of availability at different locations.

iii. Modulation and coding is as discussed in ¶5.3.1.1.

iv. Satellite amplifier has 32 W peak output power per carrier.

5.3.2 Earth Station Diagram

Users will connect to each other and to the terrestrial network through a B-ISDN interface. A functional block diagram of an earth station is shown in Figure 5-7. Cell routing is achieved through the assembly of satellite virtual packets (SVPs) containing a fixed number of ATM cells for transmission over the satellite link. It is these SVPs that are routed by the on-board switch. Doppler buffers are used to account for clock differences that result from satellite motion. Beyond the interface, all outbound non-signaling data is processed through a doppler buffer, FEC encoder with byte interleaving, scrambling, and a QPSK modulator. Because of the hopping beam architecture, a ping-pong memory is used to generate TDMA bursts. These bursts are then transmitted to the satellite through the terminal's RF equipment.

Downlink reception by the earth station is aided by a TDM frame plan that requires less processing by the earth station. The downlink 800 Mb/s TDM stream is demodulated, followed by processing of the frame header. This header alerts the earth station as to where its traffic is within the frame. This section of the frame is then extracted and read into memory, where it is read out at a slower rate for decoding. The decoded data is then descrambled and deinterleaved. Finally, the ATM switch and B-ISDN interface processes the outbound data for transmission.

5.3.3 Network Control Station

In this architecture, there will also be a network control station (NCS) responsible for traffic and network control. Instead of out-of-band or terrestrial signaling channels, signaling can be performed in-band, with a portion of one of the uplink carriers reserved for random access signaling packets. These packets may then be forwarded through the switch to the downlink beam in which the network control center resides. The network control center will then return signaling packets to the satellite to be routed to different downlink destination beams through capacity statically assigned to the NCS.

The network control center performs the following functions:

- Demand assignment (described above) for high rate connections on a Virtual Path basis. Capacity is assigned based on B-ISDN VPs. The network can fill the VPs with varying numbers of Virtual Channels, but in general the addition of a Virtual Channel to a Virtual Path will not require additional demand assignment.
- Capacity assignment and management (carrier time plan management)
- Performance monitoring and adaptive link control
- Traffic statistics collection
- Monitor of system buffer occupancies
- Operation maintenance
- Network reconfiguration
- Satellite virtual packet header assignment.

The assignment of virtual packet headers is based on the destination address of the traffic. The NCS assigns the on-board routing tag for the desired output processor or processors, and selects a virtual connection number for the duration of the satellite link. This number is analogous to a virtual channel number in ATM, and is used by earth stations for connection identification purposes. A destination earth station address is used by the output processor in correctly placing the packet within a particular earth station's slot in the TDM carrier. The quality-of-service indicator and a header error check are also appended.

5.3.4 Signaling Network

In the second architecture, the SDH and ATM protocols are terminated at the earth station to provide for network routing and statistical multiplexing. Parameters

Table 5–2: System Parameters for Architecture 2 Design

System Parameters	Uplink	Downlink
Frequency	30 GHz	20 GHz
Number of Beams	12 hopping	12 hopping
Number of Dwells/Beam	10	10
Access Method	TDMA	TDM
Modulation	QPSK	8-PSK
FEC Coding	Concat. Code	Concat. Code
Transmission Rate	305 Mb/s	1,030 Mb/s
Carrier Bit Rate (info)	200 Mb/s	800 Mb/s
No. Carriers/beam	4	1
Total No. of Carriers	48	12
Beam Capacity	800 Mb/s	800 Mb/s
Beam Bandwidth Required	820 MHz	460 MHz
Frequency Reuse Factor	3	3
System Bandwidth Req'd.	2.5 GHz	1.4 GHz
System Capacity (info)	9.6 Gb/s	9.6 Gb/s
Earth Station Diameter	3.0 m	3.0 m
Transmit Amplifier Power	10–40 W	40 W

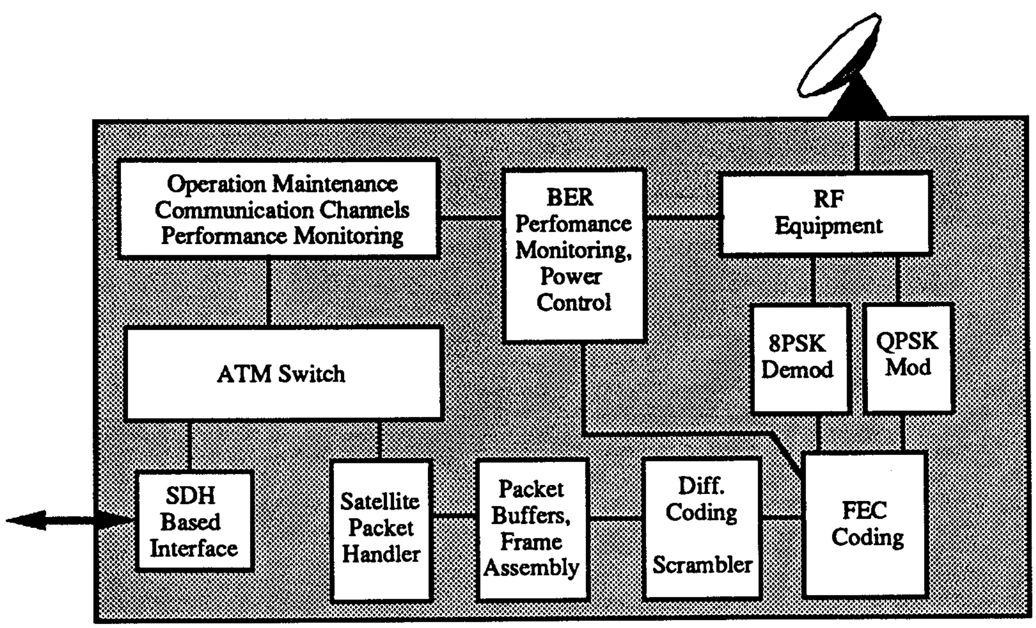

Figure 5–7: Earth Station Block Diagram for Architecture 2

such as VPI or VCI are extracted from the ATM header, while other parameters are passed transparently. The earth stations in this network include ATM switching. VPI/VCI numbers are subject to local translation at the earth station. In addition, the network control station provides additional overhead for internal network signaling and routing.

For establishment of new virtual paths through the network, a network access signaling message is incorporated into an SVP and forwarded to the network control station (NCS). On the satellite, the packet is routed to the downlink beam which contains the NCS. Based on source and destination addresses, estimates of channel bit rate required to meet the request (contained in the CBR parameter) and the requested QOS, the NCS determines if the network has sufficient resources to meet the request. If so, the capacity is reserved and the source and destination earth stations are notified of the request. Call setup will then proceed outside of the satellite network, and if the request is acknowledged by the destination address, the satellite network is able to route packets based on SVP header information provided to the earth stations. If the call setup is not acknowledged or refused by the destination, the NCS is notified to free the reserved resources. If necessary, the uplink TDMA burst durations of the source and destination stations may be expanded to handle the additional traffic.

Additional virtual channels belonging to the same virtual path do not require path setup by the NCS and are assigned the same routing header. Although this approach lowers the complexity and time necessary for call setup, it requires the network to perform additional traffic management and flow control. Earth stations that require additional capacity due to full buffers can request it at any time from the NCS. Additionally, the onboard network controller must monitor the available capacities of the downlink buffers and request additional capacity as needed. Buffers must be sufficiently large and warnings given soon enough to account for the network delay associated with signaling the NCS.

Techniques to alleviate the impact of congestion due to statistically coincidental peaks in traffic from different sources (destined for the same downlink beam) need to be investigated. The impact of satellite delay on the effectiveness of the congestion notification messages in reducing the traffic entering the satellite network needs to be examined as well.

References

[1] D. Delisle and L. Pelamourgues, "B-ISDN and How It Works", *IEEE Spectrum*, pp. 39-42, August 1991.

[2] Radio Regulations Edition of 1990, International Telecommunications Union, Geneva Switzerland, Revised March 1991.

[3] R. H. Deng and D. J. Costello, "High Rate Concatenated Coding Systems Using Multidimensional Bandwidth-Efficient Trellis Inner Codes", *IEEE Transactions on Communications*, Vol. 37, No. 10, pp. 1091-1096, October, 1989.

[4] E. R. Berlekamp et al., "The Application of Error Control to Communications", *IEEE Communications Magazine*, Vol. 25, No. 4, p. 55, April, 1987.

Chapter 6

Satellite Payload Design

This chapter discusses a possible payload implementation for each of the two candidate architectures. The first architecture is centered around four microwave switch matrices (MSMs) which provide 155.52 Mb/s pipes without on-board processing. A preliminary mass estimate for the switch matrix is 17 kg. The second network design uses an on-board, self routing switch to perform packet switching at baseband frequencies. Estimates for the mass and power requirements of the baseband processor are 132 kg and 600 W respectively (including demodulators and modulators). Mass and power requirements are estimated for the year 1996–2000 time frame, and are discussed in more detail in Chapter 7 of this report.

The chapter is organized as follows:

6.1 Architecture 1 Payload Design

6.1.1 General Payload Architecture

A block diagram of the nonregenerative satellite payload is shown in Figure 6-1. The architecture is centered around static microwave switch matrices (MSMs) which provide a space division, circuit switched architecture. Uplink carriers are switched without processing to one or more downlink carriers, depending on traffic requirements. There are 4 carriers per beam at information bit rates of 155.52 Mb/s. Each carrier group is first received and then downconverted to an intermediate frequency (between 3 and 5 GHz) before being filtered. Four 10 by 10 MSMs provide interconnectivity between any input and output beam.

This interconnectivity is not complete among all carriers but instead is such that an incoming carrier on a particular frequency can be switched to one carrier at the corresponding downlink frequency on each of the ten downlink beams. Each 10 by 10 MSM interconnects the 10 input carriers at the same intermediate frequency to 10 output carriers at the same intermediate frequency. Thus, each MSM operates at a slightly different frequency, and the system can be thought of as four independent 10 by 10 switching networks, instead of as a 40 by 40 network.

The MSMs are reconfigured via commands from the network control station. Signals leaving the MSMs are then upconverted to the downlink RF frequency, amplified, and filtered before transmission. Note that a symmetric (4 carriers per beam) architecture was selected; this choice was made due to bandwidth, power considerations, and simplicity. Asymmetry in the assignment of carriers could be accommodated by changing the MSM design. However, in order to provide full connectivity among carriers, there must be as many switches as the maximum number of carriers in each beam.

Switch reconfigurations are performed by an on-board controller (OBC), which has a separate out-of-band connection to the network control station (NCS). Signaling information could be provided by the terrestrial network or a narrowband random access channel between the earth stations and the OBC, and narrowband TDM channels for transmission between the OBC and the network control station.

A concept diagram of the signaling system is illustrated in Figure 6-2. The ten uplink random access signaling channels are multiplexed onto a single carrier. Similarly, the signaling messages from the NCS to the earth stations are demultiplexed to form ten TDM carriers.

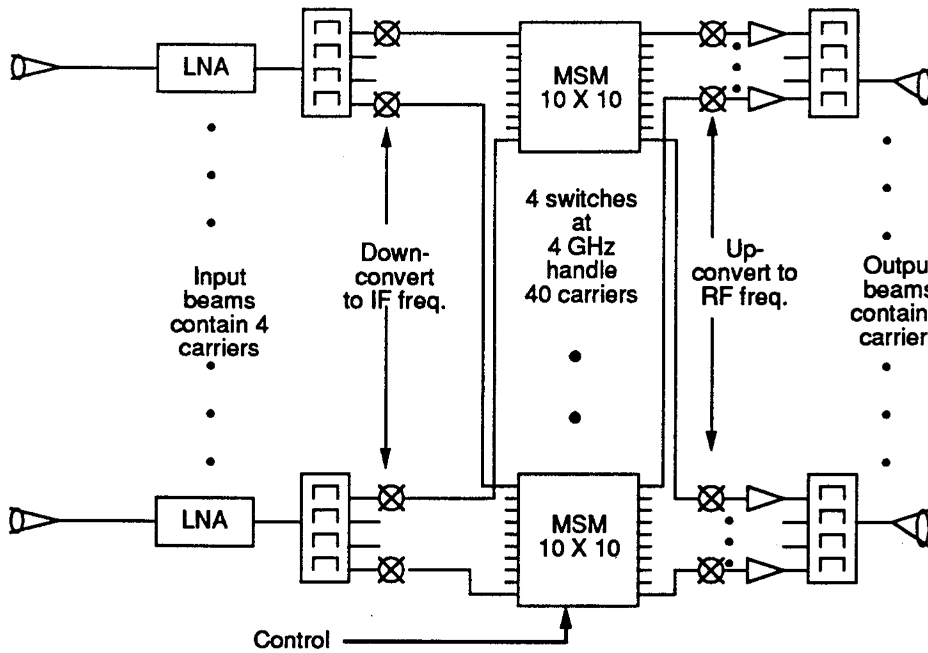

Figure 6–1: Block Diagram of Architecture 1 Payload

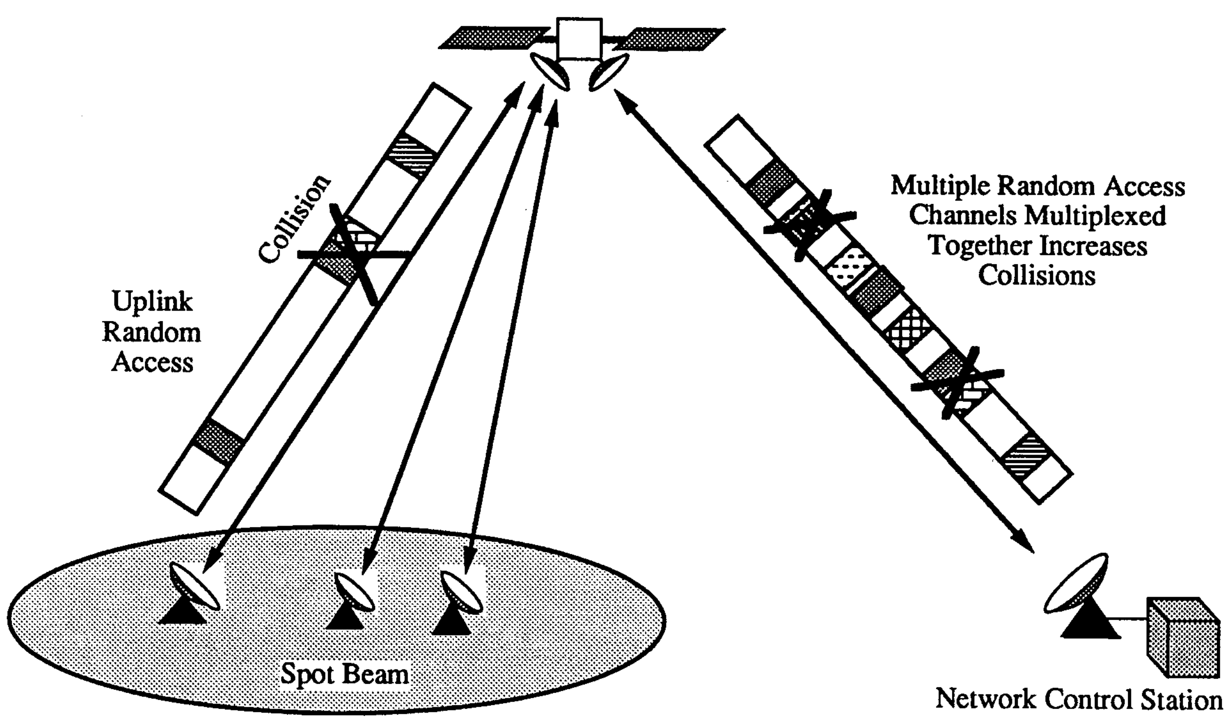

Figure 6–2: Concept Diagram of Out-of-Band Signaling System

6.1.2 Mass and Power Estimates

Because of mass and control constraints, 10 x 10 MSMs were chosen as the largest feasible switching unit for this architecture. The design incorporates internal redundancy in the switching fabric and has redundant components for reliability over the design life (see Table 7-4). An estimate for the mass of the four MSMs is 17 kg. Mass and power estimates for other components of the payload are included in ¶7.3.3 of this report.

6.2 Architecture 2 Payload Design

6.2.1 General Payload Architecture

The payload in this architecture (shown in Figure 6-3) operates at baseband frequencies, to allow for baseband processing on the satellite. At baseband, the payload can employ packet switching for higher throughput under variable traffic conditions. Additionally, the baseband processing allows for regeneration of new carriers for the downlink, leading to separately engineered uplinks and downlinks and improved link performance.

As noted above, Architecture 2 employs a hopping beam antenna system to achieve large antenna gains and to more efficiently distribute the network resources. The antenna coverage pattern consists of 12 spot beams with up to 10 dwells/beam. Each beam is allocated 4 carriers with an information rate of 200 Mb/s each on the uplink, and 1 carrier with an information rate of 800 Mb/s on the downlink. The hopping beam dwell periods are determined by the network control station for the uplink and by the on-board output processors for the downlink.

The uplink TDMA frame is illustrated in Figure 6-4 (top). Within each frame, a certain amount of synchronization and signaling information must be included, so that the larger the frame size, the greater the frame efficiency. However, larger frame sizes require more input buffering on the satellite. With the overhead estimates included on the diagram, and based on an assumption of approximately 10 users/dwell, a frame period of 2 ms yields a frame efficiency of approximately 90%. The architecture design assumes this frame period of 2 ms.

Figure 6-5 illustrates a block diagram of the baseband processor. There are 48 uplink TDMA carriers, each with an information rate of 200 Mb/s. The input carriers are first separately demodulated, and then passed to FEC decoders, which remove the concatenated coding applied at the earth station. The data is next descrambled and deinterleaved before being reassembled into packets. The reassembled SVPs are then passed to the baseband switch for routing to the correct downlink antenna beam.

After the packets have been correctly routed through the switch, they are multiplexed into 12 packet streams with a data rate of 800 Mb/s. These data will form the 12 downlink carriers. At this point, they have been routed to the correct downlink beam, but are unsorted as to destination dwell or earth station. Since the downlink hopping beam requires that the traffic be sorted according to dwell location, and since each earth station should only receive the packets destined to it, the SVPs must be sorted in each output processor. This additional sorting is performed by a partitioned memory coordinated by a control memory. The SVPs are read into the memory location dynamically allocated for a particular dwell or location, and the control memory keeps track of the occupancy of the buffer. Based on buffer occupancy, the output processor coordinates the downlink hopping beam dwell times. According to this traffic plan, packets are read out of the buffer at the appropriate time and sent through a packet scrambler and bit interleaver, a FEC encoder, and the 8PSK modulator before downlink transmission.

Figure 6-4 (bottom) illustrates the downlink TDM burst pattern. The frame period is 2 ms, symmetric with the uplink, and yielding a frame efficiency of approximately 98%. Each frame includes a reference burst for a dwell area, which provides a reference timing for all earth stations within the designated dwell area and which includes network control messages for uplink time plan allocation/deallocation, frame numbers, the downlink traffic burst position, and other control/status information. Each frame also contains dwell traffic bursts for each dwell area, which include a burst pointer to direct an earth station to its packets within the burst. Each earth station field is then made up of a length indicator and a number of contiguous SVPs. The data will be received from a high speed carrier, but it can be buffered and read out at a slower rate.

The payload of this architecture is centered around an on-board self-routing packet switch. Since there are many small spot beams which require full interconnectivity and since private-based B-ISDN networks are expected to carry a wide variety of bit rates, a self-routing packet switch, in which packets consist of ATM cells, is appropriate for this architecture. Several options exist

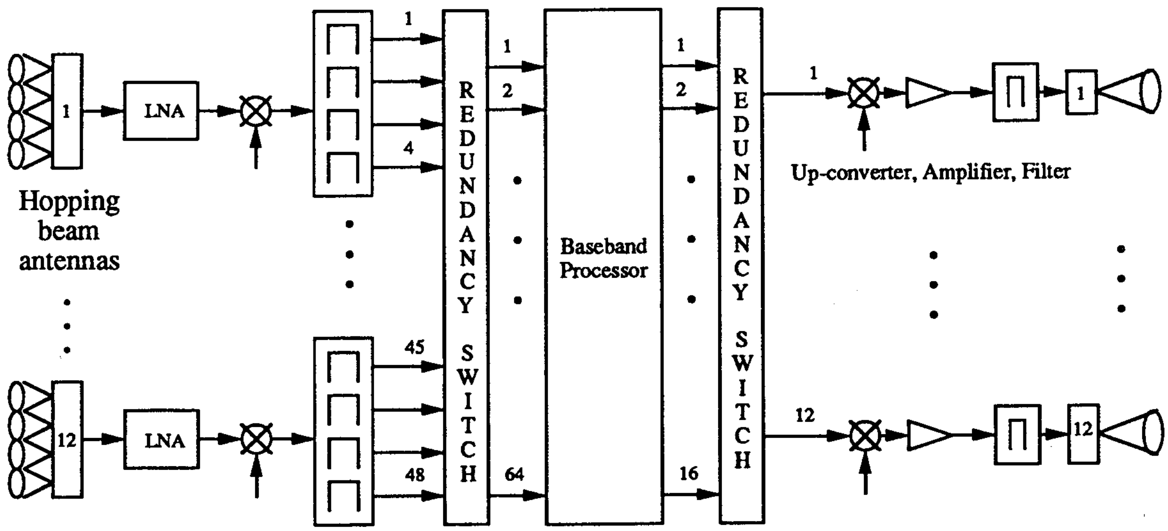

Figure 6–3: Block Diagram of Satellite Payload for Architecture 2

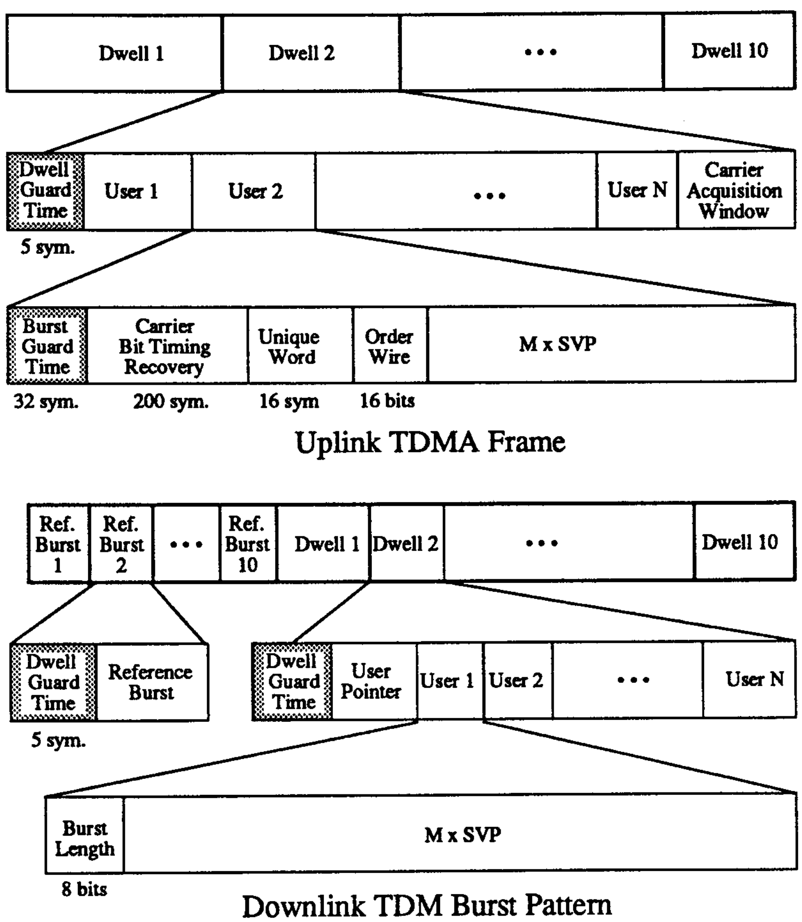

Figure 6–4: TDMA and TDM Frame Formats for Architecture 2

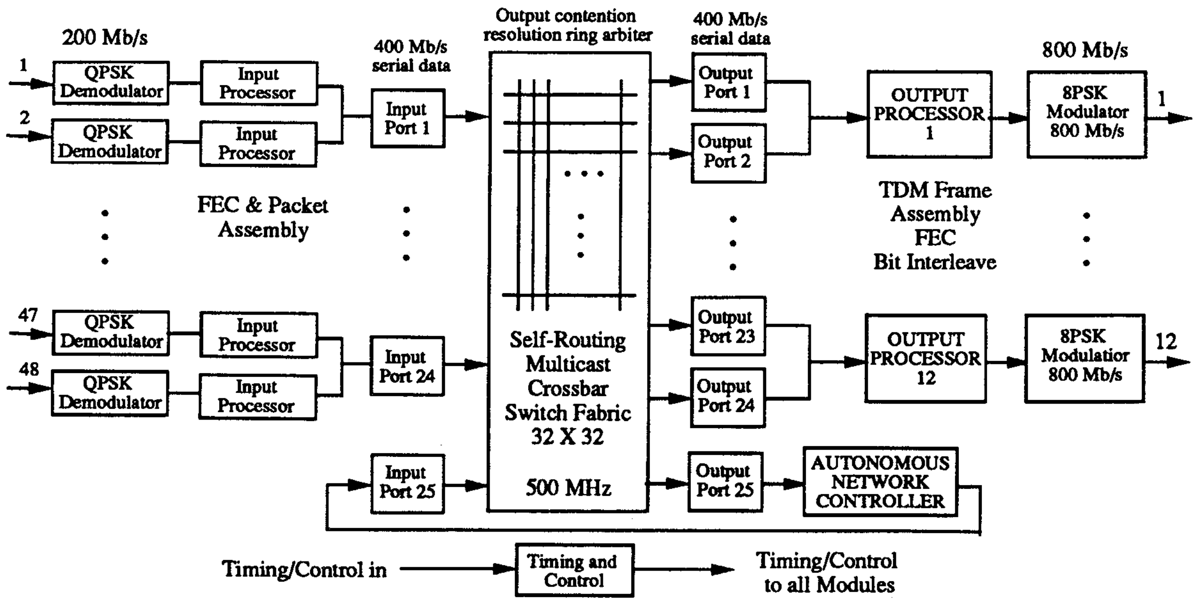

Figure 6–5: Block Diagram of Baseband Processor for Architecture 2

for the switch fabric itself. There have been many proposed designs for fast packet switching based on different performance criteria [5, 6].

