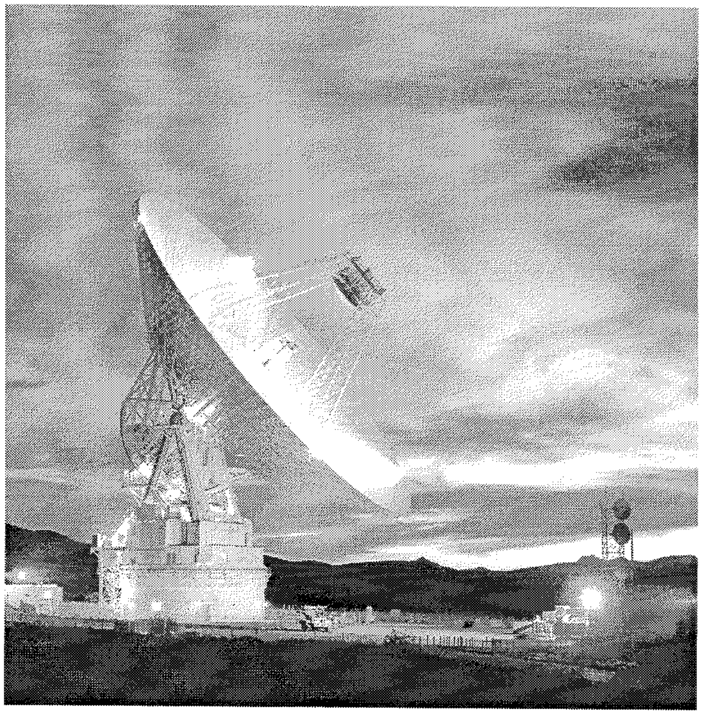
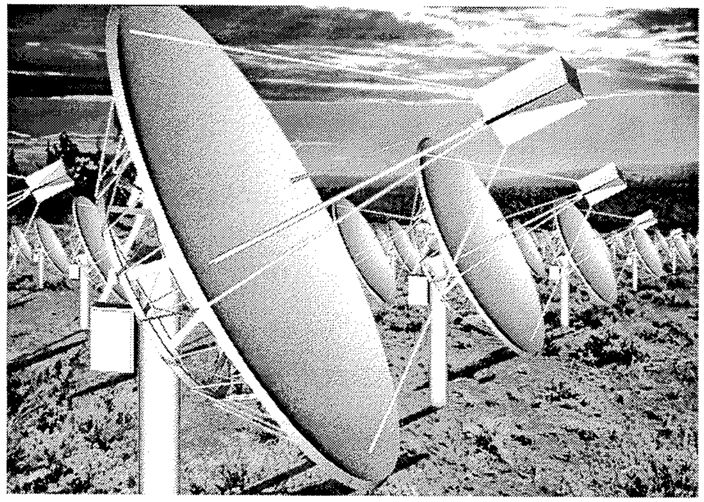
Uplink Options for an Array-Centric Deep Space Network





Presented to

2004 IEEE Aerospace Conference

by

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March 10, 2004

Introduction and Objