VLBI in the Deep Space Network: Challenges and Prospects

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Abstract

The purpose of this paper is to highlight the current status and prospects for VLBI in the NASA DSN. Although the prime purpose of the DSN is to support spacecraft operations and space research in deep space, this unique facility is also used on a noninterference basis with flight projects to support ground-based science experiments. The DSN VLBI capabilities are an integral part of a number of space- and ground-based projects. They include support of experiments at major radio astronomy VLBI networks (e.g., VLBA, EVN, APT), Space VLBI co-observing, as well as VLBI geodesy and astrometry programs. The paper will describe for the potential DSN VLBI users 1) DSN VLBI objectives, 2) the current organizational structure and 3) current, and projected capabilities.

1. Introduction

The NASA Deep Space Network (DSN) is a unique set of facilities distributed worldwide with the prime goal of supporting spacecraft operations and research in deep space. To conduct tracking of spacecraft in deep space, the DSN uses state-of-the art technology and instrumentation which is sometimes similar and often identical to radio astronomy instrumentation. From the time of the DSN's creation in the early 1960s, the radio astronomy community recognized great value in this facility for radio astronomy. Since then, the unique features of the DSN have been regularly used to do ground-based radio astronomy of which Very Long Baseline Interferometry (VLBI) is a very large part.

The DSN supports scientific experiments on a noninterference basis with the flight operations of space projects. This scientific support is carried out in three scientific disciplines: Radio Astronomy (radiometry, spectroscopy, polarization, VLBI), Radio Science (utilizing signals of interplanetary spacecraft to obtain information on the solar system's interplanetary environment, planetary atmospheres and fundamental physics), and Radar Astronomy (utilizing 0.5 megawatt transmitters).

2. *DSN VLBI objectives*

The prime function of the VLBI capabilities at the DSN is to provide direct or indirect support to flight projects. This support can include: 1) VLBI navigation (including the maintenance of the navigation reference sources catalog), 2) Platform Parameters (station locations, calibration of Earth rotation and pole motion), 3) ground-based observing in support of space astronomy missions (e.g., Space VLBI, Gravity Probe-B). The infrastructure developed for these prime VLBI capabilities is also utilized to develop and support other DSN capabilities as, for example, antenna arraying and Space VLBI telemetry acquisition and tracking (SVLBI spacecraft phase/clock synchronization and precision navigation).

Additionally, the DSN provides support for VLBI radio astronomy, geodesy and astrometry programs by 1) participating in operations of the major radio astronomy VLBI networks (e.g., Very Long Baseline Array, European VLBI Network, Asian Pacific Telescope), 2) providing an opportunity for "host country" radio astronomers to conduct their research at the Madrid (Spain) and Canberra (Australia) DSN complexes, and 3) carrying out various JPL/NASA research programs using DSN antennas.

The objectives of the DSN's participation in such research activities are 1) to realize and exploit the scientific and technical potentials of the DSN for enhancement of VLBI radio astronomy, geodesy, and astrometry sciences, and 2) to develop new DSN capabilities for support of scientific observations with ever-evolving VLBI techniques. Support of these activities requires developing and maintaining capabilities that are in addition to those required for deep space communication.

3. *Summary of VLBI science and technology developments at the DSN.*

DSN antennas have been used for VLBI since the inception of VLBI in the late 1960s. Radio astronomers were using them for pioneering VLBI experiments taking advantage of their superb sensitivity and longest baselines [1]. During the 1970s, in addition to radio astronomy experiments, the JPL/DSN group began to perform precision measurements of the position of radio sources and monitor UT1 and polar motion variations using the MKII data acquisition terminals and bandwidth synthesis technique [2]. In the 1980s, VLBI capabilities became an operational tool at the DSN to support spacecraft navigation [3]. The DSN complexes were equipped with specialized narrow bandwidth VLBI systems to support spacecraft navigation, and using the MKIII systems to provide the platform parameter calibrations. The DSN supported in part the development of the JPL/Caltech VLBI correlator and had 50% of the correlator time to support the DSN needs [4]. In addition to S- and X-band receivers which are standard DSN equipment, an L-band receiving capability has been implemented at the DSN 70m antennas to support the VEGA balloon experiment to study Venus's atmospheric dynamics [5], and a Ku band receiver at the Canberra 70m antenna has been added to support the first earth-to space VLBI experiments with the TDRSS communication satellite [6]. The 1990s marked further significant progress in the development of the DSN VLBI capabilities and operations through the upgrade of the VLBI recorders to MKIV, adding K-band receivers at 70m antennas to support co-observations with the VSOP space radio telescope, implementing an 11m tracking network with S-2 and VLBA recorders to support SVLBI spacecraft operations and antenna arraying to support operations of the Galileo spacecraft operations.

