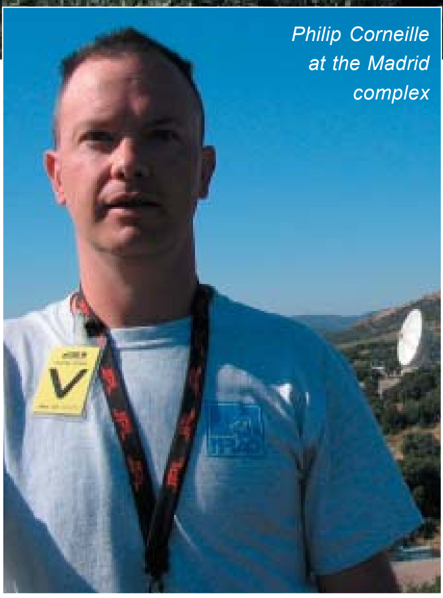
Calling interplanetary spacecraft

by Philip Corneille



Philip Corneille at the Madrid complex

NASA's Deep Space Network (DSN) is an international network of antenna ground stations that supports interplanetary spacecraft missions and radio astronomy observations for the exploration of the universe. After almost half a century in existence the DSN still plays an important role and is constantly evolving.

After the launch of Sputnik 1 almost 50 years ago the US government has been engaged in a catch-up situation with its Soviet-Russian counterpart in space research.

In February 1958, the US Department of Defense established the Advanced Research Projects Agency (ARPA) in order to coordinate and manage all existing military and civilian space activities.

The Jet Propulsion Laboratory (JPL), managed by the California Institute of Technology (Caltech), was associated with the Army's missile development programme and was asked to support the Pioneer lunar space programme.

JPL engineers already used the 'Microlock' tracking system to provide positional data for high altitude test rockets. Moreover, JPL had deployed portable radio tracking stations in Nigeria, Singapore, and California to receive telemetry and plot the orbit of the Army-launched Explorer 1, the first successful US satellite.

NASA was officially established on 1

The 26 m antenna stands nearby the newer 34 m Beam Wave Guide antennas in the background. Note the small edge-mounted 'acquisition antenna' on the lower left side of the dish and the difference in pedestal for these antennas.
P. Corneille

The new antenna control room at the Madrid DSN. Network technology and improved software allows efficient control of the five antennas. Note the red time indications for each DSN complex.
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October 1958 as a means of consolidating the separately developing space exploration programmes of the army, navy, and air force into one civilian organisation.

NASA-JPL developed the concept of the Deep Space Network (DSN) as a separately managed and operated communications facility that would accommodate lunar and deep space missions, thereby avoiding the need for each flight project to acquire and operate its own specialised space communications network.

Tracking lunar probes required large diameter, steerable parabolic dish antennas and JPL made use of the existing design of a radio astronomy antenna of the Carnegie Institute. By December 1958 JPL had established the first ground station with a 26 m antenna near the Goldstone dry lake in California in order to track the Pioneer 3 and 4 lunar missions.

In 1961 the mobile three metre antenna in Puerto Rico proved insufficient and NASA completed its worldwide net with 26 m antennas at ground stations in Woomera, Australia and Hartebeest, South-Africa. Due to political and diplomatic considerations, the latter ground station was to be relocated in Europe near the same longitude as the South Africa facilities.

A series of surveys in Spain in early 1963 eventually identified an area of dry, rolling countryside near the village of Robledo de Chavela (about 50 km west of Madrid) as a suitable location.

In August 1963, after NASA had gained permission from the Spanish government to use the land and the US state department had agreed to fund the project, construction began. The Deep Space Station was ready for system checkout in May 1965 and began participating in Mariner 4 operations in July.

The Spanish government's Instituto Nacional de Técnica Aerospacial (INTA) assumed full responsibility for staffing and operation of the Madrid Deep Space Communications Complex (MDSCC) ground station.

