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Technical Support for Defining  
Advanced Satellite Systems Concepts

Final Report for Task Order 1  
DATA DISTRIBUTION SATELLITE

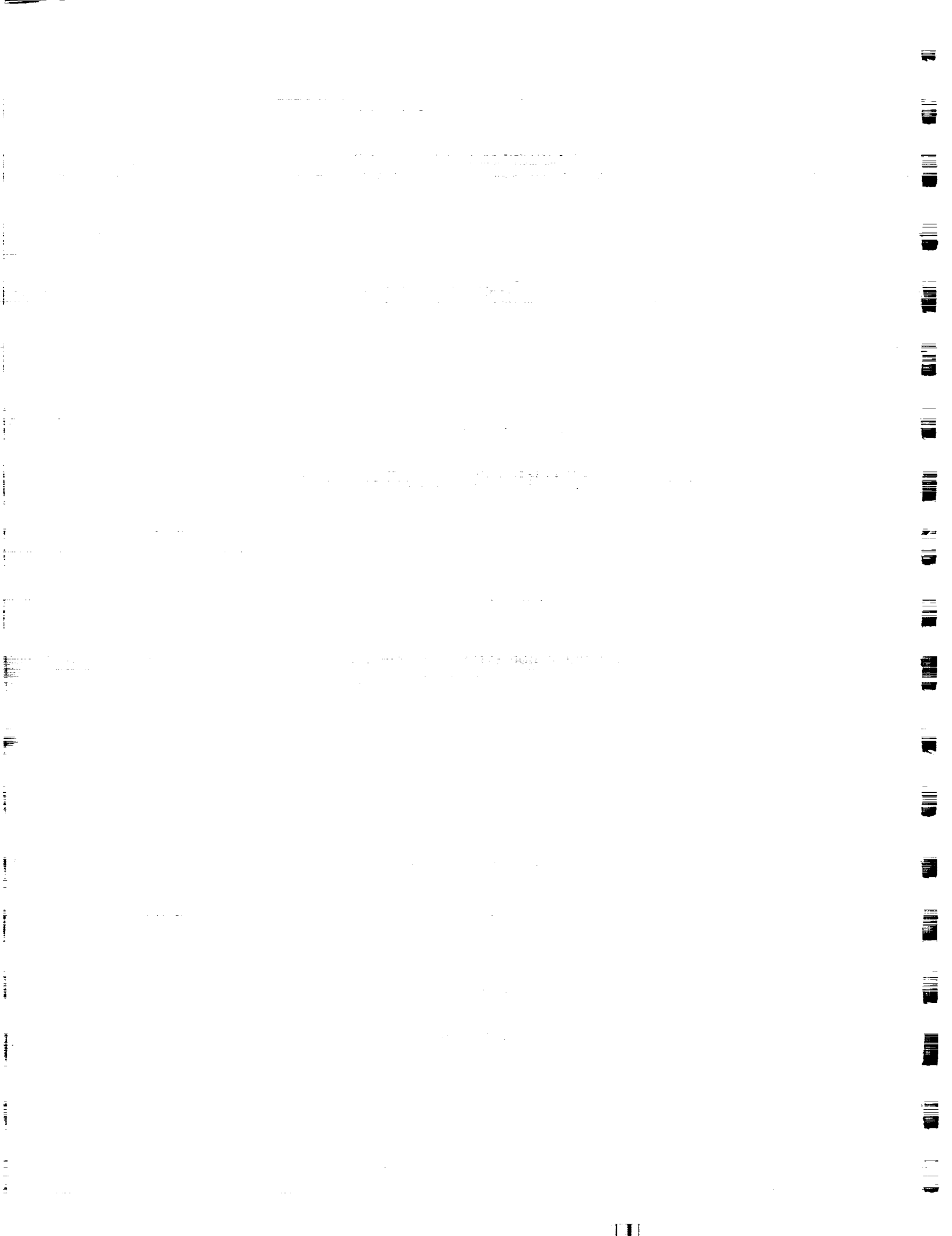
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# Summary

The amount of space-gathered data is expected to increase dramatically in the next decade as the Space Station Freedom and the Earth Observation System (EOS) are deployed. There will be a need to distribute this data throughout the United States and internationally, as well as to receive data gathered by foreign space platforms. Our current system uses the Tracking and Data Relay Satellite System (TDRSS) to relay data from space platforms back to White Sands, where the data is processed and then delivered via ground or space links to data archives and users. This system is adequate for today's volume of data, but does not provide the rapid response and interactive capabilities required for future missions.

This report describes a Data Distribution Satellite (DDS) concept for directly distributing space-gathered data to users on the ground, and allowing users access to their experiments for real time control (within the operational limits established for their space platform). The DDS would operate in conjunction with the future Advanced TDRS, perhaps even as an auxiliary payload on the Advanced TDRSS satellites. Under the concept known as "telescience", experimenters will routinely interrogate and control their experimental package remotely in virtually real time. Also, the same service would enable links among peer scientists attached to the network for consultation, advice, and data exchange. The scope of work described in this report includes the following:

1. User requirements are derived.
2. Communication scenarios are synthesized.
3. System design constraints and projected technology availability are identified.
4. DDS communications payload configuration is derived and the satellite is designed.
5. Requirements for earth terminals and network control are given.
6. System costs are estimated, both life cycle costs and user fees.
7. Technology developments are recommended and a technology development plan is given.

The most important results obtained are as follows:

- A satellite designed for launch in 2007 is feasible with 11 Gb/s capacity, 5.5 kW power, 2,150 kg beginning-of-life mass, and 15 year life.
- DDS features include on-board baseband switching, use of Ku and Ka-bands, use of FDMA uplinks with bulk demodulation on the satellite and TDM downlinks, and multiple optical intersatellite links to establish connectivity with other satellites for international data relay or data gathering.
- System user costs are competitive with projected terrestrial communication costs.
- A number of satellite communication technologies must be further developed such as optical intersatellite links; multi-channel demodulators to allow economical access by small users; an information switching processor to route circuit and packet data on the satellite; high capacity modems and codecs; high gain antenna systems supporting multiple frequency reuses; and network control technologies. These technologies should have engineering model demonstrations in a ground laboratory and then have flight model demonstrations in space.

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# Chapter 1

## Data Distribution Satellite Concept

The Data Distribution Satellite (DDS) is envisioned as an integral element of the Space Station Information System (SSIS) to directly distribute NASA science data throughout the United States as well as internationally. As part of the SSIS, it will provide networking capability for interchange of science database files amongst science users and NASA archive depositories.

Experimenters will routinely interrogate and control their experimental package remotely in virtually real time, a concept known as "telescience". Turnaround time for most data would be on the order of minutes, with quick look returns in seconds. Voice and video services would be available on demand for communication with appropriate payload specialists for experiment monitoring and change. Also, the same service would enable links among peer scientists attached to the network for consultation, advice, and data exchange.

This chapter is organized as follows:

- 1.1 Background on this Contract
- 1.2 Background on DDS Concept
- 1.3 Statement of Work for this Study
- 1.4 Organization of Report

### 1.1 Background on this Contract

The contractor is providing technical support to NASA/LeRC on a task order basis in the general area of defining advanced satellite system concepts, under NASA Contract No. NAS3-25092, *Advanced Satellite Systems Concepts* (ASSC). This report gives the results of the first Task Order, entitled the *Data Distribution Satellite*, of this contract.

The general objectives of the task order contract and a reference to previous work on the Data Distribution Satellite concept are given below.

#### 1.1.1 Objectives of Task Order Contract

The general scope and objectives of the Task Order Contract are as follows. Over the next four years (fiscal years 1989-1992), NASA will be evaluating several new advanced satellite system concepts as potential new experimental satellite programs. These are in response to new NASA mission needs as well as responding to specific recommendations of the NASA Advisory Council. These new concepts include:

- Data Distribution Satellite
- Wideband Point-to-Point Communications
- Intersatellite Communications
- Small Terminal Communications

The contractor is providing technical support on a task order basis in the general area of defining advanced satellite system concepts. The contractor is required to provide personnel and other resources as needed for technical support to NASA for the purpose of aiding NASA in the formulation, evaluation, and advocacy of certain advanced communication satellite applications. Analyses will be performed and results provided as required by NASA for the purpose of explaining and justifying potential future advanced satellite technology development and flight programs.

To accomplish these objectives, the contractor will perform specific tasks that are defined through the issuance of Task Orders to perform any of the following:

- i. Definition of preliminary concepts.
- ii. Sensitivity analyses.
- iii. Identification of critical technologies.
- iv. Formulation of preliminary technology plans.

- v. Preparation of written reports, oral reports, and graphic presentation materials.

The first task order is the Data Distribution Satellite, and is the subject of this Final Report. For purpose of reference, it should be noted that Stanford Telecommunications Inc. (Washington DC office) has a similar Task Order contract, and is concurrently working on the same Data Distribution Satellite task independently of this contractor.

### 1.1.2 Previous Work on Data Distribution Satellite Concept

Previous work on the Data Distribution Satellite concept has been done by TRW, COMSAT, and Ford Aerospace (presently Space Systems/Loral).

TRW performed the *Advanced Space Communications Architecture Study*, NASA CR 179592, March 1987, under Contract NAS3-24743. This work proposed use of bulk demodulators on the satellite to allow simultaneous access by a large number of users and presented a system architecture concept using Ka-band technology.

COMSAT Laboratories performed the *On-Board Multi-Channel Demultiplexer-Demodulator Study*, NASA CR 180321, July 1987, under Contract NAS3-24885. This work focussed on the design of the demodulator and proposed a digital implementation for the bulk demodulator.

Ford Aerospace performed the *Identifying New Services Enabled by Multi-Frequency Multi-Service Satellites Study* (MFMS) under Contract NAS3-24683. Two tasks of this study were relevant to the Data Distribution Satellite concept:

**Task 3:** *Future Communications Satellite System Architecture Concepts*, Final Report dated 9 November 1987. This work addressed the formulation of a satellite system architecture that used VSATs (very small aperture terminals) and ISDN (integrated services digital network) protocols.

**Task 5:** *Data Distribution Satellite System Architecture Concept*, Final Report dated 19 January 1989. This task evolved the Task 3 work to provide the data distribution function for ATDRS data. The system operation date was

the year 2000, and ATDRS data was accessed via uplinks from White Sands.

## 1.2 Background on the Data Distribution Satellite Concept

NASA furnished the following background information on the Data Distribution Satellite (DDS) concept as part of the ASSC RFP statement of work. The information is divided into four parts:

1. Background
2. Current System of Data Acquisition, Processing, Archiving and Distribution
3. Space Station Information System
4. Potential Improvements Made Possible by ACTS Technology
5. Summary of DDS Services

### 1.2.1 Background

NASA's current scientific data network relies on the Tracking and Data Relay Satellite System (TDRSS) to relay information from space-based sensors to the White Sands TDRS operations center, where it is sent in bulk to the Goddard Space Flight Center for archiving and further distribution to participating scientists or centers. The means of distribution from Goddard are leased common carrier facilities, operated by NASA Communications (NASCOM). This has been adequate for current needs but definite problems have arisen or can be foreseen.

First, there has been criticism by the General Accounting Office of the architecture that causes bottlenecks in data flow, and Congress and others have questioned the ability of the NASA networks to meet the requirements of the 1990's that project sharp increases in data rates. For example, the turn around time of some types of data could be as much as 30 days.

Significant enhancements of this network are planned in support of the Space Station Information System (SSIS). More extensive automated data processing is planned. Data-directed processing and routing of messages (packet communications) will be included, and will likely make use of international standards. Some capacity for real time interaction of experimenters with

their payloads will be supported. Turnaround time of data is not expected to exceed 30 minutes. In addition, control and operations of Space Station and STS will be included.

This upgraded system will possibly include an advanced TDRS (ATDRS), but otherwise, will mostly make use of leased terrestrial facilities for signal distribution.

The capabilities of transmission facilities have improved dramatically, especially with the introduction of optical fibers. However, leasing charges for such transmission links have grown substantially, particularly for the circuits capable of handling the higher transmission rates.

A second enhancement phase, the topic of this study, would make use of a DDS System to provide direct and real-time communications, and use small (1 to 2 meters) and low-cost (\$10,000 to \$20,000) earth stations. Specifically, the DDS would have the ability to directly receive TDRS data and distribute it, in real-time, to principal investigators and data centers, regardless of their location. In operation, this system would provide scientists and others the capability to read-out their own data, whatever the rate, and control their own experiments. In addition, scientists would have the same peer networking features now provided, including voice and video enhancements. This total interconnectivity, without the need for land lines, could include global coverage.

### 1.2.2 Current System of Data Acquisition, Processing, Archiving and Distribution

The current acquisition and processing of these data is depicted in Figure 1-1. This illustrates the paths for data which resulted from experiments in the vicinity of the earth. The NASA deep space network is not included here, but many of the paths are similar, except for the use of TDRS.

In this near-earth case, experimental data is relayed by TDRS to the White Sands TDRS control center. From there, depending on bandwidth needed, the data is transferred to a field processing center either by leased terrestrial line or by leased domestic satellite.

After certain processing to remove data acquisition artifacts, the data is relayed to the principal investigator for further processing and interpretation. The data is then made available to others.

In this scenario, NASA processing as well as the prin-

icipal investigator's analysis and interpretation can be a major bottleneck. Also, the requirement for NASA archiving of all data is not an insignificant task.

To enhance the efficiency of distribution of this data and further analysis and processing, NASA has established networks, such as the Program Support Communications Network (PSCN), NASA Science Network (NSN), the Space Physics Analysis Network (SPAN), etc. These interconnect many facilities, domestic and international, including Government, industrial, and academic. Leased facilities, primarily land lines, provide the interconnects.

### 1.2.3 Space Station Information System

A major enhancement of these systems is planned for the support of the Space Station. A functional illustration of the Space Station Information System (SSIS) is shown in Figure 1-2. In addition to the acquisition and distribution of the aforementioned science data, the SSIS will also include major control and operations functions as well. Packet techniques will be used so that messages and data will automatically be routed through the system. Within the scheduling constraints of TDRS, to avoid overload, the message handling will be transparent to the user.

An illustration of the downlink through TDRS is shown in Figure 1-3. A Data Interface Facility (DIF) will be located at the Secondary TDRS Ground Terminal (STGT) at White Sands. This facility processes the data and identifies whether it should be immediately routed to certain users for custom processing, or to be transmitted to the Data Handling Complex (DHC) at Goddard Space Flight Center for standard "Level 0" processing. Video and voice will usually immediately routed as well as certain special forms of data with unique formats. Level 0 processing focuses on the packet messages which have certain framing and coding artifacts that need to be removed, and this will be accomplished at the DHC.

### 1.2.4 Potential Improvements Made Possible by ACTS Technology

With the technology advanced by the NASA Advanced Communications Technology Satellite (ACTS), it would be feasible to provide direct access of NASA operational communication networks by any researcher. Using ACTS on-board switching technology and a variation on the popular VSAT service, this access could be

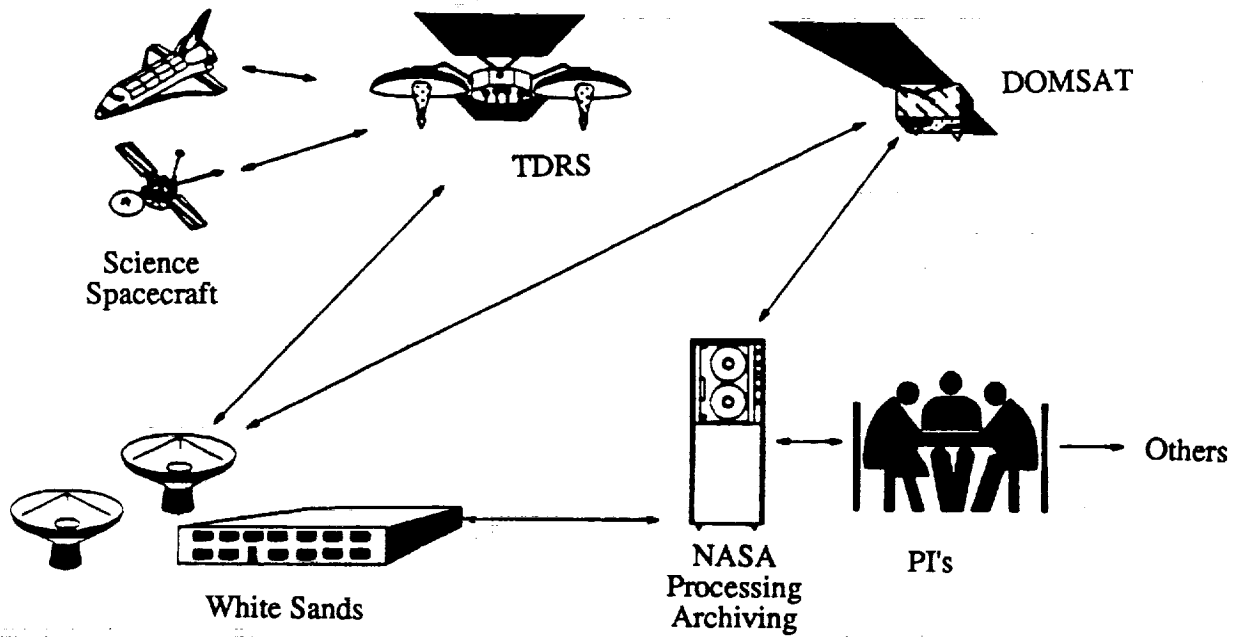


Figure 1-1: Current System of Data Acquisition, Processing, Archiving, and Distribution

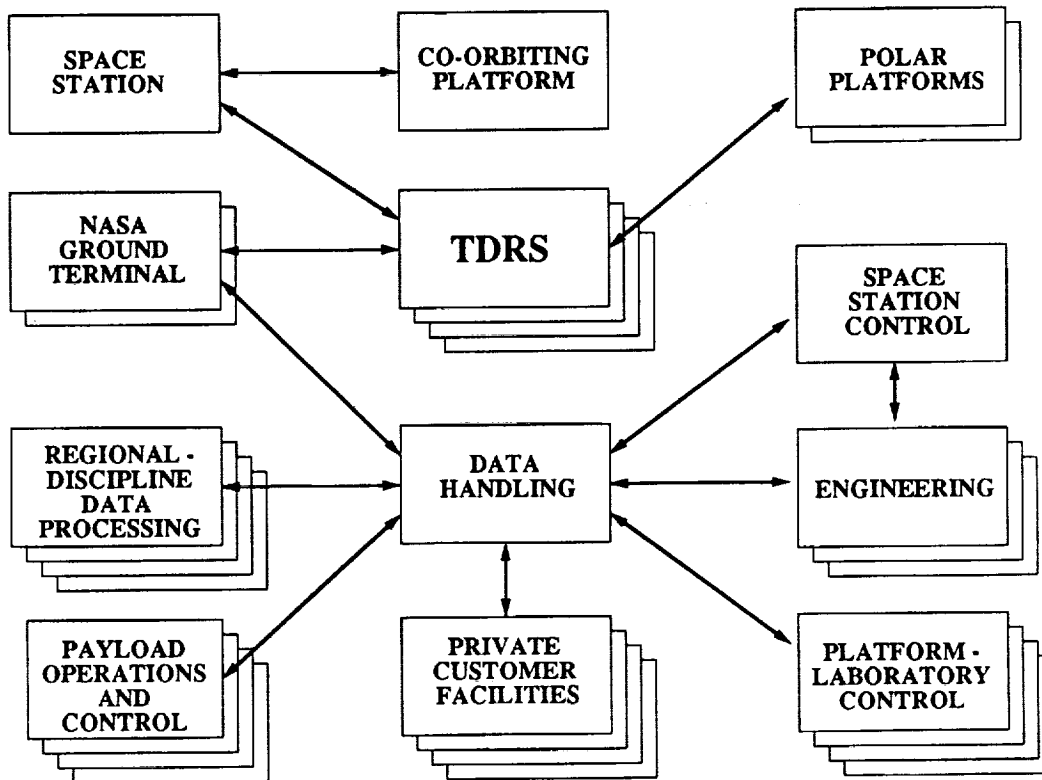


Figure 1-2: Space Station Information System End-to-End Services



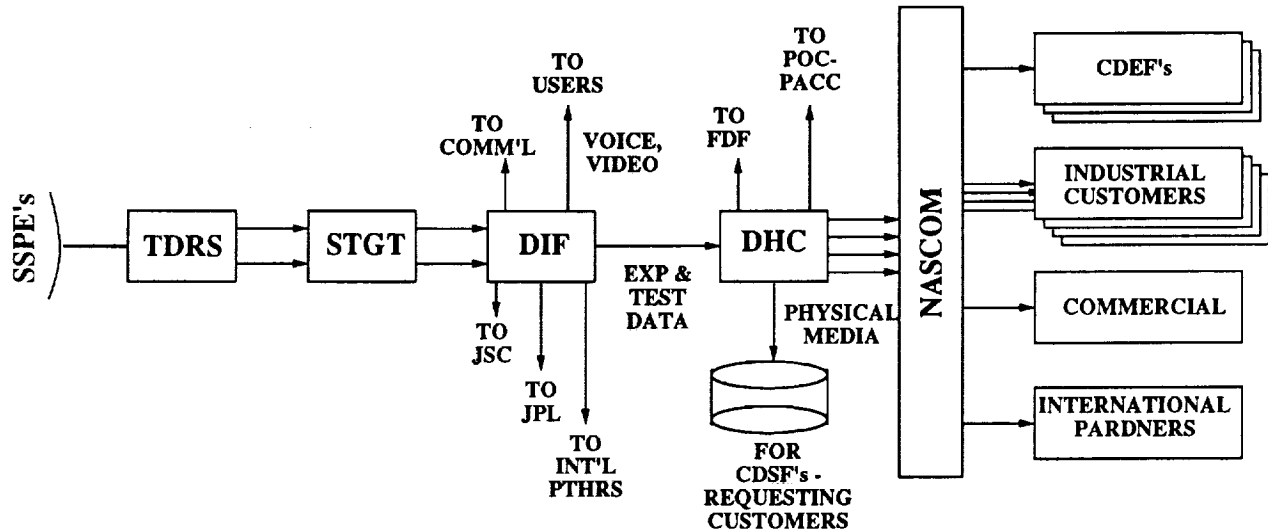


Figure 1-3: Space Station Information System Return Link Data Flow

made available to any industrial laboratory, government facility, and academic institution.

Universal access could be provided. Imagery and data would be provided as before. Voice could be introduced so that the experimenter could interact with the shuttle payload specialist or their counterpart on space station.

Access protocols would include a switched service, similar to the public telephone system, which provides dial-up access to the experiment, the payload specialist, or both. In addition, a version of the popular packet switched service would be included. These would be provided according to the new international ISDN (Integrated Services Digital Network) standard.

Experimental data would be relayed through TDRS as before. However, with ACTS technology a satellite gateway could be provided to all users, enabling inexpensive access by small earth stations such as of the popular VSAT service. This gateway could be a separate satellite system or it could be an auxiliary payload on an advanced TDRSS. The final choice would depend on how extensive the gateway service might be in terms of number of users, assigned capacity, etc.

With this new concept, data distribution is accom-

plished in a parallel fashion. It would no longer be necessary for NASA to archive all data as this would now be the responsibility of the principal investigators. However, selected subsets of special merit or utility could be archived. All researchers would have dial-up access or packet access to each other's data archives. DDS would thus enable the transition from a central archive to a distributed archive and eliminate a burgeoning burden to government resources.

### 1.2.5 Summary of DDS Services

The potential services enabled and/or enhanced by DDS are illustrated in Figures 1-4, 1-5, and 1-6. The networking of science peers for the comprehensive analysis and archiving of data is expected to be a major communications load on DDS. For this service the users would have ready access by means of small, low cost earth stations with services provided either on a dedicated or demand basis.

Space experiment monitoring and control would also be a major contributor to the DDS communications load. High Resolution Imaging Spectrometer (HRIS) and Synthetic Aperture Radar (SAR) payloads would require 300 Mb/s service. Some microgravity experi-

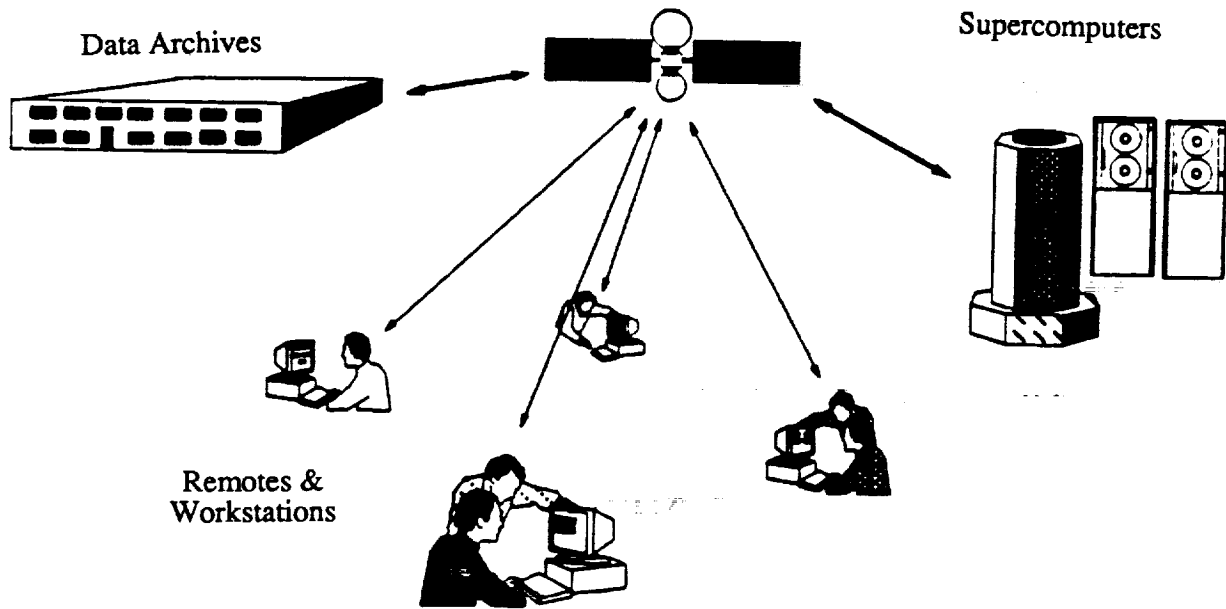


Figure 1-4: Space Science Peer Networking

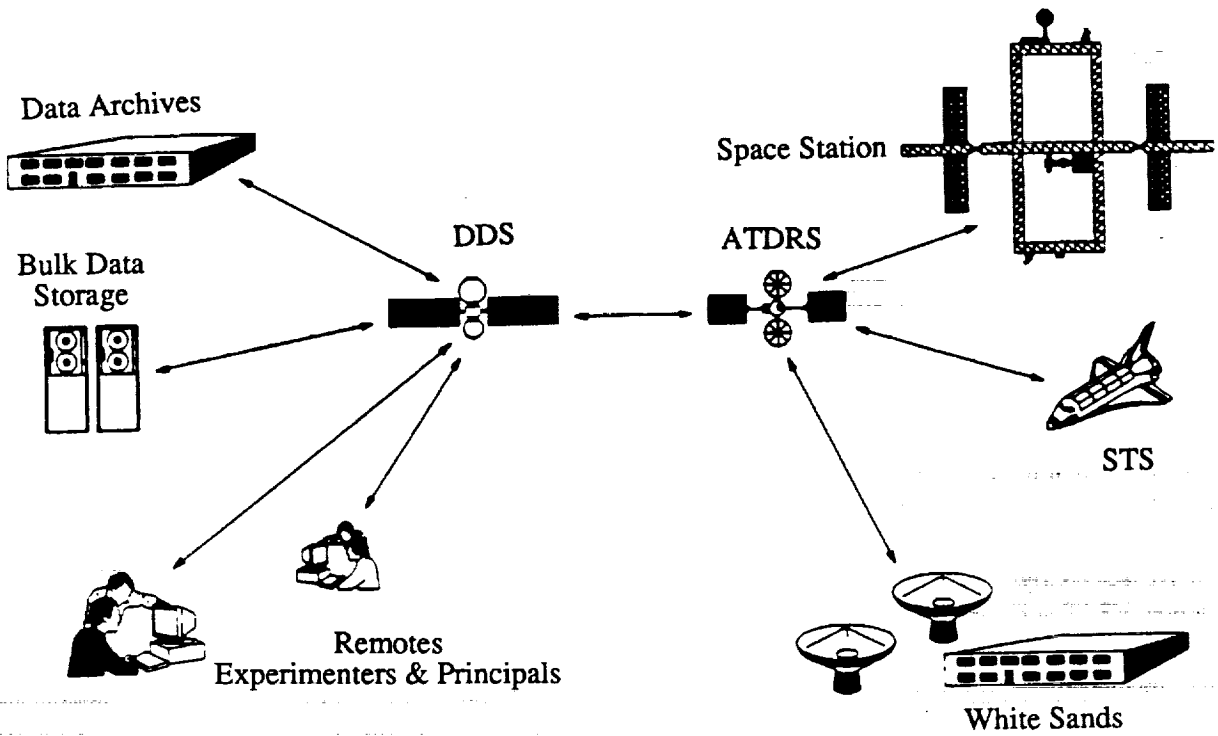


Figure 1-5: Space Experiment Monitoring and Control (Telescience)

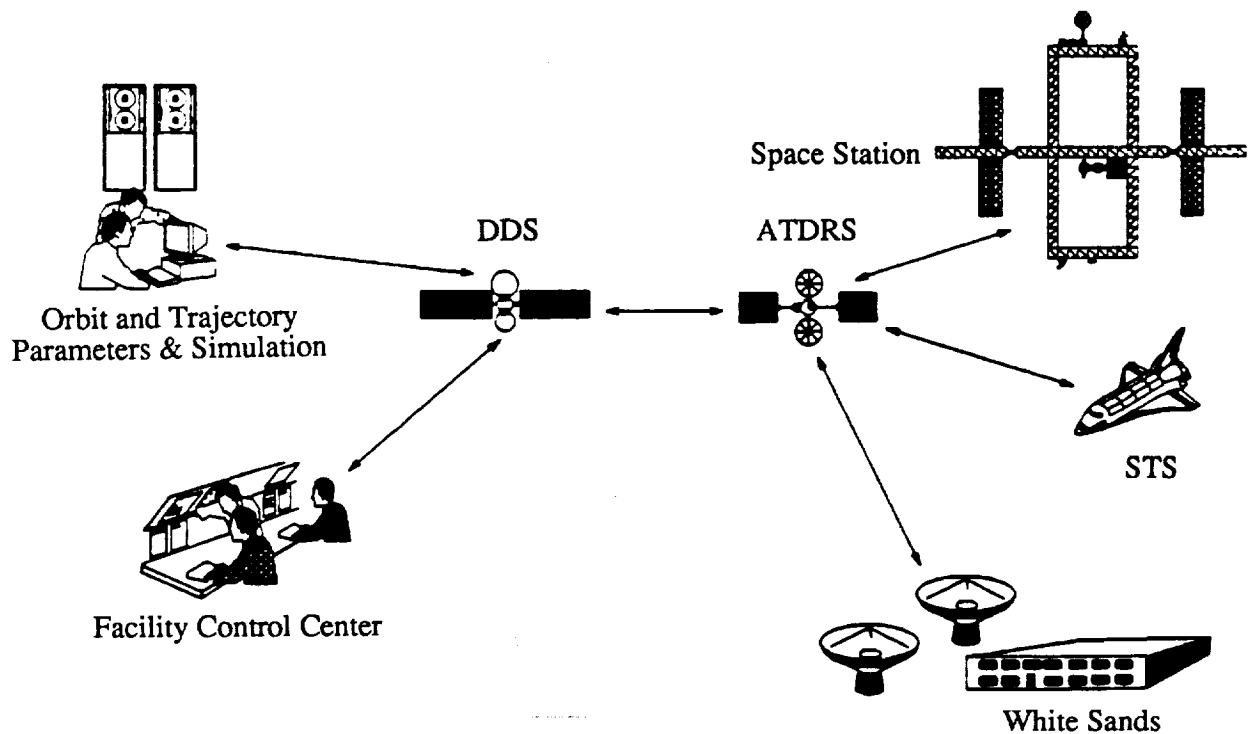


Figure 1-6: Space Facility Monitoring and Control

ments using fast frame rate HDTV may require similar service.

Also, in an era when industrialization of space (year 2000+) may be a large success, the number of payloads requiring monitoring and control may rival the Space Station. Space facility monitoring and control is not expected to be a major contributor to the communications load, but it is the most critical in priority.

In the near term, DDS would serve as a first enhancement to the SSIS by providing the above services as illustrated in Figure 1-7. The focus would be domestic return with international service provided by other facilities.

In the far term, a hybrid TDRS/DDS spacecraft platform could provide international coverage, both in space and terrestrially. The system could be internationally owned and operated, in much the same way the Intelsat and Marisat systems are. Such a concept is illustrated in Figure 1-8.

### 1.3 Statement of Work for this Study

This section gives the present Statement of Work for the Data Distribution Satellite Study which is addressed in

this Final Report. Background is given together with the Scope of the task which is divided into five subtasks.

#### 1.3.1 Background for Present Study

Acquisition of space science data is currently accomplished through use of NASA's Space Network. This network relies on TDRSS to relay information from space-based sensors to the White Sands TDRS operations center, where it is sent in bulk to Goddard Space Flight Center (GSFC) for archiving and further distribution to participating scientists or centers. The means of distribution from Goddard are leased common carrier facilities operated by NASA Communications (NASCOM).

Significant enhancements of the Space Network are planned in support of the Space Station Information System (SSIS). More extensive automated data processing is planned. Data directed processing and routing of messages (packet communications) will be included and will likely make use of international standards. Some capacity for real time interaction of experimenters with their payloads will be supported. Turn around time of data is not expected to exceed 30 minutes. In addition, control and operations of the Space

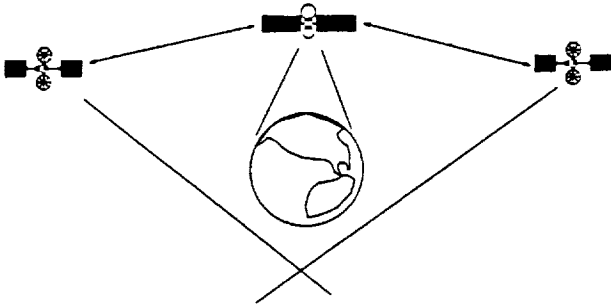


Figure 1-7: Potential Second Generation SSIS with Universal Access to Space Science

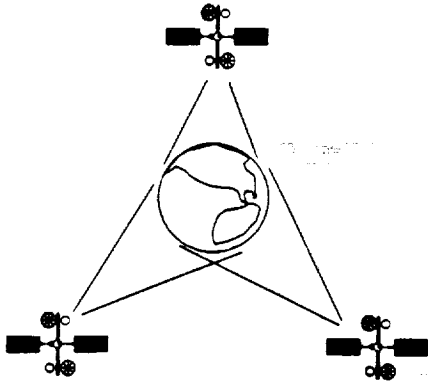


Figure 1-8: Integrated ATDRS/DDS Global System for Retrieval of Space Science Data

Station and STS will be included.

This upgraded system will possibly include an advanced TDRS, but otherwise will mostly use leased terrestrial facilities for signal distribution. In addition to the Space Network, several terrestrial-based science data networks are also in operation for the purpose of networking science peers for efficient interaction and interchange of data. Currently, these terrestrial-based peer networks make use of leased land lines, with the majority at 56 kb/s rate. There are plans for enhancing this capability to 1.5 Mb/s and higher.

The topic of this study is a Data Distribution Satellite (DDS) system which would make use of small (1 to 2 meters), low cost (\$10 to \$20 K) earth stations to provide direct, real time space access for science users. In addition, it would provide peer networking capability for these users, including voice and video as well as

data.

Specifically, DDS would enable a satellite-based peer network while, at the same time, serving as a gateway between the Space Network and a science peer network. This role would enable the distribution of data, in real time, to principal investigators and data centers regardless of their location. In operation, this system would provide scientists and others the capability to read-out their own data and control their own experiments. In addition, scientists would have the same peer networking features now provided, including voice and video enhancements. This total interconnectivity, without the need for land lines, could include global coverage.

### 1.3.2 Scope of Present Study

The contractor shall provide the resources, perform the needed analyses, and otherwise accomplish the necessary activities to do the studies and reporting defined in the following subtasks.

#### 1.3.2.1 Subtask 1: Far Term Space Data Acquisition

The objective of Subtask 1 is to define the requirements of a space system which will realize, to the extent practical, universal science user access to space experimentation (telescience) and science user to science user communications.

Toward this end, the contractor shall evaluate the feasibility of a Data Distribution Satellite System (DDS) which interfaces with an Advanced Space Data Acquisition and Communications System (ASDACS) to provide global, real time, demand access space communications for science and industrial purposes.

The evaluation shall include definition of the interaction and interfacing between the ASDACS and DDS. Since continuous coverage of space experiments is required, the ASDACS will, of necessity, have no zone of exclusion. Consequently, the ASDACS portion of the system shall be defined, but only to the extent necessary to describe the interfaces and interaction with the DDS system.

The system scenario shall include the Data Distribution function of direct access to space by principal investigators, with access obtained, on demand, in an automatic fashion. (This is not to say blocking must be excluded. Some blocking may be unavoidable, and some accesses may have to be denied because of security or a platform being "busy".)

Communications paths shall include User to Space, Space to User, and User to User. Services shall include voice, data, and video.

The contractor shall be free to define the system scenarios without regard to any limitations imposed by TDRS capabilities, or planned ATDRS capabilities. Consequently, the contractor should assume an initial operations date corresponding to the replacement of the ATDRS, when any such limitations could be alleviated by a new system. (Using information in the ATDRS Phase B RFP, ATDRS will start to be replaced in the year 2012.)

The DDS feasibility evaluation shall include:

1. The generation of compatible concepts of the DDS and ASDACS systems, including graphical and narrative descriptions of the system scenarios.
2. A delineation of services and functions performed by each of DDS and ASDACS.
3. Graphical and narrative description of the major subsystems required in DDS, including visualization of concepts, mass and cost estimates, and estimates of power requirements.
4. A determination of the critical technology advancements required to enable DDS.
5. An assessment on how such a system might interface with NASA, ESA, NASDA, and other national space agencies as well as providing for national and international science networks.
6. An estimate of probable costs for the DDS. Costs shall be expressed in the following forms:
  - a. Life cycle costs, assuming a government-owned system. A 15 year life cycle shall be assumed. Also, launch costs shall correspond to the rate for government launches.
  - b. A usage cost factor, assuming a commercially owned system, to be defined jointly by the contractor and the NASA Technical Manager.

#### 1.3.2.2 Subtask 2: Defining Orderly Steps to Realize a DDS/ASDACS

Plans for ATDRS are continuing, with a possible first launch in 1996. Though offering many enhancements, ATDRS (and the terrestrial enhancements planned in

support of ATDRS and SSIS) will fall far short of being a fully automated, demand access system. Transition to a fully demand access DDS/ASDACS system must necessarily follow the ATDRS series, as technology and/or funding would not permit such an implementation in the 1990s.

However, it is advisable to proceed with critical DDS/ASDACS technology developments and demonstrations, as the implementation cycle of advanced systems can easily span 15 years, which would likely be the probable life cycle of ATDRS. Consequently, it remains to define an optimum method of transitioning to a fully automated DDS/ASDACS system, by making use of strategic opportunities for critical DDS/ASDACS technology demonstrations and applications.

Toward this end, the contractor shall propose intermediate technology advancement steps where certain functions of the future DDS/ASDACS could be demonstrated and applied. These proposals shall emphasize the Data Distribution subsystem, but also include the compatible and critical ASDACS as well. These intermediate steps may make use of the future service growth (FSG) capability of the ATDRS system, or, they may include separate flight systems, where warranted.

These proposals shall include:

1. Graphical and narrative descriptions of the proposed demonstrations and applications.
2. Narrative justification for the recommended mode of demonstration and application.
3. Estimates of schedules and program costs for the proposed scenarios.

#### 1.3.2.3 Subtask 3: Space Industrialization Success Impact

The contractor shall evaluate the impact of successful commercialization of space on the optimum configuration of a DDS/ASDACS system.

Toward this end, the contractor shall estimate the potential communication requirements due to significant commercialization of space. These estimates shall include both an optimistic perspective as well as a pessimistic perspective.

The impact of this commercial requirement on the configuration of a DDS/ASDACS system shall be evaluated. Configurations of DDS/ASDACS, which are responsive to both government and commercial needs, shall be compared for the purpose of identifying likely

revenues from or cost sharing with the commercial users.

*This subtask was not addressed in this study per direction by NASA/LeRC at the kick-off video review. The estimates for space commercialization were not sufficiently firm.*

#### 1.3.2.4 Subtask 4: Proof of Concept Models

The contractor shall identify and describe specific Proof of Concept models which will prove functional feasibility for the critical technologies of a DDS system. The contractor shall also develop schedule and cost estimates for realizing these models in preparation for the demonstrations and applications proposed in Subtask 2. Budget and schedule guidelines shall be provided by NASA.

#### 1.3.2.5 Subtask 5: Reporting

The contractor shall prepare and present status reports, briefings, and a Final Report as detailed in the NASA Statement of Work (summarized here).

## 1.4 Organization of Report

Table 1-1 gives the organization of this Final Report by chapter. Figure 1-9 shows the interrelationships among the different parts of the work. Chapter 2 presents an executive summary of the work. Chapter 3 presents the overall requirements evaluation, and Chapter 4 discusses the design constraints. Chapter 5 synthesizes the communication scenarios from the user requirements and gives the composite data requirements. Chapter 6 gives the considerations involved in interfacing to ATDRSS.

Chapter 7 describes the communication payload configuration based on inputs from Chapters 3 - 6. Chapters 8, 9 and 10 give details of the system design - satellite, earth terminals, and system control. Chapter 11 estimates system costs, and Chapter 12 gives the technology development plans for steps to realize a DDS/ASDACS and the required proof-of-concept models.

Appendix A gives a system overview of the ATDRS system, expected to be implemented beginning in 1997 as a replacement for the present TDRS system. (The ATDRSS information is based on the RFP for the

Table 1-1: Organization of Report

Chapter	Contents
1.	Data Distribution Satellite Concept
2.	Executive Summary
3.	General Requirements
4.	System Design Constraints
5.	Link Scenario Synthesis
6.	ATDRSS Interfaces
7.	Communication Payload Configuration
8.	Satellite Configuration
9.	Earth Terminals
10.	Network & Master Control
11.	System Costs
12.	Technology Development Plans
A.	ATDRS System Overview
B.	Telescience Testbed Pilot Program

Phase B Program.) Appendix B gives a copy of the *Telescience Testbed Pilot Program* Final Report - Executive Summary.

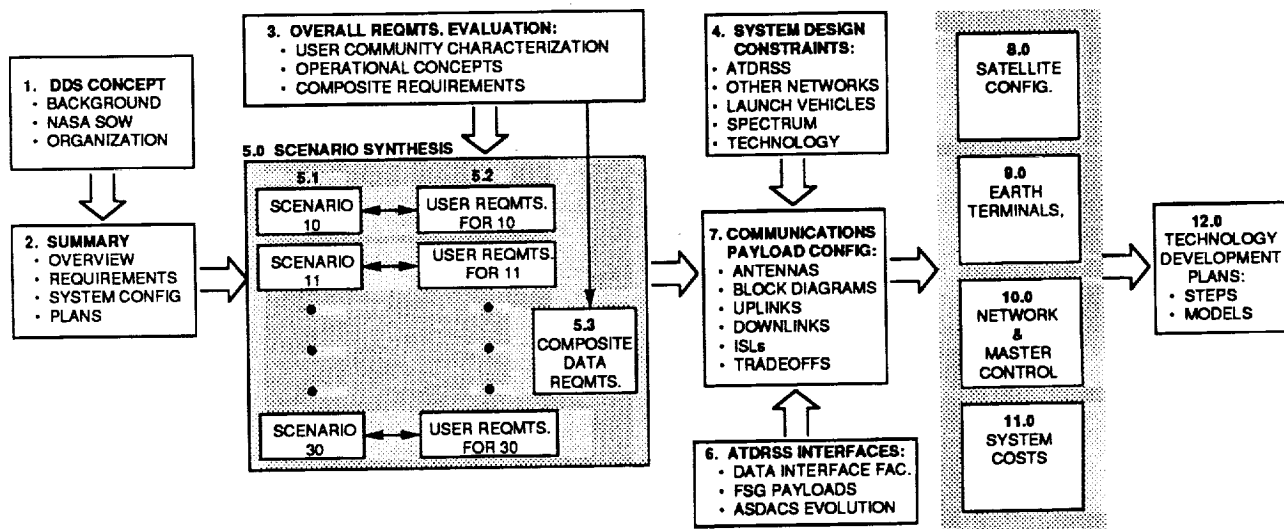


Figure 1-9: Interrelationships Among the Chapters of this Report

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## Chapter 2

# Executive Summary

This chapter is organized as follows:

- 2.1 Overview of DDS Concept
- 2.2 Requirements
- 2.3 Satellite Design
- 2.4 Ground Terminals and Master Control
- 2.5 System Costs
- 2.6 Technology Development Plans
- 2.7 Conclusions & Recommendations

### 2.1 Overview of DDS Concept

The amount of space-gathered data is expected to increase dramatically in the next decade as the Space Station Freedom and the Earth Observation System (EOS) are deployed. There will be a need to distribute this data throughout the United States and internationally, as well as receive data gathered by foreign space platforms. In addition, future space-based sensor missions will require rapid response and interactive capabilities.

This report describes a Data Distribution Satellite (DDS) concept for directly distributing space-gathered data to users on the ground, and allowing users access to their experiments for real time control. The DDS would operate in conjunction with ATDRSS, perhaps even as an auxiliary payload on the ATDRSS satellites. High capacity, optical intersatellite links would be used to establish connectivity with other satellites for international data relay or data gathering.

#### 2.1.1 Current Method of Data Acquisition and Distribution

Acquisition of space science data is currently accomplished through use of NASA's Space Network. This network relies on TDRSS to relay information from

space-based sensors to the White Sands TDRS operations center, where it is sent in bulk to Goddard Space Flight Center (GSFC) for archiving and further distribution to participating scientists or centers. The means of distribution from Goddard are leased common carrier facilities operated by NASA Communications (NASCOM). Figure 2-1 illustrates this process where there are likely to be significant processing delays before the space-gathered data reaches the Principle Investigators (PIs).

Significant enhancements of the Space Network are planned in support of the Space Station Information System (SSIS). More extensive automated data processing is planned. Data directed processing and routing of messages (packet communications) will be included and will likely make use of international standards. Some capacity for real time interaction of experimenters with their payloads will be supported. Turn around time of data is not expected to exceed 30 minutes. In addition, control and operations of the Space Station and STS will be included.

This upgraded system is planned to include an advanced TDRS, but otherwise will mostly use leased terrestrial facilities for signal distribution. In addition to the Space Network, several terrestrial-based science data networks are also in operation for the purpose of networking science peers for efficient interaction and interchange of data. Currently, these terrestrial-based peer networks make use of leased land lines, with the majority at 56 kb/s rate, with plans for enhancing this capability to 1.5 Mb/s and higher. These planned systems are adequate for today's volume of data, but cannot provide the rapid response and interactive capabilities desired by future telescience missions.

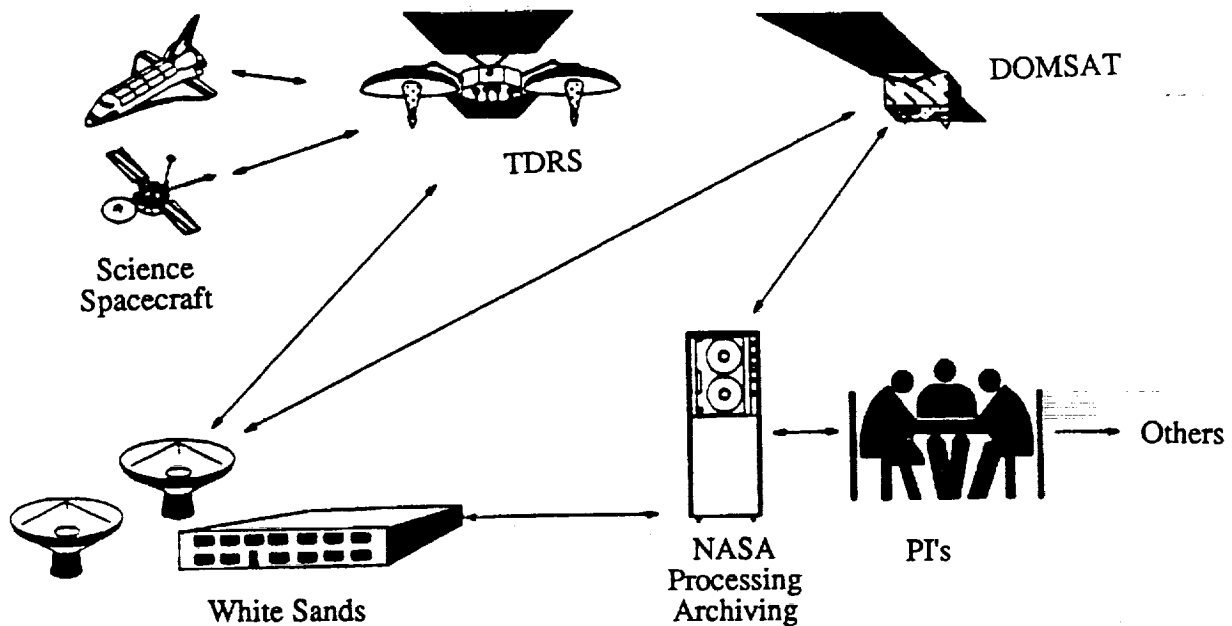


Figure 2-1: Current System of Data Acquisition, Processing, Archiving, and Distribution

### 2.1.2 Data Distribution Satellite System

The Data Distribution Satellite (DDS) system would use small (1 to 2 meters), low cost (\$10 to \$20 K) earth stations to provide direct, real time space access for science users. In addition, the DDS would provide peer networking capability for these users, including voice and video as well as data.

Specifically, the DDS would enable a satellite-based peer network while at the same time serving as a gateway between the Space Network and a science peer network. This role would enable the distribution of data, in real time, to principal investigators and data centers regardless of their location. In operation, this system would provide scientists and others with the capability to read out their own data and control their own experiments. In addition, scientists would have the same peer networking features now provided, including voice and video enhancements. This total interconnectivity, without the need for land lines, could include global coverage.

Under the concept known as "telescience", experimenters will routinely interrogate and control their experimental package remotely in virtually real time. Turn around time for most data would be on the order of minutes, with quick look returns in seconds. The same service would enable links among peer scientists and data archives attached to the network for consultation,

advice, and data exchange.

Figure 2-2 illustrates the proposed function of the DDS in providing access for experimenters to sensors or experiments on the Space Station or STS. The roles of the DDS can be summarized as follows:

- i. Alleviates data processing bottlenecks via direct distribution of space experiments data to users.
- ii. Permits wide bandwidth interactions between scientists located at home laboratories and on-orbit experiments.
- iii. Augments the capabilities of ATDRS:
  - Via intersatellite links.
  - Provides good coverage from orbit location directly over CONUS.
- iv. Enhances wideband science technology networking for improved national educational base.
- v. Supports international science data relay including a potential global environmental program.

This concept is a unique satellite application since the data source is in space and the data users are distributed on earth. The benefits include:

- Timely access to weather, crop, environmental, and military data.

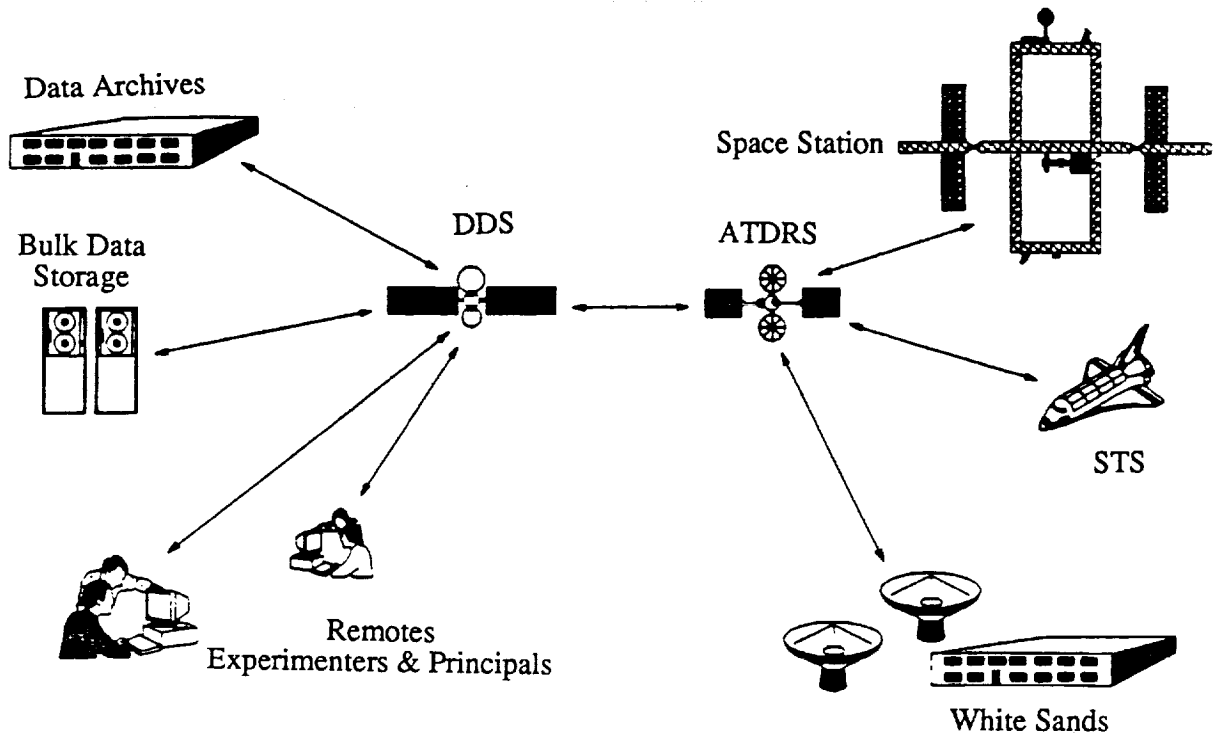


Figure 2-2: DDS Improves Space Access for Experiment Monitoring and Control (Telescience)

- Rapid interaction with payload to optimize the value of gathered data.
- Data can be distributed in parallel to multiple user communities.

Communications technologies needing development include high capacity optical intersatellite links, multichannel demodulators, on-board switching processor, high capacity modems and codecs, and antenna systems with multiple beams and frequency reuses.

### 2.1.3 Key Issues and Trends

The following key issues and trends influence the design of the DDS system and the course of the study:

#### 2.1.3.1 Key Issues

- Projected first launch of DDS is 17 years hence (2007 in support of fifth launch of ATDRS (i. e. replenishment series).
- Data requirements are preliminary, leading to need for an overall NASA "Data Requirements Model".

- The projected DDS data throughput of 10 Gb/s will require significant advanced technology development for the communications subsystem.

#### 2.1.3.2 Major Trends

- Optical intersatellite links will enable easier (less burden on satellite in terms of mass and power) data relay in space than up/down linking.
- Use of photonics on satellite will enable new generation of "switchboard in the sky".

## 2.2 Requirements

### 2.2.1 Objectives per NASA SOW

The objectives per the NASA Statement of Work (SOW) for DDS are as follows:

- Define requirements of space system to achieve:
  - Universal, real time, science user access to space experiments and sensors ("telescience")

- Science user-to-user communications ("peer networking")

- Evaluate feasibility of a DDS system which interfaces with an advanced space data acquisition and communications system (ASDACS) to provide global, real time, demand access space communications for science and industrial purposes.
- Identify critical technologies and describe proof-of-concept models which will prove the functional feasibility of a DDS system.

### 2.2.2 Composite Communications Requirements

Communications requirements were identified in three functional categories broken down as shown in Figure 2-3. The definition of each functional area is as follows:

**Telescience.** Telescience is the direct, iterative and distributed interaction of users with their instruments, data bases, specimens and data handling facilities, especially where remote operations are essential.

**Peer Networking.** This includes all non-mission related communications networking for science collaboration during all phases of an investigation.

**Other Networking.** This category represents user functions such as NASA engineering and operations, supercomputing network services, commercial & industrial space activities, and international networks.

Figure 2-4 represents a summary of the Telescience requirements for DDS. During this period of time, ATDRS will be functional and therefore options were formulated which would use the ATDRS capabilities. Various options are shown where DDS plays a significant role in satisfying the composite Telescience requirements.

It should be noted that previous studies on user requirements started with a constrained configuration - space science users and missions were told to be able to fit within existing communication capabilities (i. e. TDRSS and NASCOM). This suggests that most existing communications specifications derived from these constrained functional requirements would underestimate the required capabilities.

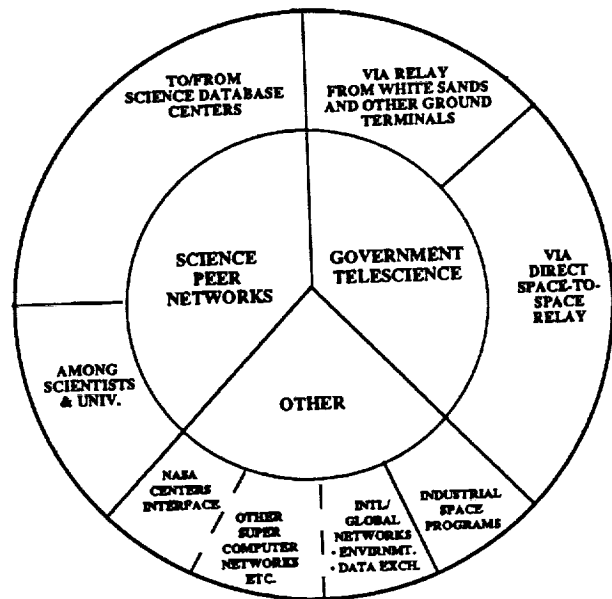


Figure 2-3: Comm. Requirement Categories

Table 2-1: Composite DDS Data Requirements

	Year 2007	Year 2015
Telescience	5 Gb/s	10 Gb/s
Peer Networking	5 Gb/s	10 Gb/s
International, Other	1 Gb/s	2 Gb/s
Totals	11 Gb/s	22 Gb/s
Uncertainty Range	2 to 25 Gb/s	5 to 40 Gb/s

The composite DDS requirements from telescience functions, peer networking, and international and other are shown in Table 2-1. These estimates attempt to give a range number (i. e., 2-25 Gb/s) which represents minimum (constrained operations - cost and schedule limitations) and maximum (totally unconstrained - reflects total user needs) communications requirements.

### 2.2.3 Communications Scenarios

The total user requirements have been allocated among various link scenarios in order to establish such parameters as data rates, data quality, tolerance to link outages (required availability), and geographic distribution of user traffic.

The potential users of a DDS communications system are not uniformly distributed throughout the United States. Thus an efficient implementation of the DDS system implies use of both spot beams and area cover-

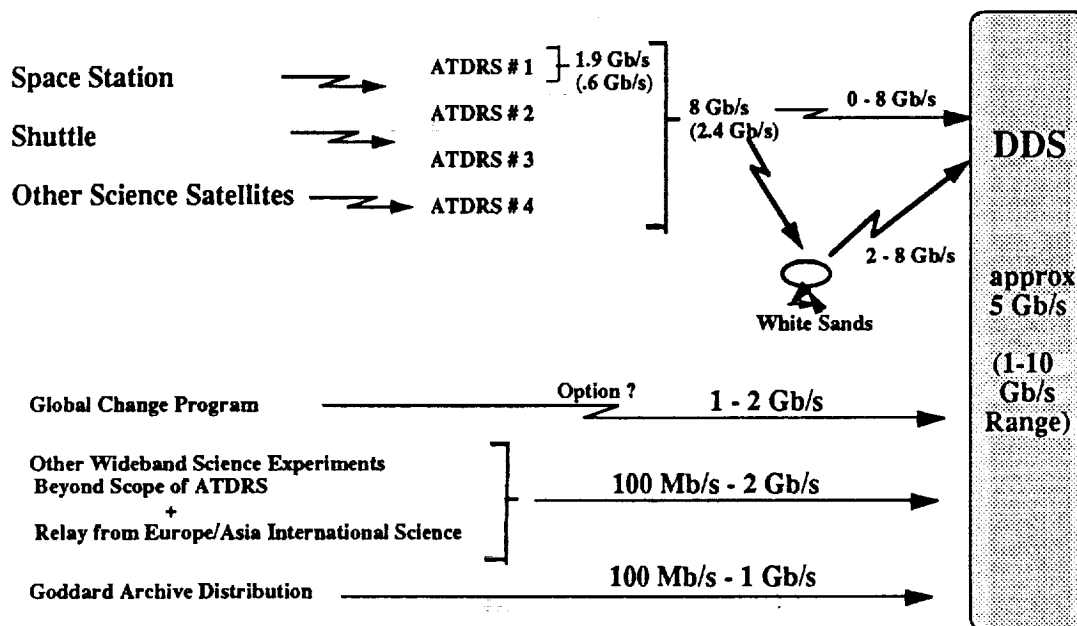


Figure 2-4: Telescience Requirements for Data Distribution Satellite

age beams. The estimate of the traffic and data rates to various geographic regions within CONUS (Continental United States) for telescience applications is closely correlated with the distribution of U. S. Earth Observing System (EOS) investigators and the proposed sites of EOS Data and Information System (EOSDIS) Active Archive Centers as shown in Figure 2-5. The distribution for Peer Networking is generally related to population density together with major university locations.

### Telescience Scenarios

The Telescience scenarios are summarized in Figure 2-6. The link scenarios associated with the category of Telescience are as follows:

1. Uplinks from science experimenters to DDS for control of on-orbit space experiments and downlinks directly to science experimenters from DDS for space experiment data distribution.
2. Uplinks and downlinks connecting control centers to DDS for link access control.
3. Uplinks and downlinks connecting White Sands with DDS in order to facilitate data relay.
4. Uplinks and downlinks connecting Goddard Space Flight Center with DDS in order to serve as a

backup and/or expansion of capability for existing terrestrial links.

5. Uplinks and downlinks for relay of data sent to remote stations by ATDRS because of line of sight limitations to White Sands.
6. Intersatellite relay of data/experiment control information between ATDRS and DDS.

### Peer Networking Scenarios

The Peer Networking scenarios are summarized in Figure 2-7, and the associated link scenarios are as follows:

1. Uplinks from many thousands of small users to DDS for science data transmittal and downlinks to these terminals from DDS for receipt of science data;
2. Uplinks and downlinks for accommodating communications of science data between DDS and the various science data base centers;
3. Uplinks and downlinks associated with access control to the peer networking system.

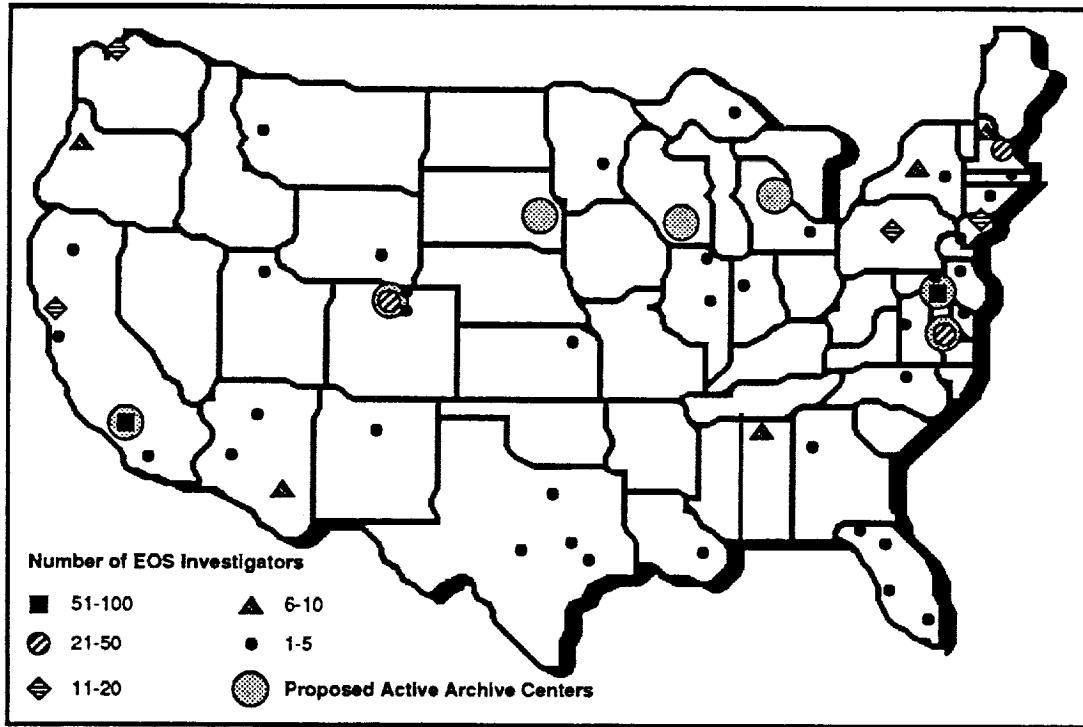


Figure 2-5: Distribution of U. S. EOS Investigators and Proposed EOSDIS Active Archive Centers

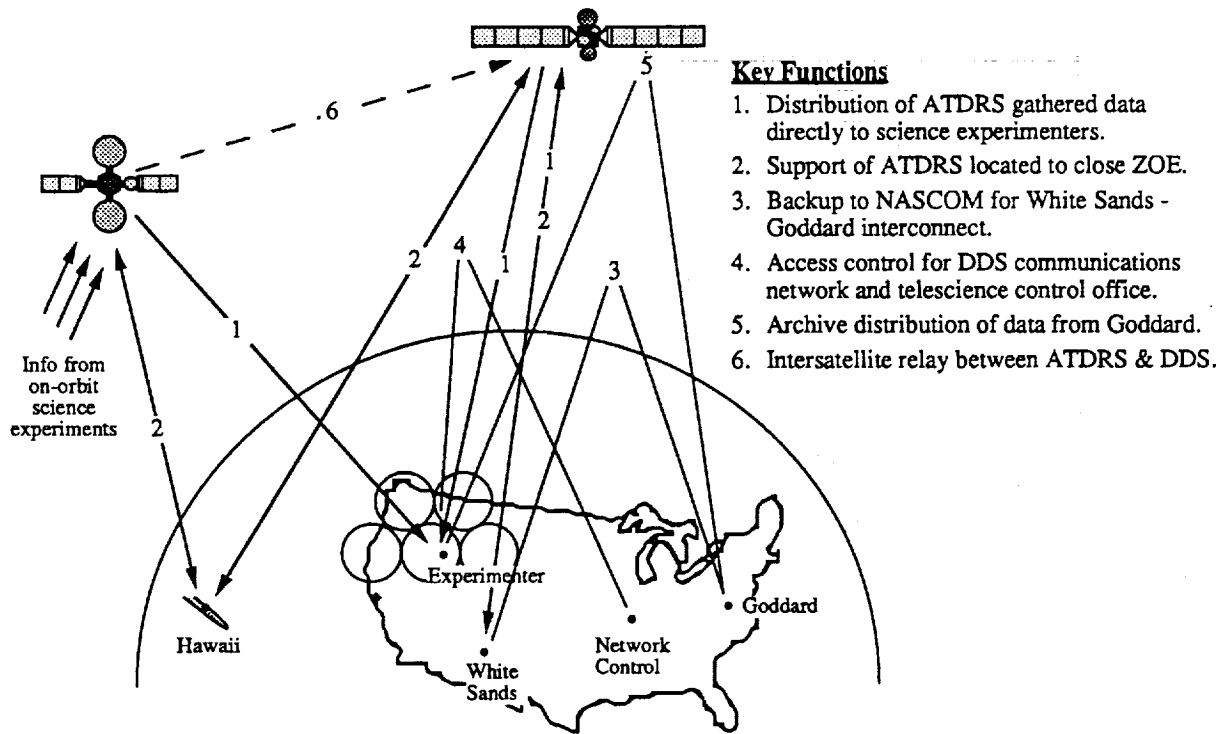


Figure 2-6: Composite Telescience Scenario for DDS

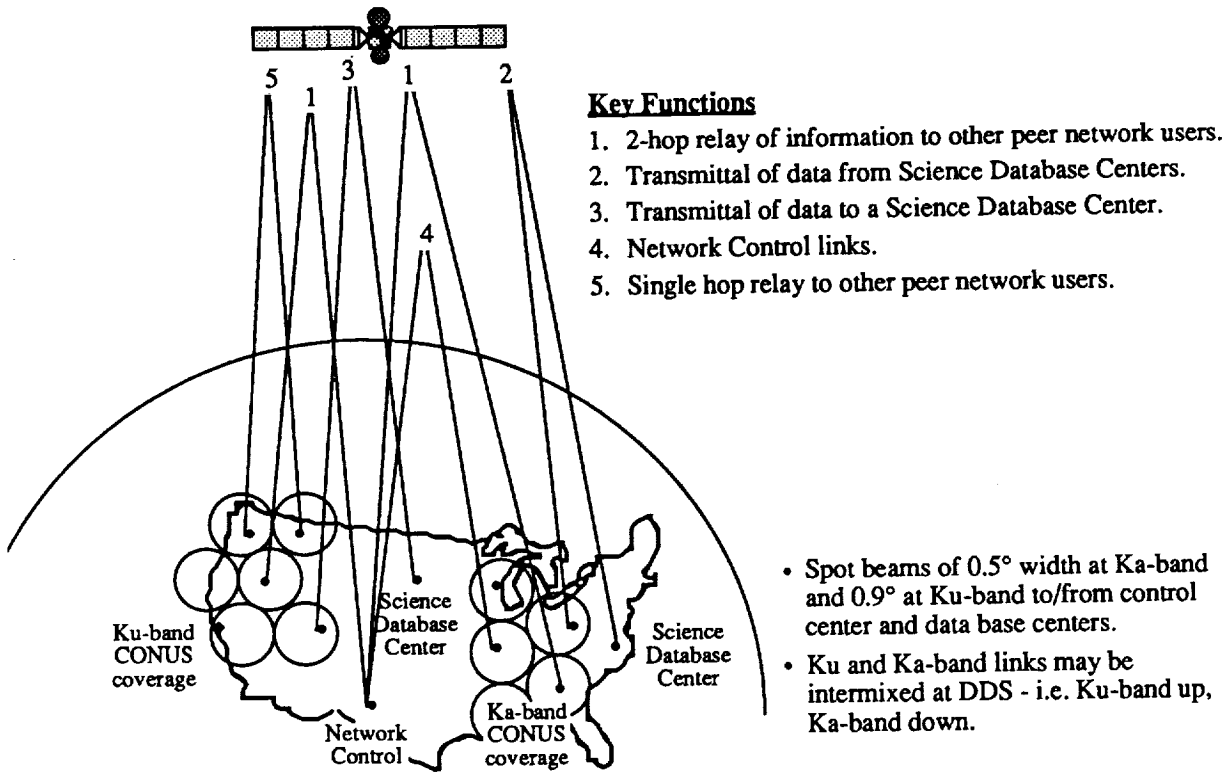


Figure 2-7: Composite Peer Networking Scenario for DDS

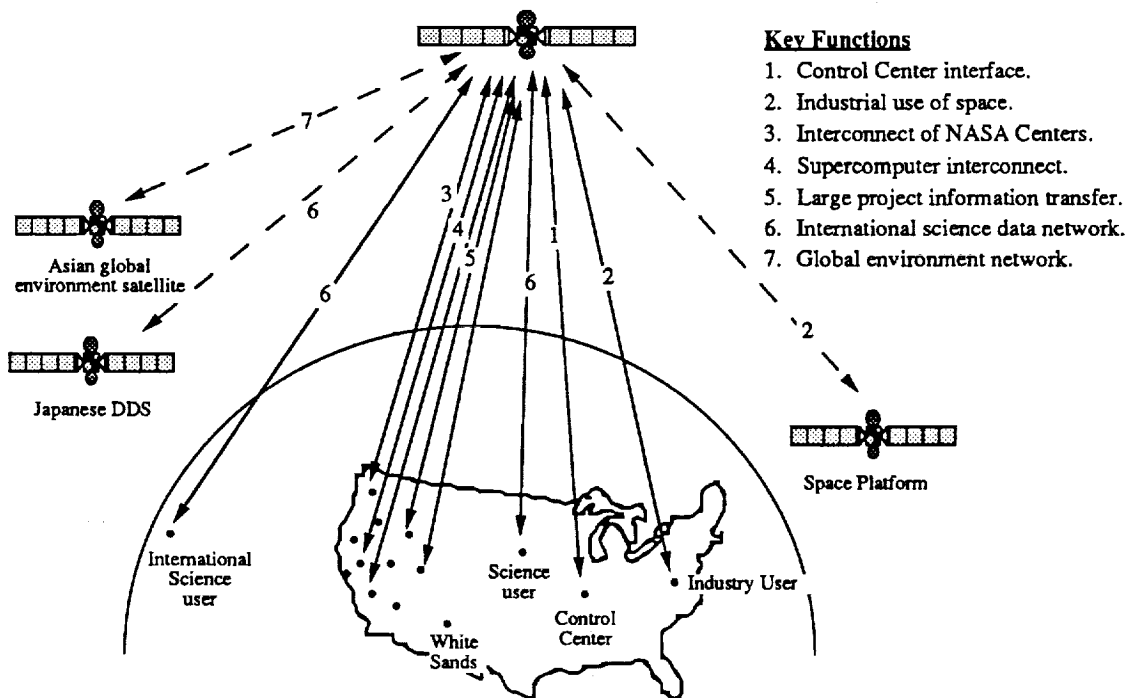


Figure 2-8: Composite Other Services Scenario for DDS

## Other Services Scenarios

The Other Services scenarios are summarized in Figure 2-8, and the associated link scenarios are as follows:

1. Uplinks and downlinks via DDS to support communications interface of the various NASA centers.
2. Up and downlinks via DDS to support a wideband super computer network.
3. Up and downlinks via DDS to support the transfer of large scale science project engineering data.
4. Links to support communications to/from international science communications networks.
5. Links to support data relay to/from global environment monitoring.
6. Links via DDS to support the industrial use of space (optional)

## 2.3 Satellite Design

The year 2007 DDS design is described in this section, with references made to the year 2015 DDS design which is described in the main body of this report.

### 2.3.1 Communications Payload Features

The baseline approach has the following features:

**High data throughput.** The baseline DDS configuration is designed to accommodate a large composite data capacity in excess of 10 Gb/s for both uplinks and downlinks.

**Use of dual frequency bands.** Use of 500 MHz spectrum at Ku-band and 500 MHz at Ka-band is required to accommodate the large data throughput. The Ku-band links will be used for high link availability (>99.5%) requirements and Ka-band links will provide efficient bulk data transfer at >98% availability.

**Full coverage of CONUS** is provided at both frequency bands through use of area coverage beams. Additional fixed spot beams are provided to high data traffic regions in order to improve communications link efficiency.

**Modulation.** A mix of modulation techniques is used. BPSK is utilized for power constrained links, 8PSK is used for spectrum constrained links, and QPSK is used for balanced conditions (simultaneous power and bandwidth efficiency).

**Coding.** FEC block coding is used on both the uplinks and downlinks for link power efficiency. Typical coding configurations include rate .749 for QPSK and rate .829 for 8PSK.

**On-board processing.** The incorporation of full demodulation and remodulation of all data streams permits baseband processing. The use of packet switching according to the B-ISDN standard eliminates the need for precise system timing synchronization and permits maximum routing flexibility (used for peer networking side of DDS).

**Data rates and protocols.** The baseline links are designed to accommodate both narrowband ISDN (144 kb/s and 1.5 Mb/s) as well as B-ISDN (160 Mb/s and 640 Mb/s) rates.

**Communications control.** A master communications control center is incorporated in order to regulate system access and gather billing information. The Control Center will also direct the reconfiguration of DDS communications equipment to match dynamic changes in user circuit and connectivity requirements.

**User flexibility.** The system is designed to accommodate a large number of simultaneous users of various data rates and antenna terminal sizes. Terminals of 1.2 m will operate effectively on clear days and larger terminals of 1.8 to 3 m may be used for higher data rates and/or higher link availability.

**Uplink configuration.** The low data rate users (6 Mb/s or less) utilize single carrier FDMA and bulk demodulation on the satellite. Dedicated demodulators are assigned to higher rate channels. This approach yields maximum bandwidth utilization at low transmitter power from user terminals.

**Downlink configuration.** The downlinks at low data rates (6 Mb/s or less) are achieved by using TDM at a burst rate of 52 Mb/s. Higher data rate signals are assigned separate single channel per carrier links. The satellite transmit power is allocated with 70% to Ku-band and 30% to Ka-band.



**Intersatellite links** among DDS, ATDRS, and other satellites are achieved via laser links which interface with the Ku-band and Ka-band uplinks and downlinks.

**Growth flexibility.** The baseline communications configuration is designed to permit a modular growth in system performance via addition of more satellites.

### 2.3.2 Satellite Antennas

The satellite antennas are a key item limiting payload performance due to constraints on allowable size and mass. Table 2-2 summarizes the RF antenna parameters. Use of larger antennas can provide higher gain and thus greater EIRP to the ground terminals, which can allow higher data rates or smaller ground terminal sizes. However, higher gain antennas are larger and require more beams to cover a given area such as CONUS, and thus beamforming network size and on-board switching complexity is increased.

A multiple number of links between the DDS and other geosynchronous satellites may be required. As shown in Figure 2-9, these links may reach to the ATDRS (four operational), the NASA platforms (EOS geostationary platforms), international relay satellites, and other DDS's. Return communication data rates to DDS from each ATDRS may reach 2 Gb/s, while the forward link from DDS to ATDRS may be 200 Mb/s. (Note that there are two ATDRS in each of two orbital locations.)

### 2.3.3 Block Diagram

The block diagram of the baseline DDS communications subsystem is shown in Figure 2-10. The DDS receives signals from the CONUS coverage area at both Ku-band and Ka-band from both area coverage beams (1/4 CONUS and 2°) as well as spot beams (0.5° and 0.9°). The match of antenna beams to appropriate demodulator capability is achieved by both fixed allocation and rf interconnect switching which is controlled via the communications command and control link.

The satellite demodulates all uplink signals. The lower rate signals go into bulk demodulators. One bulk demodulator, for example, can accommodate 327 channels of encoded 144 kb/s uplinks and provide a single TDM output at 52 Mb/s. Other higher data rate SCPC (single channel per carrier) signals in the range

of 52 Mb/s to 640 Mb/s would be accommodated by dedicated regular demodulators.

The next stage provides for decoding of the uplink signals. The information from an individual channel is grouped into blocks corresponding to the block code size and fed to the decoder. One decoder de-interleaves and decodes serially all channels from a single bulk demodulator. It is expected that D-8PSK modulation with .905 FEC coding would be used for high bandwidth efficiency for signals directed to the bulk demodulators, and that 8PSK modulation with .829 FEC coding would be used for the wideband SCPC links to dedicated regular demodulators.

After FEC decoding is achieved the outputs of the uplink data streams will consist of serial packets of information, with each packet consisting of 424 bits of data. The header on each packet is read in order to determine the appropriate output destination and routing. It is possible to uplink at one frequency band (for example Ku-band) and to route to a downlink at the alternate frequency band (Ka-band).

The buffered data is then encoded and directed to the appropriate downlink transmitter which in turn are connected to the appropriate downlink antenna coverage beam. Some of the low data rate downlinks are accommodated by using a TDM method of data formatting at an output burst rate of 52 Mb/s. The higher data rate channels of up to 640 Mb/s are accommodated by dedicated single channel per carrier links. The use of BPSK and QPSK and modulation techniques are utilized in order to conserve on satellite transmitter power.

All of the access control, allocation of equipment items, and reconfiguration switching is under the control of the master communications control center.

### 2.3.4 Communications Capacity

Table 2-3 summarizes the total communications capacity for one DDS (year 2007 launch). Breakdowns are given for uplinks and downlinks from earth, and intersatellite link capacity (transmit and receive) to other satellites. The total satellite capacity (peak load) represents the maximum amount of simplex bits that can pass through the satellite within its spectrum and power constraints under best case conditions. The peak simplex capacity is 13 Gb/s; however, the maximum realizable capacity with 15% overhead (bits for packet headers and framing) is 11 Gb/s simplex. The average achievable utilization of satellite capacity is estimated to be

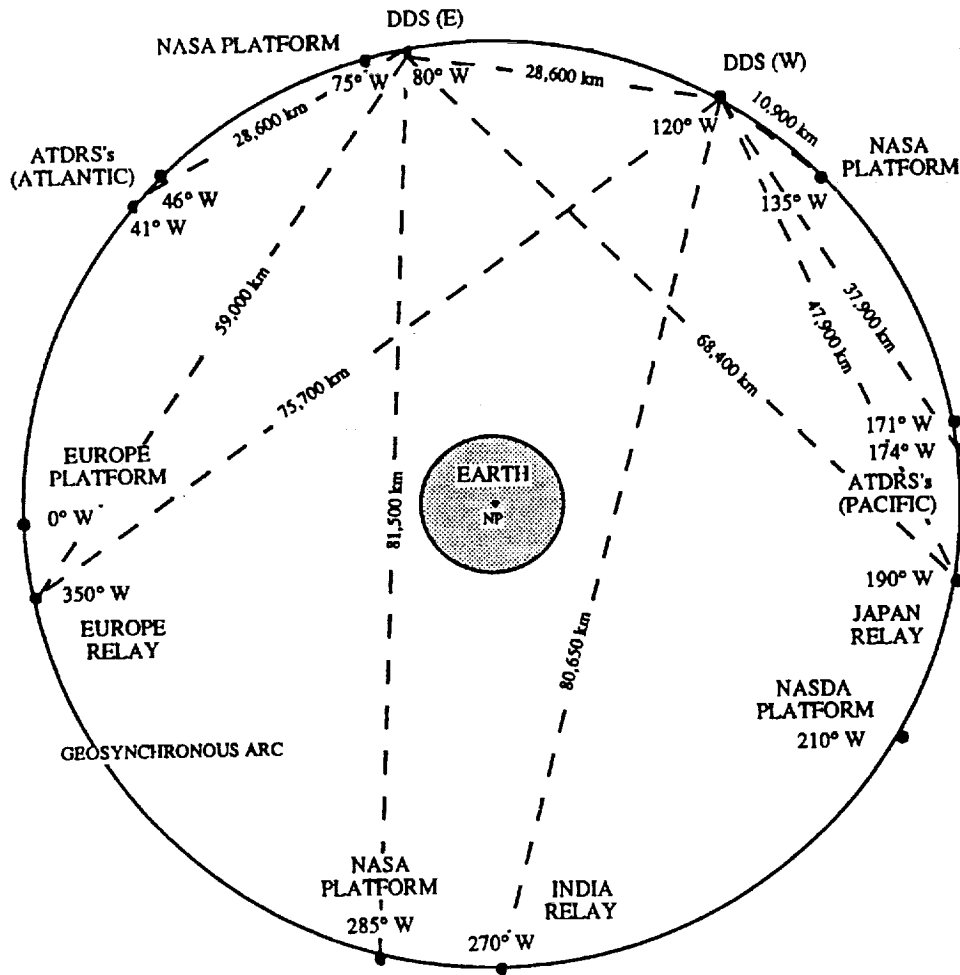


Figure 2-9: Intersatellite Link Configuration – Possible Links to DDS

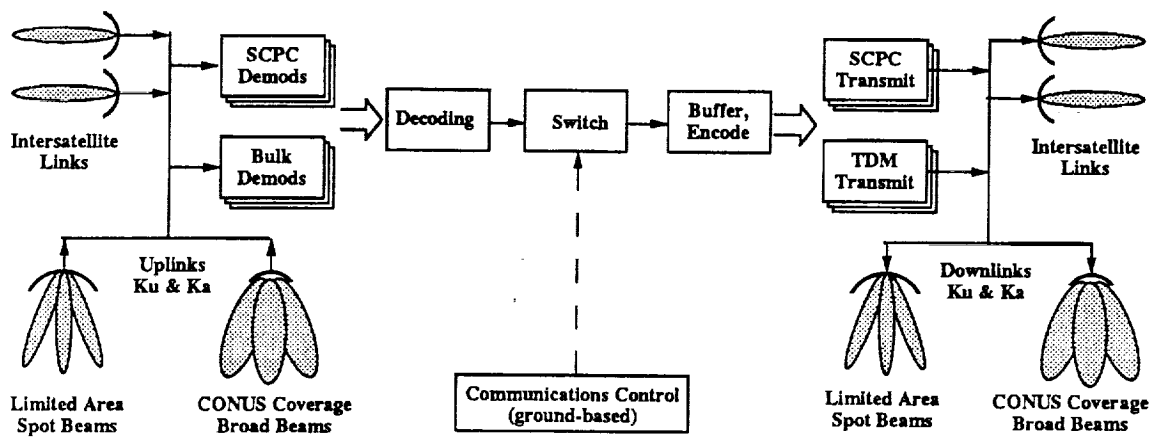


Figure 2-10: Block Diagram of the Communications Subsystem

Table 2-2: Satellite Antenna Configuration (Year 2007 Data Distribution Satellite)

	Satellite Receive				Satellite Transmit		
	#1 Ku (14.0-14.5)	#2 Ku (14.0-14.5)	#3 Ka (29.5-30.0)	#4 Ka (29.5-30.0)	#5 Ku (11.7-12.2)	#6 Ka (19.7-20.2)	#7 Ka (19.7-20.2)
Coverage							
Beams	8 of 1.73° HPBW	10 active spot beams - 0.87° HPBW of total of 15	8 of 1.73° HPBW	12-16 active spot beams of 0.5° HPBW of total of 20	27 beams of 0.87° HPBW	8 of 1.73° HPBW	12-16 active spot beams of 0.5° HPBW of total of 20
Antenna Diameter	0.9 m (2.8 ft)	1.7 m (5.5 ft)	0.4 m (1.4 ft)	1.4 m (4.6 ft)	2.0 m (6.5 ft)	0.6 m (2.0 ft)	2.2 m (7.0 ft)
Antenna Mass	14 kg	24 kg	8 kg	22 kg	36 kg	10 kg	26 kg
Polarization	4 of H 4 of V	1/2H or V only 1/2 (H + V)	4 of H 4 of V	1/2H or V only 1/2 (H + V)	1/2H or V only 1/2 (H + V)	4 of H 4 of V	1/2H or V only 1/2 (H + V)
Antenna Efficiency	65%	60%	65%	60%	60%	65%	60%
Peak Gain (dBi)	40.2	45.8	40.2	50.6	45.8	40.2	50.6
EOC Gain (dBi)	35.9 (-4.3)	42.8 (-3.0)	35.9 (-4.3)	47.6 (-3 db)	41.5 (-4.3)	35.9 (-4.3)	47.6 (-3 db)

only 16% of maximum due to (1) inefficiency in allocation of communications among discrete numbers of antenna beams and demodulator sizes, (2) time of day traffic statistics, and (3) initial traffic build up for a new service.

A year 2015 satellite design was also made, and had an even more impressive 23 Gb/s peak and 19.5 Gb/s maximum simplex capacity. This design had six intersatellite link units versus two on the 2007 design.

### 2.3.5 Satellite Configuration

Figure 2-11 shows the satellite configuration for the 2007 DDS and Table 2-4 summarizes its characteristics. The satellite design is dominated by the four 1.4 m to 2.2 m Ku and Ka-band receive and transmit antennas. The two intersatellite link antennas have only 0.15 m apertures in comparison. The RF antennas are typically implemented as multiple beam antennas, primarily on account of the large number of simultaneous spot beams required from each antenna.

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

Higher power is required to supply the greater communications capacity which enables more efficient operation, and to make available the power re-

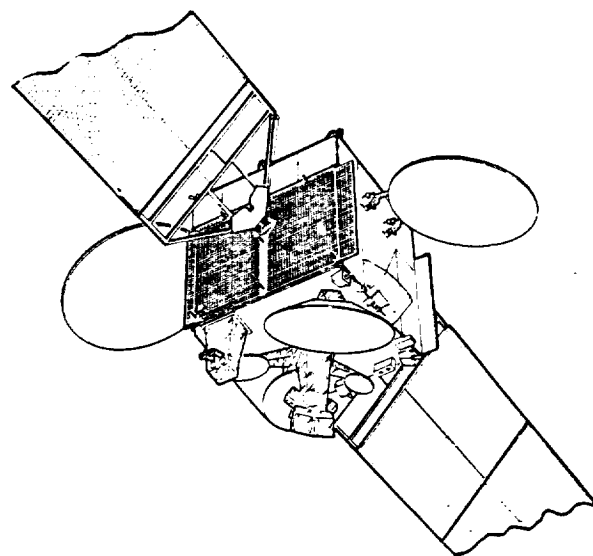


Figure 2-11: Satellite Configuration

Table 2-3: Total Communications Capacity of Year 2007 DDS Payload (Single Satellite)

Type of Link	Comm. Capacity (Gb/s)	Radiated Power (W)	References and Comments
Uplinks (receive)	13.52		Table 7-3. (5.48 Gb/s Ku-band, 8.03 Gb/s Ka-band.)
Downlinks (transmit)	11.72	740 (Ku) 248 (Ka)	Figure 7-10, Table 7-9; (2 kW Ku dc power). (6.65 Gb/s Ku-band, 5.08 Gb/s Ka-band); (800 W dc power at Ka-band).
	25.34	988	
Intersatellite links:			2 optical intersatellite link units.
Receive	3.84		¶7.6.1
Transmit	1.28	2 (optical)	2 transmit channels.
	5.12		
Totals (simplex bits)			
Receive	17.36		
Transmit	13.00		
Peak simplex capacity	13.00		Receive cannot exceed transmit capacity.
Maximum achievable	11.05		Max. simplex capacity with 15% overhead.

quired for on-board processing. Advanced battery and solar cell designs are used which have improved performance per unit mass.

**Thermal radiators** are required to dissipate the higher power from the satellite. Of the 5,500 W dc power, only 990 W is radiated away in rf power, leaving approximately 4.5 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 Ku and Ka-bands** requires double the number of antennas and beam forming networks, with consequent increase in antenna mass. However, the benefit is 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. Each separate fixed beam

would require a separate beam forming network if implemented with a phased array. Fixed beams were chosen by this study in order to reduce the complexity for the earth terminals.

An alternative design would use phased arrays with scanning spot beams, and could require more thermal radiator mass. If more than one scanning beam is required from a given antenna, separate beam forming networks would be required.

**Use of optical intersatellite links (ISLs)** in addition to the Ku-band and Ka-band links complicate the antenna farm layout. However, the benefits are increased connectivity and capacity with only a modest increase in mass. Much work remains to be done to commercialize optical ISLs.

The basis for the bus is the Ford Aerospace FS-1300 series which has a 1,850 kg wet, Beginning-Of-Life (BOL) mass capability and is presently in production for commercial applications.

The existing satellite design (1985 technology) has been upgraded to incorporate hypothesized year 2000 technology improvements. The result is a 1,990 kg dry (2,150 kg wet) satellite mass with a 731 kg payload (antenna plus communication electronics), and 5,500 W end-of-life power. Table 2-5 summarizes the mass budget and Table 2-6 summarizes the power budget for the

Table 2-4: Data Distribution Satellite Characteristics (Year 2007 Launch)

Manufacturer & model: Baseline satellite name: Lifetime: On-board switching: Launch vehicle:	Ford Aerospace FS-1300 Data Distribution Satellite 15 yr On-board baseband switching for all channels. Atlas IIAS (enhanced)
Frequency band and bandwidth: - receive: - transmit: Frequency band and bandwidth: - receive: - transmit: Optical Intersatellite Links:	Ku-band, 500 MHz 14.0-14.5 GHz 11.7-12.2 GHz Ka-band, 500 MHz 29.5-30.0 GHz 19.7-20.2 GHz Optical, 850 nm
Antenna - type: - number: - size:  - mass: - coverage (Ku-band): - coverage (Ka-band):	Offset parabolic 8 0.9 & 1.7 m receive, 2.0 m transmit, Ku-band 0.4 & 1.4 m receive, 0.6 & 2.2 m transmit, Ka-band 15 cm transmit/receive for optical ISL. 146 kg (combine 1.4 m Ka and 1.7 m Ku-band) 8 rx and 27 tx beams over CONUS, plus 10 rx spots 8 fixed area plus 16/20 spot beams, both transmit & receive
Communications electronics - number of receivers: - number of bulk demods: - number of demodulators: - SSPAs:  - mass: - dc power:	33 at Ku-band and 33 at Ka-band. 26 at Ku-band and 32 at Ka-band. 33 at Ku-band and 48 at Ka-band. 27 @ 5 W, 27 @ 10 W, and 18 @ 20 W at Ku-band 22 @ 1.5 W, 6 @ 3 W, 8 @ 5 W, 5 @ 10 W, 8 @ 15 W - Ka-band 585 kg 2,900 W peak.
Spacecraft - size (stowed): - mass, BOL: - power (EOL) at summer solstice: - primary power: - batteries: - attitude and station keeping: - attitude pointing accuracy: - apogee motor: - stationkeeping & attitude control:	2.5 m x 1.88 m x 2.64 m 2,150 kg 5,500 W Solar cells (thin silicon) 4 NiH, 280 Ah (total) 3-axis stab, ion propulsion $\pm 0.05^\circ$ Liquid propulsion Ion propulsion motor

satellite.

In addition to the above described year 2007 DDS, a design was evolved for the year 2015 DDS which had 2,390 kg dry mass, 940 kg payload, and 7 kW dc power.

## 2.4 Earth Terminals and Network Control

### 2.4.1 Earth Terminals

It is expected that several thousand earth terminals would be utilized in the systems configurations for an operational DDS System. Because of the large quantities, it is important to optimize the cost and performance of the overall terminal segment with that of the satellite and communication control segments. The earth terminals for DDS applications are expected to range in size from 1.2 m to 7.0 m diameter depending upon the specific user application requirements.

#### Very Small Aperture Terminals

(VSATs) could range in size from 1.2 to 1.8 m (4 to 6 ft) in diameter, and operate at Ku or Ka-band. It is expected that users with requirements for very high link availability would utilize Ku-band due to the lower rain margin requirements.

**Mini-Trunking Terminals (3 m).** The medium class of terminal would be utilized for either dedicated services for medium data rates or as a mini-trunking terminal for shared user services.

**Large Terminals (4 - 7 m).** The large class of terminals would be appropriate for the large data requirement users such as the White Sands interface to the TDRS network, science data base centers, the DDS network control center, and node points serving to interface to local fiber optic terrestrial networks.

### 2.4.2 Network Control

The year 2007 DDS system described in this document is envisioned as having a ground-based Network Control Center (NCC) which is the DDS operations control facility and which provides operational interfaces between users and the DDS/ATDRSS space network.

The routing of telescope data and experiment control information between the various science experimenters (located anywhere within CONUS) and their

Subsystem	Mass (kg)
Attitude control	113
Power	186
Solar array	114
Propulsion	275
Structure	244
Thermal	150
TT&C	52
Payload - Antenna	146
- Electronics	585
Integration; elect. & mech.	125
Total (dry mass)	1,990
On-orbit fuel	160
Total (BOL mass)	2,150

Table 2-5: Satellite Mass (2007 Design)

Component	Power (W)	
Receivers	350	
Demodulators	550	
Decoders	100	
Switch/Processor	250	
Encoders	160	
Modulators	100	
Transmitters	2,900	
Other/Margin	200	
Total Payload	4,610	4,610
TT&C	30	
Attitude control	135	
Propulsion	2	
Power subsystem	42	
Thermal subsystem	153	
Control electronics	80	
Harness loss	44	
Total Bus	466	466
Battery charging		424
Total Satellite		5,500

Table 2-6: Satellite Power (2007 Design)

on-orbit experiments is a primary mission of the DDS. This requires coordinated action between the Experiment Control Center (ECC) which controls access to an on-orbit experiment and its results, and the DDS Network Control Center (NCC) which is the DDS operations control facility and which provides operational interfaces between users and the DDS/ATDRSS space network.

The overall configuration for coordination of service requests from users is shown in Figure 2-12 which depicts a Telescience Experiment Control Center which has communications with various terrestrially located experimenter groups (astronomy for example). Hundreds of experimenters may be part of this group.

The Experiment Control Center (ECC) would coordinate the various requests for data distribution or experiment control interaction as a control clearing house. The ECC would then coordinate with the ATDRS NCC at White Sands for permission to utilize segments of the ATDRS link capacity and to effect control of on-orbit experiments. The ECC would also coordinate with the DDS Network Control Center for permission to utilize segments of the DDS link capacity and to effect reconfiguration of the DDS communications payload configuration.

Two problem areas have been identified:

- One is the implementation of software for scheduling and utilizing DDS/ATDRS in the presence of high priority, high data rate users. The DDS side will function all right via use of packet switching within the B-ISDN and CCSDS standards. However, ATDRSS may be a barrier to rapid access to on-orbit science resources.
- A second problem lies in the avoidance of a single failure point in the system. TDRSS is presently vulnerable to a major catastrophe at White Sands. The DDS system should form an alternate path from on-orbit experiments and sensors to the user. The DDS NCC should not be located at White Sands.

## 2.5 System Costs

System costs were estimated for a DDS system including satellites, ground terminals, and network control center. DDS system costs are expressed as both a life cycle cost and a cost usage factor.

Table 2-7: 2010 Duplex Circuit Costs

Circuit Size	Projected Terrestrial Price	Estimated DDS Price	DDS Terminal Size
64 kb/s	\$6.00/hr	\$2.13/hr	VSAT
1.5 Mb/s	\$30/hr	\$26.40/hr	VSAT
	\$20/hr	\$11.40/hr	Medium
52 Mb/s	\$258/hr	\$329/hr	Medium

### 2.5.1 Life Cycle Cost

A summary of the projected 15 year life cycle cost of the space segment and master communication control center segment for the DDS system is given in Table 2-8. The total space segment cost of \$1,063 M is combined with the network control costs to yield a life cycle cost of \$1,308 M. This corresponds to \$135 M/yr at 7% or \$160 M/yr at 10% cost of money.

This life cycle cost of \$135 M/yr for 15 years is for the entire capacity of the two DDS satellites. Conceivably, NASA could "sell" or exchange part of the capacity in return for cost or fee reductions. However, it is judged that commercial operators of the DDS system would be more likely to make such arrangements to more fully sell the DDS capacity.

### 2.5.2 Cost Usage Factor

Chapter 11 gives the system operating scenario in order to derive the total user costs for simplex circuits as given in Table 2-9. These costs include space/control segment costs and ground terminal cost (one unit), and assume a 16% utilization of DDS capacity. It is assumed that a commercial entity develops and operates the DDS system. The costs are expressed in 1990 dollars for a 15 year satellite lifetime beginning in the year 2007.

Table 2-7 summarizes DDS duplex circuit costs (twice the simplex circuit costs of Table 2-9) and compares them with estimates of 1,000 mile terrestrial circuit costs for the year 2010. Terrestrial costs are projected into the future by assuming a 4% reduction per year. The DDS system has competitive economic performance for all circuit sizes. However, terrestrial circuit costs would decrease for shorter distances while the satellite circuit cost does not vary with distance.

As an interesting example, the contents of this report consist of 20 Mbits of text and figure information. This

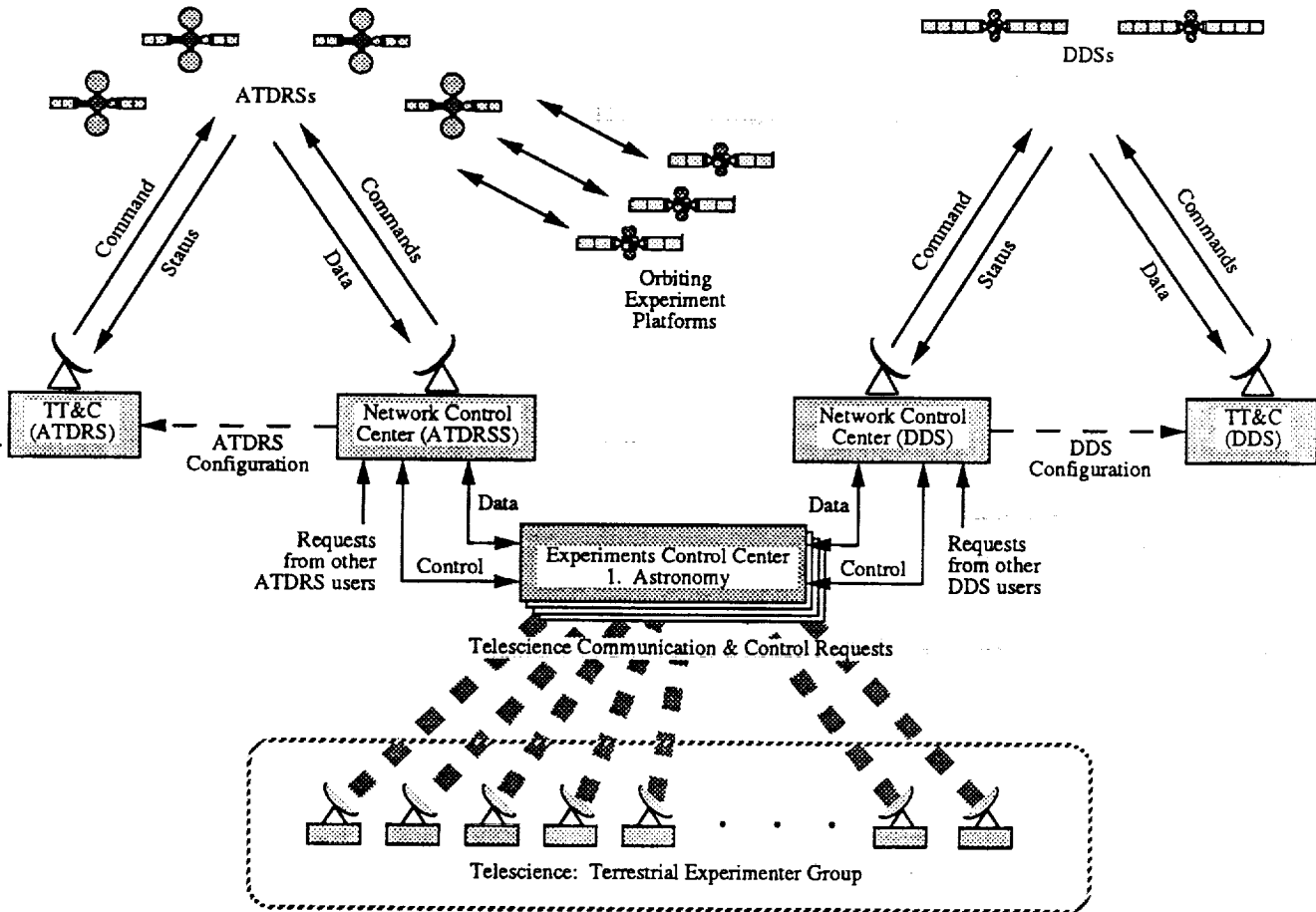


Figure 2-12: Experiment Control Center Coordinates User Requests for Control and Data

Table 2-8: Life Cycle Cost (1990 \$M) for NASA Program (2 satellites, 15 year life starts 2007)

Cost Category	Life Cycle Cost	Annual Cost at 10%	Annual Cost at 7%
Space segment costs: (2 sats, 2 launches, TT&C support)	1,063 M	136 M	114 M
Network control center: Develop & build	125 M	16 M	13 M
Operations (15 yr)	120 M	8 M	8 M
Totals	\$1,308 M	\$160 M/yr	\$135 M/yr



Table 2-9: Simplex Circuit Costs for Commercial DDS System (2 satellites, 15 year life starts 2007)

User Cost Category	Simplex Circuit Cost in \$/min for					
	1.2 m	1.8 m	1.8 m	3 m	5 m	7 m
	8 hr/day 144 kb/s	8 hr/day 1.5 Mb/s	8 hr/day 6 Mb/s	12 hr/day 52 Mb/s	24 hr/day 160 Mb/s	24 hr/day 320 Mb/s
Space/Control Cost	.015	.16	.61	2.66	8.18	16.36
Ground Terminal Cost	.025	.06	.08	.08	.42	.83
Total Cost	.040	.22	.69	2.74	8.60	17.09

could be transmitted via a 144 kb/s VSAT in 2.3 minutes of time for 10 cents cost (simplex circuit).

## 2.6 Technology Development Plans

Recommended technology developments are given along with a development plan for support of the DDS concept.

### 2.6.1 Technology Developments

Uplink and downlink antennas in seven different sizes at Ku and Ka-bands dominate the physical layout of the satellite and have an estimated 164 kg mass. Their sizes range from 0.4 m to 2.2 m, with 8 to 27 separate, simultaneous beams being formed by each antenna. There are a number of areas where the antenna technology should be pursued:

- MMIC feeds for MBAs in order to reduce mass and power consumption. Major challenges are in the packaging and thermal design. (MMIC feeds are also important for the phased array design alternative not selected.)
- Combination of several antennas into one; i. e. Ku-band and Ka-band, transmit and receive, H and V polarization. This becomes a difficult task when multiple beams are formed from each antenna with frequency reuse among the different beams. The total co-channel interference must be kept to  $C/I \geq 16$  dB, which requires low sidelobes and adequate isolation.
- Use of higher strength materials such as "metal matrix" graphite fiber reinforced plastic in the antenna subsystem to reduce mass.

**Optical Intersatellite Links (ISLs)** are required in order to achieve high data rates with minimum mass and power impact on the satellite. The key issues for optical ISLs include:

- Reduction in size and mass, with a goal of 25 kg mass, 50 W power, and a 15 cm aperture for a unit supplying a duplex 640 Mb/s 40,000 km link.
- Direct coupling of the free space photons into fiber with low loss. This allows separation of telescope and transmit/receive electronics.
- Space qualification of coherent, small linewidth sources suitable for use with optical heterodyne receivers.
- Use of heterodyne versus direct detection allows approximately 8 dB improvement in link performance, and is key for high data rate systems.

**Multi-Channel Demodulators (MCD's)** or bulk demodulators on the satellite are a key technology for enabling low cost access by VSATs. Key issues for their design include the following:

- Reconfigurability to allow change in the size and mix of user channels.
- Recommended capacity of a single unit is 52 Mb/s, reconfigurable to accept 64 kb/s, 144 kb/s, 1.544 Mb/s, or 6.2 Mb/s channels.
- Another issue is synchronous versus asynchronous operation. If the transmissions from user VSATs can be synchronized such that all symbols arrive at the MCD at the same time (synchronous operation), one sample per symbol is adequate. If the symbol arrival time is not synchronized, 8 samples per symbol may be required. The potential

for synchronous operation needs to be identified and tested.

- The allowable user channel separation (1.5 or 2 times bandwidth) is key to efficient use of the limited satellite spectrum.

**Modulation and Coding** must be considered together for optimum design. Key technology for satellite application includes the following:

- Demodulators and modulators from 52 Mb/s to 640 Mb/s are required. (MCDs have already been described.) Key issues are mass and power, and the ability to be flexible in using one of several different modulation formats.
- A multi-channel decoder is required which operates with the output of the MCD.
- Coding schemes should be realizable with codecs of small mass and low power usage. Coding gains of 3 to 5 dB (the higher the better) at rates of .75 to .90 (the higher the better) are the goals at bit error rates of  $10^{-6}$  to  $10^{-10}$ .
- Higher order modulation schemes can improve coding and MCD performance, but are more sensitive to interference and result in higher modem implementation loss.

**Power Amplifier** developments:

- The improvement in efficiency of TWTAs and SSPAs needs to be continued. (We assumed 37% efficiency for Ku-band and 31% efficiency for Ka-band SSPAs in our year 2007 satellite design, and 40% and 35% respectively for the year 2015 designs.) Other key issues include linearity, 15 yr lifetime, and high power solid state devices. Our design calls for Ku-band and Ka-band SSPAs ranging in power output from 1.5 W to 20 W (see Table 8-11).
- For the active aperture antennas with multiple beams, high power (1 W), linear MMIC devices are required at Ku and Ka-bands.

**Information Switching Processor (ISP)** is the digital routing switch on the satellite which interconnects the circuit or routes the packets from the uplink beam to

the correct downlink beam. Key design requirements for the ISP include the following:

- Space qualified design with low mass and power (12 kg and 200 W goals with 20 Gb/s throughput).
- Support ISDN and B-ISDN protocols for circuit and packet switching.
- Incorporation of input and output muxes and formatters.
- Internal redundancy adequate for 15 year lifetime.
- Incorporates storage for bit streams in contention

**Autonomous Network Controller (ANC)** would be positioned on the satellite for our year 2015 design. Although we project ground network control for the year 2007 DDS, development of a space qualified ANC should start now. The problem with a ground-based ANC is the long reaction time (due to transmission path delay) for service requests or changes.

The key design requirements include space qualification, low mass and power consumption (6 kg and 50 W goals), limited autonomous operation, and redundancy and reliability to achieve a 15 year lifetime.

**Other Communication Payload Technology** not included in the above categories is listed below:

- Antenna pointing of  $0.5^\circ$  spot beams may require use of a pilot beam. This technology may be under investigation and demonstration by the ACTS program.
- Adaptive rain fade compensation techniques such as those implemented for ACTS should be evaluated and improved for use in the Ka-band rain fade environment.

**Earth Terminal Technology** development is required to achieve low cost ground terminals.

- Cost reduction techniques for large quantities of VSATs.
- Modem for use in large numbers of VSATs. The problem is to develop low cost chips for coding and decoding, and modulation and demodulation.
- VSAT interfaces to ISDN and B-ISDN equipment and networks.

- Mini-trunking method for power combining of separate transmitters versus use of single linear amplifier.

Network Control Technology development is required in the following areas:

- Overall command and control of the satellite payload configuration which must respond to dynamic changes in user capacity and distribution over CONUS.
- Network protocols for access by a large number of small users within an ISDN environment.
- Minimization of interference among common users and neighboring satellites to the DDS.
- Simultaneous control of satellites in the same orbital position - i. e. separations of  $0.05^\circ$  or less.
- Software development for master control station.

### 2.6.2 Summary Development Schedule

An overall multi-year development plan for NASA support for a NASA Data Distribution Satellite Program with initial launch in the year 2007 is shown in Figure 2-13. The various categories of support would include the following:

1. System definition studies
2. Key technology development
3. Communications simulation laboratory
4. Demonstration experiments

The master schedule shows initiation of preliminary requirements and concept definition studies in mid-1988 with continuation of follow-on detailed studies until inclusion in the Phase A awards under a Program Development effort. The key proof-of-concept (POC) developments would be achieved in the 1992 to year 2000 period.

It is projected that an extensive communications laboratory simulation of major elements of the satellite, control center, and terminal communications network would be conducted in the 1994 to 2001 period prior to award of the Phase C/D hardware contracts for DDS procurement. A continued use of the laboratory would

also be beneficial through satellite manufacture and early on-orbit operational period.

The overall development plan also shows potential on-orbit testing during the period of years 2000 to 2006. A specific experimental flight model of DDS is not planned; however, some key elements could be evaluated through use of the ATDRS future service growth capability of the Space Station Freedom.

The DDS program plan shows Phase A awards in 1995, Phase B awards in 1997, and Phase C/D award for the satellite and network control center development and manufacture beginning in 2001. The first launch of DDS is shown in 2007 in order to coincide with the launch of the replenishment series ATDRS. A second DDS launch would be made several years later to supply backup and increased orbital communications capacity for the remainder of the 15 year life cycle.

#### 2.6.2.1 System Definition Studies

It is recommended that a continuing series of system studies be conducted over the next ten year period in order to more fully define the user requirements and system performance requirements prior to award of Phase C/D contract. Among the issues which require continuing study efforts are the following:

- Detailed requirements definition
- Network Control Center definition
- Detailed definition of DDS payload
- TDRSS interface definition
- Orbit configuration of the DDS system

#### 2.6.2.2 Key Technology Development

The DDS system will require a significant advance in the satellite communication technology versus that of current designs which largely incorporate broadband transponders. Other key developments are required for the communications control center and user ground terminal equipment. The detailed DDS configuration studies will serve to focus the requirements of key proof-of-concept (POC) technology developments. These developments become even more important if an experimental flight program is not utilized.

Some of the key future POC developments which have been identified as a result of this study include

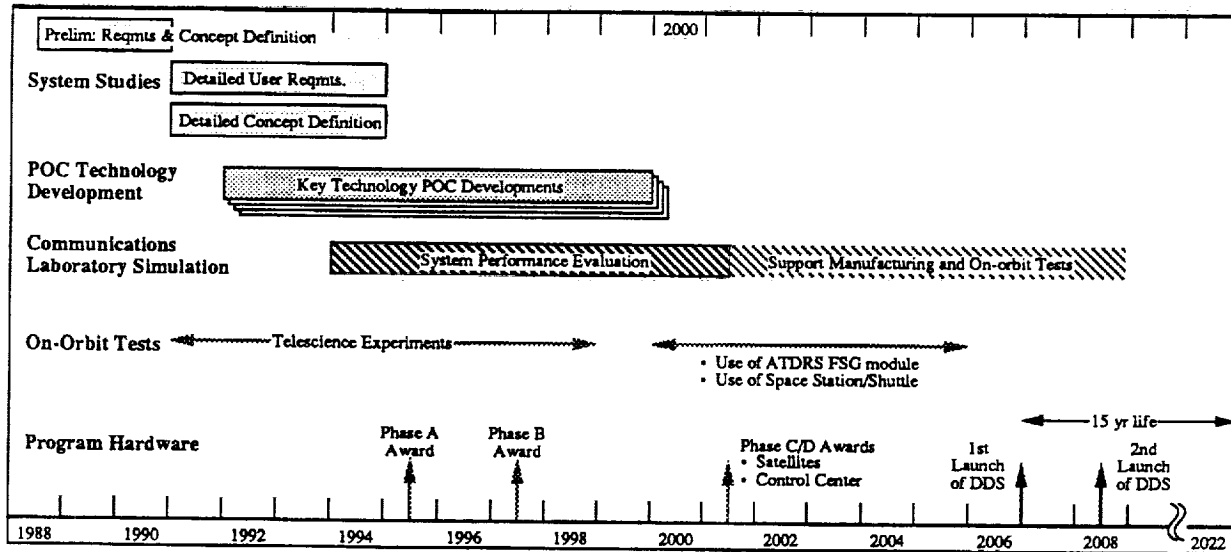


Figure 2-13: Data Distribution Satellite Concept Development Plan

the following items, which are grouped as candidates for early, middle, and later hardware developments depending on degree of technical risk.

#### Early hardware developments:

- Autonomous Network Controller
- Information Switching Processor

#### Middle hardware developments:

- Network Control Center. Develop key software to accommodate procedures and protocols of the DDS system. Determine procedures for control of DDS communications subsystem. Determine optimum location of the Network Control Center and backup sites.
- Satellite Antenna Development. Determine satellite antenna implementation to meet coverage and frequency reuse plans. Determine antenna pointing accuracy requirements.
- Satellite Receiver/Demodulator/Decoder. Determine RF front end configuration with switching flexibility. Develop satellite multi-channel demux/demods to accommodate various uplink data rates and modulation techniques. Develop satellite multi-channel decoder to function with output of multi-channel demodulator.

#### Later hardware developments:

- Decoding and Coding. Develop ground and space coder and decoders for range of DDS data rates. Integrate FEC coding with modulation methods.
- Earth Terminals. Develop key hardware for low cost VSAT designs. Determine single and dual frequency (Ku and Ka-bands) configurations to meet DDS communication requirements.
- Satellite Transmitters. Determine a multiple transmitter, multibeam technique for accommodating DDS requirements. Examine low loss RF combining versus multiple carriers per RF transmitter for implementation.

The cost estimate for each hardware POC model would nominally be \$5 M, with a range from \$2 M to \$10 M depending on the amount of technical risk reduction judged necessary. Total POC hardware development cost is judged to be in the range of \$50 M to \$100 M. The typical cycle of time from origination to concept idea, through configuration studies, key technology development, and operational system hardware manufacture may take 12 years to complete (1989-2001).

It is recommended that the POC hardware development concepts of this report be expanded in the next few years as part of a new system studies task order contract effort.

### 2.6.2.3 Communication Simulation Laboratory

The DDS communications subsystem will represent a major advance versus current satellite communication methods. In order to reduce the risks associated with a complex system implementation, it is recommended that a Communications Simulation Laboratory be established for verification of key component equipment items and overall communication systems performance of sample segments of the DDS system.

The various equipment items may be obtained as part of the POC hardware developments and/or via a separate contract for a limited capacity DDS communications model.

The Communications Simulation Laboratory could be used to evaluate the ability to accommodate dynamic changes in traffic capacity and hence help establish overall system capacity requirements. The use of the simulation laboratory may also be valuable in support of on-orbit operations by evaluation of potential fault situations.

Another aspect of the Communications Simulation Laboratory work could involve telescience prototyping as described in Appendix B, Telescience Testbed Pilot Program. Telescience experiment concepts could be simulated in the Laboratory with all the actual network and control system delays.

### 2.6.2.4 Demonstration Experiments

It is not expected that a dedicated experimental satellite will be deployed to verify the DDS advanced technology. However, after laboratory simulations and engineering model demonstration of new technologies in a ground laboratory, integrated subsystems may require a flight model demonstration in space. In order to minimize performance risk, it is recommended that some on-orbit equipment performance verification be provided.

Two suitable NASA space platforms, ATDRS and the Space Station, may be available for test experiments in the 2000 to 2007 period. In addition, telescience testbed demonstrations are desirable as a precursor to DDS usage.

**ATDRS Future Services Growth Payload** capability accommodates 109 kg, 0.3 m<sup>3</sup> volume, 260 W power, and 260 W thermal dissipation. The potential uses of this capacity in support of DDS include the following payloads:

- Direct-to-user Ka-band downlink could be used to directly deliver ATDRS gathered data to users in real time. Total cost could range from \$3.2 to \$4 M (see Table 6-4 in Chapter 6).
- Ka-band crosslink, ATDRS to DDS, could be used for direct delivery of ATDRS gathered data to users via DDS. ACTS-derived technology could be used.
- 60 GHz crosslink, ATDRS to DDS, demonstrates maturity of 60 GHz crosslink.
- Optical crosslink, ATDRS to DDS, demonstrates maturity of optical crosslinks.

This payload capacity could be utilized on early launches of ATDRS to evaluate the above applications or could be used for selected other DDS payload experiment verification.

**Space Station Freedom** could be utilized as an experiment platform in conjunction with a ground-based receiver, co-orbiting platform, and/or Shuttle to evaluate much of the key DDS communications subsystem equipment. A single-thread DDS communications system with key components, having been verified in the Communication Simulation Laboratory, could be built and flown to demonstrate performance. A basic system incorporating receiver, switch and controller, and processor could cost from \$20 M to \$30 M.

**Telescience testbeds** should be used to verify planned telescience use of DDS. It is highly desirable that scientists on earth access experiments in space via the TDRSS (and ATDRS when available) on a trial basis. Thus it is recommended that low data rate and high data rate experiments be conducted as a precursor to DDS usage.

## 2.7 Conclusions & Recommendations

### 2.7.1 Satellite Design Conclusions

The most significant satellite design drivers are identified as follows:

- The satellite layout (Figure 8-3) is dominated by six RF reflector antennas ranging in size from 0.4 m to 2.2 m diameter. Both Ku and Ka-bands are used, transmit and receive, with spot and area

coverages. The combining and fitting of the different antenna systems on the same satellite is a key design tradeoff. (In contrast, the optical intersatellite link apertures are much smaller – 15 cm.)

- Antenna pointing accuracy is required to 1/10 of a beamwidth ( $0.05^\circ$  for the  $0.5^\circ$  spot beams) in order to achieve stable edge-of-coverage gain for users. Active pointing control may be needed to compensate for thermal distortion of the satellite antennas.
- Long life (15 years) and high reliability is required for all satellite components.
- Optical intersatellite links have the potential to provide Gb/s space-to-space links in a compact package. Our estimate is that a 640 Mb/s duplex link could consume only 23 kg mass and 50 W power in 2007. This will impact all space data flows, and perhaps lead to a partition of functions where a future TDRSS gathers data via optical intersatellite links and DDS distributes data via RF up and downlinks.
- Photonic technology and standards will be used extensively in the satellite for communications signal routing and switching of 10's of Gb/s according to space and terrestrial standards and protocols.
- Bus design is assumed to follow an evolutionary process, incorporating the advanced design features under development today. Payload mass fraction (ratio of antenna plus communications electronics mass to total satellite mass) is judged to increase from 23% for Intelsat VII (1992) to 34% for DDS (2007). This is mainly due to projected improvements in propulsion and power subsystem technology.

## 2.7.2 Communication System Conclusions

Conclusions for the DDS communications subsystem are as follows:

**High throughput capacity is required** to achieve a competitive life cycle cost. Our implementation at 10 Gb/s yields low costs per circuit. Both small VSAT and larger node center terminals must be accommodated.

**Use of Ku and Ka-bands** allows high availability via Ku-band and high capacity via Ka-band for bulk data transfer.

**Spectrum efficiency is required** since only 500 MHz unshared primary bandwidth is available at each of Ku-band and Ka-band. Thus use of higher order modulation/coding techniques are needed. In addition, frequency reuse via area coverage beams and spot beams with dual polarization is needed.

**Communication requirements must be detailed.**

Currently, only preliminary functional requirements are available. There is a need to establish specific data rates, peak-average statistics, quality, and tolerance to outages for users. In addition, the geographic distribution, ground terminal implementation plan, and time variation of usage are required.

**Intersatellite links to ATDRS** and are feasible, with the optical approach preferred. Links are also recommended to Asian and European relay satellites.

**On-orbit reconfigurability is needed** to accommodate dynamic changes in user traffic.

**Bulk demodulators are needed** to allow 1,000's of simultaneous single channel per carrier uplinks.

**Network Control development is needed**, particularly regarding the DDS system and ATDRSS interface.

## 2.7.3 Recommended Technology Plan

As described in ¶2.6.2, the overall DDS development schedule involved work in the following areas:

- System definition studies
- Key technology development
- Communications simulation laboratory
- Demonstration experiments

Technology developments, as described in ¶2.6.1, are recommended in the following areas:

Uplink and downlink antennas  
Optical intersatellite links  
Multi-channel demodulators  
Modulation and coding  
Power amplifiers  
Information switching processor  
Autonomous network controller  
Earth terminal technology  
Network control technology

#### 2.7.4 General Recommendations

The following general recommendations are made:

- DDS represents a major step advance in satellite system implementation. The communication subsystem (satellites and ground terminals) and the network control are identified as the high risk elements. Technology developments and demonstrations should be accomplished in these areas as outlined in ¶2.6.
- The DDS program needs to be started now in order to achieve a year 2007 launch. For example, the ACTS studies which began in 1978 have led to an experimental satellite to be launched 14 years later (1992).
- There is a need for current follow-on efforts by NASA and Industry:
  - Define roles and interfaces to the changing TDRSS.
  - Study details of requirements and system configuration for DDS.
  - Perform proof-of-concept technology development of key communications technology (may require \$100 M over the next ten years).
- Potential support roles to be managed by NASA include:
  - Maintain a “Data Requirements Model” for all NASA and the DDS-addressable subset.
  - Establish a “Communications Simulation Laboratory”.
  - Determine the “Systems Engineering Model” of data transfer for large projects.
  - Determine “case examples” of user configurations for high data rate information distribution.

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## Chapter 3

# General Requirements

This chapter summarizes recent requirements study activities sponsored by NASA Headquarters (Office of Space Science and Applications (Code S), Office of Space Station (Code M), Office of Space Operations (Code O)) and international space agencies in Europe and Japan. Although these studies were primarily conducted to derive user requirements for the Space Station Freedom design and development, they also form a comprehensive foundation of user requirements for the DDS.

The chapter is organized as follows:

- 3.1 Introduction
- 3.2 User Community Characterization
- 3.3 Operational Concepts
- 3.4 User Scenarios
- 3.5 Peer Networking and NREN
- 3.6 Composite Requirements
- 3.7 DDS Prototype Testbed
- 3.8 References

### 3.1 Introduction

The space station era (1990–2025) with all of its projected space mission capabilities (Space Station Freedom and its associated laboratories, other ground and space research facilities – e. g. Shuttle, Hubble Space Telescope, International Solar Terrestrial Physics Program, Global Change Program including EOS, etc.) and emerging telecommunications and information system technology has the potential for significantly enhancing scientific research. As indicated in Figure 3-1, space data distribution during the Space Station era is very complex, involving distributed space and ground elements and internationally distributed users.

In general, the space program is experiencing significant evolutionary changes which strongly impact the telecommunications and information system requirements. The following are some of those key changes:

- Emphasis in space science is shifting beyond exploration and discovery towards a detailed, long term analysis of fundamental features and processes involving multi-disciplinary research teams;
- A movement from national to international teaming for all space science research as well as for commercial R&D space ventures;
- An emerging economic and functional need for telecommunication services to enable geographically distributed teams to interactively share information during the full life cycle (design and development phase, operations phase, analysis phase) of international space projects;
- The quantities of space science data that will be acquired, transmitted to ground, processed, distributed to users, analyzed, and ultimately archived during the next decade exceeds by orders of magnitude (more than 2,500 terabits by the late 1990's.) the quantities accommodated up to now;
- Communications and information system technology is evolving and appearing faster than the space science researcher can functional learn about it.

Three other introductory topics are now addressed:

- 3.1.1 Methodology for Derivation of Requirements
- 3.1.2 Space Research Operations Mode for the Space Station Era
- 3.1.3 NASA SOW Requirements for DDS

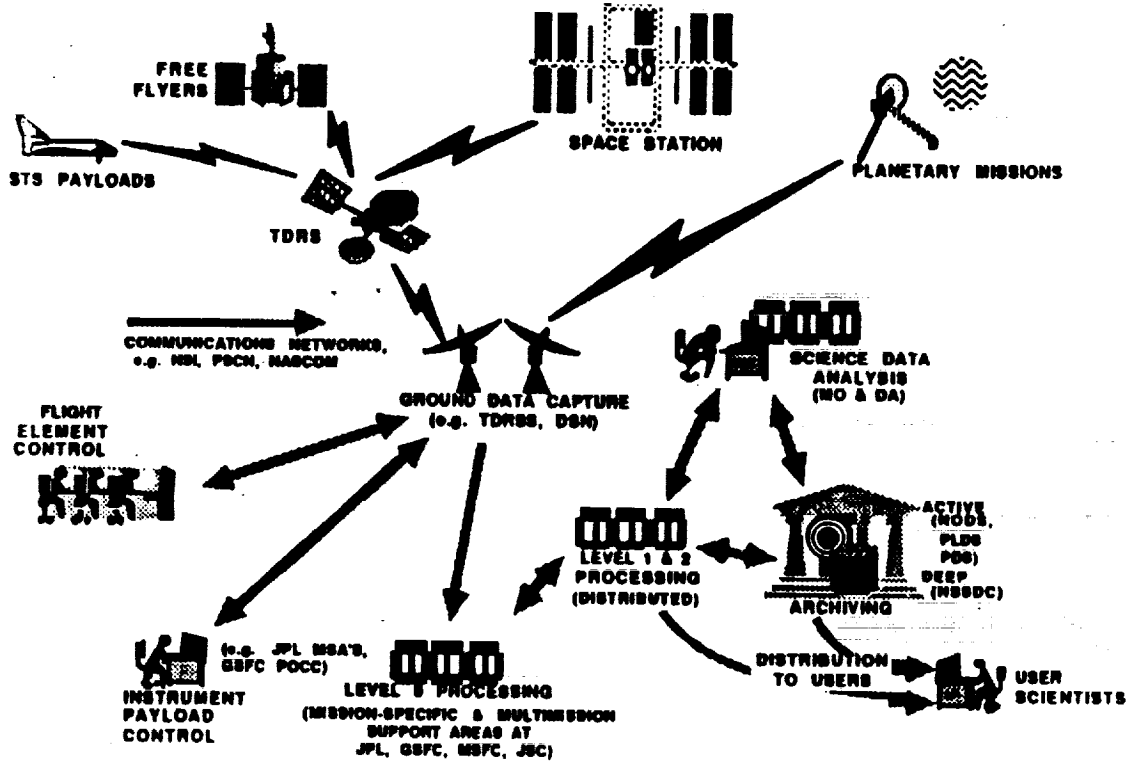


Figure 3-1: Data Distribution During the Space Station Era

**3.1.1 Methodology for Derivation of Requirements**

Information relating communications requirements to user needs was derived from the following three sources:

1. Research of published program documentation;
2. Direct talks with government (NASA) personnel and potential users;
3. Extrapolation from communications requirements derived from the Stanford University space program (taken as a typical university science user).

A graphical representation of the published documentation used in this study is shown in Figure 3-2. The documents highlighted by a dark background were considered key documents for the DDS requirements study. Figure 3-3 indicates key NASA personnel from which helpful information was derived and Figure 3-4 illustrates a typical university campus (Stanford University) and its present (1990) communications infrastructure needed for space science research.

Translating the user needs derived from the study activities described above into communications require-

ments for DDS was constrained by the following key issues:

- Overall requirements are rapidly evolving – difficult to pin down for system implementation 17 years hence. There is no master communications requirements model for NASA.
- Real requirements (unconstrained by existing communications capabilities) of the Space Station era may greatly exceed the projected capacity of TDRS/ATDRS.
- Newly evolving Earth System Sciences Program (Including the Earth Observing System (EOS)) could become a prime driver for DDS.
- Current requirements documents for NASA communications services can be characterized as:
  - Generally stating functional requirements rather than specific engineering specifications;
  - Being unclear about the implementation schedule;

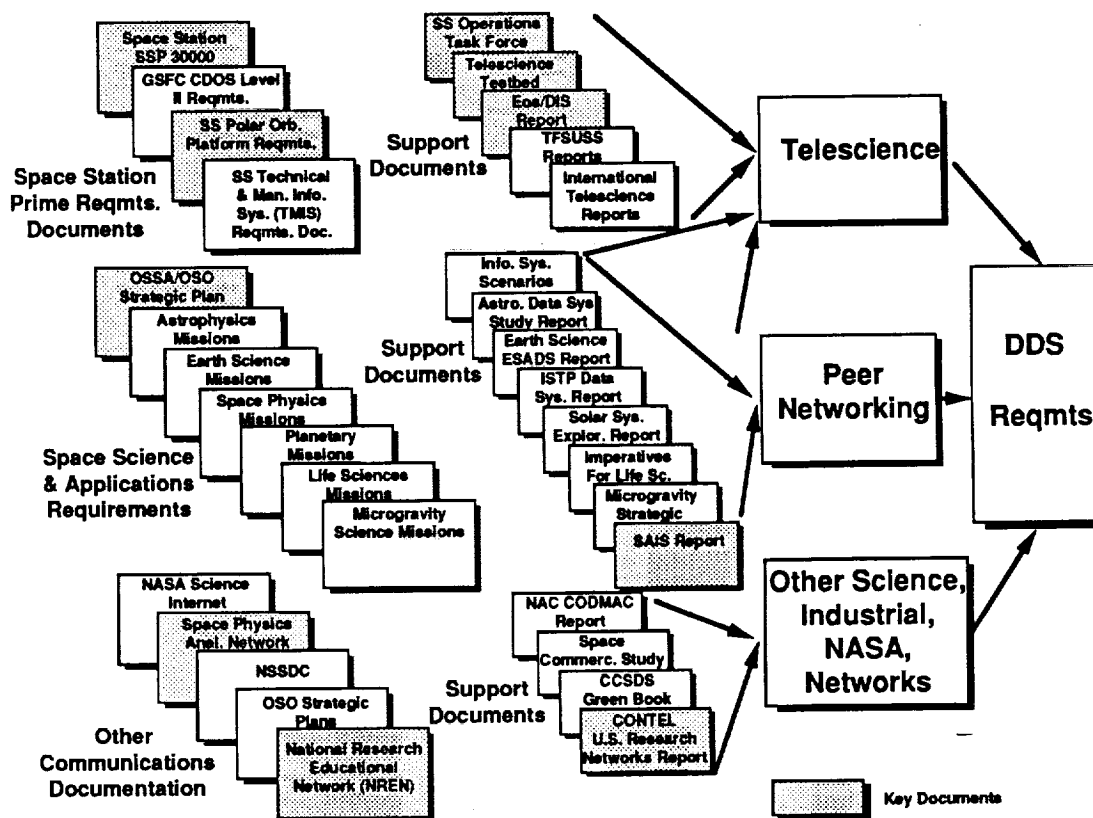


Figure 3-2: Source Documentation for Derivation of DDS Requirements

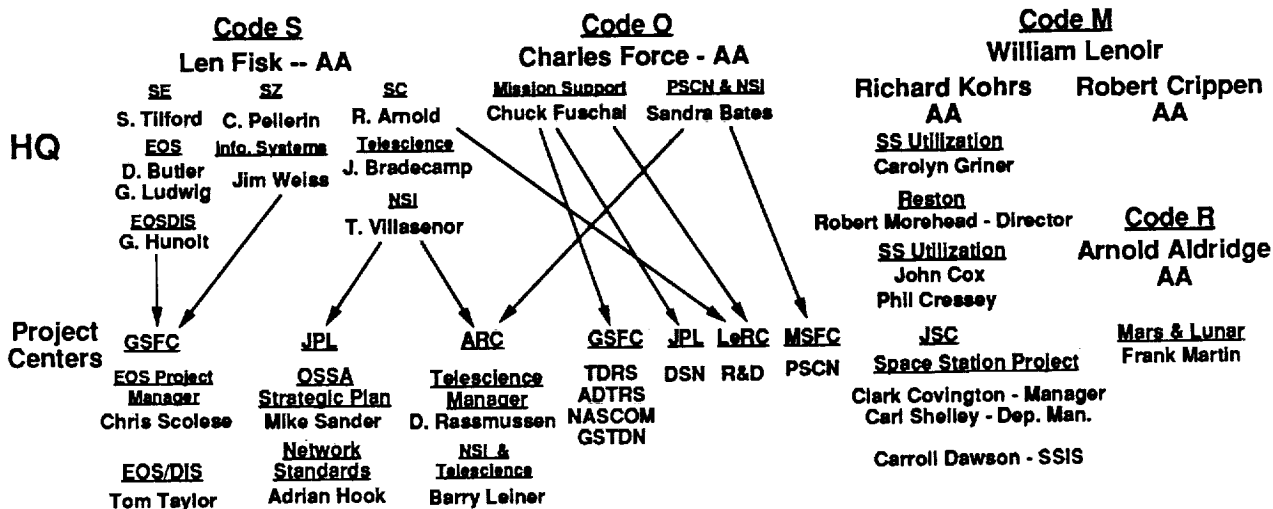


Figure 3-3: Key NASA Personnel for Requirements Process

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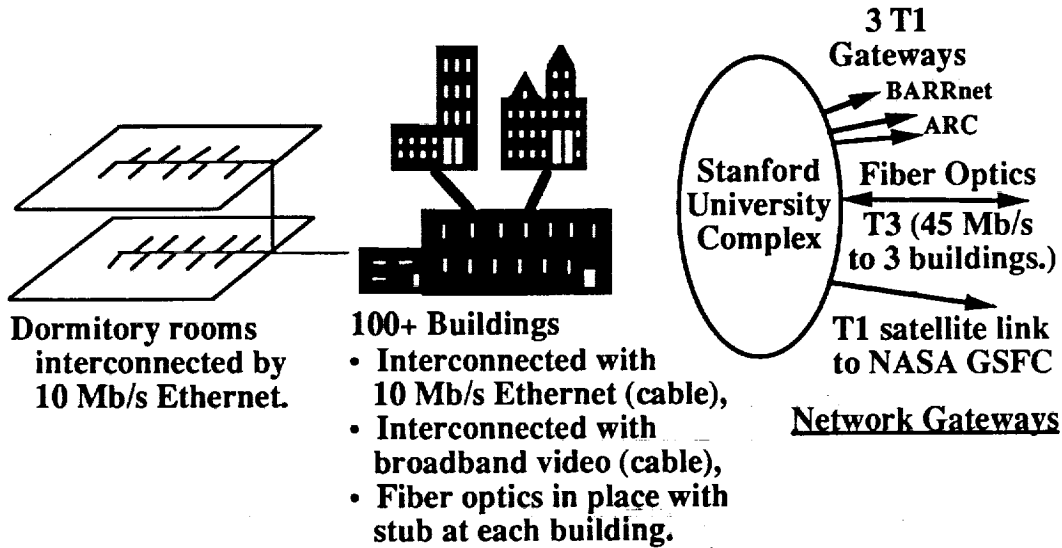


Figure 3-4: Telecommunications Infrastructure for Stanford University (1990)

- Overlapping between application offices (OSSA, OSS, OSTs) and between divisions within OSSA - representing functional requirements derived at the time of mission phase A & B studies which disregard rapid evolution of utilization scenarios and enabling technology.
- Current organizational structure of NASA inadequately supports the requirements process:
  - Matrix organization designed for R&D missions (i. e., Apollo) with a 5 year forward look and not long-term (15-20 year) operational missions (i. e., Shuttle, Space Station, EOS);
  - The annual budgetary process of NASA constrains optimization for system-wide functionality and for long-term operations.
- Role of fiber optics and other alternative communications techniques in support of future systems is also not well defined:
  - Role of satellites may be dependent on wide spread geographic coverage and lower costs.

### 3.1.2 Space Research Operations Mode for the Space Station Era

The most important change which significantly impacts requirements for telecommunications capabilities is the desire by space researchers to emulate more closely the adaptive science methodology used in most terrestrial research laboratories. This iterative, trial and error process, which is inherent to the scientific method, must be recognized and considered in any requirements definition for space station era telecommunications and information system services. To address this issue, the NASA advisory Task Force for Scientific Uses of Space Station (TFSUSS) coined the term *telescience* to describe this new operational mode.

The functional description of telescience was given as the interactive acquisition of new scientific knowledge through remote observations and experiments. The NASA HQ Office of Space Science and Applications (OSSA), as part of the Science and Applications Information System (SAIS) activities, has further defined telescience as shown in Table 3-1. The distributed interaction referred to in this figure is meant to include all members of a user team, in space and on the ground, and may involve either manned or unmanned operations. It is the general desire of the user community to conduct their operations from their home institution by on-line computer networking. Telescience was further divided into three life cycle phases coinciding with

the design and development phase, the flight operations phase, and the analysis phase of space research.

Although the telescience concept was formulated for the space science and applications community, it is seen to be equally applicable to all potential space station era users (science, technology and commercial). It should also be noted that the telecommunications requirements derived to support the telescience concept will be dynamically evolving as users gain experience and knowledge with the telescience mode of operation as well as the rapidly evolving telecommunications and information system technology. The requirements development in this study activity will be cognizant of that fact and will present results from reports which have specifically addressed this issue.

### 3.1.3 NASA SOW Requirements for DDS

The Data Distribution Satellite (DDS) concept is an outgrowth of a previous study of Multi-Frequency Multi-Service (MFMS) Satellites (NASA3-24683), Final Report for Task Order No. 5, *Data Distribution Satellite System Architecture Concept*, prepared for NASA/LeRC by Ford Aerospace Corporation, Space Systems Division, 19 January 1989.

The DDS was envisioned in this study as a adjunct to TDRS/TDAS for distributing new NASA science data throughout the U. S. as well as internationally. The DDS would also provide networking capability for interchange of science database files among science user and NASA archive depositories. The most exciting part of the DDS system was the concept of providing experimenters with the ability to access and control their experimental packages remotely (referred to as telescience). This capability would require a command and voice uplink capability, and video, high rate digital and voice down link.

The current NASA scientific data network relies on TDRSS to relay information from space-based sensors to White Sands where it is sent in bulk to the Goddard Space Flight Center for archiving and further distribution to participating scientists or centers. This current system capabilities are being strained by new requirements, particularly telescience applications, emerging from the space science community. A DDS system is a potential solution to problem on how to meet the scientific data network needs of the Space Station era.

The previous study made a preliminary assessment of the needs of the potential user community. In the year

2000 time frame it was estimated that there may be as many as 25,000 users with a combined peak traffic load of 2.5 Gb/s. The data rates involved ranged from 64 kb/s to 1.5 Mb/s. The breakdown of user requirements as given in Task 5 of the MFMS Study is indicated in Table 3-2.

It was estimated in the previous study that approximately 30% of the DDS capability would be used for communication to/from the science experiments. The remaining 70% capability was allocated for networking of science data base information. A more complete breakdown of this allocation is shown in Table 3-3.

Telescience is a relatively new concept that is still being developed. The potential benefits of telescience to the science community are enormous. The technical challenge of making such a capability widely available on an on-call basis are equally large. The communications requirements for a large scale telescience program will be very large. The command, control and safety issues that also must be addressed will require much careful study and coordination among all the parties involved.

## 3.2 User Community Characterization

At first glance, the task of accurately defining the space user classes for the next 35 years seems to be extremely difficult if not impossible. It is soon realized that the difficulty does not arise from defining the functional classes (since they remain fairly constant over time) but rather in determining their relative importance in placing requirements on the telecommunications services over a long period of time ( $\approx 35$  years). Several emerging user classes (i. e. microgravity sciences and commercial space manufacturing) may have limited impact today but will surely place large demands on the telecommunication systems in the 2010 time period. This time dependency must be understood and factored into the requirements.

There are two other dynamic parameters in the requirements equation which must be quantitatively understood:

1. The impact of new technology on the possible data rates of space-borne sensors (raising output data rates to gigabits/sec/sensor);
2. The impact of emerging space-borne processing technology (allowing for flexible compression of

Table 3-1: Definition of Telescience Concept (Science and Applications Information System)

Telescience is the direct, iterative and distributed interaction of users with their instruments, data bases, specimens and data handling facilities, especially where remote operations are essential.	
Teledesign:	The ability to send drawings, documents and specifications, to plan, manage, and coordinate science investigations among geographically distributed investigators, to perform interactive design with remote facilities, and to conduct interface and other tests of instruments by remote computer access.
Teleoperations:	The ability to conduct remote operations by making rapid adjustments to instrumental parameters and experiment procedures in order to obtain optimum performance.
Teleanalysis:	The ability to access and merge data from distributed sources and to perform analyses and studies on computers that may be geographically distributed investigators, to perform interactive located at geographically distributed institutions.

Table 3-2: Projected User Data Rates (NASA Statement of Work)

Number of Users	Type of Service Required	User Rate (kb/s)	Peak Activity Factor	Peak Load (Gb/s)
19,200	Voice/data	64	.5	.61
5,000	ISDN	144	.5	.36
1,000	T1	1,544	1.0	1.54
Total peak load (Gb/s)				2.51

Table 3-3: Allocation of Communications Capacity Among Users (MFMS Study)

Communications to/from science experiments (via TDRS). 618 Mb/s, 31%	Access & control of experiments. 108 Mb/s (6%)	
	Distribution of science data. 510 Mb/s (25%)	Direct to experimenters. 210 Mb/s (10%) To NASA archives. 300 Mb/s (15%)
Networking of science data base information. 1,389 Mb/s, 69%	Among NASA centers. 369 Mb/s (18%)	
	Among science users and NASA archives. 1,020 Mb/s (51%)	

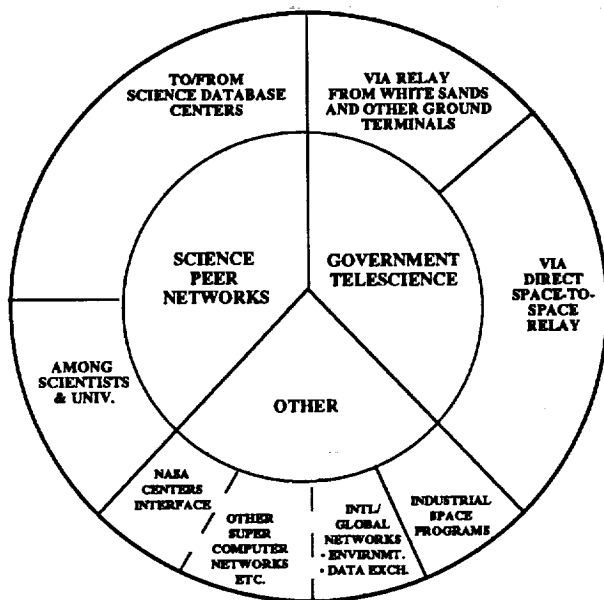


Figure 3-5: Comm. Requirement Categories

data which significantly reduces transmitted data rates).

Both of these factors could be predicted incorrectly when estimating requirements for the period beyond ten years.

Before the user classes can be identified, it is important to define a general set of communications requirement categories. These functional categories are graphically represented in Figure 3-5. Requirements are derived from three functional use areas:

- Telescience,
- Science Peer Networks,
- Other Networking.

Each functional area will demand communication services to carry out operational tasks.

The definition of each functional area is as follows:

**Telescience.** Telescience is the direct, iterative and distributed interaction of users with their instruments, data bases, specimens and data handling facilities, especially where remote operations are essential. This is inclusive of the design, operations, and analysis phases of any space mission.

**Peer Networking.** This includes all non-mission related communications networking for science collaboration during all phases of an investigation.

**Other Networking.** This category represents user functions such as NASA engineering and operations, supercomputing network services, commercial & industrial space activities, and international (global) networks.

Within these functional categories, general user classes can be identified as follows:

1. Space Science and Applications users:
  - Microgravity (life sciences and material processing)
  - Astronomy and astrophysics
  - Earth system sciences (Earth Observing, Space Physics, Planetary)
2. Space technology users
3. Commercial production users
4. Engineering and operations users

It should be kept in mind that all user classes will involve internationally distributed teams and that they will be placing demands on telecommunications services during the entire life cycle (design and development phase, operations phase, analysis and final results phase) of the projects being conducted.

### 3.2.1 Space Science and Applications Users

Space Science is entering a new phase of evolution as they transition from exploration and discovery phase toward a detailed analysis of fundamental features and processes. Research missions in the next 20 to 30 years will undertake systematic, long-term studies of the Earth and its near-space environment, a variety of other bodies in the solar system, studies involving the effects of space microgravity on materials and organisms and the universe at large. The aim is a deeper understanding of the mechanisms that govern the structure and evolution of these systems. Figure 3-6 illustrates the planned Space Science and Applications missions over the next decade.

For this study it is important to examine some of the key trends in space science research and space science information systems (OSSA/OSO Information System Strategic Plan) which will have direct implications on the overall telecommunications architecture and specifically on the Data Distribution Satellite.

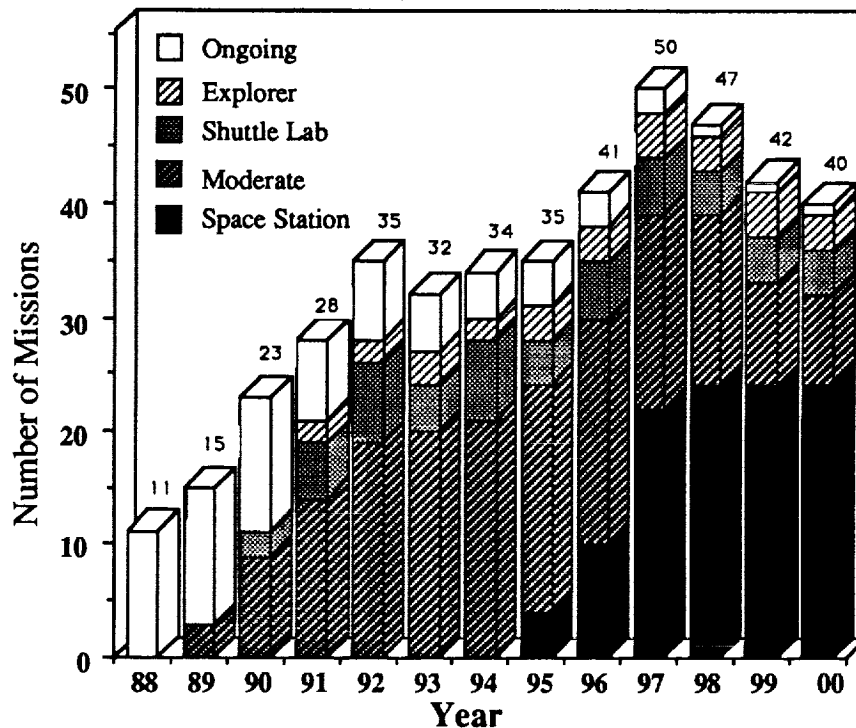


Figure 3-6: NASA OSSA Missions for the Next Decade

### 3.2.1.1 Trends in Space Science Research

1. Shift from single-investigator exploration to collaborative, in depth efforts. A basic understanding of these complex processes requires the collection and integration of multiple data sets through integrative numerical modeling aimed at predictive capabilities.
2. Growing numbers and complexity of instruments. As space science seeks a more detailed understanding of complex phenomena, greater numbers of instruments will be employed for simultaneous or complementary measurements. Moreover, the instruments themselves will be more capable and hence more complex than before. The single Principal Investigator (PI) will increasingly be joined by entire teams of scientists at distributed locations with group responsibilities for the success of large, facility-class instruments, particularly on the Earth Observing System and Space Station Freedom.
3. Lengthening mission lifetimes. Instead of the short lifetimes typical of most space missions through the 1980's the next decade will see many more missions with lifetimes in the 10-15 year range, such as the Earth Observing System and the Hubble Space Telescope, as well as Space Station Freedom, with a 30 year lifetime. These extended observing programs are needed to gather the long-term data sets required for detailed analytic study. For these missions, data operations and analysis costs, as a fraction of total mission cost, will rise accordingly.
4. Increase in numbers of missions in concurrent operation. This trend results from lengthening mission lifetime and projected increases in the numbers of missions to be launched.
5. Unification of subdiscipline projects within major disciplines. Formerly separate projects are now being viewed as contributions to research within a broader discipline. For example operation of the four Great Observatories will be closely coordinated within NASA's Astrophysics Division, and the needs of a wide variety of Earth-science subdisciplines will be addressed by a unified Earth Observing System program within NASA's Earth Science and Applications Division.
6. Increased geographic distribution of investigators.



Lengthening mission lifetimes make it infeasible for scientists to participate in space experiments continuously at a central location. Moreover, long-term data analysis is most effectively done at the scientists' home institutions. In the future, many aspects of scientific observing and data handling will be carried out remotely from investigator sites or Discipline Operations Centers (DOCs).

7. Interactive science operations. Shorter system response times are needed by many science disciplines for greater scientific productivity and operational efficiency. Typically, response times ranging from immediate up to several orbital periods are required to permit investigators interactively to set up their experiments, acquire a target, respond to unpredicted changes in the target under study (e. g., climatic changes, response to solar flares), and alter observational or experimental conditions to accommodate these changes.
8. Growing demand for operational continuity. In the past, investigators have been confronted with different operating environments and user interfaces with each new project, and at each new phase of the same project. Scientists are now demanding that information-system services, service interfaces, and programmatic requirements be consistent throughout the life cycle of an instrument or experiment - i. e., from conception through post-mission analysis and archiving of data.
9. Diversity of research modes. The traditional, case-study mode will be more widely supplemented by two additional research modes long used in some disciplines. In the survey mode, continuous data sets are gathered systematically for the study of long-term trends (e. g., global change, all-sky surveys). In the campaign mode, specific targets of opportunity are studied by a wide range of different techniques (e. g., Supernova of 1987, the Antarctic ozone hole). In addition, Space Station Freedom will provide the much longer capability for space life-sciences and microgravity experiments of much longer duration than is possible through today's Space Shuttle missions.
10. Increased interdisciplinary and multidisciplinary research. Growing numbers of research problems cross disciplinary boundaries, e. g., solar structure as an aspect of stellar evolution, influence of

the Sun on the Earth's climate, and comparative planetology with applications to Earth evolution. Archives and user access to data sets will need to be designed with these scientific interactions in mind.

11. Growing demand for archival research. More space-science research will be done through analysis of archival data. Archives of space-science data are coming to be regarded as a vital national research resource, and their preservation is a significant concern.
12. Increased international cooperation. Many of the major space missions now being planned or under development are bilateral or multilateral international collaborations. The scientific research community served by NASA is becoming more international as well.

### 3.2.1.2 Trends in Space Science Information Systems

1. Higher data rates. These follow first of all from the increased numbers and complexity of instruments on future free-flying spacecraft. In addition, future life-sciences and microgravity experiments on Space Station Freedom will require high-rate telemetry of images and other information that are presently captured by film or transmitted at restrictively low data rates.
2. Greater data volumes. These are a consequence of higher data rates combined with longer mission lifetimes. On the basis of the OSSA mission model, annual data volume is projected to rise from 500 gigabits in 1989 to more than 2,500 terabits by the late 1990's as illustrated in Figure 3-7. It should be stated that this data volume represents the amount of level zero data products being transmitted from instruments in space or on the ground to the database facility.

These estimates have been strongly constrained by existing TDRSS and NASCOM capabilities. If Level 1, 2, 3 or higher data products are included, the unconstrained data rate estimates for all Space Science operations over the next 15 years will be considerably higher (between one and two orders of magnitude larger).

3. Increased capability of supercomputer models. Machines that represent the state of the art in speed and storage capacity, together with other specialized processors, are capable of significantly increasing the accuracy of numerical modeling. These must be accessible to the distributed user community through associated support services to take advantage of their capabilities to solve more complex problems posed by scientific investigations planned in the 1990's.
4. Aggregation of standard, routine data processing and data archiving at the science-discipline level. This development reflects and parallels the trend toward aggregation of individual; research projects within a discipline.
5. Distribution of non-routine and interactive data processing and user data bases to investigator sites. Such steps are needed to accommodate increases in the numbers of widely distributed investigators and to allow these scientists to certify the resultant data products.
6. Continued centralized coordination of operational resources with distributed experiment/instrument planning, scheduling, and operations. This approach combines the efficiencies of centralized services with new opportunities for remote instrument operations.
7. Development of tools to support coordinated science operations and analysis between and within disciplines. This trend is a consequence of the new emphasis upon the investigation of large-scale phenomena, coupled with growing emphasis upon collaborative research.
8. Adoption of standard definitions, lexicons, and data-interchange formats. These are needed to provide ready access to information derived from campaign-mode, interproject, and interdisciplinary research.
9. Development of large data archives and associated master directories and catalogs with remote access through networks. Such resources are needed to meet the growing demand for archival research and to ensure its efficiency and productivity.
10. Increased need for onboard operations management capabilities. These are required to support

the trend toward exploratory and adaptive science operations contained within the telescience concept.

11. Increased necessity for security in operational and data-distribution communications. Security concerns are rising as information systems users become increasingly distributed, and as the number of international users expands. These concerns will need to be reflected in system management as well as architecture.

Although the different disciplines comprising the space science and applications user community may have unique levels of telecommunications requirements, the trends stated above are generally applicable to all of the disciplines.

### 3.2.2 Space Technology Users

Technology development is a broad category that cuts across many disciplines and includes the development and demonstration of advanced space technologies in such diverse areas as robotic systems, dynamic power systems, space structures, space instrumentation, communications technology, and space-borne computer architectures (Figure 3-8). Although the majority of missions mentioned above would be sponsored by NASA, other international space agencies, and the Department of Defense, considerable other R&D activities can be seen to come from the industrial sector. Since these efforts are primarily of a R&D nature, they belong in this user class rather than being included in the commercial production class.

It is of interest to make comparisons for similarities and differences between the space science and the space technology users' operation modes. The following technology user characteristics are prevalent today:

- Individual experiments with singular organizational management structures are common.
- At present, most technology demonstrations or R&D efforts are short duration activities. Most investigations are to only test and verify a system or procedure and record the results.
- Geographic distribution of investigators is minimal.

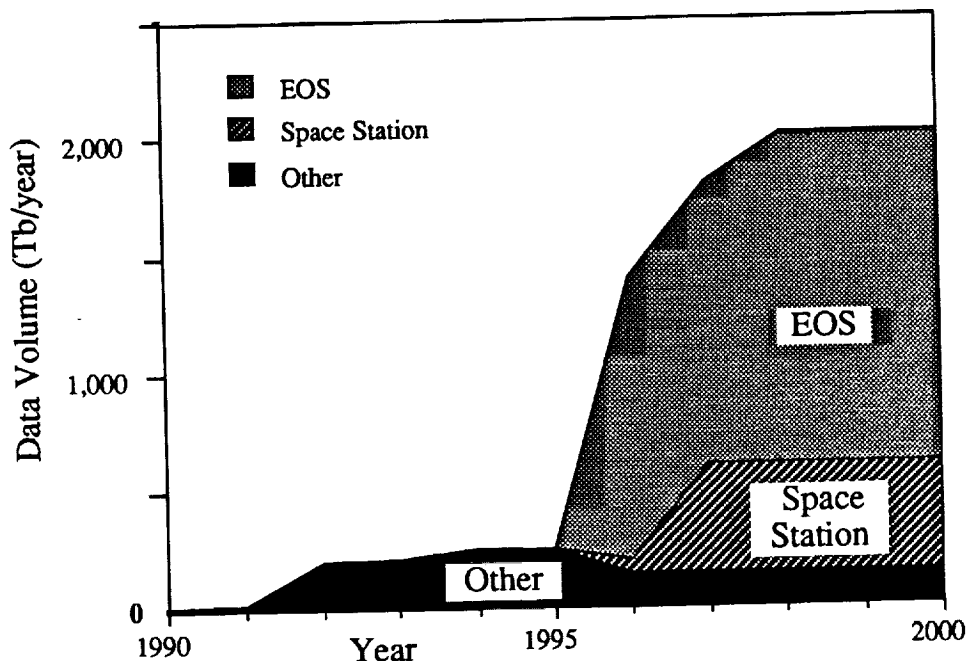


Figure 3-7: Annual Data Volume for the Next Decade

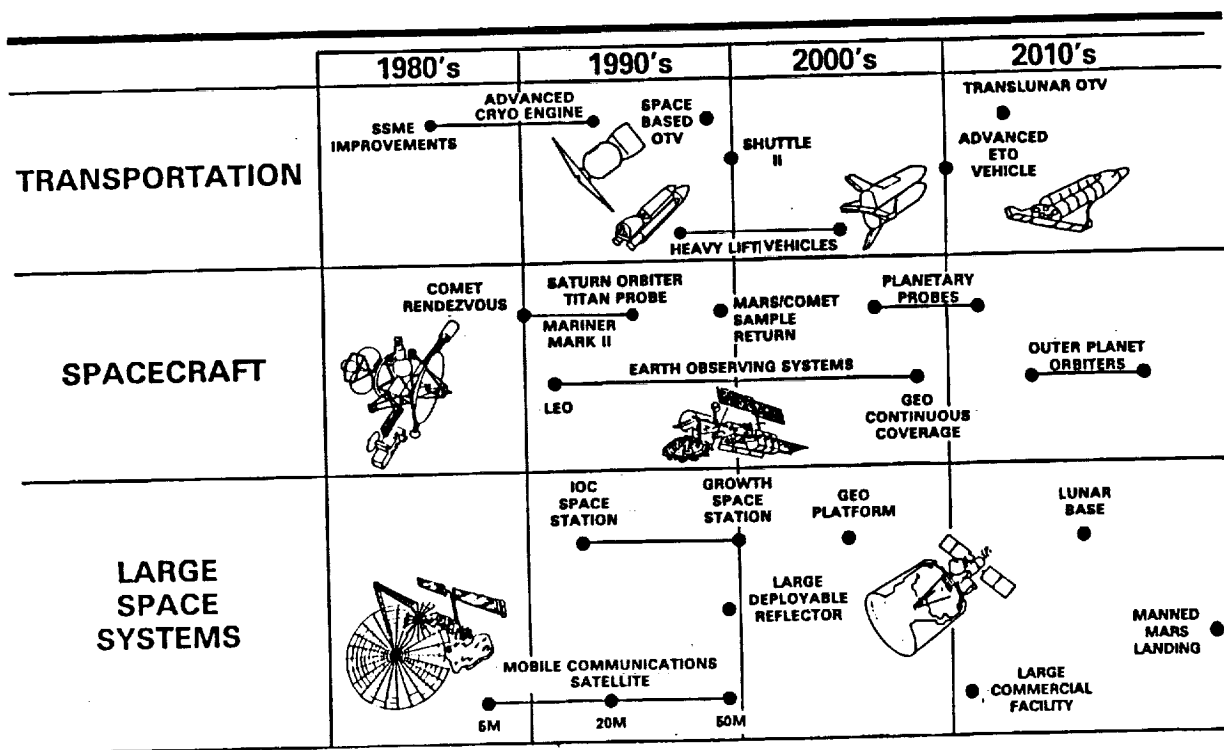


Figure 3-8: Space Technology Users

- Interactive operations. The telescience mode is required primarily during the teledesign and teleoperations phases. The teleanalysis activity has limited utility for most demonstration projects at this time.
- Need for archival research only starting.
- International team efforts are minimal. Because of the technology transfer issues or national competitiveness, most technology R&D efforts are only national in extent.

For most of the characteristics described above, they are comparable to the space science research characteristics of 15 to 20 years ago. The trend toward international efforts in industry for product developments and R&D would indicate that within 10 years the operational mode of the technology user class would be similar to the space science community. Specifically, over the next 10 to 15 years, the technology user community will show a dramatic increase in:

- Long term R&D efforts. Instead of the few (1-5) demonstration flights, a trend toward long-term experiment programs lasting 5 to 10 years will occur.
- The geographical distribution of the R&D teams. The degree of international participation on these teams will be significant.
- The creation and use of R&D subject-specific archival databases. Communications network access to historical databases of R&D experiment results will be required by international team members.
- The demand for the full services of the telescience concept. It can be seen that time-to-market, competitive edge, and productivity issues will rapidly drive industrial R&D efforts to adopt the full range of telescience services.

### 3.2.3 Commercial Production Users

This class of users is composed of private firms which plan to conduct pilot or operational production activities taking advantage of the characteristics of the space environment. These users are much more sensitive to scheduling and proprietary operations considerations, since they must meet financial and competitive business

goals of the marketplace. In comparison to the traditional space research community, many of these users have a low level of space experience, and require support in formulating their space activities and meeting procedural requirements.

Commercial space today is an economically immature field. Industry lacks the technical and financial knowledge base to make informed space investment decisions, and demand for space services is understandably tentative. At present industry sees extremely high total project cost associated with space activity. Because of high total costs, high perceived risks, and lack of a mature technical and financial knowledge base for space activity, industry is approaching space commercialization very tentatively. At present, the bulk of commercial space activity is focused on early-stage, company-focused research, and it is anticipated that such exploratory projects will remain the bulk of space activity over the next 10 years. Production in space for profit is still a distant goal. Before such a goal can be realized, new entrants to the space field need to carry out basic projects to gain technical and financial knowledge of this enterprise.

Demand for commercial space activity is determined largely by four factors:

- i. Alternatives to space,
- ii. Risk versus return appraisal,
- iii. R&D budget available, and
- iv. Total cost of the project.

To project possible demands on Data Distribution Satellite services, it is important to understand the relative importance, today and for the next 35 years, of these four factors.

**Alternatives to space.** Companies that might consider investing in commercial space activity have a number of alternatives available. A firm may elect to invest its money in ground-based research, or to use foreign space services, or to carry out a different project entirely. In addition, Space must also complete with alternative investment opportunities which drain funds away from space-based R&D. Firms contemplating costly, high-risk space-based R&D projects fear that Earth-based technology will overtake them (Figure 3-9). Because of the extremely long time needed for a space-developed

**Firms contemplating costly space-based R&D projects fear that Earth-based technology will overtake them.**

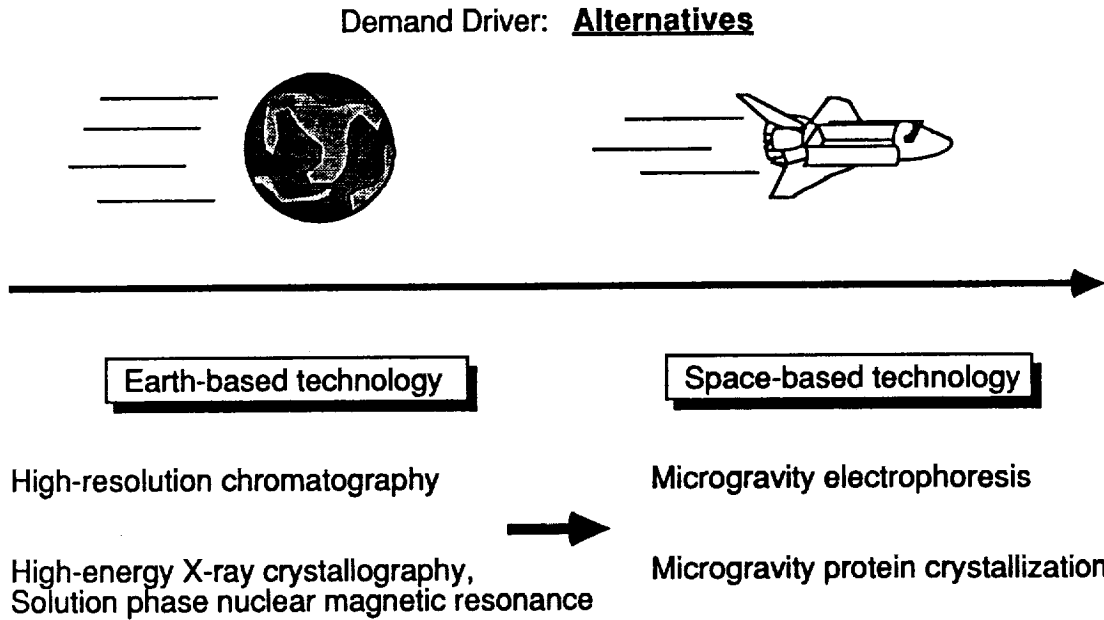


Figure 3-9: Earth-Based Alternatives to Commercial Space-Based R&D Activities

**Companies unfamiliar with space must weigh uncertain benefits against substantial up-front costs & risks.**

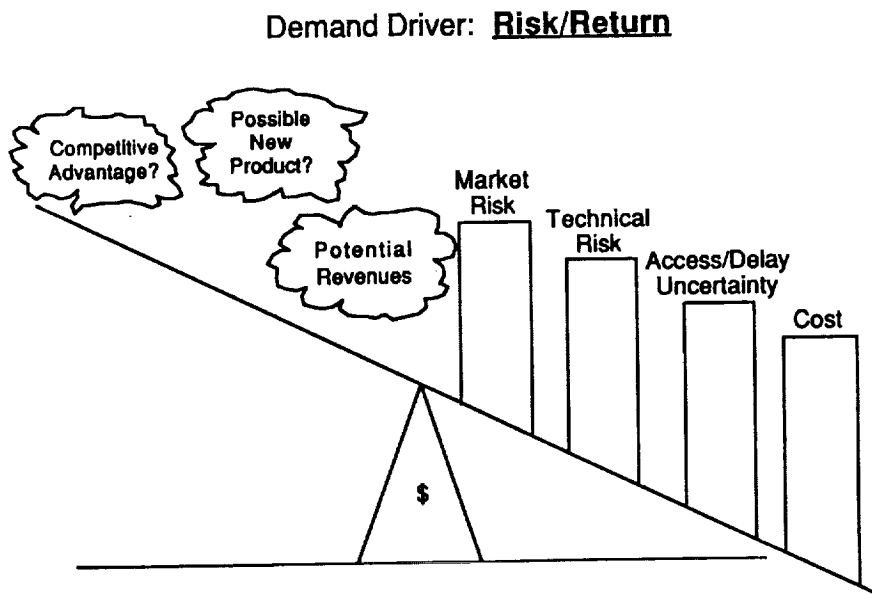


Figure 3-10: Risks Involved in Space Activities Reduce Demand for Space R&D

product to evolve from the research phase to actual commercial viability, advances in Earth-based technology pose a great risk to firms.

**Risk versus return.** Unfamiliarity with the technical requirements of space activity is a formidable barrier which raises the perceived risks of a project. Market uncertainty, due to a lack of mature markets for space-produced goods and services, is another large component of risk. Cost uncertainty, due to a lack of established economic knowledge base, also increases perceived risks. All of these risks are interrelated; for example, technological setbacks raise costs, and uncertain costs in turn affect production and marketing forecasts. Expected returns are uncertain because of the lengthy time periods involved, and also because future cash flows must be discounted for both risk and the cost of money. Financial returns to early research are uncertain due to technical and market risks, as well as the inability to assign product cash flows to early-stage R&D investments. These risk/return issues are illustrated in Figure 3-10.

**R&D budgets available.** Studies indicate that companies typically spend in the neighborhood of \$50,000 to \$200,000 per year per project on exploratory or early-stage research, i. e. research with potential but high risk of failure. The effects of exploratory research budget limits placed on space project spending can be seen today. Space-based research accounts for only a small fraction of total R&D expenditures by U. S. corporations.

Total corporate R&D spending in 1986 amounted to \$51 billion, of which about half (\$24 billion) was spent by companies in seven industries where space-based research is directly relevant (aerospace, chemicals, drugs and pharmaceuticals, electronics, information processing, metals, and semiconductors).

These companies spend on average 20% of their total R&D budgets on basic research (\$5 billion), of which 3% to 15% is spent on high-risk exploratory research (\$500 million). Almost all of this activity is funded through discretionary R&D money, for which competition among programs is intense. Only 5% to 10% of these funds are spent on space-related R&D programs; It is estimated that this amounts to between \$5 to \$10 million per

year in the U. S. (Figure 3-11)

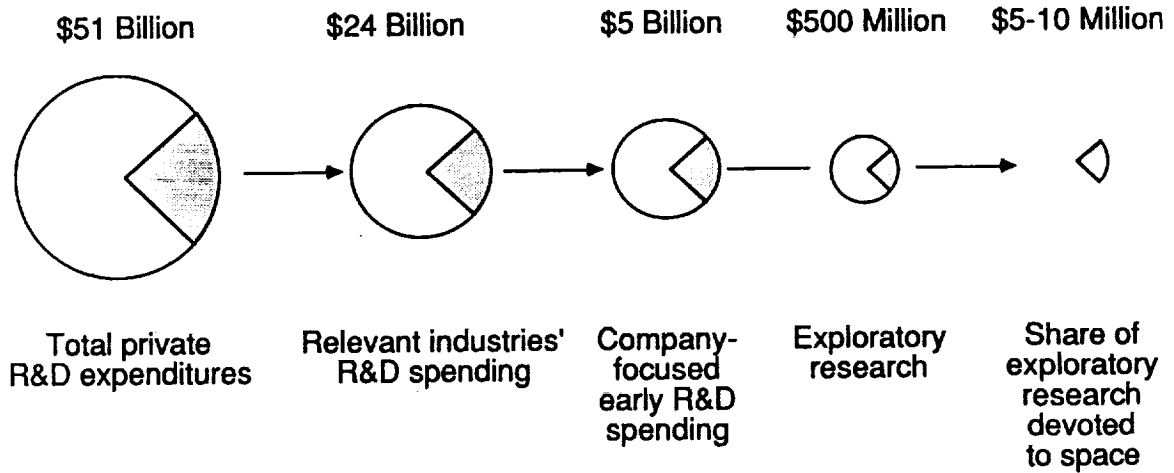
**Total costs.** Industry perceives high cost as the greatest obstacle to space activity. Of 34 companies interviewed in the 1987 Foundation for Space Business Research study, 18 ranked cost or cost uncertainty as their main obstacle to participating in commercial space activity. 21 of the 34 (62%) ranked cost or cost uncertainty either first or second in importance from a list of four risk areas analyzed by the study (Figure 3-12). These were cost, access, NASA, and proprietary considerations. A major reason for industry's concern over cost is the scarcity of cost information. Firms contemplating space projects need such information if they are to make informed investment decisions. At present, they cannot take advantage of the economic knowledge and experience of others because the information either is not available or is not presented in a usable form.

### 3.2.4 Engineering and Operations Users

Every space activity during the space station era must provide an ongoing engineering support capability to sustain the performance of operational space systems. It is anticipated that this support will be provided through distributed Engineering Support Centers (ESCs) located at funding organizations' (NASA and other space agencies) development and launch sites. The ESC provides personnel and technical analysis capabilities to support routine space systems sustaining engineering activities as well as "on call" support to the space system execute teams for analysis of unanticipated situations onboard space-borne systems. These operational users have dynamically changing requirements for distributed functional engineering data to provide the services indicated above. As the technology changes and the operational and support engineering personnel learn about it, accept it, and take ownership of it, the requirements for telecommunications services will significantly change. These requirements can not be satisfied by the baseline architecture of the Space Station Program since this baseline was established early in the life cycle and remains relatively static as the program proceeds to the operational phase. The Data Distribution Satellite could play a significant role in addressing these emerging requirements for communications between distributed functions and data bases.

**Only a small fraction of U.S. Corporate R&D expenditure is devoted to space-based research.**

Demand Driver: R&D Expenditures



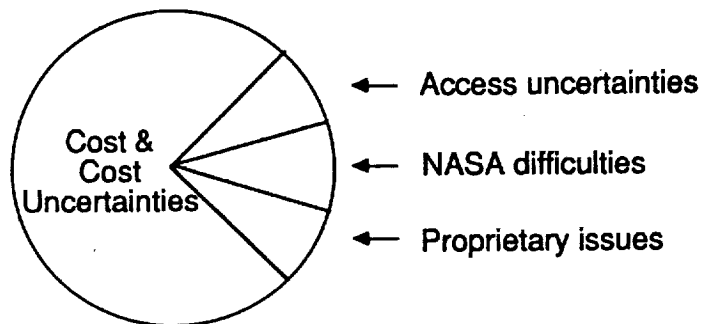
*Demand, and thus expenditures, for space R&D is low because the risks are high relative to other exploratory R&D alternatives.*

Figure 3-11: Portion of U. S. Corporate R&D Devoted to Space

**Industry perceives cost as the greatest obstacle to space activity.**

Demand Driver: Total Cost

Interview results:  
Perceived greatest obstacles to commercial space activity



Over 60% of companies interviewed rank cost and cost uncertainties as 1st or 2nd of the greatest obstacles to participating in space activity.

Figure 3-12: High Costs to Conduct Space R&D Reduces Demand for Space Activity

Space system sustaining engineering (for all international space activities) can be viewed as being divided into three major categories:

- i. Systems maintenance engineering (engineering required to keep baselined space systems operating at peak performance);
- ii. Systems design engineering (engineering analyses performed in support of design modifications); and
- iii. Payload integration engineering (engineering in support of user payload operations and integration).

#### **Systems Maintenance Engineering.**

This category includes the engineering support required to keep space systems operational. This consists of planning and execution support provided by the launch site and development center ESCs on space systems repair hardware, and ESC analyses of assigned flight hardware, including: engineering analyses, safety analyses, anomaly tracking and disposition, maintenance procedures development and verification, modification, repair, installation, testing and flight certification. It also includes the management, control, ground personnel training and scheduling required to perform these activities, as well as technical coordination with contractors and other interfaces.

**Systems Design Engineering.** This activity will be performed by the development center ESCs (routinely or upon request) on their assigned space systems hardware and software, including: performance and trends analyses, safety analyses, anomaly tracking and flight hardware systems disposition, design engineering, procedures development and verification, modification, repair, installation, testing and flight certification. This also includes the management, control, ground personnel training and scheduling required to perform these activities, as well as technical coordination with other ESCs contractors, and government interfaces.

**Payload Integration Engineering.** This category supports user payload operations and integration at the launch site or development center ESCs (routinely or upon request) on approved payloads including: space systems compatibility analyses,

safety analyses, payload to space element integration, and development of test and checkout procedures. It also includes launch site installation, testing and flight certification. Additionally, it includes the management, control, ground personnel training and scheduling required to perform these activities, as well as technical coordination with users, other ESCs, contractors, and government interfaces.

It is important to understand that operational and engineering users will have an increasing need to continuously improve the productivity and cost-effectiveness of space system sustaining engineering. This will place demands on the presently over-subscribed telecommunications capabilities (i. e., TDRSS, NASCOM, etc.) and will put demands on programs which can only be satisfied by new capabilities.

### **3.3 Operational Concepts**

The space station era (1990–2025) will be one of dramatic changes in the way we operate and utilize space systems. This is primarily due to two important elements:

- Global impacts of “information age” technology (communications and information systems). This capability enables international teams to productively and efficiently work together and share information in a timely way to address global problems.
- Space as an essential environment to address global problems. The most critical and pressing of these problems is global environment change. The interactive nature of the Earth’s environmental system is being recognized world-wide. The Earth as a system is a concept that has emerged from such critical problem studies as the global condition due to greenhouse warming, the hemispheric effects of Antarctic ozone “hole”, the potential consequences of the loss of bio-diversity due to large-scale conversion of land usage (deforestation), and change in regional rainfall patterns due to changes in climate and atmospheric circulation.

A major driver in defining the operational concepts for the next 30 years will be the International Space



Station and its associated space platforms (e. g. the polar platform of the Earth Observing System [EOS]). Although this does not represent the entirety of space systems to be utilized over the era, it will play a dominant role. Another operational concept to emerge from the Space Station efforts is the utilization concept of "tele-science".

This operational concept has now extended beyond the Space Station and is seen to be applicable to all activities which involve distributed functions and people. The next two subsections will describe the general operational concepts of the International Space Station and the Earth Observing System (EOS) Programs. It will also address and describe the emerging concept of tele-science and its impact on telecommunications and information system design.

### 3.3.1 Space Station Freedom Concept for Operations

Space Station operations can be divided into three basic categories of activity:

1. Logistics operations support,
2. Space operations support, and
3. Space operations.

These are depicted for both the manned base and platforms in Figures 3-13 and 3-14.

Logistics operations support encompasses two primary types of activities:

- i. Integrated logistics support at a centralized launch site facility, and
- ii. Prelaunch and post-landing processing of flight hardware performed at one or more launch site facilities as well as at distributed Science and Technology centers.

Integrated logistics support will include the management, engineering, and support activities required to provide personnel and materials to the Space Station elements reliably and in a cost effective manner.

Prelaunch processing of user payloads at Science and Technology Centers is at the payload-to-rack integration level; at the launch site, racks are integrated into logistics transport elements along with other space systems consumables, orbital replacement units, and operational equipment and certified ready for handover to transportation systems personnel for launch to orbit.

Space operations support activities are distributed to various NASA, international partner and user support centers and include the full complement of ground based actions which support the Station on orbit. This will include such activities as operation and management of the communications up/down links to the Station, control of those hardware functions most effectively performed on the ground (e. g., routine systems monitoring), Station resource availability and utilization assessments, space systems and user operations planning, trajectory and altitude maintenance and crew training and real-time support to crew members.

Space operations consists of all of the activities which transpire on orbit. This embodies all of the activity performed by the crew to maintain system integrity and to perform user support activities.

Operations execution includes the detailed tasks associated with implementing the various execution plan and flight increment schedules established by the Increment Execute Planning process, and applying these to the three major areas of Station activity: logistics operations support, space operations, and space operations support. These activities will be performed at NASA Support centers, as well as at international partner and user operations facilities (see Figures 3-15 and 3-16).

These facilities include:

**Space Station Support Center (SSSC)** is an Station Program supplied facility which provides for centralized systems management and control for the manned base, including the elements provided by the international partners (Japan, European Space Agency, and Canada). Crew and manned base safety are SSSC responsibilities as well. The SSSC provides the systems "templates" for development of Tactical Operation Plans, Flight Increment Plans, and increment execute plans and data. It integrates and approves the payload activity schedules developed by the Payload Operations Integration Center (POIC). Crew training facilities are closely associated with the SSSC and POIC. International partners will support the conduct of operations for their elements by providing responsible flight control staff at the SSSC, as well as providing real-time engineering support from facilities located in their own countries. The SSSC will normally be transparent to the user community during routine payload operations.

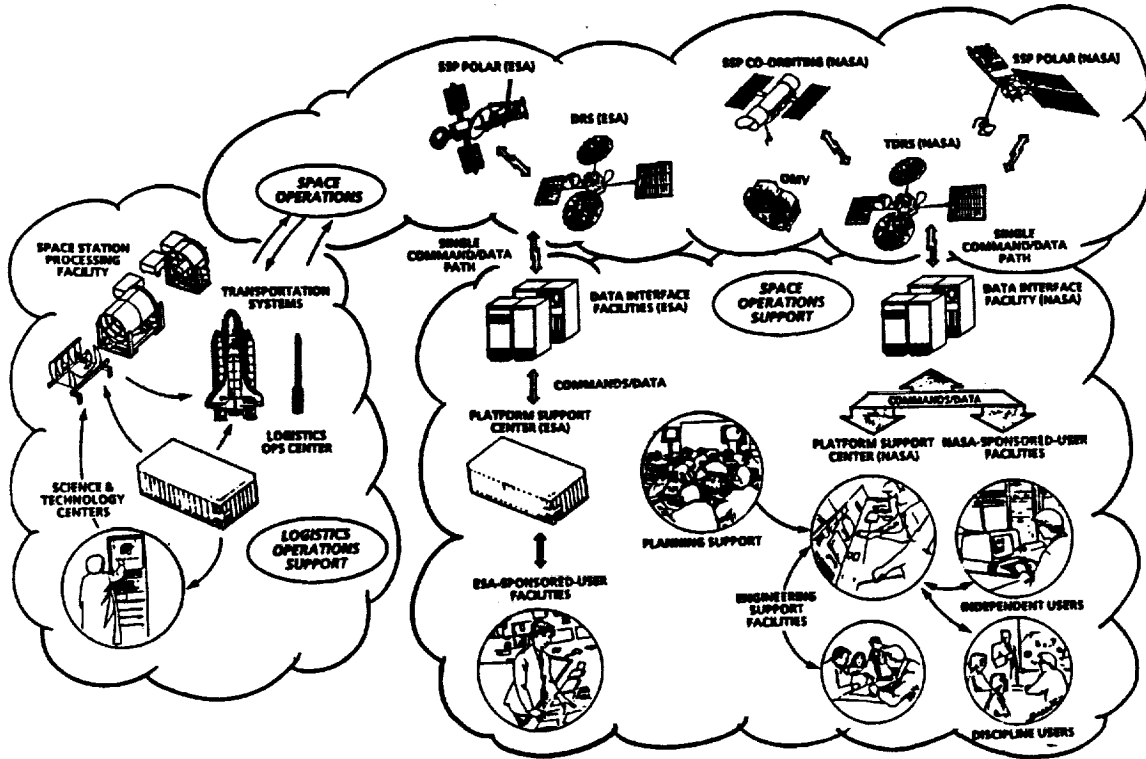


Figure 3-13: Manned Base Operations Infrastructure

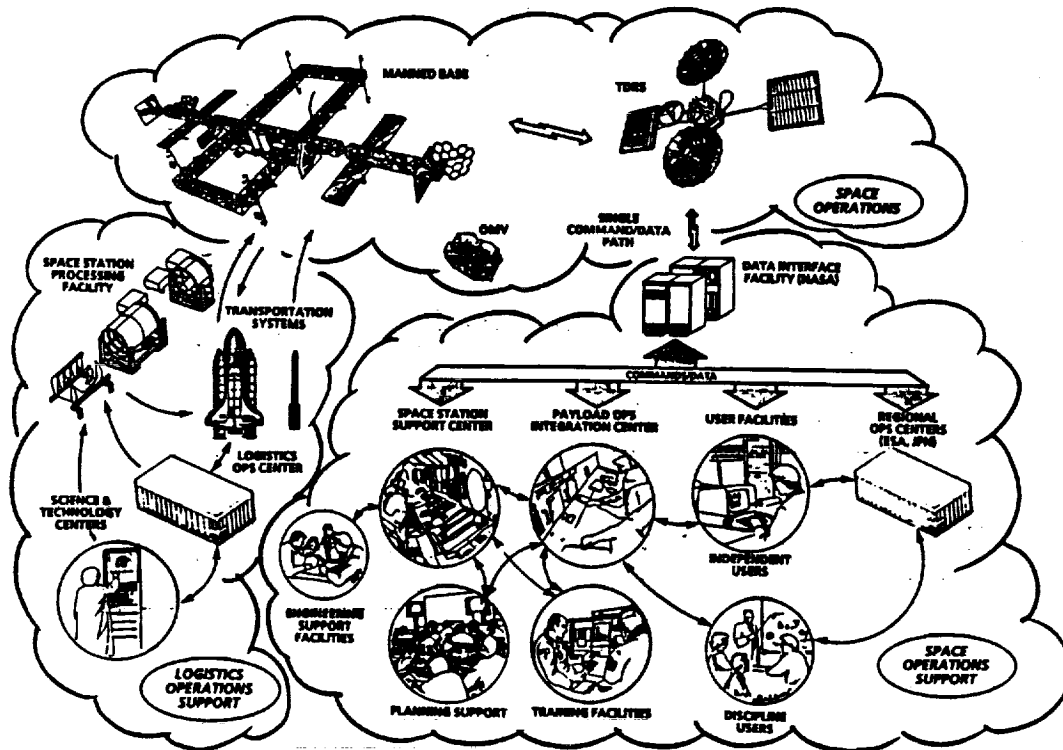


Figure 3-14: Platform Operations Infrastructure

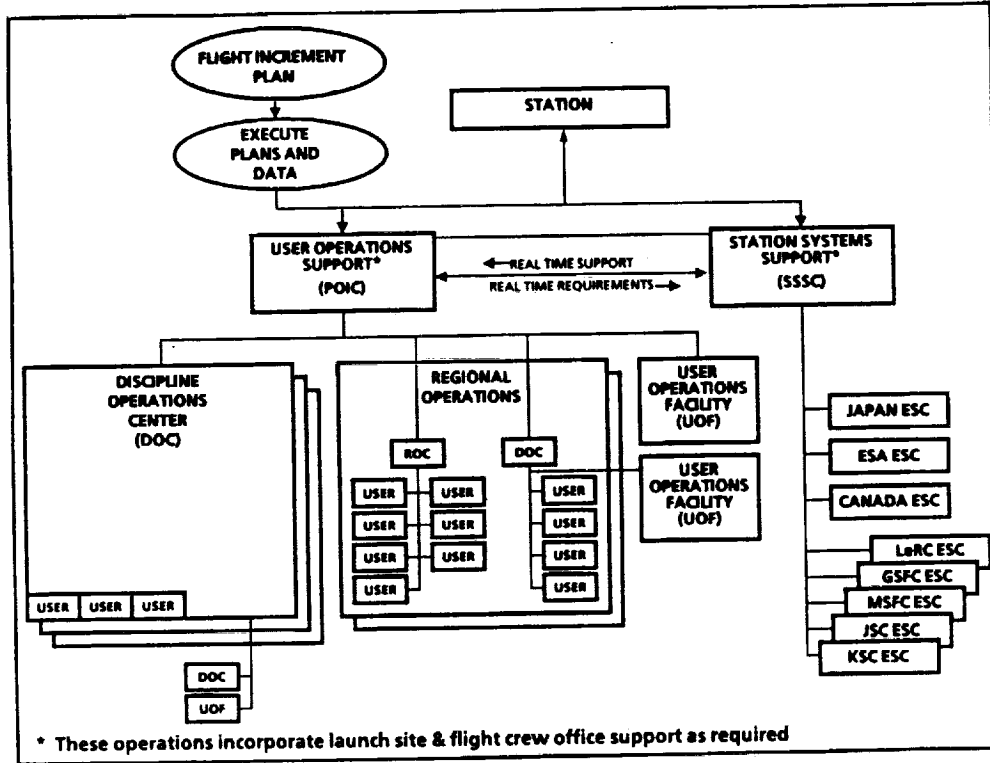


Figure 3-15: Manned Base Operations Framework: Real Time Operations, Systems and Users Support

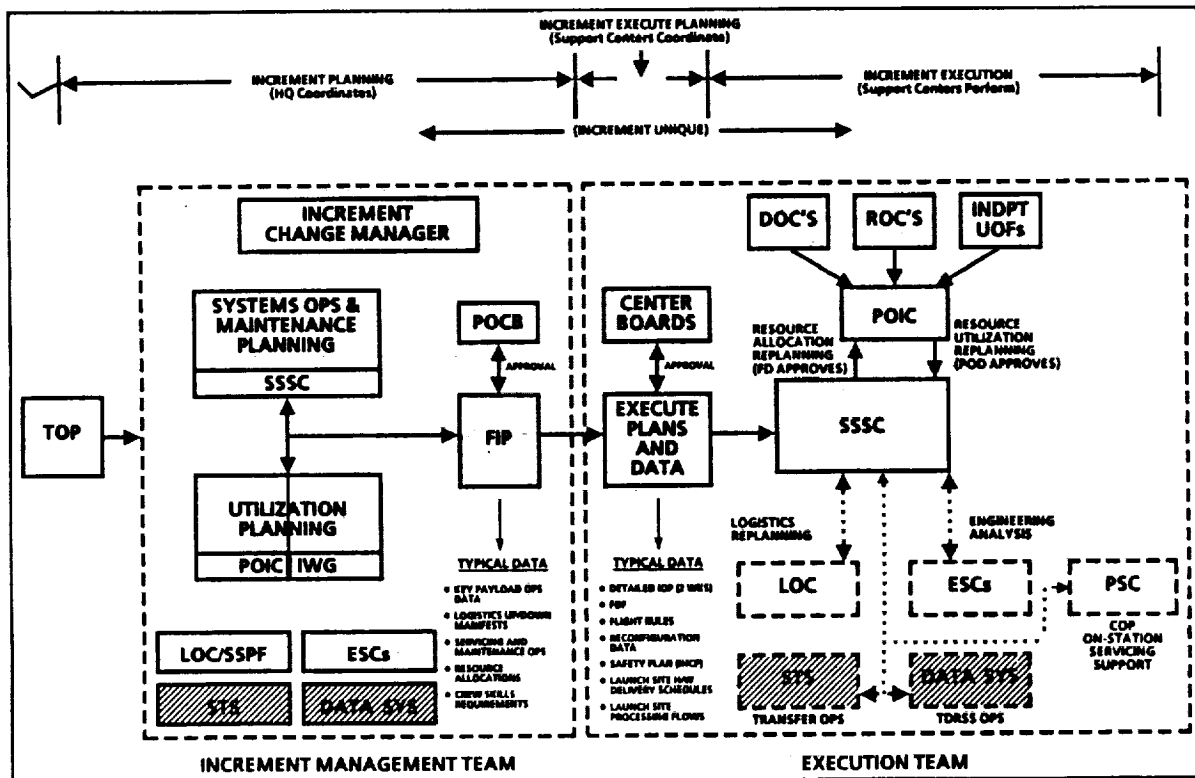


Figure 3-16: Increment Execute Planning Process Flow

**Payload Operations Integration Center (POIC)** is a Space Station Program supplied facility whose major function is to coordinate user activities for the manned base, building on the template provided by the SSSC. It integrates the user requirements according to user resource envelopes, assists users in periodic "replanning", aids the IWG in user conflict resolution, and supports the various user facilities in real-time or near real-time execution activities. On-orbit crew time and other resources available for users are managed by the POIC in cooperation with the SSSC.

**User Operations Facilities.** A variety of user supplied and operated facilities are envisioned to meet specific needs of the users. They can be equipped to support the range of user operations involved in payload management (i. e., planning and execution related to command, control and communications for experiments, data analysis and storage). These facilities shall be established according to user preference. However, it is foreseen that three basic approaches will be formulated by the user communities:

1. Discipline Operations Center (DOCs);
2. Regional Operations Centers (ROCs); and
3. Stand-alone or proprietary User Operations Facilities (UOFs).

DOCs are user supplied and operated facilities which provide support to an international discipline user group which is centered around a specific area of investigation. They are intended to allow for the sharing of technical support and overhead costs to users with similar discipline needs. The DOCs will interface with the POIC for coordination of their payload planning activity. Examples of discipline categories include materials science, life science, technology development and earth observation.

The ROCs are international user supplied and operated facilities which are geographically focused to provide support to regionally-based user groups. The intention is to share common overhead costs or technical interests with regionally grouped users. Regional operations facilities will interface with the POIC for support in scheduling and real-time replanning activities.

Stand-alone or proprietary UOFs may be desired by certain users willing to pay for the added privacy of a dedicated facility. They may be physically collocated at a Space Station Program site, or at user-selected industrial, research or academic sites. Each facility may be affiliated with a DOC or ROC, or may independently report directly to the POIC for integration of their plans and requirements with those of other users.

**Space Station Processing Facility (SSPF)** does the prelaunch processing of all space Station hardware to be transported to orbit via the STS. (Similar facilities will exist at other international launch sites.) The SSPF will perform all interface and safety verification testing for the Program before delivering payloads and carriers to the transportation operations organization for STS or ELV integration.

Payload integration will be performed in a modified "ship and shoot" mode. Users may build and/or integrate racks and experiments at "Science and Technology Centers" certified by the Program. These centers may be located at NASA Centers, international partner facilities, or UOFs, and are likely to evolve from existing institutional payload development capabilities. Launch sites will also have a capability to build up and/or integrate payloads for users. All payloads and orbital replacement units (ORUs) will undergo final interface testing at the launch site.

**Logistics Operations Center (LOC)** operations are located and managed at the launch site. The Program-supplied LOC will be responsible for the development of the manned base increment maintenance plans and assuring that the procedures, tools and materials to support these plans are available on time. In addition, it will be responsible for the storage, inventory management and maintenance of all Station system parts and payload carriers. This includes supporting a line item population on the order of 300,000 items including 2500 ORUs. A key feature of the LOC will be its extensive use of automated test equipment for in-house maintenance and repair.

**Engineering Support Centers (ESC)** are located at Space Station Partner hardware development centers and the launch site. These Program-supplied

"facilities" will provide engineering and real-time consultation support on an on-call basis. They also will perform sustaining engineering in the Development and early Mature Operations Phases. The operations framework calls for development of a transition plan which would eventually centralize sustaining engineering for U. S. orbital elements at KSC during the Mature Operations Phase. Sustaining engineering for international partner orbital elements and for ground support systems and information systems would remain distributed to the partner sites and U. S. operations centers, respectively.

#### 3.3.1.1 Platform Operations

The unmanned platforms will be operated by the contributing international partners and separate from the manned base to provide maximum flexibility in user operations. Long term operations planning will be coordinated with that for the manned base, but tactical and execution level activities will be largely independent, except for the servicing and maintenance of co-orbiting platforms at the manned base. Platform operations will be managed in a manner similar to current unmanned satellite programs, with extensive support for user tele-science operations.

It is anticipated that platform increments (the time between STS or manned base maintenance and servicing activity) will vary greatly in duration, depending on platform mission objectives and planned orbital lifetime. This results in the need to maintain a flexible approach to the flow of utilization and operations planning documentation at all management levels. Given the temporal scope of the Consolidated Utilization Plan (five years) and the Tactical Operations Plan (two years) and the fact that platform increments are, in any case, much longer than their manned base counterparts, a platform's planning documentation will be much more simplified.

U. S. platform payload and platform transfer operations will be managed and controlled by a Platform Support Center (PSC). The PSC functions for platform systems control and user support are analogous to the SSSC and POIC functions in the manned base. Support to users for payload operations will be coordinated in the PSC by the Platform Payload Operations Center (PPOC). Actual payload operations will be performed by individual users in user facilities. Platform

transfer operations will be planned and conducted in the PSC by the Platform Transfer Operations Center (PTOC). The PTOC will support specialized servicing planning requirements and interface with the manned base and STS increment planning activity. Transfer operations will be managed by the STS operations organization when the STS or STS-based Orbital Maneuvering Vehicle (OMV) is the servicing vehicle, and by the SSSC when these operations are performed by the Station-based OMV, and when the Consolidated Utilization Plan is brought within the command and control zone for servicing at the manned base.

As with the manned base, platform operations will be supported by the Programs ESCs, Logistics Operations Center, Space Station Processing Facility, and the space transportation system(s). The Space Station Information System supports user tele-science requirements by providing direct access to platform payloads.

#### 3.3.1.2 Space Station Information System

The Space Station Information System (SSIS) will be an end-to-end data and information system for the Space Station Program and its users. It is important to understand that the SSIS will not be an "all-new", completely dedicated "system" for the Program. Rather, the SSIS is better characterized as a concept or virtual network consisting of both existing and planned operational elements provided by NASA, the international partners, and users of the Space Station. The SSIS will support the functions of:

- Prelaunch checkout,
- Mission management,
- Scheduling and control,
- Software development, and
- Acquisition, transmission, recording, processing, accounting, storage, and distribution of data (including audio and video) produced by the Space Station Program, its users, and interfacing space and ground elements.

Although the SSIS is often thought of as only the flight critical operational end-to-end information system, it is apparent from the above definition that the scope of SSIS activities is much broader. The SSIS includes real-time networks supporting flight activities

(commonly referred to as "SSIS", a source of some confusion), and non real-time capabilities [i. e., the Technical Management Information System (TMIS) and the Software Support Environment (SSE)]. The Space Station Program recognizes this broad scope and supports the concept of interoperability among the three systems.

The operational SSIS contains a "core" set of space and ground elements. These elements provide the functionality required to provide direct support to flight operations and interfaces to external elements. Figure 3-17. illustrates this concept with the central region representing the operational SSIS. Certain systems, such as TMIS and the international partner systems, have functional overlaps that are considered part of the SSIS core while other systems simply interface with SSIS through "gateways" managed and controlled by the Program. This figure also make it clear that the SSIS must be capable of expansion as overall Program capabilities evolve.

The operational sub-networks within the SSIS core include onboard data and communications capabilities (e. g., Data Management System and Communications and Tracking System), ground control systems (e. g., the SSSC and POIC for the manned base; the PSC for platforms), user ground command, control, and data processing facilities (ROCs, DOCs, and UOFs), and the communications links between flight and ground elements. These links are provided by the TDRSS for space-to-ground communications and by NASCOM for ground data transport. The interface for the space links to the ground links occurs at the TDRS ground terminal at White Sands, New Mexico. The Goddard Space Flight Center (GSFC) manages and controls the TDRSS and NASCOM and provides data transport services in response to request generated by the SSSC for the manned base and its users, the PSC for the platforms and their users, and the STS Mission Control Center (MCC) for the space transportation system, the OMV, and their users. Additional network capabilities are provided by other users (e. g., the proposed Science and Applications Information System (SAIS) for NASA's science users) or by the international partners for data transport between their sites.

Figure 3-18. illustrates a very simple version of the SSIS architecture as it will exist to support manned base users. Figure 3-19 illustrates a similar architecture supporting U. S. platforms. The basic SSIS elements will be provided by different organizations both within and external to NASA. Additionally, not all of the capabilities required by SSIS are dedicated to Space Station ac-

Table 3-4: Key Space Station Data Bases

1.	Budgeting
2.	Planning
3.	Scheduling and Project Management
4.	Policy Development
5.	Performance Measurement
6.	Technical Contract Management
7.	Administrative Contract Management
8.	Program Review
9.	External Affairs
10.	International Relations
11.	Customer Relations
12.	Requirements Analysis
13.	Technical Analysis
14.	Interface Control
15.	Cost and Financial Analysis
16.	Design
17.	Design Review
18.	Acquisition
19.	Administration
20.	Implementation and Integration
21.	Test and Verification
22.	Documentation
23.	Configuration Management
24.	Training
25.	Operations
26.	Maintenance
27.	Prototyping
28.	Inventory Management

tivities (e. g., TDRSS and NASCOM support all near-earth orbiting NASA spacecraft). These factors pose complex management and integration problems for the Program.

In addition, many of the baseline requirements for functional interconnection between key Space Station data bases (ground and in space) are only being marginally considered by the TMIS activities. Some of these data bases are listed in Tables 3-4, 3-5, and 3-6. As the design, development, and operational costs of the Space Station Program become well known, considerable emphasis will be place on finding ways to reduce costs and improve productivity. This can only be accomplished by providing a functionally efficient way to transport information between distributed data bases.

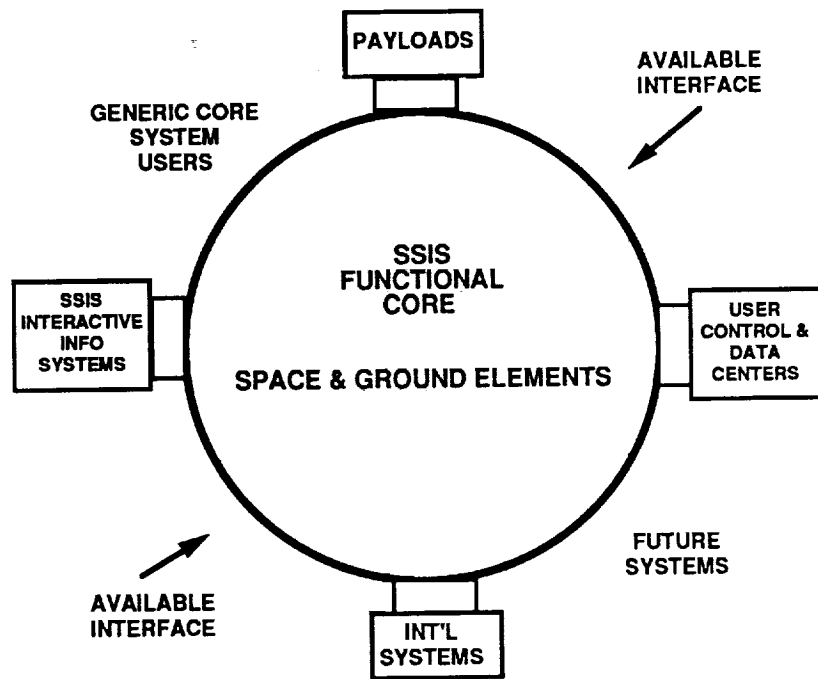


Figure 3-17: Scope of the Space Station Information System

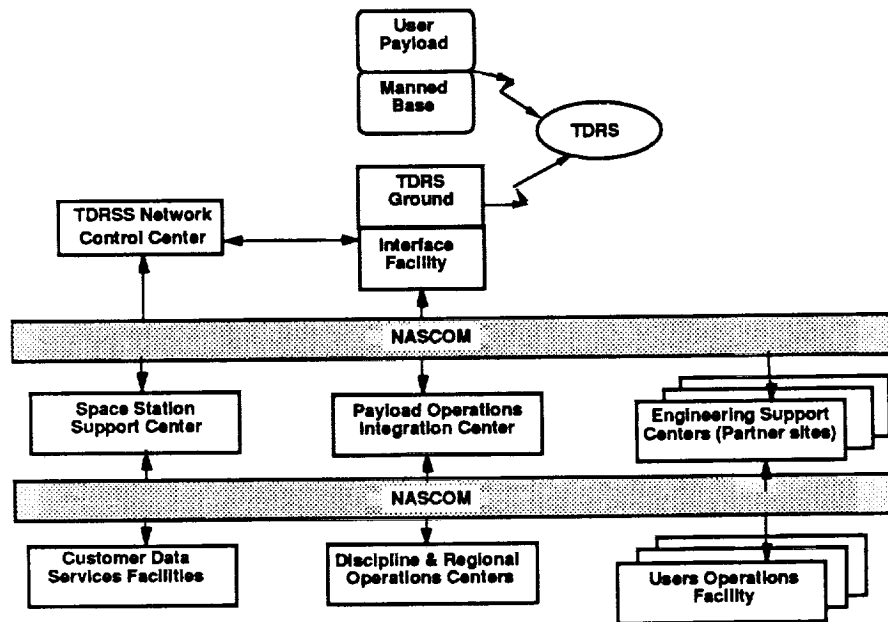


Figure 3-18: Manned Base Space Station Information System Architecture

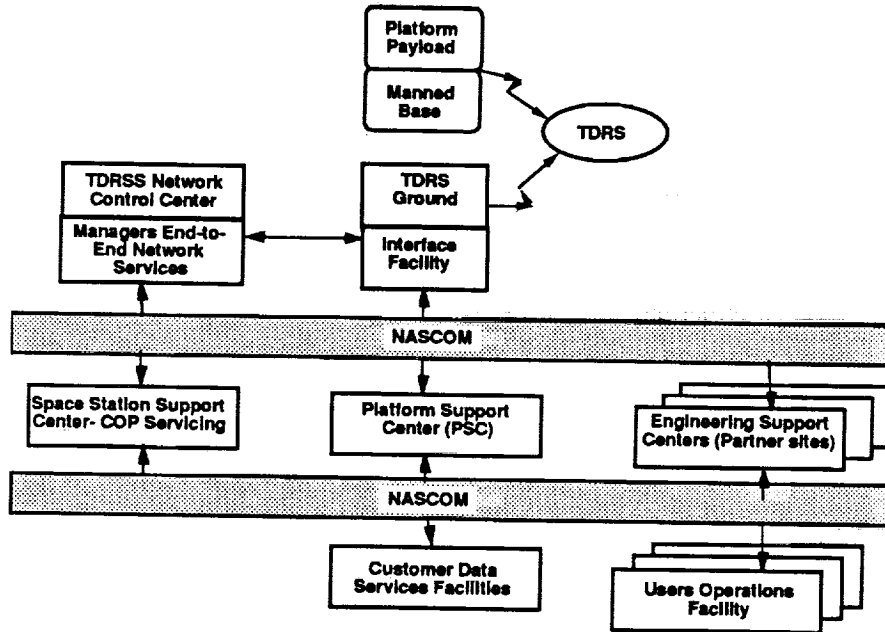


Figure 3-19: Platform Space Station Information System Architecture

Table 3-6: Databases for Manned Bases Only

Payload and System Training Simulations On-Orbit Checkout Procedures Servicing Procedures and Characteristics Crew Member Data Safe Haven Procedures Security and Privacy Master Schedule Inventory Payload Fault Isolation Data
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Table 3-5: Databases for Manned Bases and Platforms

Payload Characteristics Operational Event List Payload Fault Isolation Payload Systems Operational Procedures Application Software Loads System Software Loads Master Schedule Payload Status Core Subsystem Status Navigation Data Software Configuration Management Data Hardware Configuration Management Data Ancillary Data Instrumentation and Measurement List Buffered Recorder Data Configuration Data Fault Isolation Rules Security and Privacy
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### 3.3.1.3 Science and Appl. Information System

The Science and Applications Information System (SAIS) end-to-end perspective provides an overview of SAIS-related space and ground systems and services from a science user's perspective (Figure 3-20.). This SAIS architecture overview illustrates the functional links and interfaces between SAIS and institutional systems, and between users and the SAIS. SAIS will provide users with access to services provided by non-Space Station and non-NASA elements, on ground and on board, as well as to NASA and Space Station Services.

Universal connectivity between elements enables all nodes to have potential access to all other nodes, within



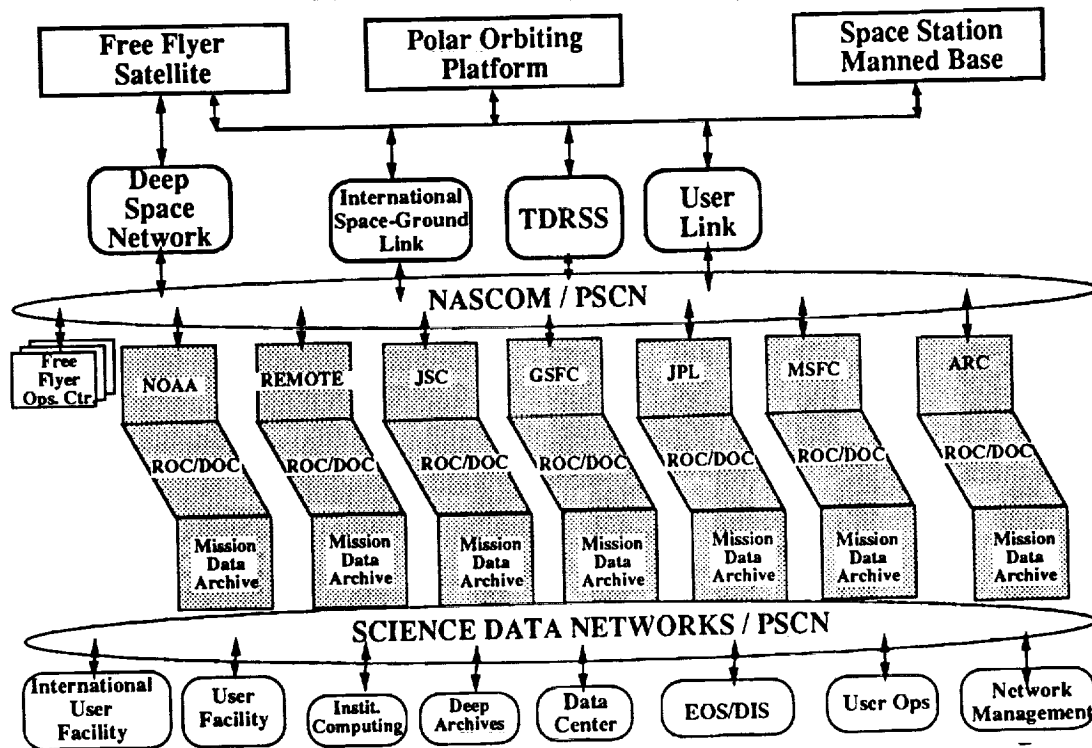


Figure 3-20: Science and Applications Information System Architecture Overview

authorized limits. All workstations on ground and on-board have access to all services. All data systems on ground and on-board have access to all directories, catalogs, and data.

The three major categories of users served by SAIS include the following:

- i. Instrument developers, managers, operators,
- ii. Instrument users,
- iii. Current and retrospective data users.

All "public" data repositories maintain associated catalogs of data holdings. The SAIS master data directory points to all NASA catalogs and non-NASA directories or catalogs. Logical connections between elements, such as between an instrument control center and the instrument it controls are indicated in the architecture overview.

### 3.3.2 Telescience Concept

The rapidly changing cultural and technological environment of the information age has led the space science and applications community to develop the "tele-

science" concept for remote operations. The concept was developed to provide a capability to the space science and applications user to:

- directly interact
- from his home institution, or a location of his choice
- with instruments, data bases, data processing facilities and one another
- in a distributed environment
- throughout the entire life cycle of an instrument or experiment.

When examined in detail, the telescience concept involves four major areas, three which deal with the life cycle phases of an instrument or experiment: design, operations, analysis; and the fourth area: telecommunications which enable these functions to be carried out among remote users. While the three life cycle phases are functionally separable, there is functional and chronological overlap among them.

### 3.3.2.1 Design

Design is intended to include the development, maintenance, and access to the corporate memory which an investigator must have from the conception of an experiment through beginning of normal observations. To illustrate what is meant here, consider the decision tree and process through which a possible investigator must pass. When a graduate student or professor at the University of North Excaliber has an idea or hypothesis concerning crops in the mid-West which he wants to pursue, he must first find out if any research has been done in this area already. If not, he then needs to find out if data has been collected which he can use; if not, is there an instrument already flying or being developed which he might use or will he have to build his own instrument. If he must build an instrument, what kind of constraints (both technical and programmatic) must he consider. During instrument design, he will need interface specifications, system design characteristics, CAE/CAD/CAM capability; during instrument test and integration, he will need system simulations, etc., and so on through the time the investigator is actually collecting data. Ideally, all of this information and much of this support would be accessible to the investigator at his home institution through a telecommunications connection. Within the telescience concept, these capabilities are referred to as teledesign capabilities.

Teledesign is the part of telescience concerned with providing access to information and tools for collaborative conferencing between internationally distributed scientists to define and develop scientific investigations, designing, building and testing scientific instruments, developing and validating the computer hardware and software used for instrument operations and data analysis, and establishing design concepts supportive of teleoperations.

Teledesign will affect many instrument life-cycle phases:

- Proposal preparation and evaluation,
- Conceptual and detailed design
- Assembly, checkout and verification
- Integration
- Launch
- On-orbit installation and checkout,
- On-orbit operations
- On-orbit servicing

### 3.3.2.2 Operations

The operations phase of an instrument (or experiment) life-cycle begins roughly with final design and extends to decommissioning of the instrument after flight or the completion of on-orbit experiment data collection. The principle to be implemented is that the instrument builder (and eventually an investigator) should be able to access and interact with his instrument, regardless of the location of the instrument. That is, whether the instrument is in his laboratory, in a test and integration facility, or in orbit. This principle has major implications on an Operations Management System (OMS) which will be called upon to manage on-orbit operations of multiple instruments and be responsible for the health and safety of the Spacecraft systems, instruments, and crew (where applicable). It also has major implications for instrument ground operations relative to health and safety of instruments, systems, and personnel. This capability is the "teleoperations" aspect of the telescience concept.

Teleoperations mode (illustrated in Figure 3-21.) for distributed flight operations is prompted by increased system complexity, escalating operations costs, and advances and cost reductions in telecommunications and data processing technologies. Present remote user facilities now readily support sophisticated hardware and software design and development, operations planning and scheduling, monitor and control functions, and data processing and analysis. From their own facilities, users will be able to communicate with:

- Other user facilities, e. g., through teleconferencing,
- Science data directories and catalogs,
- Science data bases and archives
- Institutional services, e. g., TMIS, SSIS,
- Design tools and support personnel,
- Integration and test facilities,
- Spacecraft control centers,
- Orbiting spacecraft and instruments,

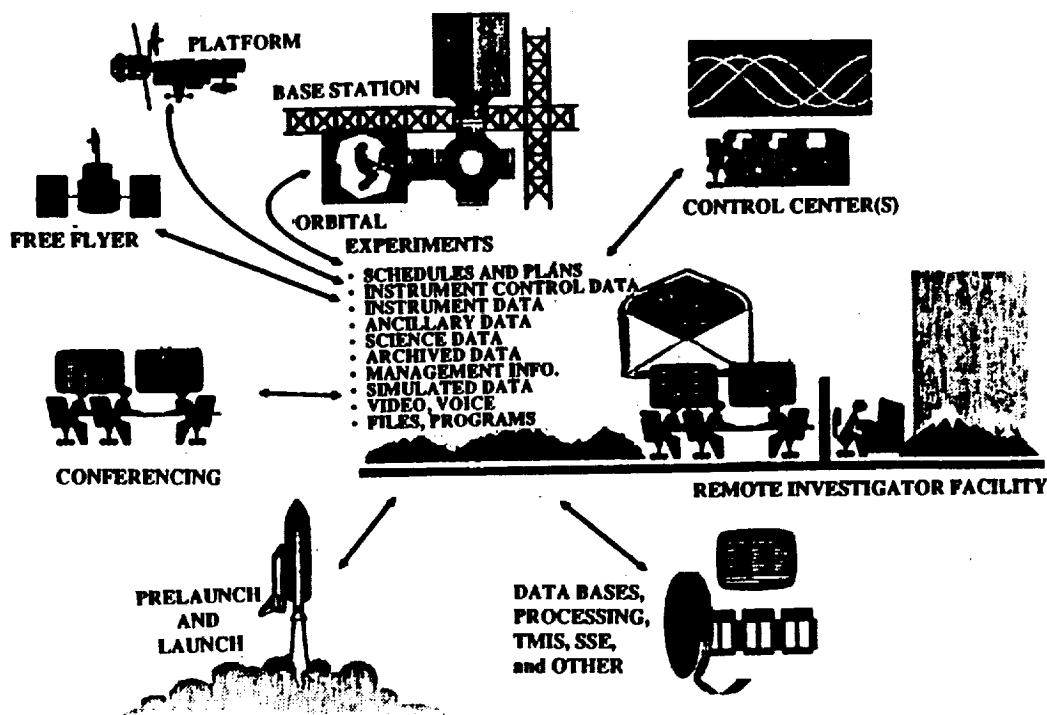


Figure 3-21: Science Operations Domain

- Space station crew members.

The philosophical principles for science operations are as follows:

- Enhance the autonomy of investigators to conduct their investigations with a minimum of constraints, interferences, and burdens;
- Enhance the interoperability of systems – OSSA and others – to allow investigator to spend more of their time investigating science; and
- Enhance the accessibility of Space Station facilities to investigators, enabling productive and timely scientific investigations.

Figures 3-23, 3-24, and 3-25 respectively illustrate the science instrument life cycle support needs, a typical science payload operations scenario, and the SAIS payload operations management concept.

### 3.3.2.3 Analysis

Analysis is intended to encompass all aspects of scientific research from the search for and access to calibrated data sets through to publication of results and the entry of value-added data and documentation back into a

scientific archive. Again, the principle here is that an investigator would be enabled to conduct his research activity from his home institution (teleanalysis mode of telepresence), through access to:

- International and multi-disciplinary data bases,
- Collaborating investigators,
- Super-computer processing and computational capability.

Teleanalysis concept was formulated to make distributed science analysis functions more efficient. It had to consider a complex, heterogeneous user analysis environment (Figure 3-26.) and provide for the functional connectivity between distributed elements.

Figure 3-27 illustrates a typical science analysis scenario starting with the individual investigator developing a research idea, locating data to exercise the idea, processing data until it becomes useful information, discussing the results with collaborating colleagues, and finally publishing the results.

In addressing the telecommunications needs for the teleanalysis mode it is important to follow the path of data from raw form to scientifically valuable information. This process is shown in Figure 3-28.

### 3.3.3 SAIS Communications Architecture Concept

The Science and Applications Information System (SAIS) Telecommunications Architecture Concept is based fundamentally on a "service architecture" concept. The SAIS architecture concept was formulated to tie together all of the space science application information systems into a single "telescience community". This overall master concept is shown in Figure 3-29.

This scientific community would have electronic access to the world space science data, information resources, and other scientists. Each member of the community - i. e., each individual information system or scientist - would contribute its share to the richness of data, information and knowledge available in the community at large.

This document describes the overall technical architecture concepts by which this telescience community would be organized. The previous telescience sections described the three "pillars" of this new telescience community: space science operations, science data management and analysis, and space science instrument design and development.

#### 3.3.3.1 Telescience City Plan

The concept for organizing the SAIS into an overall system is based on the concept of a "city plan". In this case, the plan is for a networked community of scientists and their information systems.

In a city, everyone has access to everything, subject to rules of behavior and protection of individual and group privacy, and subject of course to cost accountability. The city plan describes the method of organizing the city - including the infrastructure such as sewers and roads, the licensing rules and regulations for providers of services, and the "user interface" aspects such as the ordinances concerning public behavior.

For SAIS, this concept of a space science city plan leads directly to a very simple overall architecture concept, shown in Figure 3-22. From an overall technical point of view, SAIS is architected as a set of users accessing a set of services by means of communication services.

#### 3.3.3.2 Universal Connectivity

In a community, every household has a telephone and broadcast television, and some households have a spe-

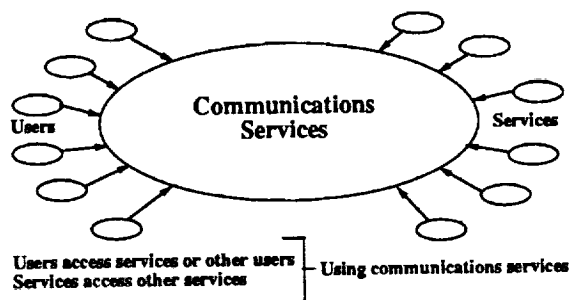


Figure 3-22: Simple End-to-end Concept for SAIS

cial data line or cable television. In this way, everyone can communicate interactively with everyone else or receive community information at some minimum level of capability, and specialized subcommunities can have higher levels of communication service relatively easily if they so require and are willing to pay the relatively low extra cost.

The corresponding communications architecture requirement in SAIS is the notion of "universal connectivity". This means simply that every user has access to every other user or service, and every service has access to every other service (to allow the provision of value added services), according to overall communications service standards.

Universal connectivity is subject to restrictions, of course, just as in a city; e. g., cable television is not actually subscribed to by all households even though they are all a "universally connected" to cable. For SAIS, constraints on universal connectivity include limitations on types of service and qualities of service (TOS/QOS), restrictions due to access control by service providers and users, and restrictions due to cost.

Universal connectivity in SAIS means specifically that a range of communications TOS/QOS is available to every SAIS user and service provider on request, subject to access control and cost accountability. The recommended approach to implementing such a communications architecture concept for SAIS is twofold:

- i. SAIS would support access to existing computer communications networks and provide an evolution potential for higher performance networks. Such TOS/QOS would be provided by the NASA Science Internet (NSI) networking program sponsored by OSSA.
- ii. SAIS would promote a new concept, the end-to-

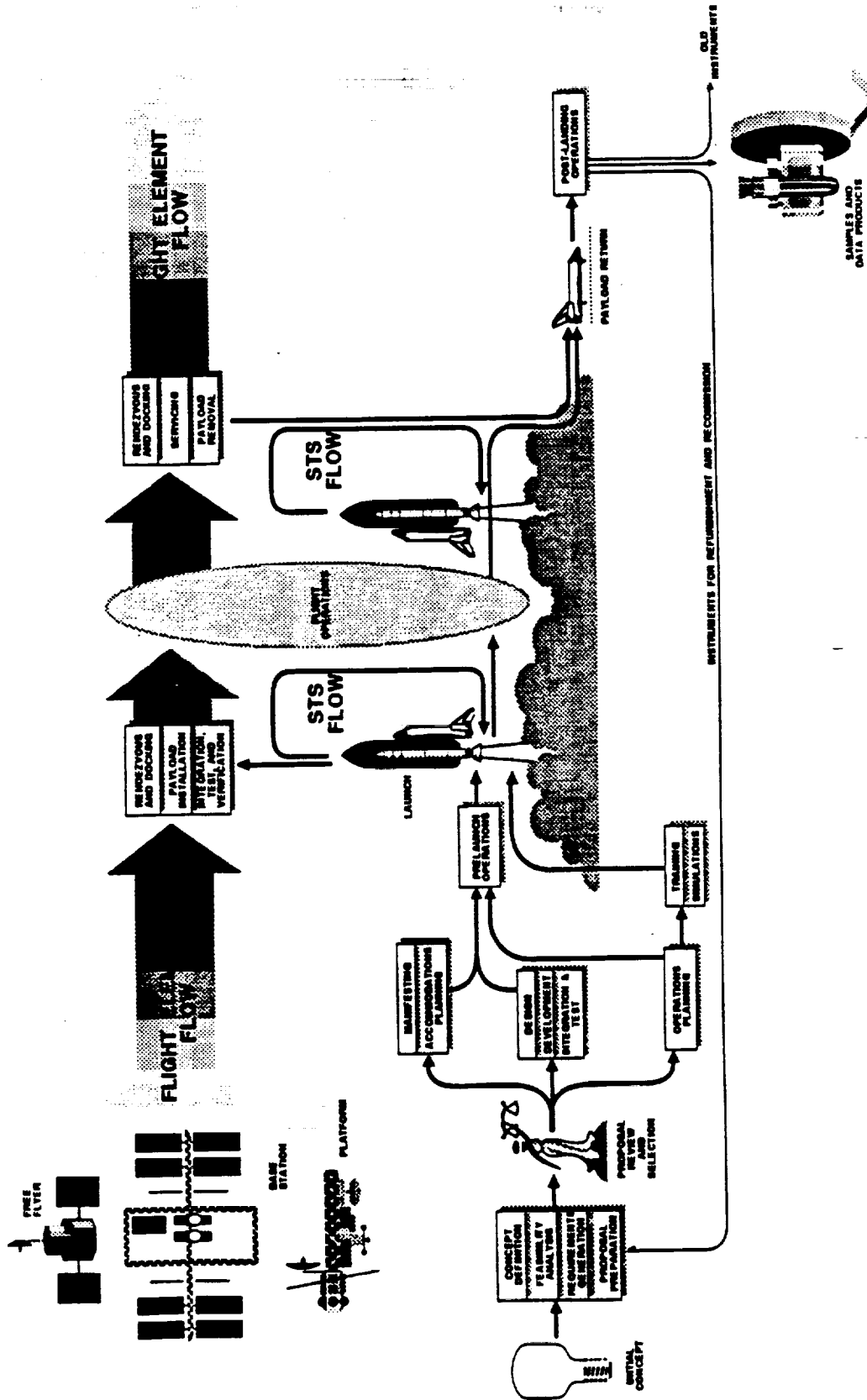


Figure 3-23: Instrument Life Cycle Support Needs

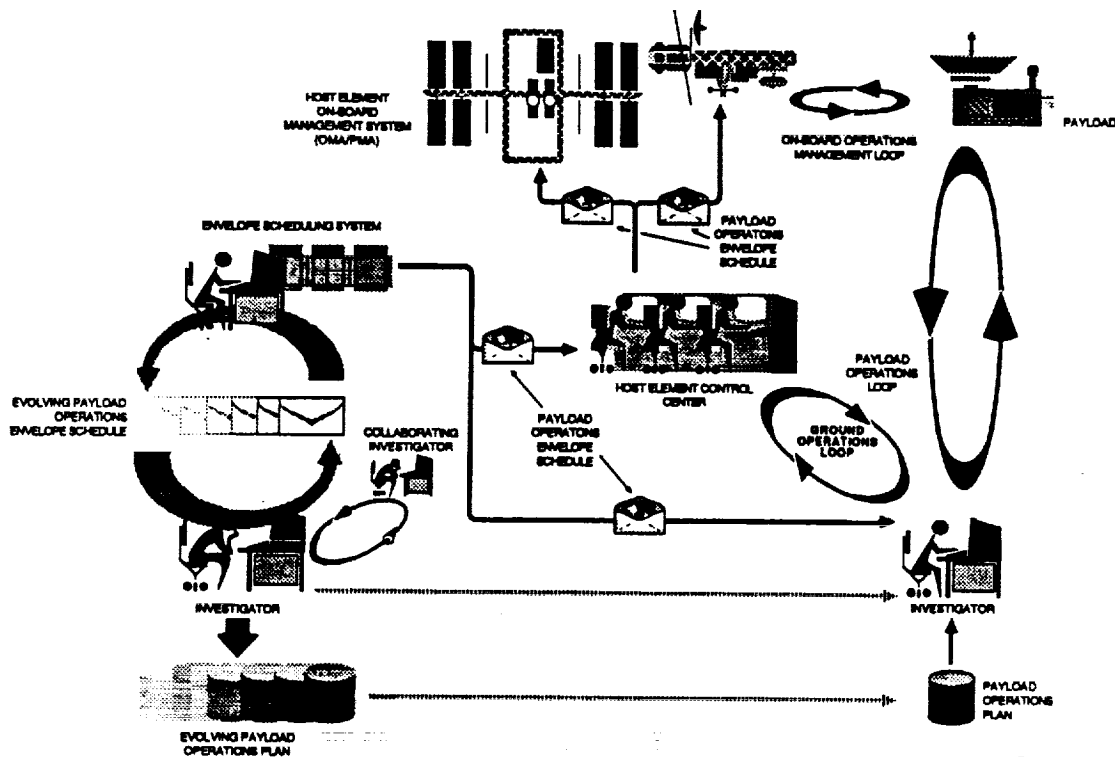


Figure 3-24: Payload Operations Scenario

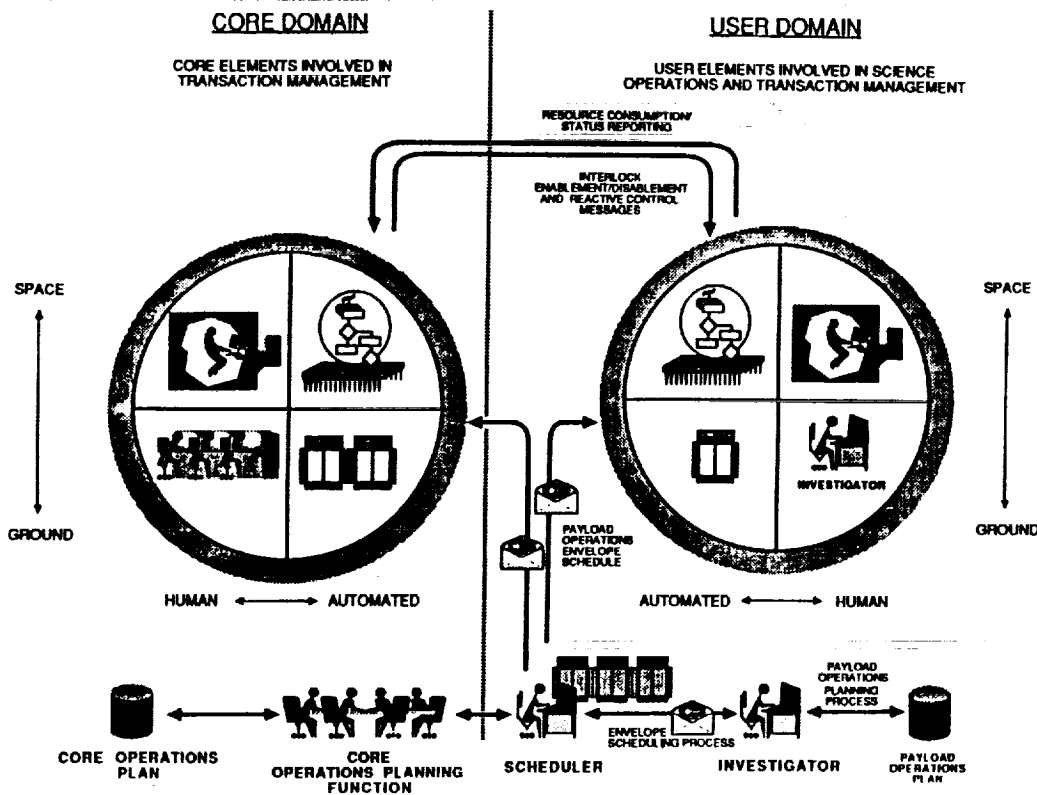


Figure 3-25: Payload Operations Management Concept

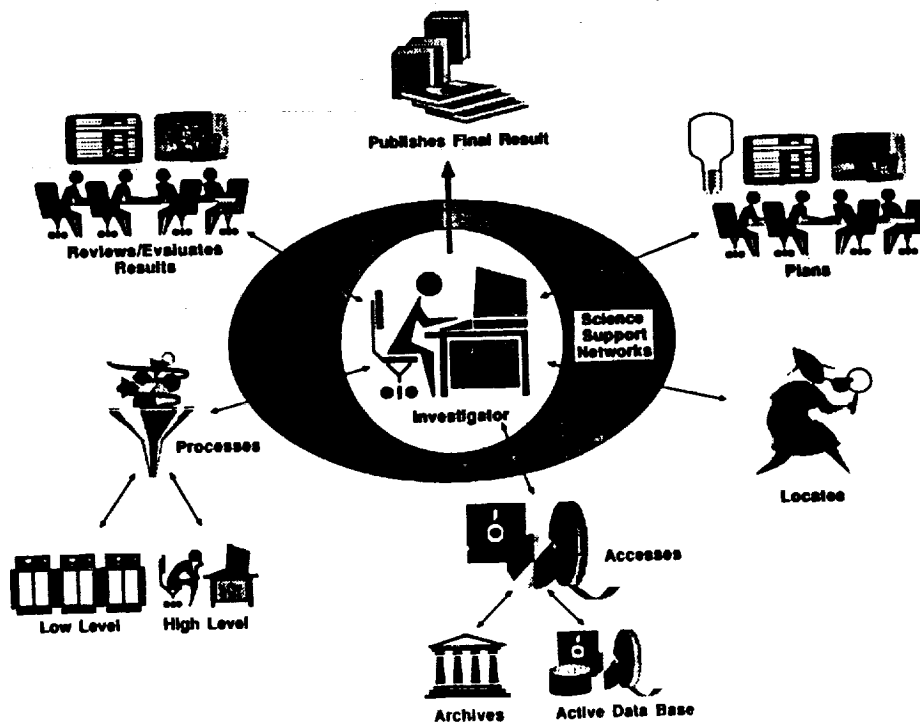


Figure 3-26: User Analysis Environment

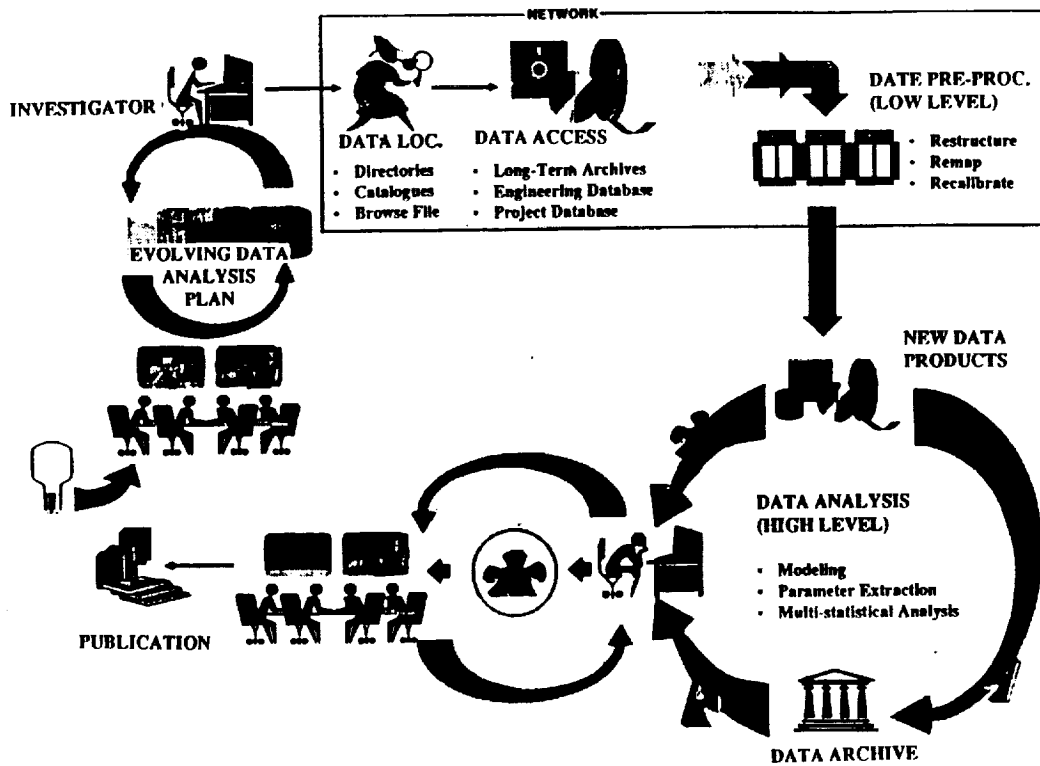


Figure 3-27: Science Analysis Scenario

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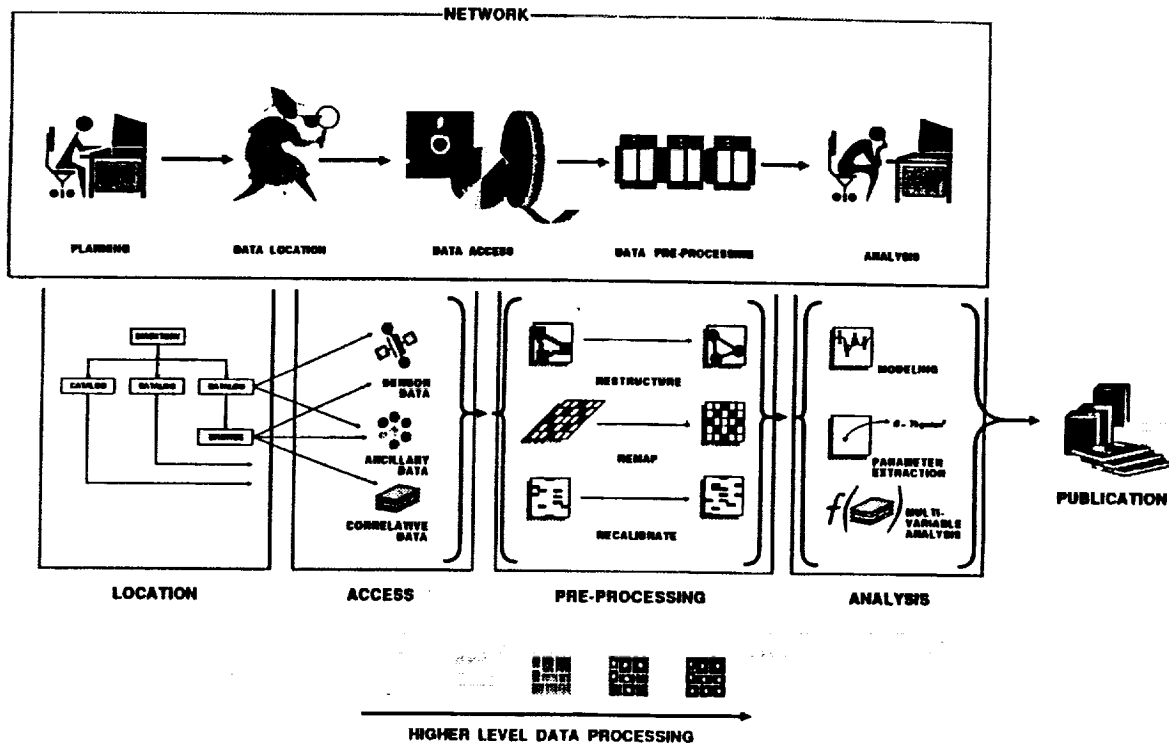


Figure 3-28: The Analysis Process: What Happens to the Data?

end logical data path (EELDP). EELDPs would provide high performance connections for relatively static path configurations required for such typical space science applications as real-time high-rate telemetry data flow.

### 3.3.3.3 Catalog Shopping

In a community, a person can get anything the community has to offer to the public if only they know what they want, they know how to go about getting it, and they can afford it. In some communities, people can get help to find the community resources they're looking for, and they can then access those resources in a simple way and at reasonable cost.

To allow the same ease of access to resources, SAIS is developing a service architecture concept based on "catalog shopping". In this architecture concept, each service provider provides access to resources and value added services according to a catalog. The catalog describes all aspects of the provider service or resource that are germane to the potential user requirements - e. g., summary listings of all services and resources available, identification of access methods and protocols that are supported, prices and charging policy

(which may involve "funny money" or real charge accounts), access restrictions, and detailed descriptions of each service and resource.

The general situation is shown in Figure 3-30. The catalog must satisfy SAIS standards, but the other services may be implemented in a variety of ways that may or may not be standardized. The only mandatory requirement is that if the provider wants to make the service available to the public, the service must be listed in the catalog along with all necessary information needed to access the service.

The service is accessed from remote locations by means of one or two protocols. The first protocol, which is almost always required, is the public method of requesting the service. This will be standardized by SAIS, and will be a "transaction-oriented" (i. e., request-response) protocol selected to be easy to implement. This Service Request Protocol describes how to ask for the service and receive acknowledgment of the request. For simple services, such as catalog lookup, the response may complete the entire service interaction.

For complex services requiring separate fulfillment, the SAIS service architecture concept allows separate Service Fulfillment Protocols to be specified by the



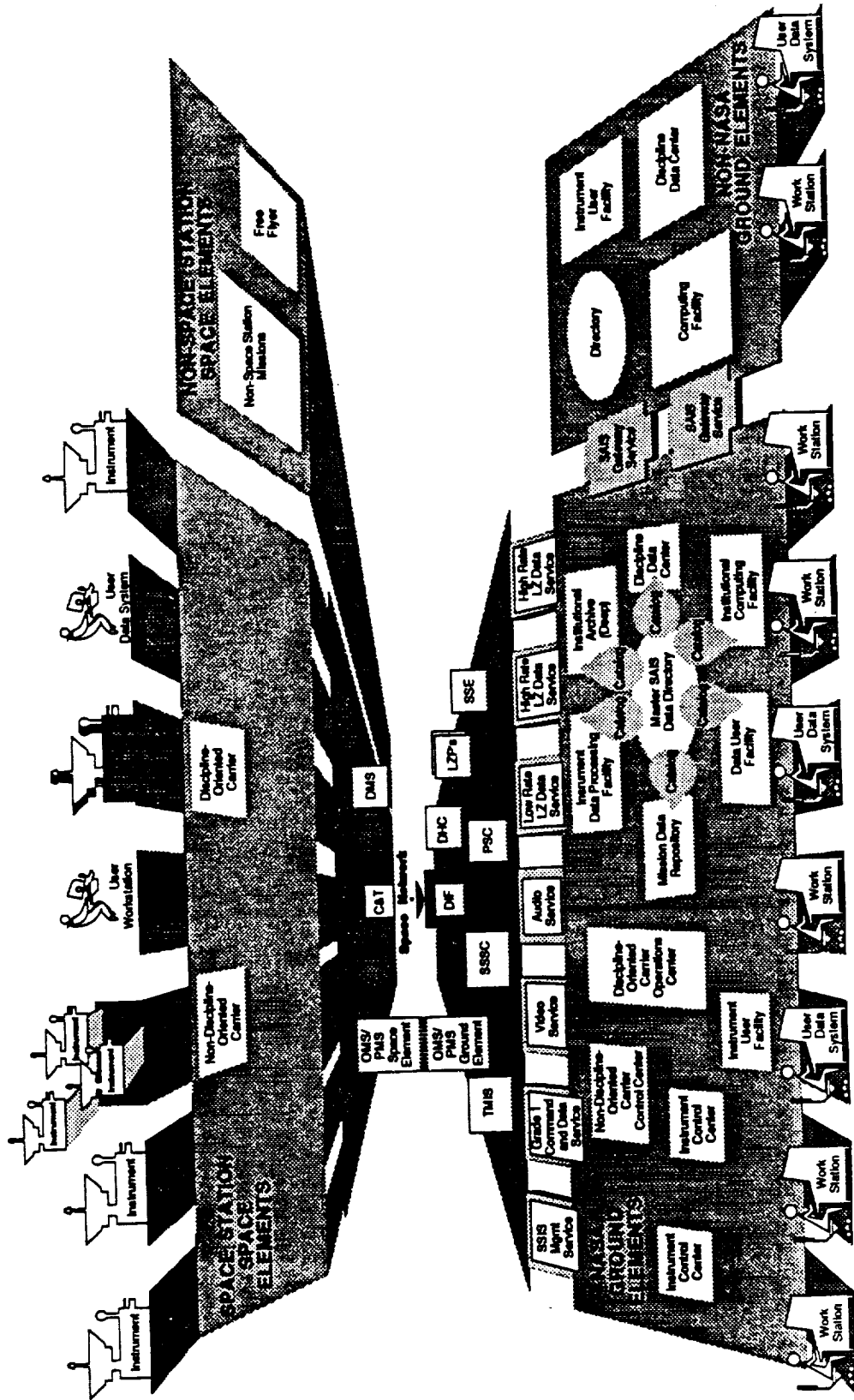


Figure 3-29: Overall Science and Applications Information System End-to-End Perspective

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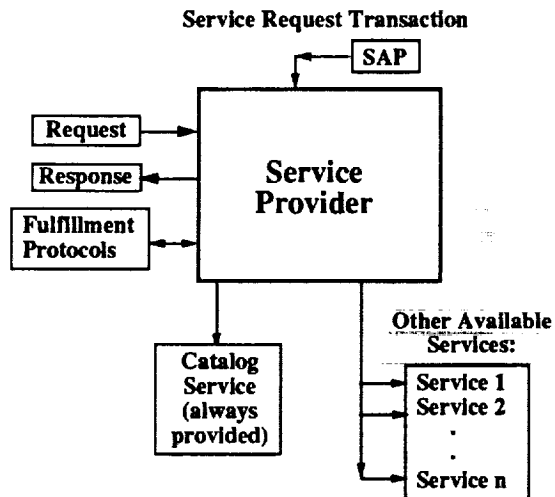


Figure 3-30: SAIS Catalog Shopping Concept

provider, according to guidelines laid down by SAIS to minimize needless proliferation of fulfillment protocols. For example, a voluminous data set could be provided using an electronic file transfer protocol sent over a separate circuit or on an optical disk sent by Federal Express.

The service interactions take place at well defined service access points (SAPs), which are logical points of interaction identified by electronic or physical addresses that are published in a SAIS Directory. This architecture concept provides a community-wide knowledge of all public service providers (published in the SAIS Directory), and a complete description of all publicly available services (published in each provider catalog). This architecture concept also allows service providers to come and go easily (with the only requirement that it keep its own catalog up to date).

### 3.4 User Scenarios

The process of identifying, accumulating, and validating a set of user requirements for the Data Distribution Satellite system is extremely complex. This is due to the fact that the traditional methodology for obtaining user requirements has some inherent weaknesses. These weaknesses fall into the following categories:

- i. Requirements are frozen in the early phases of a program, and are based on a snapshot frozen in time of the near-term technology.
- ii. Requirements are derived from users based on their present knowledge and understanding of operational concepts and procedures, application objectives, and system technology. Requirements are based on a snapshot frozen in time of the near-term utilization expectations.

Several new international efforts have been initiated to address these weaknesses. The efforts have attempted to deal with the rapid changes in technology, utilization concepts, and operations concepts. The major U. S. efforts were sponsored by the Office of Space Science and Applications (OSSA) and involved extensive involvement of the space science and applications user community. For the next 10 to 20 years, it is believed that all other user communities (i. e. technology and commercial) will only place small incremental demands on telecommunication services beyond those required by the science and applications community. Therefore, this DDS study concentrated primarily on the science and applications user requirements for the 1990 to 2025 time interval. The study approach used specific mission scenarios including the Space Station Program and the Earth Observing System (EOS) of the Global Change Program to translate user needs to communications requirements.

#### 3.4.1 Space Station Freedom Scenario

The Space Station Freedom represents one of the larger users of communications resources for the next 30 years. To begin to understand these requirements it is important to examine the key control documents which specifically address communications requirements. A compendium of these requirements are found in JSC Document 30,000. Figure 3-31 illustrates the communications services covered by JSC Document 30,000.

The overall communications architecture for Space Station Freedom is shown in Figure 3-20. Because JSC Document 30,000 was created at the start of the Space Station Phase C/D activities, it contains functional requirements for the Polar Platforms (part of EOS) although the EOS program responsibilities have been transferred from the Space Station Program Office to the Office of Space Science and Applications (OSSA - Code E).

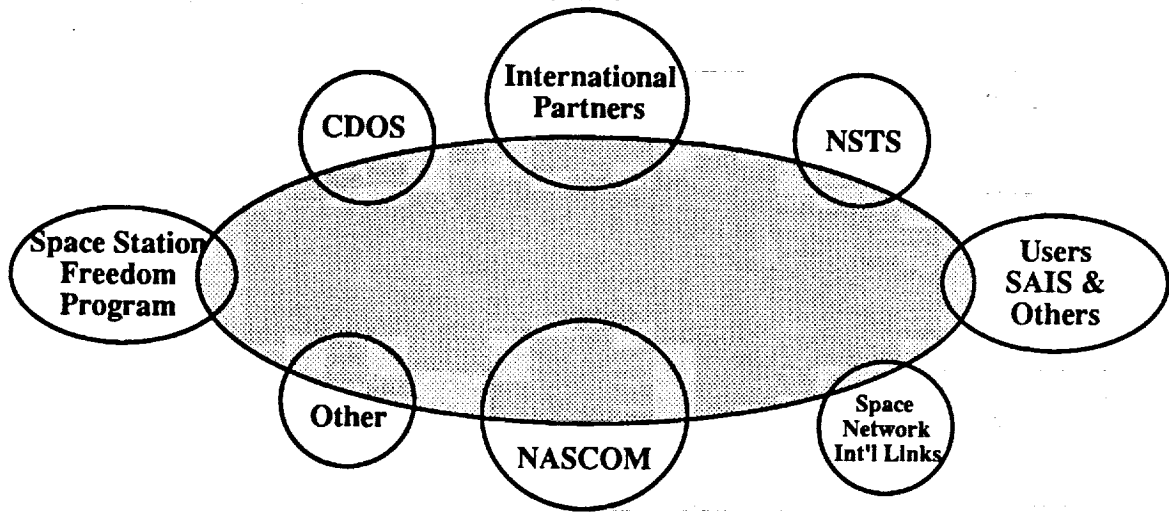
A clear problem presents itself when examining all of the Space Station requirements documents and supporting documents. In these documents most communications requirements are stated in terms of user functional needs instead of engineering specifications. A summary review of all of the documents in terms of communications specifications indicate:

- Functional requirements are generally constrained to fit within existing communications capabilities (i. e. TDRS or NASCOM);
- No attempt was made to Derive Data Rate Specifications;
- Documents have not been integrated and often given conflicting views from document to document.

Figure 3-32 illustrates the summary process for the Space Station Requirements as derived from the formal set of documents.

The OSSA initiated a study effort in 1988 to address the problem of translating space science user needs into system specifications by establishing the Telescience Testbed Pilot Program (TTPP). The Universities Space Research Association (USRA), under sponsorship from the NASA Office of Space Science and Applications, has managed and guided the TTPP. Its overall goals were set to develop an experience base to deal with issues in the design of the future information and communications systems of the Space Station era. The specific goals of this pilot program were to:

- Demonstrate that the user oriented, rapid prototyping testbed approach is a viable means for identifying and addressing the critical issues in design and specification for the Space Station Information System (SSIS) and the Science and Applications Information System (SAIS), thereby assuring that these systems will satisfy the needs of scientists for an information system in the Space Station era,



JSC Document 30,000 - 6.2.7: Space Station Information System interfaces between space and ground segments shall be capable of using the maximum throughput data rates (including overhead) of the TDRSS single access link. Data rates in excess of the maximum shall be accommodated by user support systems and will be non-SSIS functions, but must comply with SSFP policies and constraints.

Figure 3-31: Space Station Functional Requirements (JSC Doc. 30,000)

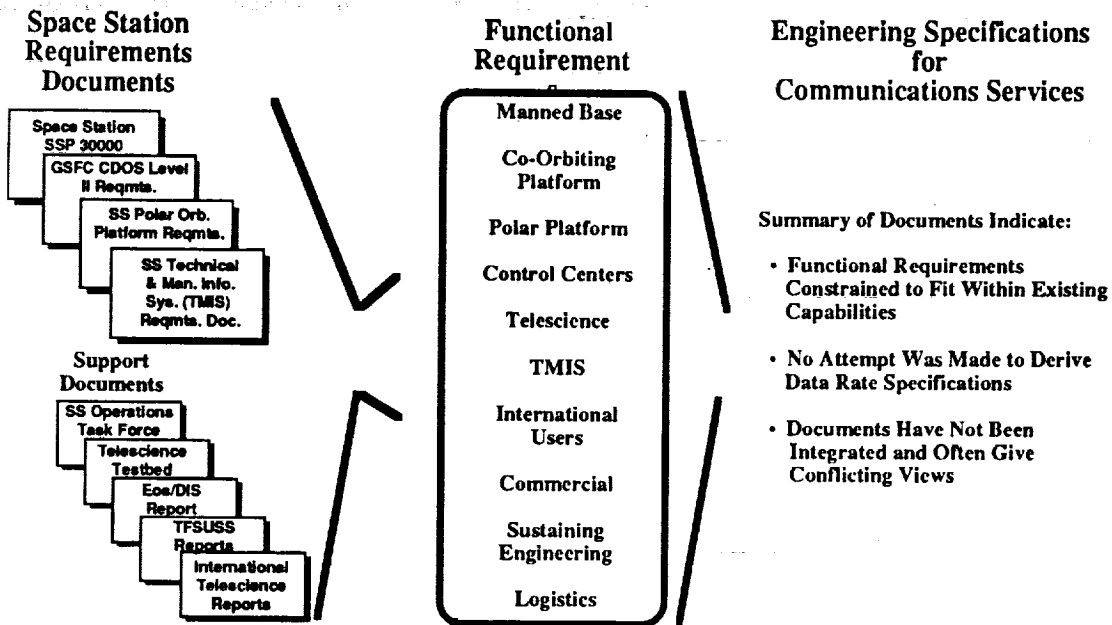


Figure 3-32: Summary of Space Station Requirements Documents

- Develop technical and programmatic recommendations for the conduct of such a testbed, and
- Develop initial recommendations for the SSIS and SAIS to be factored into the design and specification of those systems.

To accomplish these goals, fifteen universities, coupled to a number of NASA Centers (GSFC, MSFC, JPL, ARC) conducted various scientific experiments under subcontract to USRA. Each one of these experimental testbeds share the characteristic of attempting to apply new technologies and science operations concepts to ongoing scientific activities. Through this process, new understanding and experience was gained about system architectures, concepts, and technologies required to support future scientific modes of operation. The results of the Telescience Testbed Pilot Program are summarized in Appendix B.

The TTPP report, coupled with a number of other support documents, provided the baseline information for the official Space Station Requirements for the OSSA. It should be noted that this initial effort only begins to derive engineering specifications for the communications system. Most of the report in Appendix B gives scientific user functional requirements and not system specifications. To derive good system specifications requires considerable extrapolation from present user knowledge and needs of communications capabilities. This will be attempted in the following sections.

### 3.4.2 Global Change and the EOS Scenario

One of the most far reaching and influential programs to emerge in the U. S. space program is the Global Change Program. The scope of the program is shown in Figure 3-33. The program is multi-disciplinary, internationally distributed and requiring both ground and space capabilities. It is also potentially the most demanding program in terms of communications and data system requirements of any program in the history of the space program.

The center piece of the Global Change Program is the Earth Observing System (EOS). Understanding its evolving communications and information system needs allows for a good projection of the future communications capabilities required. Figure 3-34 illustrates the present (1990) view of communications capabilities required by EOS. It should be noted that this view was

constrained by having to fit within existing capabilities, i. e. TDRS, NASCOM, and science networks.

Considerable effort has been expended on studies of the EOS system. The EOS requirements documents and supporting documents are graphically shown in Figure 3-35. A summary of all of the document results indicate the following:

- Most EOS functional requirements were baselined to fit within existing capabilities (TDRSS, NASCOM, science networks);
- Minimal attempt was made to derive any data rate specifications;
- Documents produced by the Office of Space Station and the Office of Space Science and Applications have not been integrated and often give conflicting views.

Extrapolation of the functional needs expressed by the EOS documentation to the 2000–2010 time period is attempted in Table 3-7. These data rate estimates are not constrained by existing facilities or limitations of NASA's budgets. These are data rates based solely on science productivity assumptions.

To better get a feeling of the Global Change program impacts on U. S. space science and subsequent demands on telecommunications services, Stanford University was used as an example of a typical strong university involved in the Global Change Program. This would represent approximately 1% use for the U. S. universities involved in the program. Figure 3-36 represents Stanford's projected functional involvement in Global Change and its subsequent communications needs. This figure indicates that the Global Change research is multi-disciplinary, involving many investigations in space and on the Earth, and that network access to the globally distributed science and operations community is a must.

If these functional needs are extrapolated to number of users, types of communications functions, and data rates, Figure 3-37 is the results. This figure shows that the two functional areas are mostly concentrated to telescience activities and peer networking. For telescience, the communications requirements will be derived from the activities related to the design phase, the operations phase, and the analysis phase. For peer networking, the functional areas were divided into collaboration, computational modeling, and publications reporting. The data rates shown represent peak data rates

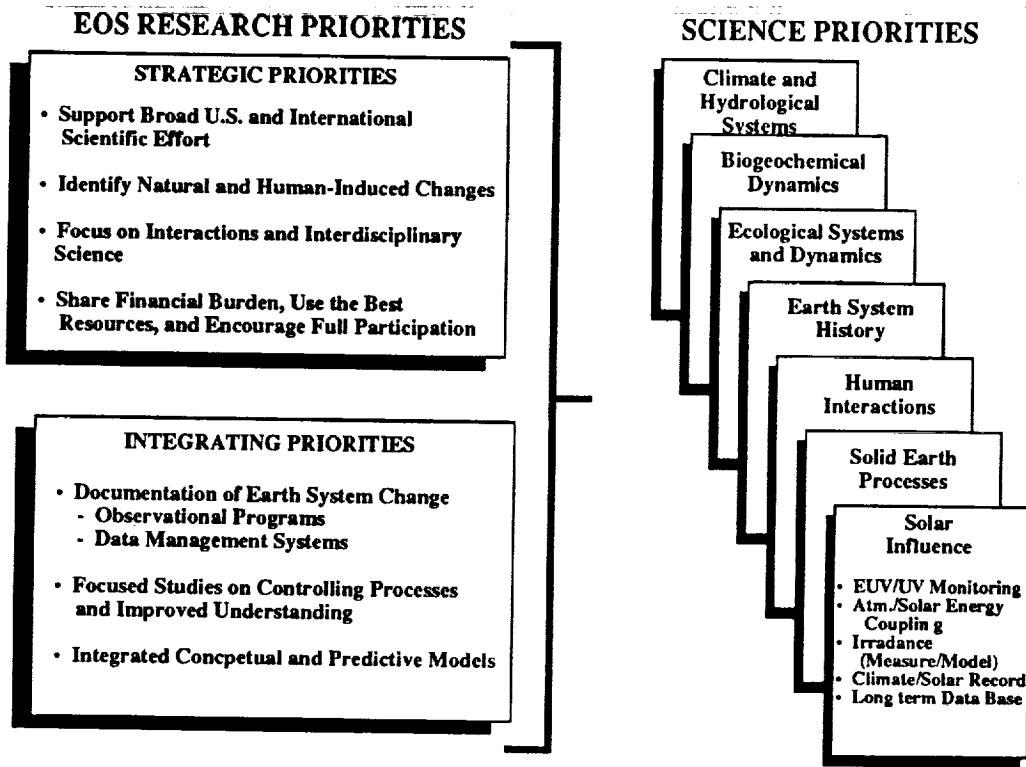


Figure 3-33: Scope of the Earth System Sciences Program

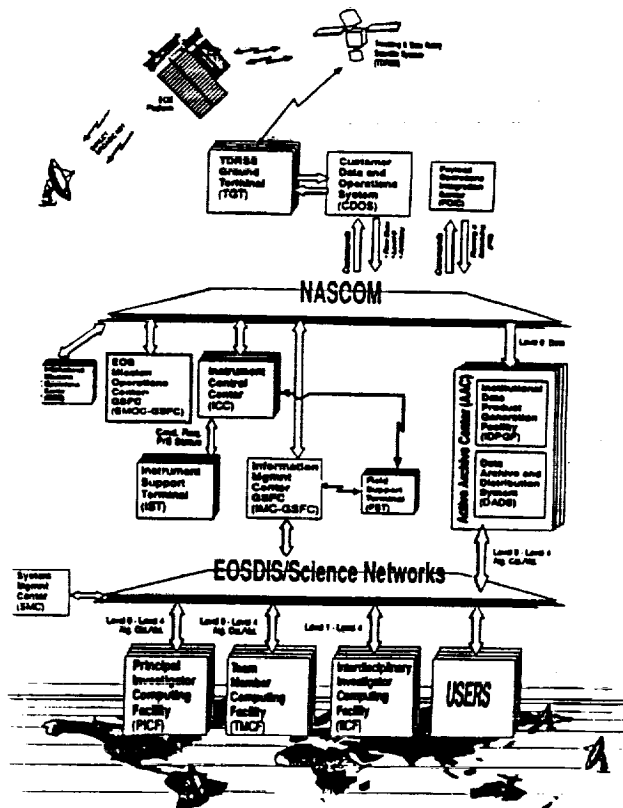


Figure 3-34: Earth Observing System Communications Requirements

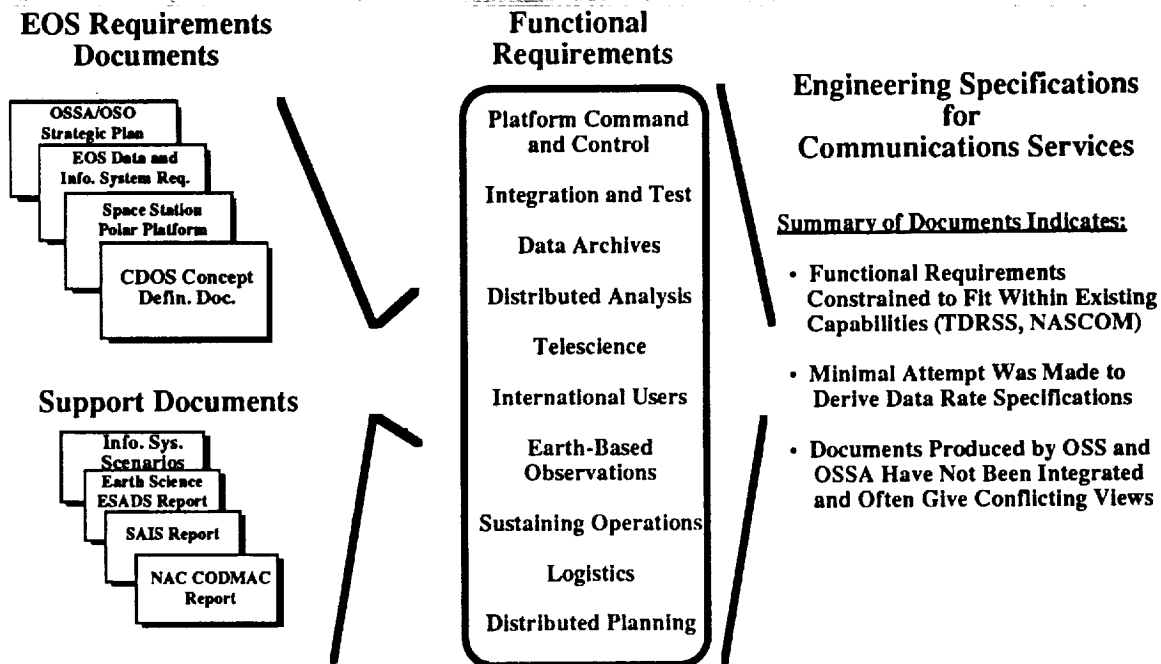


Figure 3-35: Summary of Earth Observing System Requirements Documents

Table 3-7: Extrapolation to Total Program Requirements for Earth System Sciences

Earth System Science Program Elements, 2000-2010	Data Rate
1. A group of instruments that images the Earth's surface in the visible, infrared, and microwave regions and sounds the lower atmosphere.	1.0 Gb/s
2. A complement of radar instruments that will gather information on the character and structure of the surface.	1.0 Gb/s
3. A group of instruments designed to study the composition and dynamics of the atmosphere and to measure the Earth's energy balance.	0.2 Gb/s
4. A group of instruments that monitors the solar - terrestrial energy balance.	.01 Gb/s
Total downlink data rates of Level 0 (raw) data:	2.21 Gb/s
Distribution requirements for Level 1-3 data:	0.1 - 0.5 Gb/s

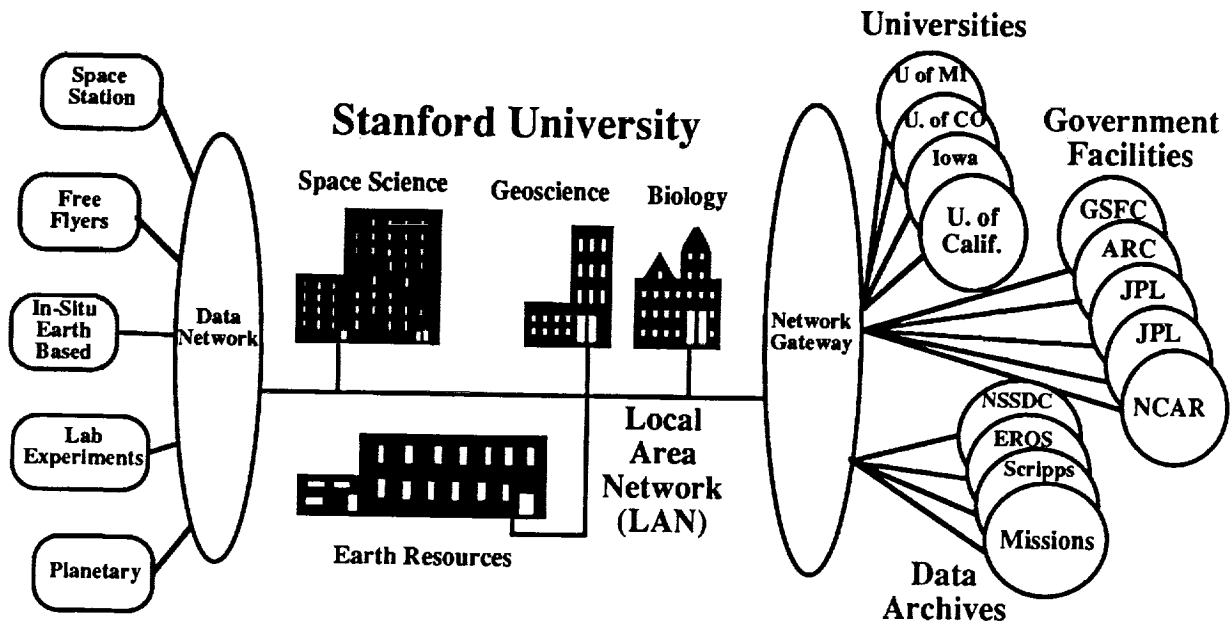


Figure 3-36: Stanford University's Telecommunication Requirements for Global Change Program

when the maximum number of users are operating simultaneously.

### 3.5 Peer Networking and NREN

#### 3.5.1 Space Science Peer Networking Architecture

##### 3.5.1.1 Introduction

Science in the Space Station era will require advanced computer and communications networks. They will be required in all phases of the research process, including design of experiments, development of experimental hardware and fielding that hardware into space, operation of the experiments, and analyzing the data, and collaborating with colleagues through the process. Computer networks are in place and are being put in place to support science, but the anticipated requirements are well in excess of planned capabilities.

Plans are being formulated by the Office of Space Science and Applications (OSSA) which will assess and attempt to provide the requisite networking and associated information services to serve the NASA scientific community in the Space Station era. It is critical that the architecture of such a system provide the required services upon implementation, interface appropriately to the Space Station Information System (SSIS) and other

systems of critical interest to NASA scientists, and allow for evolution of the system as new requirements arise and technologies become available.

The scientific community is already served by a number of networks, supported by both NASA and other agencies. These include the Space Physics Analysis Network (SPAN), the Numerical Aerodynamic Simulator Network (NASnet), the NSFnet, and the overall internet. In addition, there are plans for expanding and coordinating these networks through a NASA Science Internet (NSI) and an Interagency Research Internet (IRI) which has evolved into the National Research Educational Network (NREN).

Also impacting on any consideration of future networking for science are the efforts by the International Standards Organization (ISO) to develop a standardized layered architecture for Open Systems Interconnect (OSI) applicable to packet networks. Related to that are the efforts to standardize an Open Network Architecture (ONA) for the telephone system.

These existing and planned networks, along with the standards activities and associated commercial implementations, will satisfy many of the needs of scientists for general purpose networking and computer communications, including such facilities as electronic mail. However, there are many requirements arising from the conduct of scientific research, particularly that associ-



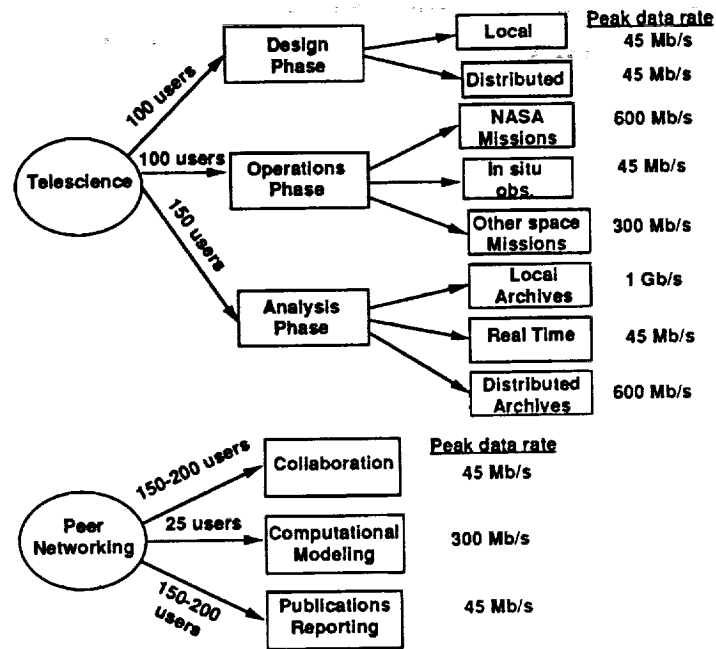


Figure 3-37: Global Change Program Data Rates at Stanford University

ated with space science and the emerging telescience operations concept, that exceeds the capabilities of a general purpose network. These include support of remote control of experimental instruments and remote data acquisition from high-bandwidth sensors. An architecture is therefore required that will support both standard (basic) networking services as well as the special purpose applications.

### 3.5.1.2 Required Networking Services

Networks provide for communication and data exchange between and amongst scientists and the resources they use. They need to support all phases of scientific investigation, from design of experiments through remote experimentation to analysis and publication of results.

The services required to support this process include both basic services and enhanced services. Basic services include:

**Electronic Mail** will increase in value as the extended interconnectivity provided by inter-networking provides a much greater accessibility of users.

**Multimedia Mail.** An enhancement to text-based mail which includes capabilities such as figures, diagrams, graphs, and digitized voice.

**Multimedia Conferencing.** Network conferencing is communication among multiple people simultaneously. Conferencing may not be done in real time; that is all participants may not be required to be online at the same time. The multimedia supported may include text, voice, video, graphics, and possibly other capabilities.

**File Transfer** is the ability to transfer data files.

**Bulk Transfer** is the ability to stream large quantities of data.

**Interactive Remote Login** is the ability to perform remote terminal connections to hosts.

**Remote Job Entry** is the ability to submit batch jobs for processing to remote hosts and receive output.

Enhanced services consist of the high-bandwidth high-performance networking services that cannot be provided on a wide scale. These include such items as:

**Digital Video** is the ability to maintain a dynamic graphic display remotely in real time.

**Sensor Data** is high bandwidth data transfer which may not require perfect reliability, but may require ordered delivery.

**Remote Instrument Control** relates to high bandwidth, low delay, interactive experiments.

The above are services provided at a fairly low level in the networking architecture. In addition, a number of user services will be required to enhance the productivity of the scientists:

**White Pages Directory Services.** The network needs to provide mechanisms for looking up names and addresses of people and hosts on the network. Flexible searches should be possible on multiple aspects of the directory listing. Some of these services are normally transparent to the user (host name to address translation is an example).

**Yellow Pages Directory Services.** Other kinds of information lookup are based on cataloging and classification of information about resources on the networks.

**Bulletin Boards.** The service of the electronic bulletin board is the one-to-many analog of the one-to-one service of electronic mail. A bulletin board provides a forum for discussion and interchange of information. Accessibility is network-wide depending on the definition of the particular bulletin board.

**Shared/Distributed Field System.** It should be possible for a user on the network to look at a broadly defined collection of information on the network as one useful whole. To this end, standards for accessing files remotely are necessary. These standards should include a means for random access to remote files, similar to those generally employed on a single computer system.

**Distributed Databases and Archives.** As more scientific disciplines computerize their data archives and catalogs, mechanisms will have to be provided to support distributed access to these resources. Fundamentally new kinds of collaborative research will become possible when such resources and access mechanisms are widely available.

**Community Archiving.** Much information can be shared over the network. Procedures and facilities are needed to store and retrieve information offline.

### 3.5.1.3 SPAN Network and International Space Science User Demographics

This important research tool of the NASA scientific community links space researchers from scores of institutions throughout the world. The SPAN system is growing within the United States, and it also is expanding to connect NASA scientists with European and Asian space research institutions. Because it is the most widely used space science network, it also provides an excellent source of information on demographics of space science users, their level of sophistication on the use of modern telecommunications, and some indication of possible future needs versus geographic location.

The growth of SPAN from its implementation in 1981 to the present has created a need for users to acquire timely information about the network. In the past, information about the network was spread by word of mouth or through relevant publications. Since that time, it has become clear that the need for information on SPAN could be satisfied by developing a central source for dissemination of such knowledge. The SPAN Network Information Center (SPAN-NIC), managed by the National Space Science Data Center (NSSDC), is an online facility which was developed to meet this need for SPAN-wide information. Access is also available to non-DECnet users over a variety of networks such as Telenet, the NASA Packet Switched System (NPSS), and the TCP/IP Internet. The database provides online key information concerning other computer networks connected to SPAN, nodes associated with each SPAN routing center, science discipline nodes, contacts for primary SPAN nodes, and SPAN reference information.

The online database has information listed both by the node name (NODEname) in alphabetic order (with the discipline of each node listed for those users who want to find someone in the same discipline) and by country and institution. This is especially useful to researchers who need to know the appropriate node name to reach their colleagues. Information from the SPAN database was utilized in this study to get geographic information on space science users, which disciplines were involved, and projection for future needs. This information was then applied to the formulation of scenarios for beam patterns for the DDS. These possible configurations are shown in a later section of this report.

### 3.5.1.4 Summary of Standard Networking Architectures

The widespread use of networking has arisen from much ground-breaking work, both in the research domain and in the development of standards. The research has been important in developing the basic technologies of networking and has resulted in much of the initial use as the networking researchers themselves grew to depend on the networks they were developing. The standards activities have allowed for the interoperability of computers and networks developed by different manufacturers for different customers.

In order that the scientific community be able to fully utilize the OSSA network and so that the OSSA network can be put in place rapidly and cost effectively, it is necessary that it use the available products. We briefly discuss here the standard architectures on which many of the research and commercial products are based.

**ISO/DoD Networking Architectures.** In the 1960's, the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense (DoD) embarked on a major research program to develop and demonstrate computer networking based on packet switching. This activity resulted in the ARPANet (the first packet switched network) using leased telephone lines. It also developed the technologies of packet switching for a number of other communications media, including a shared transatlantic satellite channel (the SATNET), a wideband domestic satellite channel (the Wideband Network or WBnet), and mobile spread spectrum radio (Packet Radio Network or PRnet).

To allow these networks to interoperate with themselves and with local area networks, being developed in the same time frame, the DARPA Internet technology was developed. The Internet technology is based on a layered architecture of protocols, ranging from the physical layer all the way through application to application protocols. At its heart lies the Internet Protocol (IP); a method for handling, routing and addressing through the various networks. This allows a host computer, workstation, or any end system to communicate with another end system regardless of to which networks the two ends are connected.

The Internet system is based on a simple datagram service provided on an end-to-end basis by

IP. Each network in the system is expected to only make a "best effort" attempt to deliver the packet to the specified destination. End-to-end reliability is achieved where needed by using an end-to-end transport protocol on top of the basic packeted delivery service provided by IP. Where such reliability is not required, other end-to-end transport protocols are provided. Additional services are then provided by using application specific protocols (such as file transfer, mail transfer, and remote login) on top of the end-to-end transport services.

The development and demonstration of ARPANet, the other networks, and Internet led to commercial development of packet switched networking. Much of this networking activity was provided by public telephone companies, which developed a networking architecture based on the provision of virtual circuit connections across each network. Interconnection of the networks was designed to take advantage of this connection-oriented service.

The proliferation of networks, both wide area and local area, in turn led to a standardization process for Open Systems Interconnect (OSI) within the International Standards Organization (ISO). The purpose of the OSI reference model is to provide an architecture to allow the description and development of standard protocols and interfaces, thus allowing interoperability between networks. The OSI model provides for seven layers of protocols with standard interfaces: physical, link, network, transport, session, presentation, and application.

Using the OSI reference model, a set of standard protocols have been developed for each of the layers. The functionality provided by the current and planned ISO standard protocols are very similar to those provided by the DARPA Internet protocol suite. The following basic services are provided:

- File transfer
- Remote login
- Electronic mail
- Addressing and routing
- Reliable end-to-end sequential delivery of packets
- Datagram service

**ISDN Evolution and Plans.** The public telephone system, recognizing that data services are an im-

portant aspect of their business, is also evolving. The Integrated Services Digital Network (ISDN) aims to provide integrated data and voice communication services to the user through a single interface. The basic service (called 2B+D) consists of two 64 kb/s circuits intended for voice and similar application, plus an additional 16 kb/s packet switched service. For higher bandwidth users or multi-user installations, 23B+D primary rate service will also be available.

**Other Commercial Offerings.** There are other networks and technologies that will have an impact on the SAIS. These range from the widespread availability of microwave and fiber optics links through private networks. A number of networks, particularly packet switched networks, are available as off-the-shelf technology, including DECnet, IBM's SNA, and X.25 networks. In addition, gateway/router technology for interconnecting wide and local area networks into an overall internet system are becoming available from a number of vendors. The OSSA networking architecture should make use of available commercial offerings where cost-effective.

### 3.5.1.5 Summary of Existing and Planned Networks

The purpose of the Science and Applications Information System (SAIS) is to provide network and information services for the OSSA scientific community. There are a number of networking activities already providing or planning to provide networking for the scientific research community. The SAIS must be designed in that context.

**NASA Science Internet (NSI).** The Program Support Communication Network (PSCN) is intended to provide communications support for non-mission-critical NASA activities (NASCOM provides the mission-critical communications). The PSCN provides circuits (the equivalent of level 1 in the OSI reference model), and so is not a network in the sense that has been discussed. However, the PSCN may be used as the required physical connectivity between packet switches to provide a network.

The NASA Science Internet (NSI) is intended to provide a basic networking service for OSSA supported researchers specifically and NASA science

in general. This is accomplished by:

1. Putting in place the needed switches and routers, connected by the PSCN, to provide wide area networking between various installations.
2. Providing the needed network user services (such as directory services) and management to assure an adequate level of service.
3. Using the DoD standard protocol suite as an interim to provide the needed end-to-end service, with an intent to migrate to the standard ISO protocol suite as it becomes available.

**Relation to Other Scientific Networks.** The NSI is designed from the beginning to be compatible with other activities providing networking for the scientific community. The most significant of these is the NSFnet. NSFnet is intended to provide initially for access to the NSF-sponsored supercomputer facilities, with a longer term goal of providing basic networking services for the broad spectrum of scientific researchers. Thus, the NSI, the SAIS, and NSFnet have similar goals, and it is important that they be accomplished in a compatible manner.

There are other networks providing support for scientific researchers. The Space Physics Analysis Network (SPAN) uses DECnet technology to provide services to a significant portion of the NASA community. The Numerical Aerodynamic Simulator installed NASnet to provide access. HEPnet used DECnet to provide these services for the High Energy Physics community. The Department of Energy National Magnetic Fusion Energy Computing Center uses a network called MFEnet to allow for access. In addition, there are a number of networks (BIONET, Stronet, Environet, etc.) that provide networking service for segments of the community.

It is informative to extrapolate Stanford University's network needs beyond the year 2000. Figure 3-4 represents Stanford University now and Table 3-8 is an extrapolation for the year 2000, 2010, and 2020. The data rates given represent extrapolations from existing network bandwidths, network gateways, and satellite communications capabilities at Stanford in conjunction with projected communications technology advances.

As an example, it is predicted that a 1 Gigabit per second fiber optics network will extend across campus by the year 2000. This bandwidth represents the maximum allowable data rate from all users at a specific time. As with all networks, the usage will expand to fill the available bandwidth. As the system approaches maximum usage at any particular time, researchers will adjust their schedules to operate at non-peak times. It is also reasonable to expect that 1 Gb/s gateways and 300 Mb/s satellite paths will be available by the year 2000. This again will represent the maximum bandwidth available. Likewise, the data given for the years 2010 and 2020 represent likely maximum capabilities for those years. These are not atypical requirements for the top 50 universities in the United States.

**Interagency Research Internet (IRI) Concept.** Recognizing the benefits of a coordinated approach to providing networking for the national scientific community, a number of the Federal agencies, including DARPA, DOE, NASA, and NSF, have planned the interconnection of their various networks under the National Research Educational Network (NREN). This would allow several major benefits:

1. Sharing of communication and other resources.
2. Coordinated access for organizations (e. g. universities) funded by multiple agencies.
3. Ubiquitous communications between researchers.
4. Coordination of networking research to benefit science.

While the required management and administration structures are being presently planned, all indications are that such an interconnected Interagency Research Internet will be funded and developed

**Space Station Information System (SSIS)** is intended to provide the required communication and computing support within the Space Station and its associated environment. This includes communications from the Space Station to a suitable point where a user can access the system as well as the

Table 3-8: Projected Growth of Stanford's Network

Year	Local Fiber	Terrestrial Gateway	Satellite Gateway
2000	1 Gb/s	1 Gb/s	0.3 Gb/s
2010	10 Gb/s	10 Gb/s	0.6 Gb/s
2020	20 Gb/s	20 Gb/s	0.6 Gb/s

needed information services to support the use of Space Station.

The SSIS will provide direct support to the primary users and resources, thus providing a networking capability directly. For other users, networking access will be provided through other systems. Furthermore, the SSIS, while providing networking services on the Space Station itself, is not intended to include the computing and communication resources directly associated with the payloads, including scientific experimental apparatus.

Thus, the SAIS must include the SSIS in its architecture, allowing scientists to both access the services provided by the SSIS and the SSIS network as a "transit" network between their experimental assets on the Space Station and their access points to the SSIS.

### 3.5.2 National Research Educational Network

In the fall of 1987, representatives of five major U. S. government agencies involved in the development and operation of existing research networks throughout the United States formed a committee which they named the Federal Research Internet Coordinating Committee (FRICC). This group represented the National Science Foundation (NSF), the Defense Advanced Research Projects Agency (DARPA), the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA), and the Department of Health and Human Services (DHHS). This group had a shared vision of a national networking concept of superhighways connecting researchers not only in the United States but throughout the world. This vision provided the guidance so that now, instead of continuing on separate paths, the way is paved to build a common superhighway known as the National Research and Education Network (NREN).

The NREN will begin to provide high-speed communications access to over 1,300 institutions across the U. S. within five years. It will support access to high-performance computing facilities and services such as full motion video, rapid transfer of high-resolution images, real-time display of time-dependent graphics, remote operation of experiments, and advanced information sharing and exchange, including national file systems and on-line libraries. NREN is a ten year program that will be implemented in three stages:

- Stage 1 upgrades the trunks in the existing backbone networks (Internet, NSFnet, ARPAnet, ESnet, etc.) of the participating agencies of the FRICC to 1.5 Mb/s (T1). The agency networks will remain distinct and individually funded but will be interconnected to permit interagency communication.
- Stage 2 Coalesces the physically distinct backbone networks into a single backbone with shared 45 Mb/s trunks (T3). The agency networks will remain logically separate by implementing control policies to ensure that the security, integrity, and resource requirements of each agency's traffic are met. The backbone will support high-speed connections to hundreds of institutions via links to mid-level networks.
- Stage 3 is the research, development, and implementation phase that will culminate in a shared network with multi-gigabit per second trunks. The objectives for this stage exceed the reach of current technology. The new technologies that are developed will drive the products and applications worldwide well into the next century.

These three stages will proceed concurrently, and yet they have been planned so that each builds on the technical and managerial foundations of the previous stage. The schedule for NREN is shown in Figure 3-38. The NREN program will be leveraged with government money up front, but it is expected to transition to a commercial operation by the turn of the century.

In the time-frame of this study NREN will have stage 3 networks in place. This capability should be able to meet all of the terrestrial link capabilities that will be required by the Data Distribution Satellite system. This will include both the science user interconnectivity as well as the terrestrial portion of telescience. Due to the standard interfaces that are being developed it should be

relatively easy for NASA to implement switches that will allow terrestrial links such as NREN to interface with interplanetary spacecraft, satellites, platforms, and manned stations in orbit.

### 3.6 Composite Requirements

The functional requirements stated above for both the Space Station Program and the Earth Sciences and Global Change Program can be extrapolated to the years 2007-2015 for the three primary categories of use:

1. Telescience,
2. Peer networking, and
3. Other functions.

#### 3.6.1 Telescience Summary Requirements

Figure 3-39 represents a summary of the Telescience requirements for DDS. During this period of time, ATDRS will be functional and therefore options were formulated which would use the ATDRS capabilities. Various options are shown where DDS plays a significant role in satisfying the composite Telescience requirements. It should be stated again that the composite telescience requirements are derived using the following baseline assumptions:

- Previous studies on user requirements started with a constrained configuration – space science users and missions were told to be able to fit within existing communication capabilities (i. e. TDRSS and NASCOM). This suggests that most existing communications specifications derived from these constrained functional requirements would underestimate the required capabilities.
- Telescience is a new operational concept and thus no experience (space science users or communications engineers) or models exist which allow for the direct derivation of communications specifications from functional user requirements. This would indicate that programs similar to the international telescience testbed program should be initiated to prototype new operations concepts and communications technology. This provides an environment where space science users and communications design engineers can optimize the needs to requirements to specifications process.

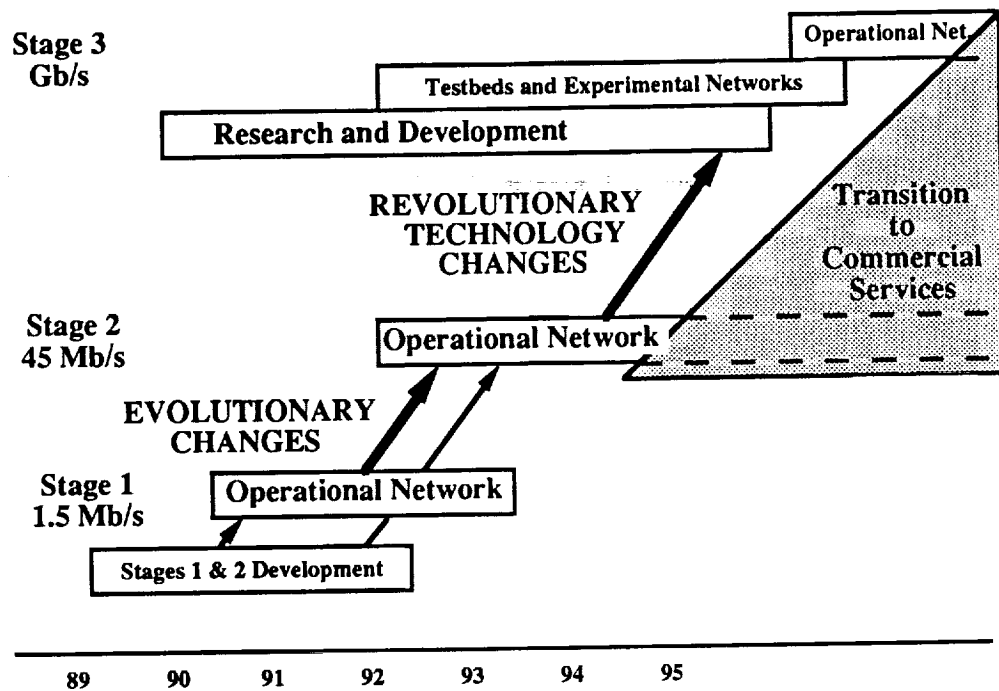


Figure 3-38: Implementation Schedule for National Research Educational Network

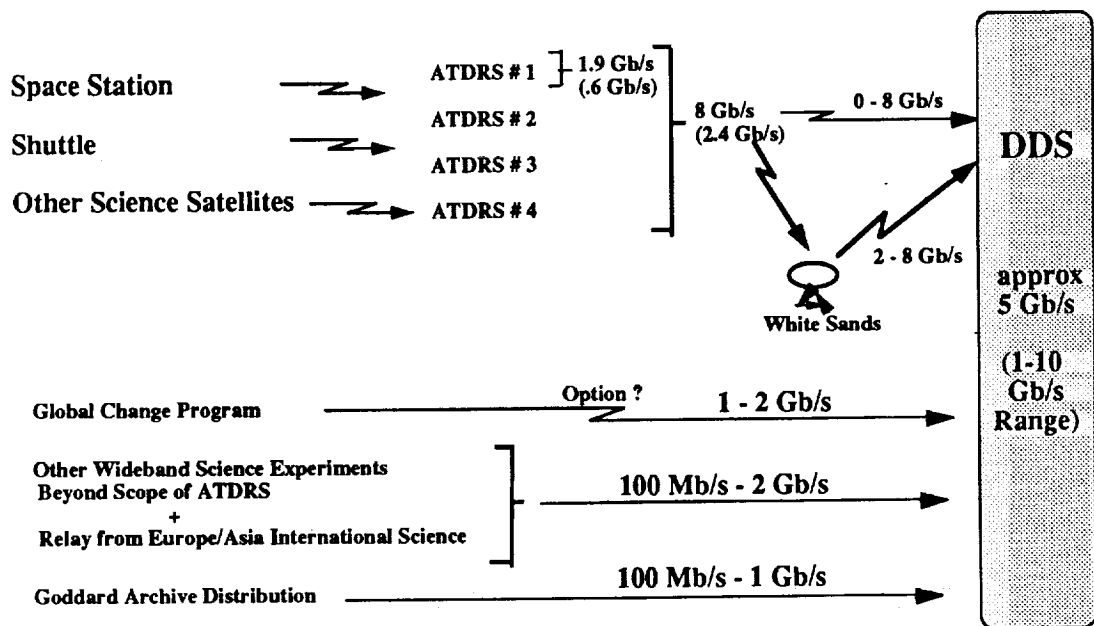


Figure 3-39: Telescope Requirements for Data Distribution Satellite

C-2

- The teleanalysis aspects of programs such as the Earth System Sciences Program (EOS, Global Change, etc.) are difficult to describe in terms of functional requirements let alone deriving communications specifications corresponding to those functional requirements. This study attempts to incorporate the dynamically emerging requirements from the Global Change Program and suggest ways in which the DDS system can satisfy some of the requirements.
- International (Europe and Japan) studies on tele-science are proceeding much faster than U. S. (NASA) efforts. The results of the international tele-science studies indicate that NASA is grossly underestimating the communications capabilities needed to satisfy the tele-science operations needs.

### 3.6.2 Peer Networking Requirements

In Figure 3-40, the peer networking summary requirements are given. These are derived by using the Stanford example (representing 1% of the user community) and extrapolating for the U. S. The impacts from emerging national fiber optics research networks (NREN) are difficult to assess. This is due to the fact that any implementation of new high speed fiber optics networks will not only provide new capabilities but will change the way and what kind of research is done in the United States.

The appearance of these new networks will stimulate a new systems engineering approach to determining the best way to satisfy the science and engineering communications needs. Hybrid architectures, which contain both satellite and terrestrial capabilities, will need to be designed which optimize functionality and possess robustness while keeping cost at a minimum. A DDS, designed as part of this hybrid architecture, can play a significant role. Collaborative science networking which employs modern multimedia techniques will be primary drivers for DDS capabilities.

### 3.6.3 Other User Summary Requirements

Figure 3-41 illustrates the best estimates of DDS requirements from other user functional needs. This capability satisfies the multimedia data communications between NASA's operational centers, international science collaboration, and wideband computational research. No one has fully experienced or realized the im-

pacts of international operated facilities in space. The Freedom Space Station, the Global Change Program, and the emerging Mars and Lunar Exploration program will constitute a triad of such efforts that will dramatically increase our need for a DDS-type system.

### 3.6.4 Composite of Summary Requirements

The composite DDS requirements (for the years 2007 and 2015) from tele-science functions, peer networking, and international and other are shown in Table 3-9. These estimates attempt to give a range number (i. e., 2-25 Gb/s) which represents minimum (constrained operations - cost and schedule limitations) and maximum (totally unconstrained - reflects total user needs) communications requirements.

The composite results must be viewed in terms of the following uncertainties:

#### Who pays for the space/control network?

Historically, NASA, Office of Space Operations (OSO), manages and budgets for all communications capabilities and services. Operational programs (e. g., Freedom Space Station, EOS, etc.) do not include these communications capabilities as part of the system engineering and design or budget process (other than giving constrained requirements to OSO during the Phase A & B activities of the program). This situation has several consequences.

- Optimization of the overall design of the communications system for maximum functionality at minimum cost is never achieved.
- Users tend to believe that the capabilities and service are free and therefore do not consider operational tradeoffs that address functionality, modes of operation, and operational costs. This second situation also produces incomplete and unreliable requirements for future communications capabilities.

**What is the role of fiber optics networks?** It is accurate to say that no integrated systems analysis and/or engineering has been done to derive an optimized hybrid (space and terrestrial elements) network configuration to satisfy the communications needs of the space program. This is primarily due do organizational or budgetary constraints. The fiber optics technology and costs are changing



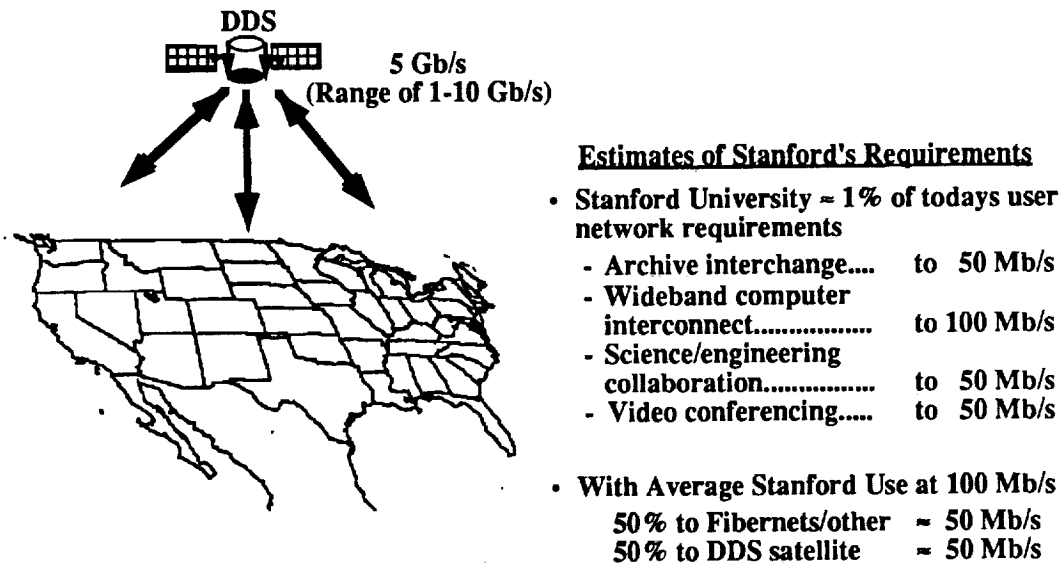


Figure 3-40: Peer Networking Requirements for Data Distribution Satellite

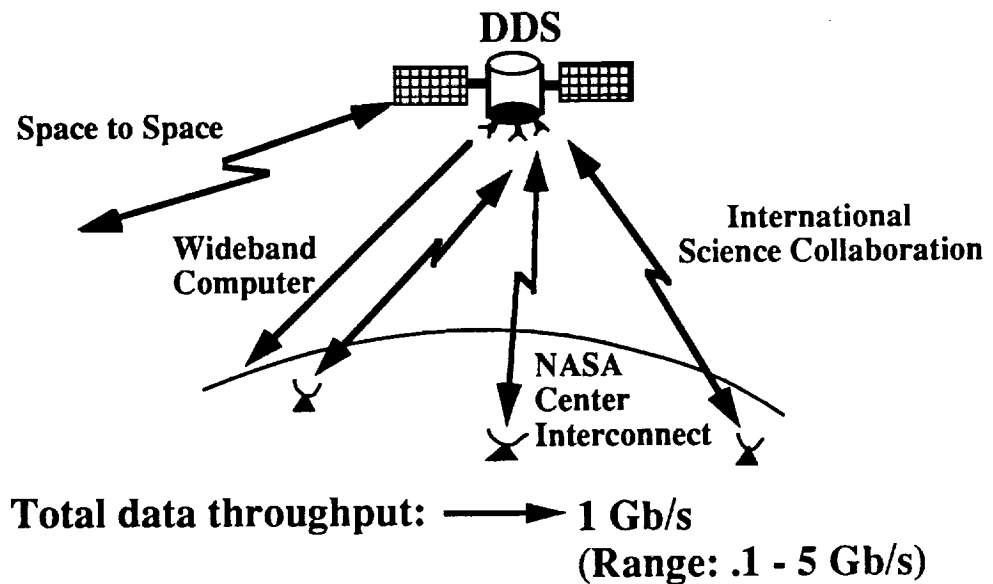


Figure 3-41: Other User Requirements for Data Distribution Satellite

Table 3-9: Composite DDS Data Requirements

	Year 2007	Year 2015
Telescience	5 Gb/s	10 Gb/s
Peer Networking	5 Gb/s	10 Gb/s
International, Other	1 Gb/s	2 Gb/s
Totals	11 Gb/s	22 Gb/s
Uncertainty Range	2 to 25 Gb/s	5 to 40 Gb/s

**Uncertainty Drivers:**

- Who pays for space/control network?
- What is role of fiber optics?
- Role of commercial vs. government networks.

drastically every year which requires a continuous reassessment of its role in providing services to the space program users.

**What is the role of commercial communications**

networks versus Government provided networks? Historically, the Federal government has played a significant role in the development of the commercial communications industry. This role has been primarily to initially finance the design and development of space communications technology (e. g., TDRSS, ACTS, ATDRSS) and then spin-off the technology to industry. NASA has always maintained management control over communications elements which are required by NASA missions. Modern hybrid configurations (space and terrestrial elements) will create a unique combination of commercial and government facilities. This will require new thinking on organizational and management issues related to these hybrid capabilities such that optimized communications services can be provided.

**3.7 DDS Prototype Testbed**

The key to the success of future communications system development projects lies in the ability to balance performance, cost, schedule and risk objectives within a dynamically changing environment. The ability of these future communications projects to meet the operational needs of a wide range of users with conflicting utilization requirements, while remaining within budget and schedule constraints and allowing for future growth and flexibility, will be the challenge. The key issues that

need to be resolved are:

- What are the key driving requirements for these future communications projects including all long term operations issues?
- What is the interaction between these requirements?
- How do they change as a function of time?
- What are the risks?

The traditional system engineering tools and methodologies presently being applied in industry and NASA projects on communications systems have not been effective in answering these crucial questions within the cost and schedule constraints. Without a thorough understanding of these requirements, the accurate decomposition of the operational system architecture from major operational performance requirements and functions down to the lower level component requirements, is impossible. In addition, the role and priority that reliability and maintainability (R&M) engineering is given in the overall systems engineering approach must be carefully reevaluated.

All systems engineering methodologies begin with mission requirements definition and specification. Generally, there are three major players in this initial requirements activity: the systems engineer, the system user (either in person or a surrogate), and the technologist. Most communications projects use a linear phased approach to carry out the system engineering:

**Concept Exploration Phase;** mission needs and objectives defined.

**Demonstration & Validation Phase;** mission definition and specification.

**Full Scale Development;** detailed design, construction, assembly and test.

**Operational Phase.**

Although there may be involvement of all three major players in the Concept Exploration activities, the system users and technologist have minimal involvement beyond this. Systems which use this engineering methodology make the basic assumption that system needs and requirements are fully understood and that the technology is identified during Concept Exploration and will remain essentially static during the other phases.

The government procurement procedures are also structured in such a way to formalize the assumption of static requirements, user needs and technology throughout the life cycle of a project. No consideration is given to the fact that the definition process is an education period where the team will refine and modify their concepts.

The process moves efficiently along from engineering to design and development whereby budget and schedule are managed carefully. System performance is judged against the initial requirements. Changing user needs or utilization concepts, evolving technology, and operations cost modeling are not allowed to influence the design or development of the system. If the system requirements are not well known initially and/or the system technology or operations concepts are dynamically evolving, the operational system will not be functionally adequate or cost effective.

### 3.7.1 Systems Engineering for the Dynamic DDS Development Environment

The Department of Defense and the Defense Advanced Research Projects Agency (DARPA) have addressed the problems associated with a dynamic development environment by initiating an industry - university - government program called concurrent engineering. The driving force behind the concurrent engineering methodology is the consideration that requirements and technology will be evolving throughout the life of a project. This requires the formulation of an engineering methodology which allows this dynamic evolution of requirements and technology over the full life cycle to influence the system design, development and oper-

ations. The process begins with the formation of an engineers - users - technologists prototype team to begin preliminary system requirements definition from best guess user functional needs.

The new process has its foundation rooted in identifying, quantitatively assessing, and managing system performance and risk. The methodology can be applied to new system designs as well as upgrades to existing operational systems. The process starts with a performance model of the system that defines not only the functions but the interrelationships between the functions. A detailed probabilistic risk assessment (PRA) of the system elements and their interrelationship is then performed. The quantitative analysis of the reliability and maintainability of an engineering system allows identification of its different technical and process failure modes and computation of their probabilities. Therefore, it permits a decision maker to choose technical solutions that maximize an objective function under resource constraints. This means, for instance, the choice of design characteristics that minimize the probability of failure during the lifetime of the system under constraints of costs, time, and performance.

Technical modifications, however, represent only one class of risk management strategies. When a system's failure is studied a posteriori, it is often pointed out that what resulted in a technical failure was actually rooted in a structural or functional failure of the organization. These organizational factors include, for example, geographic dispersion (thus, sometimes, poor communications), time constraints, user ignorances relating to requirements, and pressures of internal and external public relations. Modifications and improvements of the organization itself may address some of the reliability problems at a more fundamental level than strengthening the engineering design alone. Such modifications can include improving communications, providing education and training programs, setting effective warning systems, and ensuring consistency of standards across the organization.

At this point the prototype team establishes a set of evaluation criteria for various proposed concepts which were formulated to meet the preliminary requirements. The concepts which have high risk values can take one of two paths. With either path, the primary objective of the process is to validate the concepts in terms of satisfying the preliminary requirements and to educate the team. Both work to reduce risk. Some communications concepts can be functionally tested in a modeling

or computer simulation environment while others must be placed in a rapid prototyping testbed where "quick and dirty" point designs can be operated in a hands-on mode by the team. With both paths, rapid iteration is essential to the success of the methodology. When several competing concepts satisfactorily meet the system requirements, then a formal trade-off process must occur to arrive at the optimum concept. Quantitative risk assessment techniques can be a useful tool for this formal trade-off process.

Before formal specification can begin, care must be taken to distill all design specifications from the concepts such that vendor specific specifications from the point designs are removed. It should be stated that not all requirements will be fully specified at the end of Demonstration/Validation Phase in engineering design terms. Any Request for Proposals (RFPs) for Full Scale Development should fully identify which requirements have not been fully specified (those with high risk probabilities) and proceed with additional prototyping to fill in any additional information that will be needed to complete the system design. The present procurement system used by the Federal Government must be totally restructured to accommodate this dynamic nature of requirements, end user knowledge of system functions and technology, and the operational maintainability - availability issues.

A key to good systems engineering and management during the design - development phase is the ability to keep the design process open to evolving requirements and technology as long as practical. The fundamental tools to assist the systems engineer in this process are the system performance model and quantitative (probabilistic) risk analysis. The performance model will allow the impact of the changing requirements and environment to be quantified and documented. This information is then input into the risk analysis. While the risk analysis during the Concept Development Phase primarily dealt with user ignorance of needs/requirements, technology readiness, and system evolution, now the risk parameters of time, budgets, and schedules must be assessed and managed. It should be stated again that this risk analysis process is not a casual "seat of the pants" effort but one in which formal quantitative probabilities are determined for each individual system element along with the joint probabilities between elements. These quantitative assessments will provide an exacting means to determine when further prototyping will reduce risks and when system technology and spec-

ifications must be rigidly fixed for development.

Those requirements that are well understood at the end of Phase B can be specified and given to the design contractors for preliminary design. For requirements that have been assessed to be high risk, additional prototyping and simulation modeling can occur during the Phase C design review period. At the Preliminary Design Review (PDR) milestone a risk assessment can be made to determine which high risk elements have been reduced in risk sufficient to be specified and included in the design. If the schedule does not dictate that a high risk element be included in the design, the parallel prototyping effort can continue. Also the PDR may uncover additional risk elements that could benefit from the parallel prototyping. By the time of the Critical Design Review (CDR), most system elements must be specified and given to the design contractors. If the schedule dictates this action for an element that has been assessed to still have a medium to high risk, architectural "hooks and scars engineering" (system hooks allow for software evolution while scars allow for hardware evolution) must be incorporated into the system design. The risk assessment analysis can provide a quantitative way to evaluate which systems are susceptible to rapid technology evolution and utilization concepts and also determine the most efficient resources allocation.

## 3.8 References

### 3.8.1 Space Station Prime Requirements Documents

Space Station Freedom Program Definition and Requirements, SSP 30000, Revision B, Space Station Program Office, Reston, Virginia. Key sections include: Section 4: Space Station Operations Requirements; Section 7: Space Station Information System Definition and Requirements; Section 8: Technical and Management Information System.

This document is the baseline requirements document for the Freedom Space Station. It documents all of the functional requirements for communications services. It makes no attempt to synthesize or integrate the communications requirements in terms of data rates or peak versus average usage levels.

Space Station Freedom Polar Orbiting Platform Requirements, Space Station Program Office, Reston,

Virginia.

This document is the baseline requirements document for the polar platform element of the Space Station Program. It documents all of the functional requirements for communications services from the platform to the manned station and from the platform to the ground. It makes no attempt to synthesize or integrate the communications requirements in terms of data rates or peak vs. average usage levels.

### 3.8.2 Space Station Support Documents

**Space Station Operations Task Force Final Report, Space Station Program Office, Reston, VA, October, 1987**

This document details the operations architecture for the space station. It thoroughly explains the functional aspects of operating the Space Station from both a technical as well as an organizational point of view. Only functional operations requirements are given and no attempt is made to synthesize or integrate the communications requirements in terms of data rates or peak vs. average usage levels.

**Telescience Testbed Pilot Program, RIACS Technical Report: TR-89.7, Ames Research Center, February, 1989**

The three volume report describes a rapid prototyping effort by NASA and 15 universities to identify and address critical issues in the design and specification of the Space Station Information System (SSIS). Although this document identifies clearly the functional requirements of the space science users it does not translate these to communications engineering specifications (data rates, etc.).

**Earth Observing System Data and Information System (EosDIS) Requirements, Level I, Goddard Space Flight Center, June 15, 1989.**

The EosDIS is a concept to provide an end-to-end data and information system for the Eos Project and its community of users. The Level I, II, III, & IV requirements documents state the requirements for development of EosDIS-unique and external systems, system elements and subsystems such that they specify all of the required functional characteristics of the items and the tests required to demonstrate achievement of those characteristics. Although this document identifies clearly the functional requirements of the space science

users it does not translate these to communications engineering specifications (data rates, etc.).

### 3.8.3 Space Science & Applications Prime Requirements Documents

**Report of the Information Systems Strategic Planning Project:** prepared for the Office of Space Science and Applications (OSSA) and the Office of Space Operations (OSO), January 1990.

This report is a comprehensive analysis of the needs, trends, and priorities for the OSSA in relationship to the information systems environment of the 1990s. Although the report carefully describes the functional needs of the space science users for the next 10 years, no attempt is made to extrapolate those functional requirements to communications specifications (peak and average data rates, distribution characteristics and loading, etc.).

### 3.8.4 Key OSSA Support Documents

**Science and Applications Information-System Report:** prepared for the OSSA and Goddard Space Flight Center, December 1988.

This report was the result of the Science and Applications Information Systems (SAIS) Working Group which was composed of personnel from NASA HQ and Centers, universities and NASA contractors. The report analyzes the life cycle requirements for space science investigations during the space station era. The study divided the requirements environment into three functional phases (teledesign phase, teleoperations phase, teleanalysis phase) and the networking infrastructure to support those phase activities. Although the report is the most comprehensive in terms of overall functional information system architecture requirements, no attempt is made to extrapolate those functional requirements to communications specifications (peak and average data rates, distribution characteristics and loading, etc.).

### 3.8.5 Other Prime Communications Requirements Documents

**Space Physics Analysis Network (SPAN) Documents and Databases.** The Space Physics Analysis Network, or SPAN, has grown exponentially over the course of the last few years. The growth of SPAN from its implementation in 1981 to the present is considerable

with the number of registered SPAN host computers exceeding 2500. This expansion has created a need for users to acquire timely information about the network.

The National Space Science Data Center (NSSDC) at GSFC has created an online capability (SPAN Network Data Center (SPAN-NIC)). This online database contains information on nodes, locations, science disciplines involved and other pertinent network information. This international capability provides one of the best demographic source of information about active space science research and network requirements. This database makes no attempt to extrapolate functional network needs to communications specifications (peak and average data rates, distribution characteristics and loading, etc.) and does not project past 5 years in the future for expanded network needs.

**Program Plan for the National Research and Education Network, Subcommittee on Computer Networking, Infrastructure and Digital Communications, Federal Research Internet Coordinating Committee, 1989**

This document describes the steps to be taken by the Federal government to establish the National Research and Education Network (NREN). The NREN will be a communications network that interconnects: educational institutions; national laboratories, nonprofit research institutions, and government facilities; commercial organizations engaged in government-supported research or collaborating in such research; unique national scientific and scholarly resources such as super-computer centers, major experimental facilities, databases, and libraries. This effort makes no attempt to extrapolate functional network needs to communications specifications (peak and average data rates, distribution characteristics and loading, etc.) and does not project past 5 years in the future for expanded network needs.

### 3.8.6 Other Communications Support Documents

**U. S. Computer Research Networks: Current and Future, Contel Federal Systems Contract to NASA Lewis Research Center, January 1990.**

This report is a comprehensive reexamination of future telecommunications needs and requirements necessary to enable NASA to make management decisions in their communications program and to ensure that proper technologies and systems are addressed. The report addresses the following subtasks:

- Identify, define and describe unique networks
- Identify define and describe shared networks
- Size current Integrated Research Networks (IRN)
- Project future IRN
- Estimate present and future costs
- Conduct reviews and prepare reports

This document is the only one of the documents that specifically addresses data rates, costs and other engineering specifications related to research networks.

## Chapter 4

# System Design Constraints

This chapter discusses the key factors that constrain the system design and is organized as follows:

- 4.1 ATDRSS Constraints
- 4.2 Other Network Constraints
- 4.3 Launch Vehicle Capacity
- 4.4 Spectrum Availability
- 4.5 Technology Availability
- 4.6 System Cost Constraints
- 4.7 References

References for this chapter are given in ¶4.7, and are indicated by numbers in square brackets such as [1].

### 4.1 ATDRSS Constraints

#### 4.1.1 ATDRS Launch Schedule

The ATDRS launch schedule is given in Figure 4-1 per the Phase B Statement of Work from NASA/GSFC. Four ATDRS are launched to replace the TDRS in the 1997-2002 time frame and have a 10 year life. A replenishment series of ATDRS is launched in the 2007-2012 time frame. Thus a separate DDS platform must act with the currently planned ATDRS system up through 2012, when ATDRS will be replaced with a new system.

The ATDRS replacement, known as ASDACS in this study, could be launched in the year 2012 or later and incorporate changes to the ATDRS system in order to facilitate the data distribution function. Until this time, and DDS platform can only interact with ATDRSS via White Sands or a special FSG payload.

#### 4.1.2 Use of FSG Payload

There is an ATDRS Flight Services Growth (FSG) reserve for additional payloads of 109 kg mass, 260 W

power, 260 W thermal dissipation, and 0.31 m<sup>3</sup> volume. This payload could be used to relay data to DDS via an intersatellite link or to perform the data distribution function directly from ATDRS (see Chapter 6, ¶6.3).

#### 4.1.3 Interface to ATDRSS

In order to distribute data originating in space and gathered by ATDRSS, the DDS must either connect to an ATDRS via an intersatellite link or else connect to the Data Interface Facility (DIF) at White Sands (see discussion in ¶1.2.3 and Figure 1-3 of Chapter 1). This imposes format constraints (DIF uses CCSDS ESF format) [30] and data access constraints according to the ATDRSS Space Network Operations scheduling.

### 4.2 Other Network Constraints

The DDS system must interface with a number of other networks such as the Station Information System (SSIS), the NASCOM network [31], public switched telephone networks, and a variety of local area networks. These networks impose their own constraints in terms of specific formats, protocols, allowable data rates, and access procedures. Compatible standards, modified if necessary for satellite transmission, must be adopted for DDS use.

### 4.3 Launch Vehicle Capacity

Figure 4-2 gives a summary of current and future predicted launch vehicle capacities to Geosynchronous Transfer Orbit (GTO). For the 2007 DDS launch which requires 3,550 kg to GTO, an Atlas 2AS or comparable vehicle is selected as a low risk and low cost choice since it will be operational 15 years by the year 2007.

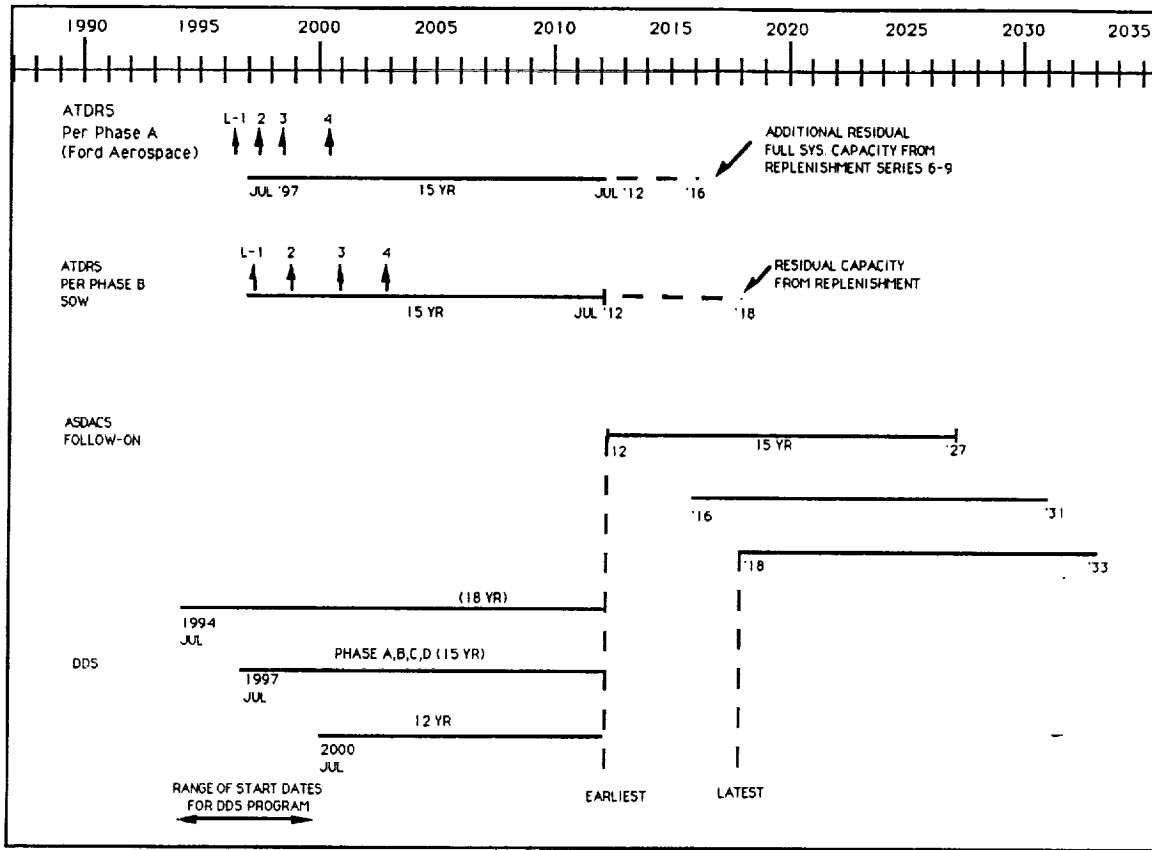


Figure 4-1: Master Schedule for ATDRS-ASDACS/DDS

For the 2015 series DDS which requires 2,500 kg to GEO, an Advanced Launch Vehicle (ALV) for injection into Low Earth Orbit (LEO) and an Orbital Transfer Vehicle (OTV) for injection into GEO are assumed. It is difficult to predict 25 years into the future what launch vehicle capacity will be. However, the DDS needs are considered well within the capabilities projected for the ALV and OTV. (The ALV capacity to LEO is predicted to be 45,000 kg in 2000 and 68,000 kg in 2010.)

### 4.4 Spectrum Availability

Frequency allocations in Region 2, United States of America, are described together with DDS frequency planning and limits on power flux density.

#### 4.4.1 Frequency Allocations

There is limited bandwidth available at Ku and Ka-bands. Government systems have no primary or per-

mitted at Ku-band; and at Ka-band, there is only 1 GHz of shared primary allocation for military systems. The situation is somewhat better for non-government system; at Ku-band there is 0.5 GHz unshared primary allocation for National systems, and at Ka-band there is 0.5 GHz unshared primary allocation and an additional 2 GHz of shared primary allocation.

Figures 4-3 and 4-4 give the frequency allocations for Ku-band downlinks and uplinks respectively, together with applicable footnotes. Figures 4-5 and 4-6 give the frequency allocations for Ka-band downlinks and uplinks respectively, together with applicable footnotes. This information is based on the *Manual of Regulations and Procedures for Federal Radio Frequency Management*, [32]. Permitted and primary services have equal rights, except that, in the preparation of frequency plans, the primary service, as compared with the permitted service, shall have prior choice of frequencies. Stations of a secondary service:

- a. Shall not cause harmful interference to stations of



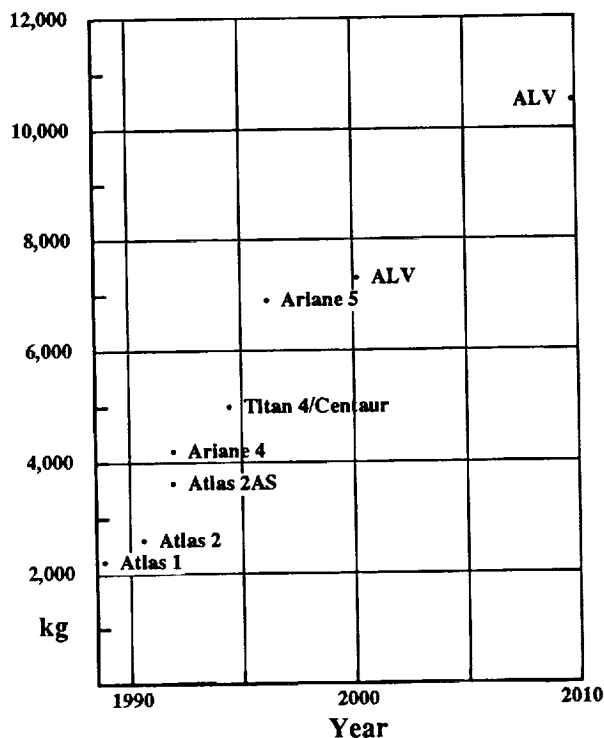


Figure 4-2: Launch Capacity to GTO vs. Time

primary or permitted services to which frequencies are already assigned or to which frequencies may be assigned at a later date;

- b. Cannot claim protection from harmful interference from stations of a primary or permitted service to which frequencies are already assigned or may be assigned at a later date;
- c. Can claim protection, however, from harmful interference from stations of the same or other secondary services to which frequencies may be assigned at a later date.

#### 4.4.2 DDS Frequency Planning

The DDS system may be operated as a government or a non-government system.

Government systems have the following constraints:

**Ku-band:** no primary or permitted allocations are available. (TDRS uses secondary services under the "Space Research" category; uplinks at 14.6-14.9 and 15.11-15.25 GHz, and downlinks at 13.4-13.75 and 13.8-14.05 GHz.) (See Figures 4-3 and 4-4.)

**Ka-band:** 1.0 GHz shared primary allocation is available for military systems only. Frequency is 30-31 GHz uplink and 20.2-21.2 GHz downlink. The sharing is with the Mobile Satellite service. (See Figures 4-5 and 4-6.)

Non-government systems have the following constraints:

**Ku-band:** (See Figures 4.3 and 4-4).

**Downlink** – 0.5 GHz unshared primary allocation for National systems (11.7-12.2 GHz). The International system allocation is at 10.7-11.7 GHz.)

**Uplink** – 0.5 GHz primary allocation, shared with Radio Navigation services 14.0-14.2, unshared 14.2-14.5 GHz. (International allocation is 12.7-13.25 GHz.)

**Ka-band:** 0.5 GHz unshared primary allocation available (29.5-30.0 GHz uplink, 19.7-20.2 GHz downlink). 2.0 GHz shared primary allocation available (27.5-29.5 GHz uplink, 17.7-19.7 GHz downlink). The sharing is with Fixed and Mobile services. The downlink band has further sharing and restrictions within 17.7-17.8, 18.1-18.3, and 18.6-18.8 GHz. (See Figures 4-5 and 4-6.)

#### 4.4.3 Limits on Power Flux Density

Power Flux Density (PFD) limits do not pose design constraints at Ku and Ka-bands. (Reference is the *Final Acts of the World Administrative Conference*, International Telecommunication Union, Geneva, 1979.)

**Earth Stations** have no limits for angles of 5° or greater above the horizon (Ref. 6038, p. 266). Limits only apply to Ka-band uplinks at 27.5-29.5 GHz below 5° elevation angle.

**Space Stations:** (Ref. 6050, p. 268). No limits are listed for 12.75-17.7 and 19.7-31.0 GHz. For 17.7-19.7 GHz (Ref. 6075, p. 272),

–115 dB ( $Wm^{-2}$ ) in any 1 MHz band 0° to 5° elevation.

–115 + 0.5(elevation – 5°) dB ( $Wm^{-2}$ ) in any 1 MHz band 5° to 25° elevation.

–105 dB ( $Wm^{-2}$ ) in any 1 MHz band 25° to 90° elevation.

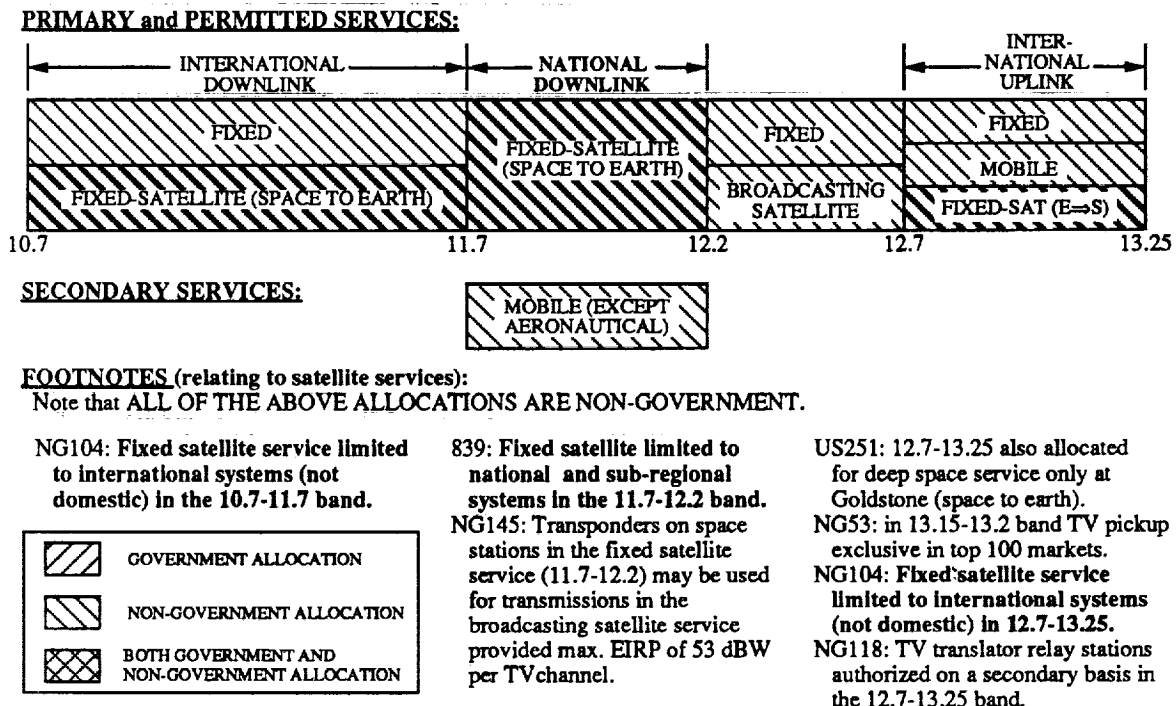


Figure 4-3: Ku-Band Downlink Frequency Allocations in the United States

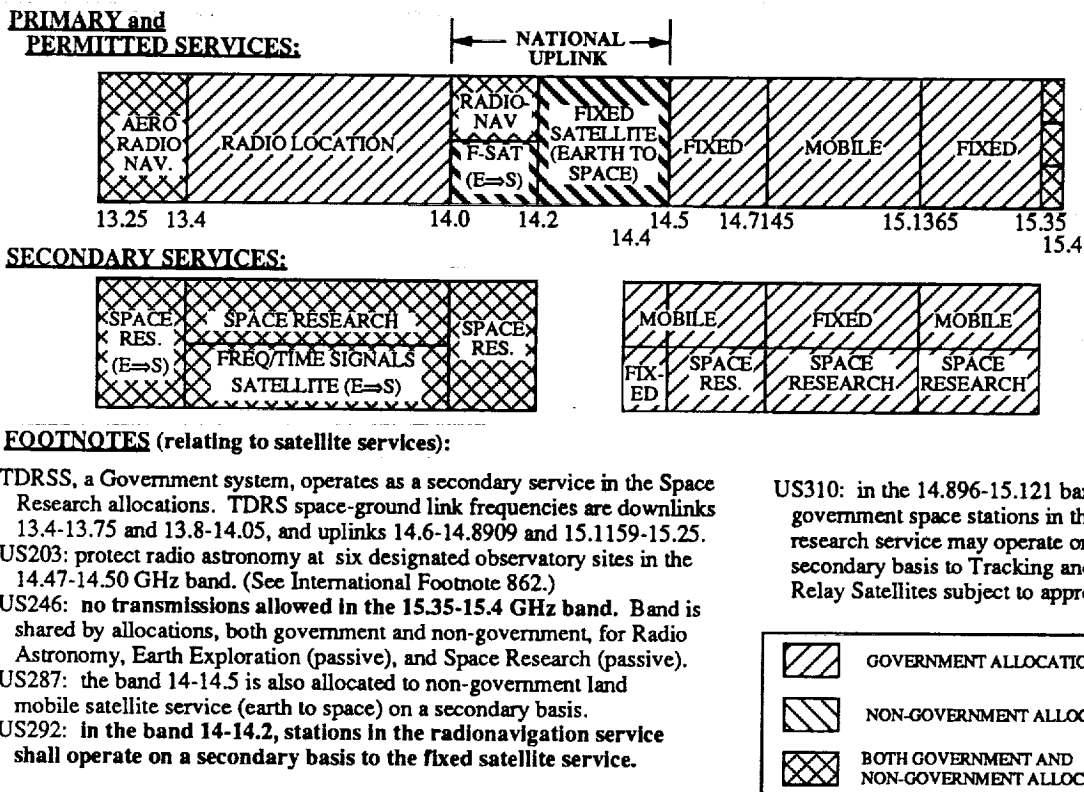
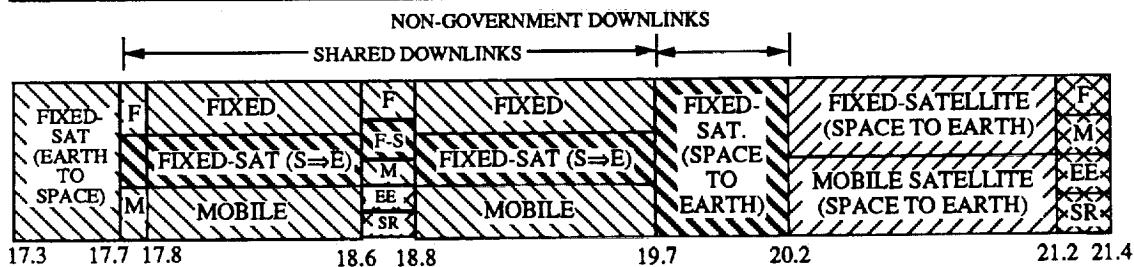


Figure 4-4: Ku-Band Uplink Frequency Allocations in the United States

**PRIMARY and PERMITTED SERVICES:**



**SECONDARY SERVICES:**



**FOOTNOTES (relating to satellite services):**

- US254: in the 18.6-18.8 band, the fixed and mobile services are limited to 35 dBW EIRP and -3 dBW power delivered to the antenna.
- US255: in the 18.6-18.8 band, the fixed satellite service is limited to a power flux density at the earth's surface of of -101 dBW/sq. m in a 200 MHz band for all angles of arrival.
- US259: stations in the radiolocation service in the 17.3-17.7 band are restricted to 51 dBW EIRP when feeder links for the broadcasting satellite service are brought into use.
- US271: the use of the 17.3-17.7 band by the fixed satellite service (earth to space) is limited to feeder links for broadcasting service.
- G117: in the 20.2-21.2 band, the Government fixed satellite and mobile satellite services are limited to military systems. (TDRSS downlinks are in this band.)

870: The 18.1-18.3 band is also allocated to the GEO meteorological satellite service (space to earth) on a primary basis.

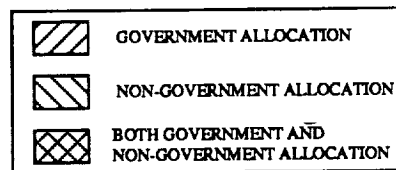
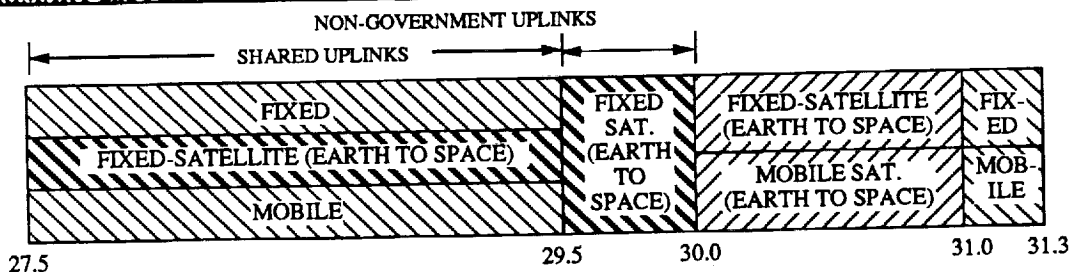


Figure 4-5: Ka-Band Downlink Frequency Allocations in the United States

**PRIMARY and PERMITTED SERVICES:**



**SECONDARY SERVICES:**



**FOOTNOTES (relating to satellite services):**

- US211: protect the radio astronomy service at 31.2-31.3 GHz. (See International Footnote 886.)
- G117: in the 30-31 GHz band, the Government fixed satellite and mobile satellite services are limited to military systems. (TDRSS uplinks would be in this band (none are planned). ACTS plans to use the 29-30 GHz uplink band.)

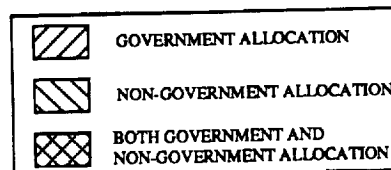


Figure 4-6: Ka-Band Uplink Frequency Allocations in the United States

EIRP equivalent of  $-115 \text{ dBWm}^{-2}$  is 48 dBW in a 1 MHz band and 63 dBW in a 30 MHz band. Antenna gains are 45 and 49 dBi for  $0.2^\circ$  and  $0.3^\circ$  beams, thus allowing from 25 W to 63 W transmit power in a 30 MHz bandwidth, within the 17.7-19.7 GHz band.

## 4.5 Technology Availability

The prediction of the state-of-the-art of technology for the 2007, 2015, and 2025 DDS designs is key to system viability. Great changes are now occurring to terrestrial communications networks due to the impact of photonic technologies. There will be corresponding impacts on satellite networking, at minimum in the interfaces to the terrestrial network.

Key areas of impact on the satellite design are discussed in the subsections listed below, and finally a summary of technology availability by year is given.

- 4.5.1 Ion Thruster Propulsion
- 4.5.2 Solar Cells
- 4.5.3 Batteries
- 4.5.4 Multiple Beam Antennas
- 4.5.5 Bulk Demodulators
- 4.5.6 Intersatellite Links
- 4.5.7 Broadband ISDN Standards
- 4.5.8 Satellite Switching
- 4.5.9 Operational Life Concepts
- 4.5.10 Summary of Technology

### 4.5.1 Ion Thruster Propulsion

The general class of "electric propulsion" includes ion thrusters, arcjets, resistojets, and MPD thrusters. Arcjets are currently planned for the new AT&T Telstar geosynchronous communications satellites being built by General Electric. Ion thrusters have superior specific impulse ( $ISP = 3,000 \text{ s}$  versus  $500 \text{ s}$  for arcjets) and a history of use on experimental satellites (NASA ATS and SERTS, Japanese ETS VI).

Ion propulsion is selected for the DDS station keeping function due to its significantly reduced fuel mass requirement compared to the current liquid bipropellant systems. This allows an increased satellite payload mass. Since on-orbit fuel requirement is typically several hundred kilograms, there is a significant potential

for mass savings. However, the ion propulsion system has more mass than the comparable bipropellant system, and requires significant electric power during use.

A study performed by Ford Aerospace for Intelsat [33] showed that for satellites with sufficient battery power for eclipse operation, no additional solar array or battery power/mass is required. For example, the Intelsat 7, high RF power, ion propulsion option satellite is an 1,800 kg dry mass satellite. For this satellite, the ion thrusters require 1,500 W for an average of 100 minutes per day. The batteries are sized to provide 3 kW power for a worst case 72 minute eclipse. Fortunately, the station keeping during the eclipse season is required at 0600 and 1800 hours, and not at the 0000 hour time the batteries are required for eclipse operation. Thus no additional battery capacity is required over that which is already required for eclipse operation.

For the case of the Intelsat 7 satellite with 10 year mission, 400 kg of station keeping and orbit raising fuel is saved by the ion propulsion versus the bipropellant system. The ion system has 150 kg more dry mass, giving a net savings of 250 kg. For a 15 year mission, an even more impressive net savings of 540 kg is achieved.

### 4.5.2 Solar Cells

Thin silicon solar cells can be used for the 2007 satellites and thin GaAs solar cells for the 2015 DDS satellites. The assumed total array specific power is 33 W/kg for both cases (ratio of dc power to solar array mass). The power subsystem (solar array plus batteries) specific power is 17 W/kg for the 2007 design and 20 W/kg for the 2015 design.

For the year 2007 case, thin silicon cells on a four panel, two wing configuration can provide 5 kW power. This is the same configuration being qualified by Space Systems/Loral for the Intelsat 7 program in the 1990s. The Intelsat 7 design uses 8 mil (0.20 mm) thick cells. The assumption is made that by the year 2007, a 20% reduction in cell thickness can be made with the consequent 10% improvement in total array specific power (W/kg) since cell mass is 50% of array mass.

For the year 2015 case, thin gallium arsenide (GaAs) are assumed using the Intelsat 7 configuration. An estimated 40% improvement in efficiency (21% vs. 13%) provides 7 kW power from the same area. Cell thickness is assumed to be 4 mil (0.10 mm), approximately 40% of the 1990 10 mil (0.25 mm) GaAs cells. However, since GaAs has about 2.3 times the density of sili-

Table 4-1: Solar Array Power Degradation

Time (yr)	Relative Power
0	1.00
1	.94
2	.92
3	.91
4	.89
5	.88
6	.86
7	.85
8	.84
9	.82
10	.81
11	.80
12	.79
13	.78
14	.77
15	.76

con, the mass will be 15% more than the Intelsat 7 mass.

An additional 5% radiation degradation is assumed for the additional 5 years of life, as shown in Table 4-1 (data for silicon solar cells used for the GOES satellite). Assuming the cells comprise 50% of the total solar array mass, a specific power improvement of 10% over Intelsat 7 is achieved.

The net result is that the 2007 thin silicon and 2015 GaAs solar arrays have the same specific powers (W/kg), but the advantage of GaAs is that it provides 40% more power from the same area. This reduces solar torque and allows for more efficient packaging and deployment.

### 4.5.3 Batteries

Advanced nickel hydrogen (NiH) batteries are used by the DDS (2007 launch), and sodium sulfur (NaS) batteries are used by the DDS (2015 launch). These battery choices are based on estimates of battery performance and technology readiness dates by NASA/JPL [17]. Since battery mass may be several hundred kilograms on a high power satellite, there is potential for significant mass savings which in turn increases payload mass.

NaS batteries have demonstrated significantly higher specific energy (Watt hours per kilogram) than the

nickel cadmium (NiCad) and nickel hydrogen (NiH) batteries currently used in satellites, and are expected to have superior performance to the advanced NiH battery. An impact on the satellite of NaS batteries is that they operate at 350° C and must be insulated from the payload.

Experts from universities, industry, and the government participated in the above-referenced 1989 NASA/JPL survey of electrochemical systems for space applications. JPL concluded that NaS batteries for geosynchronous satellite applications will be available in 2010 with 150 Wh/kg specific energy. Advanced NiH batteries will be available in 2000 with 75 Wh/kg specific energy. These are significant advances over the capability of 1990 NiH batteries which provide 45 Wh/kg specific energy.

### 4.5.4 Multiple Beam Antennas

Existing designs for multiple beam antennas (MBA) are mature for fixed single coverage areas or multiple coverage areas from the same antenna. Use of frequency selective surfaces or gridded reflectors allows the combination of different antennas into the same aperture. However, the reconfigurable antennas of today are heavy and power-hungry due to the use of ferrite components for pattern changes.

A major advance in multiple beam antenna technology can be achieved in the 2000s by the use of MMIC devices to enable an active aperture feed, and the use of active cooling to remove heat from the active antenna. However, the antenna designs proposed for our DDS concepts use fixed pattern antennas that can not benefit from the active aperture approach. A TDMA DDS concept would surely benefit from an active aperture MBA or direct radiating phased array antenna design.

There are a number of factors influencing the design of the MBA:

- Number of beams on the coverage area (see Figures 7-1 thru 7-3 in Chapter 7).
- Angular extent of coverage area in terms of antenna beamwidths. It is difficult to cover an angle more than 20 beamwidths wide without excessive scan loss.
- Amount of frequency reuse required across the coverage area. In different beams, in different parts of the coverage area, the same frequency and

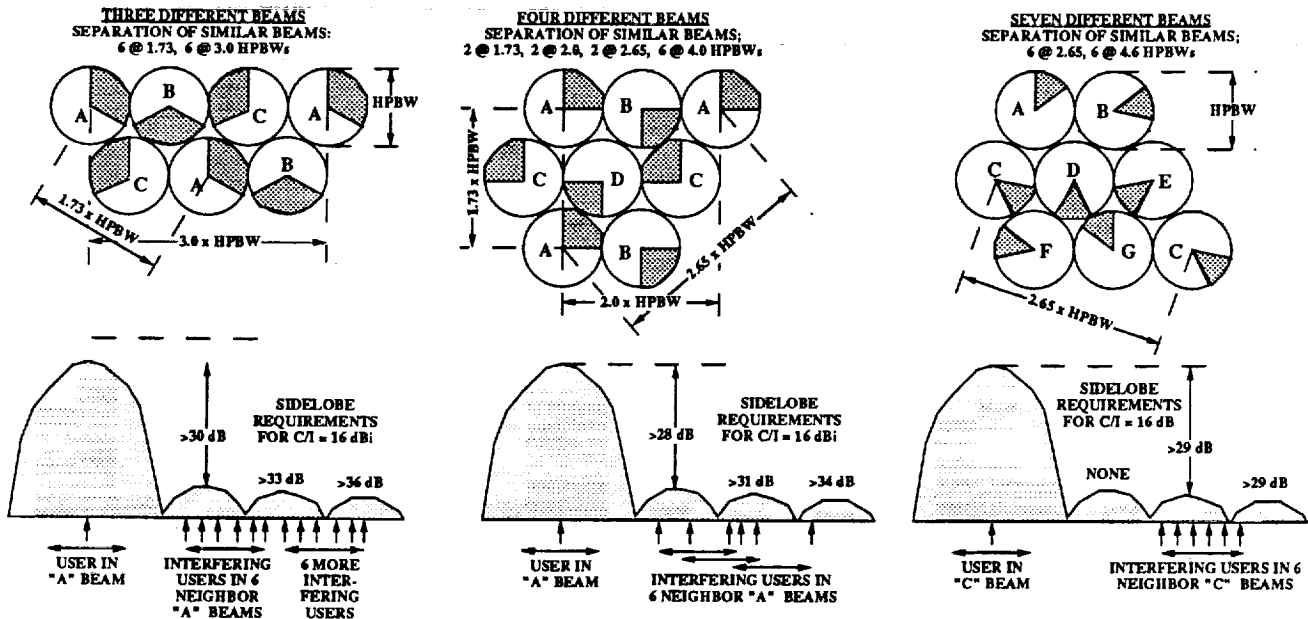


Figure 4-7: Frequency Reuse Plan Determines Sidelobe Requirements for Multiple Beam Antenna

polarization can be used if there is adequate isolation between them. This becomes a sidelobe specification problem for the MBA.

Figure 4-7 illustrates three different frequency reuse cases for a situation such as that shown in Figure 7-2 where 28 beams of  $0.87^\circ$  cover CONUS.

1. Three different beams, (A, B, and C), each uses  $1/3$  of the available spectrum (frequency and polarization). (Left of Figure 4-7.)
2. Four different beams, (A, B, C, D), each uses  $1/4$  of the available spectrum (frequency and polarization). (Middle of Figure 4-7.)
3. Seven different beams, (A thru G), each uses  $1/7$  of the available spectrum (frequency and polarization). (Right of Figure 4-7.)

As shown in the figure for each case, users in the neighboring "same letter" beams will show up as co-channel interference, and thus place sidelobe requirements on the antenna. The allowable interference level or C/I is determined by signal modulation format and acceptable interference degradation.

For the antenna to achieve the required sidelobe levels, its aperture distribution must be tapered which in turn reduces efficiency. For example, Case 1 is not practical, but Case 2 which uses 25% of the available bandwidth can be achieved with an aperture efficiency of

60%. Case 3 uses  $1/7$  of the available bandwidth, but with the easier sidelobe requirements can achieve 65% antenna efficiency.

#### 4.5.5 Bulk Demodulators

Bulk demodulator technology has been discussed in detail in Appendix A of the Task Order No. 3 Final Report [20]. A digital FFT approach is envisioned. For use in year 2007, mass estimate is 1.1 kg and power estimate is 10 W for a unit handling 400 channels of 64 kb/s (or 16 channels of 1.5 Mb/s). Bulk demodulator card size is 10 cm by 25 cm.

#### 4.5.6 Intersatellite Links

Optical intersatellite link technology is expected to make rapid progress in terms of reduction in mass and power. Table 4-2 summarizes estimates for the year 2000 of the mass, power, and volume of 60 GHz systems (36,000 km link) [20,21]. This technology is relatively mature and is not expected to change significantly by the years 2007 and 2015. However, rapid progress is occurring in the area of photonics, and optical intersatellite links have the potential to significantly reduce required mass, power, and volume.

Current estimates for an optical intersatellite link system are 80 kg mass, 200 W power, and  $0.5 \text{ m}^3$  volume

Table 4-2: Estimates of 60 GHz Intersatellite Link Mass, Power, Volume (Year 2000)

Type of Amplifier	Data Rate (Gb/s)	Aperture Size (m)	Transmit Power (W)	Mass (kg)	Power (W)	Volume (m <sup>3</sup> )
SSPA	0.5	1.2	10	52	160	2.3
	1.0	1.5	10	61	170	3.7
	2.0	1.8	10	70	180	6.2
TWTA	0.5	1.2	10	52	130	2.3
	1.0	1.2	20	52	180	2.3
	2.0	1.2	40	52	280	2.3

for a 1 Gb/s link. However, recent advances with coherent system technology, high power laser diode array sources, and fiber optic interconnections promise to greatly reduce mass and power.

Figures 4-8 and 4-9 estimate aperture size and system mass versus data rate for an advanced optical intersatellite link (ISL) system [22, 23]. System mass is around 33 kg with a 15 cm aperture for a 1 Gb/s link over 40,000 km. We believe mass can be reduced to 23 kg and power consumption to 50 W for the optical ISL in the year 2007.

4.5.7 Broadband ISDN Standards

The Data Distribution Satellite (DDS) should have a compatible interface to the public switched network in the United States as well to international networks. To develop DDS-unique protocols and channel structures is neither required nor cost effective. The CCITT (International Telegraph and Telephone Consultive Committee) is in process of defining and obtaining international agreement for a Broadband Integrated Services Digital Network (B-ISDN) standard.

The B-ISDN standard is recommended for use by the DDS for reasons of cost effectiveness and international compatibility. This section describes the standard to the extent that it is currently defined (10/89), and discusses the impact of the channel data rates and multiplexing on the satellite design. National and international standards bodies are now reaching agreements on interface standards for B-ISDN based on the SONET standard for transmission, and the ATM standard for multiplexing and switching.

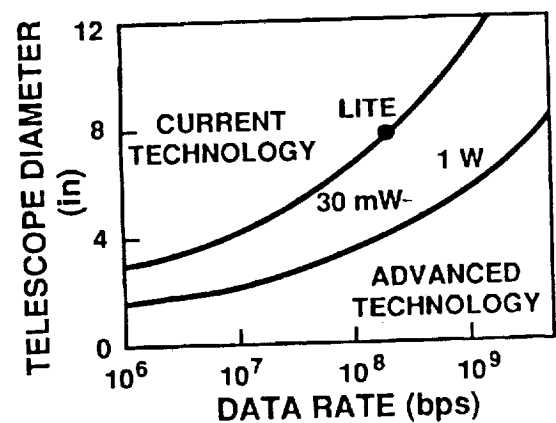


Figure 4-8: Advanced Laser ISL Aperture Size

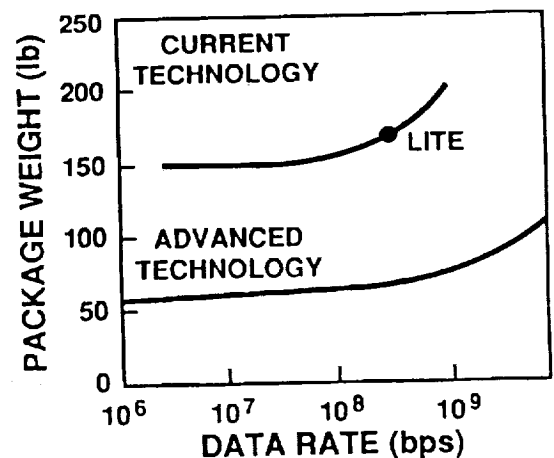


Figure 4-9: Advanced Laser ISL Package Weight

### 4.5.7.1 Synchronous Optical Network

SONET (Synchronous Optical Network) is a newly adopted standard for a family of physical layer interfaces for use in optical networks (CCITT Rec. G.707, G.708, and G.709). SONET defines standard optic signals, a synchronous frame structure for multiplexing digital traffic, and operations procedures in order to allow interconnections between systems.

The basic building block and first level of the SONET signal hierarchy is called the Synchronous Transport Signal - Level 1 (STS-1) with a bit rate of 51.84 Mb/s. (This accommodates the DS3 rate of 44.736 Mb/s, but is relatively inefficient at the European rate of 34.368 Mb/s.) The STS-1 frame structure can be drawn as 90 columns by 9 rows of 8-bit bytes, as shown in Figure 4-10. The order of transmission of the bytes is row by row, from left to right, with one entire frame being transmitted every 125  $\mu$ s (8 kHz). The first three columns of the STS-1 frame contain the section and line overhead bytes. The remaining 87 columns carry the STS-1 Synchronous Payload Envelope (SPE). Each frame contains 6,480 bits (216 overhead bits and 6,264 payload bits).

Higher rate SONET signals can be obtained by byte-interleaving  $N$  frame-aligned STS-1's to form an STS- $N$ . For example, an STS-3 carries three byte-interleaved STS-1 signals in a 155.52 Mb/s stream (Figure 4-11). A higher rate SONET signal can also be formed by "concatenation", which indicates that the payload is treated as a single unit. This is denoted by the letter  $c$  following the rate designation. For example, an STS-3 $c$  carries a single 149.76 Mb/s payload in a 155.52 Mb/s stream. (This accommodates the European 139.264 Mb/s rate or  $3 \times \text{DS3} = 134.208$  Mb/s.)

Agreement was reached by the CCITT (6/89) to support SONET (STS-3 $c$ ) at the physical layer for B-ISDN user-network interface, based on bit rates of 155.52 Mb/s, called the Synchronous Transport Module - Level 1 (STM-1), and 622.08 Mb/s [13,16]. There is also an STM-16 at 2,488.12 Mb/s [27].

A key feature of SONET is the use of payload pointers to allow ease of multiplexing and demultiplexing lower rate signals from the STS-1 payload in a pleochronous environment. The payload pointer is a number carried in each STS-1 line overhead that indicates the starting byte location, and allows for correction of any small frequency variations of the STS-1 payload. (See discussion by Ballart and Ching in reference

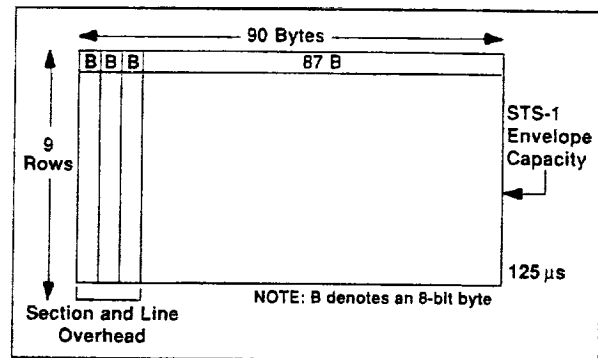


Figure 4-10: SONET STS-1 Frame Structure

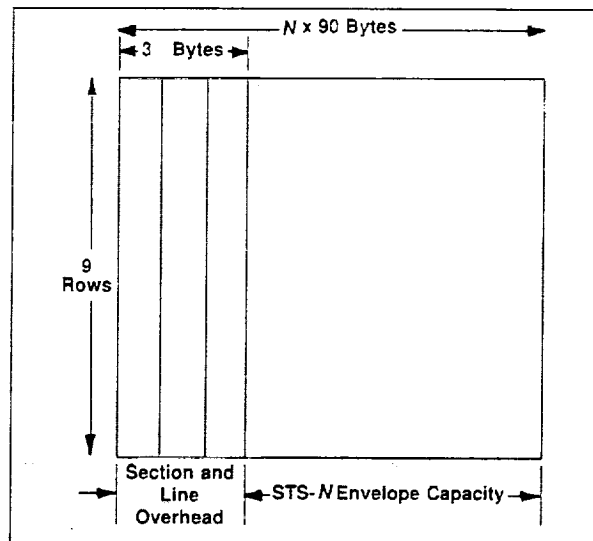


Figure 4-11: SONET STS- $N$  Frame Structure



[11].)

Sub-ST5-1 payloads are carried by SONET by payload structures called Virtual Tributaries (VTs) which have four sizes:

VT1.5: 1.544 Mb/s (DS1)

VT2: 2.048 Mb/s (CEPT-1)

VT3: 3.088 Mb/s (DS1C)

VT6: 6.312 Mb/s (DS2)

Reference [11] describes the different payload mapping possibilities.

#### 4.5.7.2 Asynchronous Transfer Mode (ATM)

Constant bit rate services at fixed discrete rates of 64 kb/s, 1.544 Mb/s, and 44.736 Mb/s can be multiplexed directly onto the SONET payload. However, bursty services and services at other discrete rates are not accommodated by SONET alone.

A new packet-like multiplexing and switching technique called Asynchronous Transfer Mode (ATM) has been proposed for carrying information within the SONET payload. In ATM, all information to be transferred is packed into fixed-size slots called "cells" which are identified and switched by means of a label in the header. The term "asynchronous" in ATM refers to the fact that cells allocated to the same connection may exhibit an irregular recurrence pattern, as cells are filled according to the actual demand. Figure 4-13 illustrates the difference between synchronous time division (STM) multiplexing and asynchronous time division (ATM) multiplexing.

The CCITT has reached an international agreement (6/89) that ATM cells should be used for carrying all information in the B-ISDN. An agreement has also been reached on an ATM cell structure consisting of a 5-octet header and a 48-octet payload, as shown in Figure 4-12. [1,13,16]

The function of the ATM header is to identify characteristics of the virtual channel on a multiplex link and is viewed exclusively as a connection-related object. The header field includes five subfields as follows:

1. Generic Flow Control (GFC). The 4-bit GFC is used to assist the customer premises in controlling the flow of traffic for different qualities of service. The GFC appears only at the UNI.

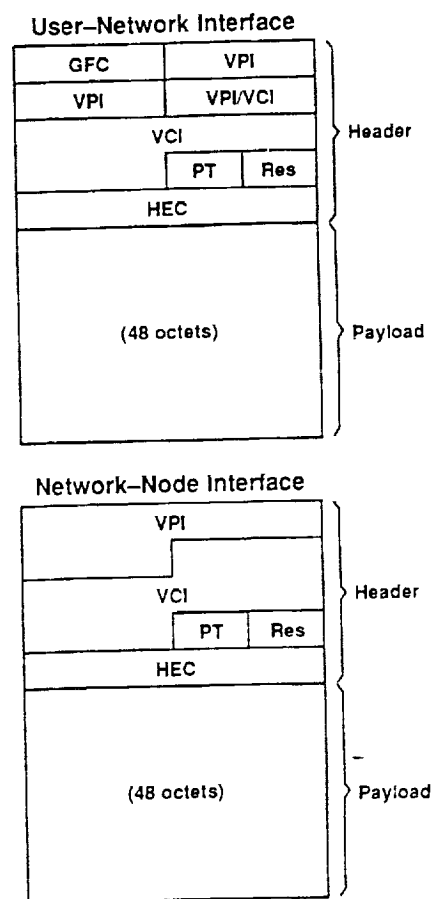
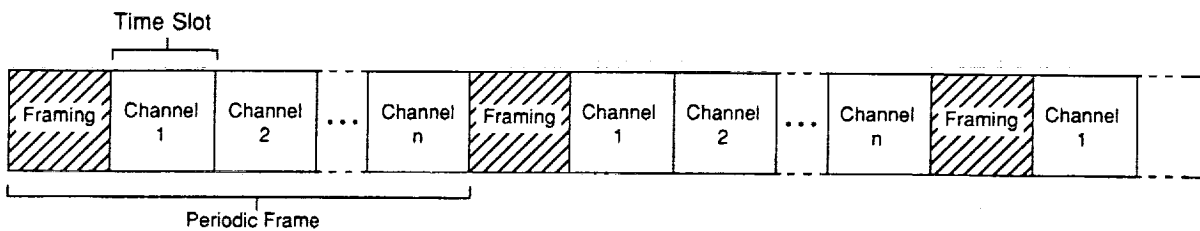


Figure 4-12: CCITT ATM Cell Structure

2. Virtual Path Identifier (VPI). The VPI provides an explicit path identification for the cell. 8 to 12 bits are available for the VPI at the UNI, and 12 bits are available at the NNI.
3. Virtual Channel Identifier (VCI). The VCI provides an explicit channel identification for the cell. 12 to 16 bits are available for the VCI at the UNI, and 16 bits are available at the NNI. The total number of bits allocated to routing (VPI and VCI) at a UNI is 24. However, the number of bits that are active on a given UNI is defined on a subscription basis and the total number shall not exceed 20.
4. Payload Type (PT). The 2-bit PT provides an indication of whether the cell contains user information or network information.
5. Header Error Check (HEC). The 8-bit HEC provides two modes of operation for error control of the cell header. The default mode provides for

## Synchronous Time Division (STM) Multiplexing



## Asynchronous Time Division (ATM) Multiplexing

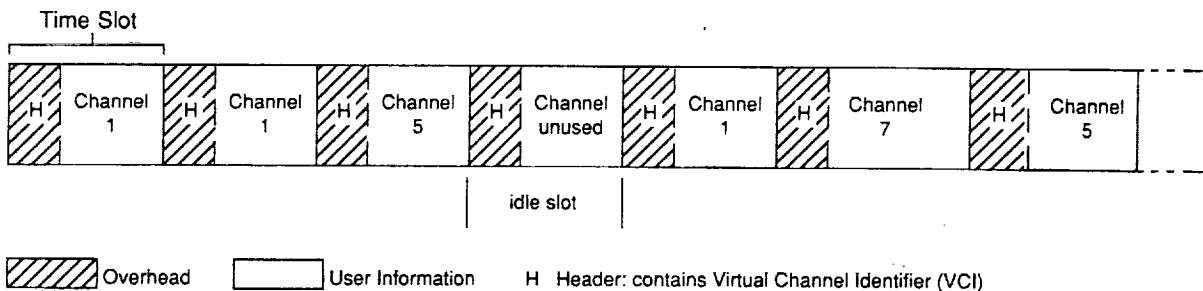


Figure 4-13: ATM Has an Irregular Occurrence Pattern of Channels Compared to STM

single-bit error correction. When an error is detected in the cell header, the receiver switches to an error detection mode in order to provide better detection of multiple errors in the cell header.

In summary, the following points can be made about ATM:

- ATM allows for bit rate allocation on demand, ranging from a cell (424 bits) up to the full channel capacity.
- ATM allows connections with varying bit rates (burst traffic)
- The channel mix at the broadband interface can change dynamically over a vast range.
- ATM requires packet switching whereby a vast number of 424 bit cells must be examined every second to determine their routing. For a STM-1 rate of 155.52 Mb/s, there are approximately 352,000 cells/second.
- ATM problems to be solved include the impact of cell loss, cell delay, and cell jitter on service quality. Another problem is the enhanced echo delay of ATM speech connections [7].

A discussion of speech and video coding technologies for ATM networks is contained in the references [24,25].

## 4.5.7.3 Description of B-ISDN (CCITT Rec. I.121)

CCITT Recommendation I.121 [1] designates ATM as the "target transfer mode solution for implementing a B-ISDN". It recognizes that ATM "will influence the standardization of digital hierarchies and multiplexing structures, switching, and interfaces for broadband signals". There are scattered references to accommodation of other transfer modes during the process of network evolution. International interfaces are based exclusively on ATM.

The remainder of this subsection gives details of CCITT Recommendation I.121. B-ISDN user-network interfaces (UNI) will be standardized at two bit rates whose approximate values are as follows (CCITT Rec. I.121, ¶6):

- 150 Mb/s (155.52 Mb/s STM-1 chosen 7/89)
- 600 Mb/s (620.08 Mb/s STM-4 chosen 7/89)

The broadband UNI need not be symmetrical. Each of these interfaces must be capable of supporting broadband services as well as 64 kb/s based ISDN services.

The structure of the 150 Mb/s UNI will be unique and will be based on the following alternatives:

1. Asynchronous Transfer Mode (ATM). This structure, shown in cases (a) and (b) of Figure 4-14, uses only labelled multiplexing with cell interleaving. This category has two possible alternatives:

- i. No frame structure is imposed on this interface.
  - ii. All cells are aligned in a frame structure constructed by periodically located synchronization cells.
2. ATM within a Synchronous Optical Network (SONET) frame. This structure, shown in case (c) of Figure 4-14, places ATM cells in the payload of a frame constructed by using overhead not based on ATM cells.

In the evolution of B-ISDN, a frame structure similar to case (e) of Figure 4-15 may also be considered as one alternative.

Five candidate structures for the 600 Mb/s UNI are shown in Figure 4-15. Cases (a), (b), and (c) are identical to those of the 150 Mb/s UNI (Figure 4-14). Structures shown in cases (d) and (e) have the payload partitioned into payload modules, where case (e) shows some of these in synchronous transfer mode (STM), for possible use in an interim period. The 600 Mb/s UNI may be constructed as if derived by interleaving of four 150 Mb/s structures.

Bit timing information will be derived by the NT1 (network termination) from the aggregate bit stream received from the network. The timing characteristics are as follows for the different cases of Figure 4-15:

- (a) No frame timing is provided. Only cell delineation is provided using randomly located synchronization cells.
- (b) Frame timing is provided using periodically located synchronization cells.
- (c) Frame timing is provided from the overhead information. The ATM stream within the payload may be self delineated or delineated by using the periodic structure of the payload.
- (d) Same as (c).
- (e) Same as (c).

Transmission of ATM can be supported by any digital transmission system - e. g. G.702, G.707-709 (SONET), and any future hierarchy that may be defined. The transmission of information by means of a stream of cells is the basic concept of ATM. It is desirable to perform this process at the highest practical bit rate.

Signalling and user information are carried on separate ATM virtual channels. A user may have multiple signalling entities connected to the network connection control management via separate ATM virtual channels. Enhanced or extended I.441 and I.451 access protocols will be used to accommodate the additional B-ISDN capabilities.

#### 4.5.7.4 User-Network Access

The general reference configuration for the broadband user-network access is shown in Figure 4-16. Several terminals are connected (via appropriate terminal interfaces at the  $S/S_B$  reference points) with the subscriber premises network which accesses the local network itself via a standardized interface. The Broadband Network Termination (BNT) is the boundary between the local access network and the subscriber premises network. In Figure 4-16, an asymmetric interface with 150 Mb/s to the network and 600 Mb/s to the subscriber is drawn as an example.

The subscriber premises networks may be quite complex networks (e. g. LANs or PABXs) with different topological structures (ring, bus, star, or mixtures thereof) and different switching features. An example of a simple installation is given in Figure 4-17 where the BNT provides the customer with multiple broadband access. The BNT could simply broadcast all downstream information to all the BTEs and could statistically multiplex all upstream ATM cells, thus also getting rid of the access contention problem relating to the multiple broadband interfaces. If basic accesses are realized (2B + D16 or 144 kb/s), the BNT will have to adapt these STM interfaces to ATM internally.

The integration of all user traffic onto the B-ISDN access system, and the subsequent distribution of that traffic to a number of distinct core networks, have created the requirement for an access control point containing call/connection signaling termination and some call control/processing functions. Access control acts as an initial filter of service requirements so that signaling describing the transport service may be routed/forwarded to the appropriate transport network control.

Rider [9] has suggested that three factors be communicated to access control to describe the bandwidth requirements of the user's application.

- i. Peak bandwidth
- ii. Average bandwidth

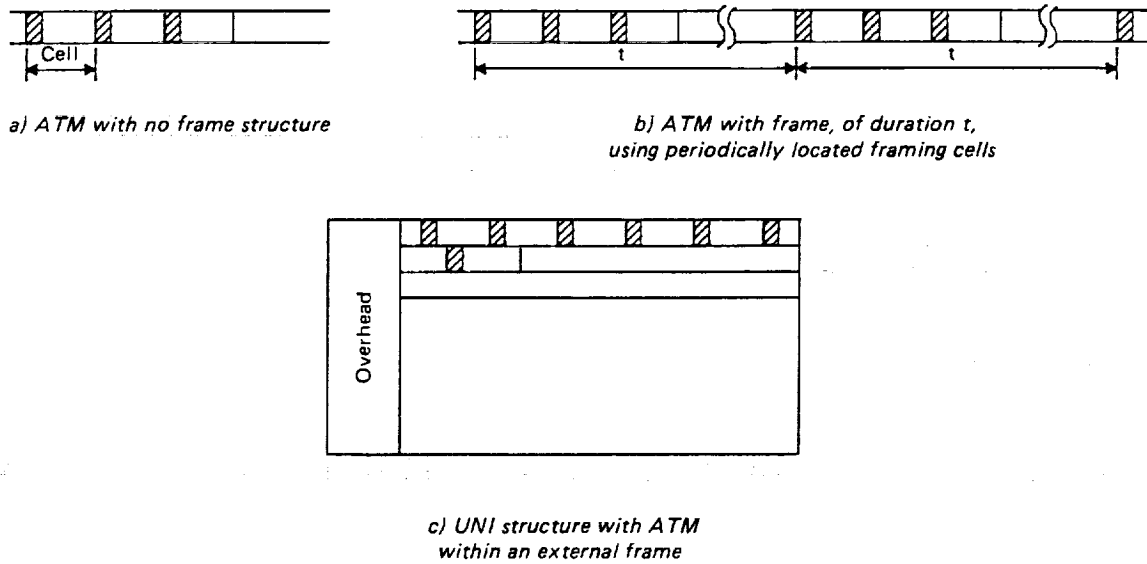
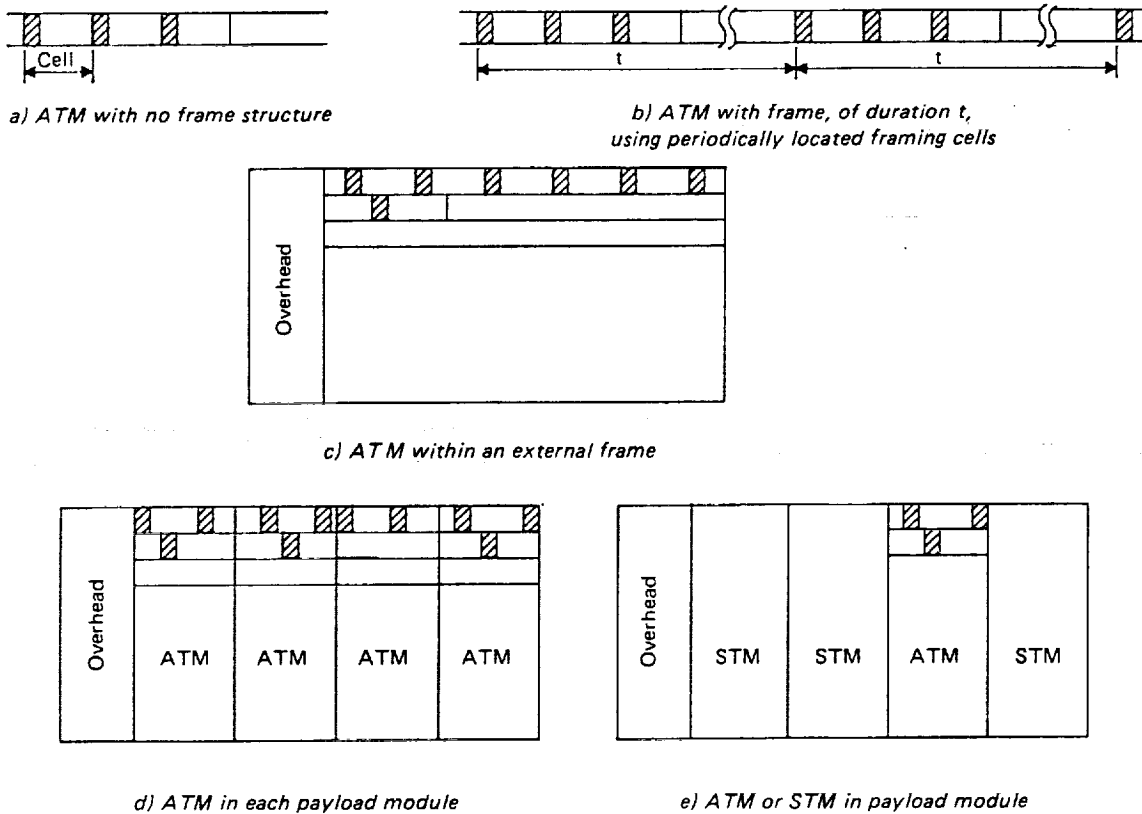


Figure 4-14: Structures for 150 Mb/s User-Network Interface



Note - These diagrams are illustrative only; the actual multiplexing methods are to be defined.

Figure 4-15: Structures for 600 Mb/s User-Network Interface

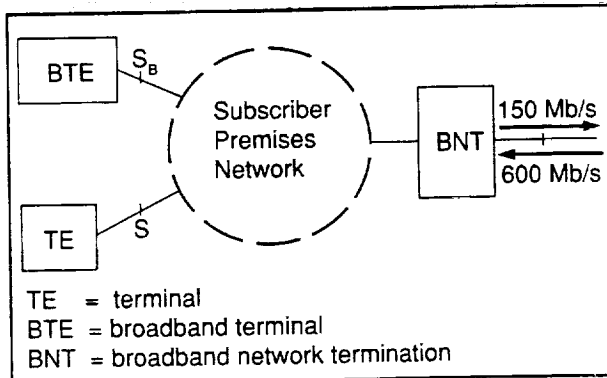


Figure 4-16: Generalized Broadband Configuration

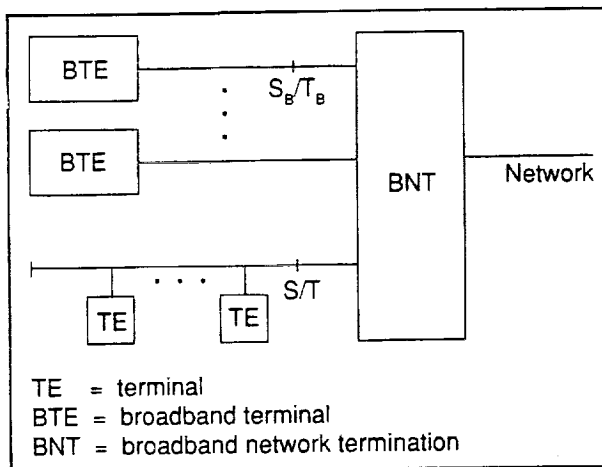


Figure 4-17: Physical Realization of Broadband Access

### iii. Periodicity (distribution of data bursts over the total communications)

Some data services such as image transfer may launch very large bursts of data into the network. It may be necessary to set limits on the ratio between service and link data rates to ensure equitable access to bandwidth for all contending services.

There are two operational modes for ATM to provide bandwidth control:

- Statistical mode provides for the contention for bandwidth across all services and would adhere to a maximum ratio of service to link data rates.
- Transactional mode allows a reservation of uncontended bandwidth for the duration of the connection. This mode operates the same as the statistical

mode except that bandwidth management ensures a zero contention condition.

The details of the protocols for ATM access networks for B-ISDN have still to be specified by the CCITT.

#### 4.5.7.5 Impact of B-ISDN on Satellite Design

Although the present definition of B-ISDN is incomplete, the basic intent is to use the SONET standard for transmission and the ATM standard for multiplexing and switching.

- Standard bit rates are 155 Mb/s and 620 Mb/s, and may be based on the SONET synchronous frame structure with 8 kHz rate.
- All information is packed into fixed size slots called cells which are identified and switched via a label in the header (40 bit header and 384 bits of information in a cell).

Several points can be made regarding these standards.

**Communications Channel Size.** The information channelization in the satellite should conform to the 155 or 620 Mb/s B-ISDN data rates (or multiples thereof) for ease of processing at the terrestrial B-ISDN network interface.

**Channel Information Carrying Efficiency.** The SONET frame structure is relatively efficient (96% for a 149.76 payload in the 155.52 Mb/s channel). However, the ATM cells are very short and only have a 91% information carrying efficiency (ratio of payload to cell size), which is combined with the SONET efficiency to yield an overall information transfer rate around 136 Mb/s for the 155 Mb/s channel (88%).

The most serious problem is that the use of the ATM protocol in a statistical (contention) mode will further degrade the channel [8]. The ATM overhead is at least 10%, and perhaps as high as 20% depending on traffic mix, due to practical considerations of buffer size and allowable cell delay time. Use of the ATM protocol in a transactional (reservation) mode could eliminate this overhead, but at the expense of losing the advantage of a packet network. This issue is expanded upon in the next paragraph.

**Grade of Service.** One of the basic features of an ATM transport structure is that packets of real-time services will get dropped, even when the network is over-engineered to a significant extent.

One can assume that the traffic statistics of the different service types will become known in the future, and the network will be able to be dimensioned for the mix of service types. However, the grade of service provided will only be as good as the estimates of the mix of traffic demand during peak periods, the models of the traffic statistics, and the capability of the network interface to monitor and control the packet/cell rate into the network. It is important to recognize that the efficiency of ATM as a multiplexing technique is still unknown, since the statistical character of the offered traffic is unclear [8].

One way to ensure grade of service is to use the peak rates for different service types to size the network by providing a specified loss probability for each node, and to base the access and control strategy on these peak rates. This is the only way in which grade of service at the packet level can actually be guaranteed. For example, at call setup, an application could provide the network with information on its peak bit rate; acceptance or rejection of the call would then be based on the availability of the peak bandwidth requirement of the service. However, with this strategy, the ATM network would end up providing what would essentially be an inefficient, expensive form of circuit switching.

With a priori knowledge of the number and type of the sources and the period of the different packet streams, the buffers can be sized so that no packets are lost (due to contention at the multiplexer or switch) and the permitted bandwidth utilization level, including packet overhead, can reach 100%. However, in an operational ATM network, unless the number of calls of each type are constrained to remain below the dimensioning level, the actual mix of traffic can easily be such that packets are dropped even though the utilization is less than the permissible level.

An interesting example is given by Gechter and O'Reilly [8]. Five synchronous traffic streams can be carried on the same 150 Mb/s link with buffer storage for four cells, average queueing delay of 3  $\mu$ s, maximum queueing delay of 13  $\mu$ s and no packet loss. However, if the flow is a mix of many traffic types, then the average delay is 38  $\mu$ s, and a buffer to hold 249 cells is required to maintain the average loss probability below  $10^{-9}$ .

**Accounting.** The question is how to charge for system usage on an ATM network? One either charges on a per-packet basis or does charging at a higher level process such as maximum bandwidth requested at call setup. Charging on a per-packet basis increases the processing load on the system by complicating the packet header handling process. However, without per-packet charging, the advantages of ATM may be lost since charges will be related to some other parameter such as maximum bandwidth.

**Multiplexing and Switching.** Another point of concern is the use of the ATM protocol on the satellite for demultiplexing and switching. The issue is a technical one between implementation of the fast packet ATM switch in VLSI circuitry and the use of photonic switching with a transactional (reservation) mode. The switching system best suited to satellite operation (i. e. combination of adequate performance, low mass, low power consumption, and cost) should be chosen. Considerable technology development in this area must be done. The next section entitled Satellite Switching gives the recommended technology of this study.

#### 4.5.8 Satellite Switching

For the DDS system to conform to B-ISDN standards and to provide connectivity among a number of space and terrestrial nodes, switching of ATM cells must occur on the satellite. The questions are:

1. What is the preferred systems approach – packet or circuit or hybrid (combination thereof)?
2. What are the optimal switching technologies? Indeed, the real question may be are there any switching technologies available for the 2015 time frame that can demux, switch, and remux a total capacity of 15 Gb/s within the mass and power constraints of the satellite?
3. What is the distribution of switching functions between space and ground, and source and sink of data?

This section highlights promising technologies that may provide answers to these questions.

##### 4.5.8.1 Use of Photonics

The installation of fiber optic trunking networks and plans to extend fiber to the local loop are stimulating a

large expenditure in photonics technology by terrestrial carriers, equipment manufacturers, and research organizations. The satellite system can benefit from photonics technologies for signal multiplexing and switching as well as for signal routing and distribution [5, 6, 26, 28, 29].

#### 4.5.8.2 Lightwave Packet Networks

Fiber optics can be used within the satellite to interconnect a number of user channels. Figure 4-19 shows an active star topology using photonics to feed an electronic, self-routing, real-time packet switch [10]. The packet switch reads the header of each inbound packet and accordingly routes the packet to the appropriate output. Buffers are required at the output of the switch to keep the packet loss rate from collisions at an acceptable level. The capacity of this switch is limited by electronic processing speed.

An approach making use of the great bandwidth of fiber optics is shown in Figure 4-20, an active wavelength division multiplexing (WDM) switch. Each receiver is assigned a unique wavelength and a transmitter wishing to access that receiver tunes its transmitter to the correct wavelength and sends its packet. The passive star coupler passes all signals to all receivers, where the correct destinations are determined by the wavelength. Alternately, each transmitter could be assigned a unique wavelength and a tunable receiver or filter be used to select, from the sea of WDM signals, on a packet-by-packet basis, the correct wavelength at each point in time. At this time, neither tunable laser sources nor tunable receivers exist with the speed required to handle the required packet rates (350,000 to 1,400,000 424-bit packets per second).

Shufflenet, a multichannel multihop lightwave network, is another switch approach that uses the user interfaces themselves as active repeaters. Tunable transmitters or receivers are not required, and the network capacity increases monotonically as more users are brought on-line. Figure 4-18 shows a network with eight users (inputs/outputs), each of which can transmit at two wavelengths and receive at two wavelengths. Since each user can access only a small, fixed set of WDM channels, packets may need to be routed through intermediate user connections to reach their destination. In other words, packets may require multiple hops (within the fiber connections of the switch) on different wavelengths to reach their destination.

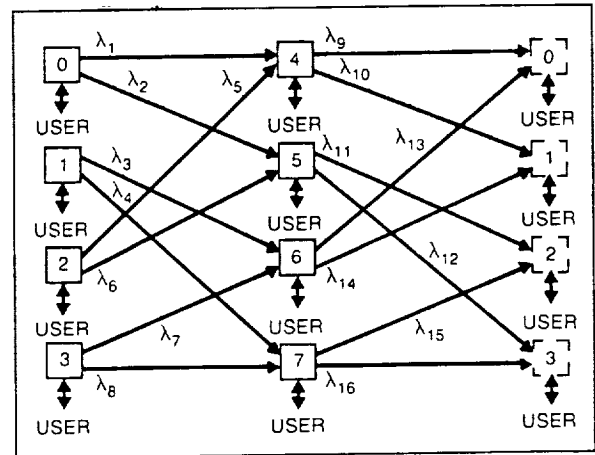


Figure 4-18: Shufflenet Interconnections

#### 4.5.9 Operational Life Concepts

Satellites performing the data distribution function such as DDS or ASDACS will be geostationary. Servicing is not expected to be available or economical for geostationary satellites in the year 2007. However, a combined servicing mission should be possible and could make economic sense for a year 2015 satellite.

The DDS operational life concept is assumed to be at least two in-orbit operational satellites plus one ground spare. For larger constellations, in-orbit spares are preferable to increase system availability (i. e., reduce downtime due to failures).

#### 4.5.10 Summary of Technology

Table 4-3 summarizes the satellite technology developments discussed in ¶4.5 and expected to be available for satellites launched in the years 2007 and 2015.

### 4.6 System Cost Limitations

Any compilation of system design constraints must include system cost limitations. The cost of communications must be competitive with alternate services, which for the United States means the existing fiber optic telephone system.

The cost of the user ground terminal will be a major system cost. For a DDS system servicing a moderate number (100s) of telescope locations with high data rate terminals (100s Mb/s), ground terminal costs

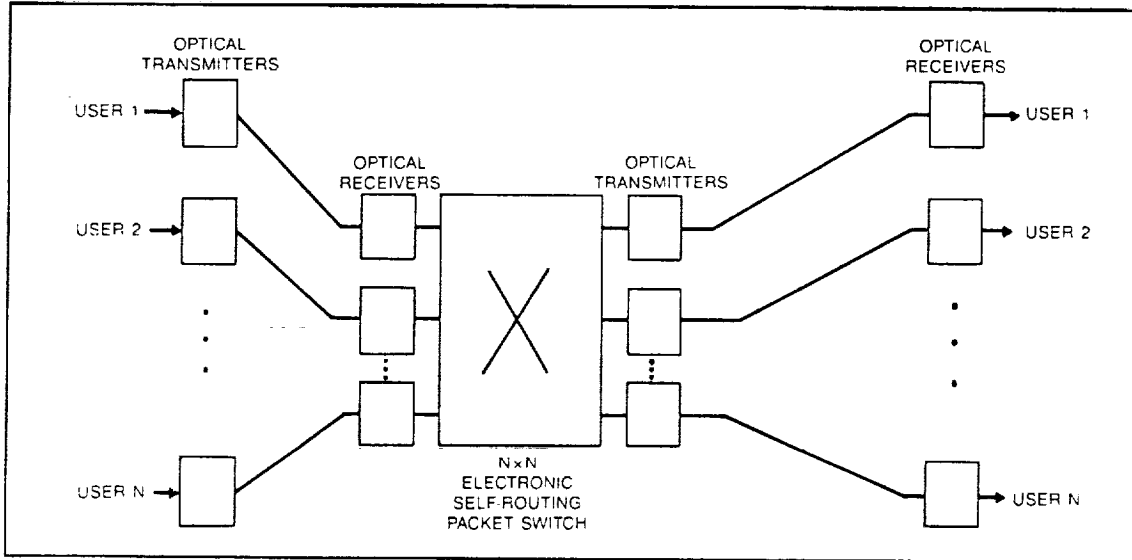


Figure 4-19: Active Star Topology with Electronic Packet Switch

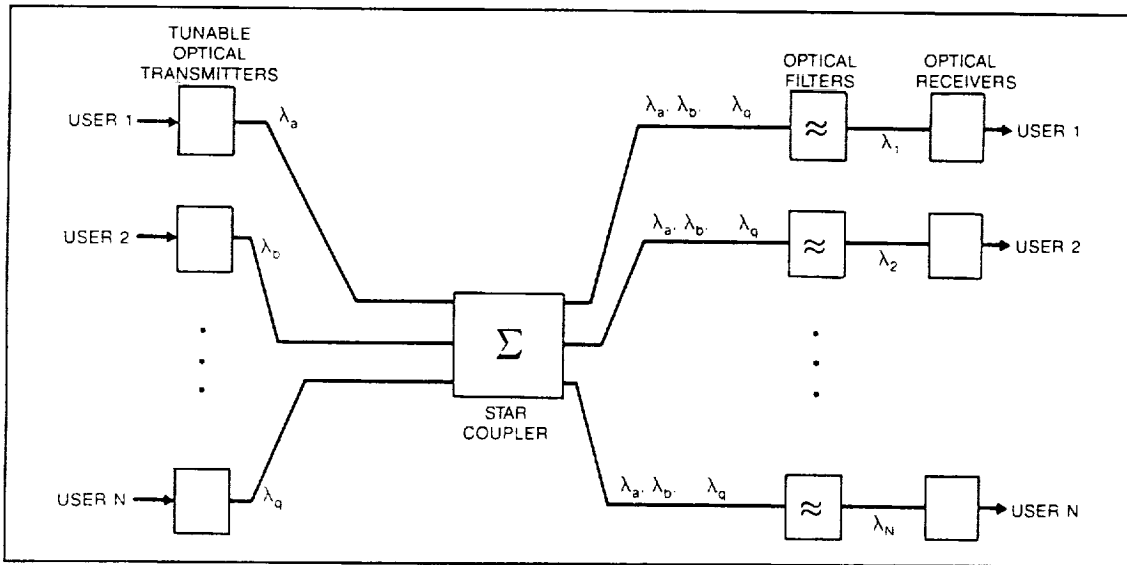


Figure 4-20: Wavelength Division Multiplexing via Use of Photonics



Table 4-3: Satellite Technology Developments (2007 and 2015 launches)

Category	Change	Benefit
Structure	None	
Thermal	Passive heat pipes	Reduced mass of thermal subsystem. Higher thermal dissipation.
Propulsion	Ion propulsion	Reduced mass for long life missions.
Attitude Control	Use of GPS & ATDRSS	More accurate and faster position determination.
	Ring laser gyro	Increased reliability, less calibration time.
Power	Advanced NiH bat. (2007)	Improved power/weight ratio.
	NaS batteries (2015)	Even better power/weight ratio.
	Thin Si cells (2007)	Reduction in solar array mass.
	GaAs solar cells (2015)	Greater efficiency (21% vs. 13%)
TT&C	None	
Comm. Payload	More efficient TWTAs	Less power required.
	SSPA availability	Greater reliability and lifetime, less mass
	Improved modulation	More efficient use of given bandwidth.
	Active aperture antenna	Use of MMICs enable higher performance.
	Bulk demodulators	More efficient access scheme; FDM up, TDM down.
	Laser ISLs	More efficient data distribution.
	VHSIC & microprocessors	Better capacity for processing and switching.
	High strength materials	15% mass reduction for antenna subsystem -
	Large scale integration	15% mass reduction for electronic components
	Photonic switching	High capacity, low mass, high speed switching.
Space Transport	ALV and OTV	Increased capacity, reduced cost.
	Orbit raising fuel	Higher specific thrust (320 vs. 310 ISP)

around \$50,000 are judged acceptable. For peer networking services among large numbers (10,000s) of low data rate users (64 kb/s), the ground terminal cost should be around \$10,000.

(An analysis of proposed DDS system circuit costs is presented in Chapter 11.)

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## Chapter 5

# Link Scenario Synthesis

This chapter is organized as follows:

- 5.1 Overview
- 5.2 Candidate User Link Scenarios and Associated Data Requirements
- 5.3 Composite Data Requirements for Candidate Link Scenarios

### 5.1 Overview

As described in Chapter 3, the composite user requirements of the DDS satellite cover a wide range of applications including telescience, peer networking, and other user categories. The purpose of this section is to define the candidate communications links of a DDS system and to associated the predicted user requirements with each component link. This will then serve as the basis for an overall communications subsystem configuration for DDS.

#### 5.1.1 Approach to Determining Candidate Link Scenarios

The general procedure for determining DDS communication link scenarios is depicted in Figure 5-1. Various link configurations are developed to accommodate each of the general classes of service associated with the goals and objectives of DDS communications. The general link configuration incorporates transmission frequencies, antenna patterns, and modulation and access techniques which are viable for space applications for the years 2007, 2015, and 2025 on-orbit operation.

The total user requirements defined in Chapter 3 are derived from a survey of user requirement reports as well as from extrapolation from specific user case examples. These requirements are then allocated among

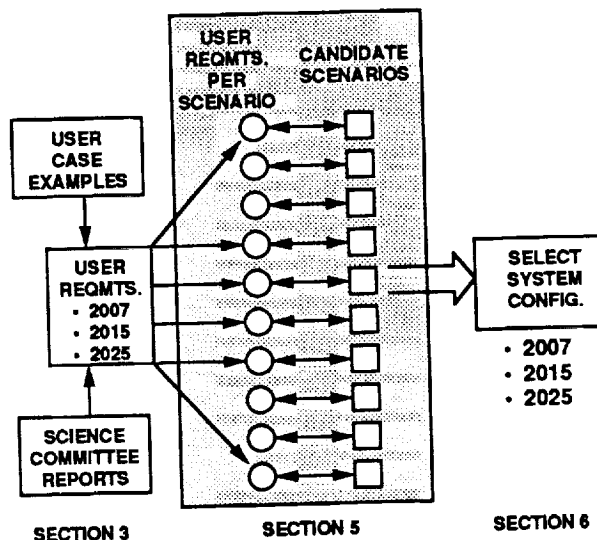


Figure 5-1: Procedure for Choosing Link Scenarios

the various link scenarios in order to establish the defining parameters of

- data rates,
- data rate peak-to-average ratio and statistical distribution,
- data quality,
- tolerance to link outages (required availability),
- geographic distribution of user traffic,
- postulated earth terminal implementation, and
- variation as a function of time.

After the link scenarios have been defined, the optimal grouping will then define the various communication subsystem configuration for DDS satellite operations for the years 2007, 2015, and 2025 operation.

Table 5-1: Candidate Communication Scenarios

Telescience (Space Science) Experiments	
1.1	Comm. to/from science experimenters
1.2	Access control
1.3	Comm. to/from White Sands
1.4	Comm. to/from Goddard (ground backup)
1.5	Comm. to/from remote earth stations
1.6	Relay from ATDRS/ASDACS

Peer Networking (Science Data Distribution)	
2.1	Communications to/from small users
2.2	Comm. to/from Science Data Centers
2.3	Access control

Other Networking	
3.1	NASA Centers interface
3.2	Wideband supercomputer network
3.3	Transfer of science project eng. data
3.4	International science comm. networks
3.5	Global environment monitoring
3.6	Support of industrial use of space (opt.)

### 5.1.2 Candidate Communication Scenarios

A total of 15 links, some of which are further divided into uplink and downlink components, have been identified as potential DDS applications. As listed in Table 5-1, six types of links are associated with Telescience, three with Peer Networking, and six with Other Networking.

The Telescience scenarios are summarized in Figure 5-2, the Peer Networking scenarios in Figure 5-3, and the Other Networking scenarios in Figure 5-4. Section 5.2 of this chapter details each of the component links.

### 5.1.3 User Requirements and Distribution

The potential users of a DDS communications system are not uniformly distributed throughout the United States. An efficient implementation of a DDS satellite implies use of both spot beams and area coverage beams. An estimate of the relative priorities of various geographic regions within CONUS (Continental United States) as related to Telescience applications is given in Figure 5-5. This estimate is based on the data of Figure 5-6 which shows the distribution of U. S. Earth

Observing System (EOS) investigators, along with proposed sites under consideration as EOS Data and Information System (EOSDIS) Active Archive Centers:

- Goddard Space Flight Center,
- Jet Propulsion Laboratory,
- Langley Research Center,
- National Snow and Ice Data Center,
- National Center for Atmospheric Research,
- University of Alaska (not shown on Fig. 5-6),
- University of Wisconsin,
- Michigan Consortium for International Earth Science Information Network.

The distribution for Peer Networking is generally related to population density together with major university locations.

The overall user data requirements are discussed in Chapter 3.

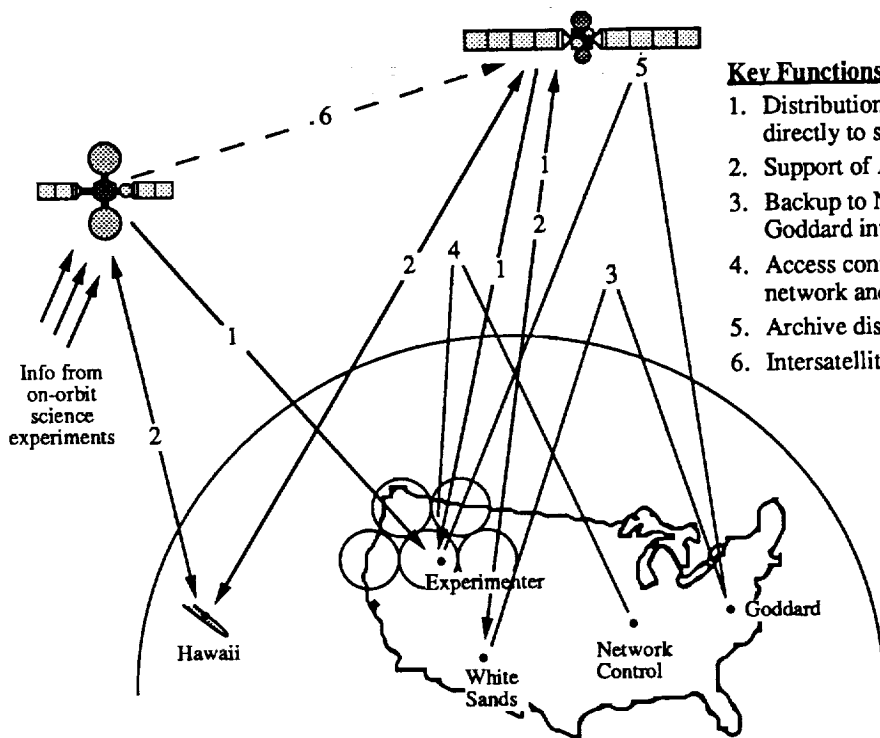
## 5.2 Candidate User Link Scenarios and Associated Data Requirements

This section defines the potential link components of a DDS system. The component links and associated implementation parameters may be combined into viable system configurations as described in Chapter 6.

### 5.2.1 Telescience Link Scenarios

The link scenarios associated with the category of Telescience are as follows:

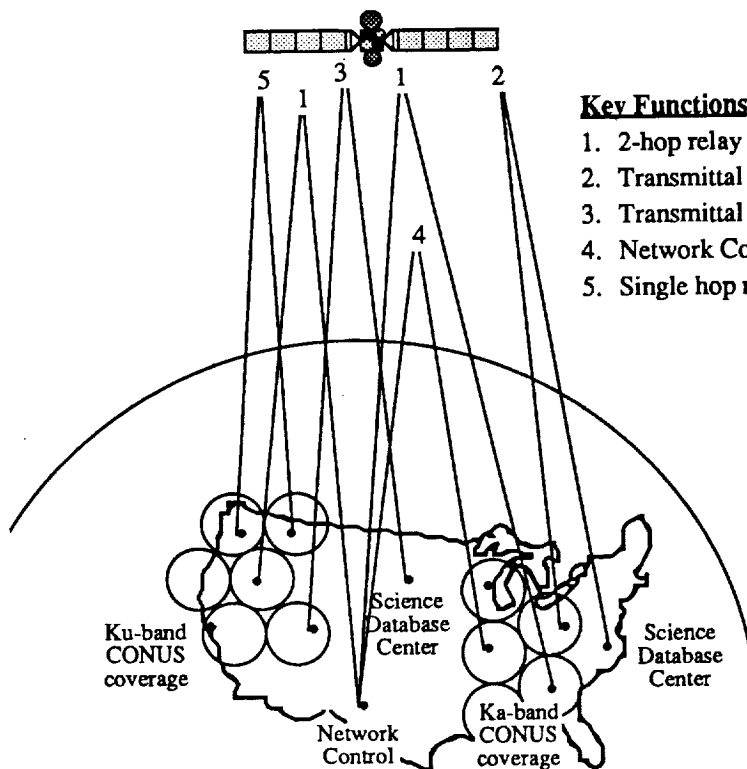
1. Uplinks from science experimenters to DDS for control of on-orbit space experiments and downlinks directly to science experimenters from DDS for space experiment data distribution.
2. Uplinks and downlinks connecting control centers to DDS for link access control.
3. Uplinks and downlinks connecting White Sands with DDS in order to facilitate data relay.
4. Uplinks and downlinks connecting Goddard Space Flight Center with DDS in order to serve as a backup and/or expansion of capability for existing terrestrial links.



**Key Functions**

1. Distribution of ATDRS gathered data directly to science experimenters.
2. Support of ATDRS located to close ZOE.
3. Backup to NASCOM for White Sands - Goddard interconnect.
4. Access control for DDS communications network and telescience control office.
5. Archive distribution of data from Goddard.
6. Intersatellite relay between ATDRS & DDS.

Figure 5-2: Composite Telescience Scenario



**Key Functions**

1. 2-hop relay of information to other peer network users.
2. Transmittal of data from Science Database Centers.
3. Transmittal of data to a Science Database Center.
4. Network Control links.
5. Single hop relay to other peer network users.

- Spot beams of 0.5° width at Ka-band and 0.9° width at Ku-band to/from control center and data base centers.
- Ku and Ka-band links may be intermixed at DDS - i.e. Ku-band up, Ka-band down.

Figure 5-3: Composite Peer Networking Scenario

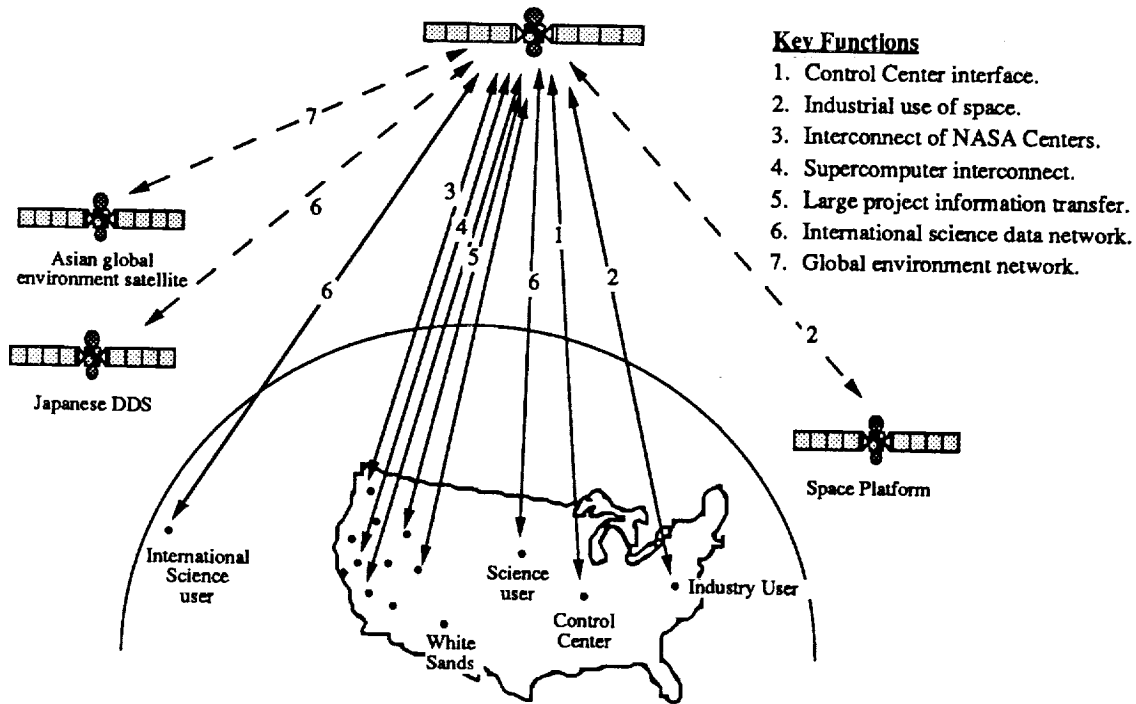


Figure 5-4: Composite Other Services Scenario

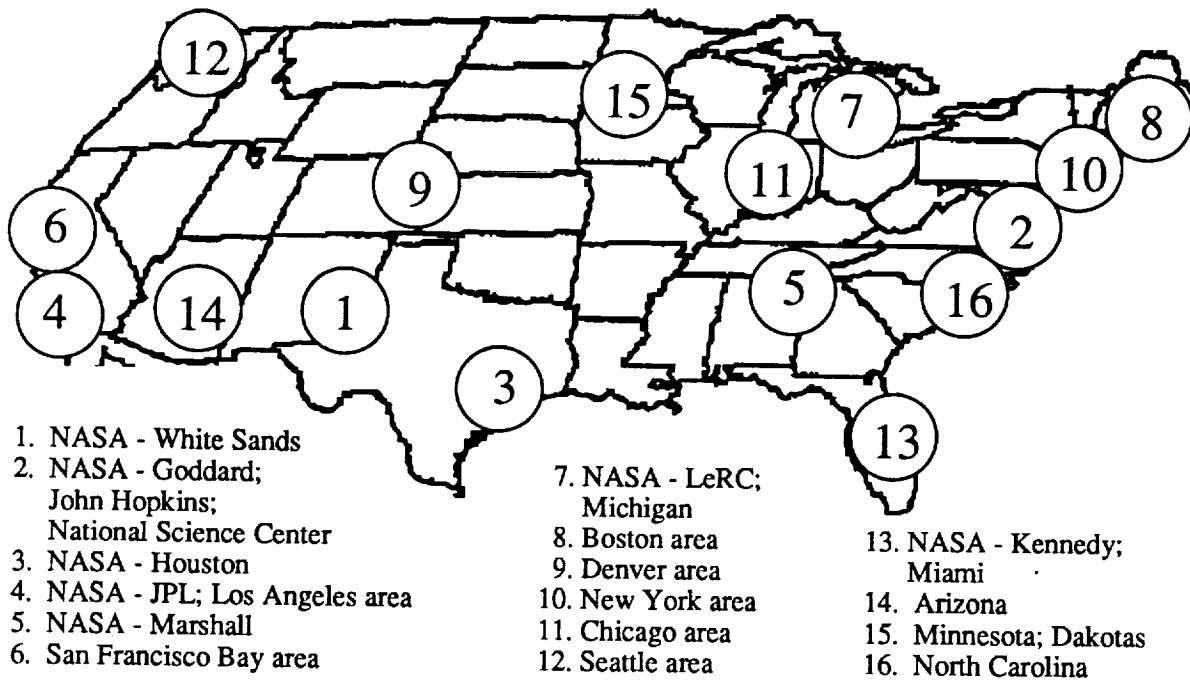


Figure 5-5: Relative Priorities of Ka-Band Spot Beams (0.5°)



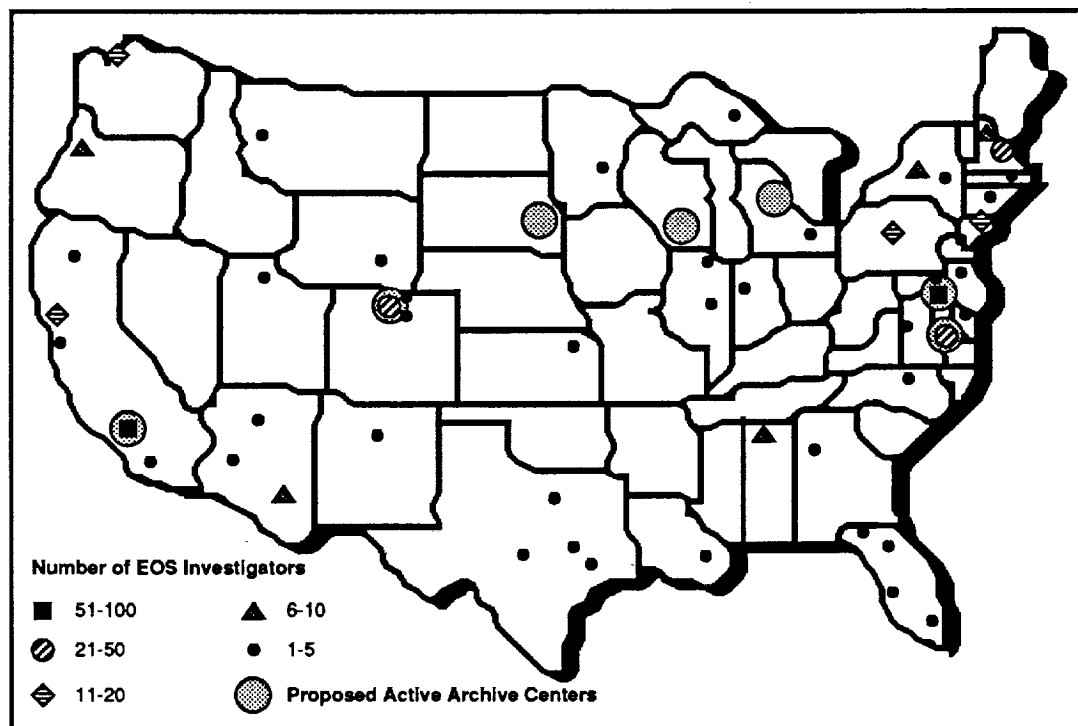


Figure 5-6: Distribution of U. S. EOS Investigators and Proposed EOSDIS Active Archive Centers

5. Uplinks and downlinks for relay of data sent to remote stations by ATDRS because of line of sight limitations to White Sands.
6. Intersatellite relay of data/experiment control information between ATDRS and DDS.

### 5.2.1.1 Link Scenario 1.1A – Uplinks from Experimenters

**Purpose:** The function of this link is to provide uplinks to the DDS satellite from up to hundreds of telescience experimenters located within CONUS. The information and/or experiment control signals are directed to DDS for subsequent relay via the ATDRSS network to the on-orbit science experiments. Another function of this link is to transmit network access control information via DDS to the appropriate telescience control center. The location of DDS at a geostationary arc position with a good view of all CONUS provides a widespread data gathering capability which is not permitted by the extreme horizon locations of the ATDRS satellites.

**Implementation:** As shown in Figure 5-7, the satellite antenna coverage is provided at Ku-band by 8 adjacent  $1.73^\circ$  area coverage beams for full CONUS coverage as well as 10 spot beams of  $0.87^\circ$  for high traffic areas. In addition Ka-band coverage is provided by 8 area coverage beams of  $1.73^\circ$  and 12 to 16 active spot beams of  $0.5^\circ$  half power beamwidth.

The earth terminal configurations typically range from antenna sizes of 1.5 m to 3.0 m diameter or more depending on data rate, quality, and link availability requirements. As an example, a VSAT transmitter power of 8.3 W is required from a 3 m antenna at Ku-band for a data rate of 6 Mb/s at  $10^{-8}$  bit error rate to a spacecraft  $1.73^\circ$  coverage beam when utilizing .905 FEC coding and D-QPSK modulation. A link availability of 99.8% is achieved in a typical rain region D-2 and 99.5% to the high rain fall region E.

**Data Requirements:** It is estimated that the composite data rate for interface and control of on-orbit experiments would be 200 Mb/s peak. This would be equally divided between Ku-band and Ka-band uplinks, with individual links ranging from 144 kb/s up to 30 Mb/s. The Ku-band transmission frequency would be used for those links requiring a high level of link availability.

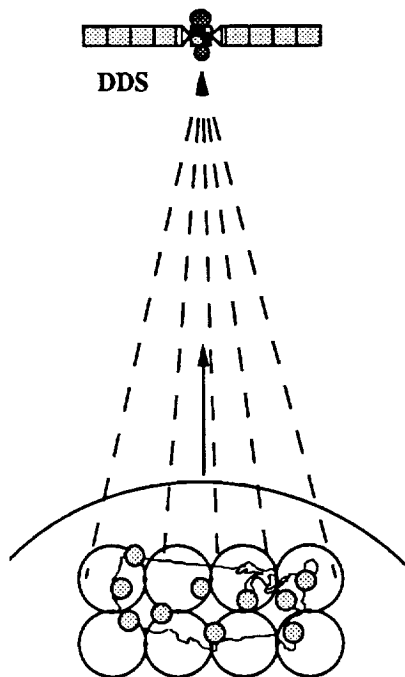
### 5.2.1.2 Link Scenario 1.1B – Downlinks to Experimenters

**Purpose:** The function of this link is to provide direct downlinks from the DDS spacecraft to up to hundreds of telescience experimenters located within CONUS. The subject information would be relayed to DDS by either an ATDRS-to-DDS crosslink or an uplink from a White Sands earth station. The information would contain near real-time results of on-orbit experiments. Another function of this link is to transmit network access control information responses in order to control the distribution of data read out among the telescience users.

**Implementation:** As described in Figure 5-8, the satellite antenna coverage is provided over all of CONUS at Ku-band by 27 adjacent beams of  $0.87^\circ$  half power beamwidth. Full CONUS coverage is also provided at Ka-band with eight adjacent beams of  $1.73^\circ$ . In addition 16 spot beams of  $0.5^\circ$  at Ka-band are provided to high traffic areas. The earth terminal sizes would generally be in the range of 1.5 m to 3.0 m diameter.

As an example a spacecraft transmitter power of 4.7 W is required from an  $0.87^\circ$  beam at Ku-band for a TDM data rate of 52 Mb/s at  $10^{-10}$  bit error rate with .729 FEC coding and QPSK modulation to a 3 m VSAT earth terminal. The link availability is then 99.8% in rain region D-2 and 98.5% in region E.

**Data Requirements:** It is estimated that the composite data rate for science data readout and link access control information would be a peak rate of 1 Gb/s. This would be divided equally between Ku and Ka-bands. The use of TDM downlinks at 52 Mb/s would permit individual experimenter links to range from 144 kb/s up to the full TDM capacity servicing the given downlink beam.

**Communications Functions:**

Provides for direct uplinks from hundreds of telescience experimenters located throughout CONUS:

- a. Information and/or experiment control destined for transmittal via the ATDRS network to on-orbit science experiments.
- b. Network access control for the telescience control center.

**Satellite Implementation:**

Antenna: 8 adjacent  $1.73^\circ$  beams cover CONUS at Ku-band;

8 adjacent  $1.73^\circ$  beams cover CONUS at Ka-band;  
10 spot beams of  $0.9^\circ$  at Ku-band;  
16 spot beams of  $0.5^\circ$  at Ka-band.

Access/modulation: single channel per carrier at rates from 144 kb/s to 6 Mb/s using bulk demods.  
D-QPSK or D-8PSK used for bandwidth efficiency.

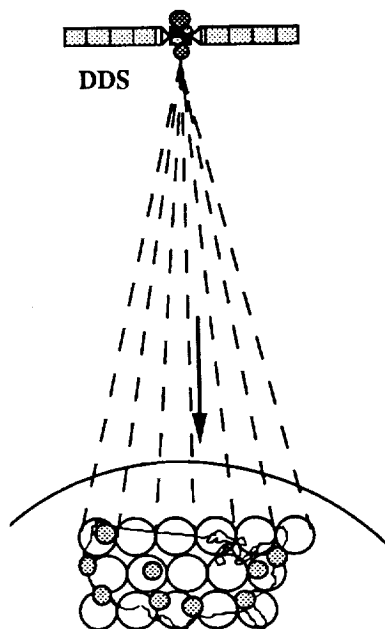
**Earth Terminal Configuration:**

Hundreds of small VSAT terminals:

Ku-band: 1.8 m to 3 m

Ka-band: 1.5 m to 3 m

Figure 5-7: Telescience Link Scenario 1.1A – Uplinks from Science Experimenters

**Communications Functions:**

Provides for direct downlinks to hundreds of telescience experimenters located throughout CONUS:

- a. Information originating in space and relayed via the ATDRS network.
- b. Network access control from the control center.

**Satellite Implementation:**

Antenna: 27 adjacent  $0.9^\circ$  beams cover CONUS at Ku-band  
8 adjacent  $1.7^\circ$  beams cover CONUS at Ka-band,  
plus 16 each  $0.5^\circ$  spot beams at Ka-band.

Modulation: TDM links at 30-100 Mb/s rates. BPSK modulation for power efficiency and ease of demod.  
Use of rate 3/4 forward error correction coding.

Transmitters: 10-30 W at Ku and Ka-bands.

**Earth Terminal Configuration:**

Hundreds of small VSAT terminals:

Ku-band: 1.8 m to 3 m

Ka-band: 1.5 m to 3 m

Figure 5-8: Telescience Link Scenario 1.1B – Downlinks to Science Experimenters

### 5.2.1.3 Link Scenario 1.2A – Uplinks from Control Centers

**Purpose:** The function of this link is to provide communications between the DDS communications control center and the DDS spacecraft for the purpose of coordinating both the access control to on-orbit experiments as well as access control of the communications access to DDS. Some of the uplink information would be used to control the DDS spacecraft communications configuration and the balance would be directed to experiments users via DDS-to-experimenter links. The control center would be located at White Sands (i.e., collocated near the ATDRS readout facility), or at Goddard Space Flight Center (SFC), or at any other convenient CONUS location.

**Implementation:** As shown in Figure 5-9, the satellite antenna coverage is provided by both a  $0.87^\circ$  half power spot beam at Ku-band as well as a  $0.5^\circ$  spot beam at Ka-band. (The area coverage beams at both frequencies may also be utilized as a back up capability). As an example, a transmitter power of 4 W is required from a 5 m antenna to communicate at 52 Mb/s to the Ka-band spot beam of  $0.5^\circ$  half power beam of the DDS spacecraft. This is based upon use of 8-PSK modulation, with .829 FEC coding, a link quality of  $10^{-10}$  bit error rate, and 3 dB of net system margin. The link would provide 99.0% availability to a center located in rain region D-2 and 98.0% to rain region E. Additional transmitter power could be utilized to enhance the link availability performance.

**Data Requirements:** It is estimated that the composite data rate for access control information for telepresence applications would be at a peak rate of 100 Mb/s. This would be divided equally between Ku-band and Ka-band.

### 5.2.1.4 Link Scenario 1.2B – Downlinks to Control Centers

**Purpose:** The function of this link is to provide the return path of communications between the DDS spacecraft and the DDS communications control center. The data would consist of

- Status of DDS communications capability utilization, and
- Access control information from users related to both experiments access as well as DDS communications link access.

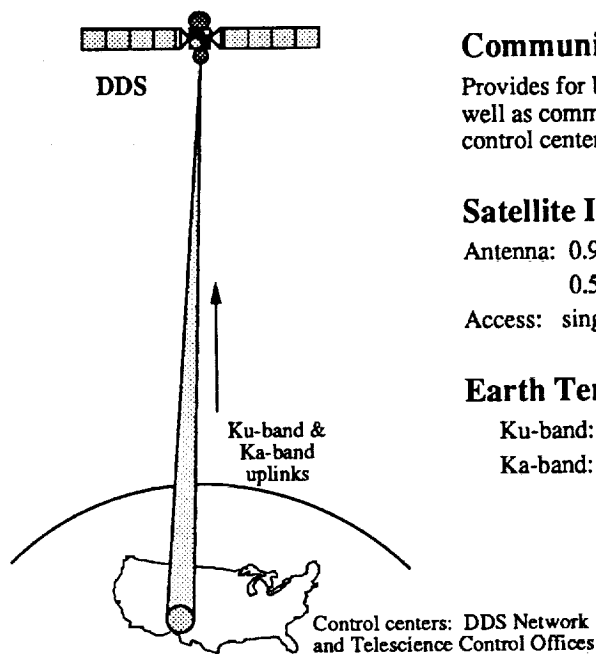
The control data requests would be generated by several experiment users as part of their uplinks to DDS.

**Implementation:** As shown in Figure 5-10, the satellite antenna coverage is provided by both a  $0.87^\circ$  beam at Ku-band as well as a  $0.5^\circ$  half power beamwidth spot beam at Ka-band. A TDM downlink at maximum capacity of 52 Mb/s would be available for capacity allocation as required.

An example link at Ka-band would require 1.5 W spacecraft power when utilizing a 5 m receiving antenna at the control center. This link would use 8-PSK modulation, at  $10^{-10}$  bit error rate, with .829 FEC coding, and have 3 dB of net system margin. A link availability of 98.0% would be provided to rain region E (worst case CONUS region).

The link availability can be enhanced by allocation of greater spacecraft power, or use of a geographic diversity earth terminal, or location of the control center in a better climate region.

**Data Requirements:** It is estimated that the composite data rate for return path access control information for telepresence applications would be at a peak rate of 100 Mb/s. This would be equally divided between Ku-band and Ka-band.

**Communications Functions:**

Provides for both access control to experiments as well as communications access to DDS. (Assumes control centers are colocated at White Sands,

**Satellite Implementation:**

Antenna: 0.9° spot beam at Ku-band.

0.5° spot beam at Ka-band.

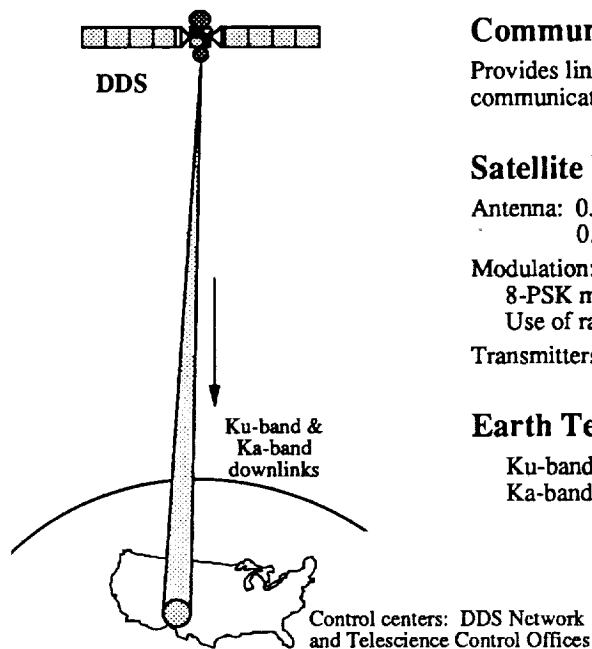
Access: single channel per carrier

**Earth Terminal Configuration:**

Ku-band: 5 m, 200 W transmit power

Ka-band: 4 m, 100 W transmit power

Figure 5-9: Telescience Link Scenario 1.2A – Uplinks from Control Centers

**Communications Functions:**

Provides links to access control for experiments and communications access to DDS.

**Satellite Implementation:**

Antenna: 0.9° spot beams at Ku-band

0.5° spot beams at Ka-band

Modulation: TDM links at 30-100 Mb/s rates.

8-PSK modulation for bandwidth efficiency

Use of rate .9 forward error correction coding.

Transmitters: 10 W at Ku and Ka-bands.

**Earth Terminal Configuration:**

Ku-band terminal: 5 m

Ka-band terminal: 4 m, plus diversity terminal

Figure 5-10: Telescience Link Scenario 1.2B – Downlinks to Control Centers

### 5.2.1.5 Link Scenario 1.3A – Uplinks from White Sands (ATDRSS)

**Purpose:** The purpose of this link is to provide for relay of data received by the ATDRS network at White Sands to the DDS spacecraft. This data, in turn, would then be forwarded directly to experimenters located within CONUS as well as to Goddard Space Center as a backup to the NASCOM terrestrial links. Another potential use is to act as a relay to remote stations (i. e., Hawaii or Andover) if some ATDRS spacecraft are widely separated to close the zone of exclusion (ZOE) or to act as an intersatellite relay directly to ATDRS.

**Implementation:** As shown in Figure 5-11, the satellite antenna coverage of the White Sands area is provided by both a  $0.87^\circ$  beam at Ku-band as well as a  $0.5^\circ$  beam at Ka-band. Uplink communications would be achieved utilizing dedicated wideband single channel per carrier methods. For example, by using a 7 m Ku-band antenna a data rate of 320 Mb/s may be achieved when utilizing a 43 W transmitter and  $0.87$  half power beamwidth DDS antenna coverage. This link utilized 8-PSK modulation, at  $10^{-10}$  bit error rate, with 0.829 FEC coding, 3 dB system margin, and 5 dB rain margin. This amount of rain margin at the White Sands location provides a link availability of 99.98%, i. e. for only 1.8 hours per year would performance be adversely effected. A second geographic diversity site antenna could also be used to enhance link availability.

**Data Requirements:** It is estimated that the composite data rate for uplinks from White Sands for tele-science applications would be at a peak rate of about 1 Gb/s. This would be equally divided between Ku-band and Ka-band. The data requirements would be greatly impacted by the amount of data compression (if any) to be performed at White Sands prior to relay. Another key factor is the enhancement of data replication for multiple site destinations is to be achieved at White Sands prior to relay to DDS or whether it is to be achieved in the DDS spacecraft.

### 5.2.1.6 Link Scenario 1.3B – Downlinks to White Sands (ATDRSS)

**Purpose:** The purpose of this link is to accommodate three types of tele-science functions.

- The first consists of the relay from DDS to White Sands of experiments data and control information which was gathered by DDS from widely distributed CONUS located experimenters. This data in turn is to be destined for ATDRSS distribution to on-orbit experiments.
- The second function is to relay ATDRS generated data from remotely located stations (Hawaii, Andover, etc.) to White Sands. This method would be utilized if the ATDRS spacecraft are widely separated to close the zone of exclusion (ZOE) and then are beyond line of sight to direct readout to White Sands.
- The third function provides for relay to White Sands of ATDRS information which was directly received by DDS via intersatellite links to ATDRS spacecraft.

**Implementation:** As shown in Figure 5-12 the DDS satellite antenna coverage of the White Sands area is provided by both a  $0.87^\circ$  beam at Ku-band and an  $0.5^\circ$  spot beam at Ka-band. An example downlink at Ku-band to a 7 m diameter antenna would require 25 W for a 320 Mb/s data rate with 8-PSK modulation, 0.829 FEC coding,  $10^{-10}$  bit error rate, and 3 dB system margin. The provided 3.4 dB of rain margin would yield a link availability of 99.98% (i. e., 1.8 hours of outage per year).

**Data Requirements:** It is estimated that the composite data rate for downlinks to White Sands for tele-science applications would be a peak rate of about 650 Mb/s. This would be divided with 300 Mb/s at Ku-band and 350 Mb/s at Ka-band.

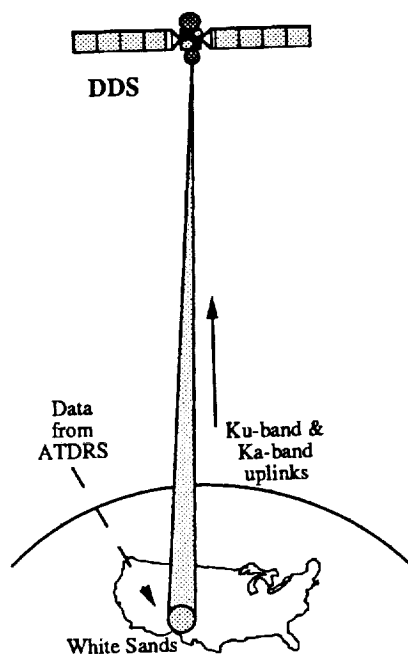


Figure 5-11: Telescience Link Scenario 1.3A - Uplinks from White Sands (ATDRSS)

**Communications Functions:**

Provides for relay of data received from ATDRS network to go:

- Directly to experimenters
- To Goddard as backup to NASCOM terrestrial link.

**Satellite Implementation:**

Antenna: 0.9° spot beam at Ku-band  
0.5° spot beam at Ka-band  
Modulation: single channel per carrier, 8-PSK for bandwidth efficiency.

**Earth Terminal Configuration:**

Ku-band: 5 m, up to 200 W, and diversity terminal.  
Ka-band: 4 m, up to 100 W, and diversity terminal.

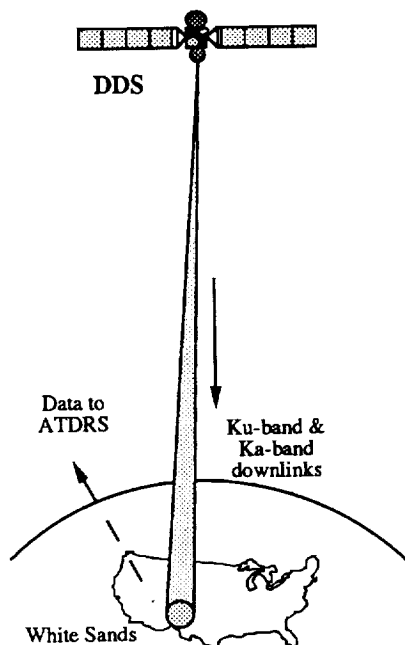


Figure 5-12: Telescience Link Scenario 1.3B - Downlinks to White Sands (ATDRSS)

**Communications Functions:**

Provides the following telescience functions:

- Relay of data/control information received from experimenters and destined for ATDRSS distribution.
- Relay of ATDRS information to White Sands. Received from remote stations (Hawaii, Andover) used to close ZOE
- Relay of ATDRS information to White Sands. Received from ATDRS via intersatellite links.

**Satellite Implementation:**

Antenna: 0.9° spot beam at Ku-band  
0.5° spot beam at Ka-band  
Modulation: SCPC links at 160-640 Mb/s rates.  
8-PSK modulation for spectrum efficiency.  
Use of rate 0.829 forward error correction coding.  
Transmitters: 10-20 W at Ku-band  
5-10 W at Ka-band.

**Earth Terminal Configuration:**

Ku-band: 5 m plus diversity terminal  
Ka-band: 4 m plus diversity terminal

### 5.2.1.7 Link Scenario 1.4A - Uplinks from Goddard Space Flight Center

**Purpose:** The purpose of this link is to accommodate two functions:

- The first is to provide a backup and/or enhancement of the terrestrial NASCOM network for linking ATDRS type communications from Goddard SFC as destined for White Sands.
- The second function is to provide for dissemination of archive science data stored at Goddard which is destined for distribution directly to science experimentation.

**Implementation:** As shown in Figure 5-13, the DDS satellite antenna coverage of Goddard SFC is provided by both a  $0.87^\circ$  beam at Ku-band and a  $0.5^\circ$  spot beam at Ka-band. An example uplink at Ku-band from a 5 m antenna would require 26 W for a data rate of 160 Mb/s using single channel per carrier 8-PSK modulation. The link would utilize 0.829 FEC coding, with  $10^{-10}$  bit error rate and have 3 dB of system margin. The rain margin of 3.0 dB would yield a link availability of 99.8% to Region D-2.

**Data Requirements:** It is estimated that the composite data rate for uplinks from Goddard SFC would be at a peak rate of about 100 Mb/s. It is expected that most of this would normally be accommodated by Ku-band transmission because of the requirement for high link availability.

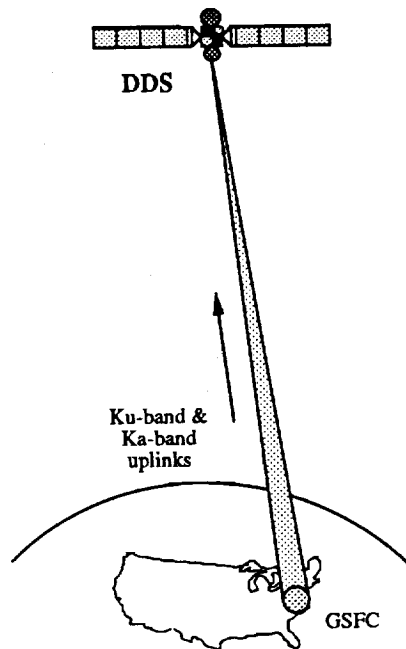
### 5.2.1.8 Link Scenario 1.4B - Downlinks to Goddard Space Flight Center

**Purpose:** The purpose of this link is to provide for distribution of ATDRS data for Goddard SFC. Some of this data would be relayed from the White Sands station of ATDRSS and serve as a backup of the NASCOM terrestrial link. Often data would be the direct relay of ATDRS information received at the DDS spacecraft by intersatellite relay.

**Implementation:** As shown in Figure 5-14, the DDS satellite antenna coverage of Goddard SFC is provided by both a  $0.87^\circ$  beam at Ku-band and a  $0.5^\circ$  spot beam at Ka-band. An example downlink at Ku-band to a 7.0 m antenna would require 18.1 W for 320 Mb/s data rate. This link would utilize 8-PSK for bandwidth efficiency, FEC coding at rate 0.829, and have a link quality of  $10^{-10}$  bit error rate with 3 dB system margin. The rain margin of 2 dB would yield a link availability of 99.8% to region D-2.

**Data Requirements:** It is estimated that the composite data rate for downlinks to Goddard SFC would be a peak rate in the range of 300 Mb/s up to 1 Gb/s. It is expected that most of this would normally be accommodated at Ku-band transmission because of the requirement for high link availability.



**Communications Functions:**

Provides a backup or enhancement of the terrestrial NASCOM network for linking ATDRS type communications from Goddard destined for White Sands.

Also provides for dissemination of archive science data stored at Goddard which is destined for distribution directly to science experimenters.

**Satellite Implementation:**

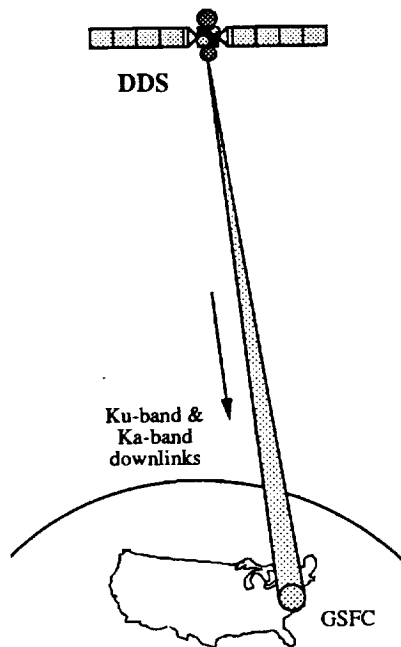
Antenna: 0.9° spot beam at Ku-band  
0.5° spot beam at Ka-band

Modulation: single channel per carrier, 8-PSK for bandwidth efficiency.

**Earth Terminal Configuration:**

- Ku-band: 5 m, 200 W, and diversity terminal.
- Ka-band: 4 m, 100 W, and diversity terminal.

Figure 5-13: Telescience Link Scenario 1.4A – Uplinks from Goddard Space Flight Center

**Communications Functions:**

Provides for distribution of ATDRS data to Goddard:

- a. Backup to the NASCOM terrestrial link between White Sands and Goddard.
- b. Direct relay of ATDRS information received by intersatellite relay.

**Satellite Implementation:**

Antenna: 0.9° spot beam at Ku-band  
0.5° spot beam at Ka-band

Modulation: SCPC links at 320 Mb/s rates.  
8-PSK modulation for bandwidth efficiency.  
Use of rate 0.829 forward error correction coding.

Transmitters: 10-20 W at Ku-band  
5-25 W at Ka-band.

**Earth Terminal Configuration:**

- Ku-band: 5 m plus diversity terminal
- Ka-band: 4 m plus diversity terminal

Figure 5-14: Telescience Link Scenario 1.4B – Downlinks to Goddard Space Flight Center

### 5.2.1.9 Link Scenario 1.5A - Uplinks from Remote ZOE Stations

**Purpose:** Some of the future configuration of the ATDRSS system would require a greater geographic separation of the ATDRS spacecraft in order to close the zone of exclusion (ZOE) for complete global coverage. These ATDRS spacecraft would no longer be in view of the White Sands station and thus would relay data via other closer proximity stations which could be located at Hawaii or Andover, Maine for example.

The purpose of this DDS uplink would be to act as a relay of the data from the remote station for subsequent transmission to White Sands or directly distributed to experimenters.

**Implementation:** As depicted in Figure 5-15, the DDS satellite antenna coverage of a remote tracking station could be provided by both a  $0.87^\circ$  beam at Ku-band and a  $0.5^\circ$  spot beam at Ka-band. The transmission technique would be single channel per carrier using 8-PSK modulation for bandwidth efficiency. A typical earth terminal would be 5 m at Ku-band and 4 m at Ka-band in order to accommodate high data rates of 320 Mb/s with high link availability.

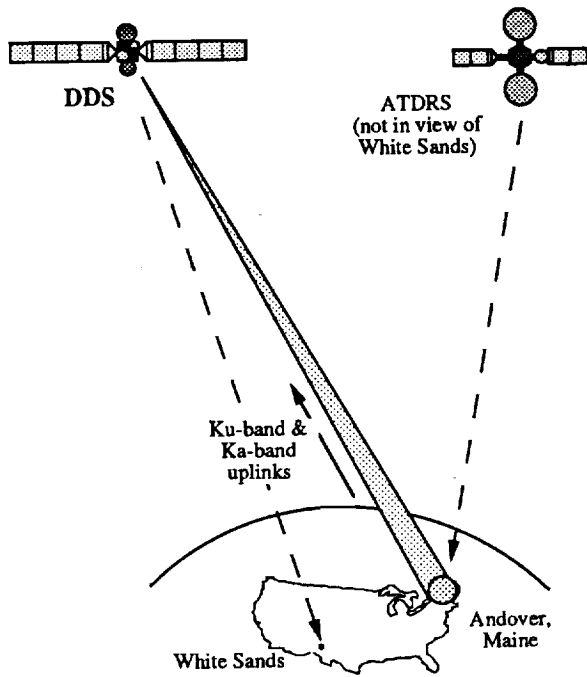
**Data Requirements:** It is estimated that the composite data rate for uplinks from remote stations to DDS would be at a peak of 600 Mb/s. This would be equally divided between Ku-band and Ka-band.

### 5.2.1.10 Link Scenario 1.5B - Downlinks to Remote ZOE Station

**Purpose:** The purpose of this link is to act as a relay of telescope uplink data originated in White Sands via DDS and destined for those extreme position ATDRS spacecraft at orbit locations not in line of sight view of White Sands.

**Implementation:** As shown in Figure 5-16, the DDS spacecraft antenna coverage is provided by both a  $0.87^\circ$  beam at Ku-band as well as a  $0.5^\circ$  spot beam at Ka-band. A dedicated single channel per carrier links at 100 Mb/s could be provided or TDM downlinks at maximum capacity of 52 Mb/s per link could be made available for capacity allocation as required.

**Data Requirements:** It is estimated that the composite data rate for downlinks to the remote station (destined for uplink relay via remote ATDRS to on-orbit science experiments) would total 200 Mb/s. This would be divided equally between Ku-band and Ka-band.



**Communications Functions:**

Provides for relay of data sent to remote stations by ATDRS because of line-of-sight limitations to White Sands (used to close ZOE). This data is all sent to White Sands; however, some may be directly distributed to other experimenters.

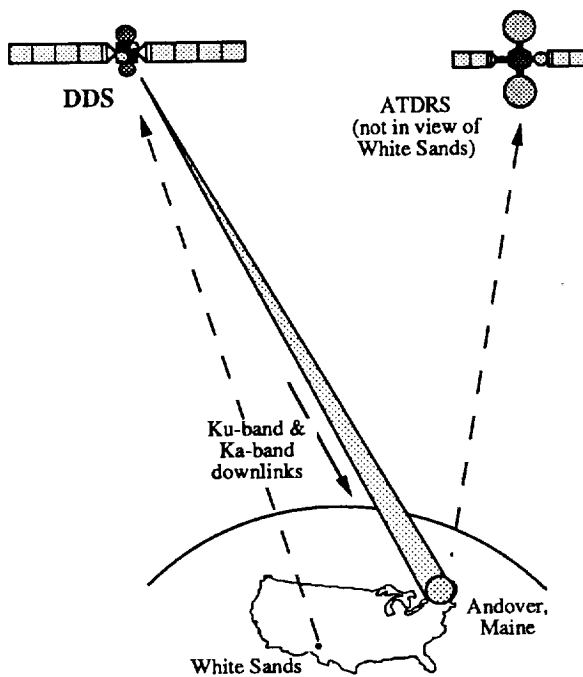
**Satellite Implementation:**

Antenna: 0.9° spot beam at Ku-band  
 0.5° spot beam at Ka-band  
 Modulation: single channel per carrier, 8-PSK for bandwidth efficiency.

**Earth Terminal Configuration:**

Ku-band: 5 m, 200 W, and diversity terminal.  
 Ka-band: 4 m, 100 W, and diversity terminal.

Figure 5-15: Telescience Link Scenario 1.5A – Uplinks from Remote ZOE Closure Stations



**Communications Functions:**

Provides for the relay of data received from White Sands and destined for ATDRS positioned to close the ZOE.

**Satellite Implementation:**

Antenna: 0.9° spot beam at Ku-band  
 0.5° spot beam at Ka-band  
 Modulation: SCPC or TDM links at 52 Mb/s rate.  
 BPSK modulation for power eff. and ease of demod.  
 Use of rate 3/4 forward error correction coding.  
 Transmitters: 10-20 W at Ku -band  
 5-25 W at Ka-band.

**Earth Terminal Configuration:**

Ku-band: 5 m plus diversity terminal  
 Ka-band: 4 m plus diversity terminal

Figure 5-16: Telescience Link Scenario 1.5B – Downlinks to Remote ZOE Closure Stations

### 5.2.1.11 Link Scenario 1.6A – Intersatellite Links to DDS from ATDRS

**Purpose:** These links provide for the transmission of data from ATDRS spacecraft directly to DDS by means of intersatellite crosslinks. The data may consist of:

- i. Overflow of the capacity of the ATDRS to White Sands link;
- ii. Information destined for direct distribution to experimenters; or
- iii. Information from an ATDRS positioned at an extreme orbit position in order to close the zone of exclusion (ZOE) for global coverage.

**Implementation:** As shown in Figure 5-17, the crosslinks may be implemented at either a 60 GHz transmission frequency or by using laser links at optical transmission frequencies. Typical 60 GHz implementation would require antenna diameters of 1 m to 3 m, 93 kg of mass and 40 W power. A typical optical system for 640 Mb/s link capacity over a 40,000 km path length would use a 15 cm aperture to generate high gain steerable spot beams and use 1 W laser diode arrays. For the relatively high data rates projected, it is expected that the laser technology will provide the superior communications approach.

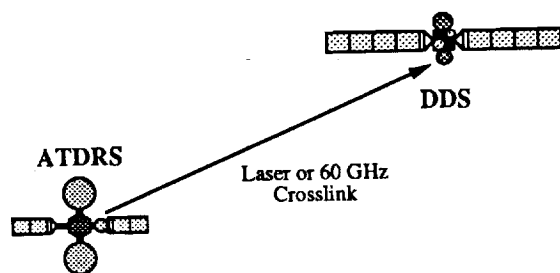
**Data Requirements:** It is estimated that a single crosslink from ATDRS to DDS would have a peak data rate of 640 Mb/s. Multiple links may be required depending upon future ATDRS network configuration.

### 5.2.1.12 Link Scenario 1.6B – Intersatellite Links to ATDRS from DDS

**Purpose:** This link provides for the transmission of data from the DDS spacecraft directly to an ATDRS spacecraft by means of intersatellite crosslinks. This data would mainly consist of control information destined for on-orbit space experiments.

**Implementation:** As shown in Figure 5-18, the crosslink may be implemented at either a 60 GHz RF transmission frequency or by using laser links at an optical band transmission frequency. It is expected that the laser technology will better accomplish the expected DDS system requirements.

**Data Requirements:** It is estimated that the crosslink from DDS to an ATDRS would have a peak data rate of 200 Mb/s. (This is about one third of the return path crosslink which is used for experiments data distribution). If more than one ATDRS were to be accommodated, then the total crosslink capacity would have to be correspondingly increased.

**Communications Functions:**

Provides for intersatellite transmission to DDS from ATDRSS satellites. The data may be overflow of the capacity of ATDRS to White Sands or information destined for direct distribution to experimenters.

**DDS Implementation:**

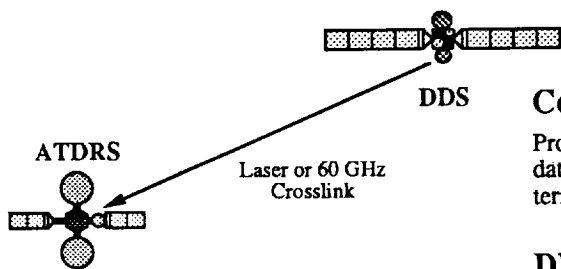
Antenna: high gain steerable spot at optical (.85 microns) or 60 GHz frequencies. Field of view limited to possible ATDRS positions.  
Data rate: 160 Mb/s minimum, 2 Gb/s max. (depends on range).

**ATDRS Implementation:**

Optical: 15 cm aperture, 1 W heterodyne; 40 kg mass, 80 W power estimates for 4-channel duplex link.  
60 GHz: 1-3 m antenna, 93 kg mass, 40 W power.



Figure 5-17: Telescience Link Scenario 1.6A - Intersatellite Links to DDS from ATDRS

**Communications Functions:**

Provides for intersatellite transmission to ATDRS of data and experiment control information received from terrestrial experimenters.

**DDS Implementation:**

Antenna: high gain steerable spot at 60 GHz or optical frequencies. Field of view limited to possible ATDRS positions.  
Data rate: 160 Mb/s per link.

**ATDRS Implementation:**

60 GHz: 1-3 m antenna, 93 kg mass, 40 W power  
Optical: 15 cm aperture, 1 W heterodyne.



Figure 5-18: Telescience Link Scenario 1.6B - Intersatellite Links to DDS from ATDRS

## 5.2.2 Peer Networking Link Scenarios

The link scenarios associated with general category of Peer Networking are as follows:

1. Uplinks from many thousands of small users to DDS for science data transmittal and downlinks to these terminals from DDS for receipt of science data;
2. Uplinks and downlinks for accommodating communications of science data between DDS and the various science data base centers;
3. Uplinks and downlinks associated with access control to the peer networking system.

### 5.2.2.1 Link Scenario 2.1A - Uplinks from Science Network Users

**Purpose:** The communications functions to be accommodated by this link will provide direct access to the DDS spacecraft from thousands of science data base users located throughout CONUS. The uplinks would include network access/control requests, information destined for storage at one or more of the science data base centers, information destined for relay directly to other science data users, and information to be relayed to a control center for subsequent direction to other science users.

**Implementation:** As shown in Figure 5-19, the satellite antenna coverage is provided to all of CONUS at Ku-band and at Ka-band by means of 8 adjacent coverage beams of  $1.73^\circ$  half power beamwidth. In addition the high traffic areas are serviced by 10 spot beams of  $0.87^\circ$  at Ku-band and by 16 spot beams of  $0.5^\circ$  at Ka-band. The uplinks are single channel per carrier at rates from 144 Mb/s to 6 Mb/s utilizing bulk demodulations in the spacecraft for multiple carrier demodulation efficiency. D-QPSK or D-8PSK would be used as the modulation technique for bandwidth utilization efficiency. The thousands of small VSAT earth terminals would generally be in the range of 1.5 m to 3 m.

As an example, a transmitter power of 8.3 W from a 3.0 m VSAT is required to accommodate a 6 Mb/s data rate to a Ku-band spacecraft antenna of  $1.73^\circ$  half power beamwidth. This link would utilize QPSK modulation at  $10^{-8}$  bit error rate, with .905 FEC coding, to a spacecraft bulk demodulation. A net system margin of

3.0 dB is provided and a rain margin of 3.0 dB provides 99.8% link availability to rain region D-2.

**Data Requirements:** It is estimated that the composite data rate for small user peer networking uplinks would be at a peak rate of 300 Mb/s. This would be divided into 100 Mb/s at Ku-band and 200 Mb/s at Ka-band.

### 5.2.2.2 Link Scenario 2.1B - Downlinks to Science Network Users

**Purpose:** This function provides direct downlinks to the thousands of science data base users located throughout CONUS. The information contains network access control responses, information retrieved from data base centers, and information received directly from other peer network users.

**Implementation:** As shown in Figure 5-19, the satellite antenna coverage is provided to all of CONUS at Ku-band via 27 adjacent beams of  $0.87^\circ$  half power beamwidth. All of CONUS is also covered at Ka-band with 8 adjacent beams of  $1.73^\circ$ . This is supplemented with 16 spot beams of  $0.5^\circ$  at Ka-band. The downlinks utilize TDM communications at a nominal rate of 52 Mb/s. BPSK modulation is used for spacecraft power efficiency as well as ease of demodulation.

As an example, a spacecraft transmitter power of 10.0 W is required for a Ku-band downlink from a spacecraft antenna beam of  $0.87^\circ$  half power beamwidth to a 1.8 m VSAT at a TDM burn rate of 52 Mb/s. This link would utilize BPSK modulation, 0.749 FEC coding, at  $10^{-10}$  bit error rate with a net system margin of 3.0 dB. The provided rain margin of 2.0 dB permits a link availability of 99.8% to rain region D-2.

**Data Requirements:** It is estimated that the composite data rate for small user peer networking downlinks would be a peak rate of 1.5 Gb/s. This would be allocated with 500 Mb/s at Ku-band and 1.0 Gb/s at Ka-band.

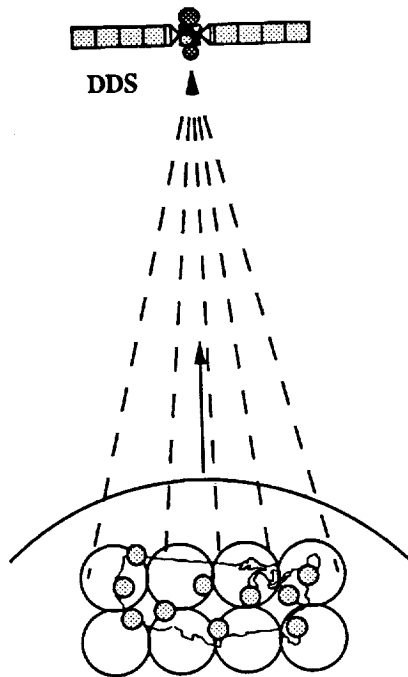


Figure 5-19: Peer Networking Link Scenario 2.1A – Uplinks from Science Network Users

**Communications Functions:**

Provides for direct uplinks from many thousands of science data base users located throughout CONUS:

- Network access control for the comm. control center.
- Data retrieval requests and information to be stored at one or more of the science data base centers.
- Information to be sent directly to other science users.
- Information to be relayed from the control center and then directed to other science users.

**Satellite Implementation:**

Antenna: 8 adjacent 1.73° beams cover CONUS at Ku-band;  
8 adjacent 1.73° beams cover CONUS at Ka-band;  
10 spot beams of 0.9° at Ku-band;  
16 spot beams of 0.5° at Ka-band.

Access/modulation: single channel per carrier at rates from 144 kb/s to 6 Mb/s using bulk demods.  
D-QPSK or D-8PSK used for bandwidth efficiency.

**Earth Terminal Configuration:**

1,000 to 50,000 small VSAT terminals:

Ku-band: 1.8 to 3 m, 25-50 W, 144 kb/s to 52 Mb/s

Ka-band: 1.5 to 3 m, 25-50 W, 1.5 Mb/s to 52 Mb/s

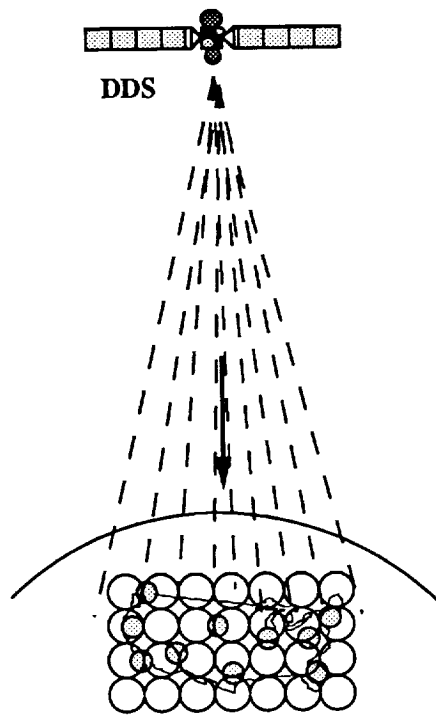


Figure 5-20: Peer Networking Link Scenario 2.1B – Downlinks to Science Network Users

**Communications Functions:**

Provides for direct downlinks to many thousands of science data base users located throughout CONUS:

- Network access control responses.
- Information from data base centers.
- Information from other peer network users (direct via DDS single hop or relayed double hop).

**Satellite Implementation:**

Antenna: 27 adjacent 0.9° beams cover CONUS at Ku-band  
8 adjacent 1.7° beams cover CONUS at Ka-band;  
plus 16 spot beams of 0.5° at Ka-band.

Modulation: TDM links at 30-100 Mb/s rates. BPSK modulation for power efficiency and ease of demod.  
Use of rate 3/4 forward error correction coding.

Transmitters: 10-20 W at Ku and 15-30 W at Ka-band.

**Earth Terminal Configuration:**

1,000 to 50,000 VSAT terminals:

Ku-band: 1.8 m to 3 m

Ka-band: 1.5 m to 3 m

### 5.2.2.3 Link Scenario 2.2A – Uplinks from Science Database Centers

**Purpose:** This function is to provide uplinks from the several science data base centers located within CONUS. The information transmitted would consist of responses to requests for information from peer network users as well as relay among data base centers.

**Implementation:** As shown in Figure 5-21, the satellite antenna coverage is provided at Ku-band via 10 spot beams of  $0.87^\circ$ . This is supplemented with 16 spot beams of  $0.5^\circ$  at Ku-band. The uplink utilizes single channel per carrier communications method. QPSK or 8-PSK is used for spectrum efficiency.

For example at Ku-band, 26 W transmit power and a 5 m earth terminal can communicate at 160 Mb/s to a satellite antenna of  $0.87^\circ$  half power beamwidth. The link would utilize 8-PSK modulation, utilize 0.829 FEC coding at  $10^{-10}$  bit error rate, and yield 3.0 dB of net system margin. A rain margin of 3.0 dB yields 99.8% link availability to a database center located in rain region D-2.

**Data Requirements:** It is estimated that the composite data rate for uplinks from data base centers for peer networking would be at a peak rate of 1.5 Gb/s. This would be allocated with 500 Mb/s at Ku-band and 1 Gb/s at Ka-band. If several data base centers are to be interconnected, it is presumed that the DDS satellite relay would be used to supplement a terrestrial fiber network interconnection.

### 5.2.2.4 Link Scenario 2.2B – Downlinks to Science Database Centers

**Purpose:** This function provides for the transfer of science data information from peer networking users to one or more of the science data base centers. The information may be stored and/or retransmitted from the data base center to other peer networking users. This link would also be used for transmittal of information retrieval requests.

**Implementation:** As shown in Figure 5-21, the satellite antenna coverage is provided at Ku-band by 27 adjacent beams of  $0.87^\circ$  half power beamwidth. Ka-band coverage is provided by up to 16 spot beams of  $0.5^\circ$ . A data processor in DDS would be used to combine the multiple network user uplinks into a composite data stream for each downlink. For example at Ku-band, a 10.2 W spacecraft transmitter and  $0.87^\circ$  antenna beam may communicate at 320 Mb/s with a 5 m earth station with 3.0 dB system margin.

This link would utilize QPSK modulation, single channel per carrier, with 0.749 FEC coding, and yield a quality of  $10^{-10}$  bit error rate. The 2.0 dB of included rain margin would yield a link availability of 99.8% to rain region D-2. If required, a site diversity terminal could be used to enhance link availability.

**Data Requirements:** It is estimated that the composite data rate for downlinks to data base centers for peer networking would be a peak rate of 300 Mb/s. This would be allocated with 100 Mb/s at Ku-band and 200 Mb/s at Ka-band.



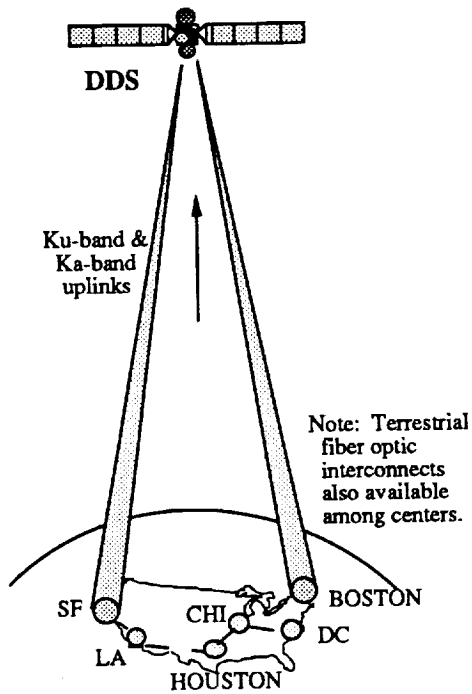


Figure 5-21: Peer Networking Link Scenario 2.2A – Uplinks from Science Database Centers

**Communications Functions:**

Provides for transmission of science information from one to several data base centers located within CONUS:

- a. Information to be directed to science data users
- b. Information for relay to other science data base centers.

**Satellite Implementation:**

Antenna: up to 10 fixed 0.9° beams at Ku-band  
 up to 10 each 0.5° spot beams at Ka-band

Access/modulation: single channel per carrier .  
 Demodulation on satellite. 4- or 8-PSK used at high data rates for bandwidth efficiency.

**Earth Terminal Configuration:**

Ku-band: 5 m, 200 W transmitter  
 Ka-band: 4 m, 100 W transmitter, site diversity option

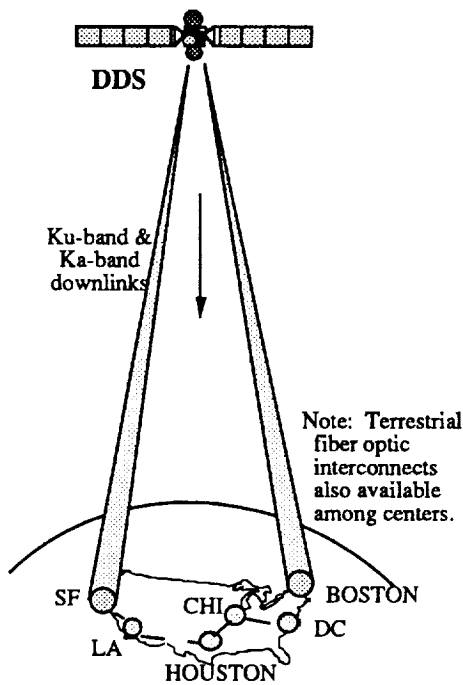


Figure 5-22: Peer Networking Link Scenario 2.2B – Downlinks to Science Database Centers

**Communications Functions:**

Provides for transmission of science data information to one or more science data base centers. This information may be stored and/or retransmitted, destined for other data base users.

**Satellite Implementation:**

Antenna: 27 spot 0.9° beams cover CONUS at Ku-band.  
 Up to 16 spot 0.5° beams at Ka-band.

Modulation: SCPC links at 30-100 Mb/s rates.  
 Use of forward error correction coding.

Transmitters: 5-20 W at Ku and 5-20 W at Ka-band.

**Earth Terminal Configuration:**

Ku-band: 5 m at each site, site diversity.  
 Ka-band: 4 m at each site, site diversity.

### 5.2.2.5 Link Scenario 2.3A – Uplinks from Comm. Control Center

**Purpose:** The function of this link is to provide communication between the DDS Communication Control Center and peer network users (via DDS spacecraft relay) for the purpose of coordinating access control to the DDS communications links. This link could also be used for a double hop relay among data base users if a centralized control was required. A single control center would be used to coordinate the access of all DDS users, i. e., for Telescience, Peer Networking, or Other services.

**Implementation:** As shown in Figure 5-23, the satellite antenna coverage is provided by both a  $0.87^\circ$  beam at Ku-band as well as a  $0.5^\circ$  spot beam at Ka-band (for back up)

For example, at Ku-band, a transmitter power of 8.8 W from a 5.0 m diameter antenna could be used to communicate at 52 Mb/s to a spacecraft with  $0.87^\circ$  antenna coverage beam. This link would be single channel per carrier, using 8-PSK modulation, with 0.829 FEC coding at  $10^{-10}$  bit error rate. The rain margin of 3.0 dB would yield a link availability of 99.8% to rain region D-2.

**Data Requirements:** It is estimated that the composite data rate for uplink access control information for peer networking (and double hop information relay) would be at a peak rate of 50 Mb/s. This would be accomplished at Ku-band because of the high link availability. A Ka-band link could also be incorporated as a backup capability.

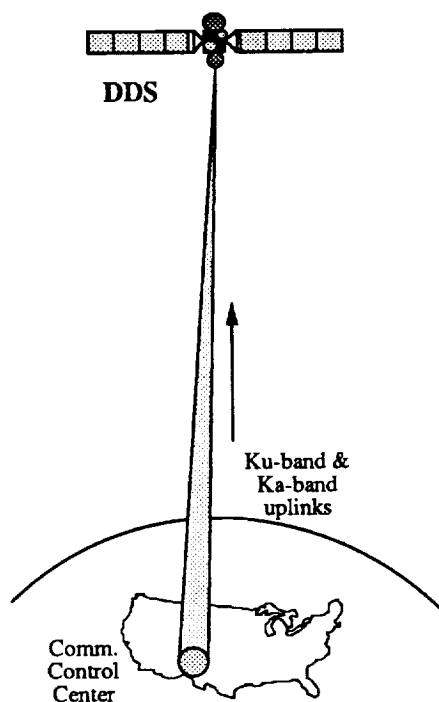
### 5.2.2.6 Link Scenario 2.3B – Downlinks to Comm. Control Center

**Purpose:** The function of this link is to provide communications between peer network users and the Communications Control Center (via DDS) for the purpose of requesting and coordinating access control to the DDS communications links. The link could also be used for a double hop relay among data base users under centralized control.

**Implementation:** As shown in Figure 5-24, the satellite antenna coverage is provided by both a  $0.87^\circ$  beam at Ku-band as well as a  $0.5^\circ$  spot beam at Ka-band (for back up)

For example, at Ku-band, a satellite transmit power of 1.7 W from a  $0.87^\circ$  antenna beam is required to communicate at 52 Mb/s to a 5.0 m diameter earth terminal. This link would use QPSK modulation with 0.75 FEC coding at  $10^{-10}$  bit error rate, and incorporate 2 dB of rain margin (99.8% link availability to rain region D-2). A site diversity earth terminal could be incorporated for improved link availability.

**Data Requirements:** It is estimated that the composite data rate for downlink access control for peer networking (and double hop information relay) would be at a peak rate of 50 Mb/s. This would be primarily accomplished at Ku-band because of the requirement for high link availability. A Ku-band link could also be incorporated as a backup capability.



### Communications Functions:

Provides for network control of the peer network:

- a. Network access control responses.
- b. Optional relay of information (second hop) originated by data base users to go in real time to other users.

### Satellite Implementation:

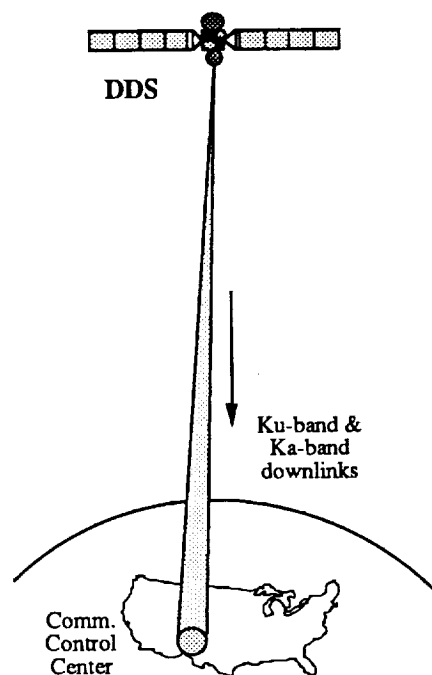
Antenna: single 0.9° spot beam at Ku-band  
single 0.5° spot beam at Ka-band

Access/modulation: single channel per carrier at 52 Mb/s.  
8-PSK used for bandwidth efficiency.

### Earth Terminal Configuration:

Ku-band: 5 m, up to 200 W transmitter, site diversity.  
Ka-band: 4 m, up to 100 W transmitter, site diversity.

Figure 5-23: Peer Networking Link Scenario 2.3A – Uplinks from Communications Control Center



### Communications Functions:

Provides for network control of the peer network:

- a. Requests for network access.
- b. Optional relay of information originated by data base users to go via second hop to other data base users.

### Satellite Implementation:

Antenna: single 0.9° spot beam at Ku-band  
single 0.5° spot beam at Ka-band

Modulation: TDM link at 100 Mb/s rates. D-8PSK modulation for bandwidth efficiency.

Use of rate .9 forward error correction coding.

Transmitters: 5-20 W at Ku and 5-20 W at Ka-band.

### Earth Terminal Configuration:

Ku-band: 5 m

Ka-band: 4 m, plus site diversity terminal

Figure 5-24: Peer Networking Link Scenario 2.3B – Downlinks to Communications Control Center

### 5.2.3 Other Services Link Scenarios

The link scenarios associated with the general category of Other Services are expected to include the following:

1. Uplinks and downlinks via DDS to support communications interface of the various NASA centers.
2. Up and downlinks via DDS to support a wideband super computer network.
3. Up and downlinks via DDS to support the transfer of large scale science project engineering data.
4. Links to support communications to/from international science communications networks.
5. Links to support data relay to/from global environment monitoring.
6. Links via DDS to support the industrial use of space (optional)

#### 5.2.3.1 Link Scenario 3.1A – Uplinks to Interconnect NASA Centers

**Purpose:** The function of this scenario is to provide the uplinks for communication interconnects among NASA and other government centers. Communications may consist of project information exchange, teleconferencing, and/or NASA may provide a role as science database centers.

**Implementation:** As shown in Figure 5-25, the satellite antenna coverage over all CONUS is provided by eight beams of  $1.73^\circ$  half power beamwidth at both Ku and Ka-bands. If very high data rates are required, then additional spot beam coverage may be provided.

An example link using a 5 m earth terminal at Ku-band requires 43 W power for a data rate of 52 Mb/s with a  $1.73^\circ$  satellite antenna beam. This single channel per carrier link would utilize 8-PSK for bandwidth efficiency, .829 FEC coding, and have a quality of  $10^{-10}$  bit error rate.

**Data Requirements:** It is estimated that the composite uplink data rate from NASA or other government centers would be 400 Mb/s. This would be equally divided between Ku and Ka-bands.

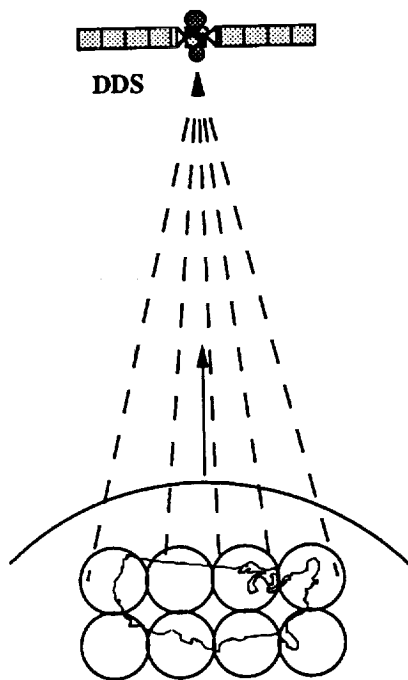
#### 5.2.3.2 Link Scenario 3.1B – Downlinks to Interconnect NASA Centers

**Purpose:** The function of this scenario is to provide the downlinks for communications interconnect among NASA or other government centers.

**Implementation:** As shown in Figure 5-26, the satellite antenna coverage over all of CONUS is provided by 27 beams of  $0.84^\circ$  half power beamwidth at Ku-band and eight beams of  $1.73^\circ$  at Ka-band. The downlinks would normally utilize TDM access techniques; however, dedicated high rate SCPC links may be used for selected sites of high data traffic.

An example downlink at Ku-band would require 1.7 W DDS transmit power in a  $0.87^\circ$  beam for 52 Mb/s link to a 5 m ground terminal. This link would use QPSK modulation at  $10^{-10}$  bit error rate with .75 FEC coding to obtain a 3 dB system margin. An included 2 dB rain margin gives 99.8% link availability to rain region D-2.

**Data Requirements:** It is estimated that the composite downlink data rate to NASA or other government centers would be 400 Mb/s. This would be equally divided between Ku and Ka-bands.



**Communications Functions:**

Provides for communications interconnect (uplink) among all NASA centers.

**Satellite Implementation:**

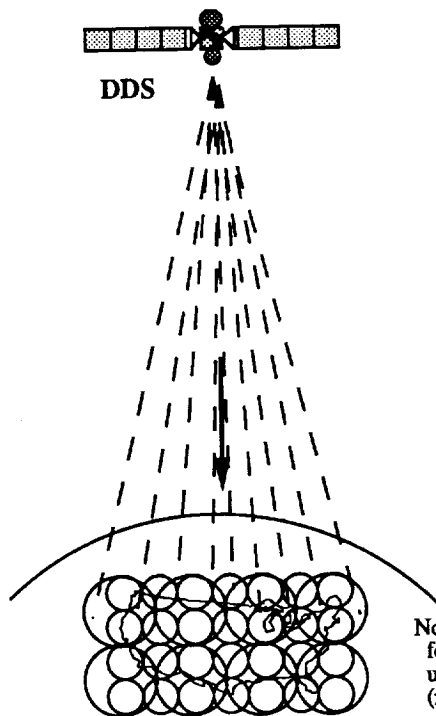
Antenna: 8 beams cover CONUS at Ku-band  
 8 beams cover CONUS at Ka-band  
 Alternate plan at Ka-band for limited area of CONUS coverage using up to 16 0.5° spot beams.  
 Access/modulation: single channel per carrier at rates from 144 kb/s to 1.5 Mb/s to 30 Mb/s.

**Earth Terminal Configuration:**

Each NASA center with fiber optic local area network connection to earth terminal:

Ku-band: 5 m, 200 W transmitter.  
 Ka-band: 4 m, 100 W, site diversity optional.

Figure 5-25: Other Services Link Scenario 3.1A – Uplinks to Interconnect NASA Centers



**Communications Functions:**

Provides for communications interconnect (downlink) among all NASA centers.

**Satellite Implementation:**

Antenna: 27 each 0.9° beams at Ku-band  
 8 each 1.7° beams at Ka-band  
 Modulation: TDM link at 30-100 Mb/s rates;  
 QPSK modulation for bandwidth efficiency .  
 Use of rate .75 forward error correction coding.

**Earth Terminal Configuration:**

Each NASA center with fiber optic local area network connection to earth terminal:

Ku-band: 5 m  
 Ka-band: 4 m, plus site diversity terminal

Note: Alternate plan at Ka-band for limited area CONUS coverage using up to 16 0.5° spot beams (not shown).

Figure 5-26: Other Services Link Scenario 3.1B – Downlinks to Interconnect NASA Centers

### 5.2.3.3 Link Scenario 3.2A - Uplinks for Wideband Computer Interconnections

**Purpose:** This scenario provides the uplinks for support of interconnections of wideband data services such as supercomputers.

**Implementation:** As shown in Figure 5-27, the satellite antenna coverage over all CONUS is provided by eight beams of  $1.73^\circ$  half power beamwidth at both Ku and Ka-bands. In addition a limited number of areas may be serviced by  $0.9^\circ$  spot beams at Ku-band and  $0.5^\circ$  at Ka-band. The earth terminals range from 3 m to 5 m diameter depending on data rate and availability requirements.

An example link at Ka-band would require 46 W power from a 3 m earth terminal for a data rate of 52 Mb/s with a  $1.73^\circ$  satellite antenna beam. This link would utilize QPSK modulation, .75 FEC coding, and have a quality of  $10^{-10}$  bit error rate. An included 3.1 dB rain margin gives 99.0% link availability to rain region D-2.

**Data Requirements:** It is estimated that the composite data rate for wideband computer interconnect would be 1.5 Gb/s peak. This would be divided with 0.5 Gb/s at Ku-band and 1 Gb/s at Ka-band.

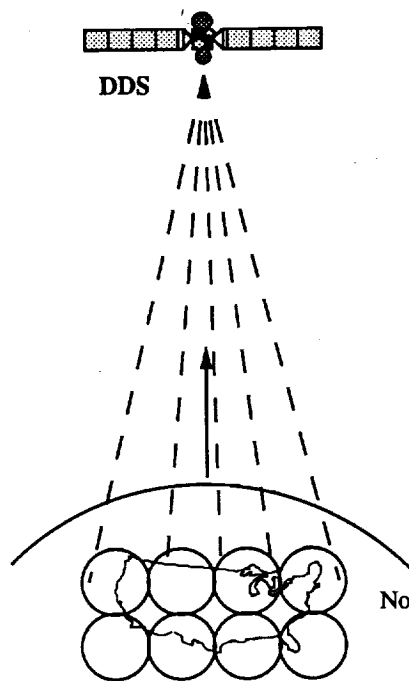
### 5.2.3.4 Link Scenario 3.2B - Downlinks for Wideband Computer Interconnections

**Purpose:** This scenario provides the downlinks for support of interconnections of wideband data services such as supercomputers.

**Implementation:** As shown in Figure 5-28, the satellite antenna coverage over all CONUS is provided by 27 beams of  $0.87^\circ$  half power beamwidth at Ku-band. CONUS coverage is also provided by eight beams of  $1.73^\circ$  at Ka-band. In addition up to 16 spot beams of  $0.5^\circ$  are available at Ka-band. The earth terminals range from 3 m to 5 m diameter depending on data rate and availability requirements.

An example link at Ka-band would require 2.6 W satellite power with a  $0.5^\circ$  beam to transmit 320 Mb/s to a 5 m earth terminal for a data rate of 52 Mb/s with a  $1.73^\circ$  satellite antenna beam. This SCPC link would utilize QPSK modulation, .75 FEC coding, and have a quality of  $10^{-10}$  bit error rate. An included 3.1 dB rain margin gives 99.0% link availability to rain region D-2.

**Data Requirements:** It is estimated that the composite data rate for wideband computer interconnect would be 1.5 Gb/s peak. This would be divided with 0.5 Gb/s at Ku-band and 1 Gb/s at Ka-band.

**Communications Functions:**

Provides uplinks for interconnect of wideband data services, including supercomputers

**Satellite Implementation:**

Antenna: 8 beams of 1.7° at Ku and Ka-bands plus limited number of 0.5° spot beams at Ka-band and 0.9° spot beams at Ka-band.

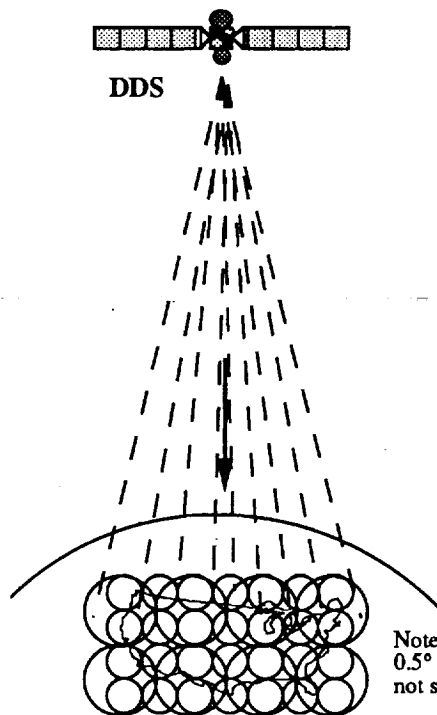
Access/modulation: single channel per carrier at rates from 30 Mb/s to 650 Mb/s. QPSK or 8-PSK modulation used for bandwidth efficiency.

**Earth Terminal Configuration:**

Ku-band: 3 m to 5 m; 50 W to 200 W transmitter.  
Ka-band: 3 m to 4 m; 25 W to 100 W transmitter; site diversity optional.

Note: 0.5° and 0.9° spot beams not shown.

Figure 5-27: Other Services Link Scenario 3.2A – Uplinks for Wideband Computer Interconnections

**Communications Functions:**

Provides downlinks for interconnection of wideband data services including supercomputers.

**Satellite Implementation:**

Antenna: 27 each 0.9° spot beams at Ku-band plus 8 each 1.7° beams at Ka-band plus up to 16 0.5° spot beams at Ka-band.

Access/modulation: single channel per carrier at rates from 30 Mb/s to 650 Mb/s. QPSK or 8PSK modulation used for bandwidth efficiency.

**Earth Terminal Configuration:**

Ku-band: 3 m to 5 m  
Ka-band: 3 m to 4 m, plus site diversity terminal (optional)

Note: Ka-band 0.5° spot beams not shown.

Figure 5-28: Other Services Link Scenario 3.2B – Downlinks for Wideband Computer Interconnections

### 5.2.3.5 Link Scenario 3.3A/B - Links for Project Management

**Purpose:** The function of these links is to provide interconnection of centers for large scale science project development and manufacturing data distribution. Examples include the Shuttle and Space Station Programs with their associated NASA centers, Program Offices, and contractors.

**Implementation:** The link implementation would be the same as that described for the interconnection of NASA centers as described in ¶5.2.3.1 (uplinks) and ¶5.2.3.2 (downlinks). See Figures 5-29 and 5-30.

**Data Requirements:** It is estimated that the composite peak data rate would be 200 Mb/s, with most being at Ka-band because high link availability would not be required.

### 5.2.3.6 Link Scenario 3.4 - International Science Data Network

**Purpose:** This scenario provides for the international exchange of science data. The links would both collect and distribute data to CONUS (or both North and South America) with transmittal and receipt of data via intersatellite links to the Asian and European sector satellites.

**Implementation:** The links to CONUS at Ku and Ka-bands would be as previously described for other services. As shown in Figure 5-31, the intersatellite links to other international satellites would be at optical frequencies (60 GHz optional).

**Data Requirements:** It is estimated that the composite data rate for the international relay of science database information would be at a peak rate of 500 Mb/s. This would be divided equally between the Asian and European satellites. The data rates to/from CONUS science data users are contained within the requirements of the previously described peer networking scenarios.

### 5.2.3.7 Link Scenario 3.5 - Global Environment Network

**Purpose:** This scenario provides regional coverage of the Americas for communications in support of a global environmental monitoring system. It is expected that intersatellite links would also be provided to satellites monitoring the Asian and European sectors for a full global coverage.

**Implementation:** The links to CONUS at Ku and Ka-bands would be as previously described for other services. Intersatellite links would be achieved at optical frequencies (60 GHz optional). See Figure 5-32.

**Data Requirements:** It is estimated that the composite data rate for receiving and transmitting information to CONUS would be 150 Mb/s peak. This would be divided with 50 Mb/s at Ku-band and 100 Mb/s at Ka-band.

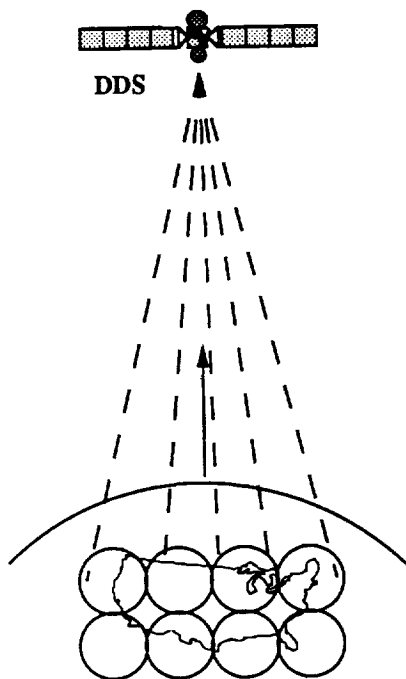
### 5.2.3.8 Link Scenario 3.6 - Industrial Use of Space

**Purpose:** This scenario provides the communication links between CONUS terrestrial facilities and industrial research and manufacturing projects in space. This may be an optional requirement for DDS because of the private sector aspects. However, an initial network support may be required until future commercial systems become established.

**Implementation:** The links to CONUS at Ku and Ka-bands would be as previously described for other services. The DDS to ATDRS or direct DDS to commercial satellite would be at optical frequencies (60 GHz optional). See Figure 5-33.

**Data Requirements:** It is estimated that the composite peak data rate for support of the industrial use of space would be 1 Gb/s. This would be divided with 250 Mb/s at Ku-band and 750 Mb/s at Ka-band for uplinks/downlinks.



**Communications Functions:**

Provides uplinks for interconnection of node centers for large scale project development and manufacturing data distribution.

**Satellite Implementation:**

Antenna: 8 beams cover CONUS at Ku-band  
8 beams cover CONUS at Ka-band

Alternate plan at Ka-band for limited area of CONUS coverage using up to 16 0.5° spot beams.

Access/modulation: single channel per carrier at rates from 144 kb/s to 1.5 Mb/s to 30 Mb/s.

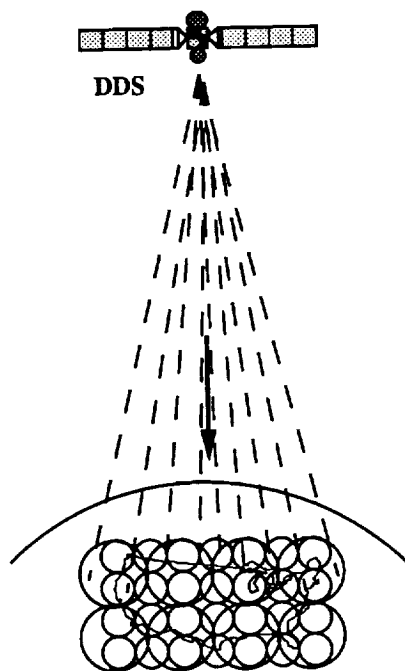
**Earth Terminal Configuration:**

Each NASA center with fiber optic local area network connection to earth terminal:

Ku-band: 5 m, 200 W transmitter.

Ka-band: 4 m, 100 W, site diversity optional.

Figure 5-29: Other Services Link Scenario 3.3A - Uplinks for Project Management

**Communications Functions:**

Provides downlinks for interconnection of node centers for large scale project development, manufacturing, and operations data distribution. Rates may exceed those of uplinks due to replication of information for multiple destinations.

**Satellite Implementation:**

Antenna: 27 each 0.9° beams at Ku-band  
8 each 1.7° beams at Ka-band

Modulation: TDM link at 30-100 Mb/s rates;  
QPSK modulation for bandwidth efficiency .  
Use of rate .75 forward error correction coding.

**Earth Terminal Configuration:**

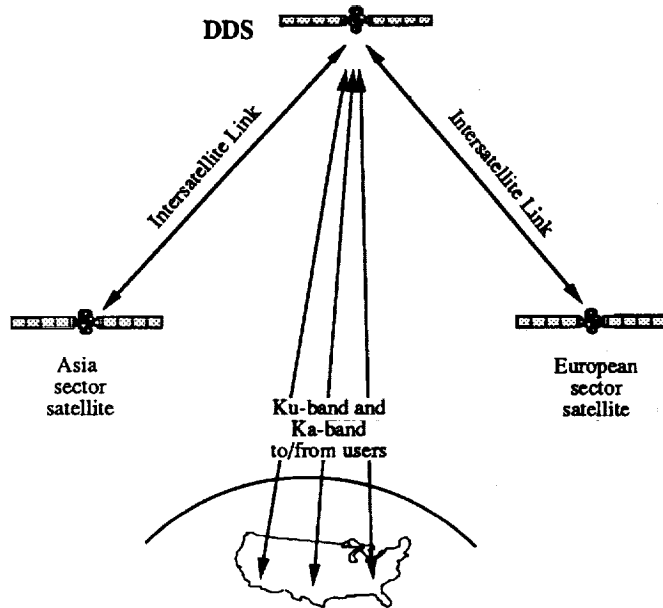
Each NASA center with fiber optic local area network connection to earth terminal:

Ku-band: 5 m

Ka-band: 4 m, plus site diversity terminal

Note: Alternate plan at Ka-band for limited area CONUS coverage using up to 16 0.5° spot beams (not shown).

Figure 5-30: Other Services Link Scenario 3.3B - Downlinks for Project Management



**Communications Functions:**

Provides for international exchange of science data. Collects and distributes data to the Americas and exchanges data with the Asian and European/Africa sector satellites.

**Satellite Implementation:**

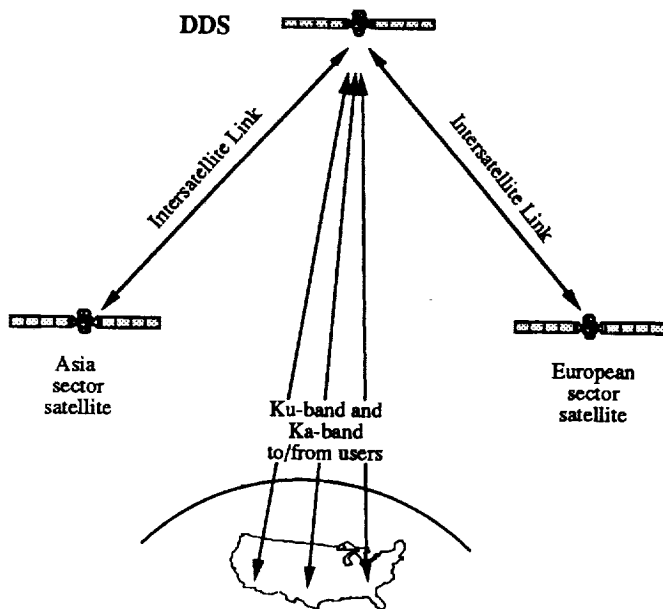
Antenna: 0.9°/0.5° downlinks at Ku/Ka-bands  
 1.7° uplink beams at Ku & Ka-bands  
 Crosslinks - optical (60 GHz optional)

Access/modulation: single channel per carrier and TDM.

**Earth Terminal Configuration:**

Ku-band: 3 m to 5 m  
 Ka-band: 3 m to 4 m

Figure 5-31: Other Services Link Scenario 3.4 - International Science Data Network



**Communications Functions:**

Provides regional coverage of Americas for communications in support of a global environment monitoring system. Also interconnects to satellites serving the Asian and European/Africa sectors.

**Satellite Implementation:**

Antenna: 0.9°/0.5° downlinks at Ku/Ka-bands  
 1.7° uplink beams at Ku & Ka-bands  
 Crosslinks - optical (60 GHz optional)

Access/modulation: single channel per carrier and TDM.

**Earth Terminal Configuration:**

Ku-band: 3 m to 5 m  
 Ka-band: 3 m to 4 m

Figure 5-32: Other Services Link Scenario 3.5 - Global Environment Network

## 5.3 Composite Data Requirements for Candidate Link Scenarios

### 5.3.1 Early Time Period Implementation (Year 2000)

The overall general communications requirements for the DDS system have been described in Chapter 3. The specific application of these requirements to candidate DDS link scenarios have been described in Section 5.2.

The resultant composite data requirements to be accommodated by DDS in the year 2007 time period are summarized in Table 5-2. This table shows a total uplink requirement from earth to a DDS satellite of 7.05 Gb/s, of which 2.60 Gb/s is at Ku-band and 4.45 Gb/s is at Ka-band. An additional 2.56 Gb/s may be received at DDS via intersatellite crosslinks.

Table 5-2 shows a total downlink requirement from a DDS satellite to earth terminals of 7.3 Gb/s, of which 2.8 Gb/s is at Ku-band and 4.5 Gb/s is at Ka-band. An additional 1.7 Gb/s may be transmitted from DDS to other spacecraft via intersatellite crosslinks.

The uplink and downlink data rates are not exactly matched because of on-board data processing, compression, and replication of data sets multiple destinations.

### 5.3.2 Future Implementation (Years 2015-2025)

The estimates for second and third generation DDS requirements become very speculative due to the great uncertainty associated with forecasts 25 to 35 years in the future.

It is estimated that the data rates associated with the initial DDS system of year 2007 could be increased by a factor of two with a moderate increase in spacecraft mass. The spectrum utilization may become the limiting factor in determining data capacity per unit spacecraft.

If much greater capacity is required, a multiple number of DDS satellites could be placed on orbit with a separation of several degrees of arc in order to reuse the frequency spectrum.

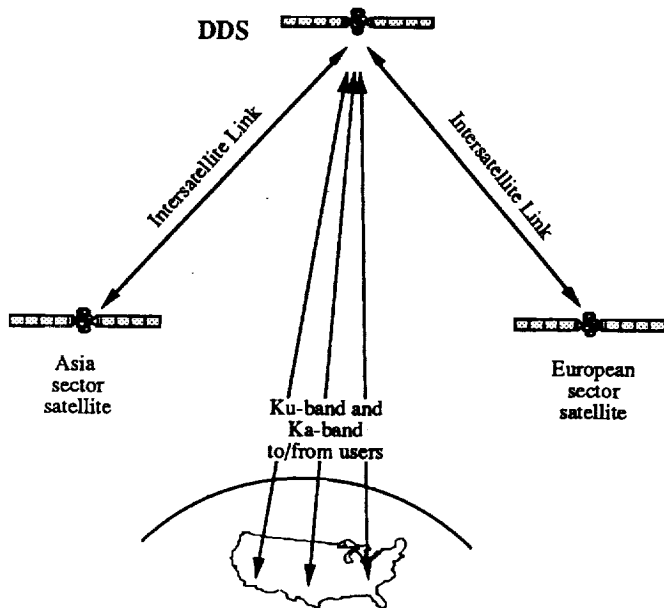
The entire concept of ATDRS may also change considerably. For example the coverage of low earth orbit spacecraft may be accomplished by three sets of ATDRS type spacecraft. The United States ATDRS could monitor the sector in proximity to the Americas, a European ATDRS could monitor the second sector, and the

Asian ATDRS could monitor the third sector. Information among sectors would be passed by intersatellite relay.

In this system concept, the United States ATDRS satellite could be positioned at the latitude of central CONUS rather than the current position at the horizon of White Sands. This position would then permit a good view angle to any earth terminal location within CONUS and thus the functions of ATDRS and DDS may be combined within a single satellite (or space platform).

Table 5-2: Composite Data Requirements - Year 2007

	Links to DDS			Links from DDS		
	Ku-band	Ka-band	X-link	Ku-band	Ka-band	X-link
<b>Telescience (Space Science) Experiments:</b>						
11. Commun. via Science Experimenters	100 Mb/s	100 Mb/s		500 Mb/s	500 Mb/s	
12. Access control		50 Mb/s			50 Mb/s	
13. Commun. via White Sands	500 Mb/s	500 Mb/s		300 Mb/s	350 Mb/s	
14. Commun. to/from Goddard (back up fiber net)	100 Mb/s			300 Mb/s		
15. Commun. via remote earth stations	300 Mb/s	300 Mb/s		100 Mb/s	100 Mb/s	
16. Relay from ATDRS/ASDACS			650 Mb/s			200 Mb/s
<b>Peer (Science Data) Networking:</b>						
21. Commun. to/from small users	100 Mb/s	200 Mb/s		500 Mb/s	1 Gb/s	
22. Commun. to/from Science Data Centers	500 Mb/s	1 Gb/s		100 Mb/s	200 Mb/s	
23. Access control		50 Mb/s			50 Mb/s	
<b>Other Networking:</b>						
31. NASA Centers interface	200 Mb/s	200 Mb/s		200 Mb/s	200 Mb/s	
32. Wideband supercomputer network	500 Mb/s	1 Gb/s		500 Mb/s	1 Gb/s	
33. Transfer of science project engineering data		200 Mb/s			200 Mb/s	
34. International science comm. networks			500 Mb/s			500 Mb/s
35. Global environment	50 Mb/s	100 Mb/s		50 Mb/s	100 Mb/s	
36. Support of industrial use of space (optional)	<u>250 Mb/s</u>	<u>750 Mb/s</u>	<u>1.00 Gb/s</u>	<u>250 Mb/s</u>	<u>750 Mb/s</u>	<u>1.00 Gb/s</u>
	2.60 Gb/s	4.45 Gb/s	2.15 Gb/s	2.80 Gb/s	4.50 Gb/s	1.70 Gb/s



**Communications Functions:**

Provides for communications links between CONUS terrestrial facilities and industry research and manufacturing projects in space.

**Satellite Implementation:**

Antenna: 0.9°/0.5° downlinks at Ku/Ka-bands  
 1.7° uplink beams at Ku & Ka-bands  
 Crosslinks - optical (60 GHz optional)

Access/modulation: single channel per carrier and TDM.

**Earth Terminal Configuration:**

Ku-band: 3 m to 5 m  
 Ka-band: 3 m to 4 m

Figure 5-33: Other Services Link Scenario 3.6 - Industrial Use of Space

## Chapter 6

# ATDRSS Interfaces

The first two sections of this chapter give overviews of the ATDRS and the Data Interface Facility (DIF) that serves as the space-ground gateway. The third section describes four future service growth (FSG) payloads for ATDRS – a direct-to-user downlink at Ka-band and three crosslinks at different frequencies between ATDRS and DDS. The fourth section describes possible evolutionary paths for the ATDRS follow-on, known as the Advanced Space Data Acquisition and Communications System (ASDACS).

This chapter sections are as follows:

- 6.1 ATDRSS Overview
- 6.2 Data Interface Facility Overview
- 6.3 FSG Payloads for Year 2007
- 6.4 ASDACS Evolution for 2015–2025

### 6.1 ATDRSS Overview

An overview of the Advanced Tracking and Data Relay Satellite System (ATDRSS) together with a glossary of acronyms is given in Appendix A of this report. This appendix is based on NASA Document 500-1, *Phase B ATDRSS Service Requirements Specification*, and describes:

1. Scope: provides ATDRSS service requirements.
2. Objectives: continuation of TDRSS with minimum impact for 1997 – 2012.
3. Architecture: see Figure A-1 in Appendix A.
4. End-to-End Architecture Overview: describes ATDRSS Space Network elements (such as ATDRS, user space terminals, Network Control Center, and Space Network User Project Control Center Interface) and other service supporting elements (such

as NASCOM and the Data Interface Facility). See Figure 6-1.

5. ATDRSS Space Network Operations Concept: for service planning, scheduling, provision, assurance, and accounting.

Appendix A, ¶A.4, describes the elements of Figures 6-1 (same as Figures A-2), and ¶A.7.2 gives a glossary of acronyms.

### 6.2 Data Interface Facility Overview

#### 6.2.1 General Information

The NASA telecommunications complex at White Sands, New Mexico, serves as the space-ground gateway between the network of space elements and the ground data distribution system. The Data Interface Facility (DIF) serves as the gateway for data that is formatted in accordance with the Consultive Committee for Space Data Systems (CCSDS) recommendations. This format is known as the enhanced standard format (ESF).

A far-term (2015) DDS payload on ATDRS or DDS that received data from ATDRS would bypass the DIF and directly communicate with users. In this case, the DDS system would need to perform the DIF functions described below. However, a near-term (2007) DDS could receive data from ATDRSS via the DIF and then relay the data directly to users. In this case, the DDS would need a ground interface to the DIF which would be designated a First Level Source and Destination.

The material in this subsection is based on NASA Document 541-072, *NASA Data Interface Facility Preliminary Requirements Definition*.

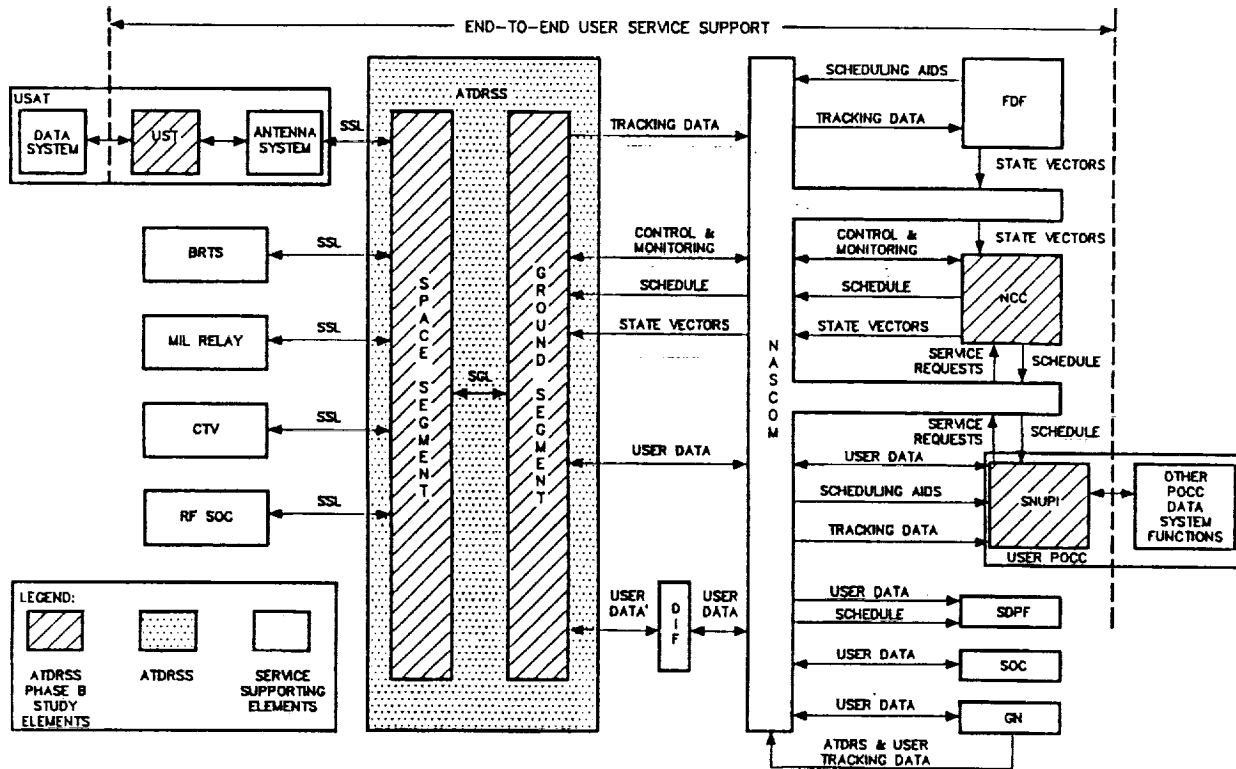


Figure 6-1: End-to-End Data Architecture of ATDRS System

### 6.2.2 DIF Interfaces

The DIF will perform the return distribution and forward multiplexing functions for the ESF data exchanged between space and ground elements via ATDRSS. Figure 6-2 shows the end-to-end interfaces for the DIF.

Currently, users of TDRS transmit and receive data in several different non-compatible formats. During the Space Station era, selected data systems on space elements will be standardized to the CCSDS ESF as the standard format.

The White Sands Ground Terminal (WSGT) – NASA Ground Terminal (NGT) and the Second TDRSS Ground Terminal (STGT) – Data Interface System (DIS) will be the centralized multiplexing and demultiplexing facilities for the TDRSS space-to-ground link (SGL). The DIS and NGT will interface with the DIF for forward and return ESF data.

The DIF will interface to first level sources (FLSs) – first level destinations (FLDs) for forward link reception and return link distribution of ESF data for ground-to-ground links. All data transmissions between the DIF and FLS/FLDs will be in accordance with the CCSDS

ESF standard.

The DIF also has an electronic interface with the Network Control Center (NCC) which provides scheduling for the TDRSS services.

Nascom will provide the ground communications interface between the DIF and FLSs and FLDs, and will support the forward and return link transmissions of ESF data.

### 6.2.3 DIF Functions

#### Forward Link Data

For forward link data (data flow from ground user to space instrument via TDRS), the DIF will accept data in the form of virtual channel data units (VCDU) from various FLS via Nascom interfaces. The VCDUs will be multiplexed together and forwarded via the appropriate TDRSS port to the supported space element.

To accomplish the forward link service, the DIF will provide:

- Processing including VCDU header decoding, VCDU analysis, and VCDU routing;

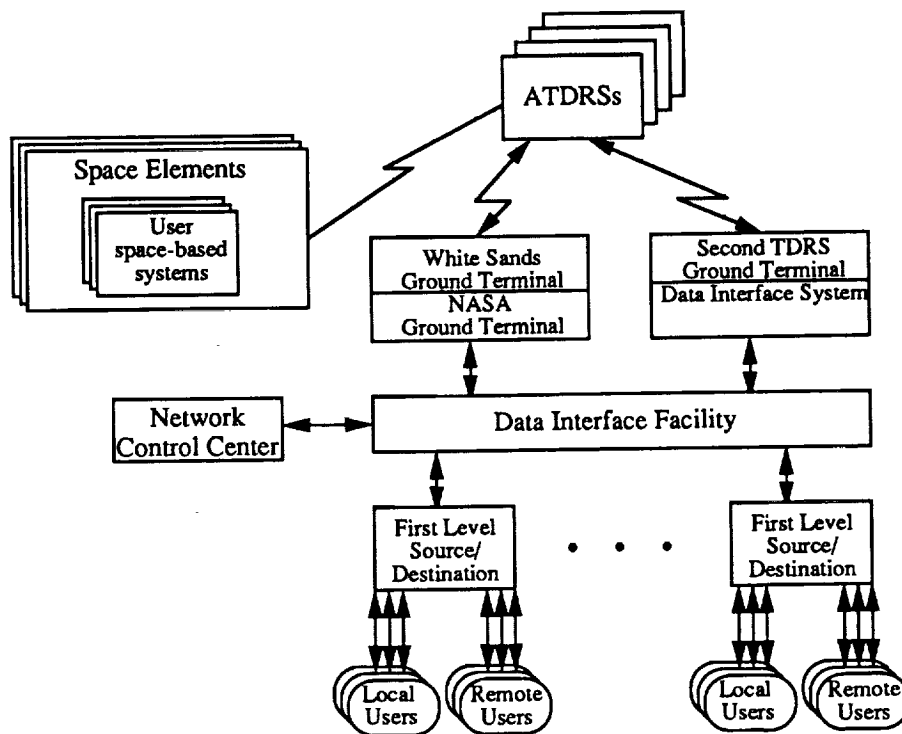


Figure 6-2: End-to-End Data Interface Facility (DIF) Interfaces

- Validation and access control;
- Composite link assembly;
- Data quality monitoring;
- Error correction;
- Retransmission handling;
- Priority determination and handling; and
- Forward link working storage and retransmission buffering.
- VCDU header decoding;
- Removal of null VCDU frames;
- VCDU analysis;
- VCDU routing;
- Priority determination and handling;
- Data quality monitoring;
- Error correction;
- Retransmission handling;
- Return link storage for working storage, retransmission buffering, line outage protection, and system outage protection.

### Return Link Data

For return link data (data flow for space instrument to ground user via TDRS), the DIF will receive data streams containing ESF data in the form of VCDUs via the TDRSS. The DIF will separate the data by virtual channels (VCs) and route that data to the appropriate FLD via Nascom interfaces.

To accomplish the return link service, the DIF will provide:

- Composite link disassembly;

### Management and Control

The DIF management and control will provide the management and control functions necessary for the DIF forward and return link transmission paths. The DIF will provide system control, system monitoring, fault isolation, status and summary reports, and all data base parameters.

An interface with the Network Control Center (NCC) element of the Space Network will support the coordination of NGT/DIS return and forward interfaces to the DIF.

The DIF will provide security measures to protect the system, software, and data from unauthorized access. Both computer security and communications security precautions will be taken. Although the DIF has access to all required VCDU overhead information, it may be that the actual user data is encrypted. If so, any required Reed-Solomon code will be based on the encrypted data.

### 6.3 FSG Payloads for Year 2007

This section discusses four future service growth (FSG) payloads for ATDRS.

#### 6.3.1 Direct-to-User Ka-band Downlink

#### 6.3.2 Ka-band Crosslink (ATDRS-DDS)

#### 6.3.3 60 GHz Crosslink (ATDRS-DDS)

#### 6.3.4 Optical Crosslink (ATDRS-DDS)

There is an ATDRS FSG reserve for additional payloads of 109 kg mass, 260 W power, 260 W thermal dissipation, and 0.31 m<sup>3</sup> volume.

### 6.3.1 Ka-Band Direct Downlink

#### 6.3.1.1 Background

Figure 6-3 shows the concept for a steerable direct downlink package on ATDRS. Wideband data could be distributed from ATDRS direct to any user ground location within the view of ATDRS.

The ATDRSS Phase A study identified the ATDRS hardware required for direct Ka-band downlinking at 21 GHz of the 650 Mb/s Ka-band single access (SA) signal. Weight and power for the hardware were estimated but no specific cost estimates were generated. Costs were identified, however, for the baseline ATDRS design. These baseline costs are for equipment similar to that required for the direct Ka-band downlink package and form the basis of the cost estimates.

This analysis also gives equipment and costs to allow any of the return service signals to be directly downlinked (at Ka-band) to a User.

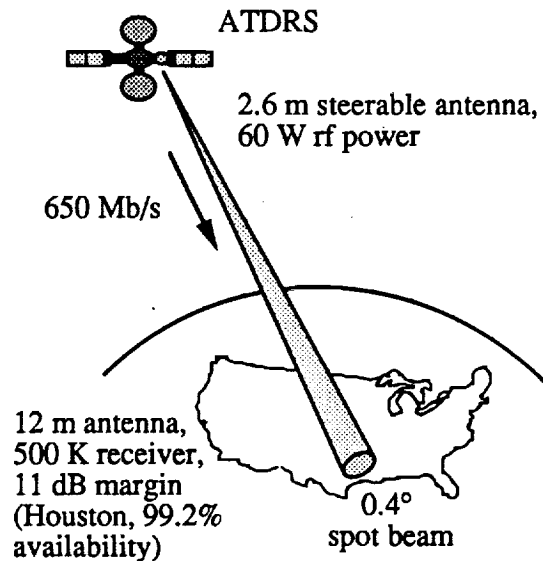


Figure 6-3: Steerable Direct Downlink Concept

#### 6.3.1.2 ATDRS Transmit Power Requirements

The Space-Ground Link (SGL) downlink budget reported in the ATDRSS Phase A Final Report shows an ATDRS Ka-band transmitter of 60 W for communicating to Houston TX from the ATDRS at 41° W longitude with 0.3% downlink outage due to weather (the approximate ATDRSS requirement).

All transmitter powers given in this section provide no margin on the ATDRS-to-ground link. Furthermore, the User satellite transmitter power is specified by NASA and cannot be increased.

A more detailed analysis shows that a 400 W transmitter is required to meet the ATDRS availability requirements at CONUS locations other than White Sands. The increase above 60 W stems from three primary contributions. The Phase A study (1) did not allow for the effect of the space-to-space (SSL) link on total  $C/N_0$ , (2) used the symbol rate in computing available  $E_b/N_0$  rather than data rate (a difference of 3 dB for QPSK systems), and (3) made no allowance for ATDRS SGL antenna pointing loss.

Nevertheless, the weight, power, and cost figures that follow assume a 60 W transmitter, for the obvious reason that the 400 W transmitter is not practical. Also, a 60 W TWT is available (AEG TL20060, 35.5% efficiency). Figure 6-4 shows that with a 60 W transmitter, the downlink outage at Houston due to weather increases to only 0.8%.



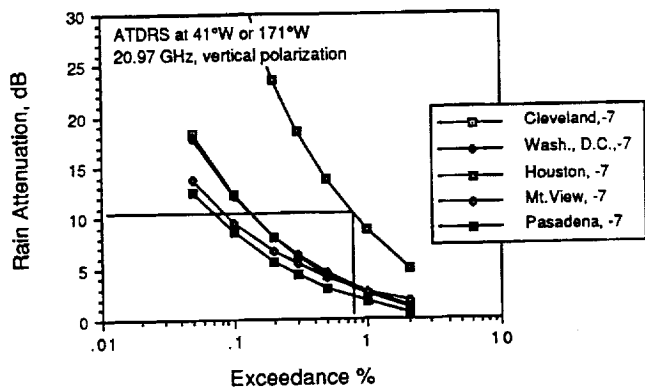


Figure 6-4: Rain Attenuation versus Exceedance for Five Cities - Houston Case

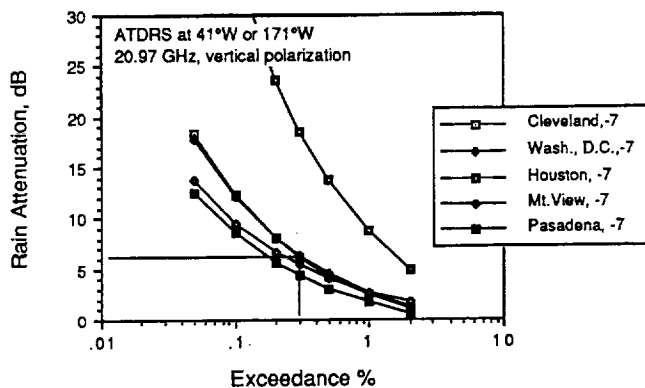


Figure 6-5: Rain Attenuation versus Exceedance for Five Cities - Cleveland Case

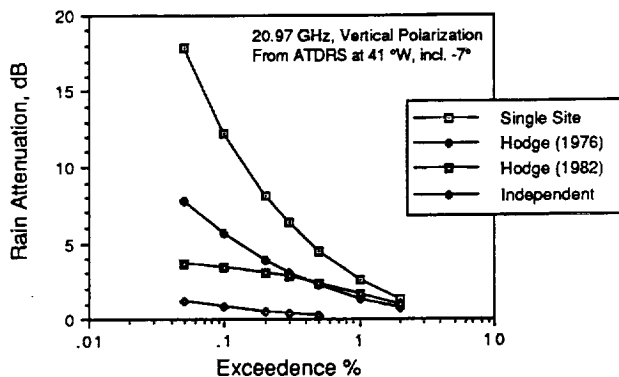


Figure 6-6: Rain Attenuation vs. Exceedance for Washington DC - Single-Site and Three Dual-Site Diversity Configurations

The 60 W transmit power may not really be needed for a direct downlink experiment.

- i. Figure 6-5 shows that weather related outage at Cleveland would be less than 0.3% with only a 20 W transmitter.
- ii. For an experiment, it may not be necessary to transmit a full 650 Mb/s. Reducing this to 300 Mb/s would reduce the above transmitter power by a factor of 0.45. Further reductions in data rate might be appropriate.
- iii. The NASA receive-only terminals at the various NASA centers may be used to provide "diversity" reception. For example, assuming that the event that rain occurs at Washington DC is independent of the event that rain occurs at Cleveland, a downlink outage (due to weather) of less than 0.3% might be achieved with only 0.5 dB of margin at both terminals (see Figure 6-6<sup>1</sup>). The corresponding ATDRS transmitter power is less than 5 W.
- iv. The rain margins used to size above transmitters are worst case (-7° inclination of ATDRS). Averaging over full figure eight of orbit reduces margin.

If the DDS satellite were located at 96° W longitude, a 0.3% outage could be achieved at Houston with a 30 W transmitter (see Figures 6-8 and 6-9.)

### 6.3.1.3 Estimates for KaSAR Service Only

Weight, power, and cost estimates are made for direct downlinking of only the Ka-band Single Access Receive (KaSAR) service (i.e., not the Ku-band or S-band services). Figure 6-7 shows a block diagram of the current strawman ATDRS payload. Modifications to this payload to provide a direct downlink capability at Ka-band for the KaSAR signal will depend on whether the direct downlink is independent of or in lieu of the normal KaSAR SGL downlink to the White Sands Complex (WSC).

If the two downlinks are not simultaneously in use, the ATDRS SGL transmitter for the KaSAR signal need

<sup>1</sup>The four curves of Figure 6-6 show rain-induced attenuation for a single site and for three models of dual-site diversity. Two of the models are due, in large measure, to Hodge and are contained in the NASA *Propagation Effects Handbook for Satellite Systems Design*, 1983. The third dual-diversity model assumes totally independent rain events at the two terminals, such as would be the case with one terminal at Cleveland and the diversity terminal at Washington.

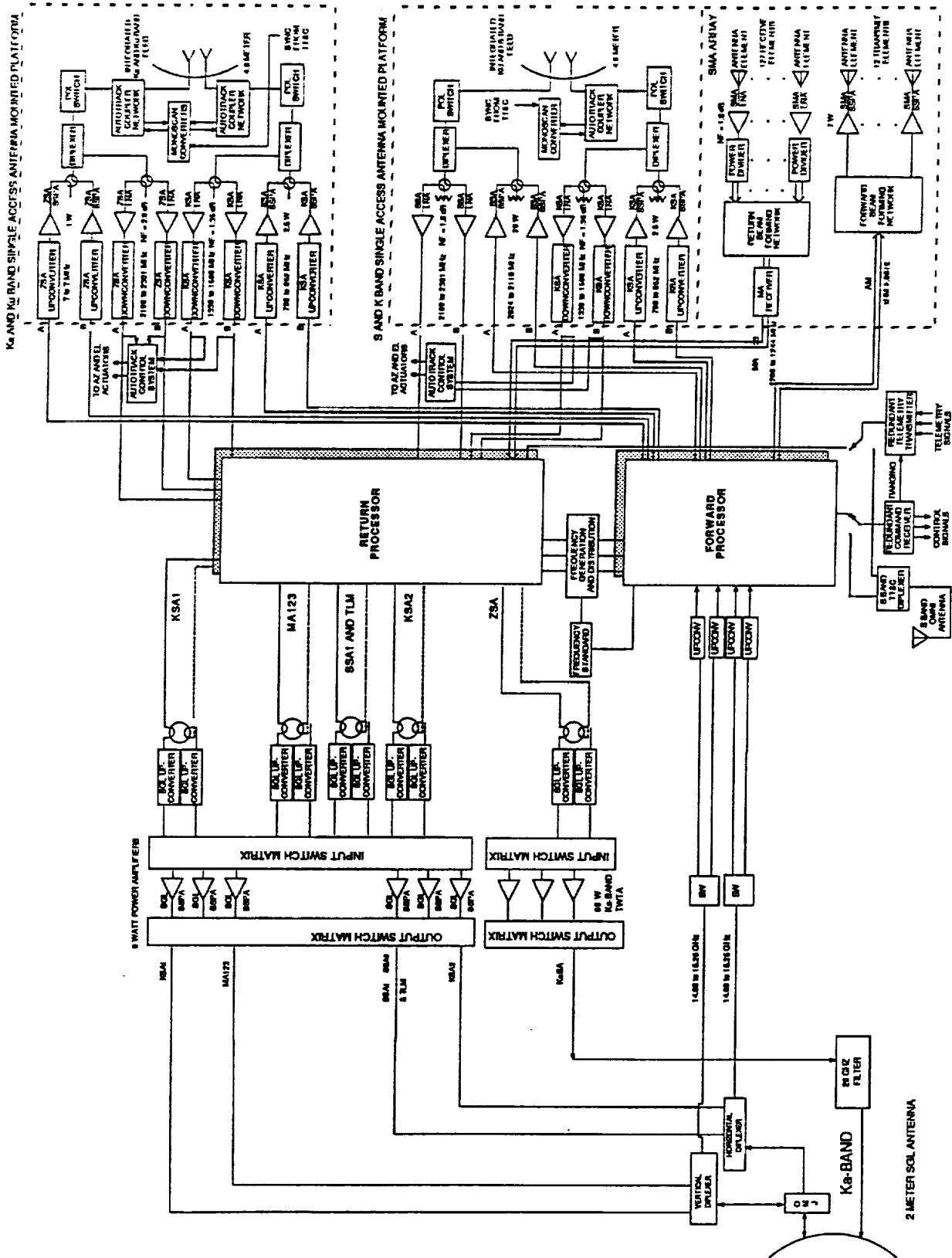


Figure 6-7: ATRSS Communications Payload Block Diagram

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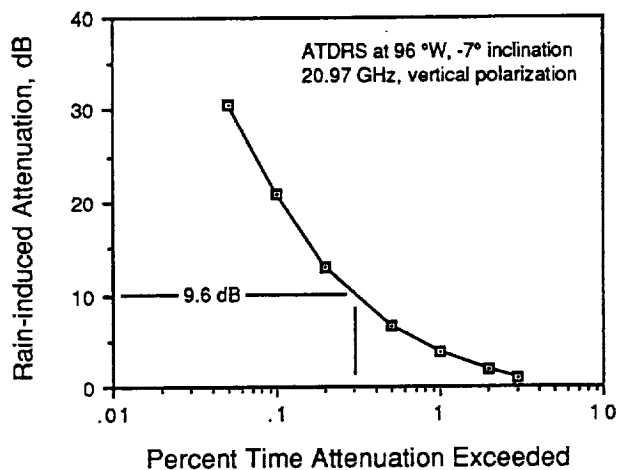


Figure 6-8: SGL Rain Attenuation vs. Exceedance for Houston (ATDRS at 96° W)

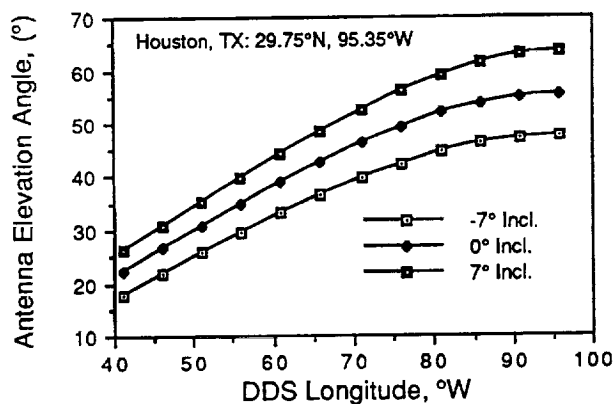


Figure 6-9: Houston Antenna Elevation Angle vs. ATDRS Longitude and Inclination

not be duplicated in the direct downlink package. Designs for both capabilities are discussed. The term "exclusive mode" designates the modification that allows only one link to operate at a time. The term "simultaneous mode" designates the modification that allows both links to operate simultaneously.

**Exclusive Mode** allows exclusive direct distribution for a Ka-band, single access link (up to 650 Mb/s). Note that this is in place of the signal transmission to White Sands. Modifications for an exclusive direct downlink mode are as follows.

- i. The existing 3x1 Ka-band output switch will be modified slightly to become a 3x2 switch.
- ii. The new (second) output will feed the Ka-band signal to a new 20 GHz filter and direct distribution antenna.

Although the output switch may be operated such that both outputs are active at the same time, it will not be operated in this manner. Only one output will be powered at any one time. Table 6-1 summarizes the hardware changes and additions with their weights, powers, and costs.

**Simultaneous Mode** allows simultaneous transmission to White Sands and direct downlink to user. Modifications for a simultaneous direct downlink (DD) mode are as follows.

- i. The 1x3 Ka-band input switch will be modified slightly to become a 1x4 switch.
- ii. One more transmitter will be added to achieve 4 for 2 redundancy (rather than 3 for 1). If more reliability is required, a second transmitter would be added with corresponding changes in the input and output switches to accommodate five rather than four TWTA's.
- iii. The 3x1 Ka-band output switch will be modified slightly to become a 4x2 switch. In this case, it will be operated such that both outputs are powered at the same time. The new (second) output will feed the Ka-band signal to a new 20-GHz filter and direct distribution antenna.

Table 6-1 summarizes the hardware changes and additions with their weights, powers, and costs.

Table 6-1: Hardware Weight, Power, and Cost for Three Modes of Direct Downlink†

Hardware Item	Code‡	Mode*	No. per ATDRS	Mass (kg)	Power (W)	Unit Cost (\$000)	
						Non-rec.	Recur.
<b>Antenna Assembly:</b>							
2.6 m reflector (includes backup and deployment structures)	Add	all	1	18.2	-	2,000	1,000
2-axis gimbal and rotary joint	Add	all	1	11.8	1	-	140
Feed assembly	Add	all	1	1.4	-	above	above
Bandpass filter	Add	all	1	0.2	-	above	above
<b>Transmitter Assembly:</b>							
1x3 and 3x2 switch matrices	Mod	E	1	$\Delta = .2$	-	5	2
1x4 and 4x2 switch matrices	Mod	S	1	$\Delta = .5$	-	15	4
5x4 and 4x2 switch matrices	Mod	Any	1	$\Delta = 1.4$	-	25	10
60 W transmitter (including waveguide, ALC, PDA, etc.)	Add	Any, S	1	4.6	200	-	300
Hybrid and Upconverter (includes LO chain, coax, and waveguide)	Add	Any	4	1.4	6	75	50

† Includes unit assembly, test, and documentation costs (increases over amounts required by basic ATDRS)

‡ "Add" means additional hardware; "Mod" means modify hardware.

\* Modes are E=exclusive, S=simultaneous, Any=any return service

### 6.3.1.4 Estimates for Any Return Service

Weight, power, and cost are estimated for the case that allows any return service signal, one at a time, to be directly downlinked to a user (in addition to being transmitted to White Sands). This makes the ATDRS modifications and additions package considerably more complex than for the single KaSAR case. A block diagram for this case is shown in Figure 6-10.

The Ku-band signals (KSA1, MA123, SSA12, and KSA2) on the lines out of the Return Processor are split with hybrids. One output from each hybrid is connected as before to the Ku-band upconverters. The other output is upconverted to a Ka-band frequency (the same for all outputs) and connected to an enlarged input switch matrix (the 1x3 matrix is modified to become a 5x4 matrix).

A fourth transmitter is added for improved reliability now that two transmitters will be powered at all times. The output switch matrix is enlarged to become a 4x2 matrix. The direct downlink antenna and RF filter are common to all three modes of operation (i.e., exclusive, simultaneous, and any modes). Note that the "any" mode allows any return service signal to be direct down-

linked, one at a time. Table 6-1 summarizes the hardware changes and additions with their weights, powers, and costs.

Other designs for the "any" mode package are possible. A trade study would be needed to determine the one most suited to the final set of requirements.

### 6.3.1.5 Cost Estimates

Equipment costs are presented in Table 6-1. They include assembly and test at the box level. They do not include integration, alignment, and test at the spacecraft level. The cost of these latter activities has been estimated in Table 6-2. A burdened average hourly labor rate of \$70 is assumed.

The costs of Table 6-2, when allocated to the direct downlink package modes, yield total spacecraft-level assembly, integration, and test costs as shown in Table 6-3 for non-recurring and recurring cost categories. The cost figures for the "any mode" option are obtained as follows:

Nonrecur. =  $14.0 + 2.1 + 1.7 (24/50 \text{ hr}) + 2.1 = \$19,900$

Recurring =  $14.7 + 3.5 + 1.8 (26/50 \text{ hr}) + 7.9 = \$27,900$

These costs do not include costs for redesign of the

Table 6-2: Direct Downlink Integration and Test Cost Estimates

Item	Hours	Cost
<b>Antenna and RF filter:</b>		
Mounting and integration of DD antenna	20	
Alignment of DD antenna	80	
Mech. & elect. integration of RF filter	10	
Test of the antenna & DD channel	100	
Non-rec. procedures and software prep. (including shop orders, etc.)	200	
Total non-recurring	200	\$14,000
Total recurring	210	\$14,700
<b>Additional transmitter:</b>		
Mounting and electrical integration	20	
Test (pre and post integration)	30	
Non-recur. procedures and software prep.	30	
Total non-recurring	30	\$ 2,100
Total recurring	50	\$ 3,500
<b>Switch matrices:</b> (Additional cost over and above that associated with 1x3 and 3x1 matrices)		
1x3 and 3x2 matrices, testing	20	
1x4 and 4x2 matrices, testing	20	
5x4 and 4x2 matrices, including non-recurring procedures and software preparation	50	
<b>Hybrid and Upconverter:</b>		
Mounting and electrical int. (10 hr/pair)	40	
Test (in addition to above channel tests) (8 hr/test for each extra channel)	32	
Trouble shooting	40	
Non-recur. procedures and software prep.	30	
Total non-recurring	30	\$ 2,100
Total recurring	112	\$ 7,840

Table 6-3: Direct Downlink Integration and Test Cost Totals by Mode

Mode	Cost (\$)	
	Non-Rec.	Recur.
Exclusive	\$14,000	\$16,100
Simultaneous	\$16,100	\$19,600
Any	\$19,900	\$27,900

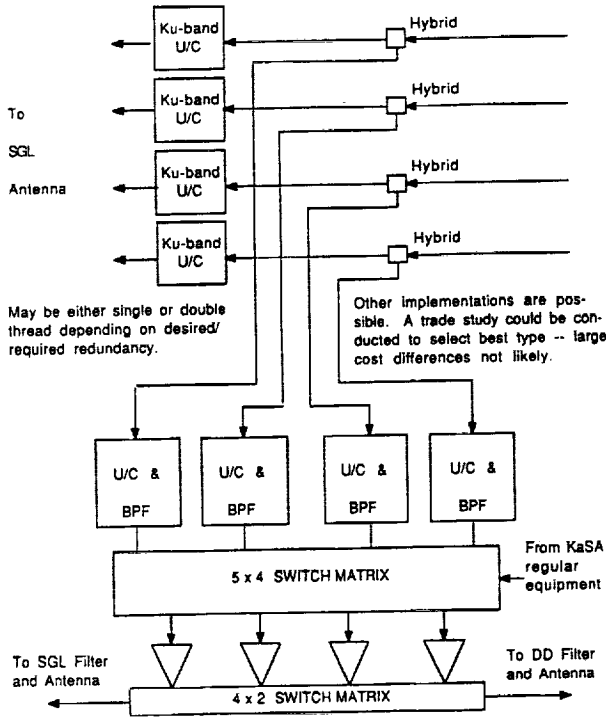


Figure 6-10: Direct Downlink Hardware for "Any Service" Mode

bus. That is, it is assumed that the eventual inclusion of the direct downlink package on the spacecraft is known far enough in advance that the bus can be structurally adequate to carry the added weight and power and to support the direct downlink antenna and deployment mechanism in the desired location.

It is further assumed that the spacecraft on which the direct downlink package will fly is manufactured from the beginning to the new payload requirements; i.e., a previously built spacecraft will not be retrofitted with the direct downlink package. This would require much more effort.

6.3.1.6 Total Weight, Power, and Cost Estimates

From the above costs for labor and hardware, the total additional cost of each data distribution mode is given in Table 6-4.

6.3.2 Ka-Band Crosslink System

The Ka-band crosslink system consists of a gimbaled 1.8 m Cassegrain antenna, an antenna pointing system that incorporates acquisition and autotracking func-

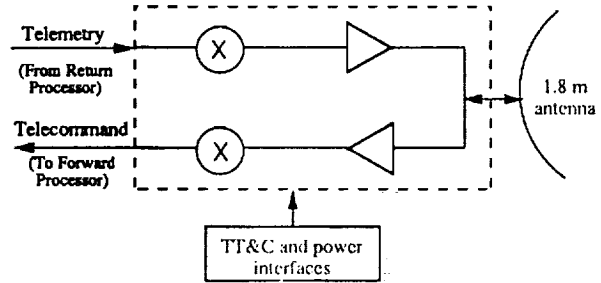


Figure 6-11: RF Crosslink System Schematic

tions, and the necessary electronics for interfacing to the ATDRS. Figure 6-11 gives a functional block diagram of the crosslink module and shows its relationship to the ATDRS payload. The telemetry channel carries the space-originated data which is returning to the earth-based user, and the telecommand channel carries data going from earth to space-based instruments.

The following paragraphs describe the:

1. Block diagram of system,
2. Acquisition and tracking system,
3. Link closure analysis,
4. Mass and power estimates.

The description is given from the standpoint of a FSG payload for ATDRS. A similar crosslink payload would reside on the DDS to receive the ATDRS crosslink transmission. However, the data rate from DDS to ATDRS (forward link) would be much less (160 Mb/s).

6.3.2.1 Block Diagram of Ka-band Crosslink

Figure 6-12 gives the block diagram of the Ka-band crosslink transponder which is a bent pipe transponder. The telemetry signals from the Return Processor are up-converted, multiplexed, and amplified via a 20 W SSPA for transmission across the crosslink. The telecommand signals are received by the crosslink antenna, amplified through an LNA, demultiplexed, and downconverted to the appropriate frequencies for interfacing with the Forward Processor. Use of an ortho-mode junction (OMJ) plus switch allows a choice to be made for crosslink transmit-receive polarization; i. e. RCP transmit and LCP receive or visa versa. The Antenna Pointing System which controls the acquisition and tracking is described in the next subsection.

Table 6-4: Summary of Impact of Direct Downlink Payload on ATDRS (single satellite)

Payload Mode	Weight (kg)	Power (W)	Costs (\$M)		
			Non-Recur.	Recurring	Total
Exclusive mode	31.8	9	2.02	1.16	3.18
Simultaneous mode	36.8	209	2.03	1.46	3.49
Any mode	43.2	233	2.25	1.68	3.93
FSG Reserve	109	260	-	-	-

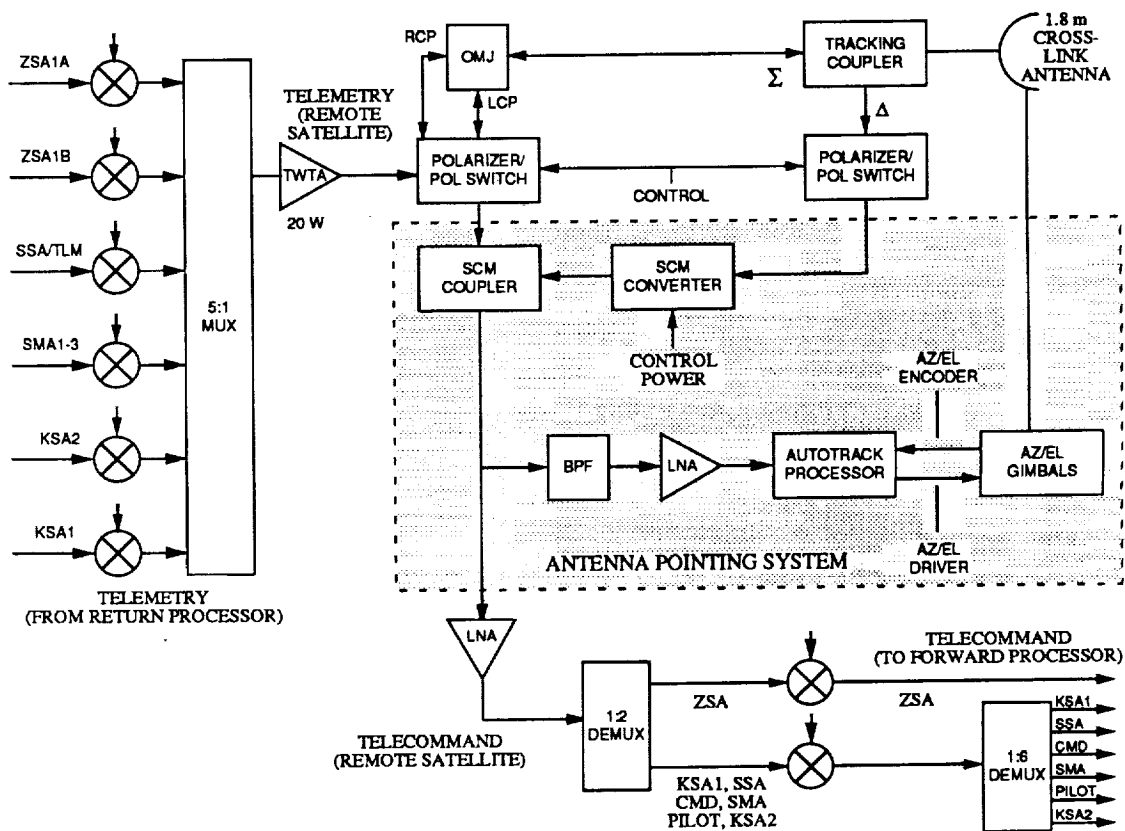


Figure 6-12: Block Diagram of Ka-Band Crosslink System (FSG Payload)

Table 6-5: Link Analysis – Ka-Band Crosslink from ATDRS to DDS

Parameter	Value	Units	Comments
Frequency	25.4	GHz	
Transmit power	13.06	dBW	20.23 W amplifier
Amplifier backoff	.00	dB	Single carrier
Transmit antenna gain	51.74	dBi	1.8 m antenna, 65% efficiency
Line & feed loss	2.00	dB	
EIRP	62.80	dBW	
Free space loss	212.59	dB	40,000 km range
Pointing loss	.10	dB	
Polarization loss	.10	dB	
Tracking loss	.10	dB	
Net path loss	212.89	dB	
Receive antenna gain	51.74	dBi	1.8 m antenna, 65% efficiency
Line & feed loss	2.00	dB	
System temperature	24.89	dB-K	309 K (20 antenna, 20 line, 289 K receiver)
G/T	24.85	dB-K	
Receive carrier level	-100.36	dBW	
Boltzmann constant	-228.60	dBW/Hz-K	
Receive C/N <sub>0</sub>	103.36	dB-Hz	
Data rate	90.00	dB-Hz	1 Gb/s data
Available E <sub>b</sub> /N <sub>0</sub>	13.36	dB	
Modem loss	3.00	dB	
Coding gain	5.70	dB	Rate 1/2, k=7 Viterbi
Required E <sub>b</sub> /N <sub>0</sub>	13.06	dB	QPSK, BER 10 <sup>-10</sup>
Margin	3.00	dB	

### 6.3.2.2 Acquisition and Tracking System

The crosslink system is capable of acquiring and tracking the target satellite via a pseudomonopulse auto-track processor, high power gimbal drive electronics, and azimuth-elevation gimbals with position encoders mounted on each gimbal to generate the actual antenna orientation.

A typical antenna pointing system performs a spiral or spatial search acquisition sequence in a cooperative mode with the target satellite, and then initiates an autotrack algorithm when the antenna is pointed to within a small degree off the target spacecraft. Since the Ka-band crosslink beamwidth of 0.4° is much greater than the pointing capability of the ATDRS crosslink antenna, an acquisition sequence is not required for the crosslink module. After slewing to the target satellite position, the autotracking algorithm is initiated and signal lock is achieved when the target spacecraft is on boresight.

A dedicated microprocessor is not required for the autotrack implementation; the spacecraft computer is intermittently used for these functions. The control loops

including corrections for spacecraft perturbations and orientation estimation errors also reside in the spacecraft computer.

### 6.3.2.3 Link Analysis of Ka-band Crosslink

The link closure analysis for a 1 Gb/s link from the ATDRS to DDS at Ka-band is given in Table 6-5. For the frequency of 25 GHz and range of 40,000 km, the required transmitter power for a 10<sup>-10</sup> bit error rate and 3 dB margin is 20 W with 1.8 m antennas. Space qualified, 3 dB noise figure LNAs are assumed to be available at Ka-band in the year 2000. Since a 1 Gb/s link is used, a bit error rate of 10<sup>-10</sup> is required. The rate 1/2 Viterbi coding requires a 2 GHz bandwidth on the demodulator, which in turn leads to 3 dB of modem implementation loss.

Given that 20 W transmit power is required to close the link and the single carrier operation, the recommended amplifier implementation is the TWTA due to its improved efficiency compared to the SSPA at Ka-band. The long history of flight proven Ka-band TWTA mitigates the reliability concerns. The emer-



Table 6-6: Mass and Power Estimates – Ka-Band Crosslink FSG Payload on ATDRS

Item	Qty. (ea.)	Unit Mass (kg)	Total Mass (kg)	DC Power (W)	Total Power (W)
<b>Antenna &amp; Controller</b>					
1.8 m dish, subreflector, struts	1	6.8	6.8		
Feed	1	0.7	0.7		
Tracking coupler	1	0.6	0.6		
Orthomode junction	1	0.2	0.2		
Polarization switch	2	0.2	0.4		
Polarizer	1	0.3	0.3		
Single channel monopulse converter	1	0.4	0.4		
Single channel monopulse coupler	2	0.1	0.2	1	1
Band pass filter	1	0.1	0.1		
Low noise amplifier	2	0.7	1.4	3	3
Tracking receiver & processor	2	1.8	3.6	8	8
Gimbal drive electronics	2	1.4	2.8	2	4
Gimbals	2	5.8	11.6	6	12
R switch	4	0.1	0.4		
<b>Transponder</b>					
Mixers	12	0.9	10.8	4	24
Low noise amplifier	2	0.7	1.4	3	3
TWTA (20 W, 45% eff.)	2	3.7	7.4	45	45
Multiplexer, 5:1	1	0.7	0.7		
Demultiplexer, 2:1	1	0.6	0.6		
R switch	20	0.1	2.0		
Coax and waveguide	1	1.6	1.6		
Totals			54.0		100
Hardening margin (5%)			2.7		-
Design margin (10%)			5.7		10
Grand Totals			62.4		110

gence of more efficient Ka-band SSPAs by the year 2000 may allow their implementation.

#### 6.3.2.4 Mass and Power of Ka-band Crosslink

Table 6-6 presents a summary of the mass and power characteristics of the Ka-band crosslink system. An efficiency of 45% is assumed for the Ka-band TWTA. All active components have a 2-for-1 redundancy.

The result is 62.4 kg mass and 110 W power for the Ka-band crosslink FSG payload on ATDRS. This compares with the allocated 109 kg mass and 260 W power in the FSG payload reserve on ATDRS.

#### 6.3.3 60 GHz Crosslink System

The primary difference between the Ka-band and 60 GHz crosslink systems is the use of a beam waveguide to transfer the 60 GHz energy across the antenna

axes. The significant loss associated with conventional waveguide at 60 GHz mandates a beam waveguide implementation. The reflector size is maintained at 1.8 m and the transmit power is reduced to 10 W (versus 20 W at Ka-band).

Otherwise the 60 GHz crosslink system is functionally identical to the Ka-band system, the only difference being the operating frequency. This higher frequency implementation requires a scaling of the tracking coupler and feed. The acquisition and tracking algorithms must also operate with different scale factors in the control laws to accommodate the narrower beamwidths associated with the higher frequency.

The following paragraphs describe the link analysis and the mass and power summary for the 60 GHz crosslink system for the ATDRS FSG payload.

Table 6-7: Link Analysis – 60 GHz Crosslink FSG Payload on ATRSS

Parameter	Value	Units	Comments
Frequency	60.0	GHz	
Transmit power	8.14	dBW	6.51 W amplifier
Amplifier backoff	.00	dB	Single carrier
Transmit antenna gain	59.21	dBi	1.8 m antenna, 65% efficiency
Line & feed loss	3.00	dB	
EIRP	64.34	dBW	
Free space loss	220.05	dB	40,000 km range
Pointing loss	.10	dB	
Polarization loss	.10	dB	
Tracking loss	.10	dB	
Net path loss	220.35	dB	
Receive antenna gain	59.21	dBi	1.8 m antenna, 65% efficiency
Line & feed loss	3.00	dB	
System temperature	25.44	dB-K	350 K (60 antenna, 60 line, 290 K receiver)
G/T	30.77	dB-K	
Receive carrier level	-98.63	dBW	
Boltzmann constant	-228.60	dBW/Hz-K	
Receive C/N <sub>0</sub>	103.36	dB-Hz	
Data rate	90.00	dB-Hz	1 Gb/s data
Available E <sub>b</sub> /N <sub>0</sub>	13.36	dB	
Modem loss	3.00	dB	
Coding gain	5.70	dB	Rate 1/2, k=7 Viterbi
Required E <sub>b</sub> /N <sub>0</sub>	13.06	dB	QPSK, BER 10 <sup>-10</sup>
Margin	3.00	dB	

### 6.3.3.1 Link Analysis of 60 GHz Crosslink

Table 6-7 gives the 60 GHz link analysis for an identical scenario as Ka-band. For 1 Gb/s link closure, 6.5 W of 60 GHz transmit power are required. The only differences between the two analyses are operating frequency, a higher line loss (3 dB), and a higher receiver noise figure (4 dB) due to the higher frequency.

Since there are 5 W space-qualified SSPAs currently under development, it is anticipated that 10 W SSPAs will be available at 60 GHz in the year 2000 time frame. The reliability of 60 GHz TWTAs over a 10 to 15 year lifetime continues to be significant issue. Within the time frame of this program, an SSPA implementation is recommended.

### 6.3.3.2 Mass and Power of 60 GHz Crosslink

Table 6-8 gives a summary of the mass and power characteristics of the Ka-band crosslink system. An efficiency of 27% is assumed for the 10 W SSPA. All active components have a 2-for-1 redundancy.

The result is 55.7 kg mass and 110 W power for the

60 GHz crosslink FSG payload on ATRSS. This compares with the allocated 109 kg mass and 260 W power in the FSG payload reserve on ATRSS.

## 6.3.4 Optical Crosslink System

### 6.3.4.1 Introduction

The potential advantages of an optical crosslink system (versus rf system) are as follows:

- Greater communication capacity (multi-Gb/s).
- Lower mass, volume, and power requirements reduce the impact on the host satellite.

The major factors mitigating these advantages are:

- Low optical transmit power available from space qualified laser diodes;
- Problem of acquiring and tracking the target satellite whose location uncertainty may be much greater than the optical beamwidth; and

Table 6-8: Mass and Power Estimates - 60 GHz Crosslink FSG Payload on ATDRS

Item	Qty. (ea.)	Unit Mass (kg)	Total Mass (kg)	DC Power (W)	Total Power (W)
<b>Antenna &amp; Controller</b>					
1.8 m dish, subrefl., struts	1	6.8	6.8		
Feed	1	0.5	0.5		
Tracking coupler	1	0.3	0.3		
Orthomode junction	1	0.2	0.2		
Polarization switch	2	0.2	0.4		
Polarizer	1	0.2	0.2		
SCM converter	1	0.2	0.2		
SCM coupler	2	0.1	0.2	1	1
Band pass filter	1	0.1	0.1		
Low noise amplifier	2	0.7	1.4	4	4
Tracking receiver, processor	2	1.8	3.6	8	8
Gimbal drive electronics	2	1.4	2.8	2	4
Gimbals	2	5.8	11.6	6	12
R switch	4	0.1	0.4		
<b>Transponder</b>					
Mixers	12	0.9	10.8	5	30
Low noise amplifier	2	0.7	1.4	4	4
SSPA (10 W, 27% eff.)	2	1.4	2.8	37	37
Multiplexer, 5:1	1	0.6	0.6		
Demultiplexer, 2:1	1	0.5	0.5		
R switch	20	0.1	2.0		
Coax and waveguide	1	1.4	1.4		
Totals			48.2		100
Hardening margin (5%)			2.4		
Design margin (10%)			5.1		10
Grand Totals			55.7		110

- Survivability of the various mirrors and alignment integrity of the bulk optics through the launch and orbital injection phases.

Significant advances have been made recently in developing high-power laser diode arrays and low-mass optical communication system concepts. MIT Lincoln Laboratories has demonstrated a flight qualified optical communication system [1,6] which was originally intended for the NASA/LeRC ACTS satellite. Although the optical communication packages on ACTS were dropped, Lincoln Laboratories has continued with its work and is developing improved designs.

The key to reducing mass and complexity of the laser crosslink package is the existence of higher power, coherent laser diode sources (arrays) with several watts of power and the resultant ability to use smaller, less costly telescope mirrors. Such space-qualified optical crosslink systems are perceived to be technologically

feasible within the next five to seven years for incorporation into ATDRS in 1998.

A block diagram of the proposed baseline system, based on anticipated 1995 technologies and derived primarily from MIT's work, is shown in Figure 6-13. This proposed system features are as follows:

- Duplex (polarization diversity) 1 Gb/s link
- 1 W laser diode array operating at 850 nm
- Non-coherent, heterodyne, 4-ary FSK, injection current modulation of the laser diode array. The system parameters are set to close a 40,000 km link with 3 dB margin and  $10^{-10}$  bit error rate. Rate 1/2, constraint length 7, Viterbi forward error correction is employed.
- Fiber optic coupling of the energy from the telescope to the electronics is used. Active track-

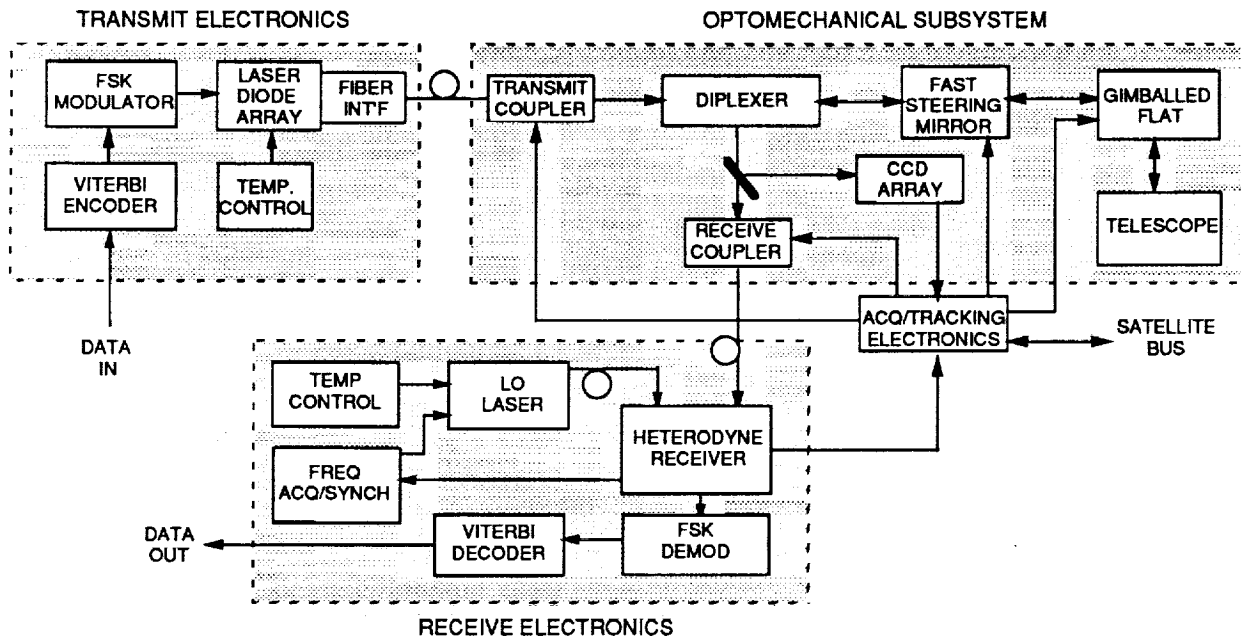


Figure 6-13: Block Diagram of Optical Crosslink System (FSG Payload)

ing off the main communication signal is achieved by nutating the fiber at the telescope, similar to monopulse radar applications. Fiber coupling eliminates the need for the heavier bulk optics with their concomitant alignment sensitivities and launch survivability issues

- High bandwidth steering mechanism for fine pointing control in the presence of nominal spacecraft vibration is used. A CCD array is used for acquisition of the target spacecraft.

The interface of the optical crosslink system to the ATRSS spacecraft is as shown in Figure 6-11 where telemetry information is transmitted through the telescope, and telecommand information is received through the telescope. There is also a TT&C and prime power interface.

#### 6.3.4.2 Subsystem Description

The following paragraphs briefly describe the proposed baseline crosslink system and the constituent optomechanical, receive, transmit, and control subsystems illustrated in Figure 6-13.

**Optomechanical Subsystem** consists of the telescope, diplexer, optics, fast steering mirror, and the fiber

couplers for the transmit and receive signals. The integration of fibers in the crosslink system minimizes the required bulk optics, and thereby significantly reduces the weight, complexity, alignment time, and optical contamination while improving launch survivability.

This technique also allows remote location of the transmit and receive electronics, thereby reducing the thermal and mechanical disturbances on a long bulk optical train between the electronics and the telescope. The free space to fiber connection is made via the transmit and receive couplers, the later of which is used to perform autotracking off the main received signal.

The basic approach in using the receive fiber coupler for closed loop autotracking is to nutate the fiber located in the focal plane of the optical system [2]. Figure 6-14 shows a schematic representation of this approach. If the received beam is on boresight, circularly scanning the fiber tip around the beam results in a constant power contour. Any deviation off boresight results in a periodic change in the received power as the fiber tip circularly scans the incoming beam. The angular error off boresight is proportional to the derivative of the free space to fiber coupling profile, and is extracted by synchronously detecting the IF power in the Acquisition and Tracking Electronics. The derived error signal is

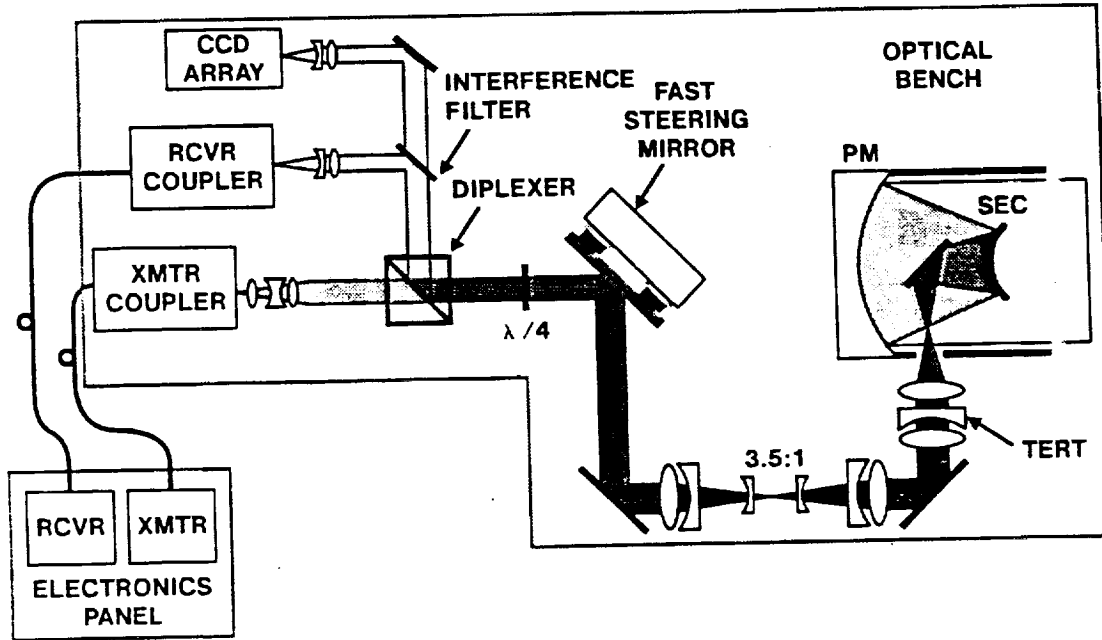


Figure 6-14: Crosslink System Features Fiber Optic Coupling Between Telescope and Electronics

used to drive the fast steering mirror back on to bore-sight.

A prototype system employing this technique is currently being demonstrated at the MIT Lincoln Laboratory [2]. It is anticipated that advances in this field will lead to a flight qualifiable version of this approach by 1998. A CCD array is used for initial acquisition of the target spacecraft and reducing the region of uncertainty prior to initiating the autotracking function.

The telescope, a relay group, and some mirrors are used to direct the beam between the aperture and a quarter wave plate (Figure 6-14). This plate converts the circularly polarized beam (and visa versa) to a linear one which is then separated between the transmit and receive beams. The fast steering mirror is used in spatially tracking the target satellite. Its bandwidth is sufficiently high (1 kHz) to maintain lock in the presence of spacecraft mechanical disturbances. Coarse pointing is achieved via a fixed telescope and a gimbaled flat. The high bandwidth (fine steering mirror) tracking loop is nested within the lower bandwidth (gimbaled flat) loop to prevent the fast steering mirror from saturating.

**Receive Electronics Subsystem** consists of a noncoherent heterodyne detection receiver where the received signal is mixed with a local oscillator. The primary advantages of heterodyne detection versus direct detection

are up to 10 dB better sensitivity and operation in the presence of strong background sun in field of view. Heterodyne detection is more complex than direct detection, as the frequency of the LO laser source must track the incoming frequency variations to provide a stable IF. A frequency acquisition – synchronization loop in conjunction with temperature compensation circuitry is required to fine tune the LO laser.

The heterodyne receiver also generates the off-axis error signal derived from the nutating fiber and drives the Acquisition and Tracking receiver in the autotracking mode. The recovered data signal is used to drive a 4-ary FSK demodulator and Viterbi decoder.

**Transmit Electronics Subsystem** generates the modulated optical beam and consists of the encoder and 4-ary FSK modulator which drives the temperature compensated laser diode array. The multiple beams emanating from the array elements are optical fed into a single fiber which connects to the transmit coupler. The laser diode array is current modulated to the four frequency tones, and the individual elements of the array are injection locked via a master-slave laser configuration.

**Acquisition and Tracking Electronics** utilize the off-axis error signal generated by the nutating receive

Table 6-9: Mass and Power Estimates – Optical Crosslink FSG Payload on ATRSS

Item	Mass (kg)	Power (W)
<b>Optomechanical Subsystem:</b>		
Telescope (22 cm)	3.0	
Gimballed flat/driver†	2.0	0
Fast steering mirror/driver†	1.0	2
R/X and T/X coupler/nutation driver	1.5	1
Diplexer	.5	
<b>Transmit Electronics Subsystem:</b>		
Laser diode array ( $\eta = 15\%$ )	.2	7
Modulator/driver	1.5	3
Viterbi encoder	.5	8
Temperature control	2.0	5
<b>Receive Electronics Subsystem:</b>		
Local oscillator laser/het. receiver	2.0	3
Viterbi decoder	.5	8
Temperature control	2.0	3
Acquisition/Tracking Electronics	.5	3
Subtotals	17.2	43
Hardening margin (5%)	.8	–
Design margin (10%)	1.8	4
Totals	19.8	47

† Intermittent duty cycle on steering mirrors.

coupler and the heterodyne receiver to generate the appropriate drive command to the fast steering mirror. This algorithm is essentially a monopulse type of function as used in radar where the amplitude difference is proportional to the off-axes error. Details of this algorithm are presented in [2]. It also drives the gimballed flat for coarse steering and point ahead functions. In the acquisition mode, it is driven by the CCD array to position the beam within a region where the autotracking function can be initiated.

#### 6.3.4.3 Link Analysis of Optical Crosslinks

Table 6-10 shows a sample link closure analysis for the baseline crosslink system. The analysis indicates that link closure is attained through 21 cm transmit and receive apertures with approximately 3 dB of system margin using a 1 W laser diode array at 850 nm over a range of 40,000 km. Note that the link analysis assumes the sun in the field of view (spectral radiance function of  $2000 \text{ W}/\mu\text{m cm}^2$  [3]) resulting in a much larger background power. The results show the advantages of

heterodyne detection, as indicated by the fact that the maximum (LO limited)  $\text{SNR}_0$  is approximately equal to the available  $\text{SNR}_0$ . The transmit and receive optical losses are based on the fiber optic coupler approach described in [2], scaled down by approximately 0.5 dB to account for the perceived advances in technology as well as space qualified designs.

#### 6.3.4.4 Mass and Power of Optical Crosslink

Table 6-9 gives a summary of the mass and power of the optical crosslink system. The total mass is 20 kg and the total power is 47 W. Note that the Viterbi encoder and decoder draw significant power. The current space qualified codecs operate at 10 Mb/s, and an extrapolation to 1998 technology would be 100 Mb/s. This implies that 10 such chips, each drawing approximately 0.8 W will be required for operation at 1 Gb/s. The temperature control circuitry in the transmitter is assumed to draw more power as the transmit laser source is of significantly greater power.

The mass and power estimates are extrapolated pri-

Table 6-10: Link Analysis – Optical Crosslink FSG Payload on ATDRSS

Parameter	Value (Scaler)	Value (dB)
Laser Wavelength (nm)	850	
Laser Transmit Power (W)	1.00	0.00
Max. Norm. Linewidth	0.24	
Max. Linewidth (MHz)	120.00	
Detection Method	Heterodyne Noncoherent	
Modulation Format	4-FSK	
Modulation Index	1.00	
Transmit Optical Path Loss		5.00
Transmit Aperture (m)	0.21	
Efficiency (%)	85	
Transmit Gain (dBi)		117.09
EIRP (dBW)		112.09
Link Distance (Mm)	40	
Free Space Loss (dB)		295.44
Pointing Loss		4.00
RMS Pointing Error (urad)	0.35	
Max. Pointing Error (urad)	2.37	
Total Path Loss (dB)		299.44
Receive Optical Loss		5.00
Receive Aperture (m)	0.21	
Receive Field of View (urad)	500	
Efficiency (%)	85	
Receive Gain (dBi)		117.09
Receive Signal Level (W)	2.98E-08	-75.25
Receive Photoelectron Counts/sec	1.28E+11	
Local Osc. Power (W)	1.00E-03	
Local Osc. Photoelectron Counts/sec	4.28E+15	
LO Mixing/Alignment Loss		1.50
LO Phase Noise Loss		0.50
Detector Efficiency Loss (%)	75.00	1.25
Detected Signal Counts/sec	6.04E+10	
Signal Level (dBW)		-78.50
Average Detector Gain	1.000	
Detector Gain Variance	0.000	
Excess Noise Factor	1.000	
Receive Filter Bandwidth (um)	0.002	
Spectral Radiance Function (W/um cm^2)	2000.000	
Background Power (W)	2.05E-05	
Background Noise Counts/sec	8.78E+13	
Dark Current (A)	1.01E-10	
Dark Current Noise Counts/sec	6.27E+08	
Equiv. Load Temperature (K)	400	
Equiv. Load Resistance (ohm)	2,000	
Thermal Noise Counts/sec	2.15E+14	
Available SNRo (dB-Hz)	2.82E+10	104.50
Data Rate (Mb/s)	1,000.00	90.00
Modem Loss		3.00
Available Eb/No (dB)		11.50
Interference Degradation (dB)		0.00
Coding Gain (dB)		5.70
Required BER	1.00E-10	
Required Eb/No (dB)		14.50
System Margin		2.70

Table 6-11: Comparison of Optical and RF Crosslinks

Link Type	Mass (kg)	Power (W)
Optical	20	47
Ka-band	63	110
60 GHz	56	110
FSG capacity	109	260

marily from references [2] and [4]. Reference [5] provides a mass estimate of 23 kg, although not broken down by subsystems, for a future space qualified crosslink systems operating at around 100 Mb/s.

#### 6.3.4.5 Comparison of Optical and RF Intersatellite Links

Table 6-11 gives a summary of the mass and power estimates of optical, Ka-band, and 60 GHz crosslinks for a 1 Gb/s FSG payload on ATDRS. The crosslink would be used to relay data gathered by ATDRS to DDS for direct distribution to earth-based experimenters and users without the need for passing through White Sands.

The conclusion is that the optical link offers significant mass and power savings over the RF links. In fact, several optical crosslinks could fit within the ATDRS FSG payload allocation. However, significant technology development effort is required to make the optical design feasible. Another interesting possibility to utilize the FSG capacity on ATDRS would be a combination of Ka-band direct downlink (37 kg mass and 209 W power) and optical crosslink (20 kg mass and 47 W power).

## 6.4 ASDACS Evolution (2015-2025)

This section describes possible evolutionary paths for the ATDRS follow-on, known as the Advanced Space Data Acquisition and Communications System (ASDACS). Figure 6-15 illustrates a possible progression for the insertion of the DDS function into the TDRS system. As shown on the left in the figure, the year 2005 DDS could obtain access to the ATDRSS either via a link from White Sands or via intersatellite links (ISLs) direct from ATDRS (using the ATDRS FSG capacity for an intersatellite link). By the year 2015, an ASDACS design could replace ATDRS and communicate directly

via ISLs with DDS. Finally, in the year 2025 the DDS and ASDACS function could be combined on a single platform with ISLs to European and Asian sector satellites.

A major tradeoff is the position of the ASDACS satellites. The present ATDRSS operates without intersatellite links, and thus the satellite locations on the geostationary arc are low in the sky as seen from the White Sands ground terminals in order to minimize the zone of exclusion. (The zone of exclusion is that part of the space around the earth not covered by ATDRSS.) The DDS must be located over the United States in order to minimize atmospheric transmission losses. For the ATDRS to be similarly located over the United States, intersatellite links among ATDRS are necessary to relay data from out-of-sight ATDRS's.

An ultimate (year 2025) ASDACS/DDS combination would be to position one ASDACS satellite over the United States and link it to two other ASDACS satellites at  $\pm 120^\circ$  longitude differences in order to supply full coverage of earth-orbiting satellites (no zone of exclusion) by ASDACS. To perform this mission with a reasonably sized ASDACS platform will require the use of optical intersatellite links, not only for connections between ASDACS satellites but also for collecting data from user satellites.

The current TDRS and proposed ATDRS designs are dominated by the large 15 ft diameter single access antennas which provide high data rate, multiple frequency (S, Ku, and Ka-band) intersatellite links (ISLs) to two user satellites. Use of much smaller optical ISLs on ASDACS satellites will allow more ISLs which in turn can service more user satellites from the same platform size as ATDRS.

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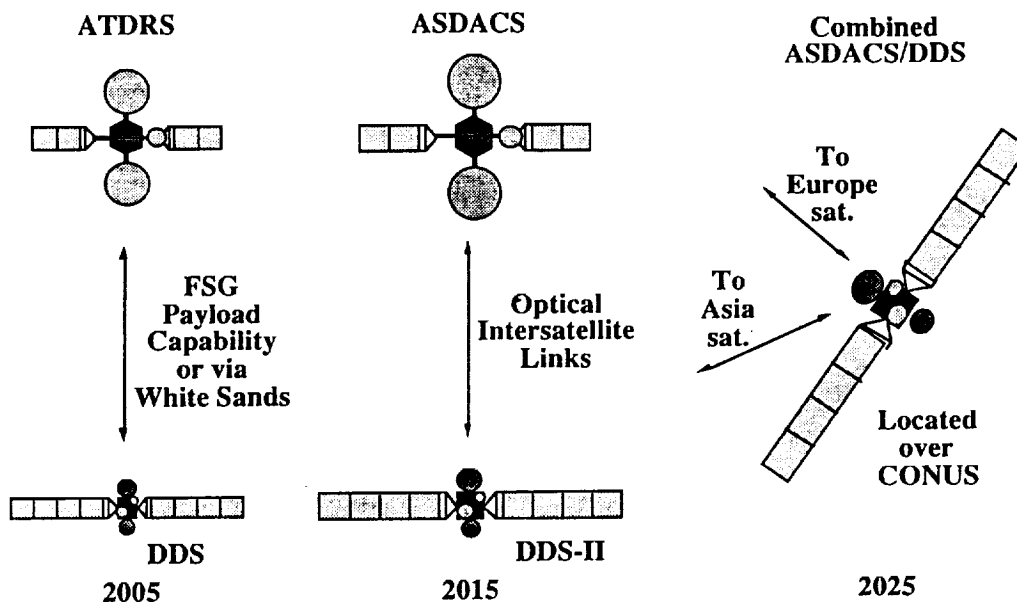


Figure 6-15: Evolution of DDS and ASDACS Configurations

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## Chapter 7

# Communications Payload Configuration

This chapter is organized as follows:

- 7.1 Overview
- 7.2 Satellite Antenna Configuration
- 7.3 Block Diagram
- 7.4 Uplinks
- 7.5 Downlinks
- 7.6 Intersatellite Links
- 7.7 Communication Tradeoffs

### 7.1 Overview

This overview first gives the general approach to configuring the payload and then discusses the key issues in the optimization of the communications payload.

#### 7.1.1 General Approach

The Data Distribution Satellite communications subsystem is required to:

- Have a data throughput in excess of 10 Gb/s;
- Communicate efficiently with a large number of user terminals of 1.8 m to 7 m diameter; and
- Provide an on-orbit reconfiguration flexibility to accommodate dynamic changes in user traffic.

The implementation of this subsystem and the associated master communications control center will represent the key technology advance for the DDS system. It is recommended that the critical technology equipment items and control software be developed and tested in a prototype laboratory simulation in advance of the satellite flight hardware design.

The general baseline approach proposed in this report incorporates the following features:

- Uses both Ku-band and Ka-band frequencies;
- Uses fixed spot beams as well as broader area coverage beams for complete CONUS coverage,
- Uses intersatellite links to expand capacity.
- Accommodates many small user uplinks by utilizing bulk demodulators,
- Uses BPSK modulation for power constrained links and 8PSK modulation for bandwidth constrained links,
- Uses FEC block coding for both up and downlinks.
- Provides for full demodulation and remodulation on the satellite,
- Routes data via packet switching,
- Uses TDM downlinks at 52 Mb/s burst rate for small users,
- Provides for output power combining into a limited number of power amplifiers, and
- Accommodates the ISDN standard rates and protocols.

The communications access control and satellite equipment reconfiguration is directed by a master communications control center.

#### 7.1.2 Key Issues in Optimization of the Communications Subsystem

The following communications subsystem implementation issues and tradeoffs are incorporated into the decisions on optimization of the baseline configuration:

**High data throughput.** The baseline DDS configuration is designed to accommodate a large composite data capacity in excess of 10 Gb/s for both uplinks and downlinks. If data requirements are significantly reduced, then alternate communication techniques may be economically viable.

**Use of dual frequency bands.** The efficient use of 500 MHz spectrum at Ku-band and 500 MHz at Ka-band is required to accommodate the large data throughput. The Ku-band links will be used for high link availability (>99.5%) requirements and Ka-band links will provide efficient bulk data transfer at >98% availability.

**Full coverage of CONUS** is provided at both frequency bands through use of area coverage beams. Additional fixed spot beams are provided to high data traffic regions in order to improve communications link efficiency. Both horizontal and vertical polarization are used to minimize adjacent beam interference.

**Modulation.** A mix of modulation techniques is used. BPSK is utilized for power constrained links, 8PSK is used for spectrum constrained links, and QPSK is used for balanced conditions (simultaneous power and bandwidth efficiency).

**Coding.** FEC block coding is used on both the uplinks and downlinks for link power efficiency. Typical coding configurations include rate .749 for QPSK and rate .829 for 8PSK.

**On-board processing.** The incorporation of full demodulation and remodulation of all data streams permits baseband processing. The use of packet switching according to the B-ISDN standard eliminates the need for precise system timing synchronization and permits maximum routing flexibility.

**Data rates and protocols.** The baseline links are designed to accommodate both narrowband ISDN (144 kb/s and 1.5 Mb/s) as well as B-ISDN (160 Mb/s and 640 Mb/s) rates.

**Communications control.** A master communications control center is incorporated in order to regulate system access and gather billing information. The Control Center will also direct the reconfiguration

of DDS communications equipment to match dynamic changes in user circuit and connectivity requirements.

**User flexibility.** The system is designed to accommodate a large number of simultaneous users of various data rates and antenna terminal sizes. The baseline DDS configuration is optimized for a 1.8 m earth terminal as the smallest user at the required availability. Smaller terminals of 1.2 m will operate effectively on clear days and larger terminals of 3 to 7 m may be used for higher data rates and/or higher link quality and availability.

**Uplink configuration.** The low data rate users (6 Mb/s or less) utilize single carrier FDMA and bulk demodulation on the satellite. Dedicated demodulators are assigned to higher rate channels. This approach yields maximum bandwidth utilization at low transmitter power from user terminals.

**Downlink configuration.** The downlinks at low data rates (6 Mb/s or less) are achieved by using TDM at a burst rate of 52 Mb/s. Higher data rate signals are assigned separate single channel per carrier links. The satellite transmit power is allocated with 70% to Ku-band and 30% to Ka-band.

**Intersatellite links among DDS, ATDRS, and other satellites** are achieved via laser links which interface with the Ku-band and Ka-band uplinks and downlinks.

**Growth flexibility.** The baseline communications configuration is designed to permit a modular growth in system performance via addition of more satellites to the DDS system.

## 7.2 Satellite Antenna Configuration

The satellite antennas are a key item limiting payload performance due to constraints on allowable size and mass. Larger antennas can provide higher gain and thus greater EIRP to the ground terminals, which can allow higher data rates or smaller ground terminal sizes. However, higher gain antennas are larger and require more beams to cover a given area such as CONUS, and thus beamforming network size and on-board switching complexity is increased.

This section describes the satellite antenna configuration and the tradeoffs involved in its selection. The discussion is divided into four parts:

- 7.2.1 Summary of Baseline Configuration
- 7.2.2 Ku-Band Antenna Coverage Tradeoffs
- 7.2.3 Ka-Band Antenna Coverage Tradeoffs
- 7.2.4 Intersatellite Link Implementation

### 7.2.1 Summary of Baseline Configuration

Because of the great diversity in user configurations and a requirements, a diversity of satellite antenna beam implementations is recommended. Many constraints and tradeoffs impact upon the selection of a candidate baseline design. Some of the key factors are as follows:

**Transmission frequency.** Because of the high capacity communications requirements, both Ku-band (14.0–14.5 GHz receive, 11.7–12.2 GHz transmit) and Ka-band (29.5–30.0 GHz receive, 19.7–20.2 GHz transmit) are utilized. Even with use of both bands, frequency reuse and other bandwidth efficiency techniques must be used.

**Area coverage versus spot beams.** Because of the wide geographic distribution of users, complete CONUS coverage must be provided at both Ku and Ka-bands. Much of the traffic is concentrated in various areas, however, which suggests use of spot beams. Thus a hybrid technique employing both wide area coverage as well as spot beams appears to be the best solution for DDS.

**Size of spot beams.** To service a high data rate user at a single site such as White Sands, a very small spot beam of  $0.2^\circ$  (limited only by the limits on satellite antenna size and satellite pointing accuracy) is desired. However, for a number of high data rate users located in the same geographical vicinity (Los Angeles area for example), a larger spot beam of  $0.5^\circ$  to  $0.9^\circ$  is required.

**Satellite implementation.** The physical size and mass of the satellite antenna system is constrained by the costs of launching the satellite to geosynchronous orbit. Because of the multiple number of antennas required, it is desirable to keep the aperture of any single antenna to about 2 m diameter.

**Scanning versus fixed spot beams.** Wide area coverage may be obtained by rapidly scanning spot beams over a geographic area. (ACTS represents the technology limitation where  $0.3^\circ$  beams are scanned over the area of CONUS.) The tradeoffs compared with multiple fixed beams are extra satellite complexity and more complex timing and control requirements for the communication users.

**On-orbit location.** The DDS satellites can be positioned over a wide arc in the geosynchronous orbit. The antenna pattern coverage and required gain to users is impacted by the selected orbital locations.

**Intersatellite links.** Laser links are recommended for DDS due to their smaller physical size and their relatively high data rates of up to 1 Gb/s. However, 60 GHz remains an alternate if low ( $< 100$  Mb/s) data rate links are adequate.

A consideration of the various constraints and tradeoffs resulted in the baseline satellite antenna configuration (year 2007) given in Table 7-1. Seven antenna apertures are used for uplink and downlink transmissions at both Ku-band and Ka-band. (Intersatellite links are discussed in ¶7.2.4.)

The satellite antenna system layout is described in Chapter 8. An antenna efficiency from 60% to 65% can be obtained from a total antenna subsystem mass of 180 kg (year 2007). The 2015 design has the same number of antennas but more active spot beams and 230 kg mass. Details of the Ku-band and Ka-band configurations are discussed below.

#### 7.2.1.1 Ku-Band Configuration

The Ku-band receive antenna (#1, Table 7-1) for all of CONUS coverage is 0.9 m diameter and generates eight beams of  $1.73^\circ$  half power beamwidth (HPBW). To achieve frequency reuse, the beams alternate between horizontal and vertical polarization. In addition, a 1.7 m antenna (#2, Table 7-1) supplies up to 10 (out of 16 locations)  $0.9^\circ$  spot beams for Ku-band receive.

The Ku-band transmit (11.7–12.2 GHz) CONUS coverage antenna (#5, Table 7-1) forms 27 beams of  $0.87^\circ$  HPBW. Some beams accommodate either horizontal or vertical polarization, and some beams receive both polarizations.

Table 7-1: Satellite Antenna Configuration (Year 2007 Data Distribution Satellite)

	Satellite Receive				Satellite Transmit		
	#1 Ku (14.0-14.5)	#2 Ku (14.0-14.5)	#3 Ka (29.5-30.0)	#4 Ka (29.5-30.0)	#5 Ku (11.7-12.2)	#6 Ka (19.7-20.2)	#7 Ka (19.7-20.2)
Coverage							
Beams	8 of 1.73° HPBW	10 active spot beams - 0.87° HPBW of total of 15	8 of 1.73° HPBW	12-16 active spot beams of 0.5° HPBW of total of 20	27 beams of 0.87° HPBW	8 of 1.73° HPBW	12-16 active spot beams of 0.5° HPBW of total of 20
Antenna Diameter	0.9 m (2.8 ft)	1.7 m (5.5 ft)	0.4 m (1.4 ft)	1.4 m (4.6 ft)	2.0 m (6.5 ft)	0.6 m (2.0 ft)	2.2 m (7.0 ft)
Antenna Mass	14 kg	24 kg	8 kg	22 kg	36 kg	10 kg	26 kg
Polarization	4 of H 4 of V	1/2H or V only 1/2 (H + V)	4 of H 4 of V	1/2H or V only 1/2 (H + V)	1/2H or V only 1/2 (H + V)	4 of H 4 of V	1/2H or V only 1/2 (H + V)
Antenna Efficiency	65%	60%	65%	60%	60%	65%	60%
Peak Gain (dBi)	40.2	45.8	40.2	50.6	45.8	40.2	50.6
EOC Gain (dBi)	35.9 (-4.3)	42.8 (-3.0)	35.9 (-4.3)	47.6 (-3 db)	41.5 (-4.3)	35.9 (-4.3)	47.6 (-3 db)

7.2.1.2 Ka-Band Configuration

The Ka-band receive (29.5–30.0 GHz) antenna for CONUS coverage (#3, Table 7-1) has eight beams of 1.73° HPBW from an 0.4 m antenna. In addition, selected areas are covered (#4, Table 7-1) by 12 to 16 spot beams of 0.5° HPBW from a 1.4 m antenna.

The Ka-band transmit (19.7–20.2 GHz) antenna for CONUS coverage (#6, Table 7-1) has eight beams of 1.73° HPBW from an 0.6 m antenna. In addition, selected areas are covered (#4, Table 7-1) by 12 to 16 spot beams of 0.5° HPBW from a 2.2 m antenna.

7.2.2 Ku-Band Antenna Coverage Tradeoffs

Both broad area coverage as well as spot beams to selected high traffic areas are required to efficiently accommodate the DDS communications requirements.

A recommended plan for full CONUS coverage for Ku-band uplinks (as well as being the same plan for Ka-band uplinks and downlinks) is shown in Figure 7-1. This plan utilizes eight active adjacent beams with alternating horizontal and vertical polarization, and using different parts of the 500 MHz frequency band. Figure 7-1 shows the -4.3 dB contours (2° circles) of 1.73° HPBW beams. The minimum gain at edge-of-coverage is 35.9 dBi assuming 65% antenna efficiency.

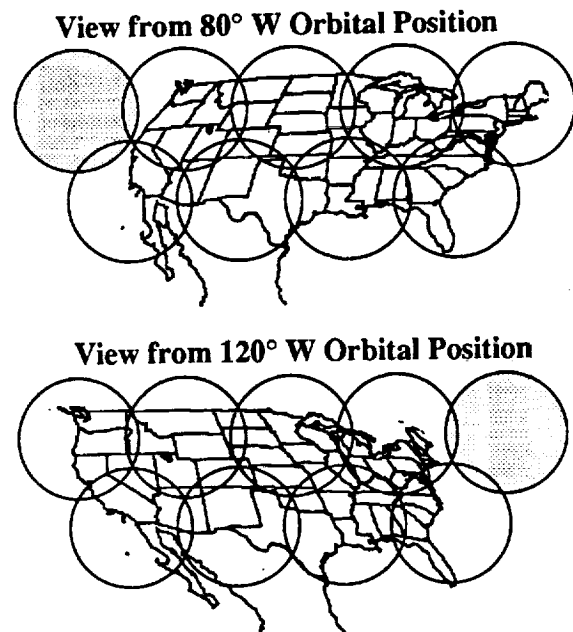


Figure 7-1: 8 Beams of 1.73° Cover CONUS

Figure 7-1 also shows the impact of the on-orbit location of DDS on the coverage pattern. The eastern orbital slot of  $80^\circ$  W longitude emphasizes the east coast coverage whereas the  $120^\circ$  W location emphasizes the west coast coverage. The final selection of orbital positions may be dictated by other factors such as intersatellite links to ATDRSS satellites.

Note also that Figure 7-1 depicts a flexible antenna configuration which permits a standard DDS to be used between the extreme on-orbit locations by activating 8 out of 9 beams as appropriate for optimal coverage.

A high gain 28-beam configuration is also provided for Ku-band downlinks to any point within CONUS. A selected number of uplink beams would also be provided for coverage of high traffic areas. The baseline assumes ten active uplink high gain beams out of 16 possible beam locations.

Figure 7-2 shows the 4.3 dB contours ( $1^\circ$  circles) of  $0.87^\circ$  HPBW beams. The minimum gain at edge-of-coverage is 41.5 dBi assuming 60% antenna efficiency. The coverage from two orbital positions is shown.

The orientation of the coverage pattern could be adjusted to provide more frequency reuse via overlapping beams in a high traffic area. Alternately, the center of a beam could be positioned on a key ground location to give maximum gain. This optimization can only be done for one or two ground locations at a time.

### 7.2.3 Ka-Band Antenna Coverage Tradeoffs

Broad area coverage of all CONUS for both Ka-band transmit and receive is provided by eight beams of  $1.73^\circ$  HPBW as previously shown in Figure 7-1.

In addition, high gain spot beams are provided for both transmit and receive to selected geographic areas for high data rate users. A total of 70 beams of  $0.5^\circ$  HPBW is required to cover all CONUS. A complete spot coverage is not required for the year 2007 DDS. The baseline design incorporates a reconfigurable waveguide switch so that any 16 beams can be selected for active use at a particular time.

Figure 7-3 shows the 3 dB contours of the  $0.5^\circ$  beams. Minimum edge-of-coverage gain is 46.3 dBi assuming an antenna efficiency of 60%. The figure also shows the impact of orbital position on coverage. For a single DDS, a location nearer  $80^\circ$  W is favored due to traffic considerations and for mitigation of the higher east coast rain margins. (Two DDSs, one at each location and interconnected via intersatellite link, form the

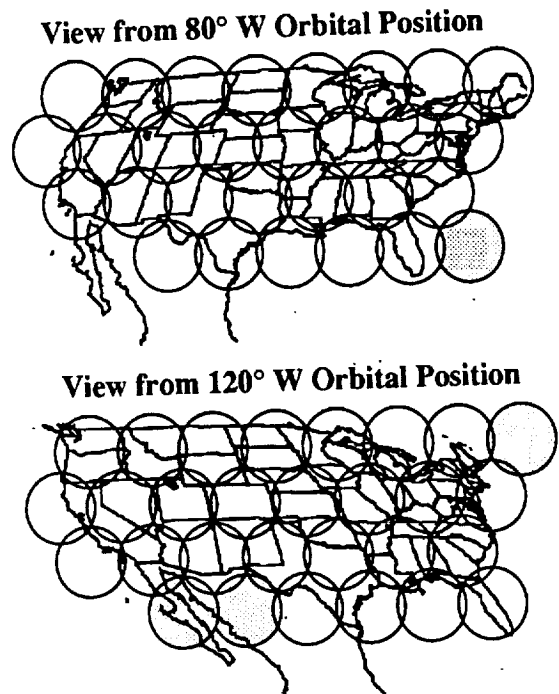


Figure 7-2: 28 Beams of  $0.87^\circ$  Cover CONUS

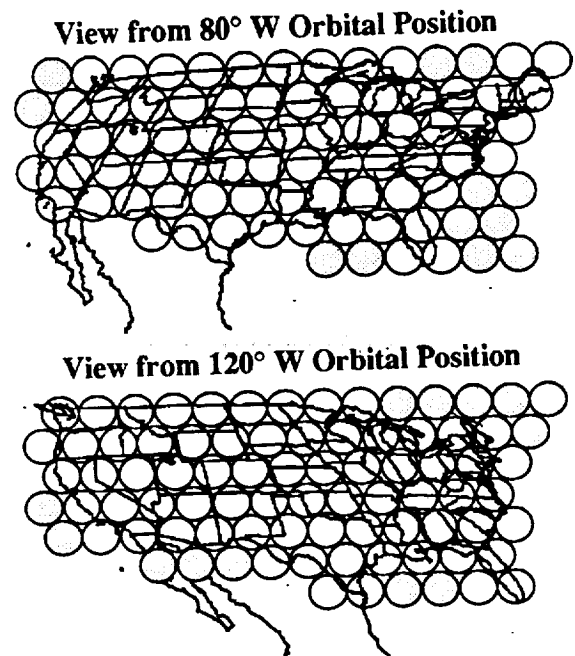


Figure 7-3: 70 Beams of  $0.5^\circ$  Cover CONUS

preferred orbital configuration.)

### 7.2.4 Intersatellite Link Implementation

A multiple number of links between the DDS and other geosynchronous satellites may be required. As shown in Figure 7-4, these links may reach to the ATDRS (four operational), the NASA platforms, international relay satellites, and other DDS. The link ranges, tabulated in the figure, vary from 5,000 to 80,000 km.

Adequate steering range must be provided for the intersatellite link antennas in order to accommodate all potential crosslink users. Return communication data rates to DDS from each ATDRS may reach 2 Gb/s, while the forward link from DDS to ATDRS may be 200 Mb/s. (Note that there are two ATDRS in each of two orbital locations.)

A description of the crosslink implementation is given in Chapters 7 and 8 of this report.

## 7.3 Block Diagram

The discussion of this section is divided into four parts:

- 7.3.1 Overview
- 7.3.2 Receive Configuration
- 7.3.3 On-Board Processing Configuration
- 7.3.4 Transmit Configuration

### 7.3.1 Overview

The block diagram of the baseline DDS communications subsystem is shown in Figure 7-5. The DDS receives signals from the CONUS coverage area at both Ku-band and Ka-band from both area coverage beams (1/4 CONUS and 2°) as well as spot beams (0.5° and 0.9°). The match of antenna beams to appropriate demodulator capability is achieved by both fixed allocation and rf interconnect switching which is controlled via the communications command and control link.

The satellite demodulates all uplink signals. The lower rate signals go into bulk demodulators. One bulk demodulator, for example, can accommodate 327 channels of encoded 144 kb/s uplinks and provide a single TDM output at 52 Mb/s. Other higher data rate SCPC (single channel per carrier) signals in the range of 52 Mb/s to 640 Mb/s would be accommodated by dedicated regular demodulators.

The next stage provides for decoding of the uplink signals. It is expected that D-8PSK modulation with .905 FEC coding would be used for high bandwidth efficiency for signals directed to the bulk demodulators, and that 8PSK modulation with .829 FEC coding would be used for the wideband SCPC links to dedicated regular demodulators.

After FEC decoding is achieved the outputs of the uplink data streams will consist of serial packets of information, with each packet consisting of 424 bits of data. The header on each packet is read in order to determine the appropriate output destination and routing. It is possible to uplink at one frequency band (for example Ku-band) and to route to a downlink at the alternate frequency band (Ka-band).

The buffered data is then encoded and directed to the appropriate downlink transmitter which in turn are connected to the appropriate downlink antenna coverage beam. Some of the low data rate downlinks are accommodated by using a TDM method of data formatting at an output burst rate of 52 Mb/s. The higher data rate channels of up to 640 Mb/s are accommodated by dedicated single channel per carrier links. The use of BPSK and QPSK and modulation techniques are utilized in order to conserve on satellite transmitter power.

The option for including data which is received from intersatellite cross links for downlink at Ku-band or Ka-band is also feasible.

All of the access control, allocation of equipment items, and reconfiguration switching is under the control of the master communications control center.

### 7.3.2 Receive Configuration

#### 7.3.2.1 Ku-Band Receive Configuration

A more detailed block diagram of the DDS satellite receiving configuration for Ku-band (14.0 to 14.5 GHz) is depicted in Figure 7-6. The uplink signals are received from two sets of satellite antenna coverage beams, downconverted to a lower frequency band, demodulated, and output as serial PCM data streams for further processing in the satellite processor equipment.

**Ku-band area beam receiving.** The top section of Figure 7-6 describes the receiving technique associated with the eight area coverage beams of 1.73° half power beamwidth which provide for complete coverage of CONUS. These beams alternate in polarization (either vertical or horizontal) and each uses only 50%



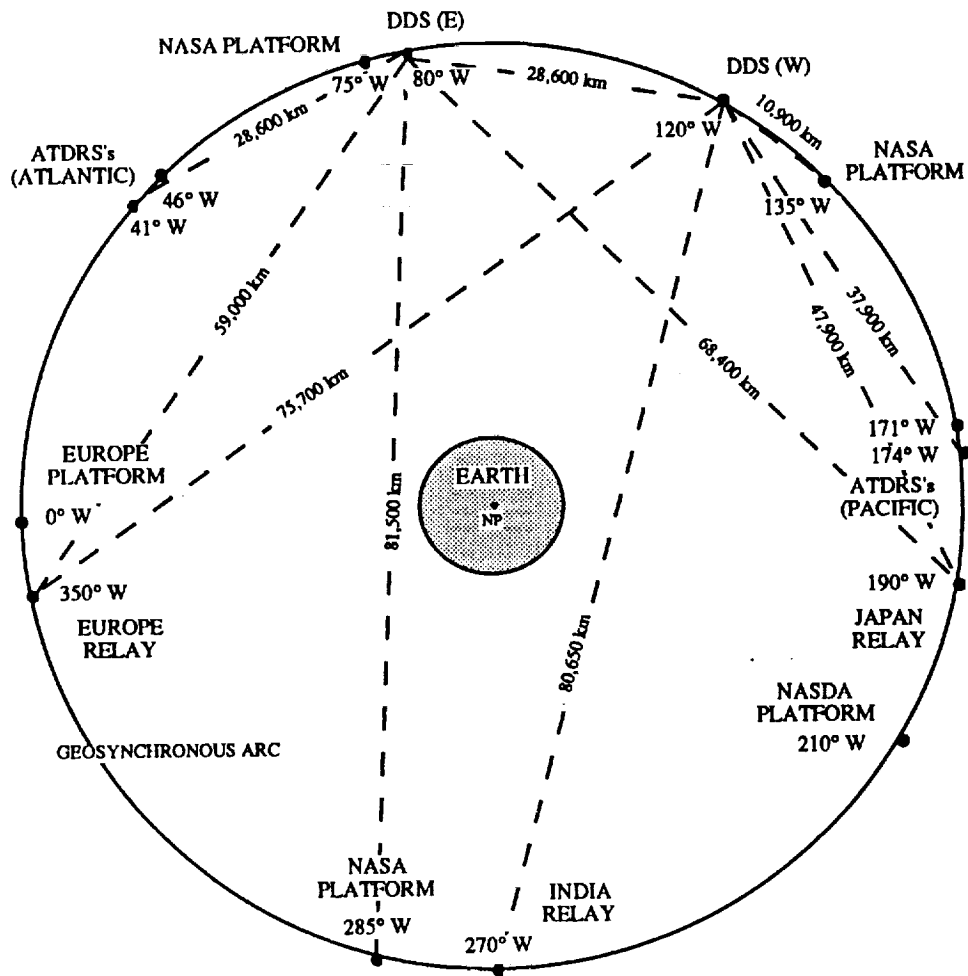


Figure 7-4: Intersatellite Link Configuration - Possible Links to DDS

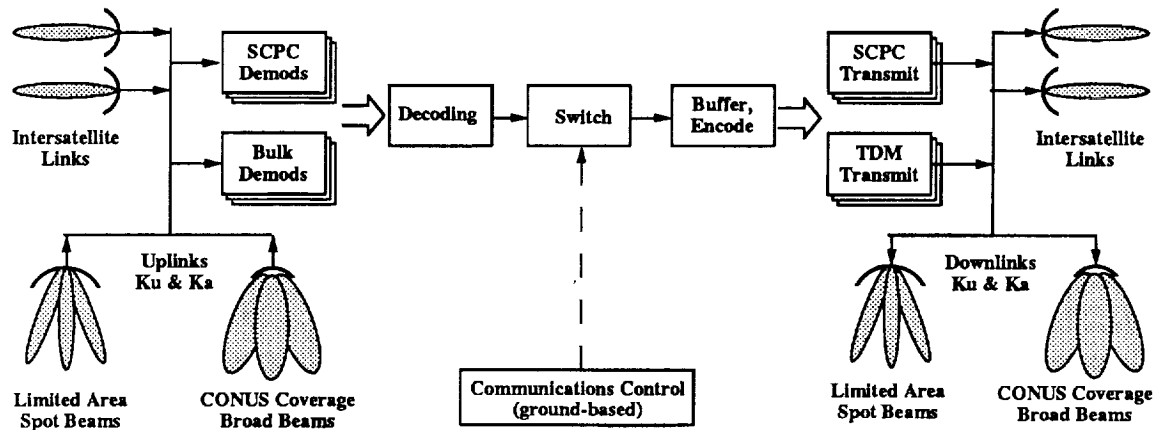


Figure 7-5: Block Diagram of the Communications Subsystem

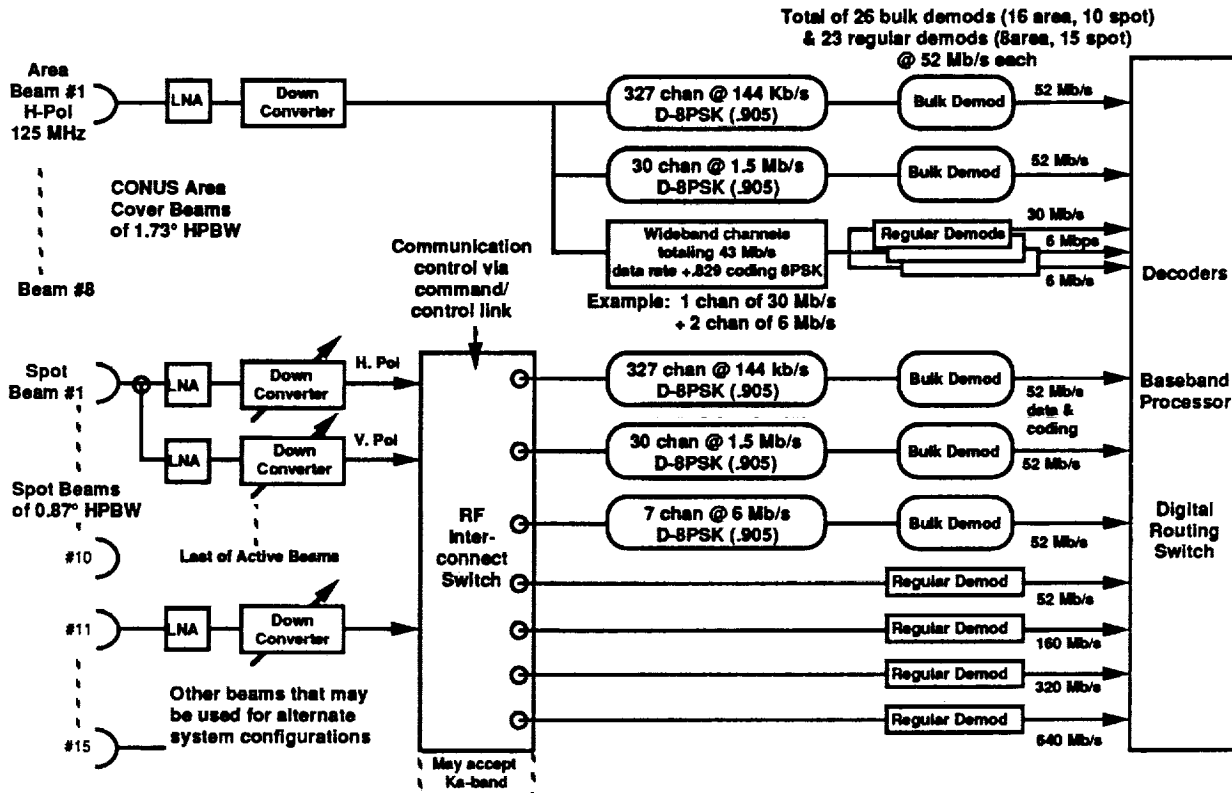


Figure 7-6: Satellite Receive Configuration - Ku-Band

of the lower half of the 500 MHz Ku-band (14.0 to 14.5 GHz) in order to minimize adjacent beam interference and to avoid interference with spot beam coverage. For example it is shown that beam 1 would have horizontal polarization and would receive signals over a spectrum of 125 MHz.

The receive signals are then amplified in a low noise amplifier with satellite noise temperature of 420 K and then downconverted to an IF frequency. The uplink signals are offset in frequency such that proper filtering directs them to the proper demodulator.

In this example three types of demodulators are assigned to beam 1 uplinks. Up to 327 separate uplink single channel per carrier signals, each at 144 kb/s of data, would be directed to a bulk demodulator which has the capability of demodulating and outputting the composite inputs into a single PCM data stream of 52 Mb/s. The output data stream also includes the FEC coding information of a .905 code which would be utilized for D-8PSK modulation. A two times channel spacing a total bandwidth of 38.1 MHz would be required to accommodate the 327 low rate uplinks within area coverage beam 1.

Other higher data rate uplinks would be directed (via uplink frequency assignment) to a second bulk demodulator assigned to area beam 2. This bulk demodulator would accommodate 30 separate uplink single channel per carrier signals, each at 1.5 Mb/s of data plus associated .905 FEC coding bits. Again a total bandwidth of 38.1 MHz is required when using D-8PSK and a two times channel spacing factor for the bulk demodulator.

The very high data rate signals would be assigned to separate regular demodulators. In the example of Figure 7-6, two channels of 6 Mb/s data rate and one channel of 30 Mb/s data rate would be accommodated by area beam 1. When using 8PSK modulation and .829 FEC coding the composite bandwidth would be 23.7 MHz.

The total bandwidth required for the three types of signals in the example of area beam 1 would total to about 100 MHz which is within the normal 125 MHz available to an average beam. Another potential reduction in spectrum could be obtained if 1.5 times channel spacing would become feasible for satisfactory bulk demodulator operation. The extra bandwidth could be utilized for more information channels or to utilize QPSK

modulation for power constrained links.

**Ku-band spot beam receiving.** The lower part of Figure 7-6 describes the receiving technique associated with spot beams ( $0.87^\circ$  HPBW) at Ku-band. It is postulated that up to 15 fixed beam assignments are implemented to cover high data traffic geographic areas but that only 10 are in active use at any particular time period. The beams alternate in polarization (either vertical or horizontal) to abbreviate near adjacent spot beam interference and each uses part or all of the upper half of the 500 MHz Ku-band spectrum in order to eliminate interference with the area coverage beams. Some of the spot beams could be implemented to receive both horizontal and vertical polarization if capacity requirements were high, and no near adjacent spot beams are required.

Each of the uplink carrier signals are amplified via low noise amplifiers and then downconverted to an IF frequency. In order to minimize the number of demodulators required in the DDS satellite, an RF interconnect switch is used to assign bulk demodulators and regular demodulators to specific spot beams as required. The rf switch is under the control of the master communications control center. The flexibility of the switch to accommodate cross transfer of uplink signals from Ka-band or intersatellite relay is also feasible.

The bulk demodulators may each be designed to accommodate a single input data rate per channel or may be designed to accommodate a range of input data rates: 144 kb/s to 6 Mb/s. The composite output data of a bulk demodulator is shown to be 52 Mb/s; however, higher rates of up to hundreds of Mb/s may be feasible for use in the year 2007 time period.

Regular demodulators may be implemented at rates of 52 Mb/s, 160 Mb/s, 320 Mb/s, and 640 Mb/s. Higher rates are technically feasible. However, spectrum utilization planning and data requirements considerations may preclude implementation.

### 7.3.2.2 Ka-Band Receive Configuration

The operation of the satellite receiving at Ka-band (29.5–30.0 GHz) is similar to that described for Ku-band. Both area coverage beams of  $1.73^\circ$  HPBW and spot beams of  $0.5^\circ$  HPBW are utilized. It is expected that up to 16 active spot beams would be oriented to receive data from the high data traffic areas.

### 7.3.3 On-Board Processing Configuration

The outputs of the satellite receiving equipment consists of about one hundred PCM encoded baseband data streams ranging from 52 to 640 Mb/s. The role of the DDS digital processing equipment is summarized in the block diagram of Figure 7-7.

Each input data stream is first decoded in order to reconstitute the original information data stream. Various types of decoders are employed. The D-QPSK and D-8PSK modulation techniques which are compatible with bulk demodulator operation may use FEC block coding at a .905 code rate. The data rate uplinks to regular demodulations may use .749 code rate for QPSK and .829 code rate for 8PSK.

It is projected that the information in each of the data streams would be contained in 424 bit sequential packets, each of which could be originated by a single transmittive user and each of which could be destined for one (or more through replication) receiving users at specific geographic locations.

Each of the 424 bit packets contains a routing header of 40 bits which provides information on the sender and on the routing destination desired (see ¶4.5.7.2). A packet reader would be used for each digital data stream to monitor the header information and to activate switching to permit routing of the 400 bit packet to an appropriate output buffer.

The output buffers are used to sequentially store the 424 bit packets which are destined for specific output transmitters and antenna beams of the DDS. If more than one set of uplink messages are being stored in the buffer at the same time period, then a time of arrival would be used to determine next entry to the buffer and other data streams would be temporarily stored in serial resistors. The communications access is always under the control of the master Communications Control Center which assures that the capacity of each buffer is not exceeded; i.e. the buffer readout capacity always must exceed the average of the buffer read-in rate.

As shown in Figure 7-7, some of the high rate uplink data streams are originated from a single source and are destined for a single output amplifier. These data streams may be directly switched to an output exciter/amplifier without requiring data buffers to mix with other user signals.

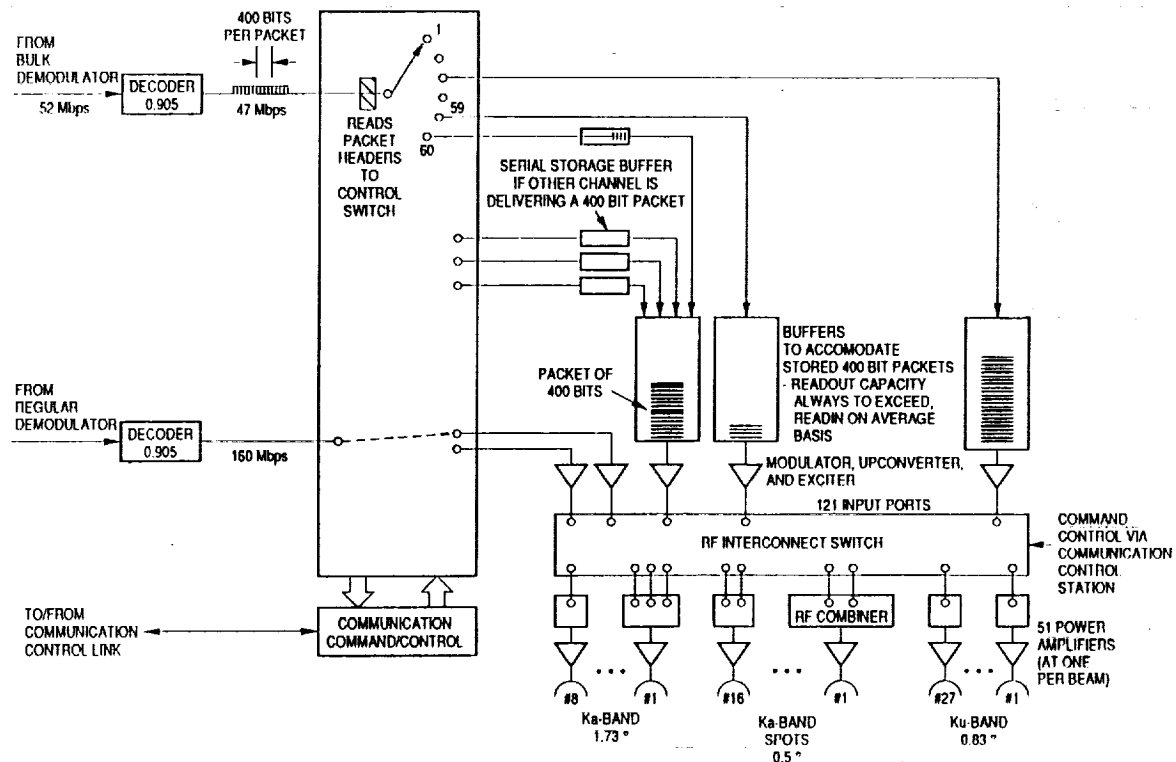


Figure 7-7: Satellite Decoding, Processing, and Digital Output Switch

### 7.3.4 Transmit Configuration

The outputs of each buffer or direct demodulator are modulated, upconverted, and amplified by an rf transmitter exciter. As shown in Figure 7-8, an rf interconnect switch and output multiplexer would then be used to combine the rf signals destined for a separate output antenna beam. The combined signals would then drive a separate power amplifier for each downlink beam. (As an alternate several power amplifiers could be connected to each downlink beam.) For the example of baseline DDS configuration (27 downlink beams of  $0.87^\circ$  at Ku-band, 8 downlink beams of  $1.73^\circ$  at Ka-band, and 16 downlink beams of  $0.5^\circ$  at Ka-band) a minimum of 51 active output power amplifiers are required.

The downlink capacity of the baseline DDS satellite will be more fully described in ¶7.5. This capacity requires the sets of exciter or power amplifier outputs as shown in Table 7-2. A total of 121 separate transmitters are required, but some could be rf combined to result in the minimum of 51 output power amplifiers, at one per output beam.

## 7.4 Uplinks

The discussion of the satellite uplink configuration is divided into four parts:

- 7.4.1 Satellite Receive Parameters
- 7.4.2 Summary of Uplink Capacity
- 7.4.3 Ku-Band Uplink Link Budgets
- 7.4.4 Ka-Band Uplink Link Budgets

### 7.4.1 Satellite Receive Parameters

The overall block diagram for a baseline DDS satellite receiving configuration at Ku-band was previously shown in Figure 7-5. A similar plan would also be used at Ka-band. All uplink signals are received via single channel per carrier transmission techniques. However, two types of demodulators are utilized.

- Low data rate signals at 144 kb/s, 1.5 Mb/s, or 6 Mb/s are grouped for bulk demodulation.
- High data rate signals of 52 to 640 Mb/s utilize regular single channel demodulators.

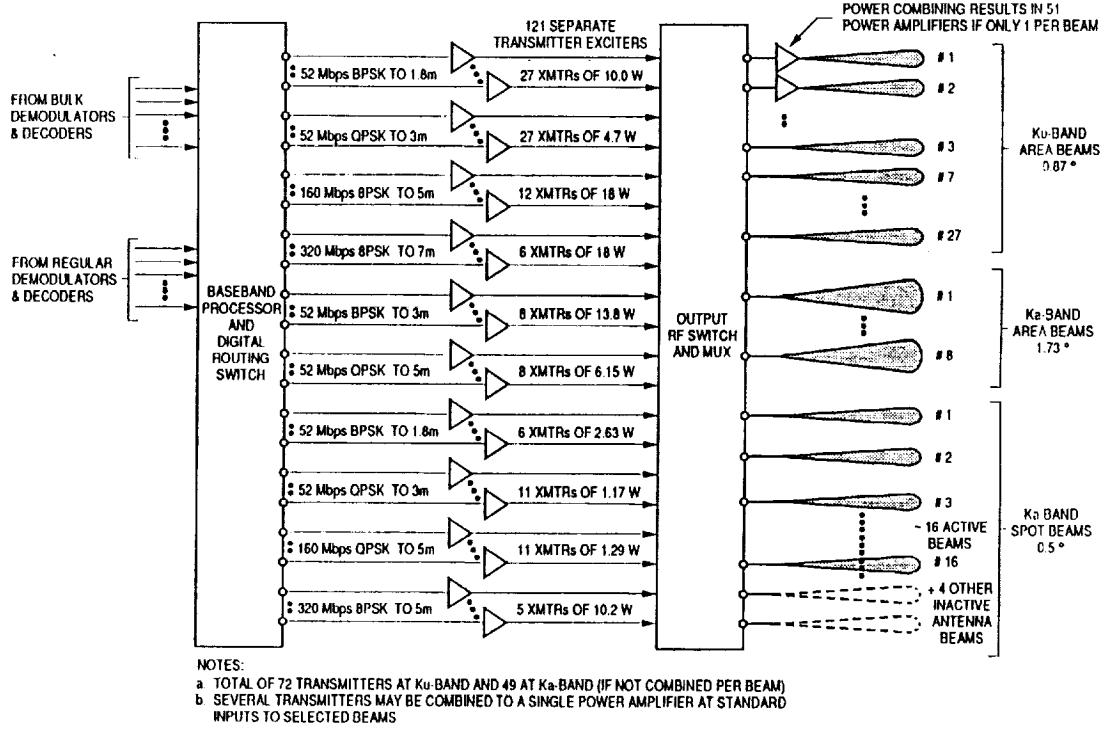


Figure 7-8: Satellite Transmitter Configuration

Table 7-2: Satellite Transmitter Numbers and Sizes

Freq. Band	No. Trans.	Size (W)	Type of Link
Ku-band:	27	10.0	52 Mb/s BPSK links to 1.8 m terminals.
	27	4.7	52 Mb/s QPSK links to 3.0 m terminals.
	12	18.0	160 Mb/s 8PSK links to 5.0 m terminals.
	6	18.0	320 Mb/s 8PSK links to 7.0 m terminals.
Ka-band: (area)	8	13.8	52 Mb/s BPSK links to 3.0 m terminals.
	8	6.2	52 Mb/s QPSK links to 5.0 m terminals.
Ka-band: (spots)	6	2.6	52 Mb/s BPSK links to 1.8 m terminals.
	11	1.2	52 Mb/s QPSK links to 3.0 m terminals.
	11	1.3	160 Mb/s QPSK links to 5.0 m terminals.
	5	10.2	320 Mb/s 8PSK links to 5.0 m terminals.

The use of differential coherent 8PSK modulation with .905 FEC coding is recommended for signals destined for bulk demodulators and 8PSK modulation with .829 FEC coding is recommended for regular demodulator assignment. The use of higher order modulation techniques provides spectrum efficiency which is required for the high data capacity of the DDS satellite.

The antenna coverage for satellite receiving at Ku-band consists of  $1.73^\circ$  beams of 35.9 dB edge-of-coverage gain and  $0.87^\circ$  spot beams of 41.5 dB edge-of-coverage gain. The Ka-band antenna coverage consists of  $1.73^\circ$  beams of 35.9 dB edge-of-coverage gain and  $0.5^\circ$  spot beams of 46.3 dB edge-of-coverage gain.

An rf interconnect switch, controlled via the satellite communications command/control link, provides flexibility in the assignment of various uplink beams to the appropriate demodulator equipment.

## 7.4.2 Summary of Uplink Capacity

The uplink configuration of the DDS satellite would be implemented in a manner to best accommodate the uplink data requirements. One plan, which serves as the year 2007 baseline design, is given in Table 7-3. This configuration provides a maximum uplink capacity of 13.52 Gb/s which is divided between 5.5 Gb/s at Ku-band and 8.0 Gb/s at Ka-band.

The large data throughput, within the constraints of bandwidth allocations of only 500 MHz at both Ku-band and Ka-band, dictates the use of spectrum efficient modulation techniques such as 8PSK. The associated earth terminal parameters required to establish a viable link are moderate as shown in the link budgets of ¶7.4.3 and ¶7.4.4.

### 7.4.2.1 Ku-Band Uplink Capacity

Ku-band uplinks will be described for the area coverage and spot beam coverages, together with the Ku-band frequency planning:

**Area Coverage.** The eight area coverage beams of  $1.73^\circ$  beamwidth accommodate 1,248 Mb/s of uplink data rate. The baseline plan assumes that each beam accommodates low rate signals with D-8PSK modulation by having one bulk demodulator for 144 kb/s signals (up to 327 channels per bulk demodulator) and one bulk demodulator for 1.5 Mb/s signals (up to 30 channels per bulk demodulator). Each of the 16 bulk demodulators

would accommodate a thrupt rate of 52 Mb/s for a total capacity of 832 Mb/s.

The higher data rate uplink signals of 6 Mb/s to 30 Mb/s are accommodated by regular dedicated demodulators. The total capacity of the wideband channels would be 52 Mb/s per each of 8 beams for a total capacity of 416 Mb/s.

**Spot Beam Coverage.** About ten active spot beams of  $0.87^\circ$  size are utilized at Ku-band. (Note: other spot beams may be implemented and activated for alternate system configuration.) Various combinations of low rate and high rate signals may be accommodated. The baseline plan assigns low rate signals within each beam to a bulk demodulator of 52 Mb/s output. One half of this output may be devoted to signals of 144 kb/s data rate and the other half to signals of 1.5 Mb/s. (An alternate technique would utilize two bulk demodulators of 26 Mb/s output, each specialized for the particular input data rate.) A total small signal capacity of 520 Mb/s is thus provided.

The high rate signal would be accommodated by regular demodulators. The baseline shows 10 links of 52 Mb/s, 10 links of 160 Mb/s and 5 links of 320 Mb/s which would be distributed among the various spot beams on a non-interference basis. The high rate capacity links would thus total to 3,720 Mb/s.

**Frequency Planning.** The assignment of user Ku-band uplink channels on a non-interfering basis within the 500 MHz bandwidth of 14.0 to 14.5 GHz is critical to successful system operation. One plan for accommodating the candidate Ku-band uplinks previously described is depicted in Figure 7-9. The lower 250 MHz of spectrum is assigned to the eight area coverage beams. The plan utilizes only 125 MHz of spectrum per beam and also the beams alternate between horizontal and vertical polarization in order to assure no interference. Three bandwidths are assigned within each 125 MHz of spectrum. The first two are 42 MHz each and are used to accommodate the bulk demodulation capacities of 52 Mb/s when using D-8PSK modulation and 0.905 FEC coding. The third bandwidth of 29 MHz is used to accommodate 52 Mb/s of wideband uplinks signals using 8PSK modulation and 0.829 FEC coding.

Table 7-3: Summary of Uplink Capacity (Year 2007)

Ku-Band Uplinks	No. & Rate	Total (Mb/s)	Comments
<b>Area Coverage Beams</b>			8 area beams of 1.73°
D-8PSK (.905)	16 @ 52 Mb/s	832	2 bulk demods per beam, 1 for 144 kb/s and 1 for 1.5 Mb/s channels.
8PSK (.829)	8 @ 52 Mb/s	416	
<b>Spot Beams</b>			10 spot beams of 0.87°
D-8PSK (.905)	10 @ 52 Mb/s	520	2 bulk demods per beam, 1 for 144 kb/s and 1 for 1.5 Mb/s channels.
8PSK (.829)	10 @ 52 Mb/s	520	
8PSK (.829)	10 @ 160 Mb/s	1,600	
8PSK (.829)	5 @ 320 Mb/s	1,600	1 polarization only
		13,520	Mb/s uplink peak capacity

Ka-Band Uplinks	No. & Rate	Total (Mb/s)	Comments
<b>Area Coverage Beams</b>			8 area beams of 1.73°
D-8PSK (.905)	16 @ 52 Mb/s	832	2 bulk demods per beam, 1 for 144 kb/s and 1 for 1.5 Mb/s channels.
8PSK (.829)	8 @ 52 Mb/s	416	
<b>Spot Beams</b>			16 spot beams of 0.5°
D-8PSK (.905)	16 @ 52 Mb/s	832	2 bulk demods per beam, 1 for 144 kb/s and 1 for 1.5 Mb/s channels.
8PSK (.829)	16 @ 52 Mb/s	832	
8PSK (.829)	16 @ 160 Mb/s	2,560	
8PSK (.829)	8 @ 320 Mb/s	2,560	1 polarization only
		13,520	Mb/s uplink peak capacity

The upper 250 MHz of spectrum is assigned to the spot beam coverage. Thus the spot beam and area coverage beam applications do not interfere. Figure 7-9 shows alternate plans (A, B, C, and D) for the spot beam spectrum allocation. A mixture of these plans would probably be utilized among the 10 uplink spot beams to best accommodate specific user uplink requirements.

**Plan A** (see Figure 7-9) shows that 180 MHz of spectrum is required to accommodate a 320 Mb/s uplink signal with 8PSK modulation and 0.829 FEC coding. Either horizontal or vertical polarization would be used to provide adequate isolation from other close proximity spot beams.

**Plan B** augments Plan A with the addition of a 29 MHz bandwidth for 52 Mb/s of 8PSK, 0.829 FEC coding signals and a 42 MHz bandwidth for a bulk demodulator spectrum to accommodate 52 Mb/s capacity with D-8PSK modulation and 0.905 FEC coding.

**Plan C** allows two uplink data rates of 160 Mb/s as well as 52 Mb/s per regular demodulation and 52 Mb/s for bulk demodulation.

**Plan D** incorporates even more 52 Mb/s spectrums with wideband capacity reduced to a single 160 Mb/s data link.

#### 7.4.2.2 Ka-Band Uplink Capacity

Ka-band uplinks are described for the area coverage and spot beam coverages, together with the Ku-band frequency planning:

**Area Coverage.** The eight area coverage beams at Ka-band would be implemented in an identical manner to the Ku-band plan previously described. The total capacity would be 1,248 Mb/s.

**Spot Beam Coverage.** The 16 spot beams at Ka-band would accommodate 6,784 Mb/s throughput. The baseline plan provides 16 links of 52 Mb/s total capacity for bulk demodulators, 16 links of 52 Mb/s signals, 16 links of 160 Mb/s, and 8 links of 320 Mb/s.

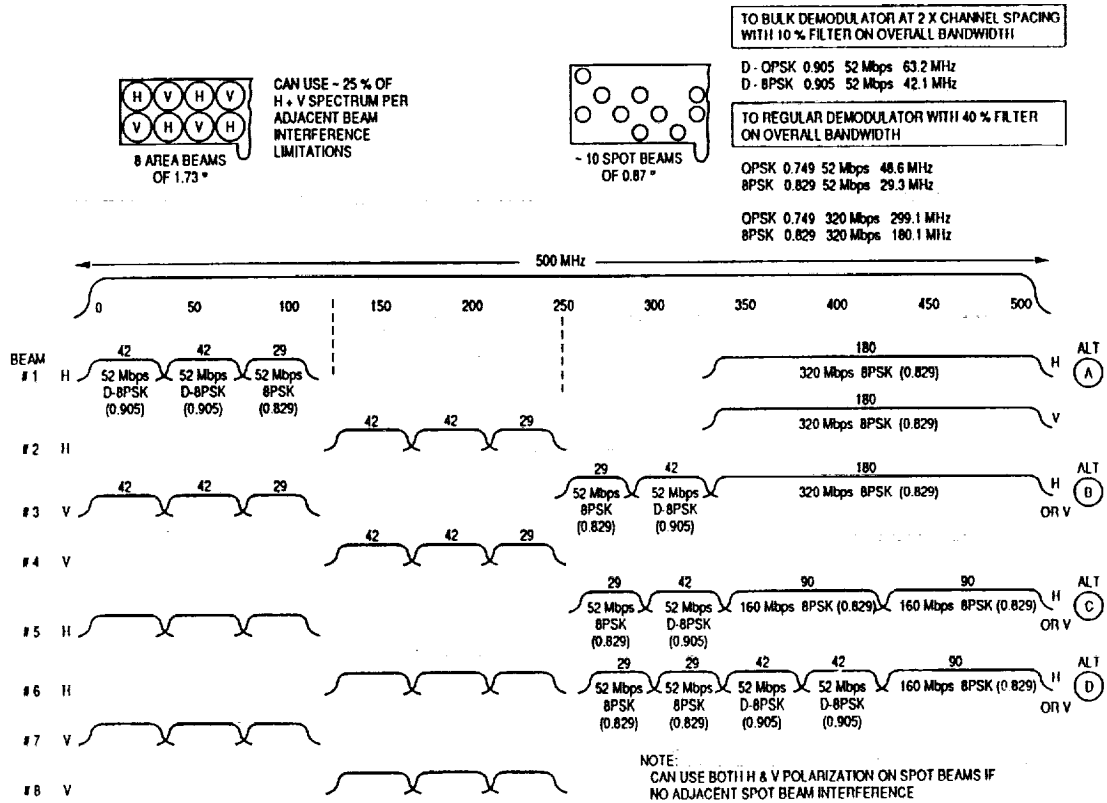


Figure 7-9: Spectrum Utilization of Ku-Band Uplinks

**Frequency Planning.** The Ka-band frequency plan to avoid interference is identical to that previously described for Ku-band and shown in Figure 7-6. The lower 250 MHz of spectrum is assigned exclusively to the area coverage beams and the upper 250 MHz is exclusively assigned to spot beam implementation.

**7.4.3 Ku-Band Uplink Link Budgets**

Link budgets are given in Tables 7-4 and 7-5 for the 1.73° area coverage and 0.87° spot beams respectively. Calculations are made at the center frequency (14.25 GHz) of the 14.0-14.5 GHz band, and 60% antenna efficiency is assumed.

The figures in italics at the top of the tables are the link parameters desired by the user and required to close the link. The figures at the bottom of the tables are the link calculations in nine columns corresponding to nine different cases.

**Area Coverage Link Budget (Ku-Band Uplinks)**

A summary of typical Ku-band uplink communications power budgets for operation into the Ku-band 1.73° area coverage antenna beams is shown in Table 7-4. All of the candidate links incorporate 3 dB of rain margin which assures 99.5% link availability to rain region E (worst case) and 99.8% to rain region D-2 (average case). A net system margin of 3.0 dB is also provided.

The first column shows that a 1.8 m VSAT terminal operating with 5.8 W transmitter rf power can transmit data at a rate of 1.5 Mb/s to a satellite bulk demodulator. This link uses D-QPSK modulation and .905 FEC coding to achieve a link quality of 10<sup>-8</sup> bit error rate.

The other columns depict the performance of earth terminals ranging in size from 3 m diameter up to 7 m diameter. For example, the last column shows that a 7 m earth terminal, operating with 132 W transmitter rf power, can transmit data at a rate of 320 Mb/s. This link uses 8PSK modulation and .829 FEC coding to achieve a link quality of 10<sup>-10</sup> bit error rate.

The tradeoffs among power, bandwidth, and other link parameters is more fully described in ¶7.5.



Table 7-4: Ku-Band Uplink Power Budgets for 1.73° Satellite Beams (0.9 m Antenna)

<i>VSAT transmit power (W)</i>	5.8	0.2	2.1	8.3	19.0	33.0	43.0	129.0	132.0
<i>VSAT antenna size (m)</i>	1.8	3.0	3.0	3.0	3.0	3.0	5.0	5.0	7.0
<i>Data rate (Mb/s)</i>	1.5	0.144	1.5	6.0	30.0	52.0	52.0	160.0	320.0
<i>Coding rate</i>	.905	.905	.905	.905	.749	.749	.829	.829	.829
<i>Modulation type</i>	DQPSK	DQPSK	DQPSK	QPSK	QPSK	QPSK	8PSK	8PSK	8PSK
<i>Bit error rate (dB)</i>	-80	-80	-80	-80	-100	-100	-100	-100	-100
<i>Bulk demodulation?</i>	yes	yes	yes	yes	no	no	no	no	no
<i>Rain Margin 3.0 dB</i>	99.5% Region E, 99.8% Region D-2 availability								
<i>VSAT transmit power (dBW)</i>	7.6	-7.0	3.2	9.2	12.8	15.2	16.3	21.1	21.2
<i>Line loss (dB)</i>	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
<i>VSAT antenna gain (dBi)</i>	46.3	50.7	50.7	50.7	50.7	50.7	55.1	55.1	58.0
<i>VSAT EIRP (dBW)</i>	52.9	42.7	52.9	58.0	62.5	64.9	70.4	75.2	78.2
<i>Space loss, 38 Mm (dB)</i>	207.1	207.1	207.1	207.1	207.1	207.1	207.1	207.1	207.1
<i>Pointing loss (dB)</i>	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
<i>Atmosphere loss (dB)</i>	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
<i>Rain margin (dB)</i>	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
<i>Sat. antenna EOC gain (dBi)</i>	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
<i>Line loss (dB)</i>	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
<i>Sys. noise temp. 420 K (dB-K)</i>	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2
<i>Satellite G/T (dB/K)</i>	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
<i>Receive C/N<sub>0</sub> (dB-Hz)</i>	79.4	69.2	79.4	84.5	89.0	91.4	96.9	101.7	104.6
<i>Data rate (dB-Hz)</i>	61.8	51.6	61.8	67.8	74.8	77.2	77.2	82.0	85.0
<i>Modem loss (dB)</i>	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
<i>Interference loss (dB)</i>	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
<i>Coding gain (dB)</i>	3.7	3.7	3.7	3.7	6.0	6.0	6.5	6.5	6.5
<i>Required E<sub>s</sub>/N<sub>0</sub> (dB)</i>	14.3	14.3	14.3	14.3	13.2	13.2	16.7	16.7	16.7
<i>System margin (dB)</i>	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

#### Spot Beam Link Budget (Ku-Band Uplinks)

A summary of typical Ku-band uplink communications power budgets for operation into the 0.87° spot beams is shown in Table 7-5. All links incorporate 3 dB of rain margin and provide an additional net system margin of 3.0 dB.

The first column shows that a 1.8 m VSAT terminal, operating with only 1.2 W transmitter power, can transmit data at a rate of 1.5 Mb/s to a satellite bulk demodulator. This reference uses D-QPSK modulation and .905 FEC coding to achieve a link quality of  $10^{-8}$  (-80 dB) bit error rate. If more efficient bandwidth utilization is required, then D-8PSK modulation could be utilized at the penalty of a fourfold (6 dB) increase in transmitter power.

The last column shows that a large terminal of 7 m diameter, operating with 27 W rf power, can accommodate a data link of 320 Mb/s. This link uses 8PSK modulation and 0.829 FEC coding to achieve a link quality of  $10^{-10}$  (-100 dB) bit error rate.

#### 7.4.4 Ka-Band Uplink Link Budgets

Link budgets are given in Tables 7-6 and 7-7 for the area coverage and spot beams respectively. Calculations are made at the center frequency (29.75 GHz) of the 29.5–30.0 GHz band, and 60% antenna efficiency is assumed.

The figures in italics at the top of the tables are the link parameters desired by the user and required to close the link. The figures at the bottom of the tables are the link calculations in nine columns corresponding to nine different cases.

#### Area Coverage Link Budget (Ka-Band Uplinks)

A summary of typical Ka-band uplink communications power budgets for operation into the Ka-band 1.73° area coverage antenna beams is shown in Table 7-6. All of the candidate links incorporate 3.1 dB of rain margin which assures 99.5% link availability to rain region E and 99.8% to rain region D-2. A net system margin of 3.0 dB is also provided.

The first column shows that a 1.8 m VSAT terminal,

Table 7-5: Ku-Band Uplink Power Budgets for 0.87° Satellite Beams (2.0 m Antenna)

VSAT transmit power (W)	1.2	.04	.42	1.7	8.5	6.8	8.8	26.0	27.0
VSAT antenna size (m)	1.8	3.0	3.0	3.0	3.0	3.0	5.0	5.0	7.0
Data rate (Mb/s)	1.5	0.144	1.5	6.0	30.0	52.0	52.0	160.0	320.0
Coding rate	.905	.905	.905	.905	.749	.749	.829	.829	.829
Modulation type	DQPSK	DQPSK	DQPSK	QPSK	QPSK	QPSK	8PSK	8PSK	8PSK
Bit error rate (dB)	-80	-80	-80	-80	-100	-100	-100	-100	-100
Bulk demodulation?	yes	yes	yes	yes	no	no	no	no	no
Rain Margin 3.0 dB	99.5% Region E, 99.8% Region D-2 availability								
VSAT transmit power (dBW)	0.7	-13.9	-3.7	2.3	9.3	8.3	9.4	14.2	14.3
Line loss (dB)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
VSAT antenna gain (dBi)	46.3	50.7	50.7	50.7	50.7	50.7	55.1	55.1	58.0
VSAT EIRP (dBW)	46.0	35.8	46.0	52.0	59.0	58.0	63.5	68.3	71.3
Space loss, 38 Mm (dB)	207.1	207.1	207.1	207.1	207.1	207.1	207.1	207.1	207.1
Pointing loss (dB)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Atmosphere loss (dB)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rain margin (dB)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Sat. antenna EOC gain (dBi)	42.8	42.8	42.8	42.8	42.8	42.8	42.8	42.8	42.8
Line loss (dB)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sys. noise temp. 420 K (dB-K)	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2	26.2
Satellite G/T (dB/K)	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
Receive C/N <sub>0</sub> (dB-Hz)	79.4	69.2	79.4	84.5	89.0	91.4	96.9	101.7	104.6
Data rate (dB-Hz)	61.8	51.6	61.8	67.8	74.8	77.2	77.2	82.0	85.0
Modem loss (dB)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Interference loss (dB)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Coding gain (dB)	3.7	3.7	3.7	3.7	6.0	6.0	6.5	6.5	6.5
Required E <sub>b</sub> /N <sub>0</sub> (dB)	14.3	14.3	14.3	14.3	13.2	13.2	16.7	16.7	16.7
System margin (dB)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

operating with 8.2 W transmitter rf power, can transmit data at a rate of 1.5 Mb/s to a satellite bulk demodulator. This link uses D-QPSK modulation and 0.905 FEC coding to achieve a link quality of  $10^{-8}$  bit error rate.

The other columns depict the reference performance of candidate earth terminals ranging in size from 3 m diameter up to 7 m diameter. For example the second to last column shows that a 5 m diameter earth terminal, operating with 178 W transmitter rf power, can transmit data at a rate of 160 Mb/s. This link uses 8PSK modulation (for bandwidth efficiency) and 0.829 FEC coding to achieve a link quality of  $10^{-10}$  bit error rate.

### Spot Beam Link Budget (Ka-Band Uplinks)

A summary of typical Ka-band uplink communications power budgets for operation into the 0.5° spot beams is shown in Table 7-7. All links incorporate 3.1 dB of rain margin and provide a net system margin of 3.0 dB.

The first column shows that a 1.8 m VSAT terminal, operating with only 0.55 W transmitter rf power, can

transmit data at a rate of 1.5 Mb/s to a satellite bulk demodulator. This link uses D-QPSK modulation and .905 FEC coding to achieve a link quality of  $10^{-8}$  bit error rate. If more efficient bandwidth utilization was required then D-8PSK modulation would be used with an increase in transmitter power to about 2.5 W.

The second to last column shows that a large terminal of 5 m diameter, operating with 12 W rf power output, can accommodate a data link of 160 Mb/s. This link uses 8PSK modulation and 0.829 FEC coding to achieve a link quality of  $10^{-10}$  bit error rate. The large size terminals would typically be used at the major data centers.





## 7.5 Downlinks

The discussion of the satellite downlink configuration is divided into four parts:

- 7.5.1 Satellite Transmit Parameters
- 7.5.2 Summary of Downlink Capacity
- 7.5.3 Ku-Band Downlink Link Budgets
- 7.5.4 Ka-Band Downlink Link Budgets

### 7.5.1 Satellite Transmit Parameters

The overall block diagram for baseline DDS satellite transmitting configuration at Ku-band was previously shown in Figure 7-8. A similar plan would also be used at Ka-band. The low data rate signals (typically at 144 kb/s, 1.5 Mb/s, or 6 Mb/s) are combined and transmitted in a TDM format. The high data rate signals of 52 to 640 Mb/s would be transmitted on a single channel per carrier basis with a dedicated transmitter exciter or power amplifier. A multiple number of rf carriers, each destined for a particular downlink antenna beam, may be combined and amplified via a single satellite power amplifier for TDM transmission.

The use of BPSK modulation with .749 FEC coding is recommended for those links requiring a high power efficiency in order to conserve satellite power requirements. If the earth terminals are of large size (5 to 7 m diameter) and if the link information capacity is large, then the use of QPSK with .749 FEC coding or 8PSK with .829 FEC coding may be employed for spectrum efficiency.

For Ku-band satellite transmission, only one antenna coverage is provided:

- 27 beams of  $0.87^\circ$  half power beamwidth provide 45.8 dB of peak gain. The edge of coverage gain at 4.3 dB coverage overlap is then 41.5 dB. The satellite antenna diameter is 2.0 m.

Note that there is no area coverage downlink beam at Ku-band. The  $0.87^\circ$  spots form a matrix covering all of CONUS.

For Ka-band satellite transmission, there are two antenna coverage patterns.

- Full CONUS coverage is obtained by using 8 beams of  $1.73^\circ$  half power beamwidth, with each beam having 40.2 dB peak gain and 35.9 dB edge-of-coverage gain.

- 12 to 16 active spot beams (out of a potential matrix of 20 or more) of  $0.5^\circ$  half power beamwidth are directed at designated high traffic areas. The spot beam antenna has a 2.2 m diameter, and peak gain is 50.6 dB.

### 7.5.2 Summary of Downlink Capacity

The downlink configuration of the DDS satellite would be implemented in a manner to best accommodate the downlink data requirements expressed in terms of the desired link capacities, data quality, and communications availability. The satellite power requirements are also dependent on the selected modulation technique and the size of the user earth terminal. A summary of the satellite rf power required to transmit Gb/s of downlink data at Ku-band via the  $0.87^\circ$  HPBW satellite antenna is given in Table 7-8.

It requires 171 W to communicate using BPSK with .616 FEC coding to a 1.8 m user VSAT antenna, whereas 861 W are required if using 8PSK modulation with .829 FEC coding. The power efficiency must also be traded off versus the bandwidth requirements. In this case, a 52 Mb/s link would require 118.2 MHz of bandwidth for BPSK (.616 FEC), whereas the 8PSK (.829 FEC) link at 52 Mb/s would require only 29.3 MHz of bandwidth.

For the example of larger user terminals, it is shown in Table 7-8 that 32 W is required to transmit 1 Gb/s to user terminals of 5 m diameter when using QPSK (.749 FEC) and 114 W when using 8PSK (.829 FEC).

The total available DDS satellite power for the year 2007 bus configuration is expected to be about 2,800 W at end of the 10 year life. Thus the allocation of the power among the various downlinks must be rationed with care in order to accommodate a projected total data throughput of about 10 Gb/s.

One plan for DDS satellite rf power allocation, which may serve as a candidate baseline design, is summarized in Figure 7-10. It is projected that 2,800 W is available to the DDS communications subsystem power amplifier equipment at the ten year end-of-life period. About 2,000 W (71% of total) would be allocated for Ku-band transmitting and the remaining 800 W (29% of total) would be allocated to Ka-band transmitting. Assuming 37% efficiency for dc-to-rf power conversion at Ku-band, this provides 740 W power to be allocated. Similarly a conversion efficiency of 31% at Ka-band would provide 248 W power.

Table 7-8: Power Allocation for Ku-Band Downlinks

Data Rate (Mb/s)	Modulation and Coding	Required Bandwidth (MHz)	RF Power (W) per Gb/s Data Rate into Ground Terminal Size of:				
			1.2 m	1.8 m	3 m	5 m	7 m
52	BPSK (.616)	118.2	384	171	65	23	12
	BPSK (.749)	97.2	432	192	73	26	13
	QPSK (.749)	48.6	533	237	90	32	16
	8PSK (.829)	29.3	1,937	861	327	114	57
160	QPSK (.749)	149.5	533	237	90	32	16
	8PSK (.829)	90.1	1,937	861	327	114	57
320	QPSK (.749)	299.1	533	237	90	32	16
	8PSK (.829)	180.1	1,937	861	327	114	57

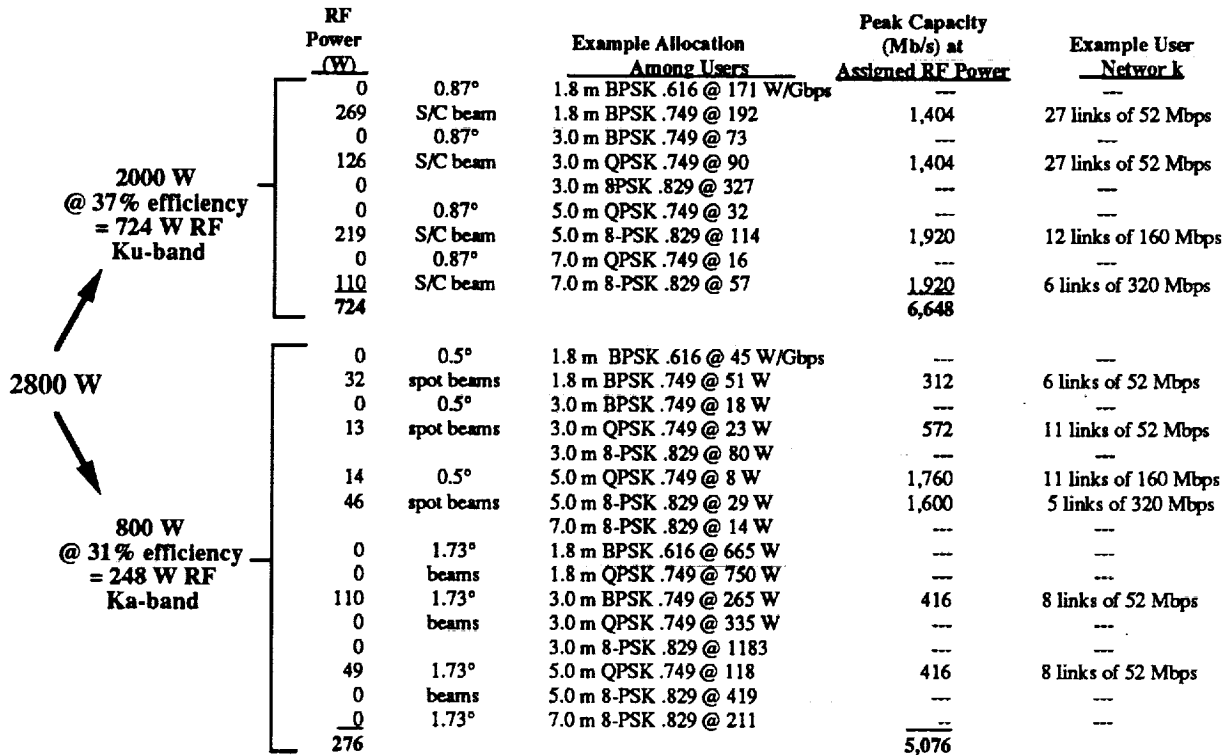


Figure 7-10: Satellite RF Power Allocation (Year 2007)

When this power is allocated among the various defined candidate downlinks it provides a total of 11.724 Gb/s of down link information transfer capacity with 6.648 Gb/s achieved at Ku-band and 5.076 Gb/s at Ka-band.

Figure 7-10 shows the power requirements of the candidate plan as well as the power requirements of alternate link configuration. Many alternate plans are feasible provided that they are within the total rf power available and also are within the total spectrum available. A balanced approach to the link configuration plan is key to the definition of an efficient DDS communications system. For example in order to achieve total capacity in excess of 10 Gb/s, it is required that satellite spot beams be used and that the high capacity user terminals be implemented with antenna apertures of 5 to 7 m diameter.

Another summary of the downlink capacity of DDS for baseline configuration is given in Table 7-9.

- 0.716 Gb/s is available to be distributed to users which have 1.8 m diameter antennas,
- 2.392 Gb/s to users having 3 m antennas,
- 5.696 Gb/s to users having 5 m antennas, and
- 1.920 Gb/s to users having 7 m antennas.

The associated modulation and coding techniques are selected as a tradeoff between power and bandwidth efficiency.

#### Ku-Band Downlink Frequency Planning

The assignment of user downlink channels on a non-interfering basis within the 500 MHz bandwidth of 11.7 to 12.3 GHz is critical to successful system operation. Plans for accommodating the candidate Ku-band downlinks previously described is shown in Figure 7-11. Because of adjacent beam interference, the downlink beams would alternate in polarization (horizontal or vertical) and each would use no more than 250 MHz of spectrum.

If a system configuration becomes very power constrained, then the links shown in section A (of Figure 7-11) which use BPSK are viable. An output capacity per beam may be 104 Mb/s QPSK (.749 FEC) link. If the system becomes bandwidth constrained then the links shown in section B (of Figure 7-11) which use 8PSK

modulation are preferred. For example 416 Mb/s capacity may be obtained within 250 MHz of spectrum by using 8 links of 52 Mb/s of 8PSK (.829 FEC).

Balanced plans for compromise between power and bandwidth efficiency are shown in section C (of Figure 7-11). A specific frequency plan allocation would be dependent upon determination of user requirements within specific geographic locations within CONUS.

#### Ka-Band Downlink Frequency Planning

The Ka-band downlinks of DDS incorporate both area coverage beams of  $1.73^\circ$  HPBW as well as spot beams of  $0.5^\circ$  HPBW. The general frequency use plan for the 500 MHz of bandwidth available between 19.7 and 20.2 GHz is similar to that previously shown for the Ku-band uplinks in Figure 7-9. One half of the spectrum is reserved exclusively for the  $1.73^\circ$  area coverage beams and the other 250 MHz is allocated for  $0.5^\circ$  spot beam use.

Adjacent beam interference is minimized by using polarization diversity and by using only selected portions of the available bandwidth per beam.

#### 7.5.3 Ku-Band Downlink Link Budgets

Only one downlink coverage pattern of  $0.87^\circ$  spot beams is provided at Ku-band. Table 7-10 gives a summary of typical Ku-band downlink communications power budgets. All of the candidate links incorporate 2.0 dB of rain margin which gives 98.5% link availability to rain region E (worst case) and 99.8% to rain region D-2. A net system margin of 3.0 dB is also provided. Calculations are made at the center frequency (11.95 GHz) of the 11.7-12.2 GHz band, and 60% antenna efficiency is assumed.

The figures in italics at the top of the table are the link parameters desired by the user and required to close the link. The figures at the bottom of the tables are the link calculations in nine columns corresponding to nine different cases.

The first column shows that a satellite rf power of 8.9 W is required to communicate at 52 Mb/s TDM burst rate to a small user terminal with 1.8 m diameter antenna. This link uses BPSK modulation and .616 FEC coding to achieve a link quality of  $10^{-10}$  bit error rate.

The other columns depict the performance of other earth terminals ranging in size from 1.8 to 7 m diameter. For example, the last column shows that a satel-

Table 7-9: Summary of Downlink Capacity (Year 2007)

	To 1.8 m Terminal	3.0 m	5.0 m	7.0 m
<b>Ku-Band:</b> Area Coverage (27 beams) • TDM BPSK (.749) • TDM QPSK (.749) - 8QSK (.829) - 8PSK (.829)	27 links of 52 Mbps (1,404 Mbps) --- ---	--- 27 links of 52 Mbps (1,404 Mbps) ---	--- --- 12 links of 160 Mbps (1,920 Mbps) ---	--- --- --- 6 links of 320 Mbps (1,920 Mbps)
<b>Ka-Band:</b> Area Coverage (8 beams) • TDM BPSK (.749) • TDM QPSK (.749) Spot Beams (16 beams) • TDM BPSK (.749) • TDM QPSK (.749) - QPSK (.749) - 8PSK (.829)	--- --- 6 links of 52 Mbps (312 Mbps) ---	8 links of 52 Mbps (416 Mbps) --- 11 links of 52 Mbps (572 Mbps) ---	--- 8 links of 52 Mbps (716 Mbps) --- 11 links of 160 Mbps (1,760 Mbps) 5 links of 320 Mbps (1,600 Mbps)	--- --- ---
<b>TOTAL</b>	<b>1,716 Mbps</b>	<b>2,392 Mbps</b>	<b>5,696 Mbps</b>	<b>1,920 Mbps</b>

Note: Total maximum capacity throughput is 11.724 Gbps

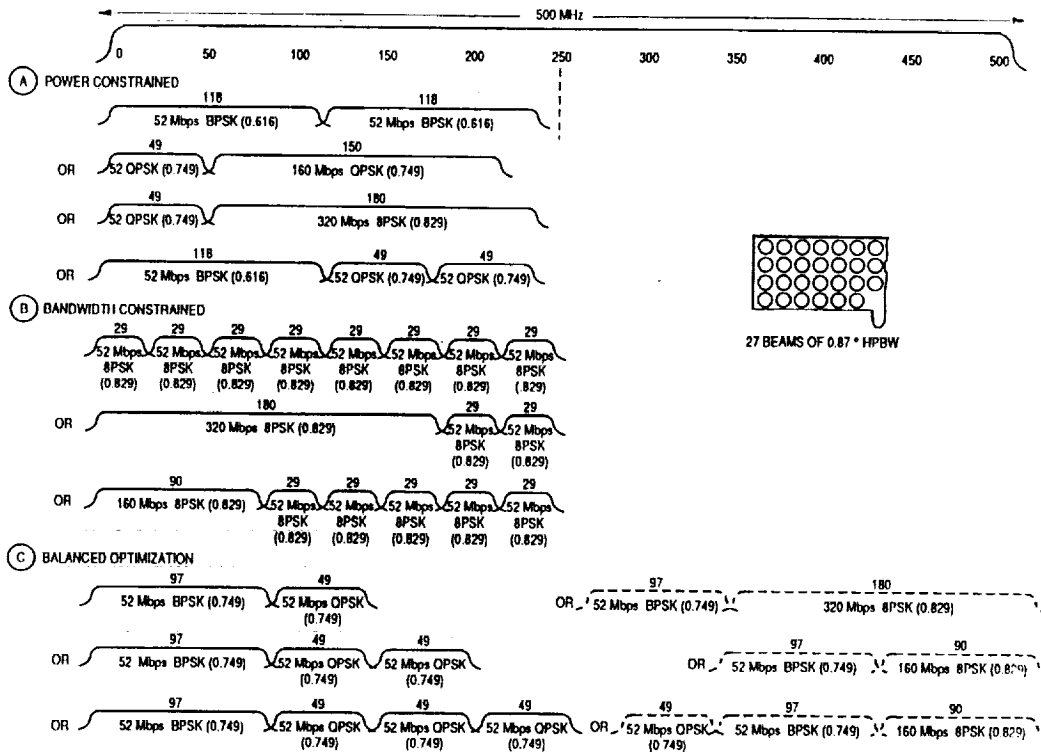


Figure 7-11: Spectrum Utilization - Ku-Band Downlinks



Table 7-10: Ku-Band Downlink Power Budgets for 0.87° Satellite Beams (2.0 m Antenna)

<i>Sat. transmit power (W)</i>	8.9	10.0	17.0	3.8	4.7	1.7	10.2	5.1	18.1
<i>VSAT antenna size (m)</i>	1.8	1.8	3.0	3.0	3.0	5.0	5.0	7.0	7.0
<i>Data rate (Mb/s)</i>	52	52	52	52	52	52	320	320	320
<i>Coding rate</i>	.616	.749	.829	.749	.749	.749	.749	.749	.829
<i>Modulation type</i>	BPSK	BPSK	8PSK	BPSK	QPSK	QPSK	QPSK	QPSK	8PSK
<i>Bit error rate (dB)</i>	-100	-100	-100	-100	-100	-100	-100	-100	-100
<i>Rain Margin 2.0 dB</i>	98.5% Region E, 99.8% Region D-2 availability								
Satellite transmit power (dBW)	9.5	10.0	12.3	5.8	6.8	2.2	10.1	7.1	12.6
Line loss (dB)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sat. EOC antenna gain (dBi)	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5
Satellite EIRP (dBW)	50.0	50.5	52.8	46.3	47.3	42.7	50.6	47.6	53.1
Space loss, 38 Mm (dB)	205.6	205.6	205.6	205.6	205.6	205.6	205.6	205.6	205.6
Pointing loss (dB)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Atmosphere loss (dB)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Rain margin (dB)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Ground antenna gain (dBi)	44.8	44.8	49.0	49.0	49.0	53.7	53.7	56.6	56.6
Line loss (dB)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sys. noise temp. 280 K (dB-K)	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5
Ground antenna G/T (dB/K)	19.3	19.3	23.5	23.5	23.5	28.2	28.2	31.1	31.1
Receive C/N <sub>0</sub> (dB-Hz)	89.9	90.4	96.9	90.4	91.4	91.5	99.4	99.3	104.8
Data rate (dB-Hz)	77.2	77.2	77.2	77.2	77.2	77.2	85.1	85.1	85.1
Modem loss (dB)	1.0	1.0	2.5	1.0	2.0	2.0	2.0	2.0	2.5
Interference loss (dB)	1.0	1.0	4.0	1.0	2.0	2.0	2.0	2.0	4.0
Coding gain (dB)	5.5	5.0	6.5	5.0	6.0	6.0	6.0	6.0	6.5
Required E <sub>b</sub> /N <sub>0</sub> (dB)	13.2	13.2	16.7	13.2	13.2	13.2	13.2	13.2	16.7
System margin (dB)	3.0	3.0	3.0	3.0	3.0	3.1	3.1	3.0	3.0

lite rf power of 18.1 W is required to communicate at 320 Mb/s to a user with a terminal of 7 m diameter. This link uses 8PSK modulation and .829 FEC coding to achieve a link quality of 10<sup>-10</sup> bit error rate.

The tradeoffs among power, bandwidth, and other link performance parameters is more fully described in ¶7.7 of this report.

**7.5.4 Ka-Band Downlink Link Budgets**

Link budgets are given in Tables 7-11 and 7-12 for the area coverage and spot beams respectively. Calculations are made at the center frequency (19.95 GHz) of the 19.7-20.2 GHz band, and 60% antenna efficiency is assumed.

The figures in italics at the top of the tables are the link parameters desired by the user and required to close the link. The figures at the bottom of the tables are the link calculations in nine columns corresponding to nine different cases.

**Area Coverage Link Budget (Ka-Band Downlinks)**

A summary of the typical Ka-band downlink communications power budgets for the 1.73° HPBW area coverage beams is shown in Table 7-11. All links incorporate 1.4 dB of rain margin which assures 98.0% link availability to rain region E (worst case) and 99.0% to rain region D-2. A net system margin of 3.0 dB is also provided.

The first column shows that a satellite rf power of 34.6 W is required to communicate at 52 Mb/s TDM burst rate to a small VSAT user terminal of 1.8 m diameter. This link uses BPSK modulation and .616 FEC coding to achieve a link quality of 10<sup>-10</sup> bit error rate.

The other columns depict the performance of other earth terminal configurations ranging in size from 1.8 to 7 m diameter. For example, the last column shows that satellite rf power of 67.5 W is required to communicate at 320 Mb/s to a user with a terminal of 7 m diameter. This link uses 8PSK modulation and .829 FEC coding to achieve a link quality of 10<sup>-10</sup> bit error rate.

Table 7-11: Ka-Band Downlink Power Budgets for 1.73° Satellite Beams (0.6 m Antenna)

Sat. transmit power (W)	34.6	39.0	13.8	17.4	61.5	6.2	21.8	38.0	67.5
VSAT antenna size (m)	1.8	1.8	3.0	3.0	3.0	5.0	5.0	5.0	7.0
Data rate (Mb/s)	52	52	52	52	52	52	52	320	320
Coding rate	.616	.749	.749	.749	.829	.749	.829	.749	.829
Modulation type	BPSK	BPSK	BPSK	QPSK	8PSK	QPSK	8PSK	QPSK	8PSK
Bit error rate (dB)	-100	-100	-100	-100	-100	-100	-100	-100	-100
Rain Margin 1.4 dB	98.0% Region E, 99.0% Region D-2 availability								
Satellite transmit power (dBW)	15.4	15.9	11.4	12.4	17.9	7.9	13.4	15.8	18.3
Line loss (dB)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sat. EOC antenna gain (dBi)	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
Satellite EIRP (dBW)	50.3	50.8	46.3	47.3	52.8	42.8	48.3	50.7	53.2
Space loss, 38 Mm (dB)	209.9	209.9	209.9	209.9	209.9	209.9	209.9	209.9	209.9
Pointing loss (dB)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Atmosphere loss (dB)	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Rain margin (dB)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Ground antenna gain (dBi)	49.1	49.1	53.6	53.6	53.6	58.1	58.1	58.1	61.1
Line loss (dB)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sys. noise temp. 310 K (dB-K)	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9
Ground antenna G/T (dB/K)	23.2	23.2	27.7	27.7	27.7	32.2	32.2	32.2	35.2
Receive C/N <sub>0</sub> (dB-Hz)	89.9	90.4	90.4	91.4	96.9	91.4	96.9	99.3	104.8
Data rate (dB-Hz)	77.2	77.2	77.2	77.2	77.2	77.2	77.2	85.1	85.1
Modem loss (dB)	1.0	1.0	1.0	2.0	2.5	2.0	2.5	2.0	2.5
Interference loss (dB)	1.0	1.0	1.0	2.0	4.0	2.0	4.0	2.0	4.0
Coding gain (dB)	5.5	5.0	5.0	6.0	6.5	6.0	6.5	6.0	6.5
Required E <sub>b</sub> /N <sub>0</sub> (dB)	13.2	13.2	13.2	13.2	16.7	13.2	16.7	13.2	16.7
System margin (dB)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

### Spot Beam Link Budget (Ka-Band Downlinks)

A summary of typical Ka-band downlink communications power budgets for operation with the DDS 0.5° HPBW spot beams is shown in Table 7-12. All links incorporate 1.4 dB of rain margin which assures 98.0% link availability to rain region E (worst case) and 99.0% to rain region D-2. A net system margin of 3.0 dB is also provided.

The first column shows that a satellite rf power of 2.4 W is required to communicate at 52 Mb/s TDM burst rate into a small VSAT user terminal of 1.8 m diameter. This link uses BPSK modulation and .616 FEC coding to achieve a link quality of  $10^{-10}$  bit error rate.

The other columns give the performance of other earth terminal configurations ranging in size from 1.8 to 7 m diameter. For example, the last column shows that a satellite rf power of 4.6 W is required to communicate at 320 Mb/s to a user with a terminal of 7 m diameter. This link uses 8PSK modulation and .829 FEC coding to achieve a link quality of  $10^{-10}$  bit error rate.

These reference link budgets at Ku-band and Ka-

band provide a framework for synthesis of candidate baseline DDS system configurations. If specific users require alternate parameters then the impact on satellite rf power may quickly be evaluated. Some users may require a higher link availability. This may be achieved with a larger antenna diameter, use of a backup space diversity antenna, or reduced data rate or quality.

## 7.6 Intersatellite Links

The capability of the DDS is greatly enhanced by use of intersatellite links (ISLs). The purpose of these links is to accommodate direct relay from ATDRS satellites and other NASA space platforms, and to supply an international relay for science data. The discussion is divided into three subsections:

### 7.6.1 Candidate Intersatellite Links

### 7.6.2 Intersatellite Link Technologies

### 7.6.3 Implementation of ISLs

Table 7-12: Ka-Band Downlink Power Budgets for 0.5° Satellite Beams (2.2 m Antenna)

<i>Sat. transmit power (W)</i>	2.4	2.6	0.9	1.2	4.2	0.4	1.5	2.6	4.6
<i>VSAT antenna size (m)</i>	1.8	1.8	3.0	3.0	3.0	5.0	5.0	5.0	7.0
<i>Data rate (Mb/s)</i>	52	52	52	52	52	52	52	320	320
<i>Coding rate</i>	.616	.749	.749	.749	.829	.749	.829	.749	.829
<i>Modulation type</i>	BPSK	BPSK	BPSK	QPSK	8PSK	QPSK	8PSK	QPSK	8PSK
<i>Bit error rate (dB)</i>	-100	-100	-100	-100	-100	-100	-100	-100	-100
<i>Rain Margin 1.4 dB</i>	98.0% Region E, 99.0% Region D-2 availability								
<i>Satellite transmit power (dBW)</i>	3.7	4.2	-0.3	0.7	6.2	-3.8	1.7	4.1	6.6
<i>Line loss (dB)</i>	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
<i>Sat. EOC antenna gain (dBi)</i>	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6	47.6
<i>Satellite EIRP (dBW)</i>	50.3	50.8	46.3	47.3	52.8	42.8	48.3	50.7	53.2
<i>Space loss, 38 Mm (dB)</i>	209.9	209.9	209.9	209.9	209.9	209.9	209.9	209.9	209.9
<i>Pointing loss (dB)</i>	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
<i>Atmosphere loss (dB)</i>	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
<i>Rain margin (dB)</i>	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
<i>Ground antenna gain (dBi)</i>	49.1	49.1	53.6	53.6	53.6	58.1	58.1	58.1	61.1
<i>Line loss (dB)</i>	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
<i>Sys. noise temp. 310 K (dB-K)</i>	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9	24.9
<i>Ground antenna G/T (dB/K)</i>	23.2	23.2	27.7	27.7	27.7	32.2	32.2	32.2	35.2
<i>Receive C/N<sub>0</sub> (dB-Hz)</i>	89.9	90.4	90.4	91.4	96.9	91.4	96.9	99.3	104.8
<i>Data rate (dB-Hz)</i>	77.2	77.2	77.2	77.2	77.2	77.2	77.2	85.1	85.1
<i>Modem loss (dB)</i>	1.0	1.0	1.0	2.0	2.5	2.0	2.5	2.0	2.5
<i>Interference loss (dB)</i>	1.0	1.0	1.0	2.0	4.0	2.0	4.0	2.0	4.0
<i>Coding gain (dB)</i>	5.5	5.0	5.0	6.0	6.5	6.0	6.5	6.0	6.5
<i>Required E<sub>b</sub>/N<sub>0</sub> (dB)</i>	13.2	13.2	13.2	13.2	16.7	13.2	16.7	13.2	16.7
<i>System margin (dB)</i>	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

### 7.6.1 Candidate Intersatellite Links

The intersatellite links for a second generation DDS satellite (year 2015) are given in Table 7-13 (see Figure 7-4 for on-orbit configuration). Six units with 24 channels of 160 to 1,280 Mb/s can receive 11.84 Gb/s and transmit 7.52 Gb/s. This represents the maximum intersatellite relay capacity of a single DDS using optical technology in 2015.

For 2007, a more modest system of 2 units with 4 channels of 320 Mb/s and 4 channels of 640 Mb/s receive (3.84 Gb/s total) and two channels of 640 Mb/s transmit (1.28 Gb/s total) are proposed for links with two ATDRS's.

### 7.6.2 Intersatellite Link Technology Issues

The choice of transmission frequency between 60 GHz and optical wavelengths is dependent upon the required data capacity of the intersatellite links. For the expected high capacity DDS requirements, laser communication links are required. Modest aperture sizes (15 cm or less) are recommended to reduce the pointing and acquisition

burden. Fiber optics would be used to connect transmitters and receivers to the aperture.

A second generation DDS would be launched about year 2012, thus the cutoff date for technology development may be year 2005. It is expected that only modest improvements will be made in current 60 GHz performance, but a large improvement in current free-space laser communications technology is expected.

A heterodyne, noncoherent FSK modulation provides high data rates with modest complexity. Laser diode sources (2-D arrays) are expected to be available with several watts of power output and at 30% efficiency. A lifetime of 10 years on-orbit should be achievable. In order to assure confidence in the performance of this advanced equipment technology development efforts and testing will be required by NASA.

The maximum expected data rate of a 1 W laser diode transmitter, coupled with a 15 cm aperture, is given in Table 7-14 as a function of link distance.

Table 7-13: Intersatellite Links – Capacity of Single Data Distribution Satellite (2015)

Satellite Link	Link Distance (km)	Receive Channels			Transmit Channels		
		Number of Channels	Rate per Channel (Mb/s)	Total Capacity (Gb/s)	Number of Channels	Rate per Channel (Mb/s)	Total Capacity (Gb/s)
DDS – DDS	30,000	4	1,280	5.12	4	1,280	5.12
DDS – ATDRS (E)	40,000	2	640	1.92	1	160	0.16
DDS – ATDRS (W)	40,000	2	640	1.92	1	160	0.16
DDS – NASA Platform	10,000	2	320	0.96	1	160	0.16
International Relay (W)	60,000	4	320	1.28	4	320	1.28
International Relay (E)	80,000	4	160	0.64	4	160	0.64
Totals		24		11.84	15		7.52

Table 7-14: Data Rate vs. Link Distance

Link Distance (km)	Data Rate (Mb/s)
10,000	10,240
20,000	2,560
30,000	1,280
40,000	640
50,000	480
60,000	320
80,000	160

### 7.6.3 Implementation of the Intersatellite Link

Figure 7-12 shows a block diagram of a candidate intersatellite relay subsystem. There are six intersatellite link (ISL) units, with each unit consisting of four duplex channels through use of wavelength division multiplexing. A very compact package is achieved by coupling the photons focussed at the telescope directly into fiber optics where demultiplexing and redundancy switching occurs. Thus the optical receivers and transmitters can remain within the body of the satellite and be coupled with low loss to the external telescopes.

A design estimate for one ISL unit determined that about 30 kg of mass and 140 W power are required to implement a duplex optical link comprising four 1 W channels of 160 Mb/s to 5 Gb/s capacity (depends on link distance). Multiples of the SONET STS-3 standard

of 155.52 Mb/s would be chosen for the specific data rates.

## 7.7 Communication Tradeoffs

This section examines some of the key tradeoffs among communications and networking parameters which were considered in determining the candidate DDS system configuration for the year 2007 implementation. The tradeoff studies include the following:

- 7.7.1 Satellite location and antenna coverage
- 7.7.2 Modulation/coding for power efficiency
- 7.7.3 Modulation/coding for bandwidth efficiency
- 7.7.4 Link data rates
- 7.7.5 Impact of rain attenuation

### 7.7.1 Alternate Satellite Orbit Positions and Antenna Coverages

#### 7.7.1.1 Orbit Position

For near term implementation of a DDS system (year 2007), it is expected that the satellite would be located over CONUS about equidistant from the Atlantic and Pacific ATDRS's (see Figure 7-4) in order to provide good coverage at high earth terminal elevation angles. The nominal midpoint location would be over White Sands at 108° W longitude. However, it is desirable

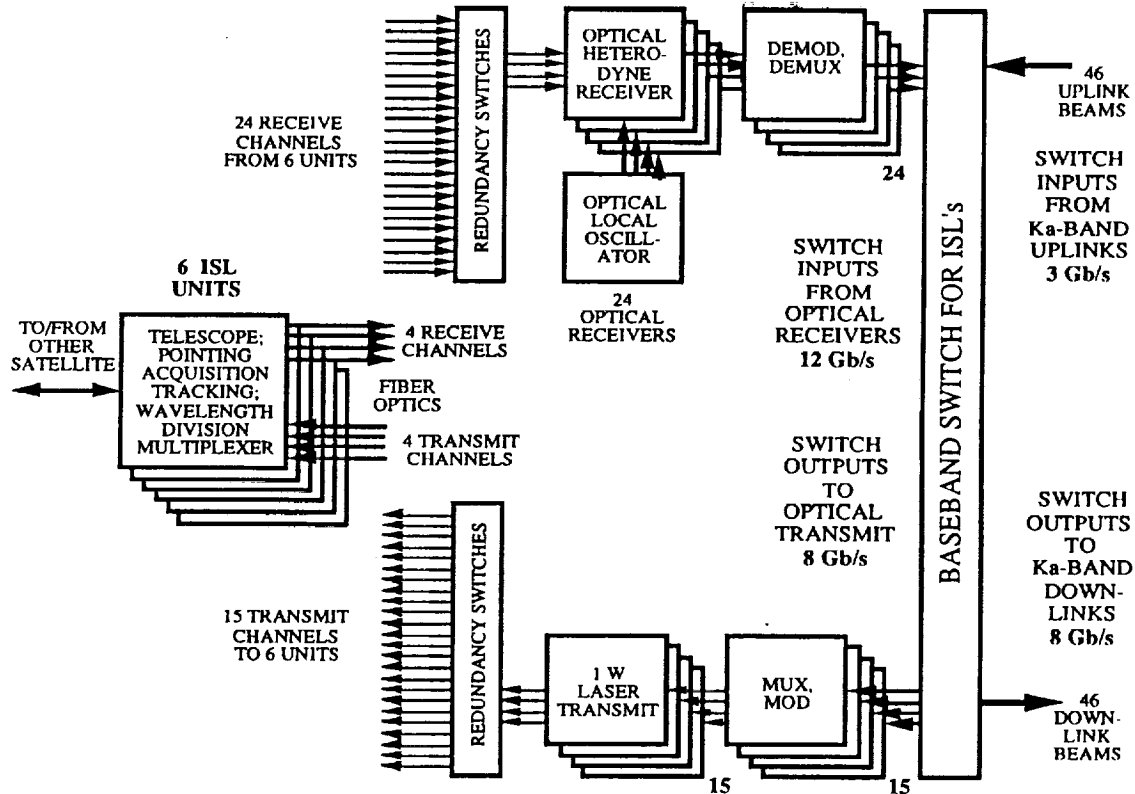


Figure 7-12: Intersatellite Link Block Diagram (2015 DDS Concept)

to favor a more easterly orbital position at  $80^\circ$  W in order to minimize rain attenuation which is worse in the southeast region and to provide greater spot beam resolution for the high traffic northeast region.

The next generation of ASDACS may be implemented in different orbit locations depending on total number of spacecraft providing coverage and on cooperative efforts with other international networks. In addition the DDS capability may be contained within the same spacecraft accommodating the TDRS functions of the DDS spacecraft could be approximately collocated with the ATDRS spacecraft in order to maximize intersatellite link data transfer. This next generation configuration could lead to an on-orbit location of the DDS payload at various locations between  $60^\circ$  W and  $140^\circ$  W.

#### 7.7.1.2 Antenna Coverage

It is expected that the nominal position of a single DDS in the geosynchronous arc will be about  $80^\circ$  W for invited system implementation. If two DDS are required on-orbit then one may be at  $80^\circ$  W (for proximity to

the Atlantic ATDRS and for good East Coast coverage) and the other at  $120^\circ$  W (for proximity to the Pacific ATDRS and for good West Coast coverage).

If a common DDS spacecraft design is to be utilized for both orbit locations (plus on-orbit space), then the antenna coverage must be adaptable. This would be accomplished by switching of several beam positions between active or inactive modes. The number and position of beams must be optimized for both orbital locations.

The complete CONUS coverage at  $80^\circ$  W and  $120^\circ$  W for eight antenna beams of  $1.73^\circ$  half power beamwidth has been shown in Figure 7-1. The views depict the 4.3 dB antenna gain contours for each case. The use of smaller spot beams for complete CONUS coverage at  $80^\circ$  W and  $120^\circ$  W for 28  $0.87^\circ$  beams and for 70  $0.5^\circ$  beams has been shown in Figures 7-2 and 7-3 respectively. The view shows the 4.3 dB gain contours for the 28 beam pattern and the 3 dB gain contours for the 70 beam pattern.

### 7.7.2 Modulation and Coding Alternatives for Power Efficiency

Because of the high throughput capacity of the DDS, it is important to have power efficient downlinks in order to have reasonable satellite solar power requirements. The use of more efficient modulation techniques such as BPSK and the use of FEC block coding with full demodulation in the DDS spacecraft will minimize power requirements. In addition, a reduced power on uplinks will make it easier to implement small, low-cost VSAT terminals. The gain in power efficiency is normally achieved at the penalty of a reduced bandwidth efficiency, and hence both factors must be considered in an overall optimization of the DDS communications system configuration.

A summary of the performance of various modulation and coding techniques is given in Table 7-15. The last column represents a figure of merit (dB) which indicates the overall performance of modulation and coding for the link. The figure of merit is the theoretical  $E_b/N_0$  for the selected modulation technique, plus modem implementation loss, plus interference losses, less the gain achieved from the coding. A smaller figure of merit is better and indicates less power per bit is required to close the link.

Table 7-15 shows that low data rate uplinks at 144 kb/s and 1.5 Mb/s which are destined for bulk demodulators in the spacecraft could be implemented with either D-QPSK modulation with a figure of merit of 14.6 dB or with D-8PSK modulation at 20.9 dB. The difference of 6.3 dB translates to a factor of four in power requirements per bit of data transmitted. A block code at rate .905 would be used in both cases.

It is expected that a bit error rate of  $10^{-8}$  would be adequate for most low data rate transmissions, but that bit error rate of  $10^{-10}$  would be required for high data rate (6 Mb/s) transmissions. This difference in link quality is achieved at a difference of about 1.2 dB in link power.

It is shown in the downlinks section of Table 7-15 that the most efficient link is achieved with BPSK modulation and block .616 code which leads to an overall figure of merit of 9.7 dB. The equivalent link, with less bandwidth, is achieved at QPSK with a block .749 code at a figure of merit of 11.2 dB. The use of 8-PSK with a block .829 code would require the least bandwidth; however, a figure of merit of 16.7 dB is required. The difference of 7 dB in power requirement per bit over the range of modulation/coding techniques represents a

factor of 5 in power.

The interference loss of Table 7-15 is based upon an adjacent channel carrier to interference (C/I) level of 16 dB. The associated loss for BPSK modulation is 1.0 dB, the loss for QPSK modulation is 2.0 dB, and the loss for 8-PSK modulation is 4.0 dB.

The implementation of intersatellite crosslinks is shown in the bottom section of Table 7-15. The use of coherent modulation yields an overall improvement of 3.3 dB in power requirements relative to the use of non-coherent modulation.

### 7.7.3 Modulation and Coding Alternatives for Bandwidth Efficiency

The high data rate throughput of the DDS, and the limited availability of frequency spectrum at Ku-band and Ka-band, requires that bandwidth efficient modulation and coding techniques be employed. It is expected that at least 500 MHz of spectrum would be made available at each frequency band subject to the limitations listed in Table 7-16. The use of spot beams with geographic separation, the use of polarization diversity between adjacent beams will permit frequency reuse.

A summary of the bandwidth requirements for candidate modulation/coding techniques is listed in Table 7-17. The bandwidth values include an excess bandwidth factor of 1.4 to allow for filtering to minimize adjacent channel interference. It is known that the bandwidth required for a 52 Mb/s data rate varies from only 27 MHz for 8-PSK modulation and .905 block coding up to 118 MHz for BPSK modulation with .616 block coding. (The benefits of reduced bandwidth, however, are only achieved at an increased power requirement).

In general the DDS communications links are bandwidth constrained on uplinks and power constrained on the downlinks. The bandwidth requirements of candidate uplinks are summarized in Figure 7-13 and those of candidate downlinks are summarized in Figure 7-14. Some of the uplinks are defined for operation into bulk demodulators which require adjacent channel spacing by a factor of 1.5 to 2.0.

### 7.7.4 Link Data Rate Alternatives

One of the goals for DDS is the Integrated Services Digital Network (ISDN) data links for year 2007 applications. The low rate level for a (2B+D) ISDN channel is 144 kb/s (basic access rate) so this should be used

Table 7-15: Modulation and Coding Choices

Data Rates	Bit Error Rate (log)	Modulation Type	Code Type	Code Rate	Req'd. $E_b/N_0$ (dB)	Coding Gain (dB)	Modem Loss (dB)	Interference Loss (dB)	Figure of Merit (dB)
<b>Uplinks</b>									
144 kb/s	-8	D-QPSK	Block	.905	14.3	3.7	2.0	2.0	14.6
1.5 Mb/s	-8	D-8PSK	Block	.905	18.3	3.9	2.5	4.0	20.9
52-320 Mb/s	-10	QPSK	Block	.749	13.2	6.0	2.0	2.0	11.2
52-320 Mb/s	-10	8PSK	Block	.829	16.7	6.5	2.5	4.0	16.7
<b>Downlinks</b>									
52-320 Mb/s	-10	BPSK	Block	.616	13.2	5.5	1.0	1.0	9.7
52-320 Mb/s	-10	QPSK	Block	.749	13.2	6.0	2.0	2.0	11.2
52-320 Mb/s	-10	8PSK	Block	.829	16.7	6.5	2.5	4.0	16.7
<b>Intersatellite Links</b>									
52-320 Mb/s	-10	2FSK noncoh.	Convolution	.50	16.5	6.3	1.0	1.0	12.2
52-320 Mb/s	-10	2FSK coherent	Convolution	.50	13.2	6.3	1.0	1.0	8.9

Table 7-16: DDS Frequency Planning Limitations

<p><b>Government Systems</b></p> <p><b>Ku-Band:</b> No primary or permitted allocations are available. (TDRS uses secondary services under the "Space Research" category; uplinks at 14.6-14.9 and 15.11-15.25 GHz, and downlinks at 13.4-13.75 and 13.8-14.05 GHz.) (See Figures 4-3 and 4-4 in Chapter 4.)</p> <p><b>Ka-band:</b> 1.0 GHz shared primary allocation is available for military systems only. Frequency is 30.0-31.0 GHz uplink and 20.2-21.2 GHz downlink. The sharing is with the Mobile Satellite service. (See Figures 4-5 and 4-6 in Chapter 4.)</p>
<p><b>Non-Government Systems</b></p> <p><b>Ku-band:</b> (See Figures 4.3 and 4-4). Downlink: 0.5 GHz unshared primary allocation for National systems (11.7-12.2 GHz). The International system allocation is at 10.7-11.7 GHz.) Uplink: 0.5 GHz primary allocation, shared with Radio Navigation services 14.0-14.2, unshared 14.2-14.5 GHz. (International allocation is 12.7-13.25 GHz.)</p> <p><b>Ka-band:</b> 0.5 GHz unshared primary allocation available (29.5-30.0 up, 19.7-20.2 GHz downlink). 2.0 GHz shared primary allocation available (27.5-29.5 GHz uplink, 17.7-19.7 GHz down). The sharing is with Fixed and Mobile services. The downlink band has further sharing and restrictions within 17.7-17.8, 18.1-18.3, and 18.6-18.8 GHz. (See Figures 4-5 and 4-6.)</p>

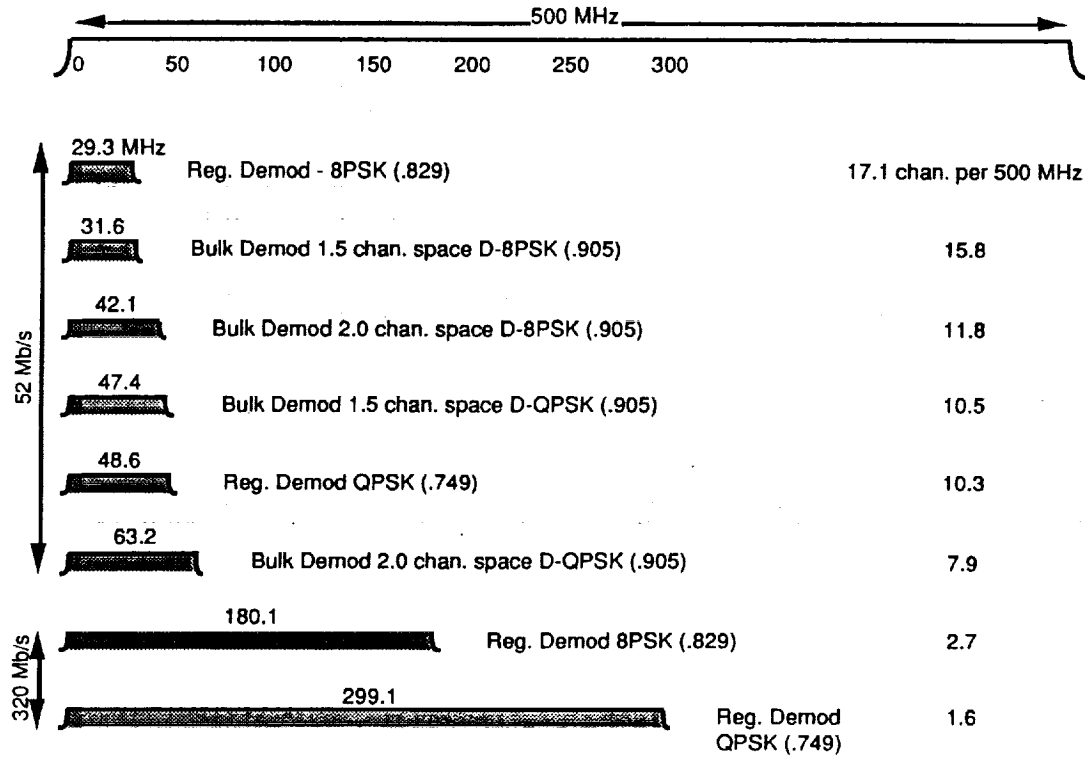


Figure 7-13: Spectrum Utilization for Candidate Uplinks

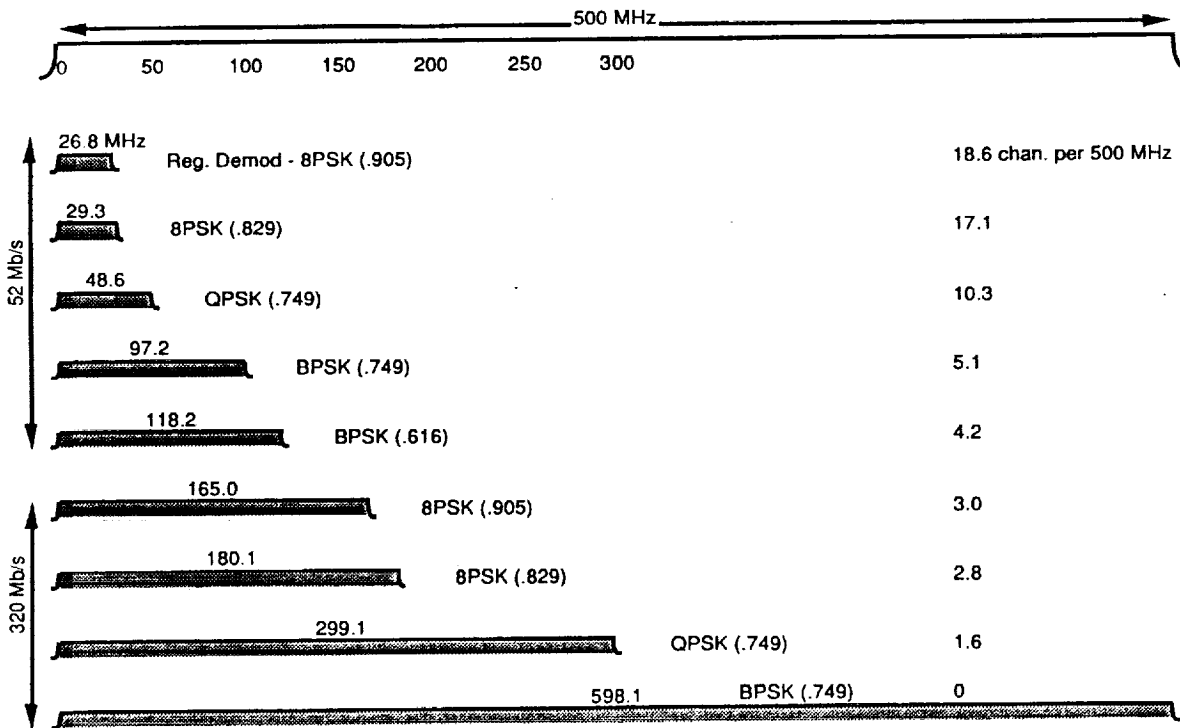


Figure 7-14: Spectrum Utilization for Candidate Downlinks



Table 7-17: Required Bandwidth for Various Modulation and Coding Techniques

Modulation Type	Code Rate	Application	Required Bandwidth (MHz) for			
			Data Rate (Mb/s)			
			52	160	320	640
2-FSK	.500	Crosslink	146	448	896	1,792
BPSK	.616	Downlink	118	364	-	-
QPSK	.750	Up & Downlinks	49	150	299	-
	.905	Uplink	41	124	248	496
8PSK	.829	Up & Downlinks	30	91	181	361
	.905	Uplink	27	83	166	331

Table 7-18: Standard Link Data Rates

Link Data Rate	Destination
<b>Uplinks</b>	
144 kb/s	Bulk demodulator
1.544 Mb/s	Bulk demodulator
6 Mb/s	Bulk demodulator
52 Mb/s	Regular demodulator
160 Mb/s	Regular demodulator
320 Mb/s	Regular demodulator
640 Mb/s	Regular demodulator
<b>Downlinks</b>	
52 Mb/s	Regular demodulator
160 Mb/s	Regular demodulator
320 Mb/s	Regular demodulator
640 Mb/s	Regular demodulator

as a standard uplink data rate for the DDS spacecraft bulk demodulators. Another standard from ISDN for medium data rates, is the (23B+D) multiplexed channel of 1.544 Mb/s (primary access rate) which accommodates T1 transmission. As shown in Table 7-18, multiples of these rates for uplinks at about 6 Mb/s, 52 Mb/s, 160 Mb/s, 320 Mb/s and 640 Mb/s may be utilized.

Because of the complete demodulation/remodulation within the DDS spacecraft and use of data buffers it is not necessary that identical downlink data rates be utilized. The use TDM for low rate down link signals a minimum downlink data rate of about 51.8 Mb/s is recommended because it is compatible with the SNET OC-1 ground network standard. Other standard downlink rates may be at 160 Mb/s, 320 Mb/s and 640 Mb/s.

The basic data rate formats must be slightly increased to accommodate headers for data routing information and the FEC block coding bits must also be included.

### 7.7.5 Impact of Rain Attenuation

A relatively high signal attenuation is incurred when communicating at Ku-band during heavy rainfall periods. This problem becomes even more severe at the higher frequency of Ka-band. The problem may be alleviated through the use of:

- Adequate link margins for rain attenuation,
- Reduced communications data capacity,
- Increased transmitter power,
- Diversity terminals separated by several kilometers.

The continental United States (CONUS) is divided into various rain climate regions as shown in Figure 7-15. The regions are designated by letters B, C, D, E, F, with further subdivisions of D into D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub>; and B into B<sub>1</sub> and B<sub>2</sub>. An example of the relative impact of rainfall among regions for the condition of 99.9% communications availability (i. e., 8.8 hours per year of outage) for Ku-band uplinks at 14.25 GHz transmission frequency for worst case elevation angles to satellites locate in the band from 70° W to 120° W is as follows:

- Region E requires 10.7 dB of rain margin,
- Region D<sub>3</sub> requires 7.1 dB of rain margin,
- Region D<sub>2</sub> requires 4.4 dB of rain margin,
- Region D<sub>1</sub> requires 2.8 dB of rain margin,
- Region B<sub>2</sub> requires 1.6 dB of rain margin,
- Region B<sub>1</sub> requires 1.1 dB of rain margin,
- Region C requires 2.4 dB of rain margin,
- Region F requires 1.4 dB of rain margin.

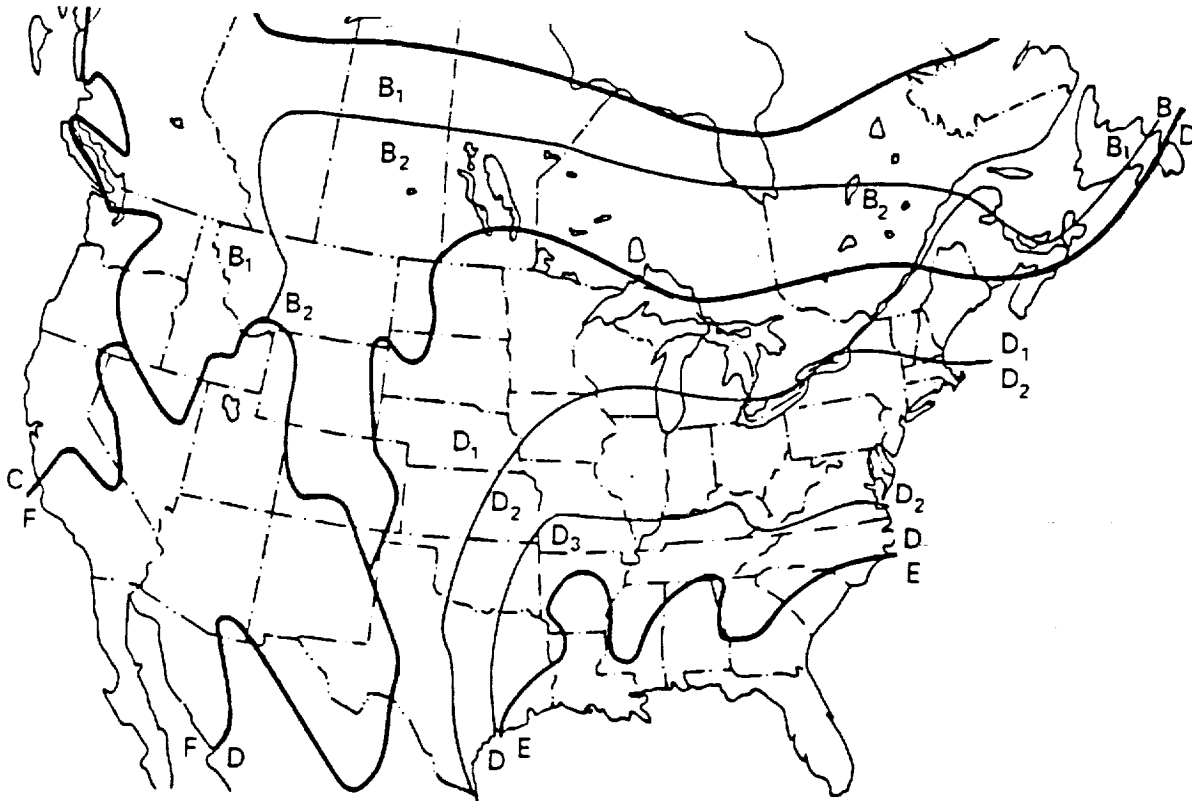


Figure 7-15: Rain Climate Regions of the Continental United States

The heaviest rainfall Region E contains southeast CONUS. However, that region does not contain many of the high traffic rate communications users.

A summary of the required rain margin for various link availability requirements for rain Region E (worst case) and rain Region D<sub>2</sub> (average conditions) is shown in Table 7-19. It is noted that the rain margins for worst case attenuation regions increase rapidly for high availability requirements. For example, 32 dB of rain margin is required for communications links to Region E for 99.99% link availability (0.9 hours per year of outage) at Ku-band uplinks at 14.25 GHz transmission frequency.

It is believed that most of the DDS user requirements may be successfully accomplished with less link availability. For example, the accommodation of a 3 dB rain margin in Ku-band uplinks would provide a link availability of 99.5% (44 hours outage/yr) in rain Region E and an availability in excess of 99.8% (18 hours outage/yr) in rain Region D<sub>2</sub>.

## 7.8 Total Communications Capacity

### 7.8.1 Capacity of a Single DDS

Tables 7-20 and 7-21 summarizes the total communications capacity of the 2007 and 2015 DDS payloads for one satellite. Breakdowns are given for uplinks and downlinks from earth, and intersatellite link capacity (transmit and receive) to other satellites per the plan of Figure 7-4. The total satellite capacity (peak load) represents the maximum amount of simplex bits that can pass through the satellite within its spectrum and power constraints under best case conditions.

The peak simplex capacity is 13 Gb/s for the 2007 satellite design and 23 Gb/s for the 2015 satellite design. In real life, the maximum realizable capacities with 15% overhead (bits for packet headers and framing) are 11 Gb/s simplex for the 2007 satellite design and 19.5 Gb/s simplex for the 2015 satellite design.

Note that these maximum capacities are not the same as the average satellite capacity. Chapter 11, System Costs, discusses the utilization factor assumptions in ¶11.5. The average achievable utilization of satellite

Table 7-19: Required Rain Margin for Various Link Availabilities and Two Rain Regions

Avail. (%)	Outage (hr/yr)	Ku-Band Margin (dB)				Ka-Band Margin (dB)			
		Uplinks (14.25 GHz)		Downlinks (11.95 GHz)		Uplinks (29.75 GHz)		Downlinks (19.95 GHz)	
		Rain Region E	Rain Region D2	Rain Region E	Rain Region D2	Rain Region E	Rain Region D2	Rain Region E	Rain Region D2
99.99	0.9	32.0	17.2	23.9	12.4	97.1	57.0	55.2	30.9
99.98	1.8	25.1	12.0	18.5	8.5	78.0	41.1	43.7	21.8
99.95	4.4	16.3	7.1	11.8	5.0	53.1	25.7	29.1	13.7
99.9	8.8	10.7	4.4	7.6	3.0	36.6	16.8	19.5	8.5
99.8	17.5	6.3	2.7	4.3	1.8	22.6	10.7	11.7	5.3
99.5	43.8	<u>3.0</u>	1.3	<u>2.0</u>	0.8	11.6	5.5	5.7	2.6
99.0	87.7	1.6	0.6	1.0	0.4	6.5	2.9	3.1	1.3
98.0	175.3	.7	0.2	0.4	0.2	<u>3.1</u>	1.3	<u>1.4</u>	0.5

Table 7-20: Total Communications Capacity of Year 2007 DDS Payload

Type of Link	Comm. Capacity (Gb/s)	Radiated Power (W)	References and Comments
Uplinks (receive)	13.52		Table 7-3. (5.48 Gb/s Ku-band, 8.03 Gb/s Ka-band.)
Downlinks (transmit)	11.72	740 (Ku) 248 (Ka)	Figure 7-10, Table 7-9; (2 kW Ku dc power). (6.65 Gb/s Ku-band, 5.08 Gb/s Ka-band); (800 W dc power at Ka-band).
	<u>25.34</u>	988	
Intersatellite links:			2 optical intersatellite link units.
Receive	3.84		¶7.6.1
Transmit	1.28	2 (optical)	2 transmit channels.
	<u>5.12</u>		
Totals (simplex bits)			
Receive	17.36		
Transmit	13.00		
Peak simplex capacity	13.00		Receive cannot exceed transmit capacity.
Maximum achievable	11.05		Max. simplex capacity with 15% overhead.

Table 7-21: Total Communications Capacity of Year 2015 DDS Payload

Type of Link	Comm. Capacity (Gb/s)	Radiated Power (W)	References and Comments
Uplinks (receive)	17.90		2007 design (Table 7-20) plus 33%. (7.3 Gb/s Ku-band, 10.6 Gb/s Ka-band.)
Downlinks (transmit)	15.50	960 (Ku) 350 (Ka)	2007 design (Table 7-20) plus 33%. (8.8 Gb/s Ku-band, 6.7 Gb/s Ka-band.)
	33.40	1,310	(2.4 kW dc Ku, 1 kW dc Ka-band power.)
Intersatellite links:			6 optical intersatellite link units.
Receive	11.84		Table 7-13.
Transmit	7.52	15 (optical)	15 transmit channels on 6 units.
	19.36		
Totals (simplex bits)			
Receive	29.74		
Transmit	23.02		
Peak simplex capacity	23.01		Receive cannot exceed transmit capacity.
Maximum achievable	19.56		Max. simplex capacity with 15% overhead.

capacity is estimated to be only 16% of maximum due to the following factors:

- Inefficiency in allocation of communications among discrete numbers of antenna beams and demodulator sizes.
- Time of day traffic statistics.
- Initial traffic build up for a new service.

DDS and a 28 Gb/s maximum achievable capacity for the year 2015 DDS. Both systems are very much "transmit limited", and a further iteration of satellite design could perhaps improve the capacity by changing some of the receive capacity to transmit capacity.

### 7.8.2 Capacity of a Two-DDS Constellation

A mature DDS system will operate with two satellites interconnected by intersatellite links (ISLs), with one over the East and the other over the West United States to provide best visibility of CONUS. The year 2007 DDS will use one of its two ISLs to exchange data with the other DDS, and the year 2015 DDS will use one of its 6 ISLs to exchange data with the other DDS. Due to the relatively close orbital spacing ( $40^\circ$  to  $50^\circ$ ) of the two DDSs, the 2007 DDSs can be linked by one channel of 2.56 Gb/s and the 2015 DDSs by 4 channels with 5.12 Gb/s total capacity (Table 7-13).

Table 7-22 gives the communications capacity of a DDS constellation with two satellites linked by intersatellite links. The link from DDS-to-DDS is not included in the capacity calculation. The result is a 20 Gb/s maximum achievable capacity for the year 2007

Table 7-22: Communications Capacity of a DDS Constellation with Two Satellites

Type of Link	2007 DDS Comm. Capacity (Gb/s)	2015 DDS Comm. Capacity (Gb/s)	Comments
Uplinks (receive)	27.04	35.80	
Downlinks (transmit)	23.44	31.00	
Intersatellite links:			
Receive	1.92	6.72	Links to ATDRS (2007) and other GEO satellites (2015).
Transmit	0.32	1.47	
Receive from DDS	( 2.56)	( 5.12)	Not included in totals.
Transmit to DDS	( 2.56)	( 5.12)	Not included in totals.
Totals (simplex bits):			
Receive	28.96	42.52	Uplinks plus ISL receive.
Transmit	23.76	32.47	Downlinks plus ISL transmit.
Peak simplex capacity	23.76	32.47	Receive cannot exceed transmit capacity.
Maximum achievable	20.66	28.23	Max. simplex capacity with 15% overhead.

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## Chapter 8

# Satellite Configuration

This chapter takes the derived communications payload configurations of Chapter 7 and sizes the satellite to accommodate these payloads. The emphasis is on the satellite mass and power, and required configuration to support the 2007 and 2015 payloads developed in the previous chapter. In the interest of clarity, there is some duplication of figures and tables from the previous chapter.

More satellite component details have been given in previous Ford Aerospace reports on this subject performed under NASA/LeRC Contract No. NAS3-24683, *Technical Support for Identifying New Services Enabled by Multi-Frequency Multi-Service Satellites*. In particular, satellite design information is contained in Section V of Task 3, Future Communications Satellite System Architecture Concepts, and in Section 4.2.1 of Task 5, Data Distribution Satellite System Architecture Concept.

The chapter is organized as follows:

- 8.1 Overview and Summary
- 8.2 Year 2007 Satellite
- 8.3 Year 2015 Satellite

## 8.1 Overview and Summary

### 8.1.1 Satellite Configuration

Figure 8-1 shows the satellite configuration for the 2007 DDS. The 2015 DDS is the same except for relative size – mass, number of solar panels, and number of ISLs. The satellite design is dominated by the four 1.4 m to 2.2 m Ku and Ka-band receive and transmit antennas. The intersatellite link antennas (two on the 2007 DDS and six on the 2015 DDS) have only 0.15 m apertures in comparison. The RF antennas are typically implemented as multiple beam antennas, primarily on ac-

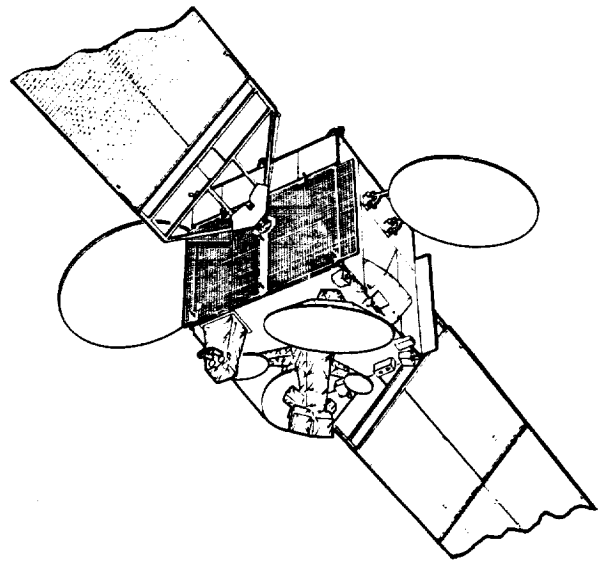


Figure 8-1: Satellite Configuration

count of the large number of simultaneous spot beams required from each antenna.

### 8.1.2 Satellite Parameters

Table 8-1 summarizes the year 2007 DDS characteristics and Table 8-2 compares the 2007 and 2015 DDSs with two communication satellites currently manufactured by Space Systems/Loral (formerly Ford Aerospace). The major differences are the higher power and higher payload mass fraction of the DDS.

The payload mass fraction (ratio of the mass of the antenna plus communications electronics to the total satellite wet mass) is 20% for Superbird and 23% for Intelsat 7 versus 34% for DDS-2007 and 37% for DDS-2015. This improvement is primarily due to the changing satellite technology in the propulsion and power subsystems. Use of ion propulsion by DDS reduces the mass of on-orbit station-keeping fuel, and battery and solar cell performance per unit mass is improved.

Table 8-1: Data Distribution Satellite Characteristics (Year 2007 Launch)

Manufacturer & model: Baseline satellite name: Lifetime: On-board switching: Launch vehicle:	Ford Aerospace FS-1300 Data Distribution Satellite 15 yr On-board baseband switching for all channels. Atlas IIAS (enhanced)
Frequency band and bandwidth: – receive: – transmit: Frequency band and bandwidth: – receive: – transmit: Optical Intersatellite Links:	Ku-band, 500 MHz 14.0-14.5 GHz 11.7-12.2 GHz Ka-band, 500 MHz 29.5-30.0 GHz 19.7-20.2 GHz Optical, 850 nm
Antenna – type: – number: – size:  – mass: – coverage (Ku-band): – coverage (Ka-band):	Offset parabolic 8 0.9 & 1.7 m receive, 2.0 m transmit, Ku-band 0.4 & 1.4 m receive, 0.6 & 2.2 m transmit, Ka-band 15 cm transmit/receive for optical ISL. 146 kg (combine 1.4 m Ka and 1.7 m Ku-band) 8 rx and 27 tx beams over CONUS, plus 10 rx spots 8 fixed area plus 16/20 spot beams, both transmit & receive
Communications electronics – number of receivers: – number of bulk demods: – number of demodulators: – SSPAs:  – mass: – dc power:	33 at Ku-band and 33 at Ka-band. 26 at Ku-band and 32 at Ka-band. 33 at Ku-band and 48 at Ka-band. 27 @ 5 W, 27 @ 10 W, and 18 @ 20 W at Ku-band 22 @ 1.5 W, 6 @ 3 W, 8 @ 5 W, 5 @ 10 W, 8 @ 15 W – Ka-band 585 kg 2,900 W peak.
Spacecraft – size (stowed): – mass, BOL: – power (EOL) at summer solstice: – primary power: – batteries: – attitude and station keeping: – attitude pointing accuracy: – apogee motor: – stationkeeping & attitude control:	2.5 m x 1.88 m x 2.64 m 2,150 kg 5,500 W Solar cells (thin silicon) 4 NiH, 280 Ah (total) 3-axis stab, ion propulsion $\pm 0.05^\circ$ Liquid propulsion Ion propulsion motor



Table 8-2: Comparison of DDS Designs with Current Communication Satellites

Satellite Parameter	Superbird	Intelsat 7	DDS 1	DDS 2
Launch Year	1989	1993	2007	2015
Launch Vehicle	Ariane 3	Atlas 2AS	Atlas 2AS <sup>†</sup>	ALV/OTV
Lifetime (yr)	10	11	15	15
Maximum Capacity (Mb/s, [MHz])	[1,800]	[2,500]	11,000	19,500
DC Power, end of life (W)	3,550	3,531	5,500	7,000
RF Transmit Power (W)	885	929	990	1,325
Battery Capacity (W)	3,210	3,310	5,000	7,000
<b>Satellite Subsystem Mass (kg):</b>				
Structure	214	209	244	280
Propulsion	113	108	275*	275*
Power and Solar Array	291	299	300	350
TT&C and Attitude Control	104	160	165	215
Thermal	91	94	150	180
Integration, elect. and mech.	83	105	125	150
Antenna	50	103	146	190
Communication Electronics	229	320	585	750
Dry Mass of Satellite (kg)	1,175	1,398	1,990	2,390
On-orbit Fuel (kg)	265	454	160*	170*
Wet Mass of Satellite (kg)	1,440	1,852	2,150	2,560
Orbit-raising Fuel (kg)	1,000	1,698	1,850	-
Launch Mass (kg)	2,440	3,550	4,000 <sup>†</sup>	2,560 <sup>‡</sup>

\* Use of ion propulsion increases propulsion mass and decreases on-orbit fuel mass.

† Enhanced version of current Atlas IIAS.

‡ Year 2015 DDS uses OTV for orbital transfer.

### 8.1.3 Satellite Power Allocation

As shown by Table 8-3, a considerable amount of power is consumed by the on-board processing equipment on the DDS. Thus the ratio of RF power radiated to DC bus power is only around 18% for the DDS satellites (compared to 25% for Superbird and Intelsat 7), in spite of a hypothesized improvement in DC-to-RF power conversion efficiency. However, utilization of spot beams results in a more efficient use of satellite power for communications.

### 8.1.4 Summary of Features

In summary, the key features of the satellite design from the standpoint of the satellite bus are as follows:

**Higher power** is required to supply the greater communications capacity which enables more efficient operation, and to make available the power required for on-board processing. Advanced bat-

tery and solar cell designs are used which have improved performance per unit mass.

**Thermal radiators** are required to dissipate the higher power from the satellite. Of the 5,500 W dc power, only 990 W is radiated away in rf power, leaving approximately 4.5 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 Ku and Ka-bands** requires double the number of antennas and beam forming networks, with consequent increase in antenna mass. However, the benefit is increased spectrum availability for com-

Table 8-3: Satellite Power Allocations for DDS Designs

Satellite Design Parameters	DDS 1	DDS 2
Launch Year	2007	2015
Lifetime (yr)	15	15
DC Power, end of life (W)	5,500	7,000
Battery Capacity (W)	5,000	7,000
Battery Type	NiH	NaS

Power-Using Component	Power (W)		Power (W)	
	DC	RF	DC	RF
Bus subsystems	466		496	
Battery charging	424		574	
Receivers, demods, decoders	1,000		1,200	
Encoders, modulators	260		280	
Switch and processor	250		250	
Transmitters, Ku-band	2,000		2,400	
RF transmit power (Ku)		740		960
Transmitters, Ka-band	800		1,000	
RF transmit power (Ka)		248		350
Intersatellite link subsystems	100		500	
Optical transmit power		2		15
Other and Margin	200		300	
Total Power (W)	5,500	990	7,000	1,325

munications, 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. Each separate fixed beam would require a separate beam forming network if implemented with a phased array. Fixed beams were chosen by this study in order to reduce the complexity for the earth terminals.

A design alternative would use phased arrays with scanning spot beams, and could require more thermal radiator mass. If more than one scanning beam is required from a given antenna, separate beam forming networks would be required.

**Use of optical intersatellite links (ISLs)** in addition to the Ku-band and Ka-band links complicate the antenna farm layout. However, the benefits are increased connectivity and capacity with only a modest increase in mass. Much work remains to be done to commercialize optical ISLs.

## 8.2 Year 2007 Satellite

Figure 8-2 shows front and side views of the Data Distribution Satellite and Figure 8-3 shows a sketch of the satellite. The 2.0 m and 2.2 m antennas mounted on the east and west panels deploy after launch. Table 8-1 gives the satellite characteristics which are discussed in §8.2.4.

### 8.2.1 Antenna Sizes

Table 8-4 summarizes the seven RF antenna coverages described in Chapter 7. To supply the different coverages, the following antennas are sized:

1. Ku-band receive (area) – 0.9 m diameter, 14 kg mass (including beamforming network).
2. Ku-band receive (spot) – 1.7 m, 24 kg mass.
3. Ka-band receive (area) – 0.4 m, 8 kg mass.
4. Ka-band receive (spot) – 1.4 m, 22 kg mass.
5. Ku-band transmit – 2.0 m, 36 kg mass.

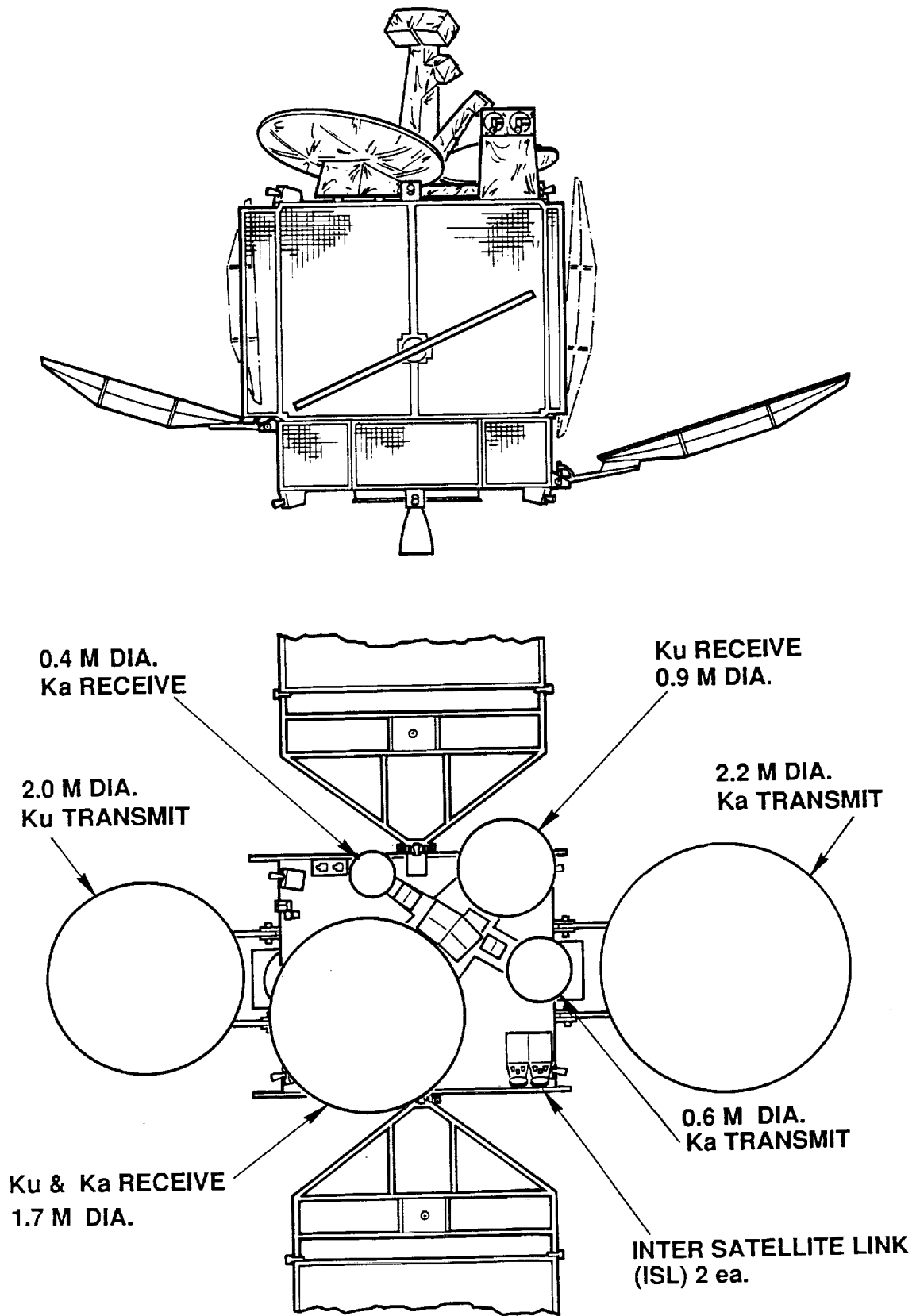


Figure 8-2: Front and Side Views of Data Distribution Satellite

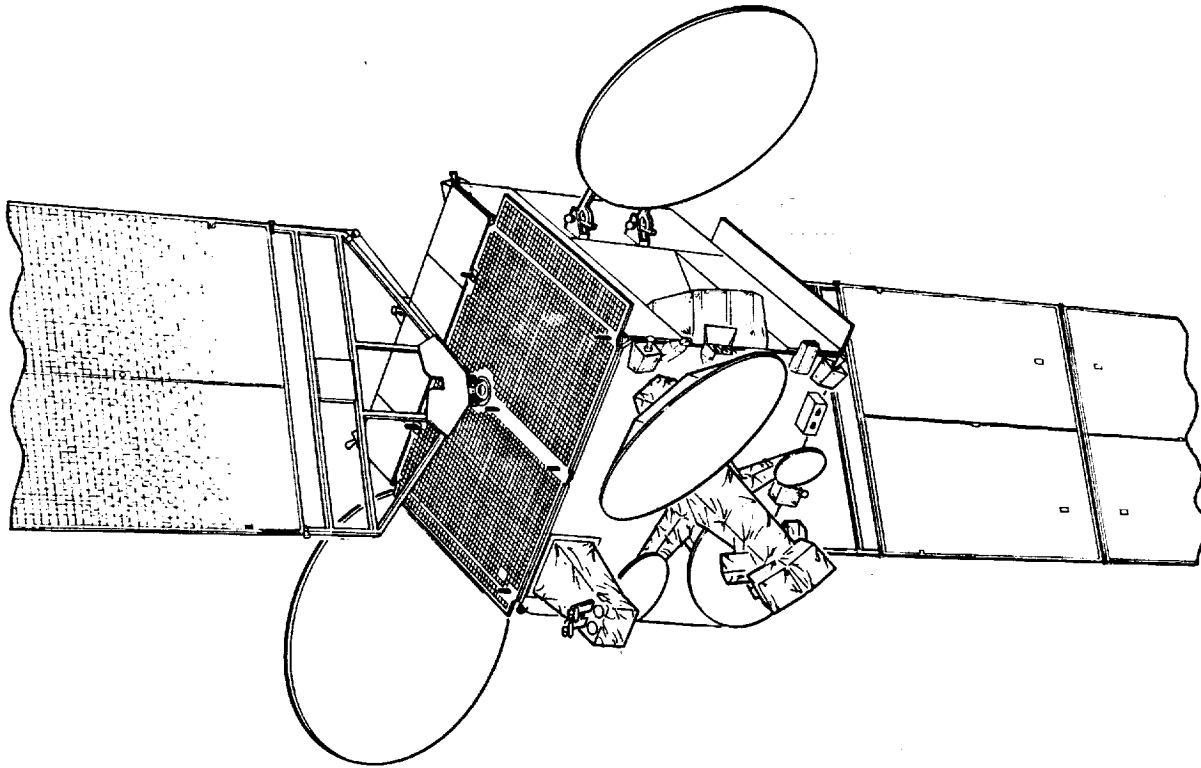


Figure 8-3: Sketch of Data Distribution Satellite

6. Ka-band transmit (area) – 0.6 m, 10 kg mass.
7. Ka-band transmit (spot) – 2.2 m, 26 kg mass.

In addition, there are two optical intersatellite link (ISL) antennas with single channel duplex links:

8. Optical transmit/receive – 0.15 m aperture, 11 kg mass (each).

As shown in the view of Figure 8-2 (bottom), the laser mirrors rotate  $\pm 90^\circ$  about a N-S axis (the long axis of the solar panels) to point the beam over a  $180^\circ$  segment of the geostationary arc.

Consideration was given to combining some of these antennas in order to reduce the number of reflectors. However, frequency reuse and isolation requirements have led to a design with separate transmit and receive antennas for both Ka and Ku bands.

The only combination which works is (2) and (4) – the Ku receive spot with 10 active spot beams out of 15 total and the Ka receive antenna with 16 active spot beams out of 20 total beams. A diplexer or frequency selective surface could be used to separate the Ku and

Ka-band signals. The combination of (2) and (4) into a single 1.7 m reflector would weigh 30 kg.

Table 8-5 gives a summary of the eight different antennas (six RF and two optical). Total antenna mass is 146 kg (162 kg without combining 2 and 4). More description of the satellite antenna configuration has been given in ¶7.2 of the previous chapter.

### 8.2.2 Receive Channel Configuration

Table 8-6 shows the available satellite receive channels at Ku-band. There are both area coverage and spot beams, and the peak Ku-band receive capacity is 5.488 Gb/s from 59 channels ranging in size from 52 Mb/s to 320 Mb/s. Figure 8-4 shows a schematic of the Ku-band satellite receive configuration which is described in detail in ¶7.3.2.1 of the previous chapter.

Table 8-7 shows the available satellite receive channels at Ka-band. Once again there are both area coverage and spot beams, and the peak Ka-band receive capacity is 8.032 Gb/s from 80 channels ranging in size from 52 Mb/s to 320 Mb/s. The Ka-band satellite receive configuration is similar to that for Ku-band as

Table 8-4: Antenna Coverages for Year 2007 DDS

	Satellite Receive				Satellite Transmit		
	#1 Ku (14.0-14.5)	#2 Ku (14.0-14.5)	#3 Ka (29.5-30.0)	#4 Ka (29.5-30.0)	#5 Ku (11.7-12.2)	#6 Ka (19.7-20.2)	#7 Ka (19.7-20.2)
Coverage							
Beams	8 of 1.73° HPBW	10 active spot beams - 0.87° HPBW of total of 15	8 of 1.73° HPBW	12-16 active spot beams of 0.5° HPBW of total of 20	27 beams of 0.87° HPBW	8 of 1.73° HPBW	12-16 active spot beams of 0.5° HPBW of total of 20
Antenna Diameter	0.9 m (2.8 ft)	1.7 m (5.5 ft)	0.4 m (1.4 ft)	1.4 m (4.6 ft)	2.0 m (6.5 ft)	0.6 m (2.0 ft)	2.2 m (7.0 ft)
Antenna Mass	14 kg	24 kg	8 kg	22 kg	36 kg	10 kg	26 kg
Polarization	4 of H 4 of V	1/2H or V only 1/2 (H + V)	4 of H 4 of V	1/2H or V only 1/2 (H + V)	1/2H or V only 1/2 (H + V)	4 of H 4 of V	1/2H or V only 1/2 (H + V)
Antenna Efficiency	65%	60%	65%	60%	60%	65%	60%
Peak Gain (dBi)	40.2	45.8	40.2	50.6	45.8	40.2	50.6
EOC Gain (dBi)	35.9 (-4.3)	42.8 (-3.0)	35.9 (-4.3)	47.6 (-3 db)	41.5 (-4.3)	35.9 (-4.3)	47.6 (-3 db)

Table 8-5: Summary of Satellite Antenna Systems

Antenna System	Coverages	Frequency (GHz)	Size (m)	Complexity	Mass (kg)
A. Ku - receive	8 ea. 1.73° cover CONUS.	14.0 - 14.5	0.9	2 pols, 8 beams.	14
B. Ku - receive	10/15 0.87° spots	14.0 - 14.5	1.7	10 beams.	30
C. Ka - receive	16/20 .5° spots	29.5 - 30.0		20 feeds.	
C. Ka - receive	8 ea. 1.73° cover CONUS.	29.5 - 30.0	0.4	2 pols, 8 beams.	8
D. Ku - transmit	27 ea. 0.87° cover CONUS.	11.7 - 12.2	2.0	2 pol., 27 beams.	36
E. Ka - transmit	8 ea. 1.73° cover CONUS.	19.7 - 20.2	0.6	2 pol., 8 beams.	10
F. Ka - transmit	16/20 0.5° spots	19.7 - 20.2	2.2	2 pol., 16 beams.	26
G. Optical Tx/Rx	1 narrow beam	(850 nm)	0.2	1 wavelength, 1 beam.	11
H. Optical Tx/Rx	1 narrow beam	(850 nm)	0.2	1 wavelength, 1 beam.	11
					146

shown in Figure 8-4. The Ka-band receive configuration is described in detail in ¶7.3.2.2 of the previous chapter.

The peak receive (uplink) capacity is thus 13.52 Gb/s (Ku and Ka-bands combined). There can be a total of 139 channels ranging in size from 52 Mb/s to 320 Mb/s. However, it is unlikely that all channels would be fully utilized at one time.

### 8.2.3 Transmit Channel Configuration

Figure 8-5 shows the allocation of satellite DC power to the RF communications payload. Intersatellite links (not shown in the figure) also use 100 W (3%) of the total communications power which is 2,900 W. Ku-band receives 69% and Ka-band 28% of the power. The dc-to-rf conversion efficiency is 37% at Ku-band and 31% at Ka-band. The figure shows allocation of power among the specific links. The peak downlink capacity is 11.724 Gb/s; 6.6 Gb/s at Ku-band and 5.1 Gb/s at Ka-band.

There are a number of reasons that the satellite is unlikely to operate at peak capacity:

- Channels may be incompletely filled depending on the amount of traffic in a particular beam.
- There is a quantization problem with respect to the downlink channels. Each beam must have at least one channel, but there is no assurance that every channel is full. Thus the likelihood of partially full channels must be accommodated in the overall satellite capacity.
- Excess power capacity may be required on the satellite to supply additional rain margin as needed. Power could be increased by using a higher power transmitter for regions suffering rain fading.

Table 8-8 summarizes the satellite transmitter numbers and sizes. RF downlinks range from 52 Mb/s to 320 Mb/s with the higher capacity links going to larger earth terminals. There are 72 transmitters at Ku-band, 49 at Ka-band, and 2 for optical intersatellite links. The total number of transmit channels is 123. The satellite transmit configuration at Ku-band and Ka-band is shown in Figure 8-6.

### 8.2.4 Mass and Power

Table 8-1 has summarized the satellite characteristics. The basis for the bus is the Ford Aerospace FS-1300 series which has a 1,850 kg wet, Beginning-Of-Life (BOL) mass capability and is presently in production for commercial applications.

The existing satellite design (1985 technology) has been upgraded to incorporate hypothesized year 2000 technology improvements. The result is a 1,990 kg dry (2,150 kg wet) satellite mass with a 731 kg payload (antenna plus communication electronics) and 5,500 W end-of-life power. Table 8-9 summarizes the mass budget and Table 8-10 summarizes the power budget for the satellite.

Table 8-11 gives a summary of the satellite payload equipment without redundancy. Redundancy considerations are as follows:

**LNAs and downconverters.** Ku-band: 2 for 1 - 8 CONUS beams; and 3 for 2 - 10 active spot beams.  
Ka-band: 2 for 1 - 8 CONUS beams; and 3 for 2 - 16 active spot beams.

**Bulk demodulators and decoders.** Ku-band and Ka-band use the same units with a total of 58 required. There are 64 units available, and spares are substituted as required.

**Standard demods and decoders.** There are 50 each 52 Mb/s units to supply the 42 units required for Ku and Ka-bands. There is 4 for 3 ring redundancy for the 26 each 160 Mb/s and 13 each 320 Mb/s demodulators and decoders.

**Processor and switches** have internal redundancy.

**Transmitters** have ring redundancy, generally 5-for-4 or 4-for-3 among the different size units listed in Table 8-11 for Ku-band and Ka-band.

It is interesting to partition the power and mass between the Ku-band and Ka-band portions of the payload for the year 2007 satellite design. Remember from Table 7-20 that Ku-band and Ka-band communications capacity is as follows:

	<u>Ku-band</u>	<u>Ka-band</u>
Uplinks	5.48 Gb/s	8.03 Gb/s
Downlinks	6.65 Gb/s	5.08 Gb/s
Totals	13.52 Gb/s	11.72 Gb/s

Table 8-6: Satellite Receive Channels – Ku-Band

Ku-Band Uplinks	No. & Rate	Total (Mb/s)	Comments
<b>Area Coverage Beams</b>			8 area beams of 1.73°
D-8PSK (.905)	16 @ 52 Mb/s	832	2 bulk demods per beam, 1 for 144 kb/s and 1 for 1.5 Mb/s channels.
8PSK (.829)	8 @ 52 Mb/s	416	Regular demodulators.
<b>Spot Beams</b>			10 spot beams of 0.87°
D-8PSK (.905)	10 @ 52 Mb/s	520	2 bulk demods per beam, 1 for 144 kb/s and 1 for 1.5 Mb/s channels.
8PSK (.829)	10 @ 52 Mb/s	520	Regular demodulators.
8PSK (.829)	10 @ 160 Mb/s	1,600	Regular demodulators.
8PSK (.829)	5 @ 320 Mb/s	1,600	Regular demods, 1 polarization only.
		5,488	Mb/s Ku-band uplink peak capacity

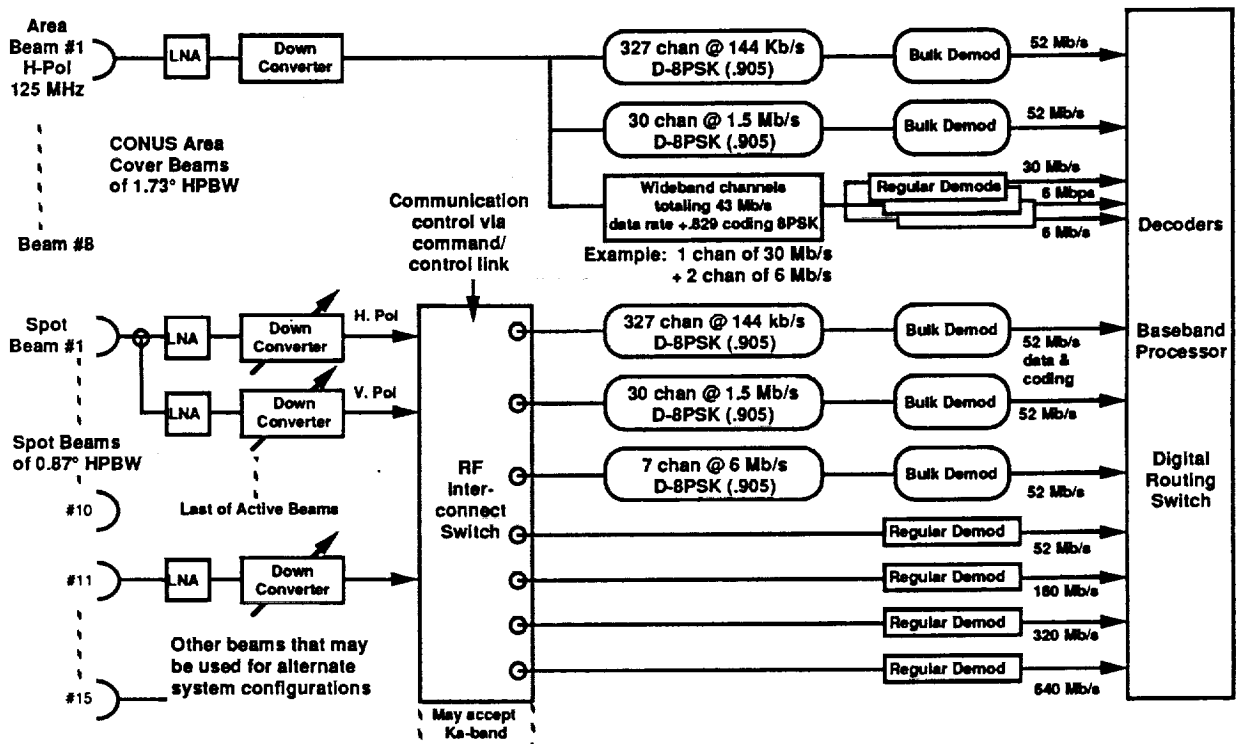


Figure 8-4: Satellite Receive Configuration for Ku-Band (Ka-band is similar)

Table 8-7: Satellite Receive Channels - Ka-Band

Ka-Band Uplinks			
<u>Area Coverage Beams</u>			8 area beams of 1.73°
D-8PSK (.905)	16 @ 52 Mb/s	832	2 bulk demods per beam, 1 for 144 kb/s and 1 for 1.5 Mb/s channels.
8PSK (.829)	8 @ 52 Mb/s	416	Regular demodulators.
<u>Spot Beams</u>			16 spot beams of 0.5°
D-8PSK (.905)	16 @ 52 Mb/s	832	2 bulk demods per beam, 1 for 144 kb/s and 1 for 1.5 Mb/s channels.
8PSK (.829)	16 @ 52 Mb/s	832	Regular demodulators.
8PSK (.829)	16 @ 160 Mb/s	2,560	Regular demodulators.
8PSK (.829)	8 @ 320 Mb/s	2,560	Regular demods, 1 polarization only
		8,032	Mb/s uplink peak capacity

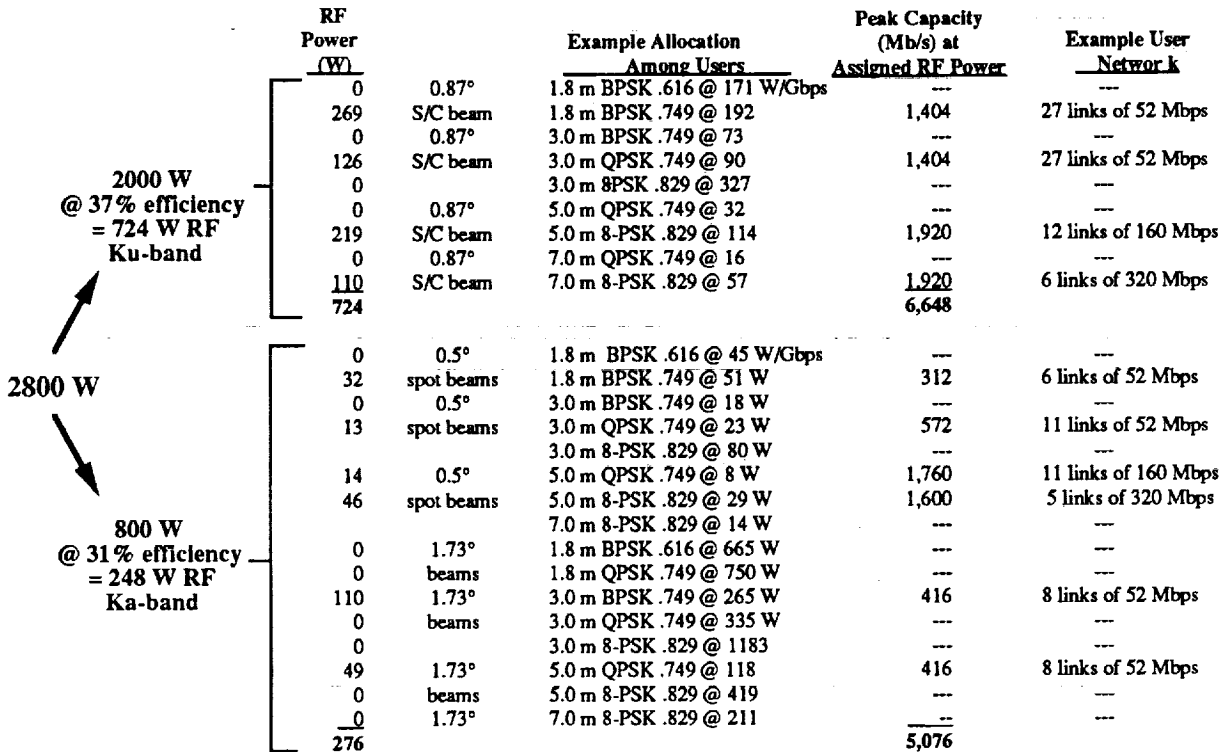


Figure 8-5: Modular Allocation of Satellite Power



Table 8-8: Satellite Transmitter Numbers and Sizes

Frequency Band	No. Trans.	Size (W)	Type of Link	Ground Terminal
Ku-band:	27	10.0	52 Mb/s BPSK	1.8 m
	27	4.7	52 Mb/s QPSK	3.0 m
	12	18.0	160 Mb/s 8PSK	5.0 m
	6	18.0	320 Mb/s 8PSK	7.0 m
Ka-band: (area)	8	13.8	52 Mb/s BPSK	3.0 m
	8	6.2	52 Mb/s QPSK	5.0 m
Ka-band: (spots)	6	2.6	52 Mb/s BPSK	1.8 m
	11	1.2	52 Mb/s QPSK	3.0 m
	11	1.3	160 Mb/s QPSK	5.0 m
	5	10.2	320 Mb/s 8PSK	5.0 m
Optical ISL	2	1.0	640 Mb/s 2FSK	0.15 m

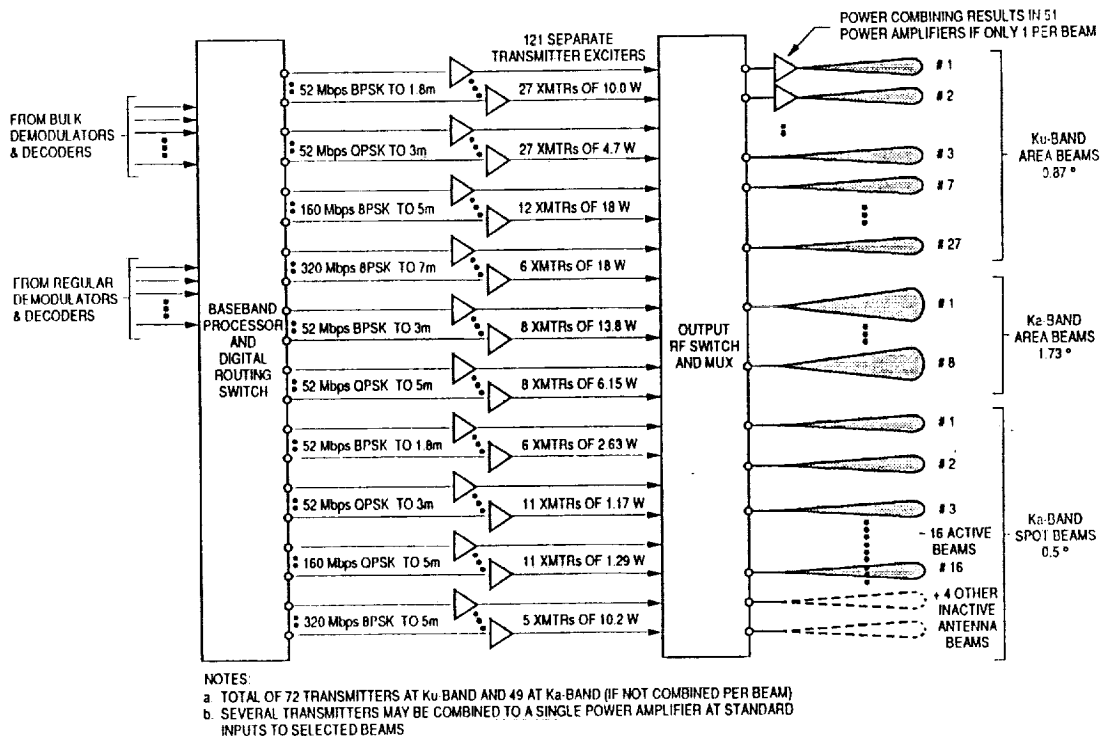


Figure 8-6: Satellite Transmitter Configuration: Ku-Band and Ka-Band

Subsystem	Mass (kg)
Attitude control	113
Power	186
Solar array	114
Propulsion	275
Structure	244
Thermal	150
TT&C	52
Payload – Antenna	146
– Electronics	585
Integration; elect. & mech.	125
Total (dry mass)	1,990
On-orbit fuel	160
Total (BOL mass)	2,150

Table 8-9: Satellite Mass (2007 Design)

Component	Power (W)	
Receivers	350	
Demodulators	550	
Decoders	100	
Switch/Processor	250	
Encoders	160	
Modulators	100	
Transmitters	2,900	
Other/Margin	200	
Total Payload	4,610	4,610
TT&C	30	
Attitude control	135	
Propulsion	2	
Power subsystem	42	
Thermal subsystem	153	
Control electronics	80	
Harness loss	44	
Total Bus	466	466
Battery charging		424
Total Satellite		5,500

Table 8-10: Satellite Power (2007 Design)

As seen from Figure 8-5, 2,000 W for Ku-band and 800 W for Ka-band are required of dc bus power to supply the rf transmit power. In addition, other Ku-band and Ka-band payload equipment consumes 730 W and 780 W respectively. The total payload power consumption is thus 2,730 W (63%) at Ku-band and 1,580 W (37%) at Ka-band. Ka-band supplies more communications capacity per unit power consumed than Ku-band, primarily due to the use of smaller spot beams by the satellite and higher gain earth terminals.

The antenna mass is 74 kg for Ku-band and 66 kg for Ka-band. The communications electronics mass breakdown is approximately equal with 300 kg for Ku-band and 285 kg for Ka-band. The total payload mass breakdown is thus 374 kg (52%) for Ku-band and 351 kg (48%) for Ka-band related equipment. Once again Ka-band supplies more communications capacity per unit mass than Ku-band.

## 8.3 Year 2015 Satellite

### 8.3.1 Satellite Parameters

The year 2015 satellite design has a communications capacity as shown in Table 7-21 of the previous chapter. The Ku-band and Ka-band capacities are approximately 33% greater than the 2007 DDS design. A major difference is the use of six optical communication packages with 24 receive channels and 15 transmit channels, which increases the optical transmit/receive capacity from 5.12 Gb/s to 19.36 Gb/s. The total power required by the year 2015 optical payload is 550 W, and its total mass is 165 kg electronics plus 66 kg antenna (vs. 46 kg and 100 W for year 2007 payload).

The 2015 satellite parameters have been summarized in Table 8-2 under the “DDS 2” column. The satellite configuration would be similar to the sketches of Figures 8-2 and 8-3, with the exception of being slightly bigger to accommodate the 20% greater mass. Even though the solar power is 27% higher than that of the year 2007 design, the area of solar arrays will be the same due to hypothesized improvements in solar array efficiencies (see ¶4.5.2). Similarly, use of NaS batteries (see ¶4.5.3) will allow great savings in the power subsystem.

In summary, the year 2007 DDS design (2000 technology) has been upgraded to incorporate hypothesized year 2010 technology improvements. The result is a 2,390 kg dry (2,560 kg wet) satellite mass with a 940 kg

Table 8-11: Satellite Payload Equipment List for Ku-Band, Ka-band, and Optical Links

Payload Equipment (2007 Design)	Number of Items		
	Ku-Band	Ka-Band	Optical
● Receivers:			
– LNA/Downconverters	33	33	–
– Optical receivers	–	–	2
– Bulk demods (52 Mb/s ea.)	26 <sup>†</sup>	32 <sup>†</sup>	
– Demodulators (52 Mb/s ea.)	18 <sup>†</sup>	24 <sup>†</sup>	
– Demodulators (160 Mb/s)	10 <sup>†</sup>	16 <sup>†</sup>	
– Demodulators (320 Mb/s)	5 <sup>†</sup>	8 <sup>†</sup>	
– Demodulators (640 Mb/s)	–	–	2
● Transmitters:			
– SSPAs (1.5 W)	–	22	
– SSPAs (3 W)	–	6	
– SSPAs (5 W)	27	8	
– SSPAs (10 W)	27	5	
– SSPAs (15 W)	–	8	
– SSPAs (20 W)	18	–	
– Laser diode array (1 W)	–	–	2

† Demodulators are interchangeable among frequency bands.

payload and 7,000 W end-of-life power. Table 8-12 summarizes the mass budget and Table 8-13 summarizes the power budget for the year 2015 satellite.

change with time, this scheme works with only a small loss in redundancy for failed units.

### 8.3.2 Layout of Optical ISLs

One issue for the year 2015 satellite configuration is the layout of the optical intersatellite links (ISLs). As seen from Figures 8-2 and 8-3, the year 2007 design is very crowded with two ISLs having to be positioned among six larger multiple beam antennas. In addition, the desired field of view for the ISLs is the full geosynchronous arc, or a strip of sky 180° by 5°.

The desired location for the ISLs is on the earth-facing panel of the satellite. However, due to use of fiber optic coupling between the optical telescope and the receive/transmit equipment, there is considerable flexibility in positioning the optical telescopes on the satellite bus. This is fortunate since the rf antenna reflectors and feed towers limit the field of view from much of the remaining free space on the earth-facing panel. Our recommended approach is to position three of the ISLs on the east side of this panel and the other three ISLs on the west side, with each three covering the 90° strip of sky on its side of the satellite. Since the ISLs are expected to be uniformly distributed to east and west and do not

Subsystem	Mass (kg)
Attitude control	150
Power	210
Solar array	140
Propulsion	275
Structure	280
Thermal	180
TT&C	65
Payload - Antenna	190
- Electronics	750
Integration; elect. & mech.	150
Total (dry mass)	2,390
On-orbit fuel	170
Total (BOL mass)	2,560

Table 8-12: Satellite Mass (2015 Design)

Component	Power (W)	
Receivers	420	
Demodulators	650	
Decoders	120	
Switch/Processor	250	
Encoders	170	
Modulators	120	
Transmitters	3,900	
Other/Margin	300	
Total Payload	5,930	5,930
TT&C	30	
Attitude control	135	
Propulsion	2	
Power subsystem	52	
Thermal subsystem	173	
Control electronics	80	
Harness loss	44	
Total Bus	496	496
Battery charging		574
Total Satellite		7,000

Table 8-13: Satellite Power (2015 Design)

## Chapter 9

# Earth Terminals

This chapter discusses the earth terminals required for use with the Data Distribution Satellite (DDS). The chapter is organized as follows:

- 9.1 Overview
- 9.2 Summary of Earth Terminal Configuration
- 9.3 Classes of Terminals

### 9.1 Overview

It is expected that several thousand earth terminals would be utilized in the systems configurations for an operational DDS System. Because of the large quantities, it is important to optimize the cost and performance of the overall terminal segment with that of the satellite and communication control segments.

The key issues for earth terminal configurations include:

**Choice of antenna size.** Smaller terminals have a lower cost, are easier to install, and have broader beam widths which makes antenna pointing easier. This must be balanced versus the lower performance parameters which requires a greater burden to be placed upon the satellite subsystems in order to achieve a required link data rate and quality.

The accommodation of TDM downlink burst rates of 52 Mb/s, large system throughput, and finite satellite power availability leads to a recommendation of a minimum VSAT antenna diameter of 1.8 m for DDS applications. A smaller size to 1.2 m diameter could be utilized for applications which can accept a lesser link quality and/or greater link outage during severe weather conditions.

**Multi-frequency operation.** The DDS will operate at both the Ku-band and Ka-band transmission fre-

quencies. If a particular user requires operation at both frequencies, then a tradeoff must be made between implementing two separate terminals or using a single terminal with a dual band feed for both transmit and receive.

**Dedicated versus shared terminals.** The concept of mini-trunking in which several users share a specific earth terminal may lead to cost advantages dependent upon the costs of the interconnect networks and the lessened availability for each user. The users may share the full capability of a terminal on a time basis or the simultaneous requirements of several users may be grouped and a larger antenna terminal utilized.

### 9.2 Summary of Earth Terminal Configurations

The earth terminals for DDS applications are expected to range in size from 1.2 m to 7.0 m diameter depending upon the specific user application requirements. A summary of the peak antenna gain, at 60% efficiency, and associated half power beamwidth (HPBW) for candidate terminal sizes is given in Table 9-1 for both Ku-band and Ka-band operation. Edge-of-coverage gains are 3 dB lower than peak gain for isolated spot beams and 4.3 dB lower for an array of beams providing area coverage.

A single antenna may be used for simultaneous operation at both frequencies if desired by the user; however, a dual frequency feed and associated rf equipment is required.

The Ku-band downlinks are expected to use the spectrum from 11.7 to 12.2 GHz and the uplinks to use the spectrum from 14.0 to 14.5 GHz. The Ka-band downlinks are expected to use the spectrum from 19.7 to

Table 9-1: Summary of Earth Terminal Parameters for DDS System

Earth Terminal Diameter (m)	Ku-Band				Ka-Band			
	Downlinks (11.95 GHz)		Uplinks (14.25 GHz)		Downlinks (19.95 GHz)		Uplinks (29.75 GHz)	
	Peak Gain (dBi)	Half power Beamwidth (°)	Peak Gain (dBi)	Half power Beamwidth (°)	Peak Gain (dBi)	Half power Beamwidth (°)	Peak Gain (dBi)	Half power Beamwidth (°)
1.2	41.4	1.50	42.6	1.30	45.7	.90	49.2	.60
1.8	44.8	1.00	46.3	.85	49.1	.60	52.7	.40
3.0	49.0	.60	50.7	.50	53.6	.35	57.2	.20
4.0	51.9	.45	53.2	.40	56.2	.27	59.7	.18
5.0	53.7	.35	55.1	.30	58.1	.21	61.6	.14
7.0	56.6	.25	58.0	.22	61.1	.15	64.5	.10

20.2 GHz and the uplinks to use 29.5 to 30.0 GHz.

As the earth terminal antenna diameter is increased, the resulting half power beamwidth is decreased and the antenna pointing becomes more difficult if small signal losses (due to pointing misalignment to specific satellite locations) are required. Manual tracking may be adequate for very small terminals; the medium size terminals would incorporate step tracking; and the large terminals would utilize autotrack techniques.

A summary of user terminal uplink configurations for operation at Ku-band is shown in Figure 9-1. The associated receiving configuration at the DDS would utilize area coverage beams of 1.73° HPBW and spot beams of 0.87° HPBW. A rain margin of 3.0 dB and system margin of 3.0 dB is provided in the associated link calculations. This provides 99.9% link availability in rain region D-2 (average case), 99.95% in region F (best case), and 99.5% in region E (worst case heavy thunderstorm areas).

As one example from Figure 9-1, it is shown that if a user with a 1.8 m diameter terminal desires to communicate at 6 Mb/s to an area coverage satellite beam, then a transmitter power of 23.2 W is required when using D-QPSK modulation and .905 FEC coding. As an alternative, if bandwidth efficiency is required, then a 100 W transmitter is required to communicate when using D-8PSK modulation. If the same example user is able to use one of the satellite spot beams, then 4.7 W transmitter power is required when using D-QPSK modulation or 20.4 W when using D-8PSK.


A similar summary of user terminal uplink configurations for operation at Ka-band is shown in Figure 9-2. Although the Ka-band earth terminals have higher

gain and thus better performance than the Ku-band terminals for a given size, higher rain margins are required to achieve the same availability.

A summary of satellite rf power required for Ku-band and Ka-band implementation of 52 Mb/s TDM downlinks is given in Table 9-2 for earth terminals of 1.8 m and 3.0 m diameter. Because of the large satellite data throughput capacity (greater than 10 Gb/s) and the added cost/complexity associated with large satellite power generation, it is important to minimize the transmit power per link. It is shown that the required satellite power per 52 Mb/s link may range from 1 W to 49 W depending upon the size of earth terminal, size of satellite antenna coverage beam, and modulation technique employed. The range of transmit power is further expanded if alternate rain margins are required. The Bit Error Rate (BER) of  $10^{-10}$  which is achieved corresponds to one error every 200 seconds.


Rain attenuation during heavy rainfall periods has a great impact on link performance for Ku-band and Ka-band transmission frequencies. A summary of required rain margin for various link availabilities for two types of rainfall regions is given in Table 9-3. See ¶7.7.5 of Chapter 7 for additional information and discussion.

As an example from Table 9-3, the link margin for atmospheric attenuation for downlinks at 19.95 GHz is 2.6 dB if the user earth terminal is located in rain region D2 and if a link availability of 99.5% (i. e. yearly outage of 44 hours) is required. If the required link availability is increased to 99.9% (i. e. yearly outage of 9 hours), then the rain margin must be increased to 8.5 dB. This could be achieved by increasing the satellite power by a factor of 4 or by doubling the size of the earth terminal

To 1/8 Conus Beams 1.73°		To Spot Beams 0.87°	
	1.2 W 5.2 13.0 W 56 52 W 224	0.24 W 1.1 2.7 W 11.4 10.8 W 45.6	0.11 W 0.47 1.2 W 5.1 4.7 W 20.4 10.8 W 39
	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s
	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905)	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)
	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s
	0.54 W 2.3 5.8 W 25 23.2 W 100 53 W 192	0.04 W 0.18 0.42 W 1.8 1.7 W 7.3 3.9 W 14 6.8 W 24.3	0.04 W 0.18 0.42 W 1.8 1.7 W 7.3 3.9 W 14 6.8 W 24.3
	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)
	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s
	0.2 W 0.9 2.1 W 9.0 8.3 W 36 19 W 69 33 W 119	7.4 W 26 14.7 W 53 7.5 W 27 54 W	7.4 W 26 14.7 W 53 7.5 W 27 54 W
	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)	QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829)	QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829)
	160 Mb/s 160 Mb/s 320 Mb/s 320 Mb/s 320 Mb/s 320 Mb/s 640 Mb/s 640 Mb/s	160 Mb/s 160 Mb/s 320 Mb/s 320 Mb/s 320 Mb/s 320 Mb/s 640 Mb/s 640 Mb/s	160 Mb/s 160 Mb/s 320 Mb/s 320 Mb/s 320 Mb/s 320 Mb/s 640 Mb/s 640 Mb/s

Rain Margin = 3.0 db  
99.5% region E  
99.9% region D-2  
99.95% region F

Figure 9-1: Summary of User Terminal Configurations for Ku-Band Uplinks

To 1/8 Conus Beams 1.73°		To Spot Beams 0.5°	
	1.8 W 7.8 18.4 W 79 74 W 318	0.14 W 0.6 1.3 W 5.6 5.0 W 22	0.06 W 0.26 0.55 W 2.4 2.2 W 9.5 8.6 W 31
	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s
	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905)	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)
	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s
	0.8 W 3.4 8.2 W 35 33 W 142 75 W 270	0.02 W 0.09 0.2 W 0.9 0.8 W 3.5 1.9 W 6.5 3.1 W 11.2	0.02 W 0.09 0.2 W 0.9 0.8 W 3.5 1.9 W 6.5 3.1 W 11.2
	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)	D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) D-QPSK (905) D-8PSK (905) QPSK (749) 8PSK (829)
	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mb/s
	16.4 W 59 49 W 178 99 W 356	1.1 W 4.0 3.3 W 12 6.7 W 24	1.1 W 4.0 3.3 W 12 6.7 W 24
	QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829)	QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829)	QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829) QPSK (749) 8PSK (829)
	52 Mb/s 52 Mb/s 160 Mb/s 160 Mb/s 320 Mb/s 320 Mb/s 640 Mb/s 640 Mb/s	52 Mb/s 52 Mb/s 160 Mb/s 160 Mb/s 320 Mb/s 320 Mb/s 640 Mb/s 640 Mb/s	52 Mb/s 52 Mb/s 160 Mb/s 160 Mb/s 320 Mb/s 320 Mb/s 640 Mb/s 640 Mb/s

Rain Margin = 3.1 db  
98.0% region E  
99.0% region D-2  
99.8% region F

Figure 9-2: Summary of User Terminal Configurations for Ka-Band Uplinks

Table 9-2: Satellite Transmit Power Required for 52 Mb/s TDM Links to Different Earth Terminals

	Satellite RF Power (W)	
	1.8 m Earth Terminal	3 m Earth Terminal
Ku-band (with 2 dB rain margin):		
From 0.87° Beam:		
• for BPSK, .75 FEC, 10 <sup>-10</sup> BER	10.0	3.8
• for QPSK, .75 FEC, 10 <sup>-10</sup> BER	12.6	4.6
Ku-band (with 1.4 dB rain margin):		
From 1.73° Beam:		
• for BPSK, .75 FEC, 10 <sup>-10</sup> BER	39.0	14.0
• for QPSK, .75 FEC, 10 <sup>-10</sup> BER	49.1	17.7
From 0.5° Beam:		
• for BPSK, .75 FEC, 10 <sup>-10</sup> BER	2.6	1.0
• for QPSK, .75 FEC, 10 <sup>-10</sup> BER	3.3	1.2

Table 9-3: Required Rain Margin for Various Link Availabilities and Two Rain Regions

Avail. (%)	Outage (hr/yr)	Ku-Band Margin (dB)				Ka-Band Margin (dB)			
		Uplinks (14.25 GHz)		Downlinks (11.95 GHz)		Uplinks (29.75 GHz)		Downlinks (19.95 GHz)	
		Rain Region E	Rain Region D2	Rain Region E	Rain Region D2	Rain Region E	Rain Region D2	Rain Region E	Rain Region D2
99.99	0.9	32.0	17.2	23.9	12.4	97.1	57.0	55.2	30.9
99.98	1.8	25.1	12.0	18.5	8.5	78.0	41.1	43.7	21.8
99.95	4.4	16.3	7.1	11.8	5.0	53.1	25.7	29.1	13.7
99.9	8.8	10.7	4.4	7.6	3.0	36.6	16.8	19.5	8.5
99.8	17.5	6.3	2.7	4.3	1.8	22.6	10.7	11.7	5.3
99.5	43.8	<u>3.0</u>	1.3	<u>2.0</u>	0.8	11.6	5.5	5.7	2.6
99.0	87.7	1.6	0.6	1.0	0.4	6.5	2.9	3.1	1.3
98.0	175.3	.7	0.2	0.4	0.2	<u>3.1</u>	1.3	<u>1.4</u>	0.5



or other alternatives.

In general a standard type service will be provided to/from the DDS, and enhanced or degraded performance for a specific user with unique requirements would be achieved by increasing the size of the user earth terminal or transmit power level. Extremely high link availability is often best achieved by utilizing a second diversity terminal located several kilometers from the primary terminal.

### 9.3 Classes of Terminals

This section examines the impact of earth terminal implementation alternatives from the viewpoint of specific user classes. The general classes are as follows:

- 9.3.1 VSATs of 1.2 to 1.8 m diameter
- 9.3.2 Mini-trunking terminals of 3.0 m diameter
- 9.3.3 Large terminals of 4 to 7 m diameter

#### 9.3.1 VSAT Terminals (1.2 - 1.8 m)

Very Small Aperture Terminals (VSATs) could range in size from 1.2 to 1.8 m (4 to 6 ft) in diameter. A summary of 1.8 meter user terminal configurations for uplinks and downlinks via the DDS is shown in Figure 9-3. The range of impact on transmitter power requirements is shown as a function of various link modulation and coding parameters for various communications data rates. The baseline configuration incorporates rain attenuation margins of 3.0 dB for Ku-band uplinks (giving 99.8% link availability to average rain region D2) and 2.0 dB for Ku-band downlinks (giving 99.8% link availability to rain region D2). The baseline Ka-band links incorporate 3.1 dB rain margin for uplinks (giving 99.0% availability to region D2). It is expected that users with requirements for very high link availability would utilize Ku-band due to the lower rain margin requirements.

A summary of candidate DDS link configurations for services to 1.8 m diameter user terminals is given in Figure 9-4. For example, a 25 W rf transmitter for the earth terminal is required to communicate at 1.5 Mb/s via a 1.73° satellite coverage beam when using D-8PSK modulation and rate .905 FEC coding at Ku-band. It is expected that this signal would be processed via a bulk demodulator on the satellite and then switched to the correct downlink beam to complete the link with the receiving terminal.

Similarly this 1.8 m terminal would utilize 39 W transmitter power to communicate at 30 Mb/s via an 0.87° spot beam at Ku-band when using 8PSK modulation and rate .829 FEC coding.

A satellite transmitter power of 12.6 W is required to implement a 52 Mb/s TDM downlink at Ku-band when using QPSK modulation, rate .749 FEC coding, and the 0.87° satellite antenna coverage beams.

#### 9.3.2 Mini-Trunking Terminals (3 m)

The medium class of terminal would be utilized for either dedicated services for medium data rates or as a mini-trunking terminal for shared user services. A summary of 3.0 m user terminal configurations for uplinks and downlinks via the DDS is shown in Figure 9-5. The range of required transmitter power is shown as a function of various link modulation and coding parameters for various communication data rates.

A summary of candidate DDS link configurations for services to 3.0 m diameter user terminals is given in Figure 9-6. For example it is shown that a 36 W transmitter is required to communicate at 6 Mb/s to a 1.73° HPBW satellite coverage beam when using D-8PSK modulation and rate .905 FEC coding at Ku-band. Similarly this terminal would require 24 W transmitter power to communicate at 52 Mb/s to an 0.87° spot beam at Ku-band when using 8PSK modulation and rate .829 FEC coding.

A satellite transmitter power of 4.6 W is required to implement a 52 Mb/s TDM downlink at Ku-band when using the 0.87° coverage beam, QPSK modulation, and rate .749 FEC coding. If bandwidth efficiency is not required, then a reduced power with BPSK modulation could be used. If increased bandwidth efficiency is required, then an increased transmitter power with 8PSK modulation could be used.

#### 9.3.3 Large Terminals (4 - 7 m)

The large class of terminals would be appropriate for the large data requirement users such as the White Sands interface to the TDRS network, science data base centers, the DDS communications control center, and node points serving to interface to local fiber optic terrestrial networks.

A summary of candidate DDS link configurations for services to 5 m diameter user terminals is given in Figure 9-7. For example, a 129 W transmitter is required by the earth terminal in order to communicate at 160 Mb/s

Ku-Band				Ka-Band			
Uplink		Downlink		Uplink		Downlink	
Conus Coverage 1.73° beams	Spot Beams 0.87°	Conus Coverage 0.87° beams 4.3	Conus Coverage 1.73° beams	Spot Beams 0.5°	Conus Coverage 1.73° beams 4.3	Spot Beams 0.5°	Conus Coverage 1.73° beams 4.3
D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 144 kb/s 144 kb/s 0.54 W 2.3	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 1.5 Mb/s 1.5 Mb/s 5.8 25	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 1.5 Mb/s 1.5 Mb/s 5.1	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 1.5 Mb/s 1.5 Mb/s 8.2 35	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 1.5 Mb/s 1.5 Mb/s 0.6 2.4	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 6.0 Mb/s 6.0 Mb/s 23.2 100	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 6.0 Mb/s 6.0 Mb/s 4.7 20.4	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 6.0 Mb/s 6.0 Mb/s 33 142
QPSK (.749) 10 <sup>-10</sup> 8PSK (.829) 30 Mb/s 30 Mbps 53 192	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 144 kb/s 144 kb/s 0.11 W 0.47	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 144 kb/s 144 kb/s 0.47	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 144 kb/s 144 kb/s 0.8 W 3.4	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 144 kb/s 144 kb/s 0.06 W 0.3	QPSK (.749) 10 <sup>-10</sup> 8PSK (.829) 30 Mb/s 30 Mbps 53 192	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 144 kb/s 144 kb/s 0.11 W 0.47	D-QPSK (.905) 10 <sup>-4</sup> D-8PSK (.905) 144 kb/s 144 kb/s 0.8 W 3.4
For 3.0 dB rain margin 99.5% avail. region E 99.8% avail. region D2 99.95% avail. region F		2.0 dB 99.5% - E 99.8% - D2 99.95% - F	For 3.1 dB rain margin 98.0% avail. region E 99.0% avail. region D2 99.8% avail. region F		1.4 dB 98.0% avail. - E 99.0% avail. - D2 99.8% avail. - F		

Figure 9-3: User Terminal Configurations - 1.8 m VSAT

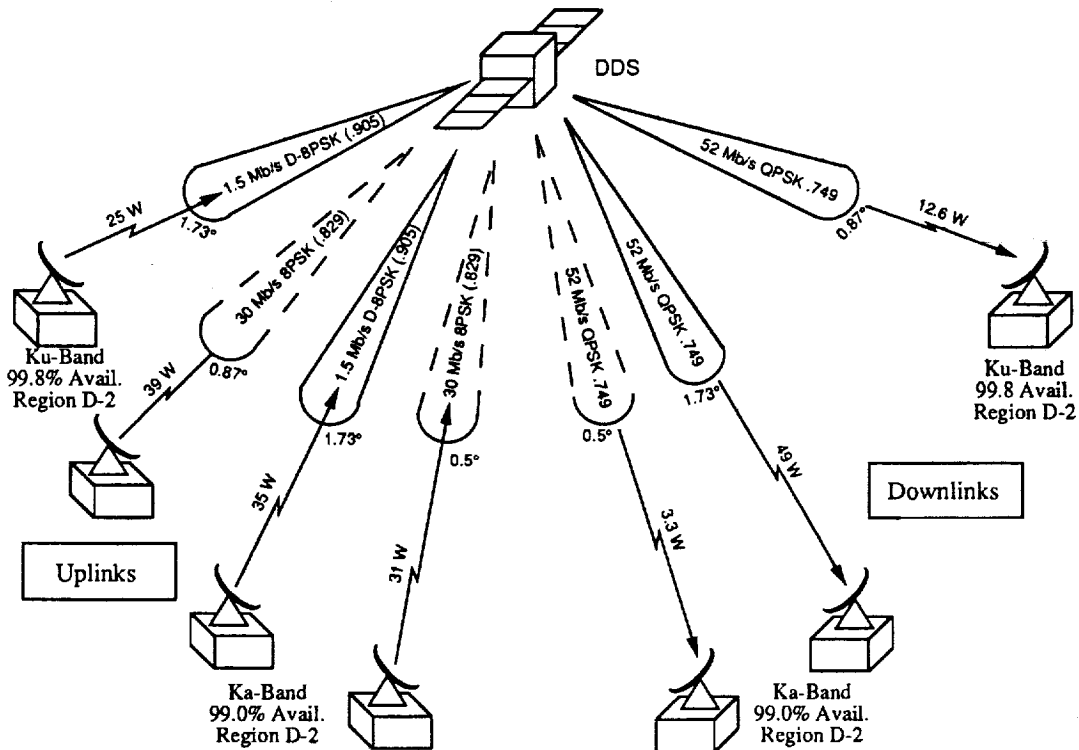


Figure 9-4: Link Parameters for 1.8 m User Terminals

Ku-Band				Ka-Band			
Uplinks		Downlink		Uplinks		Downlinks	
Conus Coverage 1.73° beams	Spot Beams 0.87°	Conus Coverage 0.87° beams		Conus Coverage 1.73° beams	Spot Beams 0.5°	Conus Coverage 1.73° beams	Spot Beams 0.5°
4.3	3.0	4.3	4.3	4.3	3.0	4.3	3.0
D-OPSK (.905) 10 <sup>-9</sup> D-8PSK (.905) D-OPSK (.905) 10 <sup>-8</sup> D-8PSK (.905) D-OPSK (.905) 10 <sup>-6</sup> D-8PSK (.905) OPSK (.749) 10 <sup>-10</sup> 8PSK (.829)	D-OPSK (.905) 10 <sup>-9</sup> D-8PSK (.905) D-OPSK (.905) 10 <sup>-8</sup> D-8PSK (.905) D-OPSK (.905) 10 <sup>-6</sup> D-8PSK (.905) OPSK (.749) 10 <sup>-10</sup> 8PSK (.829)	BPSK (.749) 10 <sup>-10</sup> OPSK (.749) 10 <sup>-10</sup>		D-OPSK (.905) D-8PSK (.905) D-OPSK (.905) D-8PSK (.905) D-OPSK (.905) D-8PSK (.905) OPSK (.749) 8PSK (.829)	D-OPSK (.905) D-8PSK (.905) D-OPSK (.905) D-8PSK (.905) D-OPSK (.905) D-8PSK (.905) OPSK (.749) 8PSK (.829)	BPSK (.749) 10 <sup>-10</sup> OPSK (.749) 10 <sup>-10</sup>	BPSK (.749) 10 <sup>-10</sup> OPSK (.749) 10 <sup>-10</sup> BPSK (.749) 10 <sup>-10</sup> OPSK (.749) 10 <sup>-10</sup>
144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mbps	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mbps	52 Mb/s 52 Mb/s		144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mbps	144 kb/s 144 kb/s 1.5 Mb/s 1.5 Mb/s 6.0 Mb/s 6.0 Mb/s 30 Mb/s 30 Mbps	52 Mb/s 52 Mb/s	52 Mb/s 52 Mb/s
0.2 W	0.9	2.1	9.0	8.4	36	19	69
0.4	0.2	0.4	1.8	1.7	7.2	3.9	14
0.3	1.2	3.0	12.6	11.9	51	27	97
0.02	0.1	0.2	0.9	0.4	3.4	3.1	11.2
For 3.0 dB rain margin 99.5% avail. region E 99.8% avail. region D-2 99.95% avail. region F			2.0 dB 99.5% - E 99.8% - D-2 99.95% - F	For 3.1 dB rain margin 98.0% avail. region E 99.0% avail. region D-2 99.8% avail. region F			1.4 dB 98.0% avail. - E 99.0% avail. - D-2 99.8% avail. - F

Figure 9-5: User Terminal Configurations – 3 m Medium Terminal

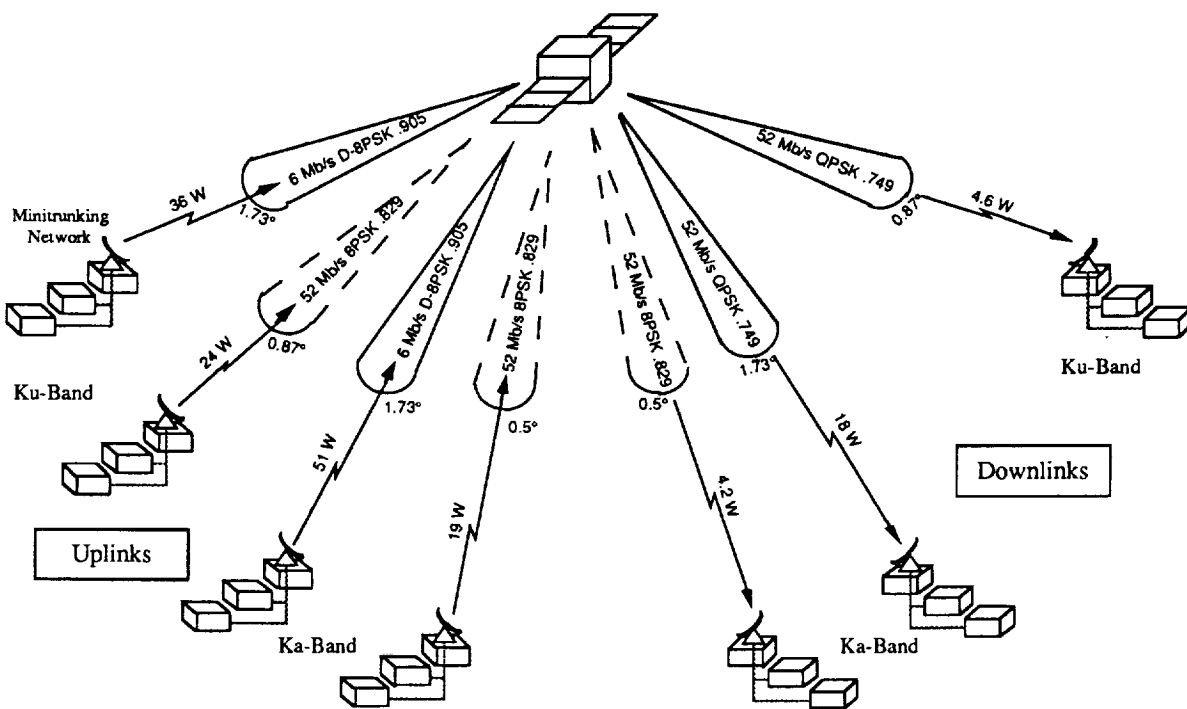


Figure 9-6: Link Parameters for 3 m User Terminals

via a  $1.73^\circ$  satellite coverage beam when using 8PSK modulation and rate .829 FEC coding at Ku-band. This signal would pass through a dedicated demodulator on the satellite. Similarly this terminal could utilize 53 W transmitter power to communicate at 320 Mb/s via an  $0.87^\circ$  spot beam at Ku-band when using 8PSK modulation and rate .829 FEC coding.

A satellite rf transmitter power of 10.2 W is required to implement a 320 Mb/s downlink at Ku-band via the  $0.87^\circ$  coverage beam when using QPSK modulation and rate .749 FEC coding.

A candidate earth terminal configuration at the White Sands site for accommodating relay of ATDRS data via DDS would include a 7 m Ku-band antenna and a 5 m Ka-band antenna. If each terminal were required to accommodate wideband data links of 320 Mb/s, then the required uplink and downlink transmitter powers would be as shown in Figure 9-8. This site is in a region of low rainfall and hence a high link availability is achieved with minimal rain margins.

For example at Ku-band, a 43 W transmitter would provide 99.98% link availability (1.8 hours per year of outage) on uplinks via the  $0.87^\circ$  satellite beam. This link would utilize 8PSK modulation for bandwidth efficiency and utilize rate .829 FEC coding for power efficiency, and yields a signal quality of  $10^{-10}$  BER.

At Ka-band, a 47 W transmitter would provide 99.9% link availability (9 hours per year of outage) on uplinks via  $0.5^\circ$  satellite beams.

Other considerations for the White Sands terminal implementation would include use of a single terminal, with both Ku-band and Ka-band feeds. The cost advantage of a single reflector must be traded versus degraded performance parameters for joint frequency operation. If very high link availability is required, i. e. almost no hours of outage, then the use of site diversity terminals should be considered.

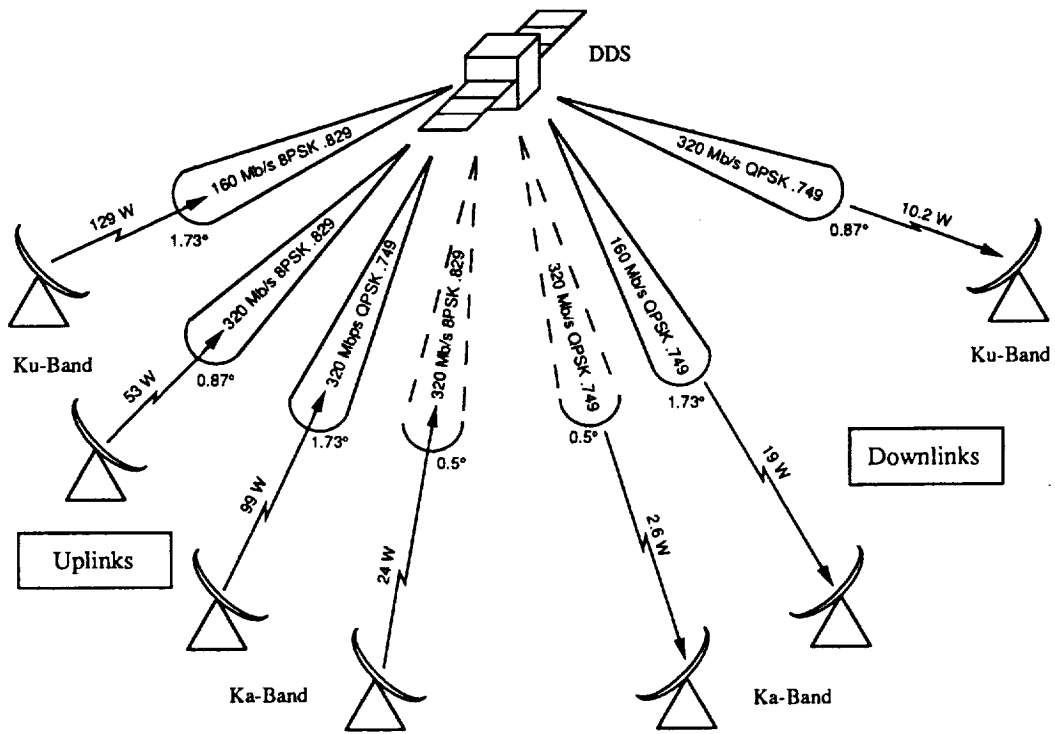


Figure 9-7: Link Parameters for Large (5 m) User Terminals

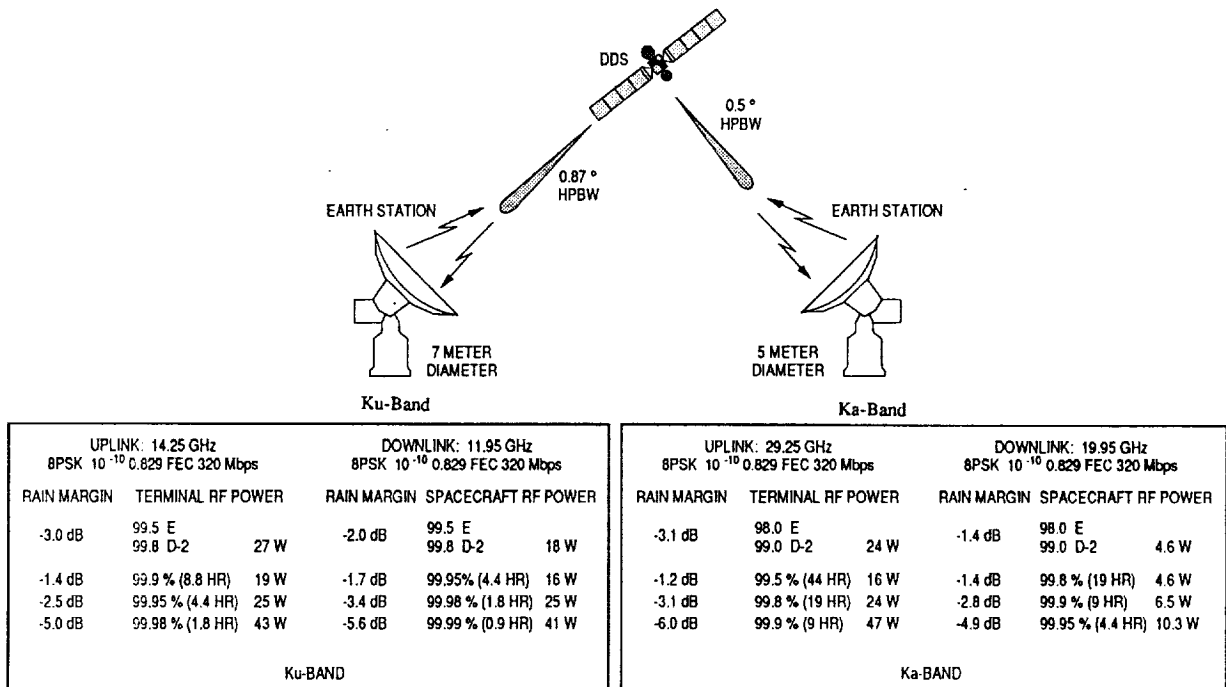


Figure 9-8: Wideband Data Links (320 Mb/s) to White Sands Earth Terminal

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## Chapter 10

# Network and Master Control

This chapter is organized as follows:

- 10.1 Overview of Control Problem
- 10.2 TT&C Control
- 10.3 Interfaces to Terrestrial Networks
- 10.4 DDS Network Control Center
- 10.5 Experiment Control Centers

### 10.1 Overview of Control Problem

The DDS network control problem is in many respects analogous to the ATDRSS Space Network problem described in Appendix A, ¶A.4. It is instructive to first summarize the behavior of the ATDRSS Space Network, and then to describe the DDS interface problem. For the future ASDACS system, which represents an integration of DDS and ATDRSS, the control problem is simplified.

#### 10.1.1 ATDRSS Space Network

Figure 10-1 presents a behavior diagram for ATDRSS Space Network operations, based upon the ATDRSS Phase B RFP (see Appendix A for references and list of acronyms). The figure is not complete, but represents the functions within and interrelationships between three elements of Space Network operations:

- ATDRSS
- Space Network scheduling
- User Project Operations Control Center (POCC)

The flow in Figure 10-1 is from top to bottom, with the "&" symbols in the circles representing concurrent operations, the rectangular boxes being functions or processes, and the rounded corner boxes being inputs or outputs.

If the DDS System were to be part of this "Space Network", then there would be a fourth box labelled "DDSS" which would be very similar to the ATDRSS box in Figure 10-1. However, our approach is to consider DDS to be a separate system with its own Network Control Center with scheduling functions and interfaces to ATDRSS (for connection with user satellites) and interfaces to ground based users.

#### 10.1.2 DDS Interfaces to ATDRSS and Users

As shown in Figure 10-2, the DDS system is envisioned to form an alternate path from ATDRS to user, either bypassing White Sands via an intersatellite link from ATDRS to DDS or forming a satellite link from White Sands to user. This allows returning data to pass directly to certain users who need real time interaction with their experiments or sensors in space.

The DDS can be viewed as an auxiliary network to be used by the User Project Operations Control Center (POCC) to access its experiment or sensor in space. User requests for service now have to obtain resources from the ATDRSS Space Network (SN) (probably by scheduling in advance) and from the DDS if direct distribution is required. The User POCC could communicate with the ATDRSS SN via terrestrial circuits or via DDS. In either case, coordination of ATDRS and DDS is required to establish user service via DDS.

#### 10.1.3 ASDACS – Integration of DDS and ATDRS

A future Advanced Space Data Acquisition and Communications System (ASDACS) could incorporate the "data distribution" function of DDS with the "data collection and relay" functions of ATDRS onto a single platform. Use of high capacity, low mass and power, optical intersatellite links would be an enabling technol-

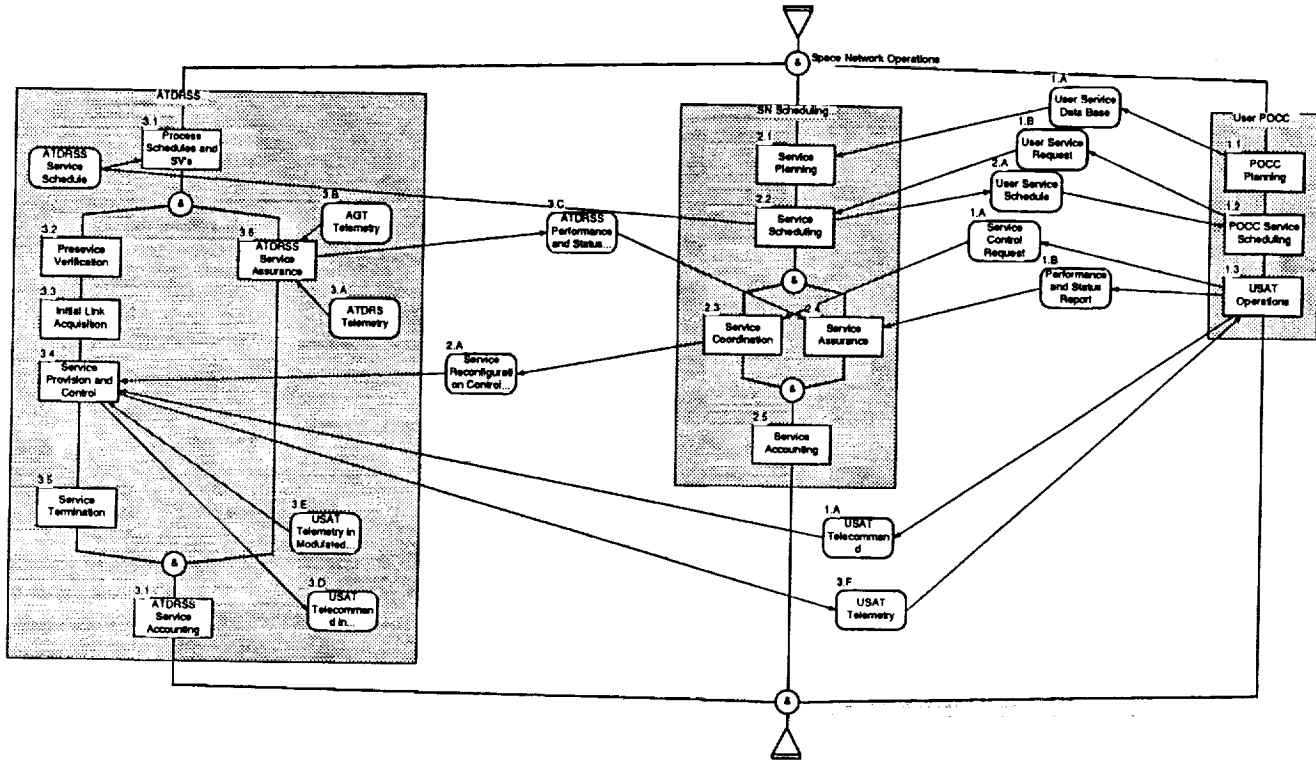


Figure 10-1: Behavior Diagram for ATDRSS Space Network Operations

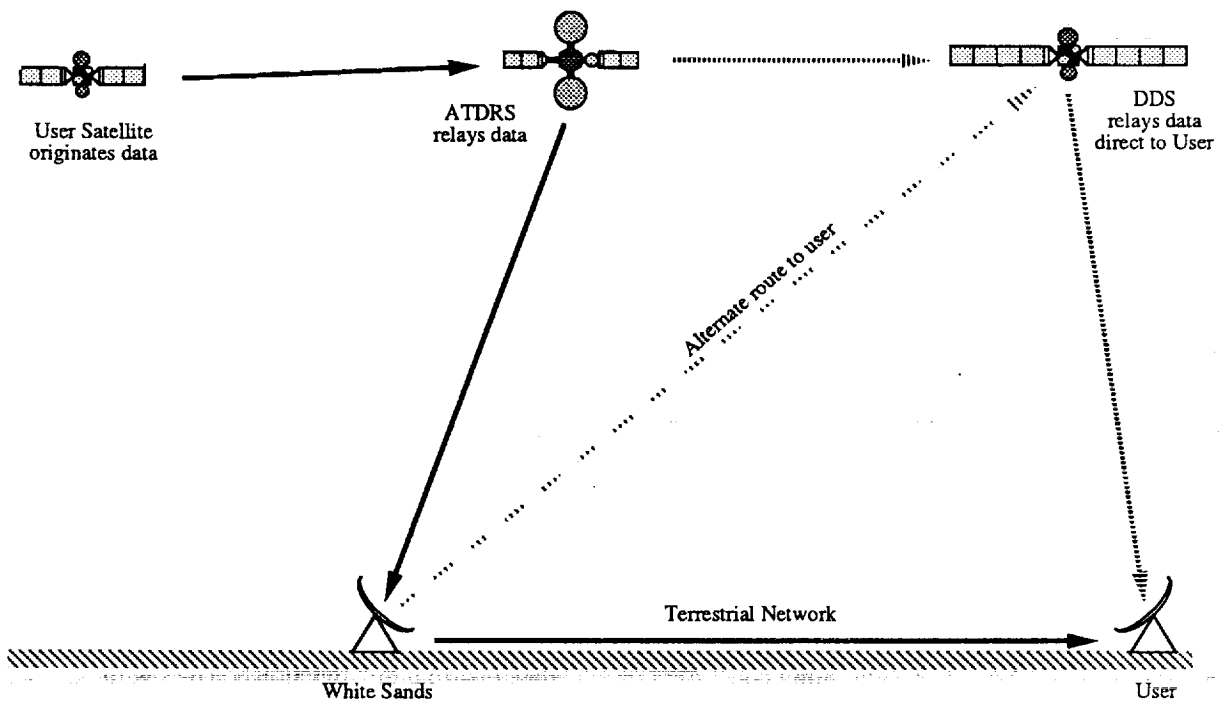


Figure 10-2: The DDS Interfaces to ATDRSS and Users



ogy for ASDACS. The large antenna subsystem mass of ATDRS could be used for direct up/down link antennas and sophisticated on-board switching.

The ASDACS control problem would be simpler than that for the separate DDS - ATDRS Systems. However, since operations would be essentially real time, certain control functions would become critical and need to be implemented via an autonomous network controller on board the ASDACS platform:

- Process access requests without the .27 second delay for ground data base consultation.
- Switch and route data without ground consultation.
- Monitor health of communications payload.
- Detect faults and perform autonomous fault correction.

## 10.2 TT&C Control

Part of the DDS control problem involves monitoring and control of the non-communications payload functions via the TT&C links to the satellite. It is envisioned that there would be a separate satellite control facility, probably shared among other satellite systems, that would perform the typical satellite bus functions such as attitude control, station keeping, and power system management during the eclipse season.

The DDS Network Control Center would interface with the TT&C facility for purpose of sending antenna pointing and other payload configuration commands to DDS. Since the TT&C control functions for DDS are similar to those for existing satellites, this discussion will move on to discuss other NCC issues.

## 10.3 Interfaces to Terrestrial Networks

The DDS System is envisioned to have three different types of interfaces to terrestrial networks:

1. LAN and WAN Interfaces
2. NASCOM Interfaces
3. Public Telephone Network

### 10.3.1 LAN and WAN Interfaces

Local Area Network (LAN) and Wide Area Network (WAN) interfaces may be common features for government and industry DDS users. A medium sized terminal could be connected to the campus LAN and aggregate DDS user signals in much the same way as the local telephone company office.

The DDS system should be compatible with standard terrestrial transmission protocols and formats, and the ground terminals will need to incorporate an interface chip to act as a gateway between the terrestrial system and the DDS system.

### 10.3.2 NASCOM Interface

High data rate NASCOM interfaces would be provided as part of the DDS system at the locations of major DDS system node terminals. Of course other users on LANs or WANs could also connect to NASCOM via their local communication facilities.

### 10.3.3 Public Telephone Network

In addition, high data rate interfaces to the public switched network would be made at locations of the major DDS node terminals (at least four to six regional locations). It is envisioned B-ISDN links would be available (160 Mb/s or 320 Mb/s) in order to supply connections for wideband as well as multiple narrowband (ISDN) users.

## 10.4 DDS Network Control Center

The DDS Network Control Center functions would be primarily ground-based for the year 2007 satellite, but there is a significant need for an autonomous network controller on the satellite for later versions of DDS. These two topics are discussed in turn.

### 10.4.1 Ground-Based NCC

The year 2007 DDS system described in this document is envisioned as having a ground-based Network Control Center (NCC) which is the DDS operations control facility and which provides operational interfaces between users and the DDS/ATDRSS space network.

Network management consists of a combination of human, hardware, and software elements. The human elements consist of network administrators who make

decisions on network management. The hardware and software elements are the automated network management tools which provide management capabilities for the network. These tools perform the following network management functions:

**Configuration management** is defining, changing, monitoring, and controlling network resources and data.

**Fault management** is detecting, diagnosing, and recovering from network faults.

**Accounting management** is recording usage of network resources.

**Resource management and user directory** is supporting directories for managing network assets and user information.

**Security management** is ensuring authorized access to the network resources and components.

**Performance management** is tracking current and long term performance of the network (trend analysis).

The technical design of the space and ground hardware can be made adequate for the projected traffic. A key problem lies in the implementation of software for scheduling and utilizing DDS/ATDRS in the presence of high priority, high data rate users. This problem is much easier for the DDS system with its use of ATM "fast packet" structures within the B-ISDN protocol. However, ATDRSS may be a barrier to rapid access to on-orbit science resources. The follow-on ASDACS represents an opportunity to implement a capability for real time access to data.

A second problem lies in the avoidance of a single failure point in the system. The ATDRSS is vulnerable to a major catastrophe at White Sands. The DDS system should form an alternate path from on-orbit experiment/sensor to user. Thus the DDS NCC should not be located at White Sands, and there should be two NCCs in different geographical locations.

#### 10.4.2 Autonomous Network Controller

The Autonomous Network Controller (ANC) is envisioned for the 2015 DDS. The ANC would be part of the DDS payload and would autonomously perform certain of the NCC functions, based upon information uploaded

from the ground-based NCC. The advantage of an on-board ANC is that it eliminates the 0.27 second transmission delay associated with ground-based decisions. This is important for bursty traffic with short connection times, where connections are set up for only very short times.

The functions to be performed by the ANC could include the following:

**Allocation of communications resources** of the DDS system within the scope of the database provided by the NCC. This includes setting up circuits and/or routing packet data originating from authorized users.

**Health monitoring and reporting** to the NCC of space and ground segment resources.

**Fault recovery** in real time for DDS communication resources.

It is recommended that NASA begin work on the ANC, but the near term approach should be to implement a ground-based NCC for most DDS functions.

## 10.5 Experiment Control Centers

The routing of telescience data and experiment control information between the various science experimenters (located anywhere within CONUS) and their on-orbit experiments is a primary mission of the DDS. This requires coordinated action between the Experiment Control Center (ECC) which controls access to an on-orbit experiment and its results, and the DDS Network Control Center (NCC) which is the DDS operations control facility and which provides operational interfaces between users and the DDS/ATDRSS space network.

### 10.5.1 Key Issues for ECC

Many key issues must be resolved before an operational system is implemented. These issues include the following:

- Role of the Experiment Control Centers. Is there a need for this function or should it be carried out by the DDS Network Control Center?
- Should several Experiment Control Centers be established, with specialization by type of experiment or should a single facility support the access control decision making?

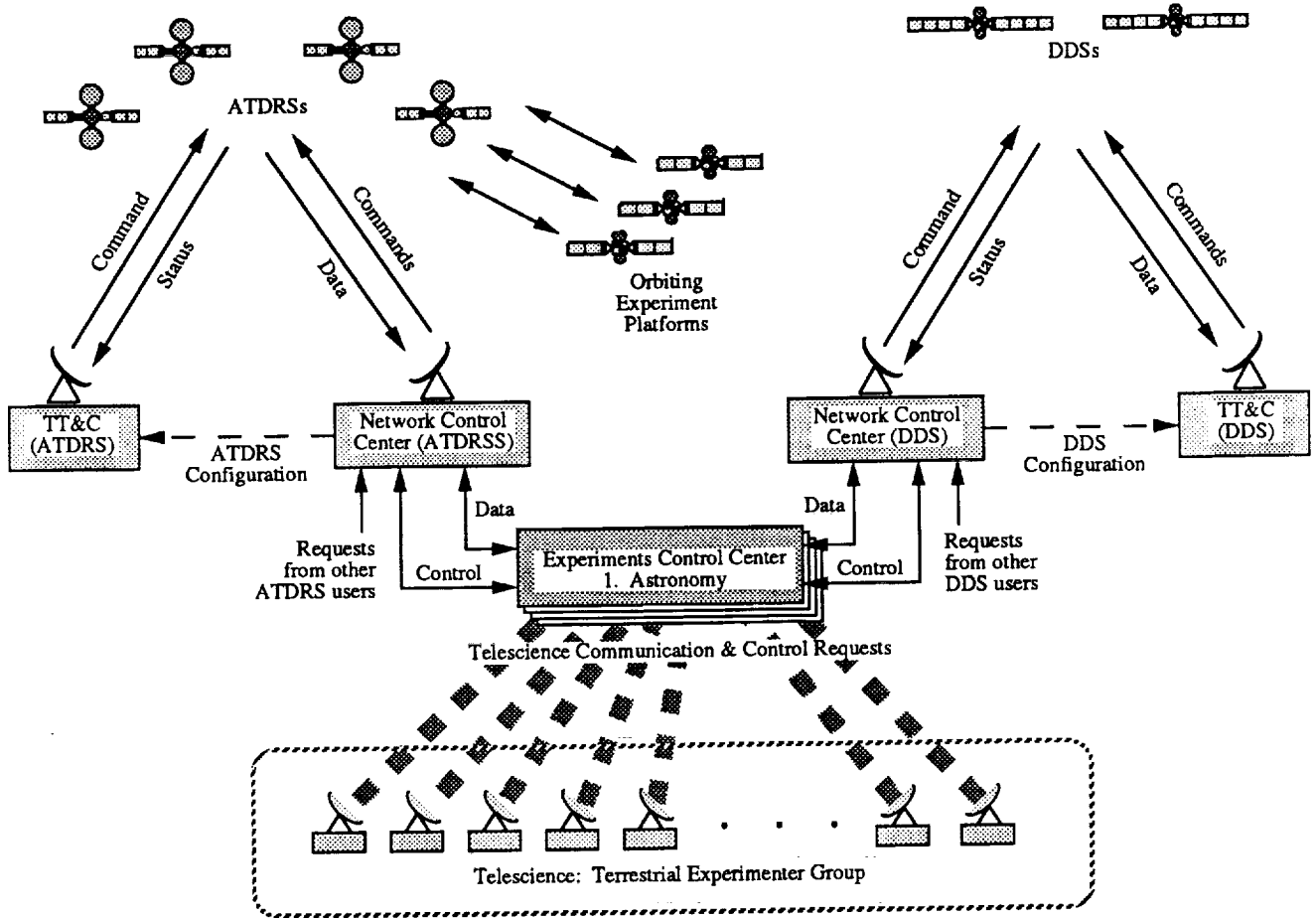


Figure 10-3: Experiment Control Center Coordinates User Requests for Control and Data

- How would the NCC resolve contention for capacity demands among several Experiment Control Centers?
- Where should Experiment Control Centers be located?
- What control functions should be provided by the prime experimenter?
- Will alternate wideband communications links connect the various users of a particular experimenter such that not all users need to access DDS downlinks directly?

As a starting baseline, it is expected that several Experiments Control Centers would be established for the purpose of coordinating the interface and distribution among the various experimenters for the various experiments. These ECCs would in turn interface with both the ATDRSS Space Network via the Network Control

Center at White Sands and with the DDS Network Control Center.

### 10.5.2 Example of ECC Operation

The overall configuration for coordination of service requests from users is shown in Figure 10-3 which depicts a Telescience Experiment Control Center (for example, Hubble Space Telescope Science Institute in Baltimore, MD) which has communications with various terrestrially located experimenter groups. Hundreds of experimenters may be part of this group. The communications links for control could be achieved in a variety of ways:

- Satellite relay via DDS
- Established NASCOM or NREN networks
- Commercial networks

The Experiment Control Center (ECC) would coordinate the various requests for data distribution or ex-

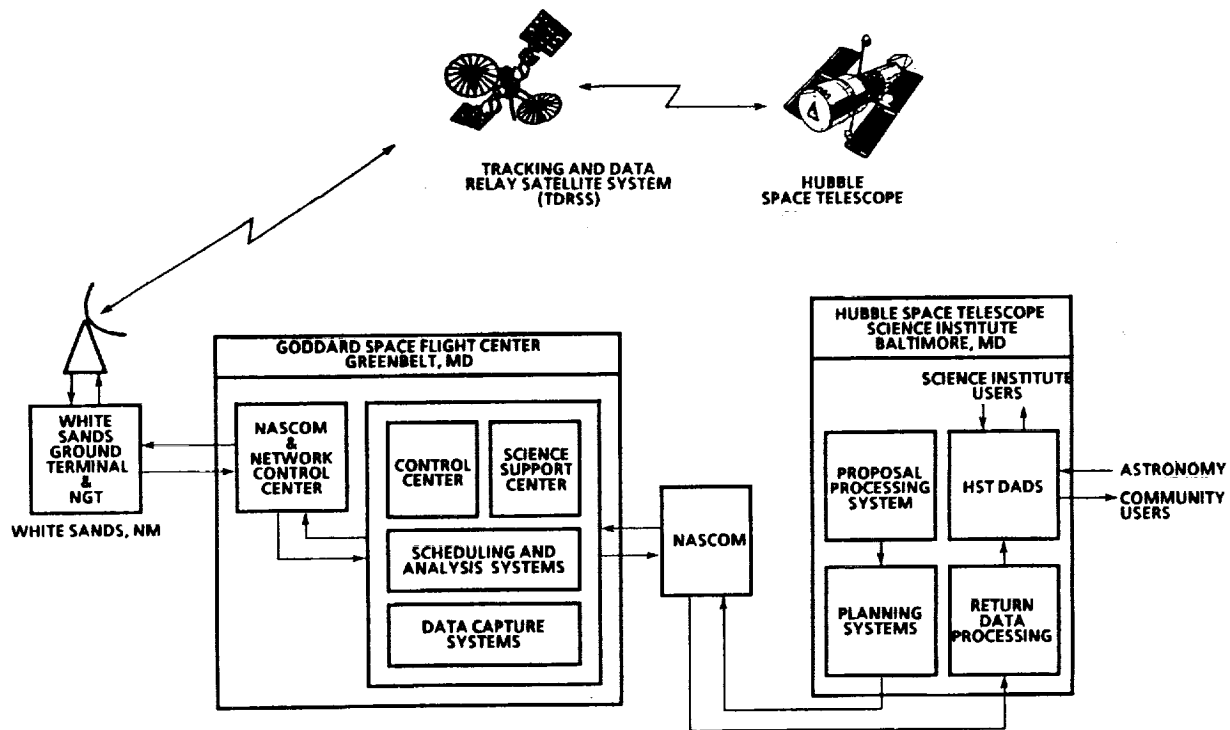


Figure 10-4: Hubble Space Telescope Data Storage and Distribution System

periment control interaction as a control clearing house. The ECC would then coordinate with the ATDRS NCC at White Sands for permission to utilize segments of the ATDRS link capacity and to effect control of on-orbit experiments. The ECC would also coordinate with the DDS Network Control Center for permission to utilize segments of the DDS link capacity and to effect reconfiguration of the DDS communications payload configuration.

Some of the telescience user requests may require changes of spacecraft antenna pointing of ATDRS or DDS spacecraft. Because these changes would impact on overall spacecraft performance, it is expected that further coordination with the appropriate TT&C stations would be required.

The Experiment Control Centers may or may not be located at a centralized facility. In some cases the primary control of a particular experiment may be located at a particular university and hence that location could serve as the ECC. For example, Figure 10-4 shows the current Hubble Space Telescope (HST) communications configuration. HST data flow is as follows:

- i. HST is connected via TDRS to the White Sands Ground Terminal

- ii. NASCOM connects White Sands to Control Center at GSFC
- iii. NASCOM connects GSFC to HST Science Institute
- iv. HST Science Institute connects to outside community of astronomy and HST data users.

If multiple ECCs are utilized, then it is required that there be a top level control facility which regulates and allocates total available network capacity resources. The typical telescience requests for services will vary from those in which response is required within minutes of time to those requiring response within days or weeks. Some examples of requests are illustrated in Table 10-1.

### 10.5.3 Example of Control Information Flow

Once the proper assignment of control and communications capacity has been coordinated, then the transfer of information as experiment control signals to a particular on-orbit experiment may be achieved by the network configuration shown in Figure 10-5.

The example shows the uplink communications from local area experimenter (bottom right) to an on-orbit

Table 10-1: Examples of Telescience Requests for Services

Service Request	Implementation Control
<p><u>Long Term</u> ... up to several days.</p> <ul style="list-style-type: none"> <li>Request to use ATDRS antenna and communications to cover a scheduled on-orbit experiment.</li> <li>Request to be included in the communications and control functions of a particular experiment.</li> </ul>	<ul style="list-style-type: none"> <li>Appropriate telescience ECC coordinates coordinates with ATDRS NCC at White Sands.</li> <li>Experimenter coordinates with prime experimenter and with ECC.</li> </ul>
<p><u>Medium Term</u> ... several hours.</p> <ul style="list-style-type: none"> <li>Request to reconfigure DDS antenna pointing and data rate allocations among terrestrial experimenters.</li> <li>Request for transfer of control info to an on-orbit experiment.</li> </ul>	<ul style="list-style-type: none"> <li>Experimenter coordinates with prime experimenter and with ECC.</li> <li>Experimenter coordinates with prime experimenter and with ECC.</li> </ul>
<p><u>Short Term</u> ... minutes.</p> <ul style="list-style-type: none"> <li>Request for changes in comm link capabilities within the bounds of previously established limits.</li> <li>Request for changes in DDS transmit power level during heavy rain period.</li> </ul>	<ul style="list-style-type: none"> <li>Experimenter has direct command to DDS via the ATDRSS Space Network NCC at White Sands.</li> <li>Experimenter has direct command to DDS via the ATDRSS Space Network NCC at White Sands.</li> </ul>

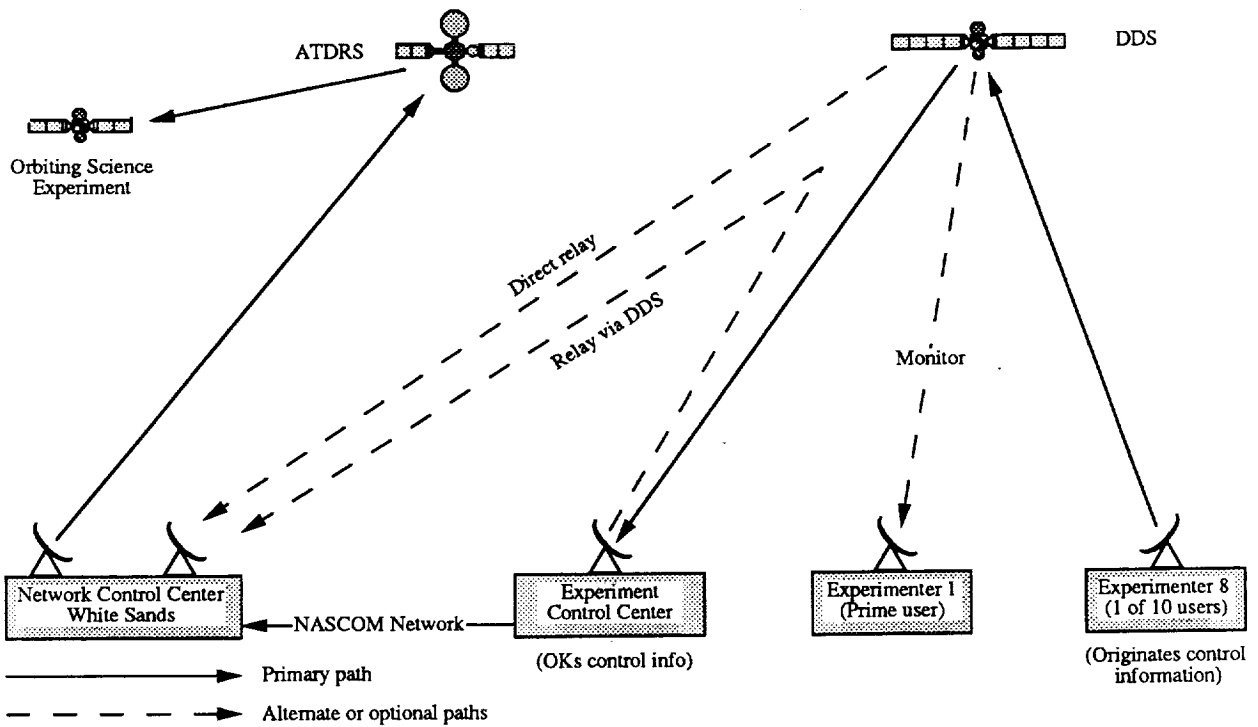


Figure 10-5: Forward Link for Control Information Flow to On-Orbit Experiment

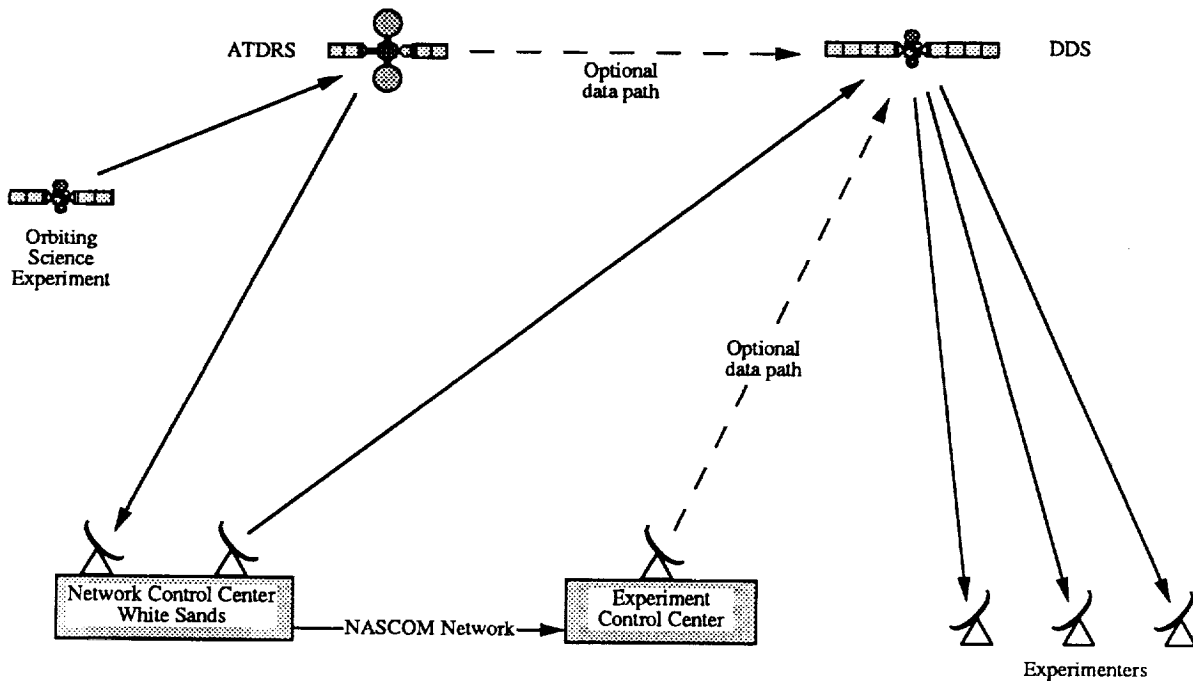


Figure 10-6: Return Link for Data from On-orbit Experiment

experiment (top left of Figure 10-5) which may be achieved after prior coordination with the Experiment Control Center. In this case, Experimenter 8, one of ten experimenters with access to the orbiting science experiment, would uplink experiment control information directly to a DDS. The primary path would relay the information to the ECC which would verify that the contents were within the allowed envelope and then pass the signals through the terrestrial NASCOM network to the NCC at White Sands. The signals would then be uplinked to a particular ATDRS for subsequent relay to the orbiting science experiment.

Alternate communications paths could link DDS directly to the Network Control Center and link the Experiments Control Center to White Sands with a second hop relay via DDS. The DDS could also provide monitor links to other experimenters (as shown for Experimenter 1 in the figure) such that they would have real time cognizance of the particular uplink communications.

Note that use of an intersatellite link from DDS direct to ATDRS is not normally possible, since the ECC and NCC need to have knowledge of and verify the acceptability of all commands given to the on-orbit science experiment.

#### 10.5.4 Example of Return Data Flow

In a similar manner, once proper assignment of return experiment data has been coordinated, then the transfer of on-orbit science experiment data to experimenters may be achieved as shown in Figure 10-6.

The science data originates from the orbiting experiment (top left of figure) and is relayed via ATDRS to Network Control Center at White Sands which in turn relays the data to the DDS. The DDS in turn would communicate to one or more experimenters simultaneously (bottom right of figure). Various DDS to CONUS data links could be employed with proper assignment of frequency band (Ku or Ka-band), coverage beam (broad area coverage or spot beam), and transmitter power level per beam in order to match data readout to particular experimenter requirements.

An alternative routing would provide for direct relay of data from ATDRS to DDS using an intersatellite crosslink. Another alternative is to use NASCOM terrestrial links to route the data to the appropriate ECC for processing, and then relay to experiment users via DDS. The role of the Network Control Center could also be expanded to include data compression of wideband signals prior to DDS relay if desired by experimenters.

# Chapter 11

## System Costs

This chapter defines an overall DDS system cost model; estimates the costs of the space segment, network control, and user ground terminals; and determines the composite pro rata user costs (or derived benefits) associated with various communication services and capacity utilization.

The statement of work for this study (see Chapter 1, ¶1.3.2.1) states that ... *costs shall be expressed in the following forms:*

- a. *Life cycle costs, assuming a government-owned system. A 15 year life cycle shall be assumed. Also, launch costs shall correspond to the rate for government launches.*
- b. *A usage cost factor, assuming a commercially owned system, to be defined jointly by the contractor and the NASA Technical Manager.*

The chapter is organized as follows:

- 11.1 Approach/Guidelines to Cost Determination
- 11.2 Space Segment Costs
- 11.3 User Terminal Costs
- 11.4 Network Control Center Costs
- 11.5 User Network and Utilization Factors
- 11.6 Composite Costs
- 11.7 Comparison of Alternate Costs

### 11.1 Approach and Guidelines to Cost Determination

#### 11.1.1 Method of Approach

The baseline model for determination of DDS system costs and associated user charges consists of the following key elements:

- a. Space segment costs (satellite, launch, and mission control)
- b. Master Network Control Center costs
- c. User terminal costs
- d. System utilization factors

A summary of the cost guidelines for the various cost elements is given in ¶11.2. The model does not include key technology developments made prior to start of system hardware contracts. Also excluded are any costs associated with user operations.

The cost model is also dependent upon the overall system implementation plan and estimates of future economic factors. The baseline plan for a DDS system for year 2007 implementation is summarized in ¶11.3. All costs are expressed in constant 1990 dollars.

#### 11.1.2 Cost Guidelines

A comprehensive set of guidelines must be established in order to give meaningful results to the cost determination for an overall DDS system. Cost guidelines will be discussed in turn for the following categories have been determined or postulated for the current study:

- Key Technology Development Costs
- Space Segment Cost Guidelines
- Network Control Center Cost Guidelines
- User Terminal Cost Guidelines
- System Utilization Factors Cost Guidelines

### Key Technology Development Costs

The DDS system incorporates advanced communications techniques including full demodulator, processing, switching and remodulation in the satellite. This is a major change from current rf transponder methods and significant R&D development will be required to assume satisfactory performance with high reliability.

It is assumed that other government and commercial programs will be incorporating some of the advanced techniques and that this technology development would be of support to DDS.

The balance of the R&D effort would be incurred in the year 1991 to year 2001 period, assuming space segment hardware contract in year 2002 with first launch in year 2007.

The greater the spin off from other programs and the greater the NASA technology development program the less the non-recurring development costs for the DDS program.

The costing estimates for DDS assume that the following developments would be separately funded by NASA R&D programs:

- \$75 M would be spent on key satellite technology development such as bulk demodulators, multi-beam antenna, decoders and encoders, and base-band switches.
- \$25 M would be spent on low cost VSAT terminal technology including power amplifiers, modems, uplink frequency control, and ISDN interface.
- \$25 M would be spent on network control and master communications control station technology.

### 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 years 2007 and 2012.
- On-orbit TT&C control of satellites over a 15 year period.

Each satellite would be designed to accommodate the full data requirements capacity, thus providing for full system operations in the event of the complete failure of one satellite.

Each satellite would be designed for a 15 year on-orbit lifetime.

No salvage value of residual space segment capacity is assumed at the end of the 15 year life cycle period.

Both satellites would be manufactured within a two year time period in order to assure manufacturing costs efficiency. Thus a minimum of design improvement would be incorporated into the second satellite. (As an alternative, the second satellite could be manufactured five years after the initial satellite and incorporate a significant design upgrade however extensive additional costs would be incurred.

### 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 DDS communications subsystem.

The antenna system would include both Ku-band and Ka-band operation. Separate antennas or a dual frequency feed with a single reflector per terminal could be used.

For improved performance and availability during severe rainfall periods, a separate terminal unit would be located several kilometers away to provide site diversity.

### User Terminal Cost Guidelines

The costs associated with the user terminals would include the terminal purchase (or lease costs) 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 assumed that the terminals would be configured on a modular basis such that users could select antenna diameters, tracking systems, power amplifiers, level of coding, modems, and digital interface units at either Ku-band or Ka-band in order to match the specific user requirements for communications data rate, signal quality, availability, and system margin.

It is postulated that the various Ku-band terminals would be manufactured in large quantities in support of DDS as well as other programs. The quantities would be tens of units for large gateway terminals (5 to 7 m),



hundreds for medium capacity (3 to 5 m), and thousands for the small VSAT terminals (2 to 3 m).

The costs associated with acquisition of land and/or buildings for the terminal site and the costs of associated with the terminal operations room or with operations personnel are not included.

### System Utilization Factors 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 of a year 2007 DDS is about 10 Gb/s for uplinks and 10 Gb/s for downlinks to earth-based user terminals (see Table 7-22).
- Because of the inefficiency in allocation of required data capacity among discrete members of satellite antenna coverage beams and around standard demodulator formats as well as non-continuous intermittent operation, it is expected that the real operations use maximum capacity of a DDS is reduced by 50% to about 5 Gb/s for uplinks and 5 Gb/s for downlinks.
- The average utilization of DDS is also reduced from peak use because of several factors including daily and hourly distribution of user requirements demands. It is expected that cost benefits would be made available to those users operating in non-peak hours in order to minimize the variance of peak to average usage.

The cost analysis of this study assumes that the average utilization of DDS capacity is 50% of the peak utilization at the end of the 15 year operational period. This represents 2.5 Gb/s of average capacity on uplinks and 2.5 Gb/s on downlinks.

- It is postulated that each DDS is designed to accommodate the maximum projected user requirements at end of 15 years on orbit. The use at the beginning of program operation is expected to be 25% of use 15 years later. Assuming a linear growth of capacity requirements with time, the average continuous data throughput is then about 1.5 Gb/s for uplinks and 1.5 Gb/s for downlinks.

### 11.1.3 Program Schedule

A summary of schedule planning for DDS system implementation is shown in Figure 11-1. The plan calls for first launch in year 2007 and second launch in year 2012.

## 11.2 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
4. Launch support and TT&C
5. Total space segment costs

### 11.2.1 Satellite Costs

Two methods have been utilized in order to assess the costs for the development and manufacture of two DDS satellites of year 2007 configuration:

1. Unmanned Space Vehicle Cost Model
2. Use of Space Systems/Loral Cost Data

These costs are in addition to the advance R&D costs described in the cost guidelines of ¶11.1.2.

#### 11.2.1.1 Unmanned Space Vehicle Cost Model

The first method was to utilize the *Unmanned Space Vehicle Cost Model*, 6th Edition (USCM6), 1988, which was developed by the U. S. Air Force. USCM6 represents twenty continuous years of research and development in the area of space vehicle cost modeling. It is a parametric cost estimation model based on cost data from 9 military satellite programs, 6 NASA programs, and 3 commercial programs (18 total programs). Table 11-1 summarizes the USCM6 data base.

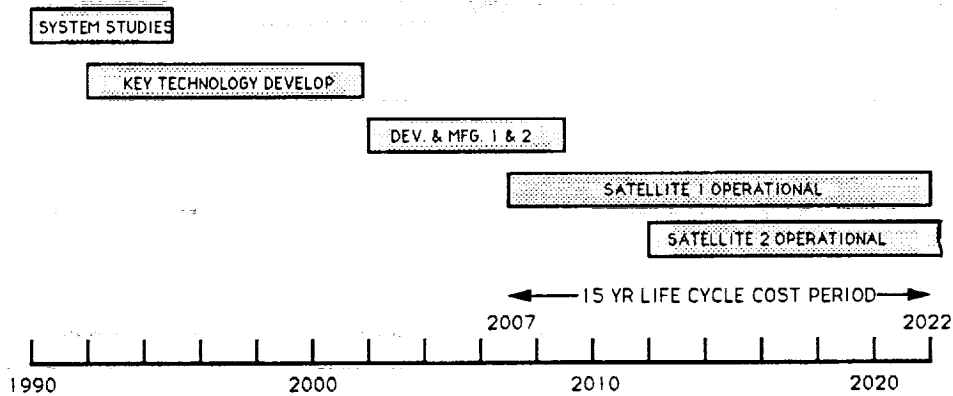


Figure 11-1: Schedule for DDS System Implementation

Table 11-1: Data Base for Unmanned Space Vehicle Cost Model, 6th Edition

Satellite System in Data Base	Dry Mass (lb)	Type of Stability	Launch Year	Number Launched	Mission
<b>Military Satellites</b>					
IDCSP	103	spinner	1967	34	Communications
TACSAT	1,431	spinner	1969	1	Communications
DSCS III A/B	1,800	3-axis	1982	2	Communications
DMSP, Block 5D-1	881	3-axis	1975	1	Meteorological
FLTSATCOM	2,281	3-axis	1978	5	Communications
NATO III	765	spinner	1980	4	Communications
GPS 9-11	835	3-axis	1988	3	Navigation
P78-2	1,019	spinner	1979	1	Experiments
S3	-	-	-	3	Experiments
<b>NASA Satellites</b>					
AE	751	3-axis	1973	1	Experiments
HEAO	-	3-axis	-	3	Astronomy
OSO	-	spinner	-	1	Astronomy
ATS-A/E	650-950	spin/3-ax	1966-69	5	Comm. experiments
ATS-F	2,433	3-axis	1974	1	Comm. experiments
TDRS	3,351	3-axis	1983	3	Communications
<b>Commercial Satellites</b>					
Intelsat IV	1,399	spinner	1971	8	Communications
Intelsat V-A	1,945	3-axis	1985	6	Communications
Marisat	670	spinner	1976	3	Communications

**Advantages and Disadvantages.** Parametric estimating has four advantages:

- i. It provides objective, unbiased, and consistent cost estimates.
- ii. The estimating process takes less time and expense, allowing the analyst to perform tradeoff studies.
- iii. Since estimates are developed from actual program cost history, they inherently reflect impacts of changes, system growth, and redirection.
- iv. Cost estimates based on engineering detail (from previous programs in the database) is available in the concept formulation phase of the program.

The main disadvantages of parametric estimating are as follows:

- i. It is assumed that the same forces that affected cost in the past will affect cost in the future.
- ii. A sufficient data base is required that is representative of the particular product's development, production, and technology environments.
- iii. Parametric relationships can become obsolete.
- iv. There is a lack of program peculiarity in the estimate. The parametric result is a generic or industry answer, not necessarily relatable to a contractor specific answer.
- v. Extrapolations beyond the range of the historical data are risky.

**Scope of the USCM6 Model.**

1. The model is an approximation of the real world based upon mathematical relationships derived from analyses of historical cost data. Implicit is the assumption that historical costs will properly reflect current and future costs.
2. The model's emphasis is on satellite bus hardware costs. Additionally, it addresses communications payloads, but not observational sensors. Model inputs consist of mass and power consumption by subsystem.
3. Model outputs are burdened costs (direct plus indirect) with G&A costs included.

Table 11-2: Satellite Cost Drivers

Subsystem	Cost Drivers
Structure	Structure mass
Reaction control	RCS mass, tank volume
Thermal	Vehicle mass, power
Antennas	Antenna mass
Comm. payload	Comm. equip. mass, power

4. A 95% cumulative average learning curve is used to derive data base first unit costs.
5. The model does not include costs for technology development and preliminary design studies.

**Cost Estimating Relationships (CERs)** for the satellite subsystems typically have mass and power as the major cost drivers. Table 11-2 summarizes the cost drivers for certain key CER categories. For example, the cost of the communications electronics is proportional to both its mass and the rf power radiated.

**Model Validation** results are given in Figures 11-2 and 11-3 for nonrecurring and recurring CER comparisons respectively. A square represents the plot points of the USCM6 subsystem level CER results (used for our cost estimates). (The diamonds give component level CER results; a triangle represents USCM5 subsystem CER results.) The x-axis represents the individual USCM6 data base systems, ranked left-to-right from the lowest cost systems to the highest cost systems. The y-axis represents the percent difference of the CER results compared with the actual values. If the CER overestimates the actual cost of the system, the plot point is positive; if the CER under-estimates the actual cost, the plot point is negative. If plot points are missing for a particular system, it means that the percent difference is greater than  $\pm 200\%$ .

The systems which are numbered in the Figures are listed by acronym in the legend to the right of the plot. Also given is a code (M, N, C) to indicate whether it is a military, NASA, or commercial satellite.

Intelsat V (I-V) is perhaps the closest of the satellites in the USCM6 data base to our DDS concept. The figures show that the model's nonrecurring cost estimate (subsystem level CER) is 33% high and the recurring cost estimate is 68% high!

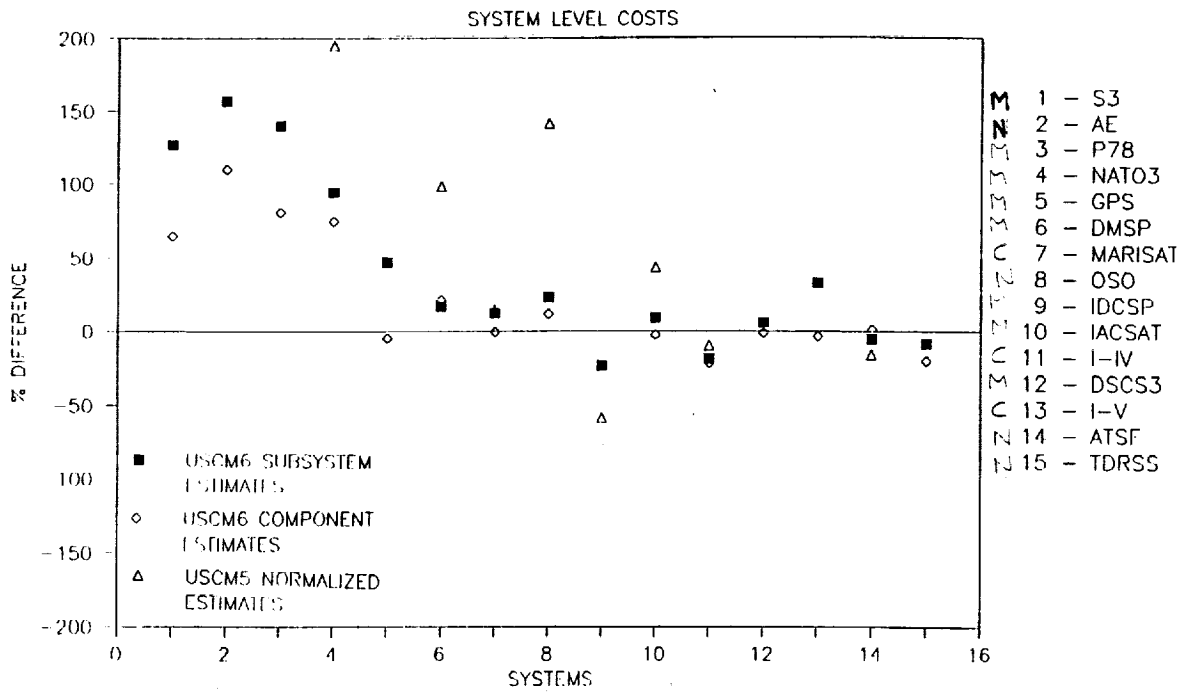


Figure 11-2: Non-Recurring Cost Estimation Comparisons for USCM6 Model

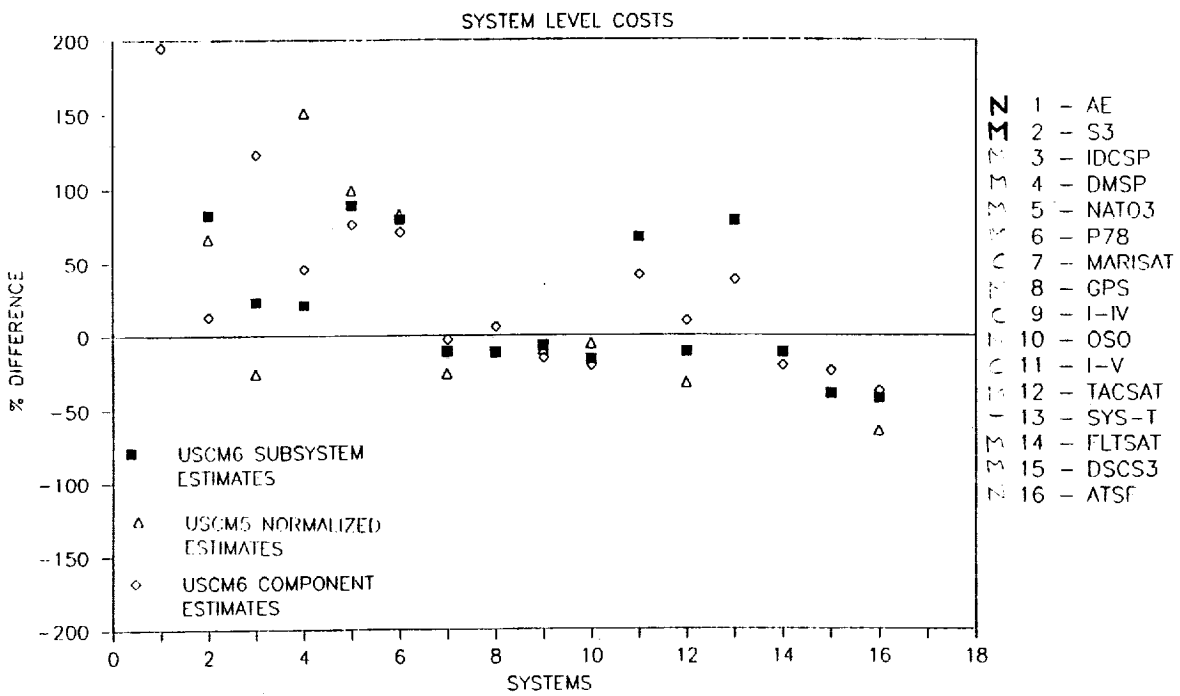


Figure 11-3: Recurring Cost Estimation Comparisons for USCM6 Model

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Table 11-3: Satellite Launch Cost (\$M, 1990)

Category	Cost (1990)
Hardware	85 M
Launch Support	12 M
Integration	12 M
Other	15 M
Total	\$124 M

Results of the USCM6 Model were normalized to yield the costs for a NASA - Government owned satellite system. These costs are lower than those of a military program, but higher than those of a commercial program.

The results of the model, when applying the projected design parameters of the year 2007 DDS given in Table 11-4, are listed in Table 11-5. These results project development (non-recurring) costs of \$260.2 M (1990 dollars) and manufacturing (recurring) costs of \$346.3 M (two satellites) which combine to a total cost of \$606.5 M in 1990 dollars.

The cost model does not contain a factor for payload complexity which is a step function above normal transponder evolution. Because of the additional complexity of a full processing data system in the satellite, an additional \$100 M of development and \$100 M of recurring costs are expected.

The model yields costs through manufacturers G&A level but does not include fee. A fee of 10% of program cost is expected. This results in a total DDS satellite costs for development and manufacture of 2 satellites of \$887 M in 1990 dollars.

If this sum were to be financed at 10% costs of capital and paid off in equal yearly payments over a 15 year life cycle cost period for DDS operations, the annual cost to the government would be \$114 M per year ( $=887 \times .1290$ ). If the government cost of money was reduced to 7%, the annual cost would be \$96 M per year ( $=887 \times .1079$ ).

#### 11.2.1.2 Use of Space Systems/Loral Cost Data

The second method used to evaluate costs was to extrapolate costs from current commercial advanced communications programs of Space Systems/Loral (formerly the Space Systems Division of Ford Aerospace). It is estimated that the relative cost of a DDS satellite bus

would be increased by the ratio of beginning of life solar power output and that the payload costs would be increased by the combined mass of the payload communications and antenna equipment. This method projects a cost for development and manufacture of two satellites of \$713 M which results in an annual cost of \$92 M at 10% interest, or \$77 M at 7% interest.

### 11.2.2 Launch Costs

The expected launch vehicle for year 2007 and year 2012 launch of DDS satellites would be the enhanced (from today's capacity) Atlas IIAS which has planned capacity of 4,000 kg to geosynchronous transfer orbit (GTO). The prices per launch, assuming annual buys at the rate of four units per year for all programs, are given in Table 11-3. There are other candidate launch vehicles such as the Ariane 4 with planned capacity of 4,100 kg to GTO. The launch support costs of the satellite manufacturer have been included in the satellite costs of ¶ 11.2.1.

### 11.2.3 Insurance Costs

No costs have been included for insurance to cover an unsuccessful launch. The use of a dual satellite configuration, each with design lifetime of 15 years and each with the capacity to accommodate all data requirements provides a measure of insurance. If insurance was desired, it is expected that the rate would 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.

### 11.2.4 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 for DDS and that no unique TT&C facility would be required. It is expected that TT&C services could be obtained at a yearly cost of \$1 M.

### 11.2.5 Total Space Segment Costs

The projected space segment costs (in \$M 1990) for both a NASA - Government DDS program and a leased commercial service are defined.

Table 11-4: Design Parameters for Various Communication Satellites

Satellite Parameters	Superbird	Intelsat	Data Distribution Satellites		
	(Japan)	VII	(2000)	(2007)	(2015)
Launch year	1989	1993	2000	2007	2015
Launch Vehicle	Ariane 3	Atlas 2AS	Atlas 2A	Atlas 2AS†	ALV/OTV
Lifetime (yr)	10	11	10	15	15
Peak capacity (Mb/s, [MHz])	[1,800]	[2,500]	3,100	22,000	39,000
DC Power, end-of-life (W)	3,550	3,531	4,600	5,500	7,000
RF Power, transmit (W)	885	929	1,000	990	1,325
Battery capacity (W)	3,210	3,310	3,200	5,000	7,000

Mass Budget	Superbird	Intelsat	Data Distribution Satellites		
	(Japan)	VII	(2000)	(2007)	(2015)
<b>Satellite Mass</b>					
Structure (kg)	214	209	260	244	280
Propulsion (kg)	113	108	114	275	275
Power (kg)	180	187	161	186	210
Solar array (kg)	111	112	97	114	140
TT&C (kg)	52	50	40	52	65
Attitude Control (kg)	52	110	43	113	150
Thermal (kg)	91	94	90	150	180
Antenna (kg)	50	103	90	146	190
Comm. Electronics (kg)	229	320	343	585	750
Electrical Integration	45	65	-	75	90
Mechanical Integration	38	40	-	50	60
Total mass, dry (kg)	1,175	1,398	1,238	1,990	2,390
Fuel, on-orbit (kg)	265	454	322	160	170
Wet mass, dry (kg)	1,440	1,852	1,560	2,150	2,560
Fuel, orbit-raising (kg)	1,000	1,698	1,430	1,850	-
Launch mass (kg)	2,440	3,550	2,990	4,000	2,560

† Enhanced version of current Atlas IIAS.

### 11.2.5.1 NASA/Government Program Costs

The total space segment costs for the development and manufacture of two satellites are projected to be in the range of \$713 M to \$887 M, with a median cost of \$800 M (1990 \$). The cost of a single Atlas IIAS launch (hardware plus associated services) is \$124 M per launch. Leased TT&C support is expected to cost \$1 M/yr. Thus as shown in Table 11-6, a total cost for the space segment is \$1,063 M if paid in 1990 dollars at time of the first launch.

If the costs are spread over 15 years with equal payments, the cost would be \$136 M/yr with 10% cost of money or \$114 M/yr with 7% cost of money. These costs are for two DDS satellites placed in orbit and operated over a 15 year period. The maximum available capacity of a two satellite DDS constellation is approximately 20 Gb/s as discussed in ¶7.8.2 of Chapter 7.

### 11.2.5.2 Commercial Program Costs

If the DDS type satellite were operated by a commercial entity with services leased to the government, then the annual costs would be adjusted for several factors, including:

**Lower cost for satellites.** It is expected that the development costs under a commercial entity would be achieved at a 40% savings relative to a NASA - Government program, and that the recurring (manufacturing) costs would be achieved at a 15% savings. This is based on experience and is due to less reporting and paperwork requirements.

**Insurance cost added.** The commercial communications carrier would probably pay an additional 16% for launch insurance in order to minimize catastrophic risk of a launch failure.

Table 11-5: Space Segment Costs (\$M, 1990) for Development and Manufacture of Two Satellites

Cost Category	2007 Costs (\$M, 1990)			2015 Costs (\$M, 1990)		
	Non-Recurring	Recurring (2 sats.)	Total	Non-Recurring	Recurring (2 sats.)	Total
<b>Satellite Bus</b>						
Structure	14.9	5.1	20.0	17.1	5.7	22.8
Attitude control	30.9	29.9	60.8	44.8	45.7	90.5
Thermal	23.6	2.5	26.1	51.9	3.4	55.3
Electrical power	50.6	31.0	81.6	93.5	40.4	133.9
TT&C	5.2	6.6	11.8	5.2	6.6	11.8
Propulsion	5.2	69.4	74.6	6.0	253.2	259.2
<b>Total Bus Cost</b>	<b>130.3</b>	<b>144.5</b>	<b>274.8</b>	<b>218.4</b>	<b>355.1</b>	<b>573.5</b>
Communications Payload	29.1	89.3	118.4	62.6	191.1	253.7
Integration & Assembly	21.0	19.6	40.6	49.1	31.9	81.0
Ground Equipment	25.2	-	25.2	42.4	-	42.4
Launch & Orbital Support	-	13.3	13.3	-	19.0	19.0
Program Management	54.6	79.6	134.2	94.6	165.5	260.1
<b>Cost Subtotal</b>	<b>260.2</b>	<b>346.3</b>	<b>606.5</b>	<b>467.2</b>	<b>762.5</b>	<b>1,229.7</b>
DDS Complexity Factor	100.0	100.0	200.0	100.0	100.0	200.0
<b>Cost Subtotal</b>	<b>360.2</b>	<b>446.3</b>	<b>806.5</b>	<b>567.2</b>	<b>862.5</b>	<b>1,429.7</b>
Fee at 10%	36.0	44.6	80.7	56.7	86.3	143.0
<b>Total Cost</b>	<b>396.2</b>	<b>491.0</b>	<b>887.2</b>	<b>623.9</b>	<b>948.8</b>	<b>1,572.7</b>

Table 11-6: NASA Program Space Segment Costs, 1990 \$M (2 satellites, 15 yr life beginning 2007)

Cost Category	Life Cycle Cost	Annual Cost at 10%	Annual Cost at 7%
Satellite cost (2)	800 M	103 M	86 M
Launch Cost (2)	248 M	32 M	27 M
TT&C Support (2)	15 M	1 M	1 M
<b>Total</b>	<b>\$1,063 M</b>	<b>\$136 M/yr</b>	<b>\$114 M/yr</b>

**Additional utilization.** A commercial program could accommodate capacity usage from non-DDS program users. In addition to the capacity required for the DDS function, an equal capacity could be sold to commercial users, thus reducing yearly charges to the government by a factor of two.

**Salvage value exists.** A commercial program could utilize the residual on-orbit capacity of a DDS system beyond the nominal 15 year life cycle cost period and thus derive additional revenue.

**Increased cost of money.** If the commercial entity finances the satellite segment costs, the cost of money would be 12% to 15% (versus 7% to 10% for government).

**Return to investors.** In order to justify the relatively high risk of on-orbit failure and the risk of potential increase of development and manufacturing costs for a very advanced, new satellite design, the commercial program is judged to require a leased annual return which is 50% higher than that calculated with no return on investment.

In general a commercial entity is not attracted to high risk ventures requiring high capital outlays and hence a NASA - Government owned program may be the only way to initiate full DDS service.

A summary of annual commercial program costs for commercial operation of the DDS is given in Table 11-7. If the nominal DDS lease cost is \$138 M/yr (with an assumed 12% cost of money), then it would be \$207 M/yr for a high risk program (added 50% premium). (DDS is judged to be "high risk" since it represents a new satellite service.)

This cost of \$207 M/yr is for two satellites placed in orbit and operated over a 15 year period beginning in the year 2007. The maximum available capacity of a two satellite DDS constellation is approximately 20 Gb/s as discussed in ¶7.8.2 and Table 7-22 of Chapter 7.

As discussed under "Additional utilization" above, the price to the Government for its DDS function utilization would be half of \$207 M/yr or \$104 M/yr. The other half of the price would be paid by commercial users of DDS capacity.

## 11.3 User Terminal Costs

It is expected that a great variety of user terminal configurations would be used for DDS system operation. They would range in size from 1.2 m for small users up to 7 m for large data gateways. Operation would be at Ku-band or Ka-band or both. Data rates would range from 144 kb/s up to 640 Mb/s. Site diversity terminals are an option for improved link availability.

The total cost associated with user costs would include initial terminal acquisition costs (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.

### 11.3.1 Small Terminal Costs

The small user of DDS would utilize terminals ranging in size from 1.2 m to 1.8 m diameter. The use of Ku-band and/or Ka-band configurations is possible.

The basic design of the terminal for use in the DDS system is configured on a modular basis with a high degree of standardization. For example, the FDM uplinks can operate at 144 kb/s, 1.5 Mb/s, or 6 Mb/s to bulk demodulators on the satellite. Dedicated uplinks at rates up to 52 Mb/s to regular demodulators are also allowed. Downlinks would be accomplished via TDM at rates of 52 Mb/s.

Individual users can select among various antenna diameters, tracking systems, power amplifiers, modems, and digital interface units to meet specific applications for either Ku-band or Ka-band operations. Users in high rainfall regions may elect larger diameter antennas or higher power amplifiers than users of the same communications services in low rainfall regions. As a result the terminal cost per type of user service may vary over a considerable range. Another dominant factor in terminal cost is the manufacturing quantity. The cost per unit in quantities of 10s, 100s, and 1,000s exceeds a 2:1 range.

The wide range of VSAT terminal configurations would result in a correspondingly wide range of acquisition costs. A 1.2 to 1.8 m low-capacity terminal at Ku-band may cost \$10,000 to \$25,000 each.

### 11.3.2 Medium Terminal Costs

A typical allocation of costs for a \$50,000 medium terminal (3 m, 30 W at Ku-band) is shown in Table 11-



Table 11-7: Commercial Program Space Segment Costs, 1990 \$M (2 satellites, 15 yr life beginning 2007)

Cost Category (2 satellites on orbit)	Life Cycle Cost	Annual Cost at 15%	Annual Cost at 12%
Satellite cost (2)	591 M	99 M	85 M
Launch Cost (2)	248 M	42 M	35 M
TT&C Support (2)	15 M	1 M	1 M
Launch Insurance (16%)	134 M	22 M	19 M
Residual Value	(15 M)	(3 M)	(2 M)
Subtotal Cost	\$973 M	\$161 M/yr	\$138 M/yr
Profit (50%/yr, high risk)		\$81 M/yr	69 M
Total Charges		\$242 M/yr	\$207 M/yr
Government DDS Charge (1/2 total)		\$121 M/yr	\$104 M/yr

8. The 26% of cost allocated to non-recurring system and equipment design costs is based upon a production quantity of 200 terminals for a specific manufacturer.

A dual Ku-band and Ka-band terminal accommodating rates up to 52 Mb/s with high availability could cost considerably more - \$100,000 to \$250,000.

### 11.3.3 Large Terminal Costs

The high data rate users of DDS would include the White Sands data relay terminal, science data base centers, gateways to wideband networks, and special users with large data rate, quality, or availability requirements. It is expected that these users would employ terminals ranging in size from 4 m to 7 m diameter. The use of a dual frequency feed (Ku and Ka-bands) is also likely.

It is expected that the initial costs of the high performance terminals would range from \$250,000 up to \$1,000,000 depending on specific configuration requirements. This would also assume manufacturing in quantities of ten or more.

### 11.3.4 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 3 m medium terminal. Thus the terminal cost per user can be considerably reduced 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.

### 11.3.5 Terminal Lease Fees

The initial capital expenditures may be reduced by leasing of terminals. It is expected that the annual lease cost would be about 20% of the initial acquisition price.

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. A highly trained technician would not be required to support standard communications.

Table 11-9 estimates terminal costs and gives the yearly lease fee assuming 20% of the terminal cost per year over 15 years for debt servicing and profit. This is equivalent to 18% return on investment for the leasing company. Maintenance costs are 10% of the terminal cost. The smallest ground terminal which supplies 144 kb/s service costs around \$3,000 per year, a small terminal which supplies 1.5 Mb/s service costs \$7,500 per year, and a medium terminal which supplies 52 Mb/s service costs \$15,000 per year. The large terminals do not get cheaper per bit capacity, but they may offer more

Table 11-8: Ground Terminal Cost Breakdown for \$50,000 Medium Terminal

<u>Non-recurring</u>		
Management and system design	\$5,000	10%
Equipment design	\$8,000	16%
<u>Recurring</u>		
Production management	\$1,500	3%
Antenna subsystem	\$6,500	13%
Electronics, antenna mounted	\$11,500	23%
Electronics, control room	\$12,500	25%
Integration hardware	\$1,500	3%
Assembly and test	\$3,500	7%
<b>Totals</b>	<b>\$50,000</b>	<b>100%</b>

Table 11-9: User Terminal Capability and Cost

User Terminal Parameters			Terminal Lease Fee		
Terminal Description	Data Rate (Mb/s)	Terminal Cost (\$)	Lease Cost (\$/yr)	Maintenance Cost (\$/yr)	Total Cost (\$/yr)
<u>Small terminals</u>					
1.2 m VSAT, 1 W	.144	10,000	2,000	1,000	3,000
1.8 m VSAT, 5 W	1.54	25,000	5,000	2,500	7,500
1.8 m VSAT, 20 W	6	30,000	6,000	3,000	9,000
<u>Medium terminals</u>					
3 m single band, 5 W	6	40,000	8,000	4,000	12,000
3 m single band, 20 W	52	50,000	10,000	5,000	15,000
3 m dual band, 2 x 30 W	52x2	80,000	16,000	8,000	24,000
<u>Large terminals</u>					
5 m, 100 W	160	250,000	50,000	25,000	75,000
7 m, 200 W	320	500,000	100,000	50,000	150,000

Table 11-10: User Terminal Costs (\$/minute) Versus Number of Hours Utilized per Working Day

User Terminal Description			Terminal Cost in \$/minute of Use					
Terminal Size	Capacity (Mb/s)	Cost (\$K/yr)	Number of hours utilized per working day					
			1	2	4	8	12	24
1.2 m VSAT	.144	3	0.20	0.10	0.05	0.03	0.02	0.01
1.8 m VSAT	1.544	7.5	0.50	0.25	0.12	0.06	0.04	0.02
1.8 m VSAT	6	9	0.60	0.30	0.15	0.08	0.05	0.03
3 m Medium terminal	6	12	0.80	0.40	0.20	0.10	0.07	0.03
3 m Medium terminal	52	15	1.00	0.50	0.25	0.13	0.08	0.04
5 m Large terminal	160	75	5.00	2.50	1.25	0.63	0.42	0.21
7 m Large terminal	320	150	10.00	5.00	2.50	1.25	0.83	0.42

redundancy and link margin.

Table 11-10 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 for a VSAT used 8 hours per day to several dollars per minute for a large terminal used 2 hours 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.

## 11.4 Network Control Costs

Several control networks are needed to control access to the DDS communications subsystem and to provide for reconfiguration of the on-orbit communications equipment. The regular on-orbit housekeeping functions for monitoring and care of other DDS subsystems would be achieved by the TT&C subsystem with costs defined as part of the space segment.

### 11.4.1 Network Control Center Costs

The communications access control to DDS would be 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 sophisticated advanced control center is expected to be about \$125 M stated in 1990 dollars. The control center facility is forecast to have yearly maintenance and operating costs of about \$8 M based upon a level of 50 to 75 personnel.

### 11.4.2 Experiment Control Centers

A second level of communications control is required to coordinate the efforts of the telepresence users. For example if inputs and outputs to a specific on-orbit science experiment are to be coordinated among a set of ten geographically distributed telepresence experiment users, then it is necessary for a Experiment Control Center to act as a "referee" in order to prevent simultaneous demands for experiment control.

It is expected that several Experiment Control Centers would be established to provide this control. These centers would interface with the communications net-

work control center in order to assure proper communications traffic regulation.

The costs of the Experiment Control Centers are considered a separate cost of experiments and are not included as part of a DDS system cost.

## 11.5 User Network Utilization Factors

The quantities of users, quantity of user terminals (some shared), and DDS capacity utilization over the 15 year life cycle cost will greatly impact user costs per circuit-minute.

### 11.5.1 User Terminal Network

In order to provide a reference for DDS system costs it is postulated that there will be:

- a. 10,000 small users time sharing among 2,500 small VSAT terminals each using the system about 8 hours per working day. (We postulate five working days per week and 250 working days per year).
- b. 1,000 medium capacity users, time sharing among 250 medium terminals each using the system about 12 hours per working day.
- c. 10 high capacity users, with dedicated use large terminals, each using the system 24 hours per working day.

The users would be geographically spread throughout CONUS with concentration in high population areas.

### 11.5.2 Capacity Utilization

The theoretical "maximum capacity" of a single DDS satellite is about 10 Gb/s of simplex circuits. (See Table 7-22 in Chapter 7 for the total communications capacity of the year 2007 two-satellite DDS constellation.) Because of the inefficiency in allocation of required data among discrete numbers of satellite antenna coverage beams and among standard demodulator formats as well as non-continuous intermittent operation, it is expected that the "maximum operational capacity" of a DDS satellite is reduced to about 5 Gb/s of simplex circuits.

The average utilization is also reduced from peak use because of daily and hourly variations in user requirements. The average utilization of DDS capacity is projected to be 50% of the peak utilization, thus reducing

the average continuous capacity at the end of the 15 year life cycle period to about 2.5 Gb/s of simplex circuits.

Assuming a beginning of program utilization at 25% of that 15 years later and a linear build-up of capacity requirements, then the average continuous data throughput is as shown in Figure 11-4. This rate at the midpoint of the operational period is about 1.5 Gb/s of simplex circuits. Compared to the peak capacity of 10 Gb/s, the projected DDS utilization is 16%. There remains another 2 times capacity before the maximum operational capacity is reached that could potentially be sold in order to increase system revenues.

For a two satellite system interconnected by inter-satellite links, the DDS utilization (average throughput) required to meet the projected Government requirements is thus approximately 3 Gb/s compared to the 10 Gb/s of the maximum operational capacity and 20 Gb/s of the maximum achievable capacity.

## 11.6 Composite Costs

The program costs are estimated for each of two program assumptions:

1. Life cycle cost over 15 years if operated as a NASA Government program; and
2. User costs (\$ per circuit minute) if operated as a commercial system.

In each case a two satellite DDS constellation is assumed with a maximum achievable capacity per satellite of 10 Gb/s, with a 15 year life beginning in the year 2007.

### 11.6.1 Life Cycle Cost of a NASA Program

A summary of the projected 15 year life cycle cost of the space segment and master communication control center segment for the DDS system is given in Table 11-11. The total space segment cost of \$1,063 M (from Table 11-6 with discussion in ¶11.2.5.1) is combined with the network control costs from ¶11.4.1 to yield a life cycle cost of \$1,308 M. This corresponds to \$135 M/yr at 7% or \$160 M/yr at 10% cost of money.

This life cycle cost of \$135 M/yr for 15 years is for the entire capacity of the two DDS satellites (The single satellite capacity is illustrated in Figure 11-4. The DDS services utilize the shaded region, or 3 Gb/s at mid-life from two satellites.) Conceivably, NASA could "sell"

or exchange part of the "other available capacity" in return for cost or fee reductions. However, it is judged that only commercial operators of the DDS system would be able to make such arrangements to sell the other available DDS capacity.

### 11.6.2 Charges for Commercial System Use

If a commercial entity were to develop and operate a system to accommodate the DDS communications requirements with space segment and master control segment costs as defined in ¶11.2 and ¶11.4 and with a network utilization as defined in ¶11.5, then the projected charges to the Government would be those defined in Table 11-12. (The 1/2 in the table indicates that the Government is only being charged for one half of the commercial program costs – the other half is being paid by other commercial users.)

The costs are expressed in 1990 dollars for a 15 year satellite lifetime beginning in the year 2007. The communications Network Control Center cost would be \$188 M (1.5 times \$125 M), with annual cost of \$27 M/yr at a 12% cost of money. Annual operational costs are assumed to be \$8 M/yr. (Again, Government charges are one half of total charges, or \$13 M/yr for NCC manufacture and \$4 M/yr for NCC operations.)

The user charge per unit capacity utilization is derived from two factors:

- i. The \$121 M total yearly space segment charges for DDS users is allocated among the different classes of users.
- ii. The two-satellite constellation has approximately 3 Gb/s DDS utilization at the midpoint of its 15 year life (Figure 11-4).

