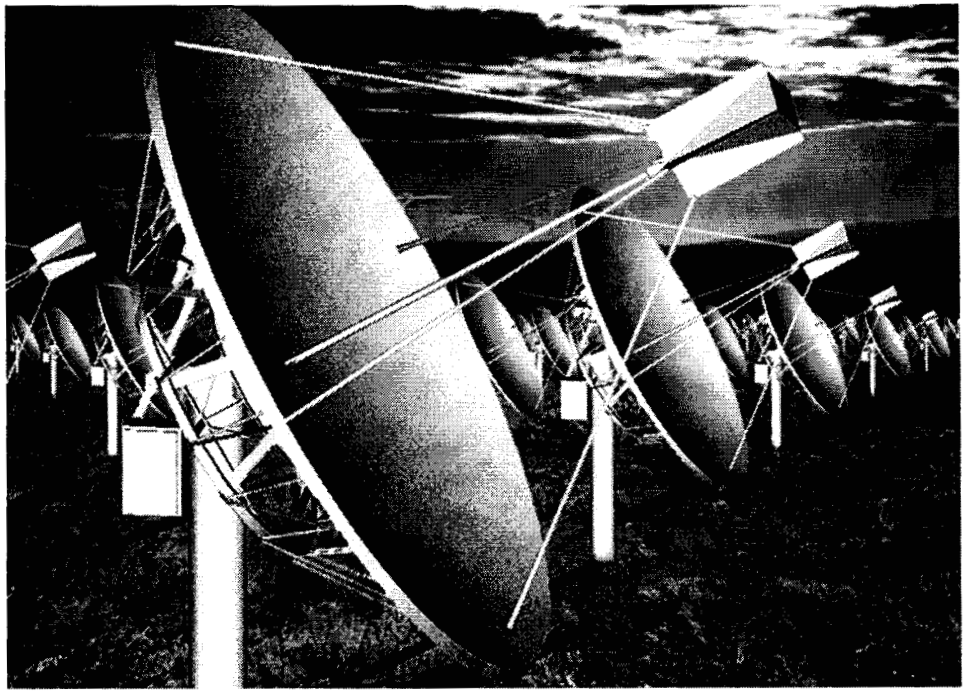
Interplanetary Network and Information Systems Directorate

An Introduction to Very Large Arrays for the Deep Space Network



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Outline

I. Purpose of Array System

II. System Description

III. Array System Processing

IV. Operations Concept

V. Concluding Remarks

I: Purpose of Array System

- The purpose of the Array System is to achieve 100 to 500 times increase in Deep Space Network (DSN) signal reception capability at an affordable cost, by 2020.
- The Array System could:
  - Greatly increase mission science data return. For example, planet mapping missions could return full surface coverage, rather than the few percent return of today's missions.
  - On-board spacecraft telecom system mass could be reduced, enabling new mission concepts and cost savings.
  - Cost per data bit could be reduced by two orders of magnitude.
- Status: Development is beginning of an Operational Prototype Array System equivalent to one or two 70-m antennas, to be completed in 2008. This will be used to validate performance, implementation and operations costs, and the operations concept.