After the Mercury and Gemini manned spacecraft missions, it became clear that NASA's Manned Space Flight Network (MSFN) needed an upgrade to support the Apollo lunar landing programme. Similar to its US and Australian locations, the Spanish complex got an Apollo 'wing' station near Fresnedillas, some 8 km north-east of Robledo de Chavela.

Moreover, MSFN control rooms were added to each main DSN location to allow them to function as complete MSFN tracking stations. Dual sets of stations were needed because of the narrow beam width of the antennas using S-band when the Apollo spacecraft were near the Moon.

While one antenna tracked the orbiting command and service module, the other covered the lunar module on the lunar surface. Fresnedillas' 26 m dish antenna was versatile as it could slew fast enough to track spacecraft in Low Earth Orbit and be accurate enough to follow spacecraft at lunar distance for extended periods of time. The antenna control room operated a Univac 1218 computer and several upgrades allowed usage of the complex up to the 1980s.

In 1985 the 26 m antenna was relocated to the Robledo DSN complex and, unlike its

The entrance of the Madrid Deep Space Communications Complex is dominated by the large 70 m antenna (DSS-63). *P. Corneille*

Australian counterpart at Honeysuckle where the complex was dismantled, the Fresnedillas location remained in use as a military tracking station.

The Pioneer 10 and 11 interplanetary space missions required the support of larger aperture antennas to provide continuous coverage. Collins Radio company together with its European subcontractors completed the MDSCC 64 m antenna in January 1973. The first operational uses of the antenna occurred during the Pioneer 10 encounter with Jupiter in December 1973 and the Mariner 10 encounter with Venus in February 1974.

However, more complex space missions venturing deeper in space pushed the technical challenges for the DSN stations even further.

DSN operations and challenges

A decade after DSN was established, it remained the only system of its nature capable to serve large numbers of space missions. Nowadays, the structure of the DSN consists of three Deep Space Communications Complexes (DSCC), each of which is located on a separate continent. These DSCC locations are placed 120 degrees apart around the world at Goldstone (USA), Madrid (Spain) and Canberra (Australia).

This strategic placement provides an eight to 14 hour view period at each location, ensuring constant observation of spacecraft as the Earth rotates, providing the vital communications link for mission engineers and scientists.

Two-way communications link between Earth and the spacecraft is made up of downlink telemetry (science data and spacecraft status) and uplink coded instructions (radio navigation and control of the spacecraft's operating modes).

The large parabolic antennas are designated Deep Space Station (DSS) and the DSS's at the MDSCC are given numbers in the fifties and sixties: DSS 54, 55, 65 and 63. Each complex consists of at least four DSS equipped with ultra sensitive receiving systems. For the Spanish complex these are - a 70 m diameter antenna, a 26 m antenna and a pair of 34 m Beam Wave Guide antennas.

The 70 m antenna, basically an upgraded 64 m with 400 kilowatts transmitter, is the largest and therefore most sensitive DSN antenna, capable of tracking spacecraft travelling more than 10 billion miles from Earth. The dish reflector, which surface must remain accurate within a fraction of a signal wavelength, and its azimuth-elevation mount atop the concrete pedestal weigh nearly 3 million kilograms. The 26 meter antenna is used for tracking Earth-orbiting spacecraft, most of which are in orbits between 100 and 650 miles above Earth.

The X-Y mount allows the antenna to point low on the horizon to pick up the fast moving Earth orbiters as soon as these come into view. The 34 m antenna has a 20 kilowatts transmitter and follows interplanetary spacecraft.

All signals are sent from the antennas to the complex's Signal Processing Center (SPC). Multiple strings of receivers and processors make it possible to recover telemetry and navigation data simultaneously from different spacecraft, each using different antennas.

The data is then transferred via landlines, terrestrial microwave links or communications satellites to the Deep Space Operations Center at JPL where the raw data is processed into usable information for real-time delivery to mission controllers and scientists worldwide.

Besides gathering spacecraft and science data, DSN also monitors the performance of the entire network. Moreover, DSN was also tasked to provide emergency support for the Tracking and Data Relay Satellite System (TDRSS), which relays communications of spacecraft in low earth orbit.

