SPACECRAFT TRACKING WITH LARGE RADIO ARRAYS. D. L. Jones[1], S. Weinreb[2], and R. A. Preston[1], [1]Jet Propulsion Laboratory, California Institute of Technology, mail code 238-332, 4800 Oak Grove Drive, Pasadena, CA 91109 (dj@sgra.jpl.nasa.gov; rap@sgra.jpl.nasa.gov), [2]Jet Propulsion Laboratory, California Institute of Technology, mail code 168-214, 4800 Oak Grove Drive, Pasadena, CA 91109 (Sander.Weinreb@jpl.nasa.gov).

Introduction: A team of engineers and scientists at JPL is currently working on the design of an array of small radio antennas with a total collecting area up to one hundred times that of the largest existing (70-m) Deep Space Network (DSN) antennas. Although inspired by the Square Kilometer Array being designed by the radio astronomy community, the proposed DSN array would be devoted to spacecraft communications and navigation. An array of this size would provide obvious advantages for high data rate telemetry reception and for spacecraft navigation. Among these advantages are a two-order-of-magnitude increase in sensitivity for telemetry downlink, flexible sub-arraying to track multiple spacecraft simultaneously, increased reliability through the use of large numbers of identical array elements and geographic diversity, very accurate (milli-arcsecond) real-time angular spacecraft tracking, and a dramatic reduction in cost per unit area. NASA missions in many disciplines, including planetary science, would benefit from this increased DSN capability. The science return from planned missions could be increased, and opportunities for less expensive or completely new kinds of missions would be created. The proposed DSN array would be by far the most sensitive radio telescope in the world.

The Deep Space Network Array Concept: The current concept for the DSN array is based on several thousand commercially mass-produced parabolic radio antennas, each 6-12 meters in diameter, and operating at 8 and 32 GHz. The total cost for this array is estimated to be far less than the cost of an equivalent collecting area provided by traditional large-diameter (34-m or 70-m) antennas.

Advantages of a Large Array for the DSN: There are a number of reasons for DSN interest in a large array of many small antennas:

- Large decrease in cost per unit of sensitivity
- Lighter, lower power, and less expensive spacecraft telemetry hardware
- Reduced pointing and stability requirements for spacecraft using lower gain antennas
- Flexible scheduling — simultaneous tracking of multiple spacecraft over wide areas of the sky with continuously variable aperture for each
- New spacecraft navigation capability: real time, high precision angular position measurements — complements range and Doppler data and provides full 3-D spacecraft positions without the need for trajectory modeling or for long tracking passes
- High reliability — graceful degradation of array performance if individual antenna elements fail; moving mechanical parts are small and light weight; simplified operations and low-tech maintenance
- Useful telemetry reception possible over low-gain spacecraft antennas during entry, descent, and landing or spacecraft emergencies
- Array is continuously expandable and upgradeable
- Array maintenance can be carried out during normal operations — high utilization rates are possible

The most frequently discussed configuration for the DSN tracking array consists of a central region containing a dense network of array elements along with a smaller number of elements spread over a large (>500 km) geographic area. Such a configuration combines ease of phasing the central elements for telemetry reception and more precise spacecraft position measurements with the longer baselines.

A separate, but potentially important, benefit for spacecraft navigation is the ability to detect and image the thermal emission from a large number of solar system targets, including asteroids and moons as well as planets. This will provide accurate positions for these targets in the same reference frame as the astrometric spacecraft tracking measurements.

New Science Opportunities: A large increase in DSN capabilities would enable new types of missions, including radio occultation measurements using very distant spacecraft, direct reception of lander, rover, or penetrator signals on earth, multi-spacecraft interferometer arrays, spacecraft with no on-board data storage, down-links with both high data rates and high duty cycles, and short-lifetime missions to hostile environments. Spacecraft without high gain antennas, high power RF amplifiers, or their associated power supplies and thermal constraints could be flown. Savings in spacecraft mass would apply to a large number of future missions, leading to potentially very substantial saving to NASA over the life of the DSN array.

For missions similar to those currently being flown, a much higher fraction of the data produced by high-data-rate instruments such as wide-area high resolution imaging, synthetic aperture radar, or hyper-spectral imaging could be returned during the mission lifetime.

Technical Innovations: How can this proposed increase in DSN performance be affordable? There are five major technology developments that have reduced the cost of large arrays dramatically. These are:

1. Precision, mass-produced parabolic dishes developed by the home satellite TV industry
2. Wide-band, low cost MMIC RF amplifiers that provide low system temperatures at moderate physical temperatures (tens of degrees K)
3. Long-life pulse tube cryogenic coolers being developed for the computer industry
4. Wide-band optical fiber data transmission
5. Continuing reductions in the cost of computing, which allows large-scale signal combination to be done with a minimum of custom-designed hardware

Our basic strategy is to take advantage of the huge investments made by industry to reduce the cost of the components and systems from which a large array can be built.

We need to use non-optimized, mass-produced systems, rather than the traditional approach of designing and building small quantities of ultimate-performance systems. This is the approach being taken in the design of the Allen Telescope Array (composed of 350 6-m diameter antennas) and in concepts for the Square Kilometer Array. The result is expected to be a significant reduction in the cost per unit sensitivity. For example, low-cost MMIC amplifiers are likely to have twice the noise temperature of optimized low noise amplifiers cooled to 15K or lower. However, it appears to be less expensive to compensate for this factor of two loss in sensitivity by doubling the total collecting area instead of by reducing the receiver noise temperature.

The <u>only</u> way to obtain an orders-of-magnitude increase in radio sensitivity is by increasing the collecting area, because both receiver temperatures and error correcting telemetry codes are already close to fundamental limits.

Summary: Future NASA missions will require high downlink data rates to maximize their scientific productivity. Higher frequency RF and optical communication systems are being developed for this purpose, but it will probably be more cost effective to provide additional downlink data rate capability with a large increase in ground antenna area, especially if the cost per unit area is reduced significantly. In addition, missions with short-duration, high priority phases such as planetary flybys, radio occultations, atmospheric probe arrivals, etc., would require less on-board data storage if higher real-time downlink rates were available. Finally, very low power signals from landers, atmospheric probes, or even ground penetrators could be received directly on Earth, giving additional geometric information and greater mission redundancy.

Placing more of the complexity and mass of a communication link on Earth rather than on a spacecraft could open up entirely new ways of doing planetary science, and the cost of a ground array can be amortized over a large number of future missions (not just planetary ones). For all of these reasons one or more large, low-cost arrays are a promising approach for NASA spacecraft tracking during the coming decades.

Acknowledgement: This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.