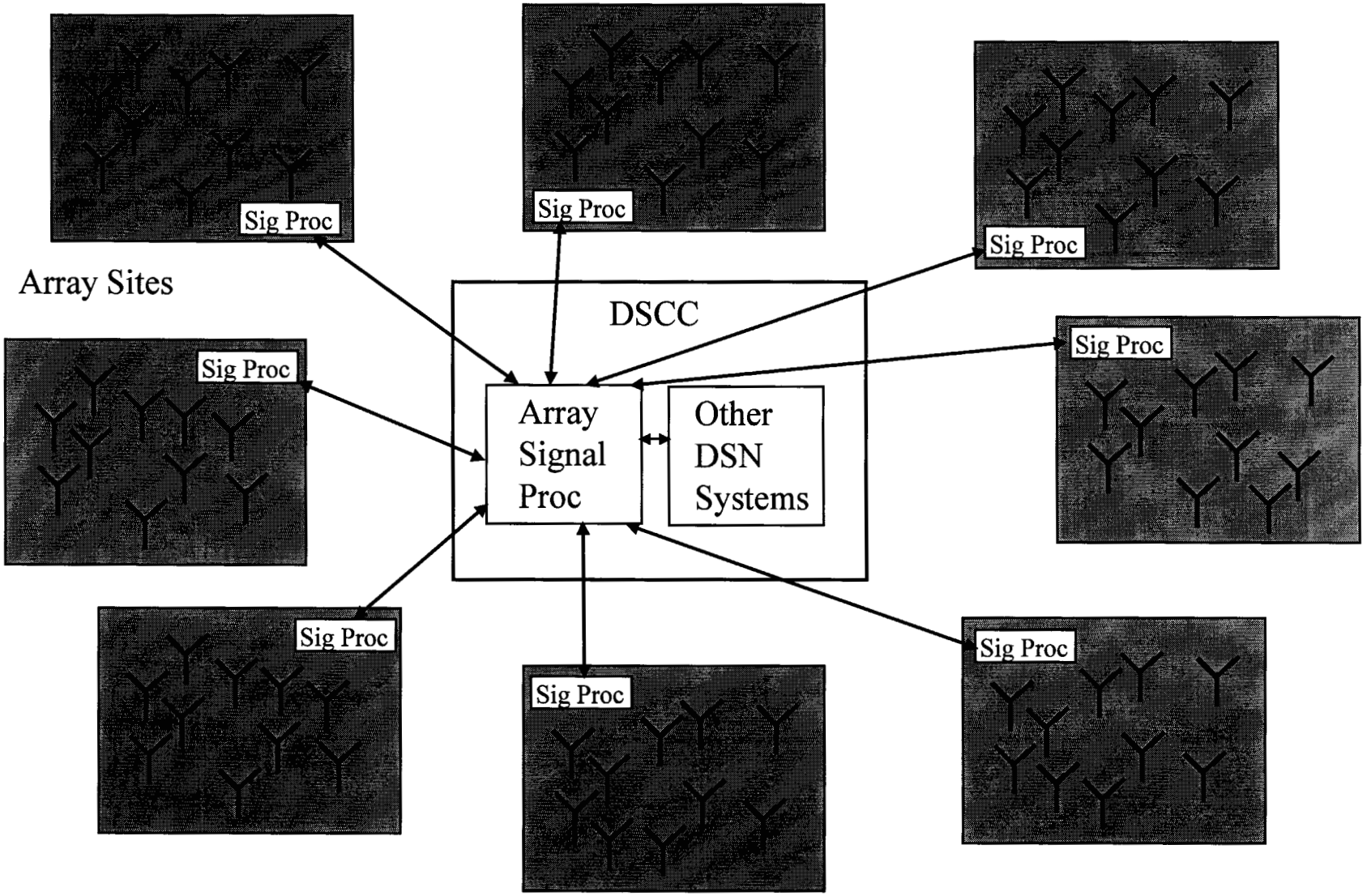
II: System Description

The key elements of the Array System are:

- A large number (~3600) of small (~12m) antennas, approximately equally distributed at approximately eight sites on each of three continents
  - The G/T goal is the equivalent of 100 70-m antennas, at both X-band and Ka-band
  - The sites are located far enough from each other to provide weather diversity for Ka-band, and baseline geometry for Delta-DOR
- A signal processing capability at each site
- An Array Central signal processing facility, located at an existing Deep Space Communications Complex (DSCC)
- Communications between antennas and site central, and between sites and the DSCC
- Array monitor and control
- Operations and maintenance personnel

II: System Description

Array System Pictorial



Key Functions of Array System

- The Array System will perform the signal reception functions of the DSN.
- Each array can be operated as several subarrays, with the subarrays pointed at different targets.
- Each subarray can receive signals from multiple sources simultaneously, provided these sources are within the beams of the physical antennas. This corresponds to the current Multiple Spacecraft Per Antenna (MSPA) capability.
- The Array System operates in conjunction with other key elements of the DSN:
  - Antennas for uplinks – existing or new DSN antennas, or uplink arrays
  - Downlink signal processing that processes the signal outputs of the array – telemetry, tracking and navigation, science
  - External monitor and control or service management from the DSCC
  - Planning and scheduling service management functions analogous to current capability.
- All mission phases will be supported by the Array System.