A number of outstanding results in the fields of astrophysics, astrometry, and geodesy were obtained in VLBI experiments with DSN antennas.

I. DSN VLBI capabilities were intensively used for astrophysical studies of very compact radio sources (extragalactic supernovae remnants, galactic and extragalactic masers, and Active Galaxy Nuclei cores). A few VLBI surveys of compact extragalactic radio sources have been conducted with the DSN providing structural information on hundreds of radio sources [7,8]. Some of the observing programs monitored changes in the structure of sources for many years (SN 1993J [9], Centaurus A [10]). The DSN 70-m antenna in Canberra was the primary co-observing telescope in the first Earth-to-space VLBI experiments with the TDRSS communication satellite between

1986-88[11]. Since 1997, the DSN 70m antennas have been providing co-observing support in L-band for the Space VLBI mission VSOP.

II. The results of the astrometry VLBI observations with the DSN made a fundamental impact on the field. Work on the VLBI astrometry catalog has been conducted at the DSN since the 1970s providing a uniform data set with a time span of about 20 years [12]. This JPL astrometric catalog of extragalactic sources which was intended to be used for spacecraft navigation became an integral part of the catalog of a few hundred compact extragalactic objects with position uncertainty typically of ~ 0.5 mas which defines the International Celestial Reference Frame (ICRF) adopted by the IAU [13] in 1997. It also provided the basis for the determination of the extragalactic-planetary frame tie with an accuracy of ~ 3 mas [14] and corrections to the Earth's precession and nutation models [15]. Additionally, because of its high sensitivity, the Goldstone 70m antenna was one of the prime antennas used to link the Hipparcos optical stars catalog to the ICRF through the VLBI measurements of the position of 11 Hipparcos catalog's stars which have a sufficiently high level of radio emission [16].

Other results in positional astronomy (astrometry) achieved with the participation of the DSN VLBI include: 1) the VLBI position and proper motion measurements of the balloon deployed in the Venus atmosphere by the VEGA spacecraft [17], 2) the proper motion measurements of the guide stars for the Gravity Probe B experiments – a mission to test the yet-to-be-verified prediction of the general theory of relativity [19], 3) the discovery of low-mass companions of a few radio stars [20], and 4) the measurement of the angular deflection of light by Jupiter's gravity field [21].

III. The VLBI measurements obtained at the DSN have been used for geodesy since the 1970s. The DSN began to participate in geodetic VLBI on a regular basis since establishing the NASA Crustal Dynamic project in 1979 [22]. A few geodetic programs are supported currently by the DSN 34 m antenna subnet including the international CORE program [23] and the European geodetic VLBI network program [24]. The results of the DSN internal Earth rotation monitoring program, which is important to maintain at the DSN for purposes of deep space spacecraft navigation, is provided to the IERS Central Bureau on a regular basis. Additionally, the JPL/DSN participates in the International VLBI Service for geodesy and astrometry as the data analysis center utilizing and maintaining the specialized software package MODEST.

4. *Current DSN VLBI programs and customers*

A list of the DSN VLBI programs and sponsoring organizations is given in Table 1.