In a satellite payload, two key features are essential to the efficiency of the satellite switch: fault tolerance and multicast capability. Because of the inaccessibility of the satellite payload, a switch design must be chosen that incorporates necessary redundancy and that has sufficiently graceful degradation in the event of failures. Also, since it is envisioned that B-ISDN satellite network users will take advantage of a satellite's inherent broadcast or multicast capability, a multicast switch architecture should be used.

6.2.2 Baseband Processor Architecture

6.2.2.1 Candidate Switch Architectures

A number of potential self-routing fast packet switch designs were examined in light of the present requirements. Several possible architectures were found to satisfy the criteria; block diagrams of these architectures are shown in Figure 6-6.

i. Shared medium design, implemented as a high speed optical ring, is particularly well suited for multicast traffic, and, assuming advances in optic technology in the next twenty years, may emerge as a preferred architecture.

Three space division approaches and one stored memory approach were also considered:

ii. Crossbar based architecture in which multicast capability is added *(this is the selected design)*;

iii. Banyan based architecture using batcher sorters to implement multicast routing;

iv. Binary tree structure, which is an efficient design for switch fabrics with a small number of input lines;

v. Shared memory approach, in which packets are written to and read from a large common memory, is a particularly promising architecture, especially considering expected memory bandwidth advances in the coming years [7].

6.2.2.2 Design of Selected Fast Packet Switch

After implementation considerations and preliminary mass and power estimates for candidate switches were examined, the self-routing multicast crossbar switch design (candidate ii.) was selected based on mass and power requirements and ease of implementation [8]. The basic crossbar design is strictly non-blocking. In other words, given that a particular input port and output port are free, there exists a free path between them regardless of the present switch configuration.

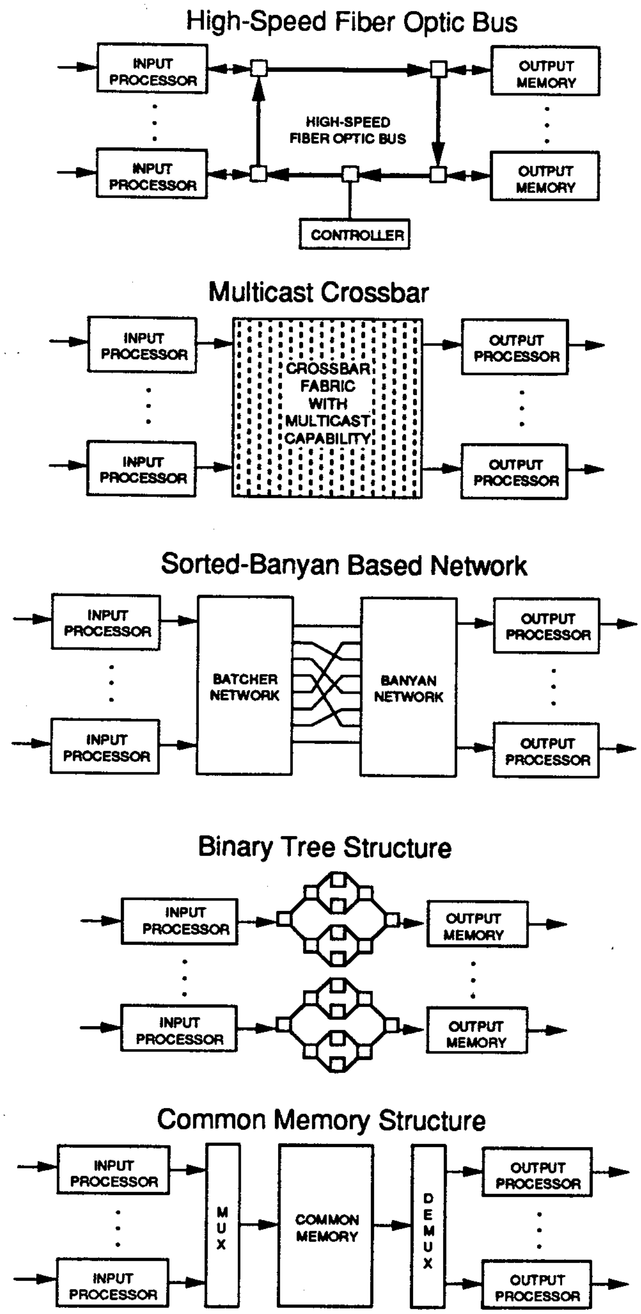

Figure 6–6: Fast Packet Switch Architectures

Output contention will arise, however, if two packets destined for the same output are sent through the switch fabric at the same time; one of the packets will be lost. Therefore, input buffering is used with a switch fabric arbiter to insure that no more than one packet destined for each output enters the switch fabric at the same time. This arbiter examines a selected number of packets in each input port's queue, thereby minimizing the decreased efficiency resulting from head-of-line blocking, in which the first packet in a buffer is blocked due to a previous selection by the arbiter.

A number of design issues arise in the input FIFO buffers in the input ports. The fast packet switch functions as a statistical multiplexer in smoothing out bursty traffic patterns on the input side. This statistical multiplexing occurs in the input port buffers. A very small buffer size would reduce the statistical multiplexing to simply deterministic multiplexing, which would result in the loss of many packets. Consequently, the buffers must be large enough to greatly reduce packet loss resulting from buffer overflow. However, larger buffers result in larger end-to-end delay in the system. Due to the bursty nature of some B-ISDN traffic, buffer sizes will need to be fairly large to keep the packet loss rate down. The optimal size of such a buffer depends on the desired packet loss rate and the traffic pattern envisioned. Furthermore, packets should be buffered according to delay or loss rate specifications in the QOS field. The buffer should be partitioned to reserve a larger segment for more important packets and to enable them to be considered for transmission ahead of packets with lower priority.

On the output side of the crossbar switch, packets are buffered in the output ports as well. Because there is one carrier per downlink beam, while there are two switch output ports per downlink beam, packets are multiplexed from the two output ports to form one packet stream. The 800 [illegible] packet stream is then fed into a partitioned buffer, which separates the traffic based on destination earth station. TDM frames are assembled, as described below, from various bursts destined to different earth stations. The TDM frames are then coded and modulated before being amplified, upconverted, and transmitted.

Several options exist for implementing multicast capability; multicast packets may be duplicated on the input or output port side, or within the switch fabric itself. The multicast crossbar switch provides multicast capability at the input ports, whereby a special routing tag

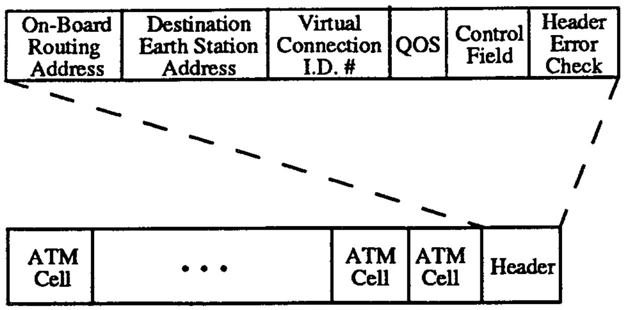

Figure 6–7: Satellite Virtual Packet Structure

on the packet reserves several connections through the switch fabric.

Fault tolerance is best implemented by means of a 1 for 3 redundancy approach. The present requirements call for 24 input and output lines at 400 Mb/s each. If the switch network is built as a 32-by-32 network, then there will be 33% redundancy in the switch fabric components. This redundancy is necessary to restore full functionality in the event of one or more path failures between an input and output line. Backup components are used in the event of a detected failure. Fault isolation may then be performed on the faulty units while offline.

Satellite Virtual Packets. To reduce on-board switch complexity and to avoid VPI retranslation at the switch, satellite virtual packets (SVPs) will be formed by appending a routing tag to a group of one or more ATM cells. SVPs may be assembled on-board the satellite before routing is performed, but it is advantageous to assemble them at the earth stations in order to simplify the on-board satellite processor. Figure 6-7 illustrates the structure of these packets, including the basic header field. SVPs simplify routing by mapping the VPI/VCI address into a simpler address for processing on the satellite. Instead of routing based on ATM headers, the on-board switching is performed based on destination downlink beam addresses included in the SVP. Essentially, the SVP header functions much the same as an ATM VPI with local significance.

The on-board routing address specifies an on-board switch output port number (1 through 32) to which the SVP is routed. In the present switch design, there are two ports active per beam. Assignment of the packets destined to a particular downlink beam will alternate between the two output ports assigned to the downlink beam. After output port processing, the packets from the two output ports will be multiplexed together.

A destination earth station address is also specified in the SVP header. This address is unique to a particular earth station within a downlink beam and is used to sort the SVPs on the basis of dwell burst location. At the output of the baseband processor, SVPs destined for particular downlink earth stations are buffered separately and then grouped into contiguous fields based on their dwell location and destination earth station. The destination earth station address provides a routing tag for this sorting. This reduces the load on the earth station address processing. Each earth station need only extract and process those packets destined for it.

Also specified in the SVP header are a virtual connection number, control field and a header error check field. The virtual connection number is used by the originating and destination earth stations as a local VCI. The use of the control field and header error check field are for orderwire information and error detection.

The QOS field may be used in order to set SVP delivery priority. The switch buffers, upon overload conditions, may then drop SVPs with lower QOS. Use of the QOS field implies that the originating earth stations fill SVPs with ATM cells of the same specified QOS and that the buffers on board the satellite take into account the QOS of each SVP, which leads to increased processing demands on both the on-board processor and the earth station.

All of these addresses must contain at least $\log_2(N)$ bits for N addresses. Although it is desirable to keep the header as small as possible to maximize throughput efficiency, if the SVPs contain many cells, it may be advantageous to increase the address fields for easier processing. For example, in a 32-by-32 switch, the output ports could be specified by 5 bits, of which each crosspoint would need to examine the whole field, or the ports could be specified by 32 bits, of which each crosspoint would just need to examine one particular bit. The SVP header field also contains a quality-of-service indicator, a control field, and a header error check.

Another tradeoff exists with regard to SVP size. A reduction in overhead, and thus greater efficiency, can be incurred if SVPs are made large and earth stations wait to fill them before transmission. However, this approach leads to larger processing delays and higher buffer memory requirements in switch input and output ports. Conversely, delays can be reduced by making

SVPs small, at the cost of lower efficiency. Minimizing SVP size is limited by processing speeds, since smaller packets lower packet interarrival time (as low as 1.2 μs with 400 Mb/s carrier). The optimal size for SVPs needs further investigation.

SVPs may contain either a fixed or variable number of packets. If SVPs have a fixed number of packets, then synchronization and header processing is made easier. However, delay may increase as the earth station waits to fill the SVP with ATM cells. This delay, though, could be bounded by a timer which fills unfinished SVPs with idle ATM cells after a certain time. SVPs with variable size can respond to traffic fluctuations more effectively, but synchronization and processing of irregularly sized SVPs becomes a problem. One mitigation to this problem would be to allow packet sizes of only a few integer multiples of cells (e.g. 2, 4, or 6 cells).

Contention and Congestion in Fast Packet Switches. Contention is an inherent property of input buffered switches. The techniques to resolve contention include output port reservation and path setups prior to packet routing. These techniques reduce a switch throughput by 20% to 40% due to scheduling algorithms or contention of path setup packets and require an increase in switching speed by 25% to 67% to maintain the desired switch throughput. It has been shown [9] that input port buffering without windowing (i. e. without provisions for more than one packet per buffer to be considered for transmission) has a maximum throughput of 0.58 under uniform traffic conditions. If, however, more than one packet is considered in each buffer, the throughput increases. The switch described in [8] uses a buffer window of four within a buffer of 128 packets; such a window size will yield a maximum throughput of 0.8 under uniform traffic conditions [9]. This is based on statistically independent packet transmission from uplink beams to different downlink beams. Otherwise, although this is unlikely, the switching speed must be increased further. With an increased switching speed, the contention problem will virtually disappear.

Congestion is a more difficult problem associated with destination directed packet switching. This problem is not unique to satellite networks and has been extensively studied for terrestrial ATM networks. A congestion control procedure must be devised as a part of the overall network control strategy, including packet queue monitoring and buffer management by the onboard processor and user earth stations, call admission control at the user and network levels, and satellite capacity allocation procedures. The benefits of using destination directed packet switching, including elimination of control memories, memory update processing, switchover coordination, and path finder procedures for channel routing, are well worth the additional processing of packet assembly and control. Congestion problems should be investigated in future studies so that the advantages of packet switching can be fully realized.

6.2.3 Mass and Power Estimates

Mass and power estimates for a space-qualified design and implementation of this switch architecture are presented in Table 6-1. (These numbers are the basis for the estimates in Table 7-7 for payload electronics mass.) One input port and one output port can be supported on a circuit board of 30 square inches. Similarly, one input processor and one output processor can be supported on a single board. One board each is also required for the switch fabric and for timing and control signal generation. In summary, 66 boards are required, with a total mass of approximately 98 kg, including support structure and power supply. Addition of demodulators and modulators add another 34 kg to give a total of 132 kg.

This mass estimate is a current technology assessment and will decrease as improvements are made in logic density. Power estimates are based on the number of gates required and the speed of each gate. The total power required for the baseband processor is estimated at 600 W including dc-to-dc converter power consumption (estimated efficiency is 85%). This number reflects the condition in which all redundant units are operating. These estimates are for current technology, and are based on the multicast crossbar architecture described in [8].

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Table 6–1: Mass and Power Estimates for Baseband Processor

Component	No.	No. In Use	Unit Mass (kg)	Unit Power (W)	Total Mass (kg)	Total Power (W)
Misc. Support	1	1	1.4	12.0	1.4	12.0
Switch Fabric	1	1	1.4	23.8	1.4	23.8
Input Port	32	25	0.6	3.6	19.2	89.2
Output Port	32	25	0.6	2.5	19.2	61.9
Input Processor	60	48	0.6	4.4	36.0	208.8
Output Processor	16	12	1.2	6.6	19.2	78.6
Demodulators	60	48	0.3	0.5	18.0	24.0
Modulators	16	12	1.0	1.0	16.0	12.0
Power Converter (85%)	1	1	2.0	90.1	2.0	90.1
Totals					132.4	600.4

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Chapter 7

Satellite Design

This chapter describes the satellite designs needed to accommodate the Architecture 1 and 2 B-ISDN payloads described in Chapter 6. The emphasis is on the required satellite mass, power, and configuration to support the Architecture 1 and 2 payloads.

The approach is to evolve the existing satellite design (1990 technology base for 1995 launch) to the B-ISDN satellite designs which assume a year 2000 technology base for a year 2006 launch. Approximately the same size satellites are used for the Architecture 1 and 2 missions.

The chapter is organized as follows:

7.1 Overview and Summary

The B-ISDN satellite designs are presented, the mass and power allocations are described, and the features of the satellite bus are summarized.

7.1.1 B-ISDN Satellite Designs

Table 7-1 compares the B-ISDN satellite designs with those of three communications satellites currently being produced by Space Systems/Loral (formerly Ford Aerospace). Superbird is a Japanese domestic communications satellite with 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.

There are two B-ISDN satellite configurations. Architecture 1 uses a microwave switch matrix to establish connectivity between uplink and downlink beams. It is a transponder satellite which can be reconfigured to change interconnections among channels. Architecture 2 uses an on-board baseband switch that allows simultaneous interconnectivity between all uplink and downlink beams. The baseband electronics consume mass and power which are used for transponders in the Architecture 1 design. However, the Architecture 2 design has a greater communications efficiency due to its on-board processing and smaller spot beams.

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 around 30% for the B-ISDN satellite designs. 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. Lower mass batteries and solar cells allow greater payload mass.

7.1.2 Satellite Mass and Power Allocations

B-ISDN satellite designs with 3,550 kg launch mass and 5 kW power are summarized in Table 7-1. Available mass and power are kept the same in order to allow a meaningful comparison of the Architecture 1 and 2 designs. Architecture 2 is judged to require more integration mass due to its greater payload complexity. However, the main difference between the two designs lies in the composition of the payload — the antennas and communications electronics.

Table 7–1: Comparison of B-ISDN Satellites with Current Communication Satellites

Satellite Parameter	Superbird 1	Intelsat 7	N-Star	B-ISDN Satellites Arch. 1	B-ISDN Satellites Arch. 2
Launch Year (first)	1992	1993	1995	2006	2006
Launch Vehicle	Ariane 3	Atlas 2AS	Ariane 44P	Atlas 2AS	Atlas 2AS
Lifetime (yr)	10	11	10 (12)	15	15
Number of satellites	2	5	2	–	–
Transponder Bandwidth, up/dn (GHz)	1.8	2.4	2.6	3.6	8.5/5.5
Max. Capacity (Gb/s)				6.2	9.6
DC Power, end of life (kW)	3.55	3.53	4.1	5.1	3.5
RF Transmit Power (W)	885	929	1,050	1,280	480
Battery Capacity (W-hr)	3,964	3,972	4,592	5,660	4,000
Satellite Subsystem Mass (kg)					
Structure	208	209	200	210	210
Propulsion	91	108	112	281*	281*
Power	174	180	188	155	107
Solar array	116	120	130	146	100
Attitude control	86	93	56	60	60
Spacecraft control electronics	–	80	74	60	60
TT&C	38	15	17	20	20
Thermal	93	94	103	120	120
Integration, elect. & mech.	114	105	131	130	150
Antenna	52	103	155	48	72
Communication electronics	246	320	370	472	433
Dry Mass of Satellite (kg)	1,218	1,427	1,536	1,696	1,613
On-orbit Fuel (kg)	273	454	422	160*	160*
Wet Mass of Satellite (kg)	1,491	1,881	1,958	1,856	1,773
Orbit-raising Fuel (kg)	1,030	1,710	1,571	1,634	1,561
Launch Mass (kg)	2,521	3,591†	3,529	3,490†	3,334†

† Equatorial launch (Ariane) would save 300 kg launch mass versus ETR launch (Atlas).
* Use of ion propulsion increases propulsion mass and decreases on-orbit fuel mass.

7.1.3 Summary of 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 based on estimates of battery performance and technology readiness 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]. Advanced NiH batteries in the year 2000 are predicted to have 75 Wh/kg specific energy, compared to 45 Wh/kg for 1990. We adopt a figure of 33 W/kg (which combines 75 Wh/kg for batteries with packaging and power conditioning overhead) to estimate the 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 Space Systems/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 5 kW dc power, 1 kW is radiated away in rf power, leaving approximately 4 kW to be disposed of by the thermal subsystem.

Use of ion propulsion 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 12 beams.

7.2 Architecture 1 Satellite Design

This section describes the satellite design to accommodate the Architecture 1 payload. Table 7-2 summarizes the satellite characteristics. 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

7.2.1 Antenna Coverage and Size

Figure 7-1 shows the antenna coverage for Architecture 1. Separate uplink and downlink multiple beam antennas supply ten 1.55° fixed beams that cover CONUS. There are two Ka-band multiple beam antennas:

- Ka-band receive (30 GHz) – 1.4 m, 22 kg mass.
- Ka-band transmit (20 GHz) – 2.2 m, 26 kg mass.

The three different beams, shown by the different shading, use different parts of the spectrum. The frequency band is reused 3 or 4 times over CONUS.

In order to improve antenna sidelobe performance, each of the ten beams for both uplinks and downlinks is formed by a cluster of 7 feeds. This is required in order to meet a -20 dB co-channel interference specification. Each 1.55° fixed beam is formed by a composite of seven 0.52° feed horns, and there are approximately 70 feed horns for the uplink and for the downlink antenna. The antenna sizes are approximately three times

Table 7-2: Characteristics of Satellite to Supply B-ISDN Service (Architecture 1)

Manufacturer & model:	LORAL FS-1300
Baseline satellite name:	B-ISDN Satellite
Lifetime:	15 yr
On-board switching:	Microwave IF switch matrix for all channels.
Launch vehicle:	Atlas IIAS
Launch year:	2006
Frequency band and bandwidth:	Ka-band, 1,400 MHz
– receive:	27.5-30.0 GHz
– transmit:	18.3–20.2 GHz
Antenna	
– type:	Offset parabolic
– number:	2
– size:	1.4 m receive, 2.2 m transmit
– mass:	48 kg
– coverage (Ka-band):	10 fixed beams cover CONUS, both transmit & receive
Communications electronics	
– number of receivers:	10 at Ka-band active, 2–1 redundancy.
– TWTAs:	40 @ 32 W active, 6–4 redundancy.
– mass:	472 kg
– dc power:	4,110 W
Spacecraft	
– size (stowed):	2.5 m x 1.88 m x 2.64 m
– mass, BOL:	1,856 kg
– power (EOL) at summer solstice:	5,050 W
– primary power:	Solar cells (thin silicon)
– batteries:	4 NiH, 280 Ah (total)
– attitude and station keeping:	3-axis stab, ion propulsion
– attitude pointing accuracy:	$\pm 0.08°$
– apogee motor:	Liquid propulsion
– stationkeeping & attitude control:	Ion propulsion motor

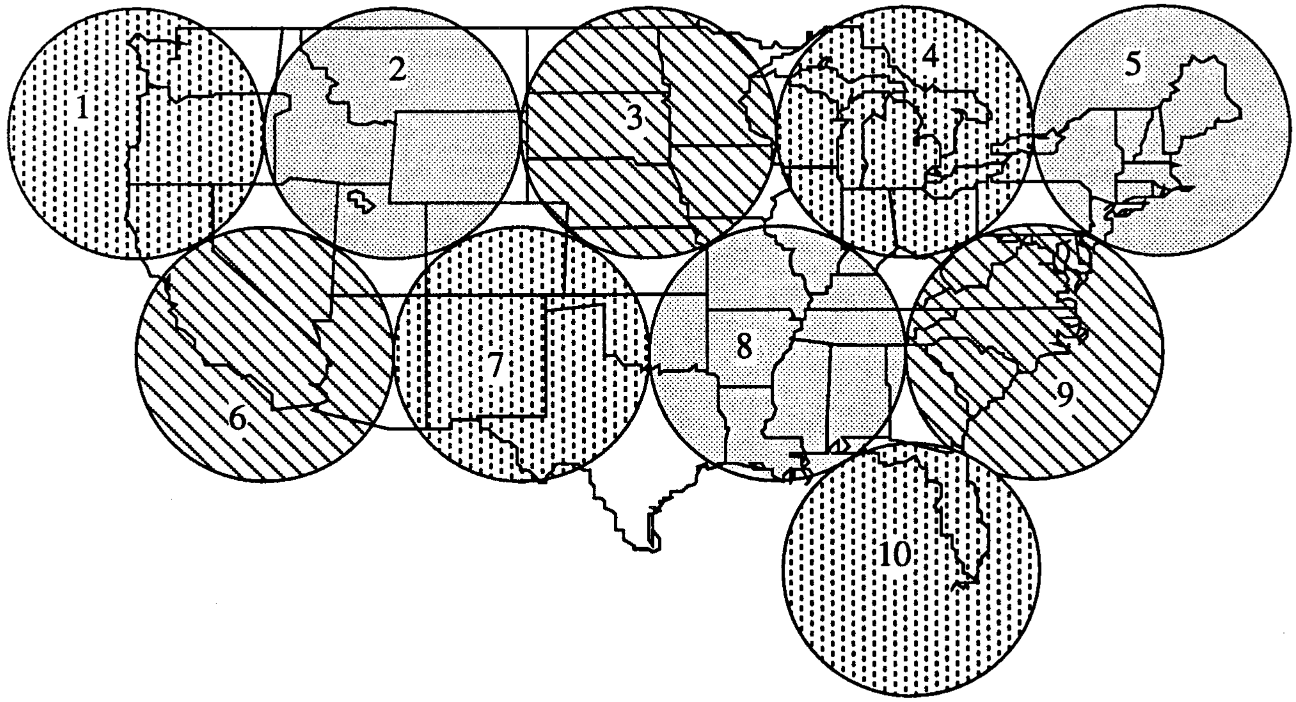

Figure 7–1: Coverage for Architecture 1 — 10 Fixed, 1.55° Spot Beams Use Three Different Frequencies

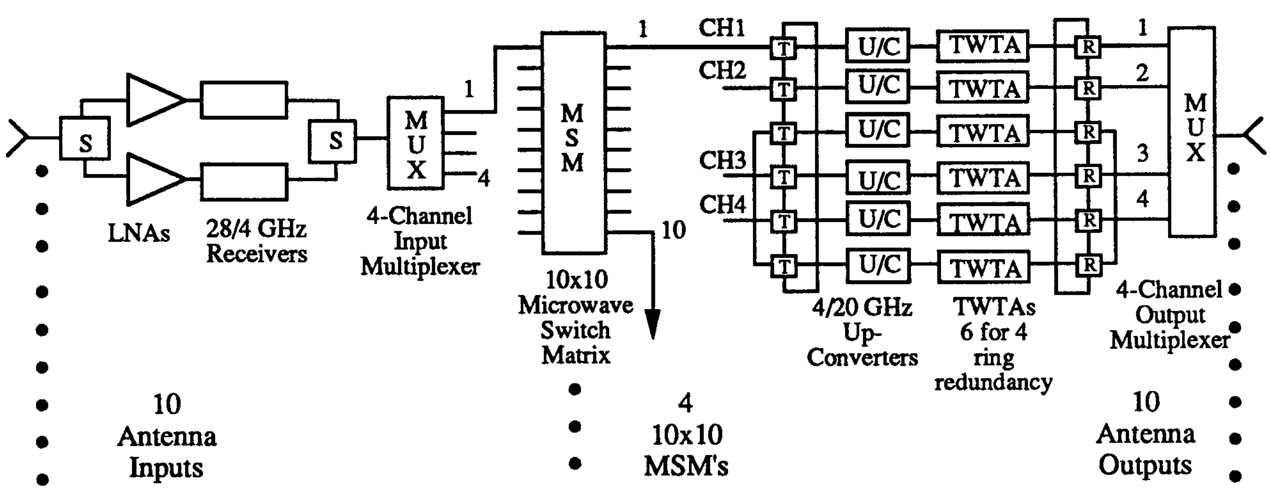

Figure 7–2: Payload Block Diagram for Architecture 1

larger than that required for a simple 1.55° spot formed by one feed horn.