II: System Description

Site Diversity

- Ka-band Weather Diversity
  - Locating the antennas at widely separated sites provides weather diversity for Ka-band.
  - Subarrays will typically use the same number of antennas from each site. This will average out the weather effects, enabling operation with fewer antennas and higher "worst-case" SNR than using only one site.
- Delta DOR and VLBI
  - Wide site separation enables Delta-Differential One-way Range (Delta-DOR) and Very Long Baseline Interferometry (VLBI).
- Availability
  - System availability is enhanced by site redundancy. Services will not be interrupted if one or even two sites have failures.

III: Array System Processing

- To the rest of the DSN and to missions, the Array System is very much like a collection of large antennas. One difference is that these large synthesized antennas can be of any size, or G/T, up to the full array capability.
- External control is very similar to controlling a number of distinct large antennas. For each synthesized antenna, the Array System needs to know the track schedule and the key characteristics of the target: position, frequency band, telemetry predicts, etc.
- The array processing functions are very similar for all tracking scenarios:
  - Signal Reception
  - Delay Modeling, Correlation and Delay Alignment
  - Beam Forming
  - Output

III: Array System Processing

Signal Reception

- The antennas selected for each subarray are pointed in the required directions. When a sub array is tracking more than one target, pointing may be based on one of the targets or on a combination of the target directions.
- The microwave elements of each sub array must be set to the desired frequency bands and polarizations.
- The signals are amplified by cryogenic low noise amplifiers, and probably translated to an intermediate frequency.
- The signals from each antenna are transmitted to the signal processing facility at each site.

III: Array System Processing

Delay Modeling and Alignment

- The Array System uses predicts and delay modeling for course alignment of the signals from the various antennas. This leaves residual errors in delay and phase.
- The residual errors are estimated using a correlator. The predicted delay and phase are corrected by the correlator estimates. The signals are aligned in delay and phase, and combined in the beam former.
- Alignment for each subarray is done first at the sites, and then the signals from the sites are aligned and combines at the DSCC.
- Phasing needs to be updated throughout a track, due to instabilities in propagation delay and instrumentation.
- The correlation process can use either the spacecraft signals or signals from a natural radio source. When using spacecraft signals, the processing needs to be matched to the carrier and subcarrier frequencies and to the modulation bandwidth.

III: Array System Processing

Beam Forming

- Beam forming is the weighted summing of the corresponding signals from all antennas in each subarray.
- When more than one spacecraft is being tracked by a subarray, or if there are more than one RF signals from a spacecraft, then there are more beam forming operations than subarrays.
- Beam forming is done in two steps:
  - At the array sites, for the signals at the sites
  - At the DSCC, for the beam signals from the array sites
- Beam forming combines the signals with proper time delay, phase delay, and amplitude.
- RFI suppression: The amplitude and phase weights can be chosen to form nulls in the synthesized beams, so as to suppress RFI. This can be done with little loss in G/T in the target direction.

III: Array System Processing

Signal Output

- The signals from the final beam formers at the DSCC are output the the Telemetry, Tracking and Command System (TT&C) at the DSCC.
- To be compatible with the current and planned TT&C, the digital signals from the beam formers will be converted to analog IF signals and output to the IF Switch at the DSCC. This will allow the array outputs to be directed to and processed by any downlink channel, under control of the Service Management System.
- The analog outputs will also be compatible with radio science equipment at the DSCC.

IV: Operations Concept

Operations Cost is Critical

- Operations cost will place a limit on total array size, because there is no point in building a system that we cannot afford to maintain.
- Operations cost includes planning, scheduling, real time operations, sustaining engineering and maintenance.
- The dominant operations cost will be maintenance, because of the large number of antennas.
- Array design will emphasize maintenance concepts and cost in order to minimize the system life cycle cost.

IV: Operations Concept

Reliability and Availability

- Antennas: High availability of antennas is not required to achieve high system availability, because of the redundancy. High reliability of antenna elements is required to keep maintenance costs low.

- Sites: High reliability of the site signal processing and control elements is important to keep costs down. For system performance, high availability is desirable, but this is not critical because there is site redundancy.

- DSCC: The signal processing and control at the DSCC needs to have very high reliability and availability, because a failure could interrupt all of the tracks in progress.

IV: Operations Concept

Planning and Scheduling

- Similarities to Today's DSN
  - Planning and scheduling will be done in advance as today.
- Differences from Today
  - There is flexibility to have a variety of effective antenna sizes.
  - Specific antennas will be assigned by the Array System and the operators.
  - There are several possible scheduling approaches:
    - Guarantee a certain G/T to each user, with some antennas held in reserve for bad weather or other degradations. Use reserve antennas for low priority tracks until needed for the prime tracks.
    - Assign users sets of antennas, with usage and margin up to the user.
    - Assign antennas based on mission priorities, with lower priority missions losing support in event of bad weather.
  - Demand access can be supported under typical weather conditions.

IV: Operations Concept

Real Time Operations

- Operation for each mission will be similar to today, with most operator effort not on the array, but on the other system elements necessary to perform the telemetry, command, navigation and other services.
- Array operation will be fully automated for nominal operations, including assignment of specific antennas to subarrays. Operator intervention will be possible for situations where real time changes are necessary. These could be spacecraft emergencies or unexpected bad weather that impacts Ka-band reception so much that antennas need to reassigned and mission priorities need to be established or utilized.
- Calibration and diagnostics will be automated, taking advantage of the correlator outputs to detect degrading performance of an antenna.
- Operator array interaction may be by one person at each DSCC, or by one person at JPL for the entire network.

IV: Operations Concept

Maintenance

- Maintenance will be done so as to minimize cost, not to minimize time to restore individual antennas to service. Sufficient antennas will be used for tracks so that failure of a few antennas will not cause failures in performance of services.
- Preventative maintenance will be done primarily to minimize cost.
  - PM will be done when this will increase the lifetime of system elements, so as to minimize cost.
  - Some system elements will not be maintained until they fail, if this is the cheapest way.
- Maintenance of assemblies will be done the lowest cost way: in-place, at an on-site facility, at a DSCC or depot facility, at JPL, or by vendors.
- There will be a full-time (one-shift) maintenance crew for each site. In addition, personnel may need to be on-call for rapid restoration to service of critical signal processing elements at the site central processing facility.

IV: Operations Concept

Sustaining Engineering

- The system will change throughout the implementation and operations phases, due to parts obsolescence, technology advances, and opportunities to reduce costs.
- It is anticipated that there will be few if any system-wide upgrades, due to cost.
- Upgrades will be made as assemblies or components fail and need replacement. Improved or lower-cost replacements will be made as appropriate.
- There will be a continuing need for sustaining engineering to develop replacements.
- There will be a need for configuration management that tracks the status and version of each instance of each system element.

V: Concluding Remarks

- Very large arrays are the most promising way to obtain orders of magnitude increase in the DSN RF reception capability.
- This would greatly enhance mission science return, and reduce the cost per bit of science data reception by two orders of magnitude.
- Cost is the key challenge. Operations and maintenance costs are critical, because these could dominate the life cycle cost of the system.
- Development of an Operational Prototype Array System is beginning. This will be used to validate performance, implementation and operational costs, and the operations concept.
- A fully operational Array System could be in place in about 10 years, with full capability in about 20 years. This would achieve the DSN vision of improving capability by an order of magnitude each decade.