NASA Deep Space Network

https://spaceodyssey.dmns.org/media/53989/deep_space_network.ppt
Deep Space Network

The Challenge:

Tracking and Communicating with Spacecraft beyond Earth Orbit:

- Lunar Exploration
- Planetary Exploration
- Interplanetary Exploration
- Astronomical Exploration
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Three complexes, approximately 120° apart:
  -- Goldstone
  -- Madrid
  -- Canberra

Functions:
  • Receipt of Telemetry
  • Spacecraft Command
  • Radiometric Tracking – of spacecraft
  • Very Long Baseline Interferometry – determine location of radio sources
  • Radio Science – determine transmission characteristics between ground and spacecraft
  • Monitor and Control of real-time data
  • Science such as radio astronomy (on space-available basis)
Signals to/from Spacecraft are Line of Sight

Coverage of DSN Stations overlap beyond 30,000km (18,000 miles), providing 8-14 hours of daily view.

This ensures reliable and useable two station coverage for lunar and deep space coverage for “uplinks” (transmission) to spacecraft and “downlinks” (receive data) from spacecraft.
One of three space communications complexes making up DSN
--multiple steerable antennae
--remote locations protected by terrain from radio interference and away from population centers.

Each complex consists of ultrasensitive receiving and processing systems which include, as a minimum, the following dish antennas:

• One 34-meter (111-foot) diameter High Efficiency antenna.
• One 34-meter Beam Waveguide antenna.
• One 26-meter (85-foot) antenna.
• One 70-meter (230-foot) antenna.
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Goldstone Ground Station Complex

Madrid Ground Station Complex
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Details of DSN Facilities

DSN Network also includes:

- The Demonstration Test Facility at Jet Propulsion Laboratory (JPL) where spacecraft-to-DSN compatibility is demonstrated and tested prior to launch.
- The Merritt Island facility at Kennedy Space Center in Florida, which supports launch operations.
- The Ground Communications Facility which connects all voice and data communications. The GCF uses land lines, submarine cable, terrestrial microwave, and communications satellites.

JPL in Pasadena houses the Network’s Operations Control Center.
DSN was originally developed by JPL (under the Air Force contract) to support initial series of Pioneer probes and became operational in 1958.

Pioneer 4 – launched March 3, 1959 was the first US spacecraft to escape earth’s gravity – intended to hit Moon, but missed. Communication maintained to 650,000 kilometers (nearly 400,000 miles)

Pioneer 5 – launched March 11, 1960 – First spacecraft to explore interplanetary space between Earth and Venus
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Progression of DSN-Supported Space Missions

DSN has been continually upgraded to improve technologies and support technical demands for new missions.

Locating the spacecraft’s signal over vast distances, commanding the spacecraft, verifying that the transmission has been correctly understood, and receiving and decoding the faint transmitted signal are fundamentals the DSN must meet.

Challenges include larger data streams, longer distance, multiple spacecraft being tracked and increased terrestrial radio interference.
To reduce costs and save onboard weight and power, spacecraft communications equipment transmit signals at very low power, usually about 20 watts, approximately the same amount required to light a refrigerator light bulb.

The spacecraft antenna focuses the signal into a narrow beam aimed at Earth.

As the signal travels, it continues to lose energy as it loses its focus; by the time it reaches Earth, the signal arriving at the antennas can be as weak as a billionth of a billionth of a watt.
Great size is needed to receive the weak signal especially at a range of over one billion miles from earth. (For radio-astronomy, signals may be as weak as a billionth of a trillionth of a watt.)

Communications use microwave frequencies – 2-32 gigahertz

“Steer-ability” is needed to aim and adjust – spacecraft, earth and planets are all constantly moving and signal travel times need to be considered.

Surface of the 70-meter reflector must remain accurate within a fraction of the signal wavelength, meaning that the precision across the surface has to be maintained within one centimeter (0.4 in.).
The antenna design uses a signal collection and focus concept similar to that in Cassegrain Optical Telescopes with the secondary reflector “fine tuning” the focus on the feed cone assembly to several “feed horns”.
Antenna’s updated design with beam waveguide reflectors allows transmitter/receiver equipment to be housed indoors.