7.2.2 Payload Block Diagram

Figure 7-2 shows the payload block diagram for one uplink and one downlink beam of Architecture 1. There are ten input beams (only one is shown) and ten output beams (only one is shown). There are four 10 x 10 microwave switch matrixes (only one is shown) to supply connectivity among the ten inputs and outputs for up to four channels per beam. There is 2-for-1 redundancy for the low noise amplifiers (LNA's) and receivers and 6-for-4 ring redundancy for the upconverters and TWTA's. The total system capacity for the Architecture 1 B-ISDN satellite is 40 channels of 156 Mb/s, or 6.2 Gb/s.

7.2.3 Payload Electronics Mass and Power

Table 7-4 summarizes the payload electronics mass and power. Major components are as follows:

LNAs and downconverters have 2-for-1 redundancy. There are a total of 20 LNAs and 20 downconverters, with 10 of each active at one time.

10 x 10 MSMs (microwave switch matrices) have internal redundancy. There are four MSMs.

Upconverters and TWTAs have 6-for-4 ring redundancy. There are a total of 60 upconverters and 60 TWTAs, with 40 of each active at one time.

Also included in the mass and power tabulations of Table 7-4 are the coaxial and waveguide interconnections and the beacon transmitters for earth terminal pointing and rain fade detection.

The major payload items in terms of contribution to mass and power consumption are the 32 W TWTAs. Current technology is exemplified by the 29 W Superbird TWTA/EPC which has a mass of 3.5 kg and power efficiency of 30%. Assumption is made that another 10 years of development (year 2000 technology) will achieve a 32 W TWTA with 3.5 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.

An alternate design for the MSM switches would be the active cross-bar switch matrix. Based on current designs, a 10x10 cross-bar switch would have 3.8 kg mass

Table 7–3: Power Budget (Architecture 1)

Component	Power (W)	
LNAs, Receivers	82	
Upconverters	120	
Transmitters	3,556	
Other/Margin	352	
Total Payload	4,110	4,110
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		424
Total Satellite		5,050

and 17 W power consumption. However, its higher switching speed is not needed for the Architecture 1 design application.

7.2.4 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 7-2 summarizes the Architecture 1 satellite characteristics.

The existing satellite design (1990 technology) has been upgraded to incorporate hypothesized year 2000 technology improvements. The result is a 1,696 kg dry (1,856 kg wet) satellite mass with a 520 kg payload (antenna plus communication electronics) and 5.1 kW end-of-life power. Table 7-1 summarizes the mass budget by satellite subsystem. Table 7-3 gives the power budget for the satellite. Figure 7-6 at the end of this chapter gives the satellite on-orbit configuration.

7.3 Architecture 2 Satellite Design

This section describes the satellite design to accommodate the Architecture 2 payload. Table 7-5 summarizes the satellite characteristics. This section is divided into four parts:

Table 7–4: Payload Electronics Mass and Power Breakdown (Architecture 1)

	Mass (kg)			Power (W)			
Equipment	Qty.	Unit	Total	Qty.	Unit	Total	Comments
28 GHz low noise amplifier	20	0.4	8	10	1.2	12	2–1 redundancy
28/4 GHz receiver	20	2.0	40	10	7.0	70	2–1 redundancy
Input multiplexer (4 GHz)	10	2.6	26				4 channel
10x10 switch matrix	4	4.2	17				Coax. switch matrix
4/20 GHz upconverter	60	1.2	72	40	3.0	120	6–4 redundancy
32 W TWTA + EPC	60	3.5	210	40	88.9	3,556	6–4 red; 36% effic.
Output multiplexer (28 GHz)	10	2.0	20				4 channel
Master LO (upconverter)	2	5.0	10	1	6.0	6	2–1 redundancy
DC/DC converters (upconv.)	30	0.4	12	20	6.0	120	Dual outputs
S-switch (28 GHz WG)	10	0.13	1				
S-switch (4 GHz coax)	10	0.07	1				
T-switch (4 GHz coax)	60	0.12	7				
R-switch (20 GHz WG)	60	0.2	12				
Coaxial cable			3				
Waveguide			2				
Beacon transmitters	4	2.0	8	2	15.0	30	
Margin			24			196	5% mass margin
Totals			472			4,110	Mass (kg), Power (W)

1. Antenna Coverage and Size
2. Payload Block Diagram
3. Payload Electronics Mass and Power
4. Satellite Characteristics

7.3.1 Antenna Coverage and Sizes

There are two separate Ka-band multiple beam antennas:

- Ka-band receive (30 GHz) – 1.8 m, 33 kg mass.
- Ka-band transmit (20 GHz) – 2.7 m, 39 kg mass.

Figure 7-3 shows the antenna coverage for Architecture 2. The uplink and downlink coverages are identical. The continental United States (CONUS) is covered by 110 each 0.40° spot beams divided into 12 areas of 7 to 10 beams. Each of the 12 beam areas is covered by a hopping beam which contains four 200 Mb/s channels. The different beam areas are covered with different parts of the available spectrum, 1.7 GHz on uplinks and 2.5 GHz on downlinks. As indicated by the three different kinds of shading in Figure 7-3, the frequency band is divided into three parts and is reused four times over CONUS.

Isolation between the simultaneous hopping beams must be sufficient to meet a -20 dB co-channel interference specification. This is achieved by coordination among hopping beams of the same frequency so that adequate separation is maintained.

7.3.2 Payload Block Diagram

Figure 7-4 shows the payload block diagram for Architecture 2, and Figure 7-5 show details of the baseband processor. There are 12 input beams and 12 output beams. Each input beam contains four 200 Mb/s channels. The 48 input channels are demodulated and passed to 48 input processors which perform error correction and packet assembly functions. These 48 data streams are combined in pairs for the 24 input ports of the baseband switch.

The 32 x 32 crossbar switch matrix supplies connectivity among 24 input and 24 output ports. (In addition there is a 25th port for the autonomous network controller.) The 24 output ports are combined in pairs to feed 12 output processors. These 12 outputs at 800 Mb/s are modulated, upconverted and amplified by 40 W

Table 7–5: Characteristics of Satellite to Supply B-ISDN Service (Architecture 2)

Manufacturer & model:	LORAL FS-1300
Baseline satellite name:	B-ISDN Satellite
Lifetime:	15 yr
On-board switching:	Baseband switching among all channels.
Launch vehicle:	Atlas IIAS
Launch year:	2006
Frequency band and bandwidth:	Ka-band, 2.5 GHz uplink, 1.7 GHz downlink.
– receive:	27.5-30.0 GHz
– transmit:	18.3–20.2 GHz
Antenna	
– type:	Offset parabolic
– number:	2
– size:	1.8 m receive, 2.7 m transmit
– mass:	72 kg
– coverage (Ka-band):	12 scanning beams cover CONUS for uplinks. 12 scanning beams cover CONUS for downlinks.
Communications electronics	
– number of receivers:	12 at Ka-band active, 2–1 redundancy.
– TWTAs:	12 @ 40 W active, 2–1 redundancy.
– mass:	433 kg
– dc power:	2,462 W
Spacecraft	
– size (stowed):	2.5 m x 1.88 m x 2.64 m
– mass, BOL:	1,773 kg
– power (EOL) at summer solstice:	3,500 W
– primary power:	Solar cells (thin silicon)
– batteries:	3 NiH, 200 Ah (total)
– attitude and station keeping:	3-axis stab, ion propulsion
– attitude pointing accuracy:	$\pm 0.05°$
– apogee motor:	Liquid propulsion
– stationkeeping & attitude control:	Ion propulsion motor

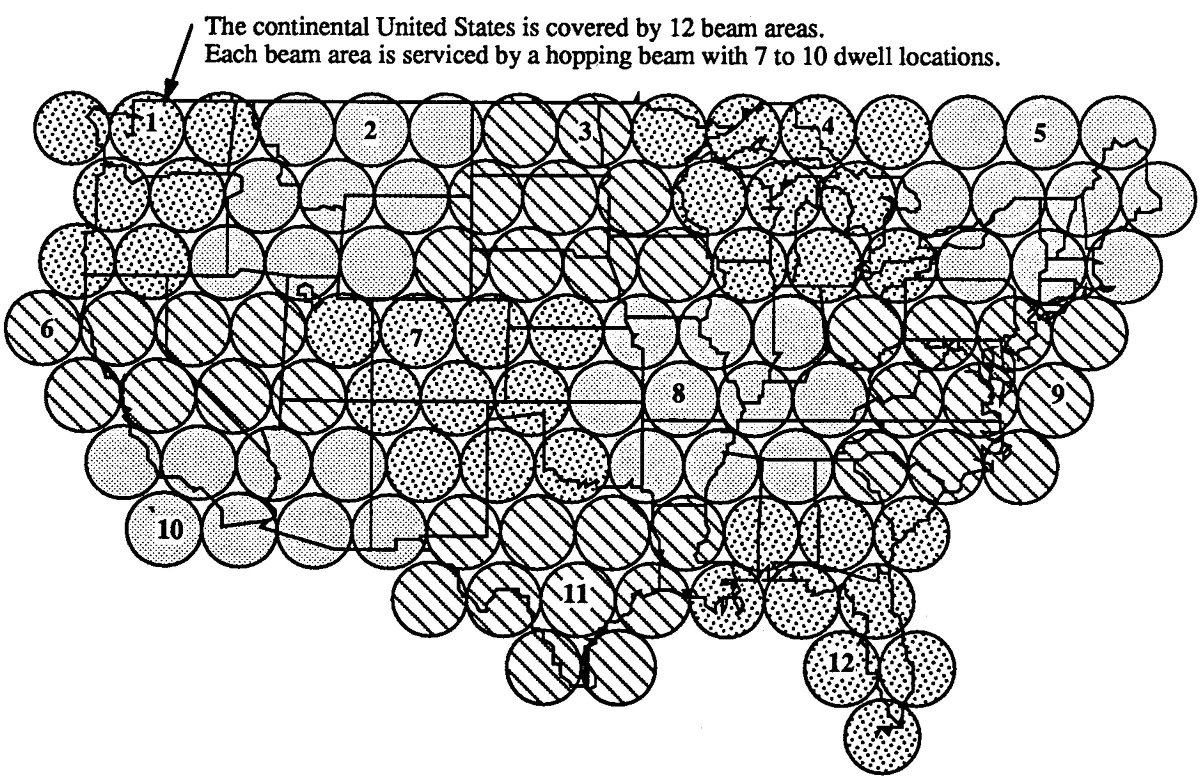

Figure 7–3: CONUS Coverage is Provided by Twelve 0.4° Hopping Beams (Architecture 2)

TWTAs.

There is 2-for-1 redundancy for the low noise amplifiers (LNA's) and receivers, and 8-for-4 redundancy for the upconverters and TWTAs. The TWTAs are grouped by frequency reuse region as shown in Figure 7-3. Each group of beams (1, 4, 7, 12; and 2, 5, 8, 10; and 3, 6, 9, 11) uses a different part of the frequency band. The 800 Mb/s downlink occupies 458 MHz bandwidth with 8-PSK modulation (712 MHz if QPSK modulation is used).

7.3.3 Payload Electronics Mass and Power

Table 7-7 summarizes the payload electronics mass and power. Major components are as follows:

LNAs and downconverters have 2-for-1 redundancy. There are a total of 24 LNAs and 24 downconverters, with 12 of each active at one time.

Baseband electronics which includes demodulators, baseband switch, and modulators have either 5-for-4 or 4-for-3 redundancy.

32 x 32 crossbar switch has 32 for 24 redundancy.

Upconverters and TWTAs have 8-for-4 ring redundancy. There are a total of 24 upconverters and 24 TWTAs, with 12 of each active at one time.

Also included in the mass and power tabulations of Table 7-3 are the coaxial and waveguide interconnections and the beacon transmitters for earth terminal pointing.

The major payload item in terms of contribution to power consumption is the 40-W TWTAs. Current technology is exemplified by the 29 W Superbird TWTA/EPC which has a mass of 3.5 kg and power efficiency of 30%. Assumption is made that another 10 years of development (year 2000 technology) will achieve a 40 W TWTA with 4.5 kg mass and 32% dc-to-rf efficiency (36% tube efficiency and 90% dc-to-dc efficiency).

The baseband processor has 132 kg mass and 606 W power consumption. It contains the hardware required to demodulate the RF signal to baseband, recover the information bits, switch the contents of the individual input data channels to the correct outputs, assemble the output data streams, and finally modulate the information onto the downlink channel carriers. Use of MMIC components is assumed for electronic components where appropriate.

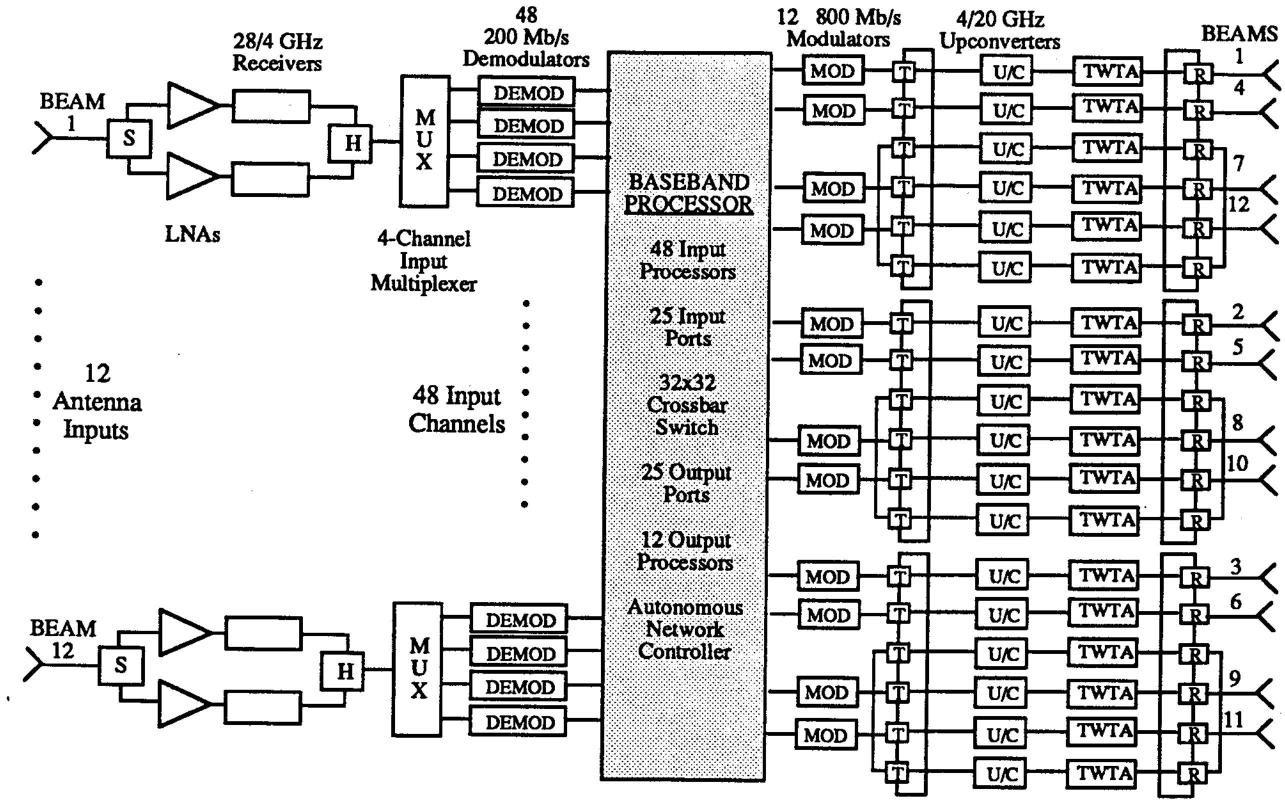

Figure 7–4: Payload Block Diagram for Architecture 2

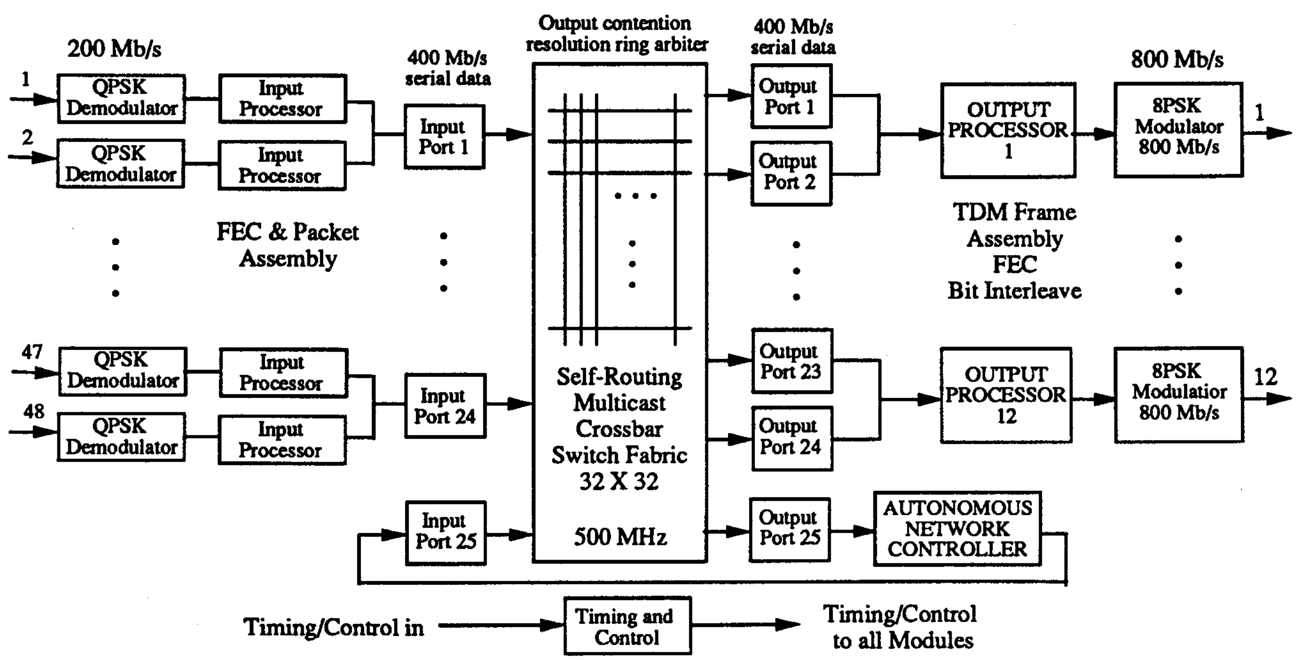

Figure 7–5: Baseband Processor Features 32 x 32 Self-Routing Crossbar Switch (Architecture 2)

Table 7–6: Power Budget (Architecture 2)

Component	Power (W)	
LNAs, Receivers	98	
Transmitters	1,500	
Baseband electronics	606	
Other/Margin	258	
Total Payload	2,462	2,462
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		424
Total Satellite		3,402

7.3.4 Satellite Characteristics

The basis for the bus is 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 7-5 summarizes the Architecture 2 satellite characteristics.

The existing satellite design (1990 technology) has been upgraded to incorporate hypothesized year 2000 technology improvements. The result is a 1,613 kg dry (1,773 kg wet) satellite mass with a 433 kg payload (antenna plus communication electronics) and 3.5 kW end-of-life power. Table 7-6 summarizes the power budget for the satellite. Figure 7-7 gives the satellite on-orbit configuration.

7.4 Comparison of Architectures

In spite of the addition of a 132 kg, 606 W baseband processor, the Architecture 2 satellite design achieves 50% more throughput capacity compared with the Architecture 1 "bent pipe" design with less mass and power consumption. In addition, the Architecture 2 design is more flexible in accommodating user traffic and has greater rain margin.

Architecture 2 achieves its better performance due to the combination of a number of factors:

- There is a 3 dB performance advantage with regeneration on the satellite.
- Uplink and downlink performance can be separately optimized according to available bandwidth, modulation and coding, and rain margin.
- Use of smaller, scanning spot beams becomes possible as a method to allocate capacity across the coverage area.

The end result is that 26-W TWTA's could be used on the satellite to deliver 800 Mb/s channels rather than the 32 W TWTA's required with Architecture 1 for 155 Mb/s channels. In fact, 40-W TWTA's are used to improve link performance by reducing required co-channel interference to -16 dB (versus -20 dB for Architecture 1) and increasing downlink rain margin to 5.6 dB which is 99.5% availability in Rain Region E.

Thus it is not surprising that many more channels (48 versus 30) can be carried on the Architecture 2 satellite design, in spite of the mass and power of the required baseband electronics. The capacity limitation is available downlink bandwidth, even when 8PSK modulation is used.

