

NASA's Communications Services

**This Description applies to proposals in response to
NASA's Announcement of Opportunity for**

Earth Venture - 2

AO NNH11ZDA010J

February 2011

NASA's Communications Services

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1.0 INTRODUCTION

This document is intended to assist in the preparation of proposals responding to the Announcement of Opportunity (AO), which is issued by NASA's Science Mission Directorate.

NASA provides many communications services for mission support. Costs accrue when using these services and estimates of these costs need to be included in proposals responding to the AO. To facilitate proposal preparation, proposers are encouraged to read this document and to contact the individuals named in Section 1.3 below for selecting and costing mission communications services.

1.1 Costing Policy

As a matter of policy, NASA includes estimated costs for mission operations and communications services in the evaluation and selection processes of all Earth-orbiting and deep space missions. The Science Mission Directorate (SMD) is implementing this policy to:

- implement formal NASA-wide full-cost accounting,
- better manage NASA's heavily subscribed communications resources,
- promote tradeoffs between on-board processing and storage vs. communications requirements, and
- encourage hardware and operations system designs minimizing life cycle costs while accomplishing the highest-priority science objectives.

1.2 Choice of Service Providers

NASA Procedural Requirements (NPR) 7120.5, NASA Space Flight Program and Project Management Requirements, requires all programs/projects to develop requirements for space operations services provided by NASA facilities during mission formulation. Such services include communications, tracking, mission operations, navigation, and data processing. NPR 7120.5 requires projects to use NASA services unless a more cost-effective life cycle can be found and demonstrated in the proposal.

Programs/projects are free to propose procurement of services from sources other than NASA consistent with NASA Policy Directive (NPD) 8074.1, Management and Utilization of NASA's Space Communications and Navigation Infrastructure. Projects should conduct trade studies comparing the use of NASA-provided services with any proposed alternatives.

Generally, NASA provided services are expected to be used to meet communications requirements. However, where appropriate and cost-effective for NASA, pre-existing non-NASA capabilities may be used. NASA provided services should be employed whenever they meet mission objectives and have a life-cycle cost to the project and/or to the SMD, which is less than or equal to any of the proposed alternatives. Contact persons listed in Section 1.3.1.2 or 1.3.2.2 for assistance in identifying appropriate service, prices, and cost trades.

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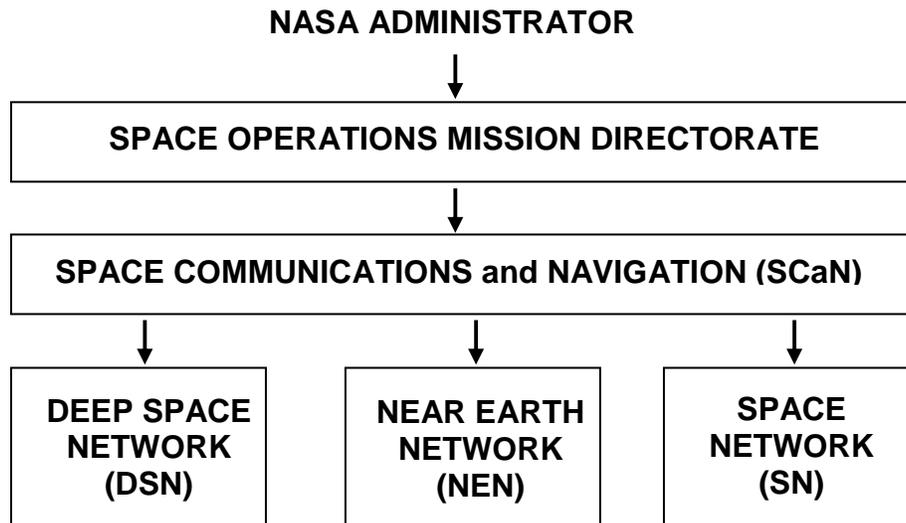
Where the SMD finds that the proposed project or PI approach does not result in the lowest life-cycle cost, the SMD may direct the project or PI to modify their approach. If utilizing NASA provided support services increases the project / PI costs, but reduces the cost to the SMD, any funding impacts to the project / PI will be resolved by the SMD.

If a trend towards project / PI-unique solutions appears to reduce individual mission cost but increases the total cost to NASA by not utilizing shared services and facilities, any resolution using the appropriate NASA-wide services strategy will be implemented in a manner in which the SMD shares in the cost savings.

1.3 NASA's Tracking Networks

The NASA Space Communications and Navigation (SCaN) program office manages and directs three tracking networks to provide services for different types of missions: the Deep Space Network (DSN), the Near Earth Network (NEN), and the Space Network (SN). Functional responsibilities for NASA's three networks are shown in Figure 1-1. The SCaN program office has the overall responsibility to be the arbiter of mission requirements versus the establishment of network tracking and navigation assets. While missions may have a desire for specific NASA facilities the SCaN office will make the final decision on the provision of network assets.

Figure 1-1: NASA Network Functional Responsibility



1.3.1 Deep Space Network

The Deep Space Network (DSN) operations are the responsibility of the Jet Propulsion Laboratory (JPL). JPL provides the operations and engineering of the DSN and provides the technical expertise needed for flight projects to use the DSN. This expertise includes optimal

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design of communications channel, antenna capabilities and performance limits, scheduling, loading and other operations considerations, and in particular, maintaining the cost algorithm for use of the DSN. Most spacecraft operating in deep space ($r \geq 2 \times 10^6$ km, Category B missions) will require services from the DSN. The DSN also can be used for Category A missions ($r \geq 700$ km to 2×10^6 km).

1.3.1.1 DSN Services

Capabilities have moved from a facilities-based services model to one based upon standard services. Detailed descriptions of these standard services can be found in the Deep Space Network (DSN) *Services Catalog* (Reference 6). These services enable both Earth orbiting and deep space science missions. Table 1-1 lists the DSN Service categories found in Reference 6. Each of the Service categories named in Table 1-1 may contain several services. Some of those individual services may require that special arrangements be made with JPL before they can be provided. Proposers who are interested in services that are not a part of the standard Tracking Telemetry and Command (TT&C) set should contact the person(s) named in Section 1.3.1.2 for additional information. See Table 2-1 for a list of standard DSN services included in the *Aperture Fee*.

Table 1-1: DSN Service Categories

Service Category ¹	Brief Description of Service's Content
<i>Some services in the categories below are not a part of the basic TT&C set and require additional programmatic arrangements with JPL.</i>	
Command Services	RF modulation, transmission, and delivery of telecommands to spacecraft.
Telemetry Services	Telemetry data capture and additional value-added data routing and processing.
Tracking Services	Radio metric data capture (Doppler and range), Delta-DOR Service
Calibration and Modeling Services	Platform (e.g., Earth orientation) and media calibration services
Radio Science Services	Open-loop receiver measurements.
Radio Astronomy / VLBI Services	Similar to Radio Science but measures natural phenomena. Wide & narrowband VLBI.
Radar Science Services	Transmits RF carrier toward user defined target; captures reflected signal.
Notes:	
1. See DSN Services Catalog (Reference 6) for details of services contained in these categories.	

1.3.1.2 Process for Requesting DSN Services

Proposers should contact the person(s) named below for information about DSN mission operations services and costs at the time when initial science operations concepts are being defined. A representative will assist proposers by providing information concerning services and costs. Further, they will assist in documenting initial requirements and estimates for DSN services in the form of a letter of commitment.

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In order to properly estimate and document the requirements for DSN services and support, a minimum lead-time of six weeks must be allowed for the study.

The resulting documentation of services and costs will be captured in the DSN Service Agreement (DSA) to be signed by appropriate Project and Network representatives by CDR. The DSA will identify all mission services, including those provided by non-DSN sources, becoming a source of end-to-end operations information and documenting any cost analyses leading to the selection of non-DSN services.

The NASA Headquarters point of contact for SCaN assets is:

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The DSN point of contact for DSN services is the Mission Support Definition and Commitments Office:

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Commitments Engineer
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M/S 126-238
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1.3.2 Near Earth Network

The Near Earth Network (NEN) operations are the responsibility of the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland under the Space Operations Mission Directorate (SOMD). The NEN currently provides Earth services from ground stations located in the United States at: Poker Flat, Fairbanks, and North Pole, Alaska; Merritt Island, Florida, Wallops Island, Virginia; Las Cruces, New Mexico; as well as in McMurdo, Antarctica; Santiago, Chile; and Svalbard, Norway. Other commercial/foreign Earth stations may be obtained by the NEN in response to customer requirements. Generally, these stations support non-deep space (Category A) missions in the 2 and 8 GHz bands; however, several are capable

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of receiving signals from deep space (Category B) missions as well. Table 1-2 shows several of the service categories.

1.3.2.1 NEN Services

NEN service categories are similar to those of the DSN listed above in Table 1-1, but include several *value added* services. Additionally, several design services are available to assist mission planners in their conceptual design phase. Table 1-2 summarizes the NEN services. Detailed descriptions of the services and capabilities of the NEN can be found in the NEN Users' Guide (Reference 8).

Table 1-2: NEN / SN Service Categories

NEN / SN Service Category	Brief Description
Commanding	RF modulation, transmission, and delivery of telecommands to spacecraft.
Telemetry	Telemetry data capture, decoding, and additional value-added data routing.
Tracking	Radio metric data capture (range, Doppler, and angles).
Mission Planning	Communications design, orbital modeling, scheduling, resource planning.
Flight Operations	Planning, controlling, and monitoring of operational spacecraft.
Flight Dynamics	Design spacecraft trajectory, predict and control of operational spacecraft.
Science Data Processing	Processing of science data, generate data products, analysis of data.
Consulting and Training	Anomaly resolution, troubleshooting, consulting.
Range Support	Control center, range communications, meteorology, launch imagery.
System Performance & Test	Telecommunications interface design, compatibility testing.
System Procedure Develop	Develop detailed processes & procedures for S/C operations.
Special Operations	Non-routine flight ops. Including: anomalies, contingencies & emergencies.

1.3.2.2 Process for Requesting NEN and SN Services

At the time when initial science operations concepts are being defined, proposers should contact the person(s) named below for information about NEN mission operations services and costs. A representative assists proposers by providing service and cost information. Further, the Networks Integration Management Office (NIMO) aids in documenting initial mission operations requirements in a preliminary Project Support Level Agreement (PSLA).

During the study phase, as the mission's concept is more clearly defined, requirements in the preliminary PSLA are revised. The resulting documentation of services and costs become the PSLA to be signed by appropriate Project and Network representatives.

The NASA Headquarters point of contact for SCaN assets are:

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The GSFC point of contact for NEN and SN services is the GSFC Networks Integration Management Office (NIMO):

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Exploration, Operations, and Communications and Navigation Systems Division
Goddard Space Flight Center
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e-mail: Scott.A.Greatorex@nasa.gov

1.3.3 Space Network

NASA's Space Network (SN) is the responsibility of the GSFC in Greenbelt, Maryland under the SOMD. The SOMD is accountable for NASA's Tracking and Data Relay Satellite System (TDRSS). TDRSS operates in the 2, 13-15 and 26 GHz band.

1.3.3.1 Space Network Services

NASA's Space Network (SN) consists of eight geosynchronous satellites. Satellite control and data capture facilities are located in: Guam (GRGT), Goddard Space Flight Center in Greenbelt, MD and White Sands, New Mexico (STGT and WSGT).

Second generation Tracking and Data Relay Satellites (TDRS) offer enhanced Multiple Access (MA) capability and higher data rates on the S-band (6 Mbps) and K_A-band (800 Mbps) Single Access (SA) channels.

SN service categories follow those for the NEN outlined above in Section 1.3.2.1 and readers should refer to Table 1-2 for the list of services. Detailed descriptions of the services and capabilities of the SN can be found in the SN Users' Guide (Reference 9).

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1.3.3.2 Process for Requesting SN Services

At the time when initial science operations concepts are being defined, proposers should contact the person named in Section 1.3.2.2 above for information about SN mission operations services and costs. A representative will assist proposers by providing service and cost information. Further, the NIMO aids in documenting initial mission operations requirements in a preliminary PSLA.

During the study phase, as the mission's concept is more clearly defined, requirements in the preliminary PSLA are revised. The resulting documentation of services and costs become the PSLA to be signed by appropriate Project and Network representatives.

1.4 Spectrum and Standards

It is NASA policy that space missions receiving funding from NASA comply with all international and United States regulations, standards, and agreements. Such regulations and standards include those promulgated by the:

- International Telecommunications Union (ITU)
- National Telecommunications and Information Agency (NTIA)
- Space Frequency Coordination Group (SFCG)
- Consultative Committee for Space Data Systems (CCSDS)

Choice of allocated frequency bands, maximum bandwidths of emissions, and maximum power flux-density on the Earth's surface must be compliant with the "Manual of Regulations and Procedures for Federal Radio Frequency Management." Specifically, space science missions in near-earth orbit are limited to the use of the following frequency bands: 2025-2110 (uplink and space-to-space), 2200-2290 MHz (downlink and space-to-space), 7190-7235 MHz (uplink), 8450-8500 MHz (downlink). For downlink bandwidths greater than 10 MHz, space science missions should use the bands 25.5-27.0 GHz (downlink) and 25.25-27.50 GHz (space-to-space). Within the 8450-8500 MHz band, no single space science mission shall use bandwidths greater than 10 MHz. Additionally, operations in the 2200-2290 MHz band shall not exceed bandwidths of 6 MHz in accordance with the NTIA Manual.

Information about the ITU and NTIA regulations may be obtained from NASA's Spectrum Management Office at NASA Headquarters or by consulting References 1 and 2. Recommendations of the SFCG are available in Reference 4.

Recommended CCSDS standards applicable to DSN, NEN, or SN support can be found in Reference 3, the CCSDS home page.

1.5 Policies

Capabilities described below result in the more efficient use of NASA's facilities. Where it is determined not to use an item, the proposal should include the rationale for its omission. Explanations are particularly important in Concept Study Report (CSR). Networks to which each item is applicable are noted following the subsection's title.

In addition to providing the operations and communications services costs as required by Section 1.1 and complying with the standards listed in Section 1.4 above, there are other NASA policies affecting proposal content. Proposers should carefully consider each item below.

1.5.1 Space Link Extension (DSN, SN)

Project Operation Control Centers (POCCs) using DSN and SN services should use a standard *Space Link Extension (SLE) Services Interface* for transferring data to and from DSN or SN sites. This interface is designed to provide international control center–network interoperability and reduce mission risk by facilitating the rapid substitution of a different earth station, not necessarily only NASA's, in the event of a ground station anomaly. The SLE Services interface will require POCCs to directly access DSN stations for the following services: Command Link Transmission Unit (CLTU), Return All Frames (RAF), Return Channel Frames (RCF), and CCSDS File Delivery Protocol (CFDP).

Seven international space agencies, including: ASI, CNES, DLR, ESA, ISRO, JAXA, and NASA, have agreed to implement the SLE Services Interface to achieve full international interoperability. Interface architecture conforms to standards adopted by the CCSDS (Reference 3).

1.5.2 X-Band and K_A-Band Communications (DSN, NEN, SN)

Category B ($r \geq 2 \times 10^6$ km) missions operating in a *Space Research* should be designed to communicate in either the 7/8 GHz or 7/32 GHz bands. Ever increasing congestion and the addition of allocations for incompatible services (e.g., IMT-2000) have restricted future operations in the 2 GHz deep space band. Accordingly, the Science Mission Directorate is recommending that use of the 2 GHz deep space band be limited to radio science and in-situ communications. Deep space missions having high data rates should operate in K_A-Band (31.8 - 32.3 GHz space-to-earth) or, if using the 8400-8450 MHz band, they should comply with SFCG Recommendations regarding bandwidth-efficient modulation. Approved methods for bandwidth efficient modulation can be found in Reference 3.

Category A ($r < 2 \times 10^6$ km) missions also have an allocation for the *Space Research* service in the 7190 - 7235 MHz (Earth-to-space) and 8450 - 8500 MHz (space-to-Earth) bands. Because of the congestion in the 2 GHz band from ever increasing use, proposers are encouraged to use the 7/8 GHz bands whenever possible. Missions operating in either the 2 or 7/8 GHz bands should comply with the spectrum emissions mask in the SFCG Handbook (Reference 4). Approved methods for bandwidth efficient modulation can be found in Reference 3.

Category A Missions with high data/symbol rates planning to operate in the 8 GHz *Earth Exploration Satellite* (EES) (8025 - 8400 MHz) should investigate capabilities in the 26 GHz band. Missions utilizing the EES service tend to have very high data/symbol rates and all missions planning to operate in the 8 GHz band should comply with the spectrum emissions mask in the SFCG Handbook (Reference 4). Approved methods for bandwidth efficient modulation can be found in Reference 3.

An allocation for the *Space Research* service has been approved for the 25.5 - 27.0 GHz band (a.k.a. 26 GHz band). High data rate near-Earth space science missions, requiring bandwidths in excess of 10 MHz, should be designed to operate in this 26 GHz band.

The Space Communications and Navigation Office is highly recommending, while polices are being worked, that all missions launching in 2016 and beyond should use Ka-band. For Deep Space missions the spectrum combination would be X and Ka (32 GHz) and for Near Earth S and Ka (26 GHz).

1.5.3 Bandwidth Efficient Modulation (DSN, NEN)

Missions operating in the 2 and 8 GHz bands (see Section 1.5.2), should employ bandwidth efficient modulation methods in conformance with SFCG and CCSDS Recommendations. Spectral Emission Masks for Category-A missions are found in the Space Frequency Coordination Group's (SFCG's) Handbook, available on the SFCG web site (Reference 4). Specific modulation methods meeting the SFCG mask are enumerated in CCSDS Recommendations 401 (2.4.17A) B-1, and 401 (2.4.18) B-1 for non-deep space and Earth resources missions respectively (Reference 3).