2. Two VLBI radio astronomy programs are currently conducted at the DSN in support of flight missions: 1) VSOP (Space VLBI co-observing at 70m telescopes) and 2) Gravity Probe-B (monitoring of the proper motion of reference radio stars).
3. Two long-term ground-based VLBI programs: one geodesy (CORE) and one astrometry (VLBI detection of the extrasolar planets) are currently supported by the NASA Space Science Office.
4. Although the prime goal of NASA's Deep Space Network is to support space flight missions, in recognition of the value of large DSN radio telescopes for radio astronomy, NASA is allocating up to 3% of the DSN antennas time for ground-based radio astronomy research (Guest observing programs). VLBI radio astronomers have been for a long time the major users of the DSN's radio astronomy guest observing time. The DSN antenna in Goldstone, CA, and Madrid, Spain, are participating in observational sessions of the EVN, VLBA, and Global VLBI.
5. The intergovernmental agreements between the US and Spain, and the US and Australia provide to radio astronomers in Spain and Australia so-called "host-country" time at the DSN telescopes. This time accounts for about 1-2 % of the DSN radio telescopes' time. The

VLBI radio astronomy experiments consume a major portion of "host country" time in Spain and Australia.

6. Additionally, the DSN/JPL maintains DSN internal VLBI programs to monitor the earth rotation parameters (Clock Sync) and astrometric catalog of the reference sources for spacecraft navigation, Catalog Maintenance and Enhancement (CAT M&E).

Table 1. DSN VLBI Programs

Sponsor, Category of Support	*Project*	*Scheduling Period (epoch)*	*Number of tracks at each epoch*	*Duration of one track(hr)*	*Antennas*	*Special Requirements*
NASA Office of Space Science, Flight projects	Space VLBI Co-observing	Every month	6-12	6-10	DSS14,63 43	High reliability of data return (>80%)
	Gravity Probe-B	4 epochs annually	1	8	DSS14,63 43	
NASA Office of Space Science, Research Programs	Geodesy VLBI (CORE)	About 20 experiments annually	1	24	DSS15,45 65	S/X, simultaneously
	VLBI Detection of extrasolar planets	Every 6 weeks		16	DSS14,63	Two antennas simultaneously
NASA Office of Space Science, Radio Astronomy Guest observations	EVN	2/12-3/05	2	12	DSS14,63	
		5/20-6/10	2	12	DSS14,63	
		9/10-10/01	2	12	DSS14,63	
		11/05-11/25	2	12	DSS14,63	
	Global VLBI	2/15-2/28	2	12	DSS14,63	
		5/20-6/10	2	12	DSS14,63	
		9/10-10/01	2	12	DSS14,63	
		11/15-11/25	2	12	DSS14,63	
	VLBA	Every month	1	8	DSS14	
NASA Office of Space Science, Host country	Host Country (Spain)	Quarterly	4	12	DSS63,65	
	Host Country (Australia.)	Quarterly	4	12	DSS43,45	
JPL, DSN	Cat M&E	Every 6 weeks	1	24	DSS15,65 45	15 & 65; 15 & 45; S/X simultaneously
	Clock Sync	Every month	2	12	DSS15, 65	Two antennas simultaneously
	Antenna Calibration	Every month	1	5	DSS14,43 63	

Figure 1 shows the DSN time utilization for VLBI experiments and programs.

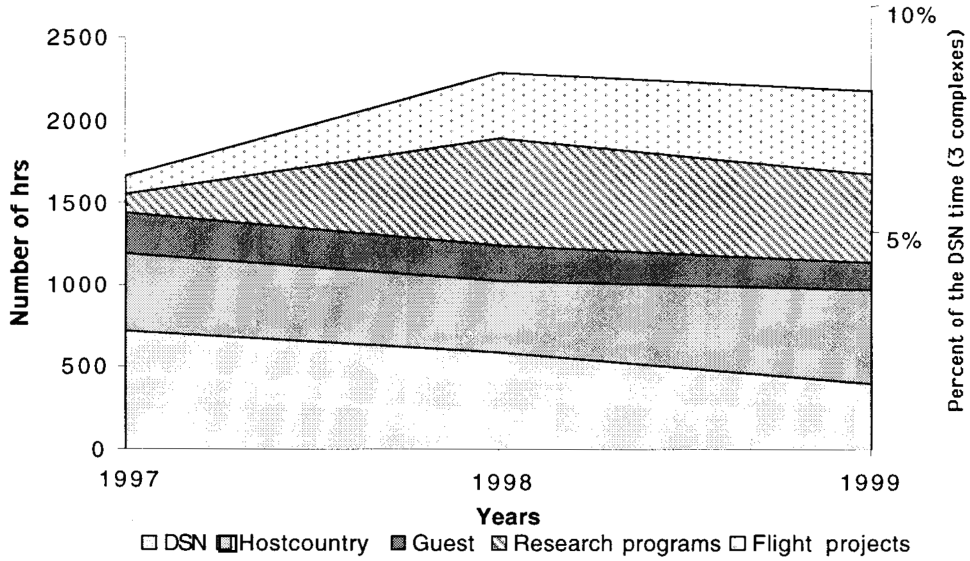

Figure 1. DSN time utilization for VLBI programs

5. *DSN VLBI Hardware and Operations status*

The DSN facilities include three major installations around the world: Goldstone, California, Madrid (Robledo), Spain, and Canberra (Tidbinbilla), Australia. The extremely large baselines between the DSN antennas/complexes and its strategic locations permit very high angular resolutions (close to the maximally possible at the surface of the earth) to be realized in VLBI observations between the DSN antennas and with other radio telescopes and interferometric networks. Additionally, high sensitivity (large collective area, state of the art LNAs) and the ability to do VLBI phase referencing (fast antenna re-pointing, antenna clusters) have made the DSN facilities very valuable astronomical resources to conduct state-of the art VLBI experiments. Table 2 provides the current status of the DSN equipment which is utilized for VLBI and other types of radio astronomy observations.

All receivers have ambient loads and noise generators to provide automated measurements of the system temperature. Additionally, a Dicke-type beam switch is available which provides the capability for K-band radiometric measurement with reduced sensitivity to atmospheric fluctuations. The MKIV recording terminals (with dual recorder transports at each station) include the control computer running the PC Field System (PCFS) which can be controlled locally as well as remotely and automatically. The system configuration also includes the power meters to monitor the IF input levels.

The Deep Space Network has evolved to support the operations of deep space missions. The security required to support these operations with high reliability creates significant differences in the operating environment for the DSN radio telescopes compared to regular radio telescopes. While the PCFS computer provides a high level of compatibility with other VLBI installations, it cannot function as a prime DSN station computer. Instead, two additional computers, the Equipment Activity Controller (EAC) and the Radio Astronomy Controller (RAC), are used to interface the PCFS computer with other DSN subsystems. In effect, the EAC and RAC make the rest of the DSN appear like a radio astronomy observatory to the PCFS while providing a high degree of security to the DSN. The EAC is the prime interface for the so-called "operational equipment," mainly the antenna and microwave electronics. It is used to perform antenna pointing according to a sequence of events provided by the PCFS, as well as antenna configuration and calibration performance check. The RAC is the prime interface to the L- and K-bands radio astronomy receivers. Its functions are to control the receiver LO frequency, noise generator, and tone generator.

Table 2. DSN Radio astronomy capabilities.

DSN Complex Location	*Antenna*	*Diameter (m)*	*Frequency Bands (GHz)*	*Tsys= SEFD (Jy)*	*Polarization / Channels configuration*	*Frequency standard / Clock*	*VLBI Recorders*	*Spectrum analyzer*	*Types of RA observations that can be performed*
Goldstone, CA, USA, (GDSCC)	DSS13	34	31.9–32.1 40-50	300 900	LCP, RCP S&X simult.	Hydrogen maser / GPS	MKIV	BW=40 MHz, Number of ch. = 2097152	Spectroscopy, Continuum, Polarization, VLBI
	DSS14	70	1.6-1.73 2.2-2.3 7.9-8.7 18-26	40 15 20 55	LCP&RCP simult.* S&X simult.				Spectroscopy, Continuum, Polarization, VLBI
	DSS15	34	2.2-2.3 8.4-8.5	165 130	LCP, RCP, S&X simult.				VLBI
Canberra, Australia, (CDSCC)	DSS43	70	1.6-1.73 2.2-2.3 7.9-8.7 12-18 18-26	40 15 20 50 55	LCP&RCP simult. S&X simult. **	Hydrogen maser / GPS	MKIV and S-2 (CSIRO)	BW=20 MHz; Number of ch. = 16384	Spectroscopy, Continuum, Polarization, VLBI
	DSS45	34	2.2-2.3 8.4-8.5	165 130	LCP, RCP, S&X simult.				VLBI
Madrid, Spain, (MDSCC)	DSS63	70	1.6-1.73 2.2-2.3 8.4-8.5 18-26	40 15 20 55	LCP&RCP simult. S&X simult.	Hydrogen maser / GPS	MKIV	BW=10 MHz; Number of ch. = 256	Spectroscopy, Continuum, Polarization, VLBI
	DSS65	34	2.2-2.3 8.4-8.5	165 130	LCP, RCP, S&X simult.				VLBI
* S and L-band single polarization only, **Fixed linear polarization in 12-18 GHz channel									