It is assumed that 1/2 of the data distribution function is used by small users for 2/3 of the total commercial system charges or \$80.7 M/yr. (The other 1/2 of the capacity is used by medium and large terminals for 1/3 of the total commercial system charges or \$40.3 M/yr.) At the midpoint of the DDS 15 year life cycle, each half of the DDS utilization represents 1.5 Gb/s (two satellite constellation). Division of the \$80.7 M/yr small user charge by the 1.5 Gb/s available small user DDS capacity yields a basic cost of \$6.13/hr per Mb/s of capacity utilized (based on 8,766 hr/yr). Thus small user space segment charges for a simplex (one-way circuit) are as follows:

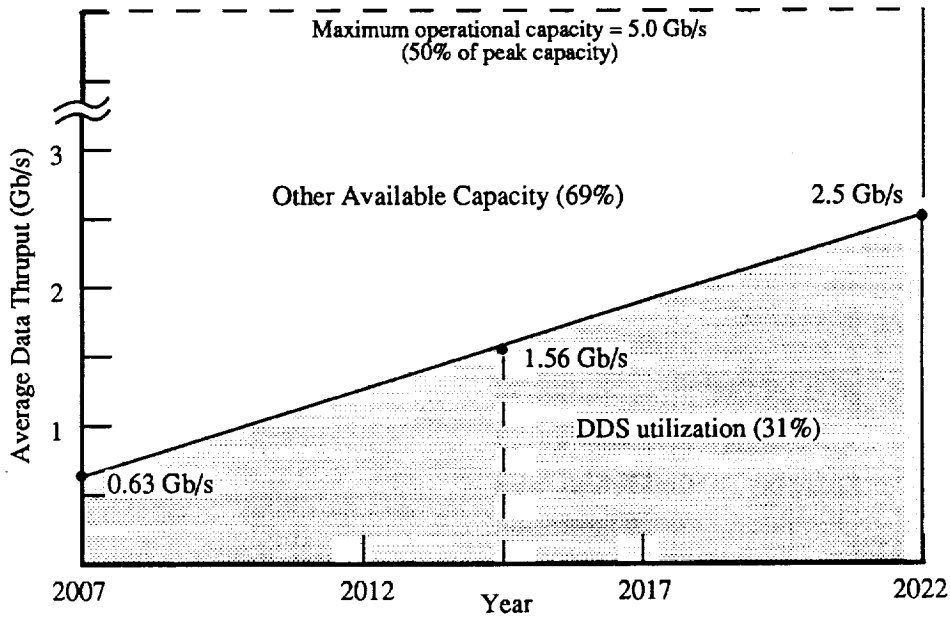


Figure 11-4: Projected Utilization of DDS Communications Capacity (single satellite)

Table 11-11: Life Cycle Cost (1990 \$M) for NASA Program (2 satellites, 15 year life starts 2007)

Cost Category	Life Cycle Cost	Annual Cost at 10%	Annual Cost at 7%
Space segment costs: (2 sats, 2 launches, TT&C support)	1,063 M	136 M	114 M
Network control center: Develop & build	125 M	16 M	13 M
Operations (15 yr)	120 M	8 M	8 M
Totals	\$1,308 M	\$160 M/yr	\$135 M/yr

Table 11-12: Government Charges (1990 \$M) for Commercial Program (2 sats, 15 yr life starts 2007)

Space Segment Charges (1/2)	\$104 M
Network Control Center Charges:	
Development and Manufacture (1/2)	\$13 M
Operations (15 yr) (1/2)	\$4 M
Total Yearly Charges (\$ 1990)	\$121 M

\$0.88/hr	(1.5 cents per min.)	for 144 kb/s
\$9.47/hr	(16 cents per min.)	for 1.544 Mb/s
\$36.81/hr	(61 cents per minute)	for 6 Mb/s

It is assumed that the other 1/2 of the DDS capacity is used by medium and large terminals for 1/3 of the total commercial system charges or \$40.3 M/yr. At the mid point of the DDS 15 year life cycle, each half of the DDS utilization represents 1.5 Gb/s. Division of the \$40.3 M/yr medium-large user charge by the 1.5 Gb/s available medium-large user DDS capacity yields a basic cost of \$3.07/hr per Mb/s of capacity utilized. Thus medium and large user space segment charges for a simplex (one-way circuit) are as follows:

\$18/hr	(31 cents per minute)	for 6 Mb/s
\$160/hr	(\$2.66 per minute)	for 52 Mb/s
\$491/hr	(\$8.18 per minute)	for 160 Mb/s
\$982/hr	(\$16.36 per minute)	for 320 Mb/s

**11.6.3 Total User Costs per Circuit Minute**

Table 11-13 adds the space/control segment costs to the ground terminal costs in order to obtain the total user cost for various standard data rate simplex circuits. There are several points that must be made regarding this table:

- The ground terminal costs are not significant for the medium and large terminal cases since the transmission costs dominate. For the small VSAT 144 kb/s case, however, the ground segment costs are greater than the space-control segment costs.
- The establishment of a duplex circuit would double the simplex circuit costs shown in Table 11-13. space-control segment costs but the ground terminal costs would be unchanged since the terminal is used simultaneously for transmit and receive.
- The cost values are very sensitive to the system utilization factor (assumed to be 16% of peak capacity). It is assumed that an amount equal to the Government required capacity is sold commercially, thus reducing space segment costs to the users by a factor of two since utilization is doubled.
- Many of the costs associated with DDS system are subject to considerable variance until firm requests and detailed designs are prepared. Key elements in user cost changes are (1) actual space and control

segment costs, (2) average continuous data capacity use as function of time, and (3) quantities of user terminals with utilization rates. For full system optimization, a cost variance analysis would need to be accomplished.

A brief tabulation of the assumptions in Table 11-13 is given below. For each circuit size, the assumed terminal size and utilization in hours per day is given. The figures above the line are for small terminals and those below the line are for medium and large user terminals.

<u>Circuit</u>	<u>Terminal</u>	<u>Utilization</u>
144 kb/s	1.2 m	8 hr/day
1.5 Mb/s	1.8 m	8 hr/day
6 Mb/s	1.8 m	8 hr/day
6 Mb/s	3 m	12 hr/day
52 Mb/s	3 m	12 hr/day
160 Mb/s	5 m	24 hr/day
320 Mb/s	7 m	24 hr/day

The circuit costs of Table 11-13 can be divided by the circuit size to obtain a cost to transmit a given amount of information. The below tabulation gives for each circuit the cost and time to transmit 1 Gb of information.

<u>Circuit</u>	<u>1 Gb Transmit Cost</u>	<u>1 Gb Transmit Time</u>
144 kb/s	\$4.63	116 minutes
1.5 Mb/s	\$2.38	11 minutes
6.2 Mb/s	\$1.75	3 minutes
6.2 Mb/s	\$0.92	3 minutes
52 Mb/s	\$0.88	19 seconds
160 Mb/s	\$0.90	6 seconds
320 Mb/s	\$0.90	3 seconds

As a point of reference, this report contains about 10 Mb of text information and 10 Mb of Figures; thus 1 Gb is equivalent to 50 reports. A digitized TV picture (1 frame) could contain 100 Mb; thus 1 Gb is equivalent to 10 color video pictures (uncompressed).

Not unexpectedly, the medium and large terminals have a considerably lower cost per bit of information transmitted than the VSAT terminals. However, this report could have been transmitted to NASA/LeRC for a cost of only 10 cents and a time of 2.3 minutes using a 144 kb/s VSAT simplex circuit.

Table 11-13: Simplex Circuit Costs for Commercial DDS System (2 satellites, 15 year life starts 2007)

User Ground Terminal	Simplex Circuit Cost in \$/min at					
	Data Rate (Mb/s) of					
	.144	1.5	6.2	52	160	320
<b>Small VSAT Terminal</b>						
Space/Control Cost	.015	.16	.61			
Terminal Cost	.025	.06	.08			
Totals	.040	.22	.69			
<b>Medium/Large Terminals</b>						
Space/Control Cost			.31	2.66	8.18	16.36
Terminal Cost			.07	.08	.42	.83
Totals			.38	2.74	8.60	17.19

## 11.7 Comparison of Alternate Costs

### 11.7.1 Need for Overall Communications Network Model

In order to compare the costs of alternate communications networks (via satellite or terrestrial), it is necessary to have a detailed overall model of user locations and data requirements. Satellite circuit costs are relatively insensitive to user locations, but terrestrial costs, particularly for high data rate fiber optic links, are very sensitive to whether the user location is connected to the fiber backbone network.

In addition to the requirements model it is necessary to prepare a performance effectiveness matrix. This would be used to apply weighting functions for accommodating variances including:

- Impact of full CONUS coverage versus partial coverage of all users.
- Impact of accommodating a big dynamic range of individual user data rate and data capacity requirements over time.
- Impact of complete versus partial ability for switching networks.
- Valuation of other DDS services including inter-satellite relay to ATDRS.
- Impact of communications outage.

### 11.7.2 Fiber Network Costs versus DDS Costs

The tradeoff of fiber optic network costs versus DDS satellite system costs must be determined in order to assure that DDS is a viable systems concept. This tradeoff is dependent upon the projected overall communications requirements model as well as the evaluation effectiveness criteria. This comparison must be continually updated, as the introduction of fiber optics technology is causing continued reductions in the terrestrial network tariffs.

Two methodologies are used to predict terrestrial network charges in the year 2010:

1. Extrapolation from today's tariffs
2. Use of Contel Study results

#### 11.7.2.1 Extrapolation from Today's Tariffs

For about 30 years up until fiber optic technology began to make its mark in 1988, there had been a reduction in telecommunication costs of around 3% to 4% per year. If we start from today's (9/90) costs for 64 kb/s and 1.5 Mb/s circuits and apply the 4% per year reduction, we obtain a reduction factor of 0.44 (2.26x) in going the 20 years from 1990 to 2010.

Consider a 1,000 mile duplex circuit. The 64 kb/s circuit price is around \$2,200 per month, and the 1.5 Mb/s T1 circuit price is around \$11,300 per month. Extrapolation to year 2010 using the 2.26x reduction factor yields around \$1,000 per month for the 64 kb/s circuit, and around \$5,000 per month for the 1.5 Mb/s T1 circuit.

Table 11-14: 2010 Duplex Circuit Costs

Circuit Size	Projected Terrestrial Price	Estimated DDS Price	DDS Terminal Size
64 kb/s	\$6.00/hr	\$1.07/hr	VSAT
1.5 Mb/s	\$30/hr	\$13.20/hr	VSAT
	\$20/hr	\$5.70/hr	Medium
52 Mb/s	\$258/hr	\$164/hr	Medium

The 64 kb/s duplex circuit price of \$1,000 per month is equivalent to \$2.00/hr for 24 hr/day use or \$6.00/hr for 8 hr/day use (using our definition of working day equal to 5 days a week or 250 days/yr for comparison with the satellite case). Using the data from Table 11-13, a 64 kb/s duplex circuit supplied by a 144 kb/s, 1.2 m VSAT in use 8 hr/day would cost \$1.07/hr.

The 1.5 Mb/s duplex circuit price of \$5,000 per month is equivalent to \$10.00/hr for 24 hr/day use or \$20.00/hr for 12 hr/day use (using our definition of working day equal to 5 days a week or 250 days/yr for comparison with the satellite case). Using the data from Table 11-13, a 1.5 Mb/s duplex circuit supplied by a 1.5 Mb/s, 1.8 m VSAT in use 8 hr/day would cost \$13.20/hr. The same circuit supplied by a 6 Mb/s medium terminal in use 12 hr/day would cost \$5.70/hr.

A similar comparison can be done for 52 Mb/s circuits using today's tariffs for the 45 Mb/s DS3 service (\$126,000 per month for a 1,000 mile duplex circuit). Applying the extrapolation factor for 2010 and adjusting for the difference from 45 and 52 Mb/s, the projected 2010 terrestrial duplex circuit tariff for a 52 Mb/s service is \$64,000 per month or \$258/hr for use 12 hr/day. This is to be compared with an estimated DDS circuit cost of \$164/hr.

Table 11-14 summarizes these results for the extrapolated monthly price of a 1,000 mile duplex circuit. Thus this methodology indicates our estimated DDS transmission costs are competitive with the predicted 2010 tariffs for terrestrial circuits in the continental United States. DDS has better economic performance for all circuit sizes. Since the terrestrial circuit prices are distance dependent while the satellite circuit costs are not, the DDS relative economic performance will improve for longer circuits and get worse for smaller circuits.

Table 11-15: Contel Prediction of IRN Costs

Year	Monthly Cost for 1000 mile, 1.5 Mb/s Circuit
1989	\$24,420
1991	\$5,450
1996	\$1,060
2000	\$685
2010	\$270

### 11.7.2.2 Use of Contel Study Results

Contel Federal Systems, Government Networks Group, did a study for NASA/LeRC entitled *U. S. Computer Research Networks* under Contract No. NAS3-25083. On 1/23/90 results were presented to J. E. Hollansworth of NASA Lewis Research Center. Results from their report estimating the cost of future Integrated Research Networks (IRN) are used here as an alternate methodology for predicting future terrestrial fiber optic network costs.

Their methodology was to estimate total IRN monthly recurring cost and the (megabits per second)  $\times$  miles (MM) supplied by the network. Division of IRN cost by MM then gives a measure of network comparison. Their results are given in Table 11-15 for a number of years from 1989 to 2010. There is a dramatic 90 times reduction in average circuit cost in 20 years!

The Contel approach just considers monthly recurring costs, and it is not clear the magnitude of the capital investment required to install the network. In view of the long life of the basic fiber (probably 30 years), one could argue that the nonrecurring costs will be small compared with the recurring costs and can be neglected.

To compare the DDS system costs with the Contel prediction, the annual DDS costs from Tables 11-11 and 11-12 must be converted to monthly costs (division by 12) and then divided by the system capacity times the average circuit length. We will take the average satellite circuit length to be 1,000 miles and use the maximum achievable capacity of 20 Gb/s (two satellites). (The 10 Gb/s is judged to be more equivalent to the Contel methodology of assigning network capacity.)

The result for the NASA system with \$135 M/yr annual cost is then \$844 monthly cost for a 1.5 Mb/s circuit (regardless of circuit length). For the \$242 M/yr commercial system, the monthly cost is \$1,513 for a 1.5 Mb/s circuit (again regardless of circuit length).



The NASA system assumptions for the DDS are probably closer to the Contel approach, so we will compare the \$844 DDS cost with the Contel 2010 cost of \$270 for the same circuit. The fiber system cost projection is 3.1 times lower! If you believe the Contel projections, satellites will not be able to compete for business that can be served by terrestrial fiber optic circuits. (Of course, primary DDS missions are to deliver space originated data back to earth and to relay data internationally, so the DDS concept still survives based on its uniqueness.)

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## Chapter 12

# Technology Development Plans

This chapter provides an estimate of the evolution of the ATDRS/DDS network, identifies the key technologies required to support overall DDS systems, and provides a preliminary plan for NASA development support.

The chapter is organized as follows:

- 12.1 Evolution of ATDRS/DDS Configurations
- 12.2 Key Technologies to Support DDS Systems
- 12.3 Development Planning in Support of DDS

### 12.1 Evolution of ATDRS/DDS Configurations

#### 12.1.1 Network Configurations

The future ATDRS and ASDACS (Advanced Space Data Acquisition and Communications System) networks may act alone or in conjunction with a flexible Data Distribution Satellite (DDS) for enhanced performance. The added DDS capability provides the following:

- Better distribution of data directly to users located within CONUS;
- Direct control of satellite experiments by users located within CONUS via dial up access to Control Centers;
- Added overall data link capacity; and
- Backup to current terrestrial links.

Other services of DDS includes accommodation of science peer networking, interface among NASA Centers, and interface to other international networks. The general evolution of the ATDRS-DDS-ASDACS network configurations is summarized in Figure 12-1.

#### Year 2007 Configuration

In the year 2007, the DDS would be placed in geosynchronous orbit at a location of 80° to 90° W longitude to facilitate good overall CONUS coverage with emphasis on the East Coast. Data from the replenishment series of ATDRS, which would be located on the horizon (as viewed from White Sands) at 41° and 46° W, and 171° and 174° W, would be directed to/from the White Sands ground terminals.

The White Sands ground terminals in turn would relay data to/from experiments via the DDS. As one option, the ATDRS FSG (future service growth) payload capacity could be used to supply a direct intersatellite link with DDS. Another option would be to put a steerable downlink antenna on ATDRS to allow a direct downlink to a user without passing through White Sands. These options could allow operational experience with direct data distribution.

#### Year 2015 Configuration

The advanced ASDACS series would replace ATDRS after year 2015. It is expected that multiple optical intersatellite links to DDS-2 would be incorporated into the baseline system design. The DDS on-orbit locations would be unchanged as shown in Figure 12-2, but one ATDRS could be moved to close the Zone of Exclusion.

#### Year 2025 Configuration

At the year 2025, it is projected that a cooperative international network of tracking and data relay satellites would be operated. If the orbit coverage were divided into three sectors; Americas, Europe/Africa, and Asia; then the ASDACS could be located over CONUS for good coverage with intersatellite links to the other sectors.

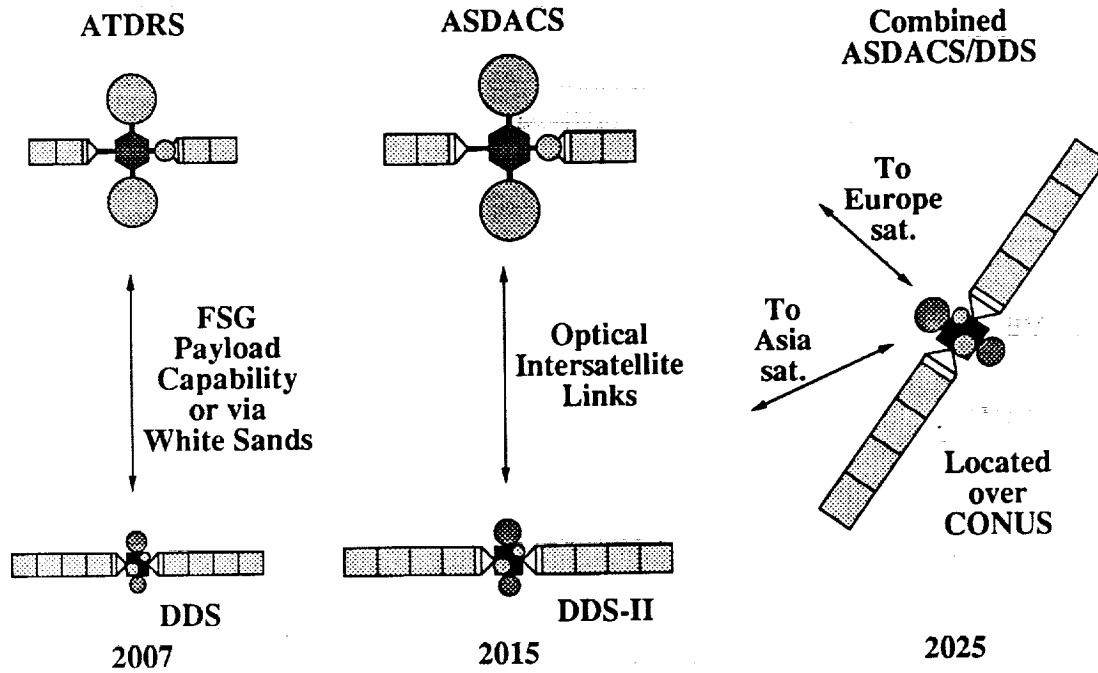


Figure 12-1: Evolution of DDS/ASDACS Configurations

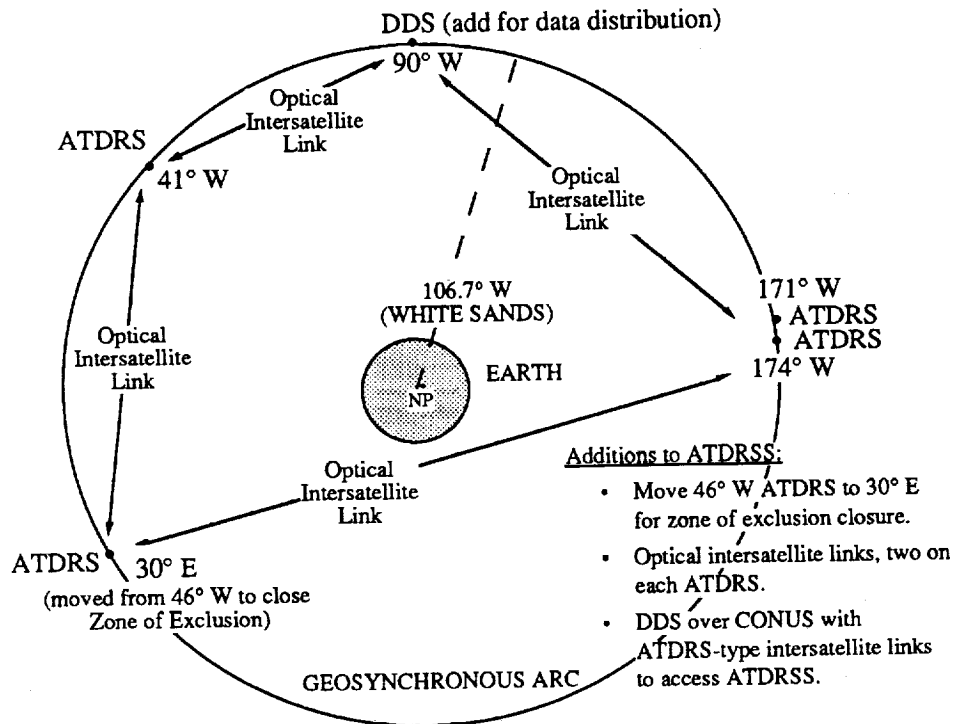


Figure 12-2: ASDACS Configuration for Year 2015

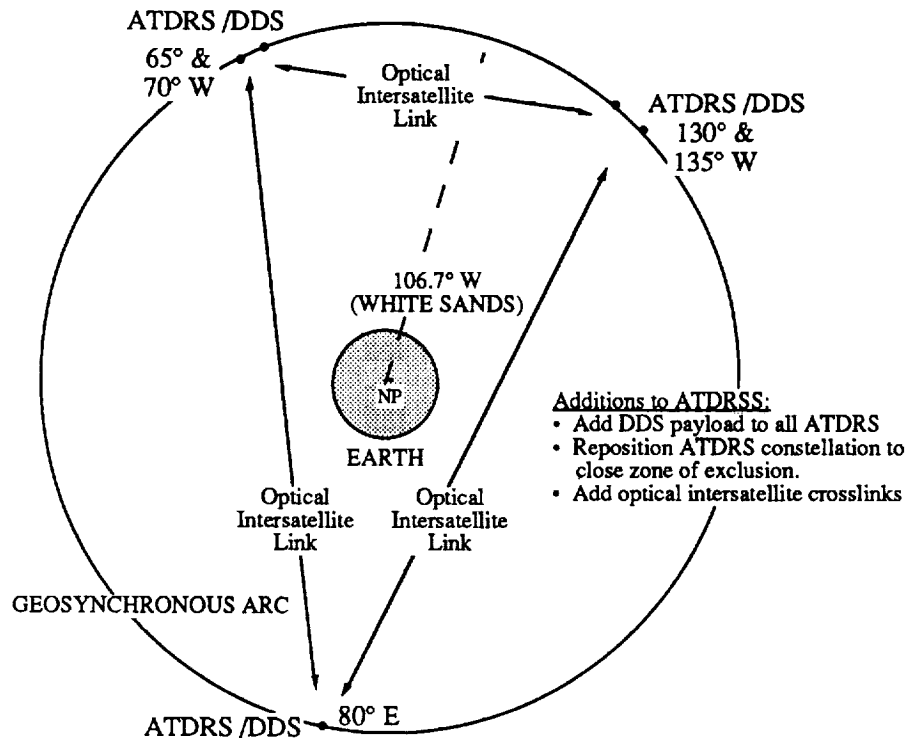


Figure 12-3: ASDACS Configuration for Year 2025

In this location, the ASDACS and DDS capabilities could be combined into a single satellite. Figure 12-3 shows one possible configuration with ASDACS (ATDRS/DDS) platforms to the east and west of the United States, and a third location on the opposite side of the geostationary arc from White Sands.

### 12.1.2 Schedule for DDS to Support ASDACS

If the DDS is to be utilized to support the ASDACS series of tracking and data relay satellites, then the schedule of Figure 12-4 may be used for technology planning. This shows an ATDRS capability over years 1997 to 2012 with residual capacity to year 2018. The expected orbit lifetime of each satellite is 10.4 years. The start of the ASDACS series may then range from 2012 to 2018. A backup of 12 to 18 years for initiation of the DDS program would then give a range of start dates from 1994 to 2000.

If the DDS is utilized to support the replenishment series of ATDRS (with first launch in 1997), then the range of start dates for the DDS program would be from 1990 to 1996 depending on expected program time span. This schedule is shown in Figure 12-5.

Some of the factors influencing the DDS develop-

ment schedule, and hence the associated technology development plan, are summarized in Figure 12-6. It is to be noted that much of the key communications technology is rapidly evolving and hence is subject to major changes if development is started too early.

## 12.2 Key Technologies to Support DDS Systems

Chapter 4, ¶4.5 has predicted the technology availability upon which the DDS system design was predicated. Table 12-1 summarizes these satellite technology developments, and serves as a basis for the discussion of this section

The discussion of the key technologies required to support the DDS concept developed in this report is organized in the following paragraphs:

12.2.1 Satellite Payload Technology

12.2.2 Satellite Bus Technology

12.2.3 Ground Terminal Technology

12.2.4 Network Protocol/Control Technology

12.2.5 Interface to Other Networks

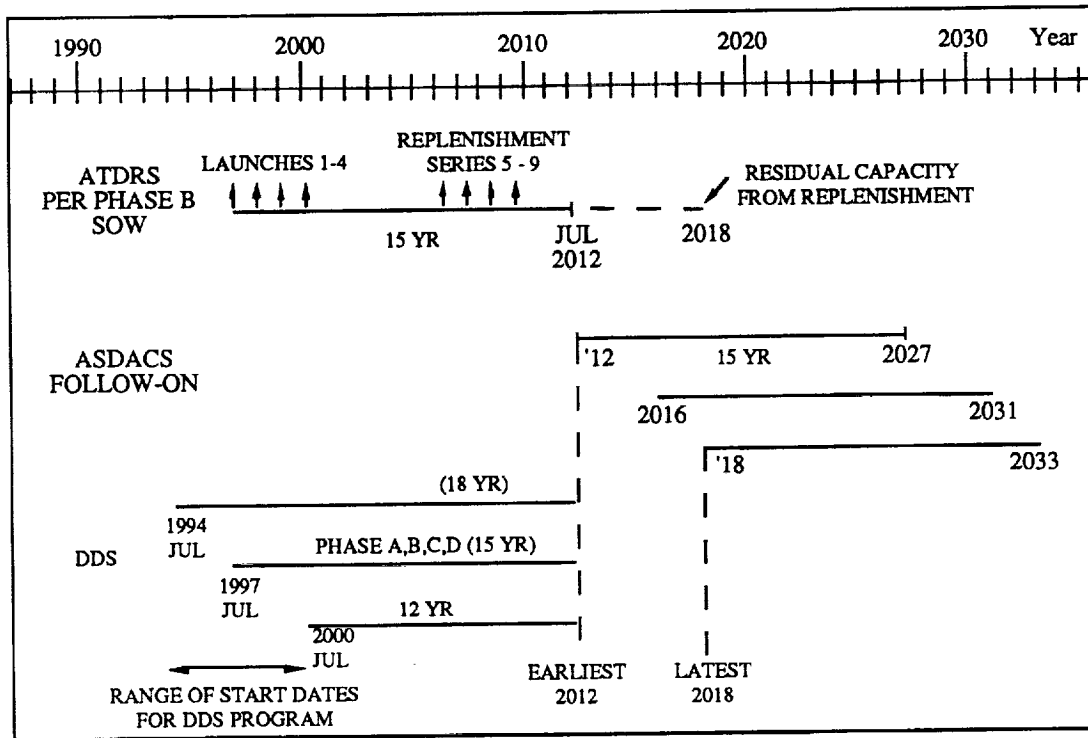


Figure 12-4: Master Schedule for DDS in Support of ASDACS

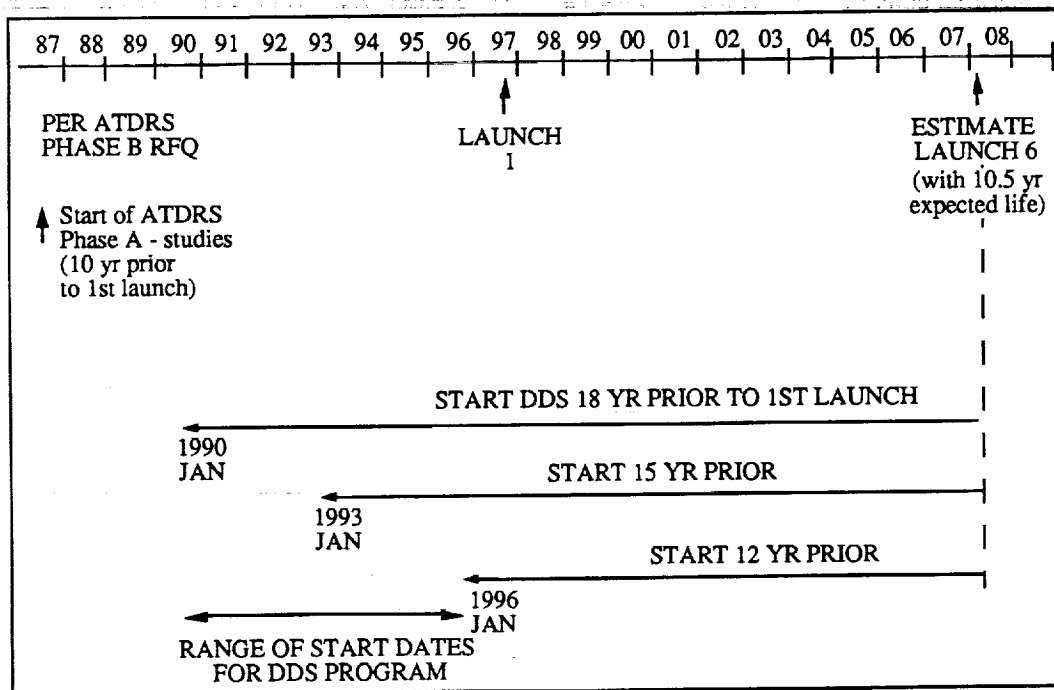


Figure 12-5: Schedule for DDS in Support of Replenishment Series of ATDRS

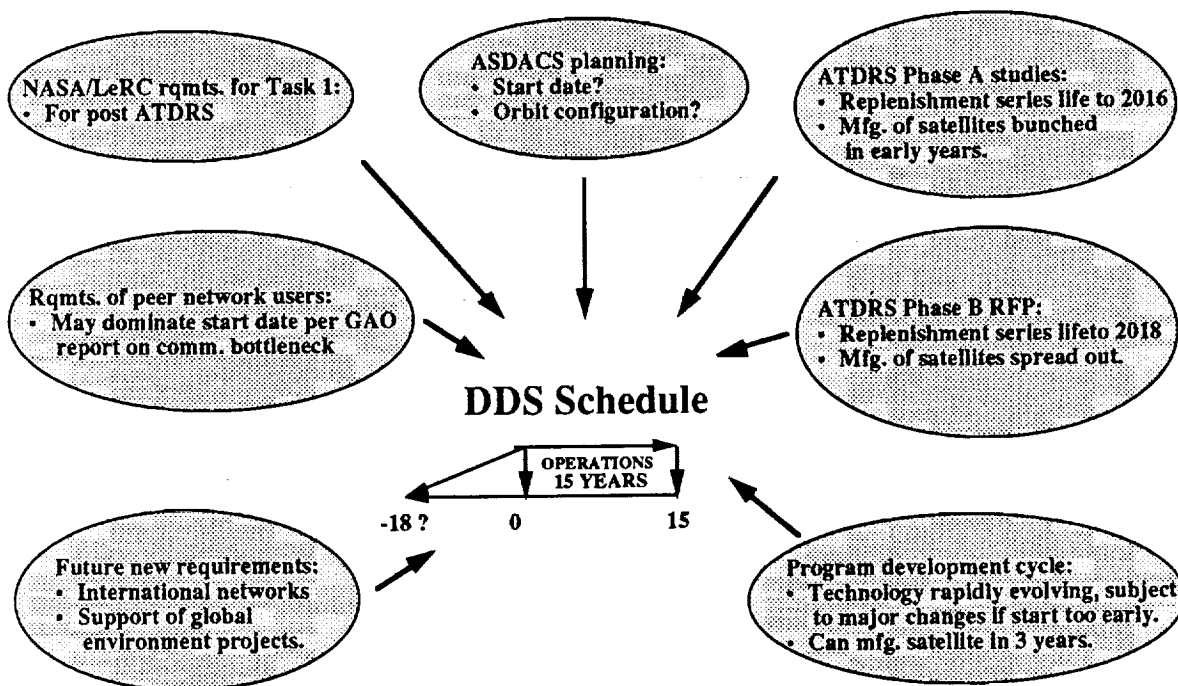


Figure 12-6: Factors Influencing DDS Schedule

Table 12-1: Satellite Technology Developments (2007 and 2015 launches)

Category	Change	Benefit
Structure	None	
Thermal	Passive heat pipes	Reduced mass of thermal subsystem. Higher thermal dissipation.
Propulsion	Ion propulsion	Reduced mass for long life missions.
Attitude Control	Use of GPS & ATDRSS Ring laser gyro	More accurate and faster position determination. Increased reliability, less calibration time.
Power	Advanced NiH bat. (2007) NaS batteries (2015) Thin Si cells (2007) GaAs solar cells (2015)	Improved power/weight ratio. Even better power/weight ratio. Reduction in solar array mass. Greater efficiency (21% vs. 13%)
TT&C	None	
Comm. Payload	More efficient TWTAs SSPA availability Improved modulation Active aperture antenna Bulk demodulators Laser ISLs VHSIC & microprocessors	Less power required. Greater reliability and lifetime, less mass More efficient use of given bandwidth. Use of MMICs enable higher performance. More efficient access scheme; FDM up, TDM down. More efficient data distribution.
Space Transport	High strength materials Large scale integration Photonic switching ALV and OTV	Better capacity for processing and switching. 15% mass reduction for antenna subsystem 15% mass reduction for electronic components High capacity, low mass, high speed switching. Increased capacity, reduced cost.

### 12.2.1 Satellite Payload Technology

The technologies for the satellite communications payload requiring development, advancement, and/or demonstration are discussed in turn.

**Uplink and downlink antennas** in seven different sizes (listed in ¶8.2.1) at Ku and Ka-bands dominate the physical layout of the satellite (Figure 8-3) and have an estimated 164 kg mass. Their sizes range from 0.4 m to 2.2 m, with 8 to 27 separate, simultaneous beams being formed by each antenna.

Our proposed system architecture uses fixed FDMA uplink beams and fixed TDM downlink beams in order to minimize the synchronization and timing problems for small VSATs using a scanning beam. This choice of multiple fixed beams from each antenna leads to use of multiple beam antennas (MBAs) rather than phased arrays which require a separate beam forming network (BFN) for each separate beam. However, use of scanning TDMA satellite beams implemented via phased arrays may be the eventual system choice, so development of the phased array should also be pursued.

There are a number of areas where the antenna technology should be pursued:

- MMIC feeds for MBAs in order to reduce mass and power consumption. Major challenges are in the packaging and thermal design. (MMIC feeds are also important for the phased array design alternative not selected.)
- Combination of several antennas into one; i. e. Ku-band and Ka-band, transmit and receive, H and V polarization. This becomes a difficult task when multiple beams are formed from each antenna with frequency reuse among the different beams. The total co-channel interference must be kept to  $C/I \geq 16$  dB, which requires low sidelobes and adequate isolation.

Possible methods include use of gridded reflectors to separate polarizations or frequency selective surfaces (FSSs) to separate the different frequency bands.

Our proposed DDS design only combined the 1.7 m Ku-band and the 1.4 m Ka-band receive antennas via use of an FSS. Each of these antennas could form around spot 20 beams at different locations over CONUS.

- Use of higher strength materials such as "metal matrix" graphite fiber reinforced plastic in the antenna subsystem to reduce mass.

**Optical Intersatellite Links (ISLs)** are required in order to achieve high data rates with minimum mass and power impact on the satellite. This technology is currently in a state of flux, with present designs such as those originally planned for the ACTS satellite being much too heavy for practical use, but dramatic new technology advances such as coherent 2 W laser diodes being demonstrated (laser diode arrays by Spectra-Diode Labs). The key issues for space optical ISLs include:

- Reduction in size and mass, with a goal of 25 kg mass, 50 W power, and a 15 cm aperture for a unit supplying a duplex 640 Mb/s 40,000 km link.
- Direct coupling of the free space photons into fiber with low loss. This allows separation of telescope and transmit/receive electronics.
- Space qualification of coherent, small linewidth sources suitable for use with optical heterodyne receivers.
- Use of heterodyne versus direct detection allows around 8 dB improvement in link performance, and is key for high data rate systems.

**Multi-Channel Demodulators (MCDs)** or bulk demodulators are a key technology for enabling low cost access by VSATs. Key issues for their design include the following:

- Reconfigurability to allow change in the size and mix of user channels.
- Recommended capacity of a single unit is 52 Mb/s, reconfigurable to accept 64 kb/s, 144 kb/s, 1.544 Mb/s, or 6.2 Mb/s channels.

It is desirable to allow a single MCD to accept part of its capacity at one data rate and the remaining capacity at a different data rate.

- Another issue is synchronous versus asynchronous operation. If the transmissions from user VSATs can be synchronized such that all symbols arrive at the MCD at the same time (synchronous operation), one sample per symbol is adequate. If the



symbol arrival time is not synchronized, 8 samples per symbol may be required. The potential for synchronous operation needs to be identified and tested.

- The allowable user channel separation (1.5 or 2 times bandwidth) is key to efficient use of the limited satellite spectrum.
- Our previous work under the *Multi-Frequency Multi-Service Satellites* Contract favors a digital implementation of the MCD. However, a key parameter is the processing speed in order to reduce mass and power requirements. Use of GaAs chips is assumed by our DDS design, but MCDs still consume 400 W power and have 78 kg total mass.

**Modulation and Coding** must be considered together for optimum design. Key technology for satellite application includes the following:

- Demodulators and modulators from 52 Mb/s to 640 Mb/s are required. (MCDs have already been described.) Key issues are mass and power, and the ability to be flexible in using one of several different modulation formats (change data rates, protocols, and even standards). Programmable digital signal processing modems could be customized after deployment.
- Coding schemes should be realizable with codecs of small mass and low power usage. Coding gains of 3 to 5 dB (the higher the better) at rates of .75 to .90 (the higher the better) are the goals at bit error rates of  $10^{-6}$  to  $10^{-10}$ .
- Higher order modulation schemes can improve coding and MCD performance, but are more sensitive to interference and result in higher modem implementation loss.

#### Power Amplifiers

- The improvement in efficiency of TWTAs and SSPAs needs to be continued. (We assumed 37% efficiency for Ku-band and 31% efficiency for Ka-band SSPAs in our year 2007 satellite design, and 40% and 35% respectively for the year 2015 designs.) Other key issues include linearity, 15 yr lifetime, and high power solid state devices. Our

design calls for Ku-band and Ka-band SSPAs ranging in power output from 1.5 W to 20 W (see Table 8-11).

- For the active aperture antennas with multiple beams, high power (1 W), linear MMIC devices are required at Ku and Ka-bands.

**Information Switching Processor (ISP)** is the digital routing switch which interconnects the circuit or routes the packets from the uplink beam to the correct downlink beam. Figure 12-7 shows the central position of the ISP in the DDS system. Key design requirements for the ISP include the following:

- Space qualified design with low mass and power (12 kg and 200 W goals).
- Supports ISDN and B-ISDN protocols for circuit and packet switching.
- Incorporation of input and output muxes and formatters.
- Internal redundancy adequate for 15 year lifetime.
- Incorporates storage for bit streams in contention

**Autonomous Network Controller (ANC)** would be positioned on the satellite for our year 2015 design. Figure 12-7 shows the potential position of the ANC on the DDS satellite.

Although we project ground network control for the year 2007 DDS, development of a space qualified ANC should start now. The problem with a ground-based ANC is the long reaction time (due to transmission path delay) for service requests or changes.

The key design requirements include space qualification, low mass and power consumption (6 kg and 50 W goals), limited autonomous operation, and redundancy and reliability to achieve a 15 year lifetime.

**Other Communication Payload Technology** Other technology not included in the above categories is listed below:

- Antenna pointing of  $0.5^\circ$  spot beams may require use of a pilot beam. This technology may be under investigation and demonstration by the ACTS program.

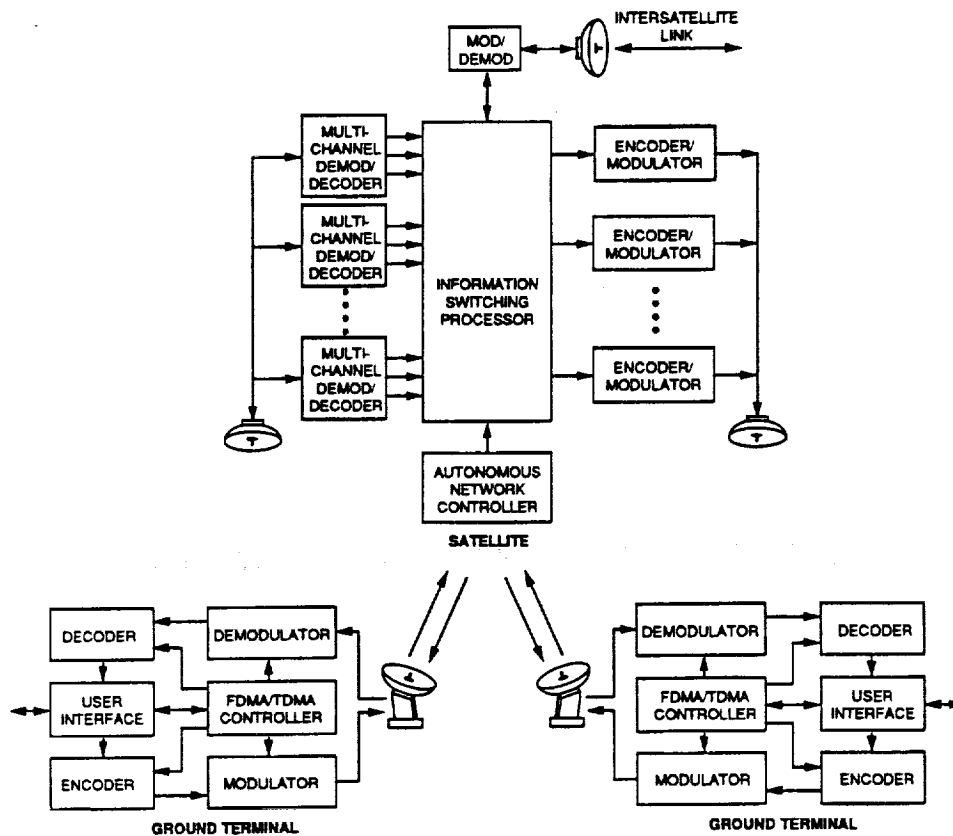


Figure 12-7: Data Distribution Satellite Communication System Components

- Adaptive rain fade compensation techniques such as those implemented for ACTS should be evaluated and improved for use in the Ka-band rain fade environment.

### 12.2.2 Satellite Bus Technology

The satellite bus supplies the physical platform and power resources required by the communications payload. Desirable platform features are to supply these resources as efficiently as possible, i. e. with as little mass and power usage by the bus.

Since the focus of this report is on the communications technology, only a listing of the most important bus technology is given. (Table 12-1 has provided an overall listing of bus subsystem technology.) The key items are as follows:

**Thermal cooling** techniques are important for a high power satellite such as DDS. Passive heat pipes with thermal radiation panels are required.

**Ion propulsion** for attitude control and on-orbit station keeping is a key technology to enable long life (15

yr) satellites. As shown by our designs, on-orbit fuel can be greatly reduced with a modest increase in mass of the propulsion system.

**Battery technology** via advanced NiH (2007) or NaS (2015) allow great improvement power/weight ratio.

GaAs and thin Si solar cells also allow improved power/weight ratio. For high power satellites, the smaller array area of more efficient GaAs cells is important to reduce solar torques and ease packaging and deployment problems.

Low cost space transportation, while not a bus technology, is another key item since it represents around 20% of the DDS System life cycle cost.

### 12.2.3 Ground Terminal Technology

These technologies are required for the development of low cost ground terminals.

- Cost reduction techniques for large quantities of VSATs.

- Modem for use in large numbers of VSATs. The problem is to develop low cost chips for coding and decoding, and modulation and demodulation.
- VSAT interfaces to ISDN and B-ISDN equipment and networks.
- Mini-trunking method for power combining of separate transmitters versus use of single linear amplifier.

#### 12.2.4 Network Protocol/Control Technology

These technologies relate to the functioning of the Data Distribution Satellite (DDS) system.

- Overall command and control of the satellite payload configuration which must respond to dynamic changes in user capacity and distribution over CONUS.
- Network protocols for access by a large number of small users within an ISDN environment.
- Minimization of interference among common users and neighboring satellites to the DDS.
- Simultaneous control of satellites in the same orbital position - i. e. separations of  $0.05^\circ$  or less.
- Software development for master control station.

#### 12.2.5 Interface to Other Networks

It is recommended that the next phase of the DDS development include the following actions.

- Prepare detailed user requirements for:
  - Experimenters
  - Inter-networking of NASA centers
  - Science data base users

The requirements would include quantities and classes of users, data rates, geographic distribution, quality and availability of links, dynamic variance of use over short and long term intervals, use of shared terminals, tolerance to short and long term outages, and interfaces to other terrestrial and satellite communication systems.

- Continue with Phase 1 system studies:

- Match design to evolving standards such as B-ISDN (Broadband Integrated Services Digital Network) for peer networking and CCSDS for space networking.
- Optimize configuration to match evolving user requirements and determine updated costs.

The DDS system concept development is expected to be an iterative process. Preliminary requirements are used to develop preliminary system configurations and associated costs. The knowledge of approximate costs is then used to obtain an updated set of requirements (many of which are very cost dependent) which then leads to an updated system configuration and more exact costs.

### 12.3 Development Planning in Support of DDS

This section addresses the following directions from the NASA Statement of Work. *It is advisable to proceed with critical DDS/ASDACS technology developments and demonstrations, as the implementation cycle of advanced systems can easily span 15 years, which would likely be the probable life cycle of ATDRS. Consequently, it remains to define an optimum method of transitioning to a fully automated DDS/ASDACS system, by making use of strategic opportunities for critical DDS/ASDACS technology demonstrations and applications.*

*Toward this end, the contractor shall propose intermediate technology advancement steps where certain functions of the future DDS/ASDACS could be demonstrated and applied. These proposals shall emphasize the Data Distribution subsystem, but also include the compatible and critical ASDACS as well. These intermediate steps may make use of the future service growth (FSG) capability of the ATDRS system, or, they may include separate flight systems, where warranted.*

The discussion of this section is divided into five parts:

- 12.3.1 Summary Development Schedule
- 12.3.2 System Definition Studies
- 12.3.3 Hardware POC Developments
- 12.3.4 Communication Simulation Laboratory
- 12.3.5 Demonstration Experiments On-Orbit

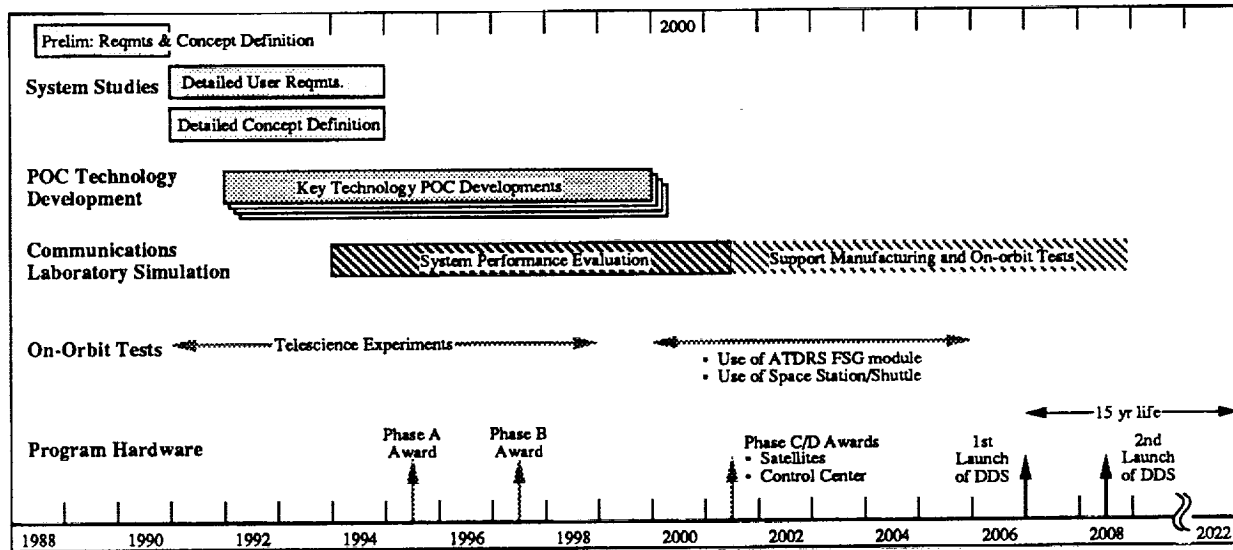


Figure 12-8: Data Distribution Satellite Concept Development Plan

### 12.3.1 Summary Development Schedule

An overall multi-year development plan for NASA support for a NASA Data Distribution Satellite Program with initial launch in the year 2007 is shown in Figure 12-8. The various categories of support would include the following:

- System configuration studies,
- Key technology proof-of-concept (POC) development,
- Communications subsystem simulation and testing in the laboratory, and
- On-orbit tests of key hardware to reduce program risk.

Each category is more fully described in subsequent sections.

The master schedule shows initiation of preliminary requirements and concept definition studies in mid-1988 with continuation of follow-on detailed studies until inclusion in the Phase A awards under a Program Development effort. The key POC developments would be achieved in the 1992 to year 2000 period.

It is projected that an extensive communications laboratory simulation of major elements of the satellite, control center, and terminal communications network would be conducted in the 1994 to 2001 period prior to award of the Phase C/D hardware contracts for DDS procurement. A continued use of the laboratory would

also be beneficial through the satellite manufacture and early on-orbit operational period.

The overall development plan also shows potential on-orbit testing during the period of years 2000 to 2006. A specific experimental flight model of DDS is not planned; however, some key elements could be evaluated through use of the ATDRS future service growth capability of the Space Station Freedom.

The DDS program plan shows Phase A awards in 1995, Phase B awards in 1997, and Phase C/D award for the satellite and communications control center development and manufacture beginning in 2001. The first launch of DDS is shown in 2007 in order to coincide with the launch of the replenishment series ATDRS. A second DDS launch would be made several years later to supply backup and increased orbital communications capacity for the remainder of the 15 year life cycle.

### 12.3.2 System Definition Studies

It is projected that the initial DDS will not be launched until the year 2007 which is 17 years from now. A hardware development and manufacturing period of 5 to 6 years may be required for an advanced DDS communications satellite. It is recommended that a continuing series of system studies be conducted over the next ten year period in order to more fully define the user requirements and system performance requirements prior to award of Phase C/D contract.

Among the issues which require continuing study ef-

forts are the following:

**Detailed requirements definition.** The DDS would be used not only to support the ATDRS data distribution, but also for peer networking and NASA data interface. In addition, the potential for international data flow, support for industrial use of space for experiments, and backup for terrestrial communication links may be considered. The requirements of the many types of users are expected to vary considerably over the next ten year time period.

Thus it is recommended that an overall communications requirements model be established and maintained, and which would be supplied with inputs provided by various contracted efforts to establish continuing user requirements. Thus study efforts would include:

- Interviews with user groups.
- Determination of specific requirements in terms of data rates, data quality, outage level tolerance, time usage periods, and geographic location of users.
- Consolidation of user requirements into an overall satellite communication model with time-of-day traffic flow by coverage area and peak loading characteristics.

**Master Control Center definition.** The various user data flows must be coordinated via a Master Control Center. Detailed studies of the protocols, access procedures, and methods for management of data flow should be accomplished.

**Detailed definition of DDS payload.** Many techniques may be utilized to accommodate user requirements. Hence studies to achieve optimized performance at low development risk, at low cost, and at high reliability over a 15 year life should be continued up to the time frame of hardware development. The configuration must match the updated user requirements model and would serve as the basis for definition of support for key proof-of-concept technology developments.

Significant detail of the communications subsystem is also required in order to establish the realistic mass and power budgets which in turn are significant in determination of overall satellite and launch vehicle configurations.

**TDRSS interface definition** should be investigated in detail in the next phase of the DDS Program.

- The DDS system could always receive ATDRSS data via a ground-based interface at White Sands. An intersatellite link between DDS and ATDRS is a more elegant solution, but TDRS and ATDRS (which is in the concept definition phase) do not, at this time, have the capability for crosslinking to another geosynchronous orbit satellite.

However, the FSG payload capacity on ATDRS is adequate to include an intersatellite link to DDS.

- The problem of DDS transmitting via the TDRSS is much more serious. The DDS desire is for scientists to control experiments, which implies real time access. Since TDRSS currently requires pre-scheduled communications, this issue must be investigated further.
- Current studies being carried out for NASA Goddard on ATDRS concepts should be closely followed with reference to DDS access to the TDRS system.

**Orbit configuration** of the DDS system should be investigated.

- The first question is how many satellites are required to meet user requirements and satisfy reliability concerns? Are ground spares satisfactory or are in-orbit spares required to meet availability requirements?
- This study proposes collocating two satellites in the same orbital position, less than  $0.05^\circ$  apart. The problem is how to control the relative orbital positions.
- The possibility of a joint TDRS/DDS platform should also be considered.

An overview of a Studies Plan in support of the DDS Program is shown in Figure 12-9. This current report was prepared as one task element of an the *Technical Support for Advanced Satellite System Concepts* Program. Follow-on system level studies could be accomplished as additional tasks within this contract or as independently funded new efforts. Figure 12-9 shows the planning for the four additional new DDS studies

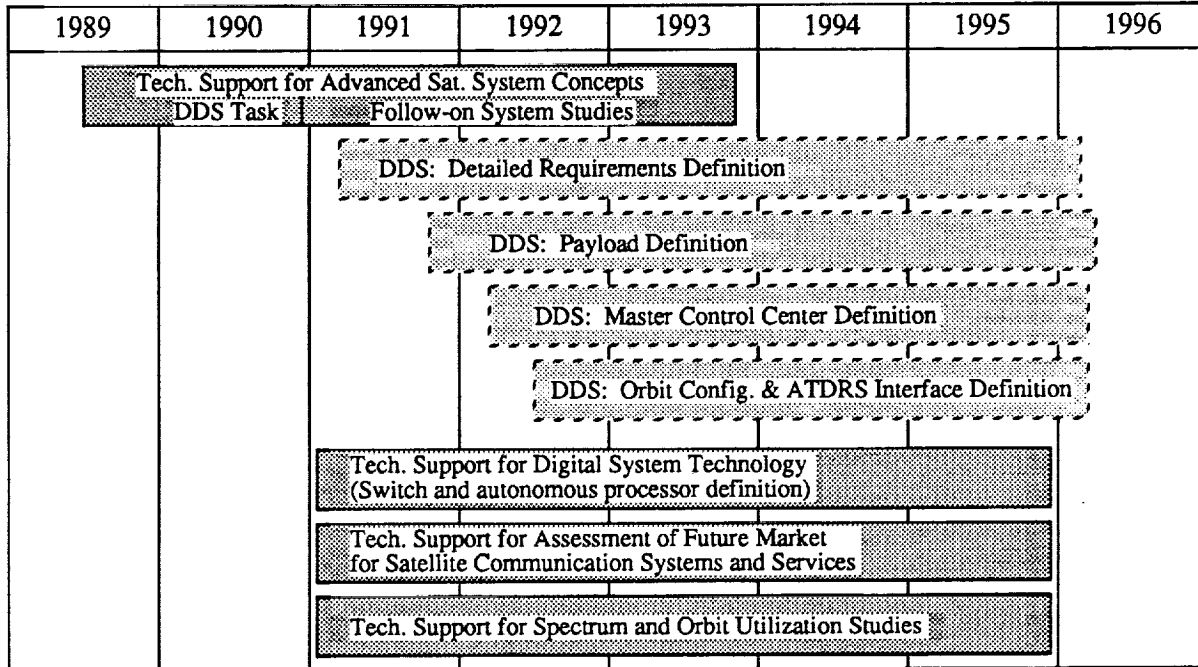


Figure 12-9: Studies Plan in Support of the DDS Program

previously described (shaded light in dotted boxes) as well as showing supportive efforts for the four currently planned efforts (dark shaded boxes).

The *Technical Support for Digital Systems Technology Development* Program will develop subsystem architectures with associated tradeoffs and feasibility studies in support of digital technology programs for satellite communication systems. Contract awards are expected in the first quarter of 1991, with tasks being assigned and accomplished over the next three to five years. This effort may serve as the focus for definition of a high throughput, fault tolerant Information Switching Processor and its associated space-based Autonomous Network Controller. Follow-on work described in ¶12.3.3 would develop proof-of-concept hardware.

The *Technical Support for Assessment of the Future Market for Satellite Communication Systems and Services* Program will access the total future communication needs, predict future changes in common carrier and private network evolution, and identify those services which can best be accommodated by satellite communication links over the next 30 year period. Contract awards are expected in the first quarter of 1991, and tasks will be accomplished over a four to five year period.

The *Technical Support for Spectrum and Orbit Utilization Studies* Program provides support for NASA inputs to international standards organizations. Analyses and evaluations will be accomplished of technologies related to satellite communications planning.

### 12.3.3 Hardware POC Developments

This section addresses the following directions from the NASA Statement of Work. *The contractor shall identify and describe specific Proof of Concept models which will prove functional feasibility for the critical technologies of a DDS system. The contractor shall also develop schedule and cost estimates for realizing these models in preparation for the demonstrations and applications proposed in Subtask 2. Budget and schedule guidelines shall be provided by NASA.*

The DDS system will require a significant advance in the satellite communication technology versus that of current designs which largely incorporate broadband transponders. Other key developments are required for the communications control center and user ground terminal equipment. The detailed DDS configuration studies will serve to focus the requirements of key proof-of-concept (POC) technology developments. These developments become even more important if an experimen-

tal flight program is not utilized.

Some of the key future POC developments which have been identified as a result of this study include the following items, which are grouped as candidates for early, middle, and later hardware developments depending on degree of technical risk.

Early hardware developments:

**Autonomous Network Controller.** Develop on-board control concept for DDS, with sufficient functionality to minimize need for "double hop" communications between users and ground-based master control.

**Information Switching Processor.** Develop partial capability satellite baseband processor and switch to accommodate DDS requirements. Determine redundancy required for 15 year lifetime in space environment. Examine methods for communications control.

Middle hardware developments:

**Master Control Center.** Develop key software for accommodate procedures and protocols of the DDS system. Determine procedures for control of DDS communications subsystem.

**Satellite Antenna Development.** Determine satellite antenna implementation to meet coverage and frequency reuse plans. Evaluate via computer analysis and test. Determine impact of dual polarization.

**Satellite Receiver/Demodulator.** Determine RF front end configuration with switching flexibility. Develop satellite multi-channel demux/demods to accommodate various uplink data rates and modulation techniques. Examine on-orbit reconfiguration of demodulators.

Later hardware developments:

**Decoding and Coding.** Develop ground and space coder and decoders for range of DDS data rates. Integrate FEC coding with modulation methods.

**Earth Terminals.** Develop key hardware for low cost VSAT designs. Incorporate MMIC and VHSIC technology. Determine single and dual frequency (Ku and Ka-bands) configurations to meet DDS communication requirements.

**Satellite Transmitters.** Determine a multiple transmitter, multibeam technique for accommodating DDS requirements. Include switching flexibility. Examine low loss RF combining versus multiple carriers per RF transmitter for implementation.

An overall outline showing the integration of currently planned POC developments at NASA/LeRC (which may be applicable to DDS) and potential new hardware POC developments is shown in Figure 12-10. The cost estimate for each hardware POC model would nominally be \$5 M, with a range from \$2 M to \$10 M depending on the amount of technical risk reduction judged necessary. Total POC hardware development cost is judged to be a minimum of \$50 M.

The typical cycle of time from origination to concept idea, through configuration studies, key technology development, and operational system hardware manufacture may take 12 years to complete as shown in Figure 12-8 (1989-2001).

It is recommended that the POC hardware development concepts of this report be expanded in the next few years as part of a new system studies task order contract effort.

#### 12.3.4 Communication Simulation Lab

The DDS communications subsystem will represent a major advance versus current satellite communication methods. In order to reduce the risks associated with a complex system implementation, it is recommended that a Communications Simulation Laboratory be established for verification of key component equipment items and overall communication systems performance of sample segments of the DDS system.

The various equipment items may be obtained as part of the POC hardware developments and/or via a separate contract for a limited capacity DDS communications model.

The Communications Simulation Laboratory could be used to evaluate the ability to accommodate dynamic changes in traffic capacity and hence help establish overall system capacity requirements. The use of the simulation laboratory may also be valuable in support of on-orbit operations by evaluation of potential fault situations.

Another aspect of the Communications Simulation Laboratory work could involve telescience prototyping as described in Appendix B, Telescience Testbed Pilot Program. Telescience experiment concepts could be

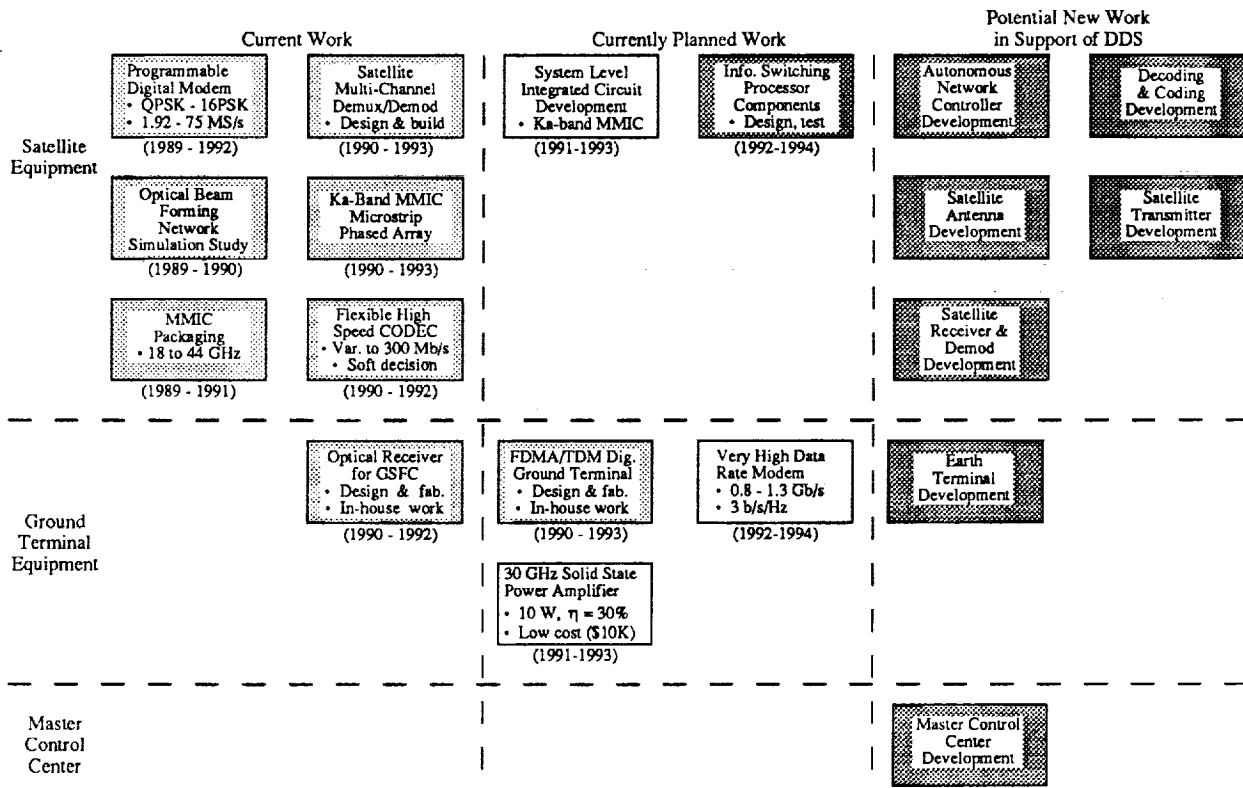


Figure 12-10: Proof-of-Concept Hardware Development Plan in Support of the DDS Program

simulated in the Laboratory with all the actual network and control system delays.

### 12.3.5 Demonstration Experiments on Orbit

It is not expected that a dedicated experimental satellite be deployed to verify the DDS advanced technology. However, to minimize performance risk, it is recommended that some on-orbit equipment performance verification be provided in addition to the extensive POC key technology development and laboratory simulations.

Two suitable NASA space platforms may be available for test experiments in the 2000 to 2007 period.

#### ATDRS Future Services Growth Payload

capability accommodates 109 kg, 0.3 m<sup>3</sup> volume, 260 W power, and 260 W thermal dissipation. The potential uses of this capacity in support of DDS include the following payloads:

- Direct-to-user Ka-band downlink could be used to directly deliver ATDRS gathered data

to users in real time. Total cost could range from \$3.2 to \$4 M (see Table 6-4 in Chapter 6).

- Ka-band crosslink, ATDRS to DDS, could be used for direct delivery of ATDRS gathered data to users via DDS.
- 60 GHz crosslink, ATDRS to DDS, demonstrates maturity of 60 GHz crosslink.
- Optical crosslink, ATDRS to DDS, demonstrates maturity of optical crosslinks.

This payload capacity could be utilized on early launches of ATDRS to evaluate the above applications or could be used for selected other DDS payload experiment verification.

**Space Station Freedom** could be utilized as an experiment platform in conjunction with ground-based receivers or co-orbiting platform or Shuttle to evaluate much of the key DDS communications subsystem equipment. A single-thread DDS communications system with key components, having



been verified in the Communication Simulation Laboratory, could be built and flown to demonstrate performance. A basic system incorporating receiver, switch and controller, and processor could cost \$30 M.

Another area for demonstration experiments involves telescience testbeds (see Appendix B, Telescience Testbed Pilot Program). In order to verify planned telescience use of DDS, it is highly desirable that scientists on earth access experiments in space via the TDRSS (and ATDRSS when available) on a trial basis. Thus it is recommended that low data rate and high data rate experiments be conducted as a precursor to DDS usage.

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## Appendix A

# ATDRS System Overview

This appendix contains information from the ATDRSS Phase B RFP. (*Phase B ATDRSS Service Requirements Specification*, Document S-500-1, pages 1-1 to 1-7, 20 November 1989; incorporating Amendment 2 dated 22 January 1990.) The verb "shall" is used to express a requirement.

### A.1 Scope

This document provides the Advanced Tracking and Data Relay Satellite System (ATDRSS) service requirements.

### A.2 ATDRSS Objectives

a. The ATDRSS objective is to ensure the capability of the Space Network (SN) to respond to future user telecommunications and tracking requirements. As an integral part of the Space Network, the ATDRSS will support telecommunications and tracking needs during the ATDRSS era (from 1997 to 2012) for the following:

- (1) Low Earth Orbit (LEO) User Satellites (USAT).
- (2) Coverage for users to Geosynchronous Earth Orbit (GEO).

b. The ATDRSS will function as a continuation of the Tracking and Data Relay Satellite System (TDRSS), accommodating growth in user requirements via a minimum risk and cost evolution from the 1996 TDRSS baseline.

c. Additional objectives of the ATDRSS are to provide:

- (1) A transparent transition of Space Network services for TDRSS era users.
- (2) Incorporation of any TDRSS product enhancements (including ground terminals) and support service commitments to TDRSS era users.
- (3) A minimum life-cycle cost capability which provides Space Network users with the necessary telecommunications, tracking, and simulation and test services.
- (4) An implementation approach which will permit service enhancements during the operational phase with minimum changes in existing hardware and software, and no impact to on-going support operations.

### A.3 ATDRSS Architecture in 1996

a. The TDRSS architecture baseline in 1996 (shown in Figure A-1) will consist of:

- (1) Two operational Tracking and Data Relay Satellites (TDRS) located at 41° and 46° West longitude.
- (2) Two operational TDRS's located at 171° and 174° West longitude.
- (3) The White Sands Complex (WSC) in New Mexico, which will include the upgraded White Sands Ground Terminal (WSGT) and Second TDRSS Ground Terminal (STGT).
  - (a) Each ground terminal will include two independent Space-Ground Link Terminals (SGLT) and one stand-alone S-band Tracking, Telemetry and Command (TT&C) terminal.

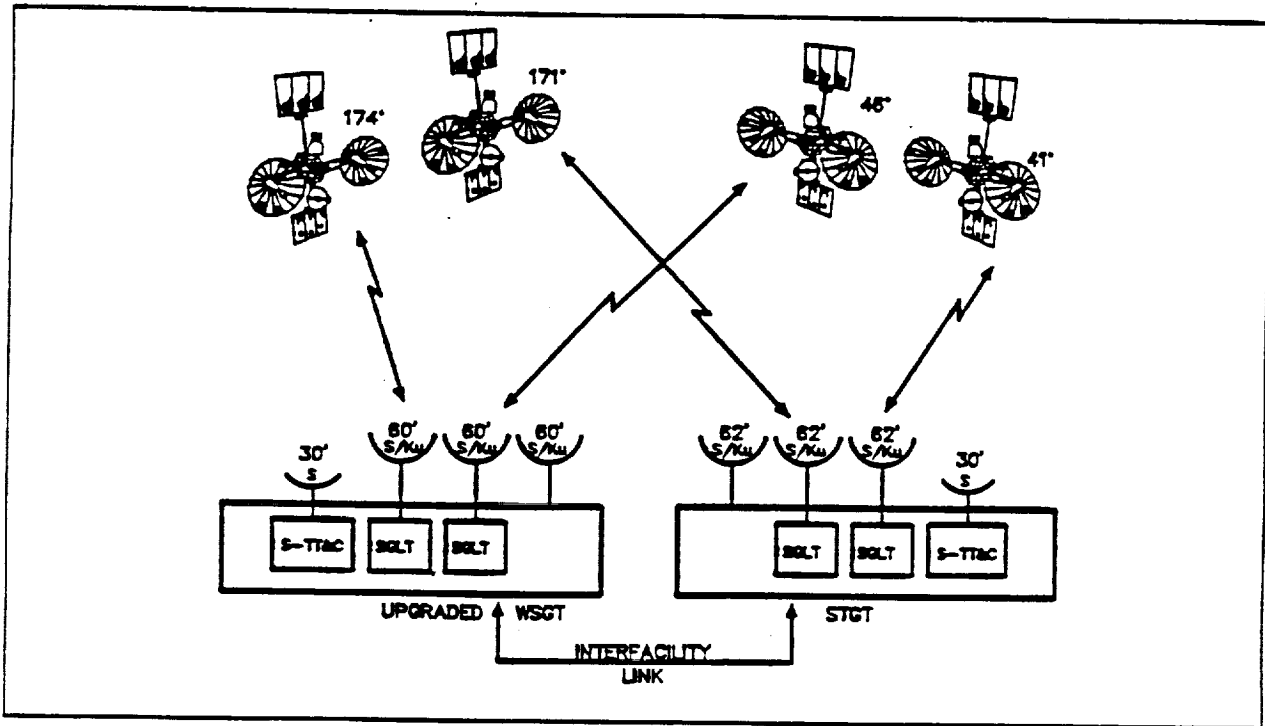


Figure A-1: TDRSS Architecture Baseline in 1996

- (b) Each SGLT will support all user telecommunications and tracking services and TDRS TT&C for a single TDRS.
- (c) The S-band TT&C terminal will provide emergency backup support for TDRS TT&C.
- b. TDRSS will support the user services described in the Space Network (SN) Users' Guide (STDN No. 101.2).
- c. Network Control Center (NCC)
- d. Space Network User Project Operation Control Center (POCC) Interface (SNUPI)
- e. The Bilateral Ranging Transponder System (BRTS)
- f. The Merritt Island Relay (MIL Relay)

## A.4 End-to-End Architecture Overview

Figure A-2 illustrates the end-to-end architecture in the ATDRSS era.

### A.4.1 Space Network Elements

The ATDRSS Space Network (SN) will consist of the following:

- a. ATDRSS Space and Ground segments
- b. User Space Terminals (UST) located in User Satellites

### ATDRSS

The ATDRSS shall consist of a space segment and ground segment.

#### a. ATDRSS Space Segment

- (1) The ATDRSS space segment shall consist of four operational ATDRS's and one identical space ATDRS in GEO. This constellation is defined as the cluster configuration.
- (2) Operational ATDRS's shall be located at 41°, 46°, 171°, and 174° West longitude.
- (3) The spare ATDRS shall be located at 79° West longitude.

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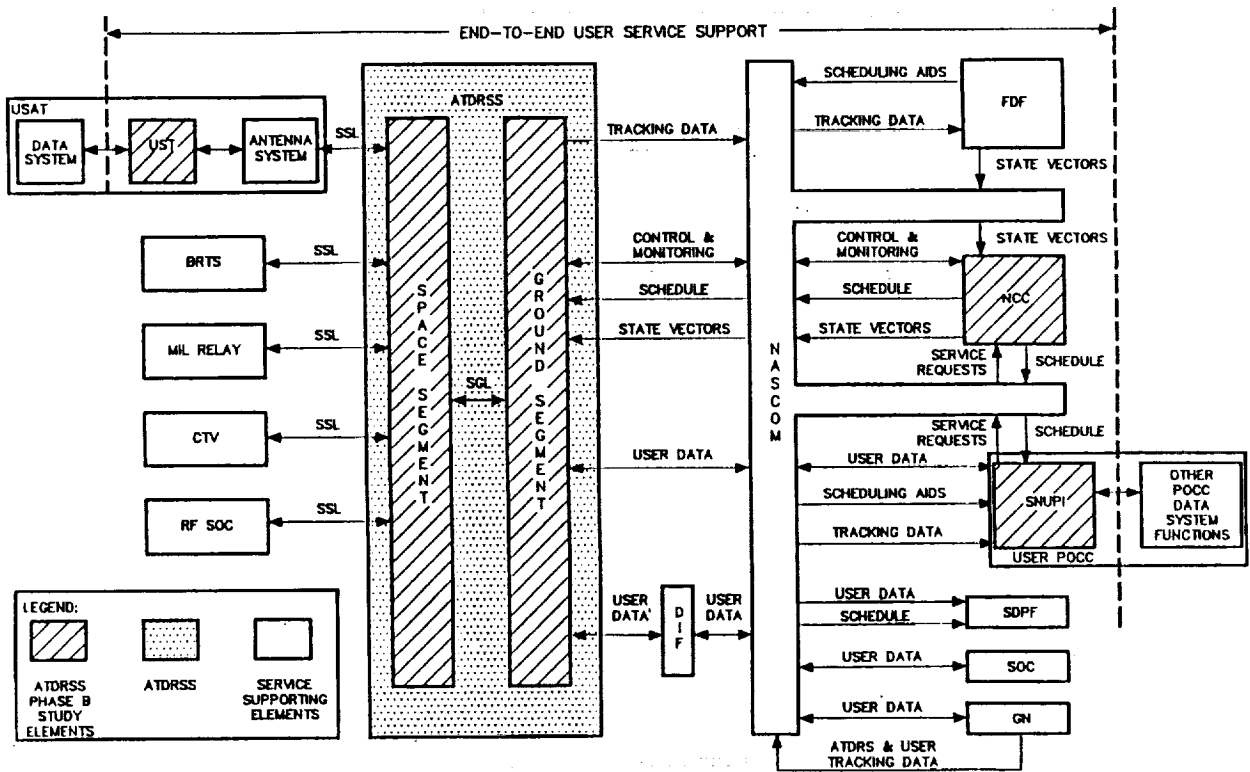


Figure A-2: End-to-End Architecture in the ATDRSS Era

- (4) Each ATDRS shall accommodate additional on-board equipment for Future Service Growth (FSG).
- (5) ATDRSS space segment requirements are specified in S-500-2, Section 5.

b. ATDRSS Ground Segment

- (1) The ATDRSS ground segment shall include two geographically separated, independent ATDRSS Ground Terminals (AGT) located at WSC in New Mexico.
- (2) AGT1 shall be an enhancement of the Second TDRSS Ground Terminal (STGT), and AGT2 shall be an enhancement of the upgraded White Sands Ground Terminal (WSGT).
- (3) Each ATDRSS Ground Terminal shall include the following:
  - (a) Three identical, autonomous ATDRSS Space-Ground Link Terminals (AS-GLT).  
Note: ATDRSS Space-Ground Link Terminals which are upgrades of Space-

Ground Link Terminals at White Sands Ground Terminal and Second TDRSS Ground Terminal shall support TDRS's or ATDRS's. New ATDRSS Space-Ground Link Terminals shall support the ATDRS's.

- (b) An S-band TT&C capability independent of the ATDRSS Space-Ground Link Terminals TT&C capability.
- (c) A Data Interface System (DIS) which shall provide ATDRSS Ground Terminal external interfaces.
- (d) An ATDRSS Operations Control Center (ATOCC) which shall support ATDRSS Ground Terminal control and monitoring.
- (4) Each ATDRSS Space-Ground Link Terminal shall:
  - (a) Receive schedule and operational messages from the Network Control Center.
  - (b) Transmit operational messages to the Network Control Center.

- (c) Receive user forward service data from user Project Operation Control Center's.
  - (d) Transmit user forward service signals to the User Satellites via an ATDRS.
  - (e) Receive user return service signals via an ATDRS.
  - (f) Transmit user return service data to the user Project Operation Control Center and Sensor Data Processing Facility (SDPF).
  - (g) Format and send ATDRS tracking data to the Flight Dynamics Facility (FDF).
  - (h) Format and send user tracking data to the Flight Dynamics Facility or user Project Operation Control Center.
  - (i) Support ATDRS TT&C functions to provide RF communication links, monitor ATDRS health and status, and control position, attitude, and configuration of the ATDRS's.
  - (j) Support simulation and test of the end-to-end Space Network telecommunications and tracking functions between the user Project Operation Control Center and User Satellite without the use of actual User Satellites.
- (5) S-band TT&C shall support all ATDRS launch, insertion, deployment, activation, and emergency operations.
  - (6) User data that does not employ Consultative Committee for Space Data Systems (CCSDS) format will be transmitted from the ATDRSS ground segment to NASA Communications System (NASCOM) via the Data Interface System (see 1.4.2g).
  - (7) ATDRSS ground segment requirements are specified in S-500-2, Section 6.

#### User Space Terminal

- a. The User Space Terminal (UST) shall support the RF link between the User Satellite and the Space Network.
- b. The User Space Terminal shall have the capability to support ATDRSS telecommunications and tracking services for Ka-band.

- c. The User Space Terminal shall support both one- and two-way tracking (including time transfer) through ATDRSS tracking services.
- d. The User Space Terminal shall interface with the User Satellite data system at baseband and with the User Satellite antenna system at RF.
- e. The User Satellite antenna system will interfere with ATDRSS via Space-to-Space Links (SSL).
- f. Ka-band User Space Terminal requirements are specified in S-500-2, Section 4.

#### Network Control Center

- a. The Network Control Center (NCC) shall be the Space Network operations control facility for the Space Network and shall provide operational interfaces between users and the Space Network. The Network Control Center shall support Space Network operations by providing:
  - (1) Service planning
  - (2) Service scheduling
  - (3) Service coordination
  - (4) Service assurance
  - (5) Service accounting
- b. Network Control Center requirements are specified in S-500-2, Section 7.

#### Space Network User Project Operations Control Center Interface

- a. The Space Network User Project Operations Control Center Interface (SNUPI) is defined as a set of interface requirements between the user Project Operation Control Centers and the Space Network. Functions supporting SNUPI requirements will be performed within each user Project Operation Control Center.
- b. Space Network User Project Operations Control Center Interface shall provide operational interface support between the user Project Operation Control Center and the Network Control Center.
- c. The Space Network User Project Operations Control Center Interface shall support the user Project Operation Control Center in:



- (1) Service planning
  - (2) Service scheduling requests
  - (3) Service coordination
  - (4) Service assurance
  - (5) Service accounting
- d. The Space Network User Project Operations Control Center Interface shall provide the data transport interface between the user Project Operation Control Center and NASCOM for operational messages and user forward and return service data.
  - e. The Space Network User Project Operations Control Center Interface shall be capable of generating test data and providing bit error rate measurement to support end-to-end simulation and test.
  - f. Space Network User Project Operations Control Center Interface requirements are specified in S-500-2, Section 8.

#### **Bilateration Ranging Transponder System**

The Bilateration Ranging Transponder System (BRTS), in conjunction with the Flight Dynamics Facility, will support accurate TDRS/ATDRS orbit determination.

#### **Merritt Island Relay**

Merritt Island Relay (MIL Relay) will provide a two-way RF relay between User Satellites at the Kennedy Space Center launch area and an on-orbit ATDRS for pre-launch testing.

#### **A.4.2 Other Service Supporting Elements**

- a. NASCOM will provide data transmission between the ATDRSS ground segment and user Project Operation Control Centers, and transmission of operational data between Space Network and service supporting elements.
- b. Flight Dynamics Facility (FDF) will provide user and ATDRS state vectors and perform user and ATDRS orbit determination and tracking data validation.
- c. Compatibility Test Vans (CTV) will provide the capability for testing spacecraft at remote ground locations for telecommunications and tracking compatibility with the Space Network.

- d. The Simulation Operations Center (SOC) will simulate operation of user, Space Network, and support elements by providing and interface to the Space Network which transmits and receives data and operational messages. The Simulation Operations Center will consist of an operations center and transportable simulation systems.
- e. The RF Simulation Operations Center will provide RF conversion and relay of simulation data between the Simulation Operations Center and an on-orbit ATDRS. The RF Simulation Operations Center will simulate the User Satellite/ATDRS interface.
- f. The Ground Network (GN) will consist of several ground terminals which will provide emergency telecommunications and tracking support between the User Satellite and the user Project Operation Control Center and/or an ATDRS and an ATDRSS Ground Terminal. The Ground Network will provide Shuttle launch/landing support.
- g. The Data Interface Facility (DIF) will be an element of the Customer Data and Operations System (CDOS). The DIF will support data handling for users employing the CCSDS format such as the Space Station Freedom Manned Base (SSFMB) and Polar Orbiting Platforms (POP).
- h. The Sensor Data Processing Facility (SDPF) will capture and process user return service data for designated Goddard Space Flight Center (GSFC) missions. The Sensor Data Processing Facility will provide the processed return service data to the user Project Operation Control Center or a mission's principal investigators, as required.

### **A.5 ATDRSS Space Network Operations Concept**

S-500-3 provides a concept for Space Network operations in the ATDRSS era.

#### **A.5.1 Service Planning**

- a. The user Project Operation Control Center, in conjunction with the Network Control Center, will establish and maintain a user services database at the

Network Control Center. The user services database will consist of user description information and user generic service requirements.

- b. The Space Network User Project Operations Control Center Interface will have the capability to support the user in the maintenance of the user's generic service requirements within the user services database at the .

### A.5.2 Service Scheduling

- a. **Service Schedule Requests.** The Space Network User Project Operations Control Center Interface will have the capability to support the user in generating, transmitting, and monitoring specific service requests.

- b. **Space Network (SN) Schedule Generation.** The Network Control Center will:

- (1) Schedule Space Network telecommunications, tracking, and simulation and test services to fulfill user specific service requests and user generic services requirements.
- (2) Resolve scheduling conflicts between user Project Operation Control Centers.
- (3) Disseminate applicable portions of the Space Network schedule to Space Network elements, service supporting elements, and corresponding users.
- (4) Receive user state vectors from the Flight Dynamics Facility or the user Project Operation Control Center and ATDRS state vectors from the Flight Dynamics Facility.
- (5) Disseminate user and ATDRS state vectors to the ATDRSS Ground Terminals.

- c. **Service Schedule Processing.** Each ATDRSS Ground Terminal will:

- (1) Receive and validate service schedules from the Network Control Center.
- (2) Map Network Control Center service mode designations into specific ATDRSS Ground Terminal equipment configuration parameters and hardware configuration commands.
- (3) Receive user and ATDRS state vectors from the Network Control Center.

### A.5.3 Service Provision

- a. **Service Provision Sequence.** During service provision, the following sequence of events will occur:

- (1) Each ATDRSS Ground Terminal will:

- (a) Perform pre-service verification functions to validate ATDRSS Ground Terminal service support readiness prior to scheduled service start time.
- (b) Configure ATDRSS equipment to allow for service initiation and link acquisition.

- (2) The Space Network User Project Operations Control Center Interface will have the capability to support the user in generating, transmitting, and monitoring ATDRSS service control requests to reconfigure and control ongoing services.

- (3) The Network Control Center will:

- (a) Receive and validate ATDRSS service control requests from the user Project Operation Control Center and transmit appropriate ATDRSS service messages to ASGTI or AGT2.
- (b) Receive state vector updates from the Flight Dynamics Facility or user Project Operation Control Center and transmit the state vectors to AGT1 or AGT2.

- (4) Each ATDRSS Ground Terminal will:

- (a) Receive and validate ATDRSS service control messages from the Network Control Center and implement appropriate equipment configuration updates.
- (b) Terminate service support as scheduled or directed by the Network Control Center.

- b. **Service Data Flow**

- (1) **User Forward Service Data Flow**

- (a) The user Project Operation Control Center data system will provide forward service data to the Space Network User Project Operations Control Center Interface.

- (b) The Space Network User Project Operations Control Center Interface will transmit user forward service data to the ATDRSS Ground Terminal. User Project Operation Control Centers using the Data Interface Facility will transmit forward service data to the Data Interface Facility. The Data Interface Facility will send data to the appropriate ATDRSS Ground Terminal as scheduled by the Network Control Center.
  - (c) The ATDRSS Ground Terminals will modulate an RF forward link carrier with user data and transmit the RF forward service signal to an on-orbit ATDRS.
  - (d) The on-orbit ATDRS will relay the forward service signal to the User Satellite User Space Terminal.
  - (e) The User Space Terminal will demodulate the forward service signal and deliver the baseband data to the User Satellite data system.
- (2) **User Return Service Data Flow**
- (a) The User Satellite data system will deliver return service data to the User Space Terminal.
  - (b) The User Satellite/User Space Terminal will perform convolutional coding, modulation, PN spreading, upconversion to RF, and power amplification.
  - (c) The User Satellite antenna system will transmit the RF return service signal to an on-orbit ATDRS which will relay the return service signal to an ATDRSS Ground Terminal.
  - (d) The ATDRSS Ground Terminal will demodulate the return service signal and perform convolutional decoding if required.
  - (e) For user Project Operation Control Centers not using the Data Interface Facility, the ATDRSS Ground Terminal will transmit return service baseband data to the appropriate user Project Operation Control Center or Sensor Data Processing Facility.
  - (f) For user Project Operation Control Centers using the Data Interface Facility, the ATDRSS Ground Terminal will transmit return service data to the Data Interface Facility, and the Data Interface Facility will send the data to the appropriate user Project Operation Control Center.
  - (g) The Space Network User Project Operations Control Center Interface will deliver the return service data to the user Project Operation Control Center data system.
- (3) **User and ATDRS Tracking Data Flow**
- (a) User tracking measurements will be transmitted to the Flight Dynamics Facility or user Project Operation Control Center.
  - (b) ATDRS tracking measurements will be transmitted to the Flight Dynamics Facility.
- A.5.4 Service Assurance**
- a. The Space Network User Project Operations Control Center Interface will transmit User Space Terminal and Space Network User Project Operations Control Center Interface status and performance data to the Network Control Center.
  - b. Each ATDRSS Ground Terminal will:
    - (1) Provide the Network Control Center with service performance and ATDRSS status information.
    - (2) Notify the Network Control Center as to the loss of a schedulable resource or a loss of redundancy.
  - c. The Network Control Center will:
    - (1) Conduct performance and status monitoring based on reports received from Space Network and service supporting elements.
    - (2) Detect faults, isolate these faults to the element and service level, and coordinate service restoration.
    - (3) Report the quality of the users ongoing services to the user upon request.

### A.5.5 Service Accounting

- a. Network Control Center will generate management, operations, and accounting reports on the quality and quantity of Space Network services provided to users. These reports will be used to support user billing.
- b. Network Control Center will log and archive information on the Network Control Center and Space Network operations.
- c. The Space Network User Project Operations Control Center Interface will perform service accounting in conjunction with the Network Control Center.

### A.6 Document S-500-1 Organization

The document S-500-1 contains the following sections (in addition to Section 1 which is reproduced here):

- Section 2: Documents.
- Section 3: ATDRSS Baseline Service Requirements Overview.
- Section 4: Telecommunications Service Requirements.
- Section 5: Tracking Service Requirements.
- Section 6: Simulation and Test service Requirements.
- Section 7: ATDRSS Operational Interface Requirements.
- Section 8: ATDRSS Enhancement Requirements.

### A.7 Definitions and Glossary

#### A.7.1 Definition of Terms

The following definitions apply to the ATDRSS terms of Document S-500-1:

**Services** include forward, return, tracking, and simulation and test support provided by ATDRSS to users.

**Link** is a communications path from transmitter to receiver.

**Forward link** is the link from an ATDRSS Ground Terminal through an ATDRS to a User Satellite.

**Return link** is the link from a User Satellite through an ATDRS to an ATDRSS Ground Terminal.

**Channel** is a link subdivision used for information transfer and/or User Satellite range measurement.

**Data channel** is a channel used for information transfer.

**Range channel** is a channel of the forward link user for User Satellite range measurement.

**Command channel** is a channel of the forward link used for transferring commands from an ATDRSS Ground Terminal to a User Satellite.

**Data group 1 (DG1)** are return link channels which employ PN modulation.

**Data group 2 (DG2)** are return link channels which do not employ PN modulation.

**Specific scheduling** is the function in which the Network Control Center reserves Space Network services in response to individual specific schedule requests from the user Project Operations Control Center.

**Generic scheduling** is the function in which the Network Control Center reserves Space Network services without receiving specific schedule requests from the user Project Operations Control Center.

**Pseudorange measurement** is the measurement of the time difference between a transmitted PN code epoch and its perceived arrival by a biased clock (multiplied by the speed of light).

#### A.7.2 Glossary for ATDRSS

A partial glossary of ATDRSS specific terms is included below:

**AGT** ATDRSS Ground Terminal

**APLS** ATDRS Position Location System

**ASGLT** ATDRSS Space-Ground Link Terminal

**ATDRS** Advanced Tracking and Data Relay Satellite

**ATDRSS** Advanced Tracking and Data Relay Satellite System

**ATOCC** ATDRSS Operational Control Center

<b>BDF</b> Beacon Data Frame	<b>SCG</b> Security Classification Guide
<b>BRTS</b> Bilateral Ranging Transponder System	<b>SDPF</b> Sensor Data Processing Facility
<b>BSF</b> Beacon Subframes	<b>SGL</b> Space-Ground Link
<b>CCSDS</b> Consultative Committee for Space Data Systems	<b>SGLT</b> Space-Ground Link Terminal
<b>CDOS</b> Customer Data Operation Systems	<b>SMA</b> S-band Multiple Access
<b>CTFS</b> Common Time and Frequency System	<b>SN</b> Space Network
<b>CTV</b> Compatibility Test Van	<b>SNIP</b> Space Network Interoperability Panel
<b>DG</b> Data Group	<b>SNUIP</b> Space Network User Project Operations Control Center Interface
<b>DIF</b> Data Interface Facility	<b>SOC</b> Simulation Operations Center
<b>DIS</b> Data Interface System	<b>SSA</b> S-band Single Access
<b>FDF</b> Flight Dynamics Facility	<b>SSFMB</b> Space Station Freedom Manned Base
<b>FOV</b> Field of View	<b>SSL</b> Space-to-Space Link
<b>FSG</b> Future Service Growth	<b>STDN</b> Spaceflight Tracking and Data Network
<b>GN</b> Ground Network	<b>STGT</b> Second TDRSS Ground Terminal
<b>GSFC</b> Goddard Space Flight Center	<b>TDRS</b> Tracking and Data Relay Satellite
<b>GSTDN</b> Ground Spaceflight Tracking and Data Network	<b>TDRSS</b> Tracking and Data Relay Satellite System
<b>ICD</b> Interface Control Document	<b>TT&amp;C</b> Tracking, Telemetry, and Command
<b>KaSA</b> Ka-band Single Access	<b>USAT</b> User Satellite
<b>KuSA</b> Ku-band Single Access	<b>UST</b> User Space Terminal
<b>MIL Relay</b> Merritt Island Relay	<b>WSC</b> White Sands Complex
<b>NASCOM</b> NASA Communications Network	<b>WSGT</b> White Sands Ground Terminal
<b>NCC</b> Network Control Center	
<b>OMV</b> Orbital Maneuvering Vehicle	
<b>PFD</b> Power Flux Density	
<b>PN</b> Pseudorandom noise	
<b>POCC</b> Project Operations Control Center	
<b>POP</b> Polar Orbiting Platform	
<b>RFI</b> Radio Frequency Interference	
<b>SA</b> Single Access	

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## Appendix B

# Telescience Testbed Pilot Program

This appendix contains a reprint of the *Telescience Testbed Pilot Program* Final Report Executive Summary which was prepared by the Research Institute for Advanced Computer Science, NASA Ames Research Center, February 1989. There are three volumes in the report:

Volume I, Executive Summary

Volume II, Program Results

Volume III, Experiment Summaries

Only Volume I, the Executive Summary is reproduced here.

The Universities Space Research Association (USRA), sponsored by the NASA Office of Space Science and Applications, carried out the *Telescience Testbed Pilot Program*. Fifteen universities, under sub-contract to USRA, conducted various scientific experiments using advanced computer and communications technologies. The goals of the pilot program were to develop technical and programmatic recommendations for the use of rapid-prototyping testbeds as a means for addressing critical issues in the design of the information system of the Space Station Freedom era.

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# Telescience Testbed Pilot Program Final Report Volume I Executive Summary

*Barry M. Leiner*

Research Institute for Advanced Computer Science  
NASA Ames Research Center

RIACS Technical Report TR-89.7  
February 1989

*The Universities Space Research Association (USRA), sponsored by the NASA Office of Space Science and Applications, conducted a Telescience Testbed Pilot Program. Fifteen universities, under subcontract to USRA, conducted various scientific experiments using advanced computer and communications technologies. The goals of this pilot program were to develop technical and programmatic recommendations for the use of rapid-prototyping testbeds as a means for addressing critical issues in the design of the information system of the Space Station Freedom era.*

*This is the final report for the Pilot Program. It consists of three volumes. Volume I provides an Executive Summary. Volume II contains the integrated results of the program. Volume III provides summaries of each of the testbed activities.*

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This work was supported in part by  
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to the Universities Space Research Association.

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# TTPP Final Report

## Volume I: Executive Summary

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# Section 1

## Introduction

Space Station Freedom (henceforth referred to as Space Station) and its associated laboratories, coupled with the availability of new computing and communications technologies, have the potential for significantly enhancing scientific research. To assure that this potential is met, scientists and managers associated with the Space Station program must gain significant experience with the use of these technologies for scientific research, and this experience must be fed into the development process for Space Station. The SESAC Task Force on the Scientific Uses of Space Station (TFSUSS) has used the word *telescience* to refer to the concept in which interactive high-performance telecommunication links are used to link the space-based laboratories and facilities, the on-orbit crew, and geographically dispersed ground-based investigator groups. Instead of being a remote outpost, Space Station is, rather, an accessible and integral part of the research infrastructure.<sup>1</sup>

The Universities Space Research Association (USRA), under sponsorship from the NASA Office of Space Science and Applications, has conducted a Telescience Testbed Pilot Program (TTPP), aimed at developing the experience base to deal with issues in the design of the future information system of the Space Station era. The specific goals of this pilot program were to:

- Demonstrate that the user-oriented rapid-prototyping testbed approach is a viable means for identifying and addressing the critical issues in design and specification for the Space Station Information System (SSIS) and the Science and Applications Information System (SAIS), thereby assuring that these systems will satisfy the needs of scientists for an information system in the Space Station era,
- Develop technical and programmatic recommendations for the conduct of such a testbed, and
- Develop initial recommendations for the SSIS and SAIS to be factored into the design and specification of those systems.

To accomplish these goals, fifteen universities conducted various scientific experiments under subcontract to USRA. Each one of these experimental testbeds share the characteristic of attempting to apply new technologies and science operations concepts to ongoing scientific activities. Through this process, new understanding and experience was gained about system architectures, concepts, and technologies required to support future scientific modes of operation.

This report contains the results of the Telescience Testbed Pilot Program in three volumes. Volume I (this volume) is the Executive Summary. Volume II contains the integrated results of the overall program. Volume III contains summaries of each of the experiments conducted under the university subcontracts. Further details of these

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1. Task Force for Scientific Uses of the Space Station, 1986 Summer Study.

experiments are contained in the various scientific and technical reports published by the participating organizations. A bibliography of these publications is included as Appendix C to this report.

## Section 2 Program Overview

The fifteen TTPP subcontractors, listed in Table I, conducted a variety of user-oriented rapid-prototyping testbeds in order to gain knowledge and experience relative to the critical issues in the design of the information system of the Space Station era. This pilot program lasted from April 1987 through December 1988, and has laid the ground work for future testbedding activities and the further quantification of requirements for an information system responsive to user needs.

**Table I  
TTPP Subcontractors**

Cornell University	University of California, Santa Barbara (UCSB)
Massachusetts Institute of Technology (MIT)	University of Colorado
Purdue University	University of Maryland
Rensselaer Polytechnic Institute (RPI)	University of Michigan
Smithsonian Astrophysical Observatory (SAO)	University of Rhode Island
Stanford University	University of Wisconsin
University of Arizona	Research Institute for Advanced Computer Science (RIACS)
University of California, Berkeley (UCB)	

The testbeds represented four scientific disciplines (astronomy and astrophysics, earth sciences, life sciences, and microgravity sciences) and investigated issues in payload design, operation, and data analysis. The investigations were selected to emulate scientific research in the Space Station era and were supported with communication and information system technologies to assess their impact and utility to ongoing scientific research. Through experience gained in these testbeds, users were better able to formulate and quantify their requirements for various aspects of the information system.

For each discipline, we list the universities and centers involved followed by a brief description of the areas of research explored.

## 2.1 Astronomy and Astrophysics

California Institute of Technology  
Cornell University  
Massachusetts Institute of Technology  
University of Arizona  
University of Colorado  
University of California, Berkeley

NASA Goddard Space Flight Center  
NASA Ames Research Center  
Jet Propulsion Laboratory

In the space station era, astronomical research will increasingly demand distributed user teams for operations planning, resource management, data reduction and integration, and archiving. In addition, the creation, simulation, and adaptation of hardware and software is certain to benefit from the use of design tools that encourage intergroup communication and communications protocols. To further these objectives, a variety of experiments were performed that focused on the detailed planning, operation, data analysis, hardware design, and software development that support contemporary astronomical research.

Specific university activities were as follows:

MIT investigated the remote operation of a telescope at Wallace Observatory using a high bandwidth (T1) link and dissemination of data on a campus-wide Project Athena network.

University of Arizona conducted investigated teleoperation of a forerunner of the Astrometric Telescope Facility, which will be an attached payload for Space Station. They also participated in the SIRTf activity, described below.

University of California at Berkeley extended control and simulation systems developed for the Extreme Ultraviolet Explorer (EUVE) to evaluate techniques for remote instrument control over local and wide area networks. Distributed development environments in use at Berkeley are being extended to facilitate coordinated development by cooperating institutions.

University of Colorado studied distributed and interactive operation of an astronomy telescope and its instrumentation at a remote ground observatory, addressing a range of teleoperations issues.

The Space Infrared Telescope Facility (SIRTf) team, consisting of Cornell University, Smithsonian Astrophysics Observatory, CalTech, and University of Arizona, investigated several issues regarding telescience applied to a Space-based astronomical facility. They evaluated distributed versus resource-centered models for development (teledesign) and remote access. The ability to interchange analysis software and perform in conference mode for design, operations and analysis was evaluated. University of Arizona has a special interest in remote control and operations of a ground-based telescope to



evaluate feasible degrees of automation, allowable time delays, necessary crew intervention, error control and feasible data compression schemes. Cornell University investigated trade-offs between on-line local processing and processing at the users' home location as well as investigating the feasibility of establishing standard formats and analysis techniques. Smithsonian Astrophysical Observatory is using remote operation of Mt. Hopkins telescope to evaluate data transmission and dissemination options.

## 2.2 Earth System Sciences

Purdue University  
University of California, Santa Barbara  
University of Colorado  
University of Michigan  
University of Wisconsin  
NASA Goddard Space Flight Center  
Jet Propulsion Laboratory

The area of Earth System Sciences encompasses the fields of Remote Sensing, Aeronomy, Solar-Terrestrial Physics and Space Plasma Physics. The science goals of the experiments included multidisciplinary investigations of the near Earth environment, support for coordinated science campaigns and cooperative data analysis. The possible telepresence studies covered most of the key issues previously described, and focused on the operational requirements of a distributed user community, the use and interaction with both real-time and archived distributed data sources, the coordination of data collection in campaign mode and the evaluation of standards for data transfer, communications and commanding.

Specific university activities were as follows:

Purdue University evaluated teleanalysis concepts using the Purdue Field Spectral Database accessed by a variety of small computers. It also investigated methods for conducting campaign style experiments and computer data security issues.

University of Colorado in coordination with UC Santa Barbara, Wisconsin, Purdue and Michigan, used the interactive control opportunities and the science database from the Solar Mesosphere Explorer Mission to investigate coordinated teleoperations and teleanalysis issues.

University of California, Santa Barbara explored teleanalysis of large dynamic data sets for earth sciences. This investigation includes the test and evaluation of data interchange standards and knowledge based techniques for assisting remote access.

University of Michigan investigated teleoperations of a Fabry-Perot Spectrometer combining human with autonomous control, forward simulation techniques to support telerobotics, and the effects of varying time delays in the control loop.

University of Wisconsin developed a bridge from NSFnet to McIDAS, allowing any TTPP participant with access to NSFnet to acquire existing meteorological products from McIDAS.

### 2.3 Life Sciences

University of Arizona  
University of Colorado  
Massachusetts Institute of Technology  
Stanford University

NASA Johnson Space Center  
NASA Kennedy Space Center  
NASA Ames Research Center

The life sciences testbeds addressed the issues involved in space life science investigations where the interactions are primarily between a ground-based PI and a remote crew member performing an experiment. The importance of interactive communications during life science experiments has been amply demonstrated on past shuttle missions. The emergence of the long-term space station flights, where the crew cannot be expected to be intensively trained in each experiment, will make this interaction even more necessary.

Specific university activities were as follows:

University of Arizona developed systems and software for remote fluid handling in support of microgravity and life sciences.

University of Colorado developed and demonstrated teleoperations capabilities for the remote operation of a life science glovebox experiment.

MIT is conducting conducted a Remote Life Sciences Operation testbed using the KSC sled with multi-media tests and evaluation of real video needs and implementation options.

### 2.4 Microgravity Sciences

Rensselaer Polytechnic Institute  
University of Arizona

NASA Lewis Research Center  
Jet Propulsion Lab

The microgravity sciences testbed will encompassed low gravity research in a variety of materials science areas including metals and alloys, electronic materials, glasses and ceramics, and electrophoretic peptide separations. Space experiments already been carried out in these areas, and those currently planned have frequently been constrained by the requirement of highly autonomous operation. Telescience offers the promise of allowing the

investigator to observe the experiment progress from a terminal in his earth laboratory and to make fine adjustments in the equipment, change experimental parameters, modify protocols, and deal with unexpected developments.

Specific university activities were as follows:

Rensselaer Polytechnic Institute investigated the level of communications capability required to successfully perform remote controlled materials processing experiments of the Space Station era. Three different types of experiments were tried with the cooperation of the Microgravity Materials Science Laboratory at Lewis Research Center.

University of Arizona developed systems and software for remote fluid handling in support of microgravity and life sciences.

## 2.5 Telescience Technologies

University of Arizona  
University of California, Santa Barbara  
University of Colorado  
University of Michigan  
RLACS  
Stanford University

Ames Research Center

The experiments described above were designed to identify the requirements for carrying out science in the space station era and the role that advanced technologies can play in that science. It can be seen from the descriptions that a number of technologies have roles to play in multiple disciplines.

In addition, there are several technology areas where it is desirable to develop and demonstrate particular capabilities applicable to a variety of disciplines and make them available to those science communities. The following is a description of the university activities to investigate these underlying technologies.

University of Arizona explored issues in robotics applied to both fluid handling and operations of astronomical observatories.

University of California, Santa Barbara, investigated techniques for users to interact with large datasets at remote sites through a browsing capability.

University of Colorado prototyped and evaluated onboard operations management concepts to verify that teleoperations can function safely without command pre-checking. They cooperated with a number of sites in evaluating the Operations and Science Instrument Support (OASIS) software package, and ported OASIS to the Sun workstation as a test of the portability of an operational real-time system written in Ada. They also investigated the use of packet telemetry, packet commands, and SFDU's in the Space Station environment.

University of Michigan has explored the role of expert systems in supporting remote coaching in both an on-line and off-line mode.

RIACS integrated various networking and local computing capabilities into a telescience workstation environment (TeleWEn), intended to provide a local computing environment for telescience. RIACS also collaborated with Ames Research Center in investigating experiment operation using computer-supported coaching. RIACS, again in collaboration with Ames, investigated the utility of networking and electronic mail in supporting a large distributed group activity (the TTPP itself).

Stanford University experimented with a model Remote Science Operations Center linked to GSFC, JSC and MSFC using real data from Spacelab 2 to test multimedia Telescience workstations and simulate remote control, monitoring and multi-media conferencing.

The next section presents highlights of the results and lessons learned through the TTPP. Details of the experiments may be found in Volumes II and III of this report as well as the various technical reports and publications listed in the bibliography (Appendix C).

## Section 3

### Highlights of Results

Sections 3 and 4 of Volume II contain the results of the TTPP. Here, we provide highlights of these results. Some of these observations and results were general and came from integrated TTPP experience. Others were developed in the context of a specific scientific discipline and could not be generalized, either because there was insufficient experience in the other disciplines or there were differences between the discipline requirements. In cases where results were from specific testbed activities, the universities are cited for cross-referencing to Volume III.

#### 3.1 General Technical Results

A number of results in teledesign, teleoperations, teleanalysis and infrastructure were found to apply across the several disciplines. In the area of teledesign, the focus was on the remote development and debugging of software.

- Remote debugging of instrument software was demonstrated to be both possible and effective. On-line access to a variety of common software tools was shown to be important and feasible.
- A need was identified for trade-off studies and simulation tools to complement testbedding in the design phases.
- Ada was demonstrated to be a useful and acceptable high level language for the design and development of real-time systems.

Teleoperations covers the spectrum from making small instrument adjustments to optimize data taking through the full interactive operations required for Life and Microgravity Sciences. Safe operations in both cases were investigated using transaction management plus interlock concepts. A number of common results and conclusions were demonstrated in the area of teleoperations.

- The benefit of using a common workstation for access to multiple instruments was demonstrated. The experience with OASIS indicated that it is possible for groups from different disciplines to use a common teleoperations workstation.
- Interconnected facilities were shown to allow multiple researchers to collaborate on experiments, e.g. have an expert at one site available for troubleshooting during experiments being conducted at other sites with other researchers. (SAO)
- All of the TTPP sites chose either Sun or microVAX workstations along with either Unix or VMS operating systems as their main workstations, supplemented by PC-AT compatibles and Macs. This class of hardware and software was found to be adequate for teleoperations.

- Teleoperations was shown to lead to improved productivity by: 1) permitting the assembly of required resources with minimal travel costs and equipment shipment, 2) enlarging access to space instruments and scientific data, 3) permitting rapid access to flight data, and 4) permitting direct PI/crew interaction.

General teleanalysis results included the following:

- A number of the research groups found minimal need for analysis during operations, because they were simply too busy.
- Viewing data requires screen refresh on order of .1 to 1 minute, almost irrespective of data characteristics. The locating of remote data was supported acceptably through 9600 bps access with subsequent file transfer through the Internet.
- Image compression methods for preserving important information while reducing bandwidth are important. The information needed to preserve varies between applications, and therefore so do the appropriate algorithms. Experimentation with various algorithms indicate that such techniques have potential.
- There is an important niche for IBM-PC compatible and Mac II class workstations, coupled to larger host computers through LANs and dial-up circuits. This lower cost alternative needs further exploration.
- Although connectivity to data sources is a primary aspect of teleanalysis, the additional ability to exchange ideas, techniques, and software among research collaborators proved to be equally important.

Infrastructure results focussed on communication requirements and workstation characteristics.

- Space to ground communications bandwidth requirements for many of the experiments were dominated by the need for video feedback. Downlink video with PI-adjustable frame rate, resolution, and gray scale is required out to the PI remote site. Adjustment capability is required by the PI to obtain the "best picture" within the currently available bandwidth. Uplink video is required to support "coaching."
- Communication requirements for low-latency transmission appear to be for high peak rates but low average rates. Such a requirement is well suited to packet switching, but the current networks have proved to be inadequate.
- Participants found that workstation interface standardization was a more important concern than the exact hardware/software configuration used. This led to the conclusion that selection of commercial off-the-shelf hardware/software configurations may be feasible and desirable for many purposes.

- The timing cycle for NASA/universities/institutions was longer than the one-year TTPP program itself, thereby limiting the ability to install the required infrastructure during this limited program.
- Exchange of information is hampered by groups using different text/graphics formats.
- TAE+ was found to provide a good set of tools for prototyping the user interface for workstations.
- The need was identified for tools to support real-time group collaboration (e.g. teleconferencing). One possibility suggested was to incorporate NASA's audio/video teleconferencing system into the testbed to support interaction between groups and to evaluate its effectiveness for scientific collaboration.

### 3.2 Astronomy

The participating astronomy and astrophysics researchers noted that theirs is an observational science. Unlike several of the other disciplines (particularly life and microgravity sciences), the subject of the typical experiment cannot be modified by the researcher. This characteristic heavily flavors the nature of telescience for astronomy, driving towards monitoring of the observations and the ability to access data quickly and "fine tune" the observing instruments. Fine tuning can greatly enhance the quality of the data obtained.

Thus, teleoperations for astronomy involves the real-time control of observations and real-time access to data. Experiments conducted under the TTPP led to the following results and conclusions:

- Fully autonomous operation is often more costly than teleoperation due to the need for higher instrument precision.
- Scientific productivity is improved through access to real-time data from the researchers' home institutions. (SAO, MIT/KSC, University of Colorado, University of Arizona)
- The instrument design process can be improved by incorporating the network interface into instrument design from the start, allowing among other things that required software updates be done remotely. (SAO, UCB, Arizona)
- Data compression holds significant promise for permitting teleoperations of telescopes while keeping to available bandwidths. CCD images typically require minutes of integration, thereby reducing the required rate of image transmission. A possible exception is solar observation of dynamic processes. An image compression technique was demonstrated that reduced the required data rate from 8 bits/pixel to .015 bits/pixel. (Arizona)

Teleanalysis is a prime requirement for the astronomy and astrophysics community, permitting databases to be accessed remotely.

- Poor connectivity and performance of existing networks made tests of such remote access difficult. (Arizona)
- The utility of a standard data analysis environment (IRAF, AIPS, FITS) was validated through several of the testbed activities.

Support of the required teleoperations and teleanalysis environments required adequate communications. The experimenters found that:

- 9600 bps links with five second delay are adequate for normal operations (not including video/images). (Arizona) Many of the participants strongly expressed the need for occasional use of a "priority channel" for command and control with overall round trip time delay of less than one second. While somewhat longer delays can be tolerated, this requires use of special techniques which rapidly become more complicated and less effective.
- Network latencies of more than 30 seconds results in remote operators resubmitting requests. Therefore, there is a need to keep latency down and make the system tolerant of repeated requests. (Colorado)
- Current networks (e.g. SPAN and Internet) are adequate for electronic mail but inadequate for most other functions. Typical transfer rates for files across the Internet were approximately 1 kbps. (SAO, Arizona)
- The Astronomy community found a need for standards (ranging from networking, e.g. Internet, through data format standards, e.g. FITS), and demonstrated their utility.

### 3.3 Earth Sciences

Earth Science participants found that their awareness of telescience possibilities plus access to telescience tools had significant positive effects on the conduct of their research. In the area of teledesign, distributed software development was an area of concern. Specific results were the following:

- Duplicate software environments are required to support collaborative development. Moving software and software environments between sites was found to be more difficult than anticipated.
- A shared 56 kbps network (similar to the current SPAN and Internet) was found to be adequate for remote debugging of software.

Teleoperations for earth sciences focussed on remote monitoring and control of sensor platforms, and the conduct of campaign-style experiments involving researchers at multiple locations conducting observations using multiple sensors. It was found that:



- There was a de facto standardization on OASIS for remote operations, and OASIS functionality was found to be basically satisfactory even though OASIS was developed for a different discipline. A need for a library of software tools to support teleoperations was identified.
- Due to time and technology limitations, the campaign experiments conducted under the TTPP were designed to require only electronic mail for coordination. Future campaign experiments are expected to require more sophisticated collaboration technology.

As in astronomy, earth science research relies heavily on access to remote data sets for analysis. The experimenters found that:

- There is a need for secure database access methods, and techniques for avoiding conflicts between real-time system operations and retrospective analysis. (Wisconsin, Purdue, UCSB)
- The testbed experience supported the need for high-level catalog and directory services for earth science datasets. Standards for data description are more important than standards for data formats.

Network access was required throughout the science process, from design through operations to analysis.

- The need was identified for verification of file transfer, analogous to return receipt for mail. There is also a need for the ability (currently available in the Z-modem protocol) to recover from communications outages in the middle of file transfers, to permit transfer of large files.
- Current networks were found to be inadequate, with too many dropped sessions for file transfers. The 9600 bps data rate was not sufficient for interactive remote display of bit-mapped graphic images. The 30 second round trip delays sometimes encountered were also found to be unacceptable.

### 3.4 Life Sciences

Life sciences research is different from other disciplines in that the astronauts may be both subjects and experimenters. Life sciences research program often finds itself constrained by limitations in communication and control, limited available crew time, and time delays in data availability.

Teleoperations for life sciences involved both the monitoring and control of remote experiments and the interaction between ground-based PIs and the crew in the conduct of such experiments.

- Coaching techniques were found to be very effective in supporting PI/crew interaction during experiments. An crew "open mike" approach, allowing effective monitoring by the PI, was most effective. Workstations incorporating

- The TTPP contractual arrangement, using a prime contract with USRA and subcontracts with universities, worked extremely well.
- Critical issues need to be identified prior to the selection of individual testbedding activities. A separate activity involving requirements integration, architecture definition, etc., is required and should be carefully coordinated with testbedding activities, driving the selection of critical issues and approaches and integrating results.
- There is a need to develop a long-term program to reduce the impact of aspects such as funding delays, delays in installing communications, and delays in procuring equipment. It typically takes 2 - 3 years from proposal to results.
- Campaign experiments (involving multiple instruments and organizations) need to be more carefully coordinated and planned, with attention paid to finding the science content and managing expectations. It is too easy to try to tackle too large a problem for a rapid-prototyping approach.
- Similarly, incorporation of state-of-the-art technology takes different time scales for different activities. There is a need for a project structure that allows for differing time schedules of different testbeds.
- The combination of electronic mail, electronic reporting, electronic mailing lists, and regular program meetings and briefings was effective in coordinating and conducting the program. Guidelines are needed to avoid excessive mail. Appropriate facilities and staffing are needed to maintain electronic mailing lists. Summary reports by the USRA program manager with pointers to detailed reports would be helpful in reducing information overload.
- Databases need to be designed to manage electronic communications with priority schemes and extensive cross-referencing

## Section 4 Conclusions

The Telescience Testbed Pilot Program proved the effectiveness of having multiple users, developers, and technologists join together in the investigation of critical information system issues. The multi-disciplinary nature of the effort had a number of benefits. Users from various disciplines were exposed to technologies developed under other disciplines, some of which was able to be directly transferred. Users were able to compare their results with those of other disciplines and come to common understandings about the roles and requirements of specific technologies. Significant scientific benefits were gained through the exposure of researchers to the most modern computing and communications technologies.

The telescience approach to scientific investigations in remote or dangerous locations has been validated. The general objectives of less crew time, more and better science, and increased scientific productivity can be attained through this approach. This achievement has been made possible by recent technology advances in communications systems, control systems, computers, remote vision and sensing, visual displays, and robotics, coupled with new understanding about new modes of scientific research to take advantage of these technologies. These technologies are sufficiently mature that telescience concepts can be included in all future missions, but additional research is required to ensure operational reliability and to fully exploit the advantages of these new techniques.

The user-oriented testbedding approach was also shown to have great value. Through the explicit insertion of advanced technologies in a coordinated and supported way, the scientific programs were able to explore both the applicability of advanced technologies and simultaneously to further their scientific research.

Thus, the need for such a program was clearly demonstrated if NASA is to move aggressively towards developing an integrated multi-disciplinary information system approach. Such a system is required in support of the future scientific missions, which themselves will involve researchers from many disciplines attacking the great challenges that face NASA in the future.

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16. Abstract A description is given of a Data Distribution Satellite (DDS) system. The DDS would operate in conjunction with the Tracking and Data Relay Satellite System to give ground-based users real time, two-way access to instruments in space and space-gathered data. The scope of work includes the following: (1) user requirements are derived; (2) communication scenarios are synthesized; (3) system design constraints and projected technology availability are identified; (4) DDS communications payload configuration is derived and the satellite is designed; (5) requirements for earth terminals and network control are given; (6) system costs are estimated, both life cycle costs and user fees; and (7) technology developments are recommended and a technology development plan is given.  The most important results obtained are as follows: (1) a satellite designed for launch in 2007 is feasible and has 10 Gb/s capacity, 5.5 kW power, and 2,000 kg mass; (2) DDS features include on-board baseband switching, use of Ku and Ka-bands, use of FDMA uplinks with bulk demodulation on the satellite and TDM downlinks, and multiple optical intersatellite links; and (3) system user costs are competitive with projected terrestrial communication costs.					
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