It is recommended that Category B missions employ bandwidth efficient modulation whenever operating in the 8400 - 8450 MHz band at symbol rates above 2 Msps. CCSDS Recommendation 401 (2.4.17B) B-1 lists acceptable modulation schemes.

1.5.4 CCSDS File Delivery Protocol (DSN, NEN)

To improve station usage efficiency as well as reduce mission risk and costs, the DSN strongly recommends that all users employ the CCSDS File Delivery Protocol (CFDP), to transfer data files to and from a spacecraft. CFDP enables the automatic transfer of a complete set of specified files and associated information from one storage location to another replacing an expensive labor-intensive manual method. It can transfer a file from a source point to a destination site using an Automatic Repeat Queuing (ARQ) protocol. In this acknowledged mode, the receiver notifies the transmitter of any undelivered file segments or ancillary data so that the missing elements can be retransmitted guaranteeing delivery. An unacknowledged mode is also permitted. CFDP information can be found in the CCSDS File Delivery Protocol Blue Book available under the Advanced Orbiting Systems category on the CCSDS web site (Reference 3).

The NEN is implementing CFDP Class 2 service, which will be available in the 2013 timeframe. Proposers should contact the person(s) named in section 1.3.2.2 for implementation details.

1.5.5 Multiple Spacecraft Per Antenna (DSN)

Where a multiplicity of spacecraft lie within the beamwidth of a single DSN antenna, it may be possible to capture data from two or more spacecraft simultaneously using the Multiple Spacecraft Per Aperture (MSPA) system. MSPA decreases DSN loading and will save the project's money (see Section 2.1.3).

There are a few constraints. First, only a single uplink frequency can be transmitted. Generally, this means that only one spacecraft at a time can operate in a two-way coherent mode, while the remainder must be in a one-way (i.e., non-coherent) mode. Second, multiple-independent receivers are required at the Earth station. This sets a practical limit of two spacecraft that can be served simultaneously. Third, ranging and two-way coherent Doppler data can only be obtained from the single spacecraft operating in a two-way coherent mode. For a Project to avail itself of the MSPA savings, the following conditions must apply:

- 1) All spacecraft must lie within the beamwidth of the requested antenna.
 - a. Projects must accept reduced link performance from imperfect pointing.
- 2) Spacecraft downlinks must operate on different frequencies.
- 3) Only one spacecraft at a time can operate with an uplink in a coherent mode.
 - a. Commands can only be sent to the spacecraft receiving an uplink.
 - b. Ranging & coherent Doppler are available from the spacecraft in a 2-way mode.
 - c. Remaining spacecraft transmit 1-way downlinks with telemetry only.

1.5.6 Delta Differenced One-Way Range (DSN)

Delta Differenced One-Way Range (DDOR) can be used in conjunction with Ranging and Doppler data to:

- 1) Increase spacecraft targeting accuracy (when used with range and Doppler data).
- 2) Improve mission reliability (when used with range and Doppler data).
- 3) Reduce tracking time (if pass duration is driven by tracking data capture).

Projects should investigate whether this data type offers sufficient improvement in one or more of the above parameters to justify the cost in terms of spacecraft implementation, operational complexity, and Earth station scheduling. Under the proper conditions, DDOR can offer significant benefits including a reduced mission cost.

For DDOR to be usable:

- 1) The spacecraft must transmit two tones (the greater the frequency separation the better).
- 2) Two DSN Earth stations must observe the spacecraft and natural radio sources.

1.5.7 Relayed Data (DSN)

Some missions may propose dropping probes, landers, or even rovers to explore the atmosphere and/or surface of a planet/body. Others may insert orbiters around the same body. The result can be a multiplicity of spacecraft on or around a planet/body. While Mars has been the recent focus, it is foreseeable that other planets or objects in space could be of equal interest in the future.

Where several spacecraft are relatively close together and positioned far from the Earth, it makes sense to send data to and from small vehicles via a relay (Proximity Link). Typically, this has been an orbiting spacecraft carrying a special transceiver operating at UHF frequencies. Relaying data from surface objects can save money and reduce size and power requirements of landed equipment. Proposals for landed objects in the vicinity of an orbiting spacecraft should consider whether a data relay makes sense for their application. Some *Announcements of Opportunity* (AOs) have required orbiting spacecraft with certain characteristics to carry Proximity Link hardware. A specific relay link design [Proximity Link] has been adopted by the CCSDS and its specifications can be found in Reference 3.

1.5.8 Coding

Most missions employ error detecting – error correcting codes to substantially improve telemetry link performance. DSN users are reminded that their encoders should conform to the *CCSDS Telemetry Channel Coding Blue Book* (CCSDS 231.0-B-1, September 2003). Acceptable codes include: 1) Convolutional $r = 1/2$, $k = 7$ only; 2) Reed-Solomon 223/255 only; 3) concatenated Convolutional / Reed-Solomon and 4) Turbo codes with rates: $1/2$, $1/3$, $1/4$, or $1/6$, block sizes: 1784, 3568, 7136, and 8920.

1.5.9 Critical Event Communications

NPR 8705.4, Risk Classification for NASA Payloads, Appendix B, requires telemetry services during all *Critical Events*. *Critical Events* are defined as those which, “if not executed successfully (or recovered from quickly in the event of a problem), can lead to loss or significant degradation of mission.” These events include launch, early orbit operations, and those listed as follows:

- Spacecraft separation
- Orbit insertion
- Powered flight
- Entry/Descent/Landing
- Critical Maneuvers (e.g., DSMs)
- Flybys

An Earth station is normally required during launch, early orbit and separation. It could be one of the DSN or NEN Earth stations if the launch trajectory permits. The SN is also frequently used for launch support. In cases where there are gaps, another Agency's Earth station or a small portable station may be required. The costs for *Critical Event* support must be included in the proposal. For information about costing this support, see Section 2.3.

2.0 NETWORK SERVICES COSTS

Generally, mission proposals must include both launch and communications/navigation costs. This section explains how to obtain costs for the DSN, NEN, and SN.

2.1 Costs for Using the Deep Space Network

Proposed Category B missions operate in deep space and frequently have lower signal levels and restricted communications bandwidths, as compared to missions orbiting close to Earth. In developing their mission concept, proposers should perform trade-offs among the elements of the end-to-end data system. The elements include instrument format design, flight data system, the space communications features, and the several elements of the ground data system. The integrated contact time and the contact frequency of the spacecraft with the DSN are typically important parameters in these trade studies. To simplify DSN costing, an algorithm has been developed permitting users to calculate the *DSN Aperture Fee* and included services.

The DSN consists of control, communications, test facilities at JPL, and Earth station complexes located near Goldstone, California; Canberra, Australia; and Madrid, Spain. The DSN provides communications services between spacecraft and Earth station complexes together with the ground communications among the complexes and the DSN control center located at JPL in Pasadena, California.

Testing to establish compatibility between the spacecraft's Radio Frequency Subsystem (RFS) and DSN stations is available at the JPL Development Test Facility (DTF-21) or by using the Compatibility Test Trailer (CTT-22) at a remote site. RFS compatibility testing is highly recommended and should be completed about eighteen months prior to launch.

DSN 34-meter, and 70-meter diameter antennas operating in the 2, 7, 8 and 26 GHz bands provide radio frequency communications. User costs vary with aperture size and utilization level. Generally, DSN services are included in the *Aperture Fee* (see Equation 2-1 below).

2.1.1 DSN Aperture Fees

Cost numbers supplied in this Section are for planning purposes only. To ensure accurate application of this information and to validate cost estimates please contact the DSN representative listed in Section 1.3.1.2. DSN personnel should always be consulted to validate these costs in the CSR.

The algorithm for computing DSN *Aperture Fees* embodies incentives to maximize DSN utilization efficiency. It employs *weighted hours* to determine the cost of DSN support. The following equation can be used to calculate the *hourly Aperture Fee* (AF) for DSN support.

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$$AF = R_B [A_W (0.9 + F_C / 10)] \quad (2-1)$$

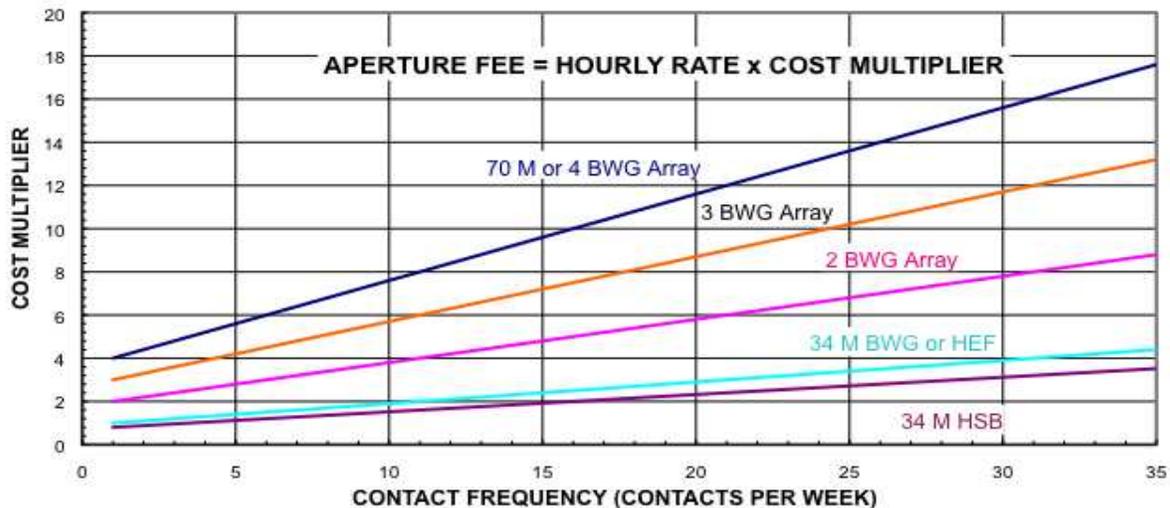
Where:

- AF = weighted *Aperture Fee* per hour of use.
- R_B = contact dependent hourly rate, adjusted annually (\$1057/hr. for FY09)
- A_W = aperture weighting:
 - = 0.80 for 34-meter High-Speed Beam Waveguide (HSB) station.
 - = 1.00 for a single 34-meter station (i.e., 34 BWG and 34 HEF).
 - = 2.00 for a two 34-meter station array.
 - = 3.00 for a three 34-meter station array.
 - = 4.00 for a four 34-meter station array (70-meter equivalent).
 - = 4.00 for 70-meter stations.
- F_C = number of station contacts, (contacts per calendar week).

The *weighting factor* graph below shows relative antenna costs graphically illustrating how *hourly costs* vary with *station contacts* and the relationships between antennas. It demonstrates the benefits of restricting the number of spacecraft-Earth station contacts each week.

A station contact, F_C , may be any length but is defined as the lesser of the spacecraft's: scheduled pass duration, viewperiod, or 12 hours.

For a *standard pass*, a 45-minute setup and a 15-minute teardown time must be added to each scheduled pass to obtain the *station contact* time (other configuration times apply to Beacon Monitoring and Delta-DOR passes – see relevant cost sections below). Note that scheduled pass-lengths should be integer multiples of 1-hour with a maximum of 12 hours per pass.



Total DSN cost is obtained by partitioning mission support into calendar weeks, grouping weeks having the same requirement in the same year, multiplying by weighted *Aperture Fee*, and summing these fees over the mission's duration. *Aperture Fees* include several services in the following categories: command, telemetry, tracking, radio science, radio astronomy, radar science, routine compatibility testing, and the DSN Commitments Engineer and services.

2.1.2 DSN Costing Calculations

Calculate DSN costs (*Aperture Fee, AF in \$/Hr.*) by selecting a specific antenna and then determining the number and duration of tracking passes required to satisfy project commanding, telemetry, and navigation for launch, cruise, maneuvers, and science phases. Each tracking pass, except Beacon Mode, DDOR, and a few others must be increased in length by one-hour for re-configuration. Once the pass length and number of passes is determined, multiply the aggregate hours by the hourly *Aperture Fee*, adjusted to the applicable *fiscal year*, to compute the mission's cost (in FY Dollars) using equation (2-1).

A form entitled *DSN Mission Support Costs*, Table 2-2, can be used to calculate DSN *Aperture Fees* in real-year or fiscal year Dollars. An Excel 2000 personal computer program is available for the preparation of the cost estimates. To obtain a copy, either contact the person named in Section 1.3.1.2 or the DSN web site (Reference 5).

New to the DSN Aperture Fee Tool is the cost for multiple 34M antennas in an array configuration (e.g., two 34Ms, three 34Ms, and 4 34Ms).

2.1.2.1 Included Services

Several value added services are available from the DSN and are included in the *Aperture Fee*. Table 2-1 names those services. For additional details, consult Reference 6.

Table 2-1: Services Included in DSN Aperture Fee

Service	Service
Command 1. Command Radiation 2. Command Delivery	Radio Science 1. Experiment Access 2. Data Acquisition
Telemetry 1. Frame 2. Packet 3. Telemetry File	Radio Astronomy / VLBI 1. Signal Capturing 2. VLBI Data Acquisition
Tracking 1. Validated Radio Metric Data 2. Delta-DOR Data	Radar Science 1. Experiment Access 2. Data Acquisition
Calibration and Modeling 1. Platform Calibration 2. Media Calibration	

2.1.3 Multiple Spacecraft Per Antenna DSN Costing - DSN Fee Reduction

Some flight programs, such as those surveying Mars, have clustered several spacecraft about a planet/body. It is possible to simultaneously capture telemetry signals from two or perhaps more spacecraft provided that they lie within the beamwidth of the Earth station's antenna.

If this situation applies and the constraints, set forth here and in Section 1.5.5, are acceptable, then it may be possible to reduce the Antenna cost by half for spacecraft operating without an uplink in a non-coherent mode. To calculate the cost, first compute the *Aperture Fee* using equation 2-1 above. Thereafter, apply the correction factor according to the formula:

$$AF' = (0.50) AF \tag{2-2}$$

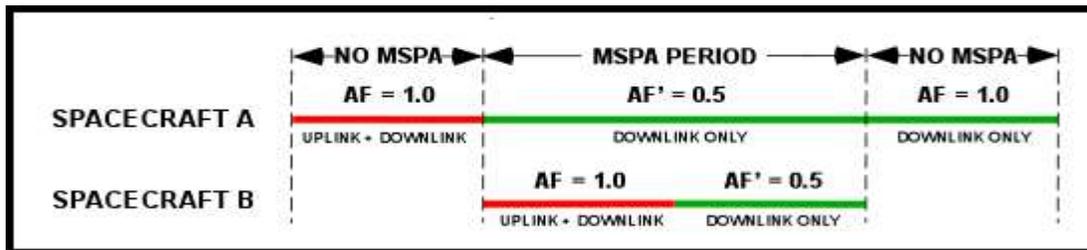
Where: AF' = weighted *Aperture Fee* per hour of use for spacecraft operating without an uplink in the MSPA mode. (Spacecraft having an uplink when operating in an MSPA mode should use the aperture fee (AF) computed according to equation 2-1.)

The reduced price, AF' , reflects the lack of capability resulting from no uplink communications. It is based upon the loss of commanding and ranging services to the spacecraft operating in a one-way non-coherent mode. If MSPA users agree, all could time-share the uplink and then re-allocate cost savings according to their individually negotiated sharing arrangements. When switching the uplink from one spacecraft to the next, full costs, AF , begin to apply to the new two-way coherent user at the onset of the switching operation.

Note: MSPA exists if, and only if, the same DSN antenna is simultaneously supporting two or more spacecraft without regard to whether an uplink is required by either.

Some examples may prove helpful. If a single DSN antenna is capturing telemetry from two spacecraft simultaneously, one with an uplink and the other in a one-way mode, the one with the uplink is at full cost (AF) [equation 2-1] while the other without the uplink calculates its cost at $AF' = 0.5 AF$. Where neither of the two spacecraft has an uplink, then each pays an *Aperture Fee'* (AF') of $0.5 AF$. **If the pass of one spacecraft begins before the other, or lasts beyond another, then there is no MSPA and that user is charged the full *Aperture Fee*, AF irrespective of whether there is an uplink.** Figure 2-1 may help to clarify the rules.

Figure 2-1: MSPA Aperture Fee



Note: Proposals employing the MSPA reduced-cost algorithm should also include Letter(s) of Agreement from the other simultaneous MSPA users stating the relevant conditions including how the uplink will be shared (see Section 3.3).

2.1.4 Clustered Spacecraft Aggregated DSN Costing

Occasionally a mission comprises several spacecraft flying in a geometric formation, but with spacing too large to utilize MSPA. Rather than request simultaneous support from several DSN stations, the project may agree to sequentially contact each spacecraft. From a project viewpoint, it is desirable to treat sequential DSN communications with several spacecraft as a single DSN contact for costing purposes. This section outlines the conditions when aggregation is permitted.

DSN *station configuration* is a key element in establishing the continuous nature of a contact. If a new configuration is required for each spacecraft in the cluster, then support of several spacecraft assumes the character of individual contacts arranged in a sequential order. Conversely, if everything at a DSN station, except the direction in which the antenna is pointing remains fixed when transitioning to a different spacecraft, the essential character is one of a single contact.

Station configuration involves loading predicts containing: transmit and receive frequencies, Doppler frequency estimates, spacecraft identification numbers, data routing information, measuring station ranging delay, etc. These may be unnecessary when the several spacecraft:

- Operate on the same frequency and polarization,
- Require identical data routing, and
- Do not use ranging.

For missions consisting of a multiplicity of spacecraft, each of which receives commands and/or transmits telemetry sequentially to and from a single DSN Earth station in a series of contiguous communications, then aggregation of individual pass times into a single contact may be reasonable.

Clustered Spacecraft Aggregated DSN Costs are calculated by:

- Adding a single setup and tear-down time for the aggregated period,
- Including costs for time needed to move the spacecraft from one spacecraft to the next,
- Treating the series of links during a pass as a single contact for the costing algorithm,
- Computing the cost following equation 2-1 in Section 2.1.1.

All missions consisting of a cluster of spacecraft not meeting the above criteria should calculate their costs using equation 2-1 in Section 2.1.1 treating each sequential communication with a member of the cluster as a separate and individual contact.

2.1.5 Data Relay DSN Costing

Data between a landed object and a DSN station, which is relayed through an orbiting spacecraft, may be unaccompanied or interspersed with data from other sources. At any specific time, a DSN station may be communicating with one or more surface objects.

Proposals for missions employing relays should include their pro-rata share of the DSN station cost. **Pass cost can be found by calculating the time required to return the total amount of relayed data, assuming that only this data being transmitted from the orbiting relay element or by assuming 1-hour, whichever is greater.** Station configuration times need not be considered. Proposals should state their rationale and assumptions for their computed share of the DSN cost carefully, completely, and in sufficient detail so that evaluators can independently verify the computations.

2.1.6 DDOR DSN Costing

Under the correct geometric circumstances, Delta Differential One-way Range (DDOR) can result in a net reduction in needed tracks (see Section 1.5.6). This is so because adding DDOR passes can reduce the number of contacts needed to collect long data arcs of coherent Doppler and ranging measurements necessary to compute a spacecraft's trajectory. DDOR can also be used as an independent data source to validate orbit solutions. However, two widely separated Earth stations are required simultaneously to view the spacecraft and the natural radio sources.

DSN 34M and 70M stations can be used to collect DDOR data. To calculate a cost for a DDOR pass, users should determine the: 1) DSN stations desired for the DDOR pass, 2) Amount of DDOR data required to obtain the spacecraft's position, 3) Pass length needed to obtain the data, 4) Setup time of 90-minutes (a 45-minute *standard pass* setup period for the station plus an additional 45-minutes for DDOR). The tear-down time remains at 15-minutes for each DDOR pass (*Note: This is 90-minute setup plus 15-minutes tear-down time for each station in the DDOR configuration.*), and 5) Cost of the pass by summing the cost for the two desired DSN stations plus setup and tear-down times over the length of the pass.

2.1.7 Beacon Tone Monitoring DSN Costing

Beacon Tone Monitoring is a low-cost method for verifying spacecraft health. A spacecraft transmits up to four predetermined tone frequencies (subcarriers) indicating its current condition. Spacecraft must be designed to monitor their subsystems and direct an appropriate tone be transmitted. Beacon Tone Monitoring is particularly useful during long cruise periods when little or no science data is being collected.

Beacon Tone tracks (exclusive of configuration time) are generally short (40 to 60-minutes) and must occur at scheduled times when the spacecraft is in view of a DSN complex. DSN 34m or 70m stations capture tones and project personnel are informed of the frequency received. They, not DSN personnel, must determine the meaning of the received tone.

Because no science or housekeeping data is received, it is possible to reduce the configuration times and hence cost for Beacon Tone Monitoring. Proposers calculating a cost for Beacon tone Monitoring should compute *Aperture Fee (AF)* for the requested DSN antenna using a setup time of 15-minutes and a teardown time of 5-minutes (rather than 45-minutes and 15-minutes respectively). The minimum pass length, including configuration times, is 1-hour (40-minute pass plus 20-minutes of setup and tear-down time).

2.1.8 Compatibility Testing DSN Costing

DSN encourages pre-launch compatibility testing as a means to eliminate post launch anomalies and expensive troubleshooting. The DSN maintains two facilities known as the Development and Test Facility (DTF-21), and a Compatibility Test Trailer (CTT-22). Except for the high power transmitter, antenna, and low noise-receiving amplifier, which are not included, these facilities are configured much like an operational DSN Earth station.

Approximately eighteen months prior to launch, projects should bring their Radio Frequency Subsystems (RFS) to DTF-21 for testing. Testing requires approximately two weeks and includes such items as RF compatibility, data flow tests, and transponder calibration. Additional testing can be arranged by utilizing CTT-22 at the spacecraft manufacturing facility, if required.

Because this testing materially improves the likelihood of mission success, no charge is made for the use of the DTF-21 facility for a single set of compatibility tests. Rather, it is included in the hourly-dependent rate, R_B , used in Equation 2-1. For the use of the CTT-22 facility the only charge is to cover the travel and per-diem costs of the DSN personnel and the transportation cost of moving the test trailer to the user facility.

2.2 Near Earth Network and Space Network Costing

NEN and SN services are highly mission dependent. Proposers are advised to contact the GSFC NIMO listed in Section 1.3.2.2 above to obtain a cost estimate for their mission.

For the purposes of initial rough estimates, the following rate may be used for NEN S-band and X-band service:

- \$557.00 per NEN pass (one pass is ≤ 30 minutes).

The standard rates for using the SN:

- Single Access Service-Forward command, return telemetry, or tracking, or any combination of these, the rate is \$131.00 per minute
- Multiple Access Forward Service - \$29.00 per minute
- Multiple Access Return Service - \$14.00 per minute.

2.3 Critical Event Support Costing

If *Critical Event* support can be obtained from one of NASA's standard networks (DSN, NEN, SN) then calculating costs is relatively simple. Costs are computed in the same way as for routine telemetry support. If it is not possible to use one of the NASA networks because no station element is in view or they are otherwise unavailable, then the task of computing *Critical Event* support becomes somewhat more complex.

For the launch, early orbit, and separation phases, it may be possible to use the SN although a small Earth station is generally sufficient. Several possibilities exist. First, it may be possible to arrange with another space agency for use of their station provided that it has a reasonable

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view period. Second, commercial stations may exist that would be able to provide the needed support. Third, it may be possible to contract for use of an existing, or alternatively construct, a small transportable station, which can be placed in a location with a suitable view period.

Because mission requirements vary over such a broad range, it is not possible to provide a simple means to calculate the cost of telemetry support for this early mission phase. For assistance in establishing alternative solutions and/or in costing the required support, please contact the person named in Section 1.3.1.2 if the proposed mission utilizes DSN support primarily or the person named in Section 1.3.2.2 if the proposed mission uses either NEN or SN support primarily.

3.0 REQUIRED PROPOSAL INFORMATION

The AO contains the specific requirements for the format and content of the proposal. Communications, tracking and navigation items include downlink information data volume; uplink information; for all transmit and receive modes, mode timeline and data rates; and ground network utilization including ground stations, downlink parameters (frequencies, periods, capacities, margins, etc.) and retransmit capability. The DSN, NEN and SN commitment offices (Reference 5 and Reference 7) can assist with the preparation of the communications, tracking and navigation sections of the proposal.

4.0 REFERENCES

Prospective users of NASA facilities can obtain additional information from the following documents:

1. *Radio Regulations*, International Telecommunications Union, Geneva, Switzerland, Latest Edition.
2. *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications & Information Administration, U.S. Department of Commerce, Washington D.C., Latest Edition. **Information is available at:** <http://www.ntia.doc.gov/osmhome/redbook/redbook.html>
3. Consultative Committee for Space Data Systems (CCSDS). Blue Books published by the CCSDS Secretariat, NASA Headquarters, Washington D. C. 20546. **Copies of CCSDS Recommendations and Reports are available at:** <http://public.ccsds.org/publications/default.aspx>
4. *Handbook of the Space Frequency Coordination Group*, ESA Frequency Manager and SFCG Secretariat, European Space Agency Headquarters, 8-10 Rue Mario Nikis, 75738 Paris, France. **Copies of the document are available at:** <http://www.sfcgonline.org/>
5. *DSN Commitments*. **Web site located at:** <http://deepspace.jpl.nasa.gov/advmiss>
6. *DSN Service Catalog*, DSN No. 820-100, JPL D-19002, Jet Propulsion Laboratory, **latest copy available at:** <http://deepspace.jpl.nasa.gov/advmiss>
7. *NEN and SN Commitments*. **Web site located at:** <http://esc.gsfc.nasa.gov/space-communications/nimo.html>
8. *Near Earth Network Users' Guide Revision 1*, 450-NENUG, 450/Exploration and Space Communications Projects Division, **latest copy available at:** <http://esc.gsfc.nasa.gov/space-communications/NEN.html>
9. *Space Network Users' Guide Revision 9*, 450-SNUG, 450/Exploration and Space Communications Projects Division, **latest copy available at:** <http://esc.gsfc.nasa.gov/space-communications/sn-sne.html>

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5.0 GLOSSARY

AF	Aperture Fee
AF'	Aperture Fee discounted for Multiple Spacecraft per Aperture applications
A_w	Aperture Weighting (For costing DSN stations)
AO	Announcement of Opportunity
ARQ	Automatic Repeat Queuing
ASI	Agenzia Spaziale Italiana (Italy)
b/s	Bits per second
BWG	Beam Wave Guide (Refers to specific DSN 34M antennas)
Category A	Missions whose distance from Earth is $< 2 \times 10^6$ km.
Category B	Missions whose distance from Earth is $\geq 2 \times 10^6$ km.
CCSDS	Consultative Committee for Space Data Systems
CDR	Critical Design Review
CE	Commitments Engineer
CTT	Compatibility Test Trailer
CFDP	CCSDS File Delivery Protocol
CLTU	Command Link Transmission Unit
CNES	Centre National d'Etudes Spatiales (France)
CSR	Concept Study Report
dB	Decibels
dBi	Decibels (relative to an isotropic radiator)
DDOR	Delta Differenced One-way Range
DLR	Deutsches Zentrum für Luft- und Raumfahrt (Germany)
DSA	Deep Space Network Service Agreement
DSN	Deep Space Network
DTF-21	Development Test Facility-21 (Compatibility test area located at JPL)
EES	Earth Exploration Satellite (A communications service designated by the ITU)
ESA	European Space Agency
F_c	Frequency of Contacts (For costing DSN stations)
FY	Fiscal Year
GHz	Gigahertz (1×10^9 cycles per second)
NEN	NASA's Near Earth Network
GRGT	Guam Remote Ground Terminal
GSFC	Goddard Space Flight Center
HEF	High Efficiency (Refers to specific DSN 34M antennas)
Hr	Hour
HSB	High Speed Beam waveguide (Refers to specific DSN 34M antenna)
Hz	Hertz (cycles per second)
IMT-2000	International Mobile Telephone-2000 (3 rd generation mobile telephone system)
ISRO	Indian Space Research Organization
ITU	International Telecommunications Union
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory

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K	Kilo (1×10^3) or Kelvin
K _A -Band	Frequency band: Deep Space (Category B) 31.8 - 32.3 GHz downlink Near-Earth (Category A) 25.5 - 27.0 GHz downlink
Km	Kilometers
LEOP	Launch and Early Orbit Phase
M	Meters
MA	Multi-Access
MD	Maryland (abbreviation)
MHz	Megahertz (1×10^6 cycles per second)
MSPA	Multiple Spacecraft per Aperture
NASA	National Aeronautics and Space Administration
NEN	Near Earth Network
NIMO	Networks Integration Management Office at GSFC
NPR	NASA Procedural Requirements
NTIA	National Telecommunications and Information Administration
PI	Principal Investigator
POCC	Project Operations Control Center
PSLA	Project Service Level Agreement
r	Range (Earth to spacecraft)
RAF	Return All Frames
R _B	Base Rate (For costing DSN stations)
RCF	Return Channel Frames
RFS	Radio Frequency Subsystem
SA	Single Access
SCaN	Space Communications and Navigation
SFCG	Space Frequency Coordination Group
SLE	Space Link Extension
SMD	Science Mission Directorate
SN	Space Network (TDRSS)
SOMD	Space Operations Mission Directorate
STGT	Second TDRSS Ground Terminal
TDRSS	Tracking and Data Relay Satellite System
TT&C	Tracking, Telemetry, and Command
WSGT	White Sands Ground Terminal
X-Band	Frequency band (Space Research Segment): Deep Space (Category B) 7145-7190 MHz uplink, 8400-8450 MHz downlink Near-Earth (Category A) 7190-7235 MHz uplink, 8450-8500 MHz downlink