The DSN VLBI Schedule Processor (DVSP) provides a bridge between a user which submits its VLBI schedule file through the Internet and the secure networks internal to the DSN. The schedule (VEX format) is preprocessed at the DVSP to check its validity (including correctness of the scheduled DSN time, format, etc.). In the event the schedule files have problems, a message to the submitter will be generated. The valid VLBI schedule file is used to generate the station predicts (pointing, sequence of events), which then are sent to the station operations personnel and to the PCFS for execution during the scheduled time. After the experiment, the DVSP holds the log file for retrieval by the experimenter or someone at whatever correlator is to be used. It should be noted that this method of schedule processing is a significant departure from current DSN practice. In effect, the experimenter is totally responsible for the content of the schedule.

Since the configuration of a DSN telescope is often changed to support different projects, it creates the possibility for telescope configuration errors. To make VLBI observations at the 70m DSN telescopes more reliable, especially at K-band, a set of so-called "pre-calibration" procedures is performed before every observing session. These fully automated sets of procedures are appended to the schedule file and include i) initialization of the antenna and the microwave electronics, and ii) a pre-calibration procedure that will verify system performance from the microwave through the recorder.

The DSN VLBI capability includes also the XF type VLBI correlator (Block II) which is capable of processing the MKIV VLBI data. The correlator has four MKIV playbacks. It is used mainly to process the DSN/JPL internal VLBI programs data.

The nominal gain curves of the DSN antennas are given in Table 3.

Table 3. Nominal gain curves of the DSN antennas used for VLBI

$G(\theta) = G_o - G_1(\cos\gamma - \cos\theta)^2 - G_2(\sin\gamma - \sin\theta)^2 - A_z / \sin\theta$ (where: G is in dBi, θ is an elevation angle)								
	Vacuum Component of Gain							
Parameter	*L-band*	*S-band*	*X-band*			*K-band*		
	All stations	*All stations*	*DSS14*	*DSS43*	*DSS63*	*DSS14*	*DSS43*	*DSS63*
G_o (dBi)	60.17	63.34	74.17	74.1	74.28	81.06	80.57	81.82
G_1 (dBi)	0.088	0.088	0.99	1.047	1.049	6.885	7.282	7.296
G_2 (dBi)	0.104	0.104	0.473	1.979	1.766	3.288	13.76	12.28
γ (deg)	46.27	46.27	45.78	46.21	46.83	45.78	46.21	46.83
*Weather condition**	*A_z Atmospheric Attenuation, dB*							
Vacuum	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0%	0.029	0.029	0.033	0.035	0.035	0.059	0.062	0.061
25%	0.0298	0.0298	0.035	0.041	0.041	0.13	0.176	0.174
50%	0.0307	0.0307	0.036	0.045	0.045	0.202	0.291	0.290
80%	0.0317	0.0317	0.039	0.052	0.052	0.288	0.432	0.431
90%	0.032	0.032	0.041	0.059	0.059	0.348	0.527	0.526

* Qualitatively, the weather condition is described as follows:
0% - clear, dry, lowest weather effect; 25% average clear weather, 50% clear humid or very light clouds, 90% very cloudy, rain. As an example, 90% means that 90 percent of the time an attenuation is less than or equal to a given value.