The current MDSCC director is Dr Jesus Gimeno and former directors included Dr Agustin Chamarro and Dr José Urech. The latter developed and demonstrated the concept of combining the output of two antennas to improve telemetry reception.

By the 1980s, signal combining was used to get higher data rates when the Voyager spacecraft were near Uranus. The ability to array several antennas together in order to effectively increase the overall dish area was also successful in communications with the Galileo spacecraft near Jupiter between 1995 and 2003. Because of the increasing demands on the entire DSN, NASA added an extra five 34 m antennas to the system by the late 1990s.

Another way of making effective use of

The new 34 m Beam Wave Guide antenna with the access ramp to its below-ground pedestal equipment room. *P. Corneille*

DSN antenna time was demonstrated by the 'multiple spacecraft per antenna' concept by tracking Mars Global Surveyor and Mars Pathfinder from a single antenna.

However, DSN management is constantly challenged to add extra tasks for science purposes, which have included - radio astronomy observations (both single-dish and very long baseline interferometry), Search for Extra Terrestrial Intelligence (SETI), crustal dynamics and radar science.

Moreover, the older antennas, particularly the 70 m dishes, were reaching the end of their lives and required parts replacements. During a planned downtime for installing upgrades to the 70 m (DSS-63) antenna, cracks were detected in major bearings and DSS-63 was scheduled to be out of service for three months.

Although smaller dishes could substitute for most of the tracking and communication done with the 70 m antenna, additional antennas might be needed. Despite the efforts of NASA's Science Mission Directorate to set priorities with flight projects using DSN, a 2006 report by the Government Accountability Office (GAO-06-445) pointed out that serious doubts existed as to whether DSN will be able to keep up with both near-term and future demands.

NASA concurred with the report by making changes to the DSN roadmap for the future.

The future of DSN

The future has already started at MDSCC as NASA's Telecommunications and Mission Operations Directorate had chosen the MDSCC to add an advanced 34 m Beam Wave Guide (BWG) antenna.

Projections for predicted usage in the new millennium (eg new Mars missions) indicated the greatest need for increased communications capacity would be at the Madrid complex.

Building the new 34 m antenna would bring MDSCC's capacity to support Mars missions to be almost 300 hours within Mars view periods per week.

Schwartz-Hautmont Construcciones Metalicas SA of Tarragona was selected to build the extra antenna, which was operational in November 2003. The design of the 34 m BWG antenna is based on that of the 34 m high-efficiency antenna and provides the same basic performance parameters.

A major change in the design is the addition of five precision radio frequency mirrors that reflect radio signals along a Beam Wave Guide tube from the vertex of the antenna to an underground pedestal equipment room. This allows easier access to the sensitive electronics for maintenance and modifications (such as adding new electronics for transmitting and receiving at additional radio frequency bands when needed to support future deep space missions).

The new antenna is the biggest piece in about $54 million worth of improvements that NASA's Office of Space Science has set as priorities for upgrading the DSN's capabilities. Together with the new BWG antennas, cost-effective network technology is used to operate the antennas in arrays and to control the system components. However, there are some remaining issues.

In spite of the Australian DSN complex, coverage of the southern hemisphere remains limited. In order to limit the rate of future data loss events, NASA considers to expand the network in order to get full Southern hemisphere redundancy of its northern hemisphere facilities.

International cooperation with tracking stations of other space agencies could help deliver the promised performance.

NASA will continue its efforts in order to maintain the DSN as the largest and most sensitive scientific telecommunications system in the world, especially as the agency's 21st century vision for space exploration, that called for human and robotic missions to the Moon, Mars and beyond, requires a modern and reliable communications network to handle all data transfers to and from manned and unmanned spacecraft.

Receiver racks for the 70 m antenna (DSS-63) in the Signal Processing Center from where all raw data is send to the Jet Propulsion Laboratory for interpretation. *P. Corneille*

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