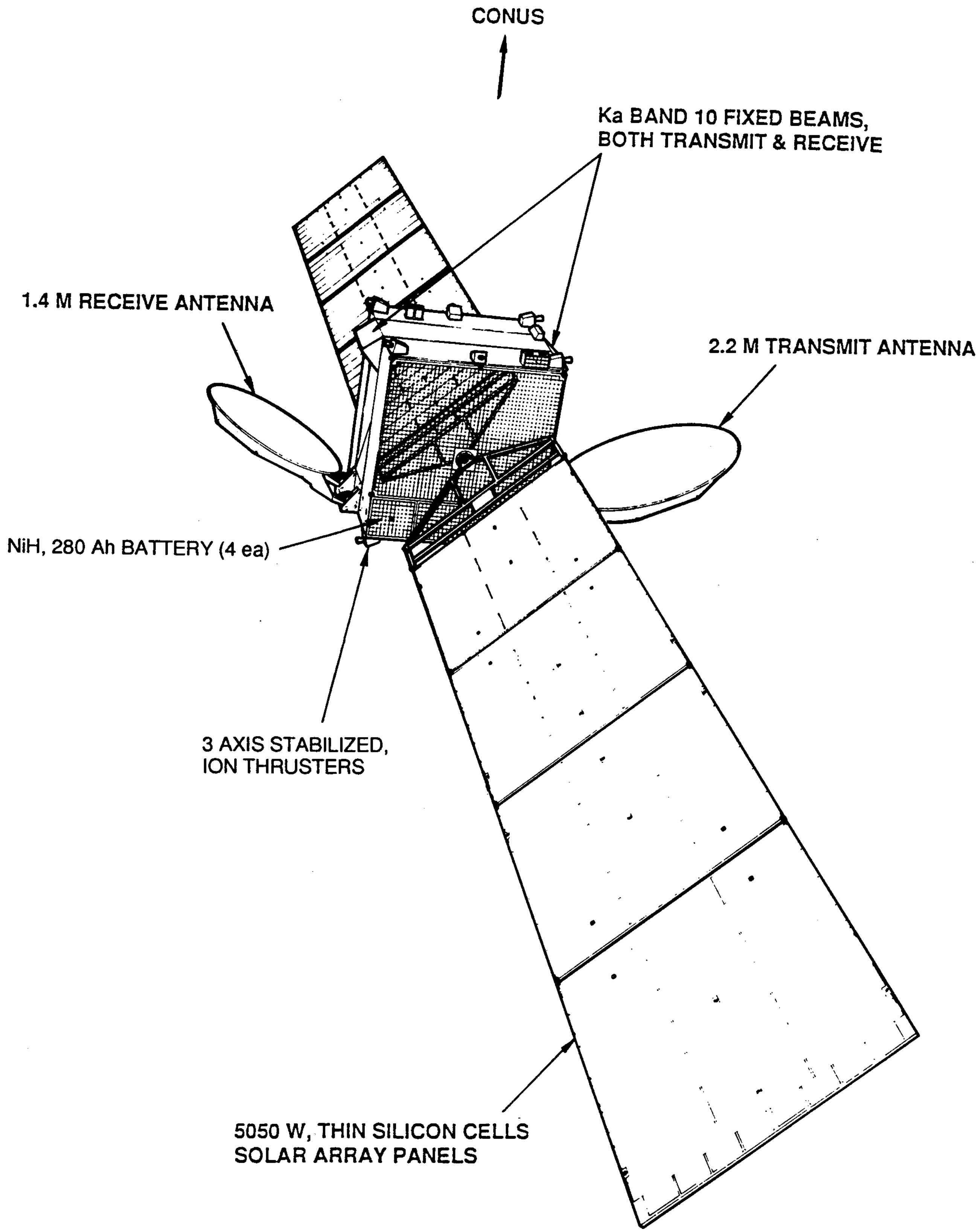

Figure 7–6: B-ISDN Architecture 1 Satellite On-Orbit Configuration

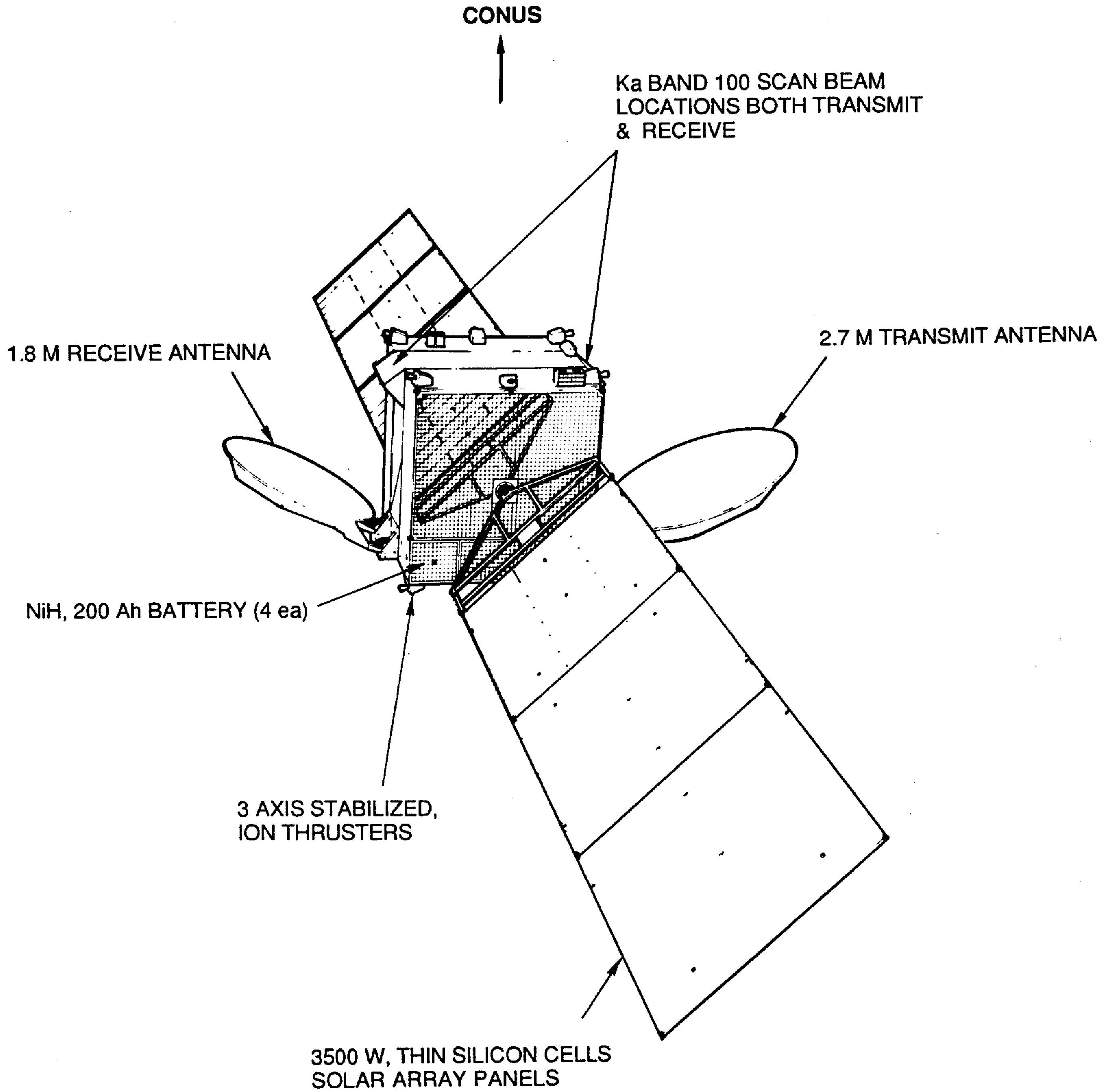

Figure 7–7: B-ISDN Architecture 2 Satellite On-Orbit Configuration

Table 7–7: Payload Electronics Mass and Power Breakdown (Architecture 2)

	Mass (kg)			Power (W)			
Equipment	Qty.	Unit	Total	Qty.	Unit	Total	Comments
Low noise amplifiers	24	0.4	10	12	1.2	14	2–1 redundancy
Receivers (28/4 GHz)	24	1.8	43	12	7.0	84	2–1 redundancy
Input demultiplexers	12	2.6	31				4 channel
<u>Baseband Processor</u>							
Demodulators	60	0.3	18	48	0.5	24	5–4 redundancy
Input processor	60	0.6	36	48	4.4	211	5–4 redundancy
Input port	32	0.6	19	25	3.6	90	Extra ports used for control
Switch fabric/support	1	3.0	3	1	36.0	36	2–1 redundancy
Output port	32	0.6	19	25	2.5	63	
Output processor	16	1.2	19	12	6.6	79	
Modulators	16	1.0	16	12	1.0	12	
DC/DC converter	2	1.0	2	1	91.0	91	85% efficiency
Subtotals			132			606	
Autonomous Network Controller	2	1.5	3	1	15.0	15	2–1 redundancy
Upconverter (4/20 GHz)	24	1.2	29	12	4.0	48	8–4 redundancy
TWTA/EPC (40 W)	24	4.5	108	12	125.0	1,500	8–4 redundancy, 32% eff.
Master LO	2	5.0	10	1	6.0	6	2–1 redundancy
DC/DC convertor (upconverter)	12	0.4	5	6	7.0	42	2–1 redundancy
Redundancy switches			26				
Waveguide and coaxial cable			7				
Beacon transmitters	4	2.0	8	2	15.0	30	2–1 redundancy
Subtotals			412			2,345	
Margin			21			117	5% margin
Totals			433			2,462	Mass (kg), Power (W)

Chapter 8

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 communication services and capacity utilization. The chapter is organized as follows:

8.1 Cost Guidelines

Cost guidelines are discussed in this section.

8.1.1 Key Technology Development Costs

The B-ISDN 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.

8.1.2 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.

8.1.3 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 tens of units for the network control terminals (5 m) and hundreds or thousands of B-ISDN user terminals (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.

8.1.4 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 B-ISDN communications subsystem.

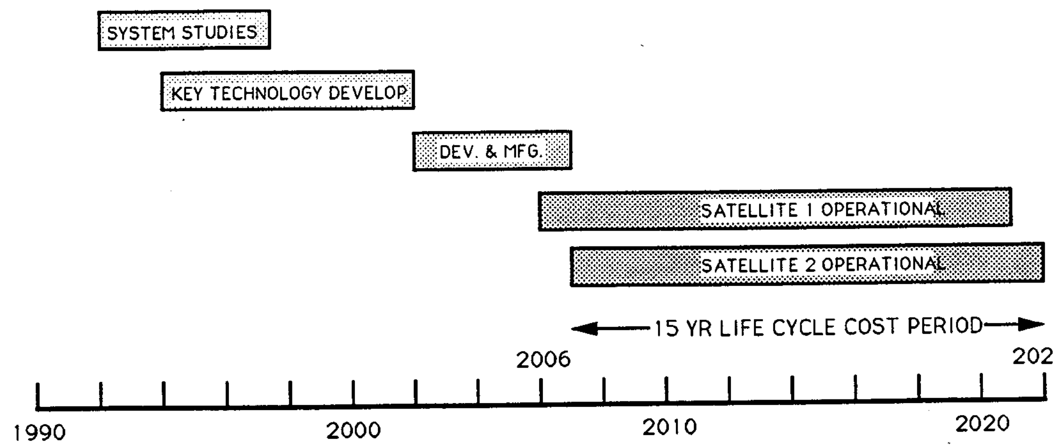

Figure 8–1: Schedule for B-ISDN Satellite System Implementation

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.

8.1.5 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 6.2 Gb/s for a single Architecture 1 satellite and 9.6 Gb/s for a single Architecture 2 satellite.
- The Architecture 1 system can achieve from 10% to 20% utilization.
- The Architecture 2 system can achieve from 15% to 30% utilization. This is a significant improvement over Architecture 1 due to more flexibility in allocating and filling capacity due to hopping spot beams and TDMA/TDM access.

8.1.6 Program Schedule

A summary of schedule planning for system implementation is shown in Figure 8-1. The plan calls for manufacturing to begin in 2002 with two launches in 2006.

8.2 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 support, and (5) total space segment costs.

8.2.1 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 8-1 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.)

The Architecture 1 design is similar to current designs in that it is a transponder satellite using an IF switch matrix scheme. Architecture 2 uses on-board demodulation, decoding, and baseband switching which are new technologies, and thus additional costs for payload complexity are added.

Table 8–1: Cost for Development and Manufacture of Two Satellites

Cost Category	Arch. 1 Costs ($M, 1992) Non-Recurring	Recurring (2 sats.)	Total	Arch. 2 Costs ($M, 1992) Non-Recurring	Recurring (2 sats.)	Total
Satellite Bus	72.7	114.2	186.9	74.3	116.7	191.0
Communications Payload	13.6	59.2	72.8	22.0	95.0	117.0
Integration & Assembly	6.4	15.5	21.9	20.0	16.0	36.0
Ground Equipment	15.1	–	15.1	25.1	–	25.1
Program Management	32.9	74.1	107.0	44.6	89.3	133.9
Cost Subtotal	140.0	263.0	403.0	186.0	317.0	503.0
Payload Complexity Factor	–	–	–	50.0	50.0	100.0
Fee at 10%	14.0	26.3	40.3	23.6	36.7	60.3
Total Cost	154.0	289.3	443.3	259.6	403.7	663.3

Table 8–2: 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

8.2.2 Launch Costs

The expected launch vehicle for year 2006 launch of the B-ISDN satellites would be the Atlas IIAS which has planned capacity of 3,600 kg to geosynchronous transfer orbit (GTO). The price per launch, assuming two launches, is given in Table 8-2. The launch support costs include mission operations and TT&C support for the launch.

8.2.3 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.

8.2.4 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.

8.2.5 Total Space Segment Costs

A summary of annual program costs for the B-ISDN satellites is given in Table 8-3. The annual cost based on an 18% rate of return is also given.

For the Architecture 1 concept with 6.2 Gb/s maximum capacity per satellite, the life cycle cost is $420 M per satellite or $82 M per satellite per year over a 15 year period beginning in the year 2006.

For the Architecture 2 concept with 9.6 Gb/s maximum capacity per satellite, the life cycle cost is $551 M per satellite or $108 M per satellite per year over a 15 year period beginning in the year 2006.

8.3 Ground Terminal Costs

Several Ka-band ground terminal configurations are used, ranging in size from 3 m for user terminals up 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.

8.3.1 User Terminal Costs

For Architecture 1, the user terminal size is 3 m with 140 W transmit power at Ka-band. Data rate is 155 Mb/s for transmission and reception via fixed

Table 8–3: Space Segment Costs, 1992 $M (2 satellites, 15 yr life beginning 2006)

Cost Category (2 satellites on orbit)	Architecture 1 Life Cycle Cost	Architecture 1 Annual Cost at 18%	Architecture 2 Life Cycle Cost	Architecture 2 Annual Cost at 18%
Satellite cost (2)	443 M		663 M	
Launch Cost (2)	248 M		248 M	
TT&C Support (2)	15 M		15 M	
Launch Insurance (16%)	134 M		176 M	
Total Costs	$840 M	$164 M/yr	$1,102 M	$216 M/yr

beams. QPSK or 8PSK modulation with a concatenated block and trellis code is used with a channel bandwidth of 90 MHz or 160 MHz. The transmitter and receiver are tunable to one of four different frequency bands. Manufacturing quantity is expected to be several hundred (300–500).

For Architecture 2, the user terminal size is 3 m with 20 W transmit power at Ka-band. Data rates are 200 Mb/s for uplinks and 800 Mb/s for downlinks via hopping beams. Uplinks use QPSK modulation with a block code (178 MHz bandwidth). Users transmit on one of four channels depending upon availability. Downlinks are a single channel of 800 Mb/s with 8PSK modulation and a concatenated block and trellis code with 458 MHz bandwidth. Manufacturing quantity is expected to be several thousand (2,000).

Users in high rainfall regions or with high availability requirements may elect larger diameter antennas or 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 (HPA's) and high speed codecs for the concatenated codes. Table 8-4 estimates user terminal costs for the Architecture 1 and 2 users. The Architecture 2 terminal has a lower cost because of its lower transmit power and greater production quantity which allows a reduction in non-recurring cost allocation and increased manufacturing efficiencies.

8.3.2 Network Control Terminal Costs

The network control terminal cost breakdown is given in Table 8-4. Although of larger size than the user terminals, many of its components such as modems and codecs are the same as in the respective Architecture 1 or 2 user terminals.

8.3.3 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 becomes very favorable statistically if, for example, 30 circuits are shared by 60 users who only use their circuit half the time. The user circuit cost can be cut in half with only the penalty of an occasional wait for a free circuit.

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.

8.3.4 Terminal Lease Fees

The initial capital expenditures may be reduced by leasing of terminals. Table 8-5 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 8-6 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 of use 24 hours per day to several dollars

Table 8–4: Ground Terminal Costs (1992 $M)

	Arch. 1 User Terminal	Arch. 2 User Terminal	Network Control Terminal
Terminal Parameters			
Size	3 m	3 m	5 m
Transmit Power	140 W	20 W	200 W
Total Number of Terminals	300–500	2,000	4
Data Rate (up/down)	155 Mb/s	200/800 Mb/s	200/800 Mb/s
Access Scheme	FDMA	TDMA	FDMA/TDMA
Modulation (up/down)	QPSK	QPSK/8PSK	QPSK/8PSK
Coding (up/down)	Concat.	Block/concat.	Block/concat.
Non-recurring Costs			
Management and system design	$7,000	$3,000	$20,000
Equipment design	$10,000	$5,000	$50,000
Recurring Costs			
Production management	$3,000	$2,000	$20,000
Antenna subsystem	$10,000	$8,000	$20,000
Electronics, antenna mounted	$27,000	$16,000	$30,000
Electronics, control room	$32,000	$35,000	$40,000
Integration hardware	$5,000	$5,000	$10,000
Assembly and test	$6,000	$6,000	$10,000
Total Costs	$100,000	$80,000	$200,000

Table 8–5: User Terminal Annual Costs

	Annual Terminal Cost (1992 $)		
Terminal Type & Cost	Lease Cost ($/yr)	Maintenance Cost ($/yr)	Total Cost ($/yr)
Architecture 1, $100,000	20,000	10,000	30,000
Architecture 2, $80,000	16,000	8,000	24,000

Table 8–6: User Terminal Costs per Minute vs. Number of Hours Utilized per Working Day

	Annual	Terminal Cost, $/minute of Use					
	Cost	Number of hours utilized per working day					
Terminal Type	($/yr)	1	2	4	8	12	24
Architecture 1	30,000	2.00	1.00	0.50	0.25	0.17	0.08
Architecture 2	24,000	1.60	0.80	0.40	0.20	0.13	0.07

per minute for use of 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.

8.4 Network Control Costs

The regular on-orbit housekeeping functions for monitoring and care of B-ISDN 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 to have yearly maintenance and operating costs of about $4 M to $8 M based upon a level of 10 to 20 people (see Table 8-7). The Architecture 1 system requires less control and has simpler billing than the Architecture 2 B-ISDN system.

8.5 Capacity Utilization

The theoretical "maximum capacity" of a single satellite is 6.2 Gb/s and 9.6 Gb/s of simplex circuits respectively for the Architecture 1 and Architecture 2 designs. However, average capacity utilization will be considerably less due to a number of factors.

- Inefficient allocation of capacity among a discrete numbers of satellite antenna coverage beams. This will be more of a problem with the fixed beams of Architecture 1 than with the hopping beams of Architecture 2.

- Inefficient allocation of capacity within channels. This will be more of a problem with unshared user channels, particularly with Architecture 1. With Architecture 2, the user pays only for the bits transmitted. With Architecture 1, the user pays for the full 155 Mb/s channel during the time it is assigned.

- The average utilization is reduced from peak use because of daily and hourly variations in user communication needs.

- Capacity is reduced by the B-ISDN frame overhead (97% efficiency), and for Architecture 2 by the TDMA beam hopping efficiency (estimated at 90%).

The average utilization of capacity is estimated to be in the range of 10% to 20% of the peak utilization for Architecture 1, and 15% to 30% for Architecture 2. For example, use of the full satellite capacity 8 hours per day, 250 days per year, equals 23% average utilization.

8.6 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.

8.6.1 Space/Control Costs for Simplex Circuit

Table 8-7 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 Architecture 1 annual cost is $188 M for 12.4 Gb/s maximum capacity (2 satellites). The Architecture 2 annual cost is $244 M for 19.2 Gb/s maximum capacity (2 satellites). Additional costs are incurred for the user ground terminal.

Table 8-8 gives the space/control cost per simplex circuit minute as a function of satellite utilization. At 100% utilization, Architecture 1 costs $28.83 per minute per Gb/s, and Architecture 2 costs $24.16 per minute per Gb/s simplex circuit capacity. Utilization is estimated to be between 10% and 20% for Architecture 1, and between 15% and 30% for Architecture 2.

Since the B-ISDN systems can combine and switch traffic from a number of users to a number of different destinations, user circuit size may be less than the B-ISDN 155 Mb/s rate. Table 8-8 gives simplex circuit costs for 1.5 Mb/s, 6 Mb/s, 52 Mb/s, and 155 Mb/s circuits.

8.6.2 Total User Costs per Circuit Minute

Table 8-9 adds the space/control segment costs to the ground terminal costs in order to obtain the total user cost of a 155 Mb/s simplex circuit for different system utilizations and ground terminal usage. Note that these results are for a simplex (one-way) circuit and charges for one ground terminal. A duplex circuit (two-way)

Table 8–7: Space Segment & Network Control Annual Costs, (2 satellites, 15 yr life starts 2006)

	Annual Cost	
	Arch. 1	Arch. 2
Space Segment Charges	$164 M	$216 M
Network Control Center Charges:		
Development and Manufacture	$20 M	$20 M
Operations (15 yr)	$4 M	$8 M
Total Yearly Charges ($ 1992)	$188 M	$244 M

Table 8–8: Space/Control Costs for Simplex Circuits vs. System Utilization

System Utilization	Simplex Circuit Cost, $/min							
	Architecture 1 Data Rate (Mb/s)				Architecture 2 Data Rate (Mb/s)			
	1.5	6.2	52	155	1.5	6.2	52	155
5%				89.37				74.90
10%	0.45	1.79	14.99	44.69				37.45
15%	0.30	1.19	9.99	29.79	0.24	1.00	8.38	24.97
20%	0.22	0.89	7.50	22.34	0.18	0.75	6.28	18.72
25%				17.87	0.14	0.60	5.03	14.98
30%				14.90	0.12	0.50	4.19	12.48

and two ground terminals would cost double the value in Table 8-9.

There are several points that must be made regarding this table:

- The ground terminal costs are not significant for the 155 Mb/s circuits. The transmission cost represents 90% to 99% of the cost, depending on the case. This suggests that the system has not yet be completely optimized — perhaps it would be better to transmit at a lower rate or use more expensive ground stations so that the space to ground system cost ratio is more nearly equal.

- The establishment of a duplex circuit will double the simplex circuit costs shown in Table 8-9.

- The costs vary directly according to the system utilization factor which ranges from 10% to 20% for Architecture 1 and 15% to 30% for Architecture 2.

The circuit costs of Table 8-9 can be divided by the circuit size to obtain a cost to transmit a given amount of information. The below tabulation gives the cost and time to transmit 1 Gb of information at 155 Mb/s from an Architecture 1 system at 15% utilization and an Architecture 2 system at 20% utilization, assuming 1 hr/day terminal usage.

Architecture	1 Gb Transmit Cost	1 Gb Transmit Time
1	$3.42	6.5 seconds
2	$2.18	6.5 seconds

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). This report could have been transmitted to NASA/LeRC for a cost of only 0.3 cents and in a time of 0.007 seconds!

8.7 Discussion

Table 8-9 suggest that Architecture 1 costs can be around $31/minute (15% utilization, 2 hr/day user terminal use) and Architecture 2 costs can be around $20/minute (20% utilization, 2 hr/day user terminal use) for a 155 Mb/s simplex circuit.

The user terminal cost only represents about 3% of the total cost, which suggests that better system optimization could be achieved by using more expensive

Table 8–9: Total (Space plus Ground) Cost for 155 Mb/s Simplex Circuit

System Utilization (%)	Ground Terminal Use (hr/day)	Architecture 1 Costs, $/min Space/ Control Cost ($/min)	User Terminal Cost ($/min)	Total User Cost ($/min)
10%	1	44.69	+ 2.00	= 46.69
	2	44.69	1.00	45.69
	4	44.69	0.50	45.19
	8	44.69	0.25	44.94
15%	1	29.79	2.00	31.79
	2	29.79	1.00	30.79
	4	29.79	0.50	30.29
	8	29.79	0.25	30.04
20%	1	22.34	2.00	24.34
	2	22.34	1.00	23.34
	4	22.34	0.50	22.84
	8	22.34	0.25	22.59

		Architecture 2 Costs, $/min		
15%	1	24.97	+ 1.60	= 26.57
	2	24.97	0.80	25.77
	4	24.97	0.40	25.37
	8	24.97	0.20	25.17
20%	1	18.72	1.60	20.32
	2	18.72	0.80	19.52
	4	18.72	0.40	19.12
	8	18.72	0.20	18.92
25%	1	14.98	1.60	16.58
	2	14.98	0.80	15.78
	4	14.98	0.40	15.38
	8	14.98	0.20	15.18
30%	1	12.48	1.60	14.08
	2	12.48	0.80	13.28
	4	12.48	0.40	12.88
	8	12.48	0.20	12.68

ground stations in order to reduce the higher space segment costs. For example, use of 4.2 m rather than 3 m earth terminals would reduce satellite EIRP and hence satellite transmit power requirements by 3 dB. This could reduce space segment costs by as much as 50%.

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Chapter 9

Technology Development Plan

This chapter identifies and describes the necessary technologies which are critical or enabling to the application of satellite to B-ISDN service. Also provided are plans for the development of such technology, including schedules and costs. This chapter is organized as follows:

9.1 Identification of Technologies

Satellite architectures designed to handle traffic at B-ISDN rates must rely on advanced high-speed technology. The discussion of critical technology development is divided into (1) hardware development, and (2) systems engineering development.