The 70m antenna pointing performance at K band is a very critical factor to perform reliable well-calibrated observations. Currently, the accuracy of the antenna pointing models at DSN antennas is between 3 and 5 millidegrees (11-18 angular sec). With the antenna beamwidth at this wavelength of about 12 millidegrees, the estimated error in the signal amplitude may be a few tens of percent. The goal of the DSN is to improve the accuracy of antenna pointing models to 1.2 millidegrees.

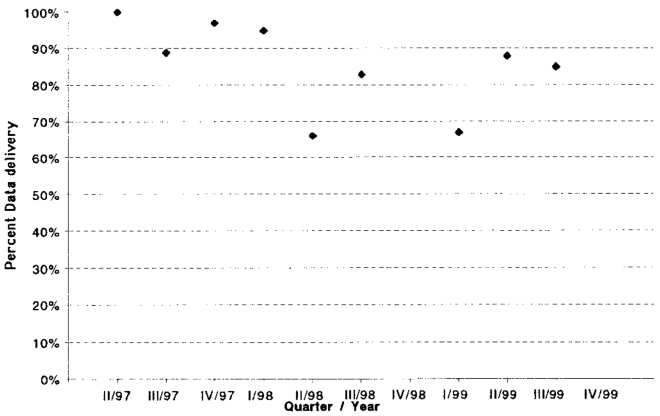

Figure 2. DSN VLBI performance

Figure 2 illustrates the DSN VLBI performance in terms of the percent data delivered (ratio of the actual recording time taken from the station LOG to that requested by the experimenter) through the last 2.5 years of the VLBI co-observing with the Space VLBI mission, VSOP.

6. *DSN VLBI Organization*

The Plans and Commitments Office of the JPL's Tracking and Mission Operations Directorate (TMOD) is the prime organization within the DSN which establishes and maintains the interface with the DSN VLBI external customers. Among its responsibilities are: 1) establishing appropriate technical and organizational interfaces with the projects and VLBI organizations, 2) managing the space VLBI co-observing operations and VLBI operations for radio astronomy and geodesy, 3) organizing a review of the proposals for guest observations at the DSN, 4) providing the requests for the allocation of the necessary DSN time, 5) disseminating of the information on the technical and operational characteristics of the DSN VLBI to potential customers, 6) providing the guest radio astronomers with the necessary expertise to successfully execute observations with the DSN radio telescopes.

The development and implementation of VLBI capabilities at the DSN is the responsibility of the DSN Engineering Office while operation and maintenance are under the purview of the DSN Operations Office, both within the TMOD. These offices respond to the requirements provided by the Plans and Commitments Office, allocates the budget for necessary developments, manage implementation and maintenance of the VLBI equipment including the correlator.

The day-to-day VLBI operations including 1) preparation of the observational sequence of events and stations predicts (pointing), 2) operation of station equipment, 3) monitoring of the performance and delivering the data tapes and auxiliary data to the correlators, and 4) operating the JPL correlator, BlockII, are the responsibilities of the JPL/NASA contractors' personnel. The Customer Service Representative (CSR) and Network Operations Engineer (NOPE) are the prime contact for users to monitor the status of the project and resolve inconsistencies in the schedule. The station radio astronomy engineer and "friend" of the DSN telescopes (in Madrid and Canberra) usually help with the setup of the experiment configuration, calibration and conduct the observations. (For contact information see http://dsnra.jpl.nasa.gov)

7. *Opportunities and challenges*

The Space VLBI requirements have been the major driver for the upgrades and improvements of the VLBI DSN system in the last decade. They have initiated at the DSN the upgrade of the VLBI recorders to MKIV and the upgrade of the K-band receivers at the 70m sub-network. A new VLBI user interface and operational system based on a PCFS and three other controllers (DVSP, EAC, RAC) provides simpler access to users to the VLBI DSN system and more reliable operations. Additionally, the 11m antenna sub-network has been built through the extensive use of VLBI technology to collect high data rate spacecraft telemetry (up to 144 Mbit/s) and provide the clock synchronization and high accuracy navigation in order to support the Space VLBI missions operations.