An array of several 34-meter antennas can serve as the equivalent of the 70-meter antenna when the larger antenna is scheduled for maintenance, or 34-meter antennas can be linked incrementally to meet mission demands.

Currently three 34–meter beam waveguide antennas are operational at Goldstone, two at Madrid and one at Canberra.
The DSN Operations Center is located at the JPL facilities in Pasadena, California.

DSOC personnel monitor and direct operations, and oversee the quality of spacecraft telemetry and navigation data delivered to network users.
Example:

- Cassini image data are compressed and use image data rates between about 40 kilobits (kbs) to 165 kbs per second.

- Cassini images are compressed at 2:1 and transmitted at X-band at approximately 165 kbs.

- It takes approximately 2 minutes to transmit the red, green, and blue images required to construct a color image.
When the spacecraft’s signal arrives at Earth, it is spread over a large area, and the ground antenna is able to receive just a small part of the signal. Arraying allows the capture of these very weak signals and enables a higher data rate.

For the Galileo mission to Jupiter, the DSN arrayed up to five antennas from three tracking facilities. The result was a factor of 3 improvement in data return compared with that of a single 70-meter (230-foot) antenna.

The smaller antennas generally are easier to build and maintain than the larger dishes.

NASA and other space agencies are using arrayed antennas more and most of the future system improvements are based on arrays plus advances in data compression and encoding techniques.
Interplanetary data transmission rates have shot up 10 orders of magnitude in the past 50 years, thanks in part to higher frequency bands of radio waves. Optical transmissions with lasers promise to extend that pace, to the point at which high-definition television broadcasts from Jupiter might be possible.
The LLCD is NASA's first attempt at two-way space communication using an optical laser instead of radio waves.

In October 2013, the LLCD made history by using a pulsed laser beam to transmit data over the 239,000 miles between the moon and Earth at a record-breaking download rate of 622 megabits per second (Mbps) and an error-free upload rate of 20 Mbps.

Challenges remain regarding the effects of Earth's atmospheric absorption and distortion by weather and smog.
Additional support has been provided to DSN by Parkes Radio Telescope in Australia – ”The Dish” (of 2000 movie fame – story of its support of the first moonwalk) and by the Very Large Array in New Mexico.

They provide additional coverage and bandwidth, especially when DSN facilities are not usable due to maintenance and/or weather.
Support agreements are in place between networks, especially between NASA and ESA.

NASA Near Earth Network provides communications coverage during initial phases of launch and orbital check-out.

Deep Space Networks are also established for Russia, India and China.
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For More Information:


Optical Deep Space Communication

Additional Slides added by Greg Kesden, Spring 2019
Optical vs RF Beam Divergence

- Optical communications has lower divergence compared to RF
- Comparison of RF and optical beam spreads from Saturn.

Credit:
- Prof. Brandt-Pearce, UVA
- https://slideplayer.com/slide/4759507/
Direct vs Indirect Optical Link

• Optical deep-space communications can be implemented in two ways:
  • Direct optical link: A direct optical link is set up between the earth station and space-craft
    • Atmosphere disperses and attenuates the transmitted and received signals
    • High power transmitter and large receivers can be used
  • Indirect optical link: the optical signal is sent from a satellite outside the atmosphere
    • Atmosphere effect is mitigated
    • Transmitter and receiver sizes are limited

Credit: Prof. Brandt-Pearce, UVA
https://slideplayer.com/slide/4759507/
Forward Error Correction

Additional Slides added by Greg Kesden, Spring 2019
Forward Error Correction

• Obviously needs to be very high performance
  • Handle a lot of error
  • Not waste any more bit time than needed in doing it
  • Based upon fairly intense coding theory
    • Not nearly as accessible to teach as parity, or Hamming’s code, or CRCs

• Techniques
  • Turbo codes
    • Developed in the early 1990s
    • Used in space communication since shortly thereafter
  • Polar codes
    • First described in 1999
    • Used in 5G
    • Possible application to deep space