9.1.1 Hardware Development

High-speed FEC decoders with low power dissipation are required. The FEC codes for the B-ISDN payload were chosen for superior BER performance and bandwidth efficiency by concatenating several coding systems. The power consumption of the resulting codecs must be low and the actual codec performance at these B-ISDN rates must be verified.

Low power, high bandwidth memory and logical components are required. High speed, low-power memory components are required for the buffering needed in the input and output ports of the multicast crossbar switch. In addition, high speed logic components will be required for the input ports, the switch fabric and the output ports.

Terrestrial network interfaces:

a. **FEC Applications.** To support the high B-ISDN speeds cost effectively, it is desirable to use an appropriate FEC over the satellite links. This, however, results in residual burst errors which will have an adverse impact on the ATM header error correction (HEC) procedure. The ATM HEC has been specified to correct only one bit error in the header.

   Thus, to make the effective use of the ATM HEC, it is very useful to perform suitable interleaving functions before the ATM cells are transmitted on the satellite link. The corresponding deinterleaving function at the receiving earth station in Architecture 1 (and appropriate deinterleaving and interleaving functions onboard the satellite in Architecture 2) will disperse the error bits. Appropriate algorithms and their hardware implementation are needed to achieve the desired performance requirement of very low loss for ATM cells.

b. **Network Congestion Control.** Since the ATM cells carry virtual traffic [virtual path (VP) and virtual connections (VCs)], the volume of the real traffic entering the satellite network via the terrestrial network interface can vary considerably. The resultant congestion due to sudden burst of traffic activity can lead to ATM cell losses unless appropriate Forward and Backward Congestion Notification (FCN and BCN) bits in relevant ATM cell headers to inform the traffic sources the state of the satellite network.

9.1.2 Systems Engineering Development

Adaptive rain fade compensation techniques should be developed to combat rainfade by the increase of the satellite EIRP in the affected area, the use of ground station diversity, and/or the decrease in communications capacity.

B-ISDN signaling standards. A number of services envisaged for B-ISDN are multipoint or multicast in nature and satellite networks are ideally suited for providing these services. Currently, the ISDN signaling standards are specified for point-to-point connections only. It is therefore highly desirable if B-ISDN signaling standards can be extended to cover multipoint/multicast applications.

Fast packet switch control and design issues. Congestion is a difficult problem associated with the control and management of the satellite capacity. The problem is not unique to satellite communications and in fact, it has been studied extensively for terrestrial ATM networks. However, some of the techniques proposed for terrestrial networks are ineffective to cope with long propagation delay in the satcom environment. To alleviate the delay impact on the classical congestion control methods, the predictive techniques using neural network formulation may be useful. A congestion control procedure must be devised as a part of the overall network control, including packet queue monitoring and buffer management by the onboard processor and user earth station, call admission control at the user and network levels and satellite capacity allocation procedures.

Traffic characterization and quality of service maintenance techniques. Since the effectiveness of the satellite B-ISDN system design is closely related to the traffic pattern described by its burstiness, destinations (i. e., the amount of broadcast, multicast and point-to-point traffic), bit rates and the quality of service (QOS), techniques should be developed to characterize these system parameters.

To provide a committed level of QOS to all the VPs accepted by the satellite network, it is essential to have an effective bandwidth negotiation, enforcement and policing techniques. The policing and enforcement involve monitoring, control and management of the traffic entering into the satellite network. The bandwidth negotiation can take place at the VP setup time and will be based on the traffic characterization and the QOS requirement.

Performance measuring techniques. In order to comply with the "service on demand" requirements, fast and accurate techniques are needed to measure the quality of service in conjunction with the service provided.

9.2 Technology Development Plan

The Technology Development plan as part of the B-ISDN Satellite Program is given in Table 9-1. The following steps are assumed:

- The procurement cycle of B-ISDN 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 the year 2000.
- The selection of spacecraft contractors in 2001.
- The launch of the first satellite with the commencement of B-ISDN network operation by early 2006. (See schedule given in Figure 8-1 of Chapter 8.)

Table 9–1: Technology Development Plan

Item	Start	Finish
B-ISDN 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		
FEC codecs	1/96	9/98
Memory and logic components	1/96	9/98
Terrestrial network interfaces	9/96	1/99
Rain fade compensation	9/96	1/99
B-ISDN signaling standards	9/96	1/99
Fast packet switch control	9/96	1/99
Traffic characterization	9/96	1/99
Performance measuring techniques	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 (2 satellites)		1/06

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Appendix A

Telecommunication Outages and Disasters

Tables A-1 and A-2 list some recent disasters that have affected the telecommunications capabilities of the public switched telecommunications network and private services sharing these facilities. The listing is divided into land disasters and submarine cable cuts.

In general the telephone system was regarded as ultra-reliable until about 1987. By that time the microwave and satellite links were being replaced by fiber optic cables with awesome capacities. A fiber optics cable cut became a significant event. Previously, the capacity of a single microwave link or a satellite transponder was measured in hundreds to a few thousands of two-way voice circuits. Fiber optic cables with several tens of thousands of circuits were installed and the earth stations and microwave towers were dismantled and sold for scrap. Once the fiber cables were installed there was no turning back, there wasn't enough capacity left in coaxial cable and the remaining microwave links to restore the fibers now filling with the rapidly expanding telecommunications traffic.

A real blow came in the Hinsdale, Illinois, central office fire in May 1988. This unattended switching office not only provided local service to Chicago suburbs, but also contained the only path to AT&T and MCI long-distance trunks for many other Chicago area Central Offices. The fire also wiped out certain cellular radio facilities. Businesses in the affected area were without service for two to eight weeks. The concerns about a single point of failure were illustrated. Unfortunately, there seems to be even more reasons to be concerned about the terrestrial facilities.

Cable outages due to physical cuts or lightning strikes that get into the conductors needed to power the repeaters have continued. Figure A-1 gives the number of cable outages by year and the average number of hours to restore a single cut. The average time to restore is around 6 hours, but these figures are biased by the increasing frequency of a telephone employee cutting an active fiber cable, in which cases it is easy to locate and get to the cable in a hurry. The number of circuits affected by a fiber outage ranges from 20,000 to 200,000. A fiber outage of 1.6 Gb/s is common.

Any restoration service would like to know in advance where the outage will occur so the capacity can be set aside. This is the case for the North Atlantic undersea cables where Intelsat provides restoration services for a monthly fee for right of access on demand and an hourly fee while traffic is being handled. When the capacity is not needed which is most of the time, Intelsat leases the capacity to part-time users on a preemptable basis. The provision for submarine cable restoration has been a constant source of revenue for Intelsat. In 1988 Intelsat received \$7.2 million for restoring 165,600 channel days, and in the first 11 months of 1989, a total of 156,890 channel days were restored.

The North Atlantic Ocean uplink and downlink locations are readily identifiable for Intelsat — the East Coast of the United States and the West Coast of Europe. In the domestic U. S. market it is not that easy. Figure A-2 maps the major disasters reported between 1987 and mid-1991. There is not a uniform or predictable distribution of problem areas. The problems tend to cluster in the heaviest population areas, but this may be because the effects of a cable cut cannot be hidden as easily as in a less populated area.

The trend in telephone outages is not good. Software errors first came to national attention in January 1990 when AT&T's Signaling System No. 7 (SS7) and its Common Channel System No. 7 (CCS7) crashed. Subsequently more CCS7 problems have knocked out widely separated parts of the nation in the Regional Bell Operating Companies (RBOC) and MCI facilities. These software bugs seem to be triggered by heavy traffic.

Table A–1: Telecommunication Disasters on Land, 1987–1991

Date	Location	Disaster	Description of Communication Disruptions
Winter 1975	New York City	Fire	Lower East Side without service for 22 days
1985	Mexico City	Earthquake	Major parts of Mexico City were without telephone service. Central office floors collapsed.
1987	Brooklyn, NY	Fire	Central office fire left the Bushwick section of Brooklyn without service for 2 weeks.
Sep. 1987	Trenton, NJ	Cable cut	AT&T cut off dedicated circuits for up to 7 hours.
Sep. 1987	Plano, TX	Cable cut	Outage lasted 2.5-hour for AT&T in Dallas.
Oct. 1987	Butler, IN	Cable cut	Train derailment cut AT&T service to Chicago and the East Coast for 9 hours.
Feb. 1988	Philadelphia Newark, NJ	Cable cut	Dedicated circuits cut for up to 9 hours.
May 1988	Hinsdale, IL	Fire	Central office fire affected both local and long distance calls in the greater Chicago area for 2 to 8 weeks. 150,000 businesses were affected. Each day, 3.5 M calls could not be made. $150 M in damages.
Summer '88	Phoenix	Cable cut	Fiber cable cut; central office overload made redundant route almost useless.
Aug. 1988	Northern Cal.	Cable cut	MCI cable cut.
Nov. 1988	S. Amboy, NJ	Cable cut	Fiber cable carrying 200,000 calls per hour was cut.
Nov. 1988	Sayerville, NJ	Cable cut	AT&T lost millions of calls for over 9 hours.
Mar. 1989	Florida	Lightning	MCI lost 36 T-3 circuits (about 1.62 Gb/s).
May 1989	Minneapolis	Lightning	MCI lost service in Minnesota and North Dakota for up to 13 hours.
July 1989	Ohio	Cable cut	MCI cable cut in Washington-to-Chicago cable. Service restored in 6 hours.
Summer '89	Atlanta, GA	Software	Central office switch failure.
Sep. 1989	Puerto Rico, Virgin Islands	Hurricane	St. Croix and Puerto Rico were cut off by Hurricane Hugo.
Sep. 1989	South Carolina	Hurricane	There were 45,000 customers without telephone services by Hugo.
Oct. 1989	San Francisco	Earthquake	Overload of local facilities due to an unusual volume of calls.
Dec. 1989	Akron, OH	Cable cut	US Sprint lost the Akron/Columbus/Cleveland cable for 3 hours.
Jan. 1990	Nationwide	Software	AT&T switching system No. 7 crashed. Interexchange signaling was inoperative. AT&T was unable to load new software into remote switches because of the failure and congestion that resulted. All 114 of the 4ESS switches were affected. Required 9 hours to restore most service. CCS7 processors were involved. 65 million calls were not completed.
Sep. 1990	Ohio	Cable cut	MCI NY/Chicago/DC cable cut for 7 hours; 50,000 call capacity.
Oct. 1990	Oak Brook, IL	Fiber cut	63,000 trunk and 27,000 special service lines of Illinois Bell were cut for up to 12 hours.
Jan. 1991	Newark, NJ	Fiber cut	AT&T worker cut 16 fibers handling 100,000 calls (1.7 Gb/s). Stock market and air traffic control were crippled for 3 hours. 60% of traffic in/out of New York City was cut
Feb. 1991	Ft. Wayne, IN	Fiber cut	Construction crew cut cable, restored it in 6 hours.
Mar. 1991	PacBell	Fiber cut	Fiber cable cut by PacBell workers. Outage lasted 5.5 hours in in Orange County, CA, and affected 54,000 calls.
June 1991	DC, MD, VA, WV	Software	CCS7 processor in Baltimore got into trouble. Problem spread throughout Bell Atlanticom's C&P network. 6.7 million subscribers were affected for 8 hours.
June 1991	Annandale, VA	Fiber cut	C&P cable cut by road crew. Cellular and LATA calls affected.
June 1991	Perryville, MD	Fiber cut	US Sprint/Wiltel fiber cut on railroad bridge. DC to NY traffic cut.

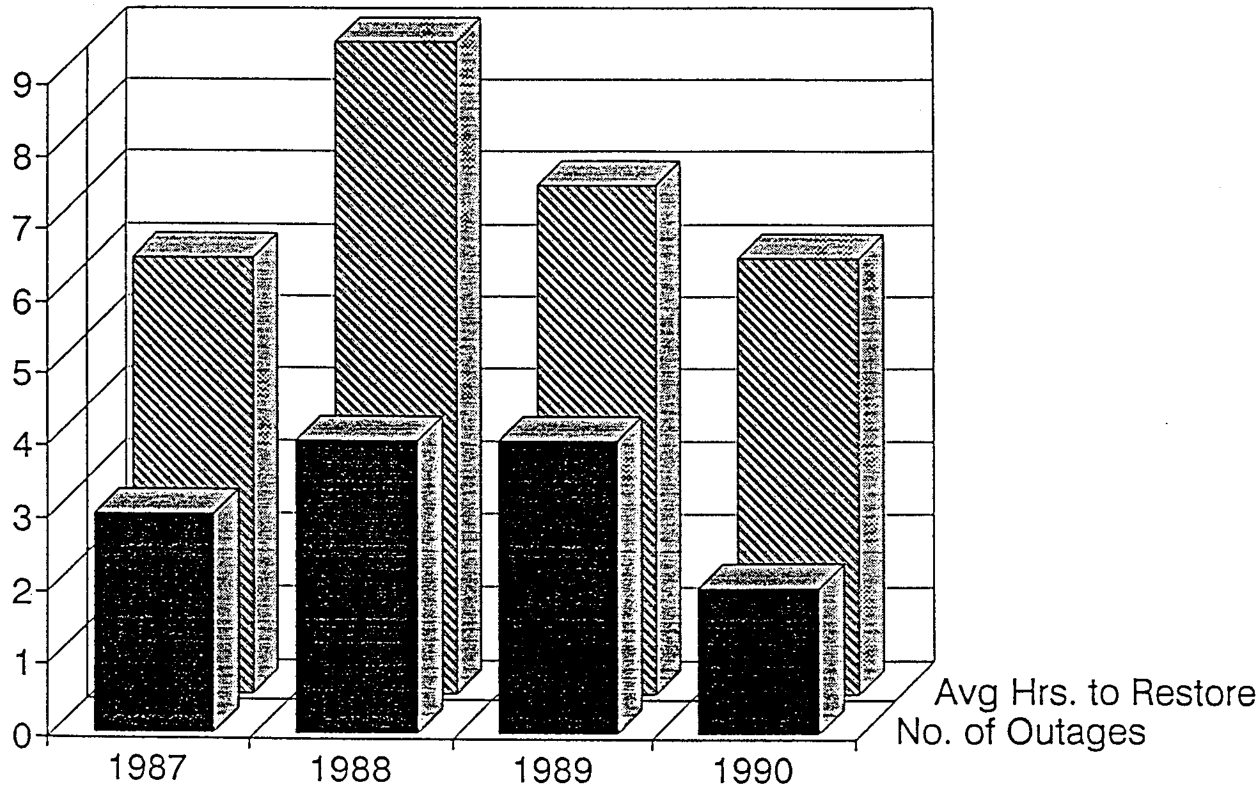

Figure A–1: Major Cable Outages from Lightning or Cuts – Number per Year and Hours to Restore

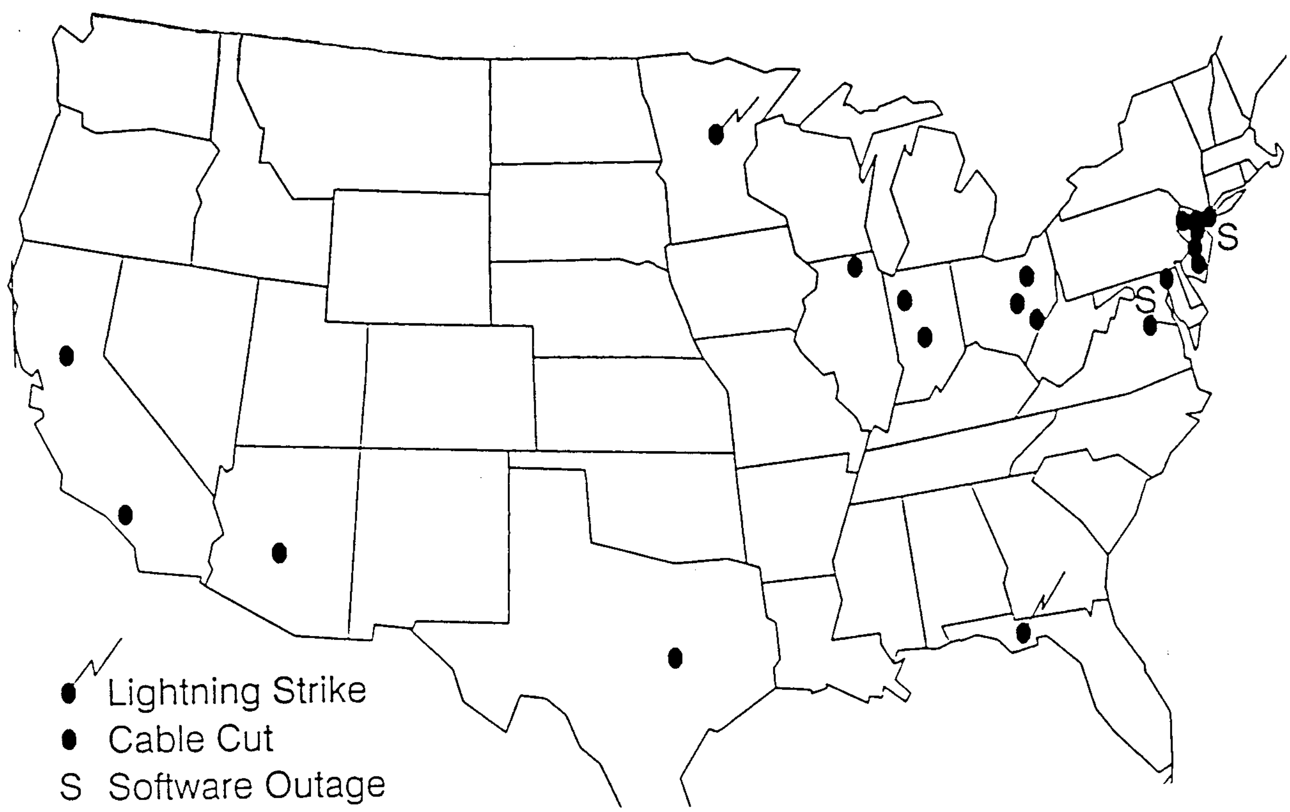

Figure A–2: Locations of Major Telecommunication Outages, 1987–1991

Table A–2: Telecommunication Disasters involving Submarine Cables, 1989–1991

Date	Location	Disaster	Description of Communication Disruptions
7/17/89	TPC-3	Repeater	Repeater failed off Guam. Outage lasted 33 days.
8/4/89	AIS	Cable cut	Australia-Indonesia-Singapore cable out for 5 days.
8/6/89	Bermuda	Unknown	2 cables to USA failed.
8/10/89	TAT-7	Cable cut	Clammer cut cable 50 miles from New Jersey.
8/15/89	TAT-8	Fiber cut	Fishing trawler cut cable off France. Cable was relaid in a different route and buried.
1989	Haw 2	Unknown	Complete cable failure; will not be repaired.
1989	Meridian	Damaged	Spain-Belgium cable.
1989-1991	TAT-8	Fiber cut	Restoration via Intelsat transponders. Sharks have taken bites out of the cable, and fishing dredges have torn the cable. Capacity: 40,000 simultaneous calls and 296 Mb/s. At least four cuts in the first year of operation (1989-1990).

MCI's problems arose when lightning knocked out a fiber cable in Florida. When its SS7 switch tried to divert traffic around the failed section, the CCS7 overloaded and parts of the network crashed. MCI was in the process of reconfiguring its network to avoid that sort of event. Switching systems have gotten very complex. The addition of new services like fractional T1 and automatic re-dial will make the systems even more complex and prone to failure.

AT&T has started to tie its CCS7 links together via its Telstar 303 satellite in order to provide an independent path for the network control signals. AT&T has 141 SS7 offices.

However, the B-ISDN network will place the signalling and control function inside the B-ISDN channel. Present networks put these functions on other circuits outside the toll channel. B-ISDN channels will be harder to restore as the routing and signalling information is lost as soon as the cable is cut or the central office crashes.

A possible satellite application is to provide an independent path for the signalling and control information. There are at least 150 long haul SS7 offices (AT&T and MCI) and the signalling information could require 450 T3 channels. One can assume 10 hours per year of restoration time. This is based on the theory that if the network can keep its signalling and supervisory network intact, it can restore itself quickly, thus reducing the time the satellite link is needed.

Hurricanes and earthquakes are presently considered random events. We estimated one hurricane or major earthquake per four years. The use of VSATs was proven after Hurricane Hugo. COMSAT is providing a transportable cellular telephone system. A satellite link (via SBS-2) to a mobile telephone switching office in Clarksburg, Maryland, is providing service to the Federal Emergency Management Agency.

The disaster services have large but brief peaks. The percentage of the year in which these services are needed are shown in Table A-3. The peak to average traffic is unreasonable to be commercially successful. Most of the potential traffic is due to hurricanes or earthquakes. It doesn't make sense for an operator of a ten-year satellite to wait four years to provide a service for a few hundred hours. However, a time shared network providing a variety of specific services such as CAD/CAM, financial, supercomputer interconnection, etc., including restoration could be operationally justified and financially viable.

Table A–3: Disaster Services Have Large but Brief Peaks

Unit	Frequency	Uplink Locations	Downlink Locations	Data Rate (Mb/s)	Number of Stations	Time in Use (hr/yr)	Peak Traffic (Mb/s)	Portion of Year in Use
Cable Cuts (man or lightning):								
one cut	4/yr	SS7 offices	SS7 offices	1,600	150	12	1,600	0.55%
Software Errors (signalling channel backup):								
one SS7 error	0.5/yr	SS7 offices	SS7 offices	45	150	10	45	0.11%
Hurricane or Earthquake:								
Local exchanges	0.25/yr	Coastal	Inland	6	100	360	630	4.11%
Major exchanges	0.25/yr	Coastal	Inland	1,600	8	120	12,800	1.37%
Cellular (relief)	0.25/yr	Coastal	Inland	1	15	720	9	8.22%

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Appendix B

Link Budgets

This appendix gives the link budgets used for the satellite design in Chapter 7. Tables B-1 and B-2 summarize the parameters considered and some of the choices for link parameters for Architectures 1 and 2 respectively.

B.1 Architecture 1 Link Budgets

Architecture 1 uses transponders on the satellite with end-to-end error correction coding. Table B-1 gives the four primary candidates for modulation and coding; QPSK and 8-PSK modulation, each with block and concatenated coding. This table is followed by the four link budget calculations corresponding to the four columns in Table B-1.

Fig. B-1: Architecture 1 Link Budget: QPSK, Block Code, 98% Availability in Region E

Fig. B-2: Architecture 1 Link Budget: QPSK, Concatenated Code, 98% Availability in Region E

Fig. B-3: Architecture 1 Link Budget: 8-PSK, Block Code, 98% Availability in Region E

Fig. B-4: Architecture 1 Link Budget: 8-PSK, Concatenated Code, 98% Availability in Region E

For purposes of comparison, the uplink and downlink power was kept the same among the four choices and the earth terminal diameter allowed to change. The preferred choice is 8PSK with concatenated code since it gives the smallest earth terminal diameter (3.08 m or 10.1 ft) while still fitting four channels within the 1.7 GHz available downlink bandwidth. If there are problems with implementing the concatenated code, the next choice is QPSK with block coding. This requires a fractionally larger earth terminal (3.3 m or 10.8 ft) for the same performance.

B.2 Architecture 2 Link Budgets

Architecture 2 demodulates and decodes the uplink signals on the satellite, and remodulates and recodes the downlink (with a different modulation and coding if desired). Table B-2 gives two uplink and two downlink calculations. Earth terminal size is fixed at 3 m. Uplink power of 8.4 W or 18.2 W is required for 98% or 99% availability (Region E) with 200 Mb/s links. Two downlinks are tabulated, QPSK with block coding and 8-PSK with concatenated coding, both for 800 Mb/s channels. The 8-PSK modulation scheme is preferred due to its better bandwidth efficiency, but the 800 Mb/s decoder for the concatenated code may be difficult to build.

This table is followed by the four link budget calculations corresponding to the four columns in Table B-2.