It is likely that the space VLBI missions will be the most demanding customers for the DSN VLBI in the future. Particularly, future SVBI missions will need 1) ground telescope co-observing support (only one antenna in space; at least one other antenna required to have the interferometric fringes), 2) ground telescopes with large apertures (antenna in space rather small), 3) high-precision apertures capable to operate at millimeter wavelengths, and 4) telescopes located around the world and especially located close to the spacecraft tracking stations to enable real-time correlation. These future SVLBI VLBI needs for co-observing are naturally fulfilled by the DSN capabilities.

The future space and ground-based VLBI technology driven by science tends to evolve to 1) higher frequencies (space VLBI – 22, 43, 86 GHz, millimeter wavelength VLBI), 2) wideband (up to 1-8 Gbit/s) recording and processing, 3) precision calibration, and 4) highly reliable VLBI operations. These and other capabilities listed in Table 4 need to be implemented at the DSN to enable support for future space VLBI missions as well as to participate in the work of the major radio astronomy and geodesy VLBI networks.

Table 4. New VLBI capabilities needed at the DSN

VLBI networks / programs	*Observing frequency bands (GHz)*	*Data rates (Gbit/s)*	*DSN VLBI existing capabilities can be employed*	*New DSN VLBI capabilities needed*
Space VLBI missions: Radioastron, VSOP-2, ARISE	0.32 - 86	0.144 - 8	Antennas: 70m subnet Recording: MKIV Receivers: L, X, K bands; Polarization: LCP/RCP at K-band	Antennas: 34 m subnet Recording: S-2, MKIV upgrade, S-3 Receivers: 5 GHz band (at 70m), 43 GHz and 86 GHz bands (at 34m) Polarization: LCP/RCP Configuration: two bands or two polarization simultaneously.
Centimeter VLBI networks (EVN, VLBA, APT)	0.32 – 43	1 - 8	Antennas: 70m subnet Recording: MKIV Receivers: L, X, K bands; Polarization: LCP/RCP at K-band	Antennas: 34 m subnet Recording: S-2, MKIV upgrade, S-3 Receivers: 5 GHz band (at 70m), 43 GHz band (at 34m) Polarization: LCP/RCP Configuration: two bands or two polarization simultaneously, fast frequency switching.
Coordinated Millimeter VLBI Array (CMVA)	84 - 88	1 - 8	Antennas: 34 m subnet Recording: MKIV	Recording: MKIV upgrade, S-3 Receivers: 86 GHz band (at 34m) Polarization: LCP/RCP
International VLBI Service (IVS) for astrometry and geodesy, CORE	S/X	1 - 8	Antennas: 34m subnet Recording: MKIV Receivers: S/X bands Configuration: two bands simultaneously	Recording: MKIV upgrade, S-3

The DSN already began the implementation of the S-2 VLBI recording at the DSN complexes. Additional to the S-2 recorder in CDSCC which is maintained by CSIRO, the DSN will install in the next two years S-2 recorders at all three complexes and interface them with the operational DSN equipment. Also, the DSN is developing a software correlator which will eventually be installed at each complex and used for real-time fringe verification. Currently, the prototype of this correlator is used for the ground-based testing of the SVLBI project Radioastron space radio telescope. To provide support for the internal DSN VLBI projects, the DSN is implementing a new VLBI correlator successor to Block II. The correlator will be capable of processing the MKIV data and will have four playbacks.

The DSN is currently undergoing through significant organizational changes which may influence the interfaces with the DSN VLBI science users. Two major paradigms are the themes of these changes: the service provider and full cost accounting. VLBI became one of the services (along with other science services: Radio astronomy, Planetary radar, Radio science) which the DSN provides customers. These may, for example, introduce certain difficulties in rapidly implementing the new capabilities. "Full cost accounting" will eventually assign a cost of the DSN operations to every project supported by the DSN. The algorithm and procedures are still evolving. The impact of the implementation of full cost accounting on the DSN science services is not clear yet.

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