Fig. B-5: Architecture 2 Uplink Budget: QPSK, Block Code, 98% Availability in Region E

Fig. B-6: Architecture 2 Uplink Budget: QPSK, Block Code, 99% Availability in Region E

Fig. B-7: Architecture 2 Downlink Budget: QPSK, Block Code, 99.5% Availability in Region E

Fig. B-8: Architecture 2 Downlink Budget: 8-PSK, Concatenated Code, 99.5% Availability in Region E

Table B–1: Architecture 1 Link Choices: Modulation and Coding

2/18/92	**QPSK**	**QPSK**	**8PSK**	**8PSK**
	Block code	**Concat. code**	**Block code**	**Concat. code**
Link calculation results				
Earth terminal diameter (m)	**3.30**	**2.42**	**5.29**	**3.08**
Earth terminal diameter (ft)	10.8	7.9	17.4	10.1
Earth terminal transmit power (w)	140 W	140 W	140 W	140 W
Satellite antenna beam size (degrees)	1.55°	1.55°	1.55°	1.55°
Satellite transmit power (W)	30 W	30 W	30 W	30 W
Modulation type	QPSK	QPSK	8PSK	8PSK
Coding type	Block	Block/Trellis	Block	Block/Trellis
Coding rate	0.749	0.66	0.829	0.777
Reqd. bandwidth per channel (MHz)	139	158	84	89
Channels per (1.4/3 =) 467 MHz	3.4	3.0	5.6	5.2
Channels per (1.7/3 =) 567 MHz	**4.1**	**3.6**	**6.8**	**6.4**
Additional margin vs. block code	—	+2.7 dB	—	+4.7 dB
Performance vs. QPSK	—	—	-4.6 dB	-2.6 dB
Conclusions:				
1. 8PSK has greater co-channel interference loss and modem loss compared to QPSK.				
2. QPSK concatenated code gives best performance, but doesn't allow enough channels per beam.				
3. Concatenated codes give improved performance, but is decoder economically feasible?				
4. 10 fixed beams, 1.55°, uplinks and downlinks. -20 dB co-channel interference.				
Assumptions:				
1. BER = E-10				
2. -20 dB co-channel interference				
3. Rain margin 98% Region E (3.1 dB/1.4 dB, uplink/downlink)				
4. 156 Mb/s information rate				
5. 3 dB link margin				
6. QPSK achieves 1.5 b/s/Hz, 8PSK achieves 2.25 b/s/Hz				
7. Earth/space transmit powers constant at 140 W & 30 W, earth station diameter is varied to close link.				

Parameter	**Uplink**	**Downlink**	**Units**	**Remarks**
Carrier Frequency	28.50	19.30	GHz	
Noise Bandwidth	100	100	MHz	Per B-ISDN channel
Transmit Power	21.46	14.77	dBW	**140 W VSAT HPA**
HPA Backoff	0.00	0.00	dB	**30 W Satellite HPA**
Feed/Line Loss	1.00	1.00	dB	**3.30 m VSAT antenna diameter**
Transmit Antenna Gain	57.66	41.03	dBi	60 % efficiency, VSAT antenna
Edge-of-Coverage Gain Loss	0.00	4.30	dB	
EIRP	78.12	50.50	dBW	
Free Space Loss	213.14	209.76	dB	38,000 km range
Rain Margin	3.10	1.40	dB	**98% (99%) avail., Reg. E (D2)**
Atmosphere Loss	0.60	0.40	dB	0.69 m diameter, sat. transmit antenna
Pointing Loss	1.00	1.00	dB	65 % efficiency, satellite antenna
Net Path Loss	217.84	212.56	dB	**10 downlink beams (1.55°)**
				0.47 m diameter, sat. receive antenna
				65 % eff, sat. receive antenna
				10 uplink beams (1.55°)
Receive Antenna Gain	41.08	54.27	dBi	
Feed/Line Loss	1.00	1.00	dB	280 K, satellite antenna temp.
Edge-of-Coverage Gain Loss	4.30	0.00	dB	130 K, sat. feed/line temp.
System Temp. (recr. input)	26.77	25.04	dB-K	2.50 dB, sat. receiver noise figure
Effective G/T	9.01	100.00	dB/K	226 K, sat. receiver temp.
				475 K, satellite system temp.
Rec'd Carrier Level	-103.94	-108.79	dBW	
Spec'd C/I	50.00	50.00	dB	100 K, VSAT antenna temp.
Boltzmann's Constant	-228.60	-228.60	dBW/Hz-K	290 K, VSAT feed/line temp.
Received C/(No+Io)	97.89	94.77	dB-Hz	2.10 dB, VSAT receiver noise figure
				180 K, VSAT receiver temp.
				319 K, VSAT system temperature
	End-to-End Link			
Composite C/(No+Io)		93.04	dB-Hz	
Interference loss		1.00	dB	**20 dB co-channel interference**
Modem loss		2.00	dB	
System Margin		3.00	dB	**QPSK modulation,**
Coding Gain		6.00	dB	**Block code, R = 0.749**
Req'd Eb/No		13.10	dB	**1E-10 Bit error rate**
Maximum Data Rate		81.94	dB-Hz	**156 Mb/s**

Figure B–1: Architecture 1 Link Budget: QPSK, Block Code, 98% Availability in Region E

Parameter	Uplink	Downlink	Units	Remarks
Carrier Frequency	28.50	19.30	GHz	
Noise Bandwidth	100	100	MHz	Per B-ISDN channel
Transmit Power	21.46	14.77	dBW	**140 W VSAT HPA**
HPA Backoff	0.00	0.00	dB	**30 W Satellite HPA**
Feed/Line Loss	1.00	1.00	dB	**2.42 m VSAT antenna diameter**
Transmit Antenna Gain	54.96	41.03	dBi	60 % efficiency, VSAT antenna
Edge-of-Coverage Gain Loss	0.00	4.30	dB	
EIRP	75.43	50.50	dBW	
Free Space Loss	213.14	209.76	dB	38,000 km range
Rain Margin	3.10	1.40	dB	**98% avail., Region E**
Atmosphere Loss	0.60	0.40	dB	0.69 m diameter, sat. transmit antenna
Pointing Loss	1.00	1.00	dB	65 % efficiency, satellite antenna
Net Path Loss	217.84	212.56	dB	**10 downlink beams (1.55°)**
				0.47 m diameter, sat. receive antenna
				65 % eff, sat. receive antenna
				10 uplink beams (1.55°)
Receive Antenna Gain	41.08	51.58	dBi	
Feed/Line Loss	1.00	1.00	dB	280 K, satellite antenna temp.
Edge-of-Coverage Gain Loss	4.30	0.00	dB	130 K, sat. feed/line temp.
System Temp. (recr. input)	26.77	25.04	dB-K	2.50 dB, sat. receiver noise figure
Effective G/T	9.01	100.00	dB/K	226 K, sat. receiver temp.
				475 K, satellite system temp.
Rec'd Carrier Level	-106.64	-111.48	dBW	
Spec'd C/I	50.00	50.00	dB	100 K, VSAT antenna temp.
Boltzmann's Constant	-228.60	-228.60	dBW/Hz-K	290 K, VSAT feed/line temp.
Received C/(No+Io)	95.19	92.08	dB-Hz	2.10 dB, VSAT receiver noise figure
				180 K, VSAT receiver temp.
				319 K, VSAT system temperature
	End-to-End Link			
Composite C/(No+Io)		90.35	dB-Hz	
Interference loss		1.00	dB	**20 dB co-channel interference**
Modem loss		2.00	dB	
System Margin		3.00	dB	**QPSK modulation,**
Coding Gain		0.00	dB	**Concat. code, R = 0.66**
Req'd Eb/No		4.40	dB	**1E-10 Bit error rate**
Maximum Data Rate		81.95	dB-Hz	**157 Mb/s**

Figure B–2: Architecture 1 Link Budget: QPSK, Concatenated Code, 98% Availability in Region E

Parameter	Uplink	Downlink	Units	Remarks
Carrier Frequency	28.50	19.30	GHz	
Noise Bandwidth	100	100	MHz	Per B-ISDN channel
Transmit Power	21.46	14.77	dBW	**140 W VSAT HPA**
HPA Backoff	0.00	0.00	dB	**30 W Satellite HPA**
Feed/Line Loss	1.00	1.00	dB	**5.29 m VSAT antenna diameter**
Transmit Antenna Gain	61.76	41.03	dBi	60 % efficiency, VSAT antenna
Edge-of-Coverage Gain Loss	0.00	4.30	dB	
EIRP	82.22	50.50	dBW	
Free Space Loss	213.14	209.76	dB	38,000 km range
Rain Margin	3.10	1.40	dB	**98% avail., Region E**
Atmosphere Loss	0.60	0.40	dB	0.69 m diameter, sat. transmit antenna
Pointing Loss	1.00	1.00	dB	65 % efficiency, satellite antenna
Net Path Loss	217.84	212.56	dB	**10 downlink beams (1.55°)**
				0.47 m diameter, sat. receive antenna
				65 % eff, sat. receive antenna
				10 uplink beams (1.55°)
Receive Antenna Gain	41.08	58.37	dBi	
Feed/Line Loss	1.00	1.00	dB	280 K, satellite antenna temp.
Edge-of-Coverage Gain Loss	4.30	0.00	dB	130 K, sat. feed/line temp.
System Temp. (recr. input)	26.77	25.04	dB-K	2.50 dB, sat. receiver noise figure
Effective G/T	9.01	100.00	dB/K	226 K, sat. receiver temp.
				475 K, satellite system temp.
Rec'd Carrier Level	-99.85	-104.69	dBW	
Spec'd C/I	50.00	50.00	dB	100 K, VSAT antenna temp.
Boltzmann's Constant	-228.60	-228.60	dBW/Hz-K	290 K, VSAT feed/line temp.
Received C/(No+Io)	101.98	98.87	dB-Hz	2.10 dB, VSAT receiver noise figure
				180 K, VSAT receiver temp.
				319 K, VSAT system temperature
		End-to-End Link		
Composite C/(No+Io)		97.14	dB-Hz	
Interference loss		2.00	dB	**20 dB co-channel interference**
Modem loss		2.50	dB	
System Margin		3.00	dB	**8PSK modulation,**
Coding Gain		6.50	dB	**Block code, R = 0.829**
Req'd Eb/No		16.70	dB	**1E-10 Bit error rate**
Maximum Data Rate		81.94	dB-Hz	**156 Mb/s**

Figure B–3: Architecture 1 Link Budget: 8-PSK, Block Code, 98% Availability in Region E

Parameter	Uplink	Downlink	Units	Remarks
Carrier Frequency	28.50	19.30	GHz	
Noise Bandwidth	100	100	MHz	Per B-ISDN channel
Transmit Power	21.46	14.77	dBW	**140 W VSAT HPA**
HPA Backoff	0.00	0.00	dB	**30 W Satellite HPA**
Feed/Line Loss	1.00	1.00	dB	**3.08 m VSAT antenna diameter**
Transmit Antenna Gain	57.06	41.03	dBi	60 % efficiency, VSAT antenna
Edge-of-Coverage Gain Loss	0.00	4.30	dB	
EIRP	77.52	50.50	dBW	
Free Space Loss	213.14	209.76	dB	38,000 km range
Rain Margin	3.10	1.40	dB	**98% (99%) avail., Reg. E (D2)**
Atmosphere Loss	0.60	0.40	dB	0.69 m diameter, sat. transmit antenna
Pointing Loss	1.00	1.00	dB	65 % efficiency, satellite antenna
Net Path Loss	217.84	212.56	dB	**10 downlink beams (1.55°)**
				0.47 m diameter, sat. receive antenna
				65 % eff, sat. receive antenna
				10 uplink beams (1.55°)
Receive Antenna Gain	41.08	53.67	dBi	
Feed/Line Loss	1.00	1.00	dB	280 K, satellite antenna temp.
Edge-of-Coverage Gain Loss	4.30	0.00	dB	130 K, sat. feed/line temp.
System Temp. (recr. input)	26.77	25.04	dB-K	2.50 dB, sat. receiver noise figure
Effective G/T	9.01	100.00	dB/K	226 K, sat. receiver temp.
				475 K, satellite system temp.
Rec'd Carrier Level	-104.54	-109.38	dBW	
Spec'd C/I	50.00	50.00	dB	100 K, VSAT antenna temp.
Boltzmann's Constant	-228.60	-228.60	dBW/Hz-K	290 K, VSAT feed/line temp.
Received C/(No+Io)	97.29	94.17	dB-Hz	2.10 dB, VSAT receiver noise figure
				180 K, VSAT receiver temp.
				319 K, VSAT system temperature
	End-to-End Link			
Composite C/(No+Io)		92.45	dB-Hz	
Interference loss		2.00	dB	**20 dB co-channel interference**
Modem loss		2.50	dB	
System Margin		3.00	dB	**8PSK modulation,**
Coding Gain		0.00	dB	**Concat. code, R = 0.777**
Req'd Eb/No		5.50	dB	**1E-10 Bit error rate**
Maximum Data Rate		81.95	dB-Hz	**157 Mb/s**

Figure B–4: Architecture 1 Link Budget: 8-PSK, Concatenated Code, 98% Availability in Region E

Table B–2: Architecture 2 Link Choices: Modulation and Coding

2/4/92	**QPSK**	**QPSK**	**QPSK**	**8PSK**
	Block code	**Block code**	**Block code**	**Concat. code**
Link calculation results	**Uplink**	**Uplink**	**Downlink**	**Downlink**
Earth terminal diameter (m)	3.00	3.00	3.00	3.00
Earth terminal transmit power (w)	**8.4 W**	**18.2 W**		
Modulation type	QPSK	QPSK		
Coding type	Block	Block		
Coding rate	0.749	0.749		
Information transmit rate (Mb/s)	200	200		
Reqd. bandwidth per channel (MHz)	178	178		
Channels per (2000/3 =) 667 MHz	3.7	3.7		
Channels per (2500/3 =) 833 MHz	**4.7**	**4.7**		
Number of uplink channels (12 beams)	48	48		
Total uplink capacity (Gb/s)	9.6	9.6		
Satellite antenna beam size (degrees)	0.40°	0.40°	0.40°	0.40°
Annual Availability	98.0%	99.0%	99.5%	99.5%
Satellite transmit power (W)			**40.0**	**40.0**
Number of channels			12	12
Total satellite RF power (W)			480	480
Modulation type			QPSK	8PSK
Coding type			Block	Block/Trellis
Coding rate			0.749	0.777
Information transmit rate (Mb/s)			800	800
Reqd. bandwidth per channel (MHz)			712	458
Channels per (1.4/3 =) 467 MHz			0.7	**1.0**
Channels per (1.7/3 =) 567 MHz			**0.8**	1.2
Number of downlink channels (12 beams)			12	12
Total downlink capacity (Gb/s)			9.6	9.6
Conclusions:				
1. Downlink frequency reuse plan is difficult with QPSK, good with 8PSK.				
2. Concatenated code gives improved performance, but is decoder feasible?				
3. 12 hopping uplink/downlink beams, 0.4° size.				
Assumptions:				
1. BER = E-10				
2. -20 dB/-16 dB co-channel interference uplinks/downlinks				
3. Rain margin 98% Region E =3.1 dB/1.4 dB, uplink/downlinks				
99% Region E = 6.5 dB/3.2 dB, uplink/downlink				
99.5% Region E = 11.6 dB/5.7 dB, uplink/downlink				
4. 200 Mb/s uplinks and 800 Mb/s downlinks				
5. 3 dB link margin				
6. QPSK achieves 1.5 b/s/Hz; 8PSK achieves 2.25 b/s/Hz				

Parameter	Link Analysis Value Units	Link Data Value Units	Remarks	
Carrier Frequency		28.50 GHz	**Uplink, VSAT to S/C**	
VSAT Transmit Power	9.24 dBW	**8.4 W**		
Line Loss	1.00 dB			
VSAT Antenna Gain	56.83 dBi			
VSAT Antenna Diameter		**3.00 m**		118.1 in
Antenna Efficiency		60 %		
EIRP	65.07 dBW			
Free Space Loss	213.14 dB			
Range		38,000 km		
VSAT Pointing Loss	1.00 dB			
Atmosphere Loss	0.60 dB			
Rain Margin	**3.10 dB**	**98.00 %**	**Annual Availability in Region E**	
Net Path Loss	217.84 dB	**175 hr/yr outage**		
S/C Antenna Gain	52.39 dBi	**110 beams,**		**0.40° beams**
S/C Antenna Diameter		1.80 m		70.9 in
Antenna Efficiency		60 %		
Edge of Coverage Gain Loss	4.30 dB			
Line Loss	1.00 dB			
System Temp. @ Rcvr. Input	26.77 dB-K	475 K		
S/C Antenna Temp.		280 K		
Receive Line Temp.		130 K		
S/C Receiver Temp.		226 K	Noise Figure =	2.5 dB
Effective G/T	20.33 dB/K			
Received Carrier Level		-105.68 dBW	Flux =	-102.2 dBW/m^2
Boltzmann's Constant	-228.60 dBW/Hz-K			
Received C/No	96.16 dB-Hz			
Data Rate	83.01 dB-Hz	**200.00 Mb/s**		
Interference Degradation	1.00 dB		C/I =	20.0 dB
Modem Implementation Loss	2.00 dB			
Coding Gain	6.00 dB		**Block coding,**	**R=0.749**
Available Eb/No	16.15 dB			
Required Eb/No	13.10 dB	**1E-10 BER**	**QPSK**	
Margin	3.05 dB			

UPLINK (SS/L)	**98.0 %**	**Annual Availability in Region**	**175 hr/yr outage**
	200.00 Mb/s	**Data rate**	
	110 beams	**0.40° beams**	
VSAT parameters:	**3.00 m**	**VSAT diameter**	
	8.4 W	**VSAT transmit power**	

Figure B–5: Architecture 2 Uplink Budget: QPSK, Block Code, 98% Availability in Region E

Parameter	Link Analysis Value Units	Link Data Value Units	Remarks	
Carrier Frequency		28.50 GHz	**Uplink, VSAT to S/C**	
VSAT Transmit Power	12.60 dBW	**18.2 W**		
Line Loss	1.00 dB			
VSAT Antenna Gain	56.83 dBi			
VSAT Antenna Diameter		**3.00 m**		118.1 in
Antenna Efficiency		60 %		
EIRP	68.43 dBW			
Free Space Loss	213.14 dB			
Range		38,000 km		
VSAT Pointing Loss	1.00 dB			
Atmosphere Loss	0.60 dB			
Rain Margin	**6.50 dB**	**99.00 %**	**Annual Availability in Region E**	
Net Path Loss	221.24 dB	**88 hr/yr outage**		
S/C Antenna Gain	52.39 dBi		**110 beams,**	**0.40° beams**
S/C Antenna Diameter		1.80 m		70.9 in
Antenna Efficiency		60 %		
Edge of Coverage Gain Loss	4.30 dB			
Line Loss	1.00 dB			
System Temp. @ Rcvr. Input	26.77 dB-K	475 K		
S/C Antenna Temp.		280 K		
Receive Line Temp.		130 K		
S/C Receiver Temp.		226 K	Noise Figure =	2.5 dB
Effective G/T	20.33 dB/K			
Received Carrier Level		-105.72 dBW	Flux =	-102.3 dBW/m^2
Boltzmann's Constant	-228.60 dBW/Hz-K			
Received C/No	96.11 dB-Hz			
Data Rate	83.01 dB-Hz	**200.00 Mb/s**		
Interference Degradation	1.00 dB		C/I =	20.0 dB
Modem Implementation Loss	2.00 dB			
Coding Gain	6.00 dB		**Block coding, R=0.749**	
Available Eb/No	16.10 dB			
Required Eb/No	13.10 dB	**1E-10 BER**	**QPSK**	
Margin	3.00 dB			

UPLINK (SS/L)	**99.0 %**	**Annual Availability in Region**	**88 hr/yr outage**
	200.00 Mb/s	**Data rate**	
	110 beams	**0.40° beams**	
VSAT parameters:	**3.00 m**	**VSAT diameter**	
	18.2 W	**VSAT transmit power**	

Figure B–6: Architecture 2 Uplink Budget: QPSK, Block Code, 99% Availability in Region E

Parameter	Link Analysis Value Units	Link Data Value Units	Remarks	
Carrier Frequency		19.30 GHz	**Downlink, S/C to VSAT**	
S/C Transmit Power	16.02 dBW	**40.0 W**	Power per channel	
Line Loss	1.00 dB			
S/C Antenna Gain	52.53 dBi			**110 beams over CONUS**
Edge of Coverage Gain Loss	4.30 dB			
S/C Antenna Diameter		2.70 m	0.40° beams	106.3 in
Antenna Efficiency		60 %		
EIRP	63.25 dBW			
Free Space Loss	209.76 dB			
Range		38,000 km		
VSAT Pointing Loss	0.50 dB			
Atmosphere Loss	0.40 dB			
Rain Margin	**5.70 dB**	**99.50 %**	**Annual Avail. in Reg. E,**	
Net Path Loss	216.36 dB	**44 hr/yr outage**		
VSAT Antenna Gain	53.45 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	27.41 dB/K			
Received Carrier Level		-100.66 dBW	Flux =	-105.9 dBW/m^2
Boltzmann's Constant	-228.60 dBW/Hz-K			
Received C/No	102.90 dB-Hz			
Data Rate	89.03 dB-Hz	800.00 Mb/s		
Interference Degradation	1.80 dB		C/I =	16.0 dB
Modem Implementation Loss	2.00 dB			
Coding Gain	6.00 dB		**Block coding, R=0.749**	
Available Eb/No	16.07 dB			
Required Eb/No	13.10 dB	**1E-10 BER**	**QPSK**	
Margin	2.97 dB			

DOWNLINK (SS/L)	**99.5 %**	**Annual Avail. in Reg. E,**	**44 hr/yr outage**
	800 Mb/s	**Data rate**	
	110 beams	**0.40° beams**	
	40.0 W	**S/C power per channel**	
	480 W	**Total S/C RF power (12 active channels)**	
VSAT parameters:	**3.0 m**	**VSAT diameter**	

Figure B–7: Architecture 2 Downlink Budget: QPSK, Block Code, 99.5% Availability in Region E

Parameter	Link Analysis Value Units	Link Data Value Units	Remarks
Carrier Frequency		19.30 GHz	**Downlink, S/C to VSAT**
S/C Transmit Power	16.02 dBW	**40.0 W**	Power per channel
Line Loss	1.00 dB		2 dB output mux loss
S/C Antenna Gain	52.53 dBi		**110 beams over CONUS**
Edge of Coverage Gain Loss	4.30 dB		
S/C Antenna Diameter		2.70 m	0.40° beams 106.3 in
Antenna Efficiency		60 %	
EIRP	63.25 dBW		
Free Space Loss	209.76 dB		
Range		38,000 km	
VSAT Pointing Loss	0.50 dB		
Atmosphere Loss	0.40 dB		
Rain Margin	**5.70 dB**	**99.50 %**	**Annual Avail. in Reg. E,**
Net Path Loss	216.36 dB	**44 hr/yr outage**	
VSAT Antenna Gain	53.45 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	27.41 dB/K		
Received Carrier Level		-100.66 dBW	Flux = -105.9 dBW/m^2
Boltzmann's Constant	-228.60 dBW/Hz-K		
Received C/No	102.90 dB-Hz		
Data Rate	89.03 dB-Hz	800.00 Mb/s	
Interference Degradation	4.00 dB		C/I = 16.0 dB
Modem Implementation Loss	2.50 dB		
Coding Gain	11.20 dB		**Concatenated code, R=0.777**
Available Eb/No	18.57 dB		
Required Eb/No	16.70 dB	**1E-10 BER**	**8PSK**
Margin	1.87 dB		

DOWNLINK (SS/L)	**99.5 %**	**Annual Avail. in Reg. E,**	**44 hr/yr outage**
	800 Mb/s	**Data rate**	
	110 beams	**0.40° beams**	
	40.0 W	**S/C power per channel**	
	480 W	**Total S/C RF power (12 active channels)**	
VSAT parameters:	**3.0 m**	**VSAT diameter**	

Figure B–8: Architecture 2 Downlink Budget: 8-PSK, Concatenated Code, 99.5% Availability in Region E

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Appendix C

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.

C.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 C-7).

C.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 C-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 C-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 C-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 C-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 C-1) and cost of a single ground terminal (see Table C-6). The B-ISDN systems have lower total ground terminal costs

Table C-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 C-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 C-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 C-6), and (2) the user's pro rata share of the space segment plus NCC cost (given in Table C-4). The formulas and data in this table is used to produce the total user costs given in Table C-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 C-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 C-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.

C.3 Cost Conclusions and Drivers

It is clear from Table C-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 C–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 C–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 C–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 C–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 C–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 C–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 C–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 C–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.

Appendix D

AIAA-92-1831-CP

Satellite Delivery of B-ISDN Services*

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Abstract

This paper will address the role of technology in the satellite delivery of B-ISDN services. Satellites excel in serving remote users and in providing multicast and broadcast services. Benefits to potential users employing these satellite broadband services will be examined together with their respective network architecture. Two application requirements are then proposed. The critical technologies needed in the realization of these architectures will be identified.

1. Introduction

The Integrated Service Digital Network (ISDN) concept is to provide the user with easy access to a multiplicity of services over a single connection to the network. Voice, data, and even low rate video are simultaneously feasible in a single access with this scheme. The basic access is 144 kb/s, but greater data rates are possible. In general, an end-to-end ISDN connection will involve a local and a public network. The former is intended to interconnect subscribers and the local exchange; and the latter to interconnect the local exchanges via local, national, and international trunks. ISDN is primarily designed for local communications and flexible access to the public networks.

With the advent of increasing power and penetration of desktop computers, high speed LANs and their connections, emerging use of imaging for information handling, and the growing importance of telecommunications in education and health care, the need for Broadband ISDN services is apparent. This **B-ISDN** is expected to offer multimedia services capable of providing services on demand, i.e., the ability to vary the service quality, bandwidth, and connectivity under the user's command.

The basic access of B-ISDN is 155 Mb/s- more than enough for digital TV and sufficient for HDTV. The efficiency and flexibility of B-ISDN results from a quasi-packet type of communications called Asynchronous Transfer Mode (**ATM**). In this scheme, voice and video are broken up and packaged in 53 byte cells, carried from the source across multiple nodes and possible multiple networks, and finally reconstructed as a continuous stream at the destination. The network does not distinguish voice, video, or data cells but processes all in common high speed hardware. Efficiency results by utilizing the intermittent lulls in communications, especially data, to insert more information with additional cells. Flexibility results from using common hardware and channels to carry and process a variety of communications.

The growing use of optical fiber amongst major communications center, and even to residences should spur the introduction of B-ISDN. Extremely wide bandwidth is made available by these facilities, and economics would demand that these facilities be efficient and flexible in the provision of a variety of services via a common format such as ATM. Fully compatible and transparent interfaces between the satellite and the terrestrial-based B-ISDN will be a major challenge in the realization of global communications into the 21st century.

2. Potential Applications

In an information-based society, all segments of society need access to the information infrastructure in order to enjoy opportunities that otherwise would be available to only a few. For example, most current users of wideband services are concentrated in large center, downtown business districts, and suburban office parks, where their needs are served by specialized overlay networks. However, many potential users — regional offices, small businesses, schools, medical facilities, and residual customers — are widely dispersed and have no access to these overlay networks. To become full participants in the emerging information-based economy and social structure, these users need a public switched network than can support all of their information needs. Hence, a satellite-based B-ISDN would be ideally suited to bridge these scattered wide-bandwidth information centers to enhance service offerings, improve transmission efficiency and/or lower service charges.

Because of the serious impact that service interruptions can have on telecom users, most service providers are seeking to evolve their network to become more survivable - i.e., to make them self-monitoring, self-diagnosing, and self-healing so that traffic is automatically routed around cable cuts or switch failures without the loss of connections or data. This issue of survivability will become even more important when B-ISDN is used to carry various types of traffic using a single integrated network. Therefore, network operators will have strong incentive to use satellite systems not only as a backup to provide network survivability but also as a vehicle to provide B-ISDN services to remote users.

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* This paper is based upon work sponsored by the National Aeronautics and Space Administration under contract NAS3-25092.

Satellite-based networks are extremely flexible and fast in providing a set of primary communications services to business customers from distributed locations via small or medium ground terminals located at or closely to the customer's own premises. These business satellite networks can support services for the transmission of text, voice, data, video and graphics. Typical features of these services include:

- Fully digital transmission;
- Wide range of customer bit rates;
- Variety of circuit provision modes;
- Transparency to the type of services carried;
- Point-to-multipoint transmission capability;
- The ability to accommodate new users swiftly through the rapid installation of earth stations at customer premises.

3. Broadband Services

When the capacity available to the ISDN user is increased, so is the range of services B-ISDN is capable of providing both interactive and distribution services. The interactive services involve two-way exchange of information between two subscribers or a subscriber and a service provider. Conversational services (e.g., video telephony, videoconference, and video surveillance), messaging services (e.g., voice mail, information editing, and video mail), and information retrieval services (e.g., videotext, video, film, and document retrieval) are under this category.

The distribution services provide a continuous flow of information which is distributed from a central source to authorized users connected to the network. These include telenewspapers, information transmitted in coded form for commercial use and databases to be updated on a regular basis.

4. Frequency Allocations

One of the key considerations in defining the network architectures is bandwidth availability. Because of the high bandwidth requirements for B-ISDN services, Ka-band was chosen for the satellite architectures. Current frequency allocations as defined by CCIR are given in [1]. Only portions of the Ka-band not shared by other types of satellite services on a primary basis were considered for use. Sharing with terrestrial fixed and terrestrial mobile services was not expected to be a problem. Bands that are allocated to fixed satellite services on a primary basis and to mobile satellite services on a secondary basis were also considered readily usable.

Figure 1 shows the current frequency allocations in the range from 17.7 to 20.2 GHz. In this range, bandwidth is allocated to be shared among a variety of non-government services, including fixed satellite space-to-earth services. The band from 17.7 to 19.7 GHz is allocated to fixed satellite space-to-earth services on a primary basis, along with terrestrial fixed and mobile services. However, some portions of this band are reserved for special types of fixed satellite space-to-earth services. Of the total allocation between 17.7 and 19.7 GHz, only the portions from 18.3 to 18.6 GHz and from 18.8 to 19.7 GHz have been considered for use. The band from 19.7 to 20.2 GHz is allocated to fixed satellite space-to-earth services on a primary basis, and to mobile satellite space-to-earth services only on a secondary basis. As a result, 1.7 GHz of bandwidth, including the bands from 18.3 to 18.6 GHz and from 18.8 to 20.2 GHz, is assumed to be available on the downlink.

Figure 2 shows the current frequency allocations in the range from 27.5 to 30.0 GHz. In this range, bandwidth is allocated to be shared among a variety of non-government services. The band from 29.5 to 30.0 GHz is allocated to fixed satellite space-to-earth services on a primary basis, and to mobile satellite earth-to-space services only on a secondary basis. The band from 27.5 to 29.5 GHz is allocated to fixed satellite earth-to-space services on a primary basis, along with fixed and mobile terrestrial services. As a result, 2.5 GHz of bandwidth, in the band from 27.5 to 30 GHz, is assumed to be available on the uplink.

Although the Ka-band provides sufficient bandwidth, its use has some disadvantages. Rain fades at these frequencies are large, especially on the uplink. This forces systems to incorporate either large clear-sky margins or power control on the uplink. Also, at Ka-band frequencies, significant depolarization occurs during rain, so that cross-polarization isolation degrades rapidly. Consequently, in the following architectures, cross-polarization is only used to add to other isolation techniques, such as frequency and spatial isolation.

5. Network Architectures

Two satellite network architectures for the support of B-ISDN services will be described. The first architecture could augment terrestrial networks by providing multicast and broadcast services as well as remote user access to the terrestrial network. These services are provided by a network architecture in which a nonregenerative Ka-band spot beam satellite is used to support transmission of B-ISDN at 155.52 Mb/s. The second architecture supports private B-ISDN networks and acts as the gateway to the public network for these networks. This network architecture is based on a Ka-band satellite system that employs hopping-beam TDMA and on-board baseband switching to interconnect private network earth stations.

5.1 Multicast/Broadcast and Remote Access Network Architecture

The multicast/broadcast and remote access network architecture is shown in **Figure 3.** This architecture provides 155 Mb/s pipes to connect remote users to the B-ISDN or to supplement or expand the connectivity of an existing B-ISDN. These pipes can be used to distribute wideband signals (such as high definition video) to multiple users and also can be used to provide high rate remote access capability for point to point or point to multipoint services. It is assumed that narrowband multipoint and remote access services are provided by other systems. To provide interconnection of high rate carriers in a spot beam environment, this architecture employs static microwave switching (MSM) onboard the satellite

These satellite system will interconnect network modes via a SDH interface at 155.52 Mb/s. A functional block diagram of an earth station providing SDH transmission capabilities is shown in **Figure 4.** At the earth station only the SDH section overhead is processed; the SDH line and path overheads and the payload are passed transparently to the destination earth station. Doppler buffers are used to account for clock differences that result from satellite motion.

In addition to the traffic earth stations, there will be a network control station (NCS) in one of the beams which coordinates the allocation of channels to earth stations and controls the on-board microwave switch matrix via an uplink command channel. This station would also act as the TT&C site for the spacecraft. Out-of-band signaling channels will be used to provide signaling between traffic stations and the network control station. The out-of-band signaling channels could be provided either through the terrestrial network or through a narrowband random access channel supported by the Ka-band satellite. This signaling will be used to establish 155.52 Mb/s SDH connections between user earth stations. Users will access the system by requesting 155.52 Mb/s SDH connections between earth stations. If the required bandwidth is available the network control station will send the appropriate frequency assignments to the traffic stations and will configure the on-board MSM.

To provide bit error performance comparable to that expected from fiber optic systems while keeping earth station costs to a minimum, a high performance modulation and coding scheme is required. At bit error rates on the order of 10^{-12}, Reed-Solomon codes offer relatively large coding gains. Additional coding gain can be achieved by concatenating convolutional inner codes with Reed-Solomon outer codes. Recently, concatenated coding schemes that utilize Reed-Solomon outer codes and trellis inner codes in conjunction with higher order modulation schemes have been shown to offer high levels of coding gain with good bandwidth efficiency. One such modulation and coding scheme **[2]** uses rate 8/9 trellis coded octal-PSK modulation concatenated with a (255,223) Reed-Solomon outer code. Extrapolation of the results presented in [2] show that this scheme could provide a bit error rate of 10^{-12} at an E_b/N_0 of 5.7 dB. This represents a coding gain of over 8 dB compared to uncoded BPSK or QPSK. Use of this code results in a transmission rate of 200 Mb/s or 66.7 Msymbols/s. The use of Nyquist filtering with a 33% rolloff gives a signal bandwidth of 89 MHz. It is assumed that a channel spacing of 100 MHz should be adequate and that up to 17 channels could be accommodated by the available Ka-band bandwidth.

The antenna coverage pattern for architecture 1 is shown in **Figure 5.** CONUS coverage is provided by using ten 1.6^{o} spot beams for both uplink and downlink transmission. A frequency reuse factor of 3 is used to avoid interference between adjacent beams. The downlink beams are divided into three groups so that no two members of the same group are adjacent. The available Ka-band bandwidth is divided into three blocks, and one block is assigned to each of the beam groups. In this architecture only 12 of 17 available channels are utilized. Beam groups A, B, and C are assigned 4 channels each. The coverage is symmetric for the uplink and the downlink. Any combination of channel allocations could be used to meet projected traffic requirements provided that the number of channels allocated to the three groups does not exceed the available bandwidth and that required satellite transmit power is available. As mentioned above, because of Ka-band carrier depolarization during rain, orthogonal polarizations are not used to provide isolation within a single beam. However, adjacent beams of the same group are cross-polarized to augment isolation.

Various transmission parameters for this architecture are summarized in **Table 1.** The link budgets assume: (a) earth station antenna size and transmit power are 5 m and 50 W, respectively with power control to 200 W to combat rain fade, (b) rain margins are assumed for 99.5% availability in Rain Region E (southeastern U.S.), (c) the aforementioned code or similar code is used, (d) satellite amplifier of 90 W peak output power per carrier.

5.2 Private Network Architecture

An architecture designed for a private-based B-ISDN network is shown in **Figure 6.** This architecture provides user to user connectivity, but also serves as the gateway to the outside terrestrial B-ISDN network. Because of the variety of user bit rates and service types in such a network a flexible, interactive network architecture was chosen. The satellite provides this flexibility via an on-board fast packet switch.

This architecture employs carriers of 200 Mb/s with TDMA transmission on the uplink to allow private network earth stations to transmit ATM cells to an onboard packet switch. High speed 400 Mb/s downlink TDM carriers transport the packets to the destination earth station. The combination of TDMA access and onboard switching allows network earth stations to efficiently support combinations of low rate and high rate traffic. In addition, the satellite employs hopping beam antennas on the uplink in order to provide sufficient antenna gains at these bit rates and to maximize throughput efficiency. Hopping beam antennas are not used on the downlinks, but could be easily added to this architecture should increased link margin be desired.

Users will connect to each other and to the terrestrial network through a B-ISDN interface. A functional block diagram of an earth station is shown in **Figure 7**. Routing is achieved through the assembly of satellite virtual packets (**SVPs**) containing a fixed number of ATM cells for transmission over the satellite link. It is these SVPs that are routed by the on-board switch. Doppler buffers are used to account for clock differences that result from satellite motion. The rest of the earth station consists of modems, codecs, and RF equipment designed to operate in TDMA mode on the uplink and TDM mode on the downlink.

The network is responsible for two types of B-ISDN management: connection management and virtual traffic management. These functions are located mainly at the network control station (NCS) located in one of the beams, but are also included in the earth stations and on-board processor. Connection management involves establishing the routing needed to transport ATM cells from earth station to earth station through the on-board switch. This is accomplished by mapping VPI/VCIs into satellite virtual packet addresses that are used for routing within the satellite network. Different SVP addresses are used to identify particular switch outputs and destination earth stations within the satellite network. Traffic management consists of properly allocating network resources to accommodate dynamically varying virtual traffic within these connections. For example, uplink and downlink bandwidth must be managed to adapt to changing traffic patterns. For the uplink, this entails managing of the TDMA burst time plan to provide each earth station with adequate capacity. For the downlink, capacity will be dynamically allocated within the TDM frame on a frame-by-frame basis based on outbound buffer occupancy on board the satellite.

Both the connection management and traffic management for the satellite network are centralized in the NCS. For connection management, the NCS assigns virtual addresses for routing through the satellite network, provided that the required bandwidth is available. The NCS also forwards this signaling information to both the uplink and downlink earth station. For traffic management, although the satellite switch architecture is self-routing, some amount of flow control must be maintained by the network to avoid buffer overflow. The NCS must keep track of outbound buffer occupancy at the earth station and adjust TDMA burst periods as needed. The NCS must also manage the outbound buffers on board the satellite to minimize packet loss.

Techniques to alleviate the impact of congestion due to statistically coincidental peaks in traffic from different sources (destined for the same downlink beam) need to be investigated. The impact of satellite delay on the effectiveness of the congestion notification messages in reducing the traffic entering the satellite network needs to be examined as well.

Figure 8 shows the antenna beam coverage. The twelve large solid circles indicate the beam areas (1.5^o) for the individual beams, and the smaller inner circles within a beam represent 0.4^o size dwells on the uplink. The beam areas are symmetric for both links. The large beams are divided into three groups so that no two members of the same group are adjacent. In addition, hopping beam dwell patterns are coordinated to maximize isolation. Consequently, the available Ka-band bandwidth is divided into three blocks, one for each group. Each beam has the same fixed capacity of 400 Mb/s. Again, orthogonal polarization is only used to supplement other isolation techniques.

This architecture uses a concatenated coding scheme that provides even higher coding gain, at the cost of reduced bandwidth efficiency, than the coding described for the first architecture. This coding is applied to both the uplink and downlink carriers. The use of an inner rate 3/4 convolutional code concatenated with a (255, 223) Reed-Solomon outer code and QPSK transmission results in a transmission rate of 610 Mb/s and a modulation rate of 305 Msymbols/s for each beam. Nyquist filtering with 33% roll off is used to give a total beam bandwidth of 407 MHz. Extrapolation of the results presented in [3] show that a rate 1/2 convolutional code concatenated with a (255,223) Reed-Solomon code will provide a bit error rate of 10^{-12} at an E_b/N_o of about 3.5 dB. It is assumed that a concatenated coding scheme using a rate 3/4 convolutional code and a (255,223) Reed-Solomon code could provide a bit error rate of 10^{-12} at an E_b/N_o of about 4.5 dB. Such coding techniques will need to be developed.

A summary of the satellite architecture is given in **Table 2**. The link budgets assume: (a) earth station antenna size and transmit power are 3.0 m and 10 W, respectively with power control to 40 W, (b) rain margins are assumed for 99.5% availability in Rain Region E (southeastern U.S.), (c) the aforementioned codes are used, (d) satellite amplifier of 75 W peak output power per carrier.

6. Payload Designs

6.1 Nonregenerative Satellite

A block diagram of the nonregenerative satellite payload is shown in **Figure 9**. The architecture is centered around static microwave switch matrices (MSMs) that function as a space division, circuit switched architecture. B-ISDN traffic is switched without processing from one uplink carrier to one or more downlink carriers, depending on traffic requirements. There are 4 carriers per beam at information bit rates of 155.52 Mb/s. Each of the FDMA signals is filtered after reception and then downconverted to an intermediate frequency (between 3 and 5 GHz) for the MSM. Four 10 by 10 MSMs provide interconnectivity between any input and output beam. The MSMs are reconfigured via commands from the network control station. Signals leaving the MSMs are then upconverted to the downlink RF frequency, amplified, and filtered before transmission. Note that a symmetric (4 carriers per beam) architecture was selected; asymmetry in the assignment of carriers could be accommodated with modifications to the MSM architecture. MSM configuration is the responsibility of the network control station (NCS). Each time a new circuit is set up, the interconnection pattern of one or more of the MSMs is altered by the NCS.

Mass and power estimates for a space-qualified design and implementation of this architecture are given in **Table 3**. Note that the present design does not incorporate redundancy for fault tolerance. Redundancy may be added by adding additional components and redundancy switching to the payload. Present mass and power requirements for the switch are 40 kg. and 88 W respectively. These numbers are expected to decrease given improvements in MSM and RF component technology.

6.2 Regenerative Satellite

As detailed in Section 5.2, the architecture selected for the private-based network is centered on an on-board fast packet switch. This type of baseband processor is appropriate for such a network since there are many small spot beams which require full interconnectivity and since private-based B-ISDN networks are expected to carry a wide variety of bit rates. Several options exist for the switch fabric itself. There have been many proposed designs for fast packet switching based on different performance criteria [**4, 5**]. In a satellite payload, two key features are essential to the efficiency of the satellite switch: fault tolerance and multicast capability. Because of the inaccessibility of the satellite payload, a switch design must be chosen that incorporates necessary redundancy and that has sufficiently graceful degradation in the event of failures. Also, since it is envisioned that B-ISDN satellite network users will take advantage of a satellite's inherent broadcast or multicast capability, a multicast switch architecture should be used.

A block diagram for the proposed payload architecture is given in **Figure 10**. The uplink employs a hopping beam antenna with dwell timer determined by traffic patterns. On the satellite each carrier is filtered and downconverted. The 24 separate TDMA carriers are routed by the redundancy switch, which sends the incoming carriers to 24 currently operating switch paths. The traffic in each beam is then buffered based on earth station address, and TDM frames are assembled which contain a header and fields of contiguous SVPs destined for the same earth station. The TDM header contains for each earth station a length and pointer field which notifies the earth station as to where to look in the frame for its packets. The TDM carriers are then upconverted, amplified, and transmitted on the proper downlink beam in a single TDM stream.

After implementation considerations and preliminary mass and power estimates for candidate switches were examined, a self-routing multicast crossbar switch design was selected based on mass and power requirements and ease of implementation [**6**]. The basic crossbar design is strictly non-blocking; in other words, given that a particular input port and output port are free, there exists a free path between them regardless of the present switch configuration. Output contention will arise, however, if two packets destined for the same output are sent through the switch fabric at the same time; one of the packets will be lost. Therefore, input buffering is used with a switch fabric arbiter to insure that no more than one packet destined for each output enters the switch fabric at the same time. This arbiter examines a selected number of packets in each input port's queue, thereby minimizing the decreased efficiency resulting from head-of-line blocking, in which a blocked packet precludes other packets from being selected by the arbiter.

Figure 11 shows a block diagram of the baseband processor itself. Carriers are first demodulated and decoded, after which packets are assembled and sent to the input ports at a serial line speed of 200 Mb/s, where they are read into a FIFO buffer. This buffer should be deep enough to account for varying traffic patterns; optimal size needs to be determined. To resolve output contention, an arbiter based on a token ring algorithm determines which packets are sent to the switch fabric during each cycle. The switch fabric operates at a higher speed than the incoming line speed, since time must be allotted to operate the ring arbiter and to provide for less than 100% throughput efficiency of the buffered packets (due to head-of-line blocking).

Packets are then buffered in the output ports and processed, coded, and modulated for retransmission on the downlinks. Several options exist for implementing multicast capability; multicast packets may be duplicated on the input or output port side, or within the switch fabric itself. The multicast crossbar switch provides multicast capability at the input ports, whereby a special routing tag on the packet reserves several connections through the switch fabric.

Fault tolerance may be best implemented by means of a 1 for N redundancy approach. The present requirements call for 24 input and output lines at 200 Mb/s each. If the switch network is built as a 32 by 32 network, then there will be 33% redundancy in all baseband elements. This redundancy is necessary to restore full functionality in the event of one or more path failures between an input and output line. More redundancy, at a higher cost in mass and power demands, can be implemented if necessary. Redundancy switching is necessary to switch to backup components in the event of a detected failure. Fault isolation may then be performed on the faulty units while offline.

Since the fast packet switch routes traffic based on downlink beam destination, at some point the traffic must be sorted or routed to the proper earth station. This can be accomplished in two ways. If sorting is performed on-board the satellite, a number of advantages arise. For example, the processing load on each earth station would be lowered by an order of magnitude. Furthermore, the filtering and sorting based on destination address could be performed at a central location instead of being distributed to each earth station. However, this centralized sorting would increase the on-board processing necessary on the satellite.

The alternative to this scheme is to avoid extra on-board processing and have each earth station filter the entire beam traffic for packets destined to it. This constitutes a major load on the earth station at high bit rates, which may require the use of parallel processing in filtering the downlink traffic. The proper strategy to select will be based the projected number of users and the cost constraints on the earth stations. The above architecture assumes the first approach; sorting the traffic based on earth station address and then appending a TDM frame header to notify earth stations where their traffic is within the frame. Instead of having to process each SVP in the carrier, the earth station need only process the TDM header and extract the proper packets.

As mentioned above, to reduce on-board switch complexity, satellite virtual packets (**SVPs**) will be formed by appending a routing tag onto ATM cells. SVPs simplify routing by mapping the connection address into a simpler address for processing on the satellite. Instead of routing based on ATM packet headers, the on-board routing is performed based on destination downlink beam and earth station routing tags. A header field is appended to each SVP, in which each downlink beam is assigned a particular output port (1 through 32). Each downlink beam receives data from two switch output ports multiplexed together. Assignment of traffic to a particular beam will alternate between one output port and the other. The input port and crossbar switching elements are then able to route packets based on the examination of a single bit. If a packet is inactive, it is simply assigned to an inactive port. In addition to a downlink beam address for use by the switch, a second address in the SVP identifies packets destined for a particular earth station. At the output of the switch, SVPs destined for particular downlink earth stations are buffered separately and then placed in the TDM stream during the correct dwell time. This method reduces the load on the earth station address processing; it need only receive the packets destined for it.

Another tradeoff exists with regard to SVP size. A reduction in overhead, and thus greater efficiency, can be incurred if SVPs are made large and earth stations wait to fill them before transmission. However, this approach leads to larger processing delays and higher buffer memory requirements in the switch input and output ports. Conversely, delays can be reduced by making SVPs small, at the cost of lower efficiency. Minimizing SVP size is also limited by processing speeds, since smaller packets lower the packet interarrival time (as low as 1.2 μs with a 400 Mb/s carrier). The optimal size for SVPs is currently being investigated.

Mass and power estimates for a space-qualified design and implementation of this switch architecture are presented in **Table 3**. One input port and one output port are supported on a circuit board of 30 square inches. Similarly, one input processor and one output processor are supported on a single board. One board each is also required for the switch fabric and for timing and control signal generation. In summary, 66 boards are required, with a total mass of approximately 80 kg. This mass estimate is a current technology assessment and will decrease as improvements are made in logic density. Power estimates are based on the number of gates required and the speed of each gate. The total power required for the baseband processor is estimated at 500 W. This number reflects the condition in which all redundant units are operating; if the redundant units are not operating, the power estimate drops to 375 W. These estimates are for current technology, and are based on the multicast crossbar architecture described in **[6]**.

7. Technology Requirements

Satellite architectures designed to handle traffic at B-ISDN rates must rely on advanced high-speed technology. The following areas are identified for critical development:

High-speed FEC decoders must be developed for use in these systems. The codes described above were selected for superior performance and bandwidth efficiency, but may be difficult to implement at the speeds required. These codes are intended to represent typical coding gains that may be obtained by concatenated coding systems. Actual performance at B-ISDN rates must be evaluated.

Wide bandwidth, power efficiency memory components are necessary for various elements in the second architecture.

Adaptive rain fade techniques to combat rain fades at these frequencies should be investigated.

Fast-packet switch architectures include many components that need to be explored. Many of the design and control issues hinge on the realistic prediction of B-ISDN traffic pattern, especially with regard to burstiness, amount of multicast traffic, and variation in service quality.

B-ISDN signaling standards have yet to be determined by international organizations. Such standards will have an impact on the effective integration of satellites into the B-ISDN. This paper has emphasized the ability of satellites to effectively complement the terrestrial B-ISDN; therefore, signaling evolution should accommodate satellite as well as terrestrial transmission systems.

8. Summary and Conclusion

This paper has described the potential application of satellite networks towards the delivery of B-ISDN services and has identified various types of potential users. In order to accommodate the high bandwidth requirements intrinsic to broadband services, the use of Ka-band is deemed necessary. For fixed satellite services, 1.7 GHz of bandwidth for downlink (space-to-earth) transmissions and 2.5 GHz of bandwidth for uplink (earth-to-space) transmission s is readily useable at Ka-band.

Two different types of network architectures capable of providing these services have been described. The first architecture is intended to complement terrestrial B-ISDNs by providing efficient high-rate multicast and broadcast services as well as remote user access to the B-ISDN via a circuit-based switch design. The network achieves an overall system capacity of 6.2 Gb/s through the use of 10 spot beams and a non-regenerative repeater employing microwave switch matrices. The second satellite architecture is intended to support private-based B-ISDNs, and to serve as the gateway to terrestrial B-ISDNs for those networks. This design, which institutes B-ISDN routing on a packet basis, provides a total system throughput of 4.8 Gb/s via a regenerative satellite payload containing a self-routing, fast-packet switch architecture and a hopping beam antenna array on the uplink.

The payload configuration corresponding to each of these two network architectures has been delineated and their respective mass and power requirements estimated. It is found that critical technologies needed in the realization of these payload configurations hinge heavily on the availability of low-power high-speed processing elements.

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[2] R. H. Deng and D. J. Costello, "High Rate Concatenated Coding Systems Using Multidimensional Bandwidth-Efficient Trellis Inner Codes," *IEEE Transactions on Communications*, Vol. 37, No. 10, pp. 1091-1096, October, 1989.

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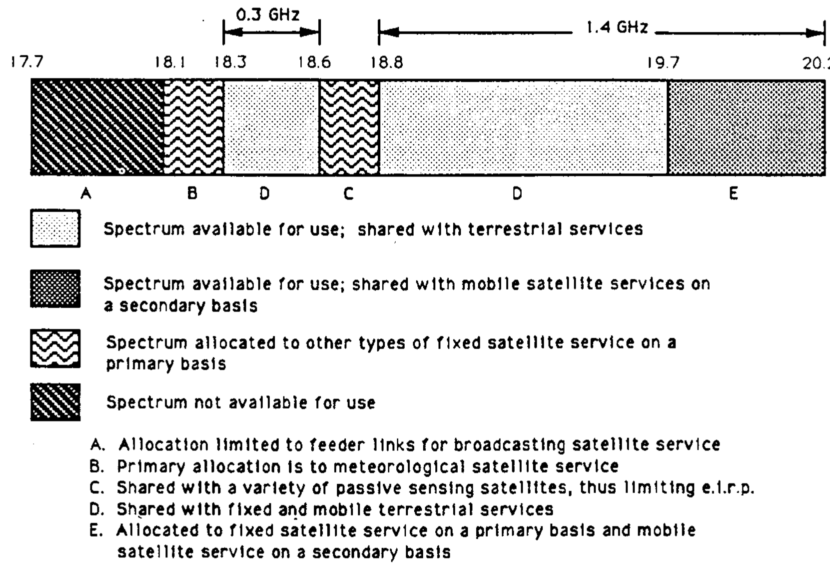

Figure 1: Downlink Frequency Allocations

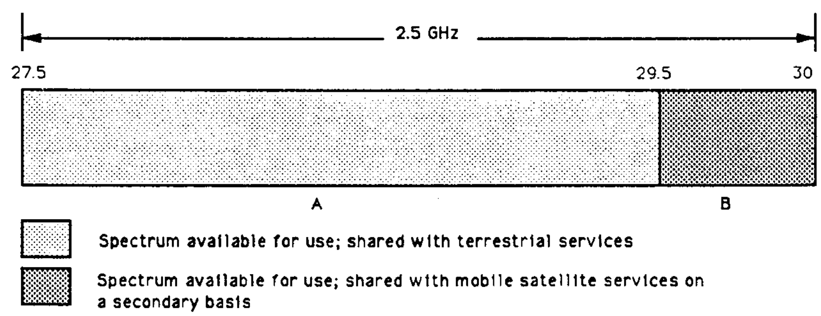

Figure 2: Uplink Frequency Allocations

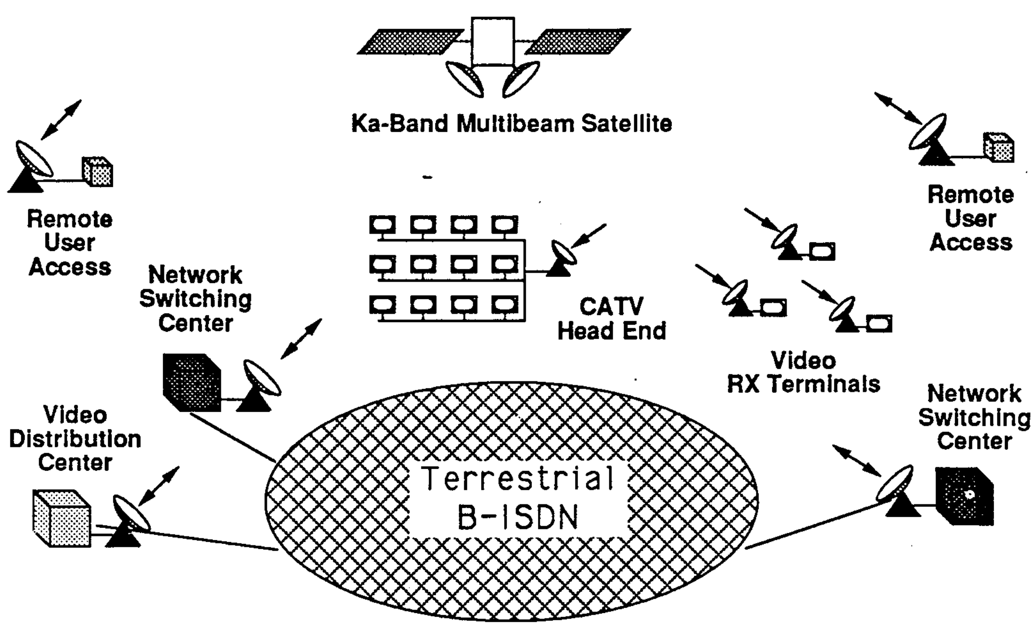

Figure 3: Multicast, Broadcast, and Remote Access Architecture (No. 1)

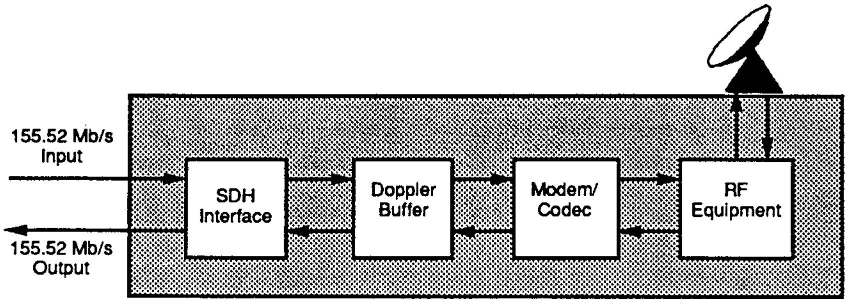

Figure 4: Earth Station Block Diagram for Architecture 1

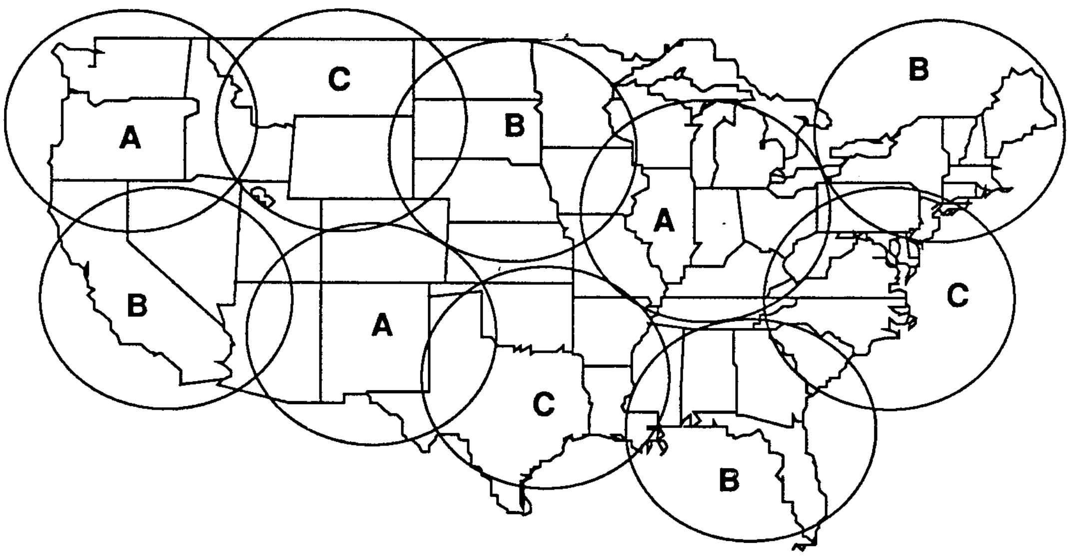

Figure 5: 10 Fixed Beams Cover CONUS for Architecture 1

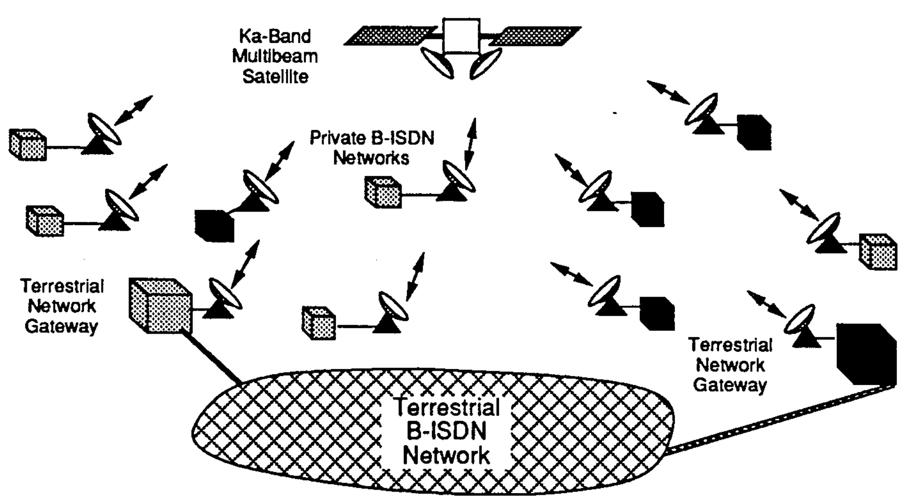

Figure 6: B-ISDN Private Network Architecture (No. 2)

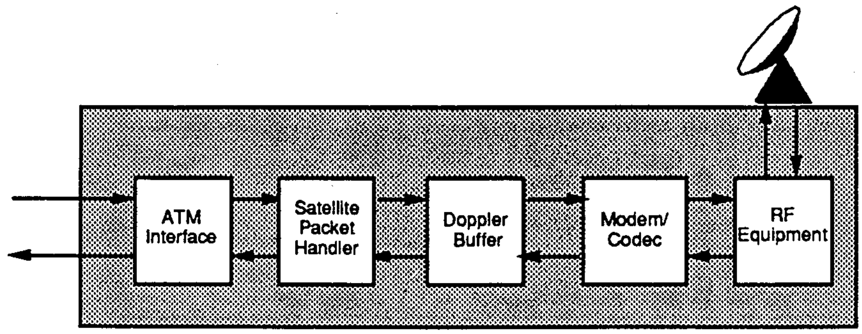

Figure 7: Earth Station Block Diagram for Architecture 2

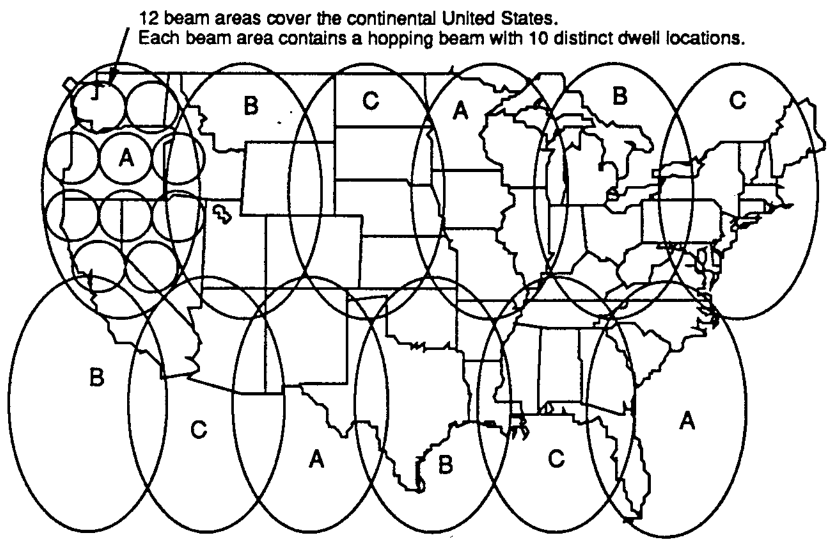

Figure 8: 12 Hopping Beams Cover CONUS for Architecture 2

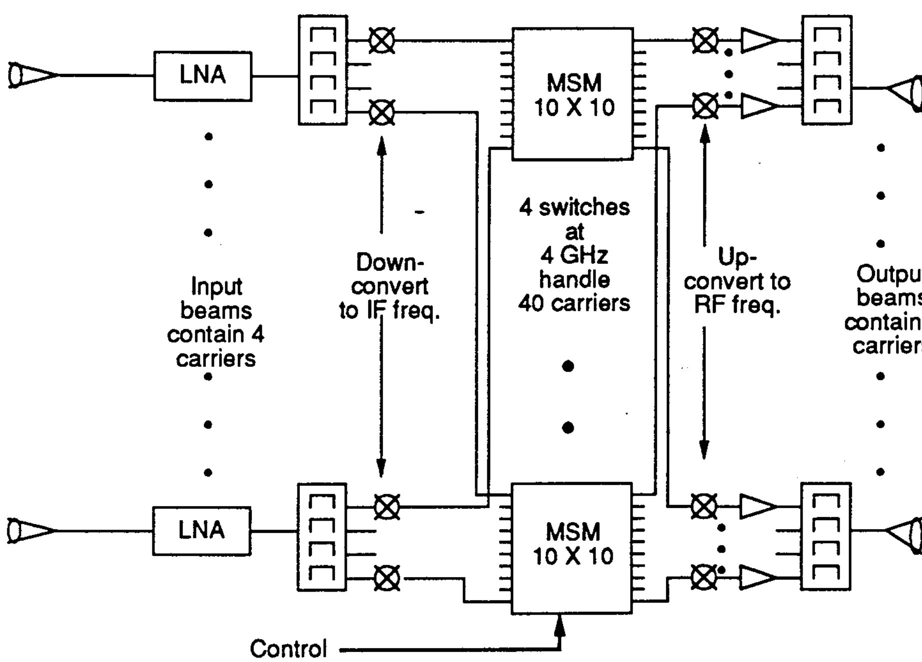

Figure 9: Payload Block Diagram for Architecture 1

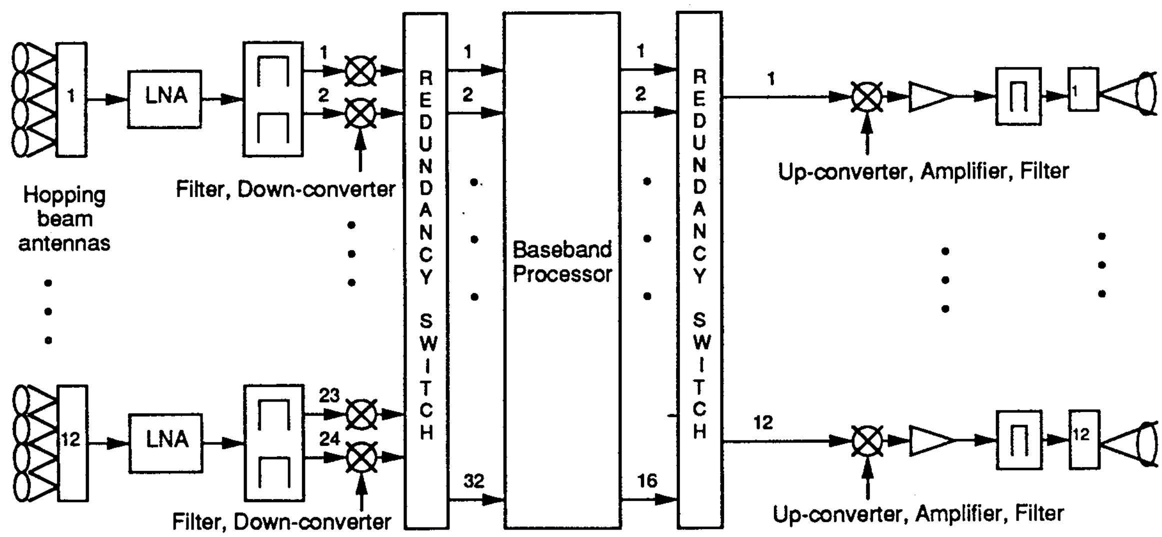

Figure 10: Payload Block Diagram for Architecture 2

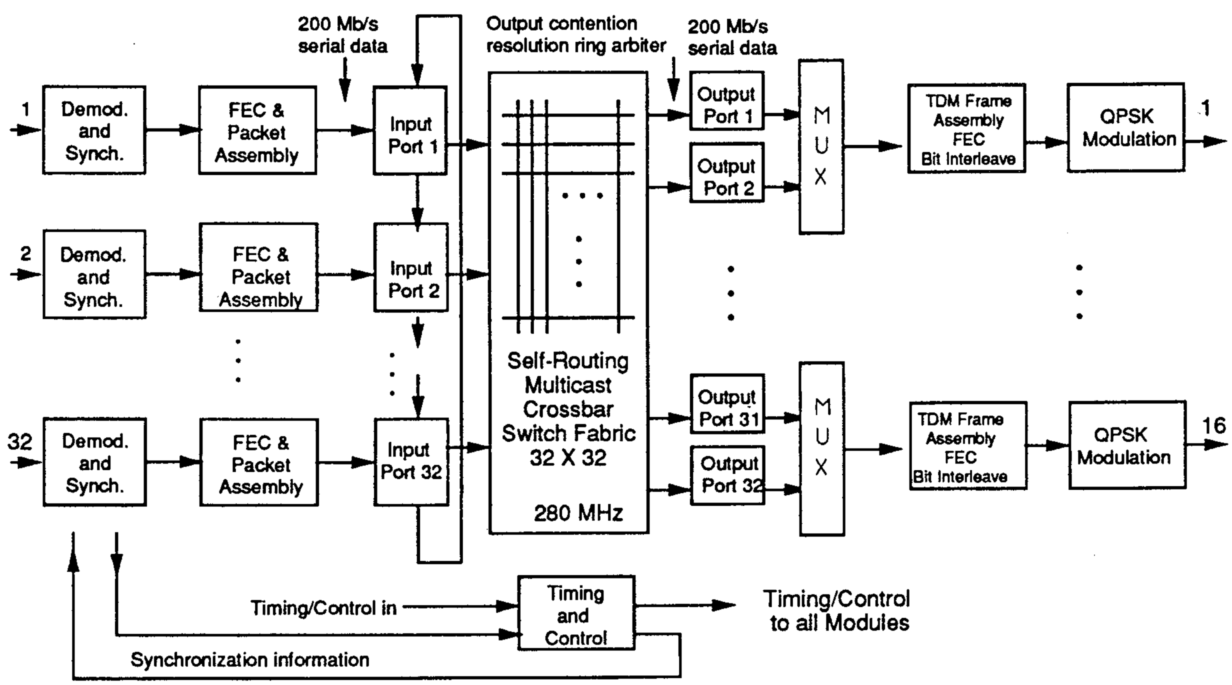

Figure 11: Baseband Processor for Architecture 2

Table 1 Transmission Parameters for Architecture 1

System parameters	Uplink	Downlink
Frequency	30.0 GHz	20.0 GHz
Number of beams	10	10
Access	FDMA	FDMA
Modulation	Octal-PSK	Octal-PSK
FEC coding	Concatenated code	Concatenated code
Transmission rate	200 Mb/s	200 Mb/s
Carrier information bit rate	155.52 Mb/s	155.52 Mb/s
Number of carriers per beam	4	4
Total number of carriers	40	40
Beam capacity	622 Mb/s	622 Mb/s
Beam bandwidth required	400 MHz	400 MHz
Frequency reuse factor	3	3
System bandwidth required	1.2 GHz	1.2 GHz
System capacity (information)	6.2 Gb/s	6.2 Gb/s
Clear sky C/N	20.3 dB	25.0 dB
Clear sky equivalent C/N	18.4 dB	
Required C/N	8.1 dB	
Clear sky link margin	10.3 dB	
Rain fade (- power control)	8.6 dB	5.7 dB
Link margin (up or down fade)	2.2 dB	1.9 dB
Earth station antenna diam.	4.7 m	4.7 m
Transmit amplifier power	30 W	40 W

Table 2 Transmission Parameters for Architecture 2

System parameters	Uplink	Downlink
Frequency	30 GHz	20 GHz
Number of beams	12 hopping	12
Number of dwells/beam	10	—
Access	TDMA	TDM
Modulation	QPSK	QPSK
FEC coding	Concatenated code	Concatenated code
Transmission rate	305 Mb/s	610 Mb/s
Carrier information bit rate	200 Mb/s	400 Mb/s
Number of carriers per beam	2	1
Total number of carriers	24	12
Beam capacity	400 Mb/s	400 Mb/s
Beam bandwidth required	410 MHz	410 MHz
Frequency Reuse Factor	3	3
System bandwidth required	1.25 GHz	1.25 GHz
System capacity (information)	4.8 Mb/s	4.8 Mb/s
C/No available	104.1 dBHz	96.4 dBHz
C/No required	89.2 dBHz	90.2 dbHz
Margin	14.8 dB	6.4 dB
Rain margin	11.6 dB	5.7 dB
Remaining Margin	3.2 dB	0.5 dB
Earth station antenna diam.	3 m	3 m
Transmit amplifier power	30 W	75 W

Table 3 Mass & Power Estimates (Architectures 1 & 2)

Architecture 1: No On-Board Processing

Summary	Number	Mass (ea.)	Power (ea.)	Total Mass	Total Power
Switch Matrix (MSM)	4	7.0 kg	8.0 W	28 kg	32 W
Input Port	40	0.1 kg	0.7 W	4 kg	28 W
Output Port	40	0.2 kg	0.7 W	8 kg	28 W
Totals				40 kg	88 W

Architecture 2: On-Board Processing

Summary	Number	Mass (ea.)	Power (ea.)	Total Mass	Total Power
Switch Fabric	1	2.4 kg	22.2 W	2.4 kg	22 W
Input Port	32	0.6 kg	5.4 W	19.2 kg	172 W
Output Port	32	0.6 kg	3.8 W	19.2 kg	122 W
Input Processor	32	0.6 kg	3.1 W	19.2 kg	99 W
Output Processor	32	0.6 kg	2.8 W	19.2 kg	90 W
Totals				79.2 kg	505 W

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1992	Final Report

4. TITLE AND SUBTITLE

Applications of Satellite Technology to Broadband ISDN Networks

5. FUNDING NUMBERS

WU-144-50-50
C-NAS3-25092

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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3825 Fabian Way
Palo Alto, CA 94303-4606

8. PERFORMING ORGANIZATION REPORT NUMBER

None

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

CR189199

11. SUPPLEMENTARY NOTES

Project Manager, Grady H. Stevens, Space Electronics Division, NASA Lewis Research Center, (216) 433-3463.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Publicly Available
Subject Category - 32

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

Two Satellite architectures for delivering B-ISDN service are evaluated. The first is assumed integral to an existing terrestrial network, and provides complementary services such as interconnects to remote nodes as well as highrate multicast and broadcast service. The interconnects are at a 155 Mbs rate and are shown as being met with nonregenerative multibeam satellite having 10-1.5° spots. The second satellite architecture focuses on providing private B-ISDN networks as well as acting as a gateway to the public network. This is conceived as being provided by a regenerative multibeam satellite with on-board ATM processing payload. With up to 800 Mbs service offered, higher satellite EIRP is required. This is accomplished with 12-0.4° hopping beams, covering a total of 110 dwell positions. It is estimated the space segment capital cost for architecture one would be about $190M whereas the second architecture would be about $250M. The net user cost is given for a variety of scenarios, but the cost for 155 Mbs service is shown to be about $15-22/minute for 25% system utilization.

14. SUBJECT TERMS

Broadband ISDN; Packet switching; On board processing; Satellite communications; Multibeam antennas; Ka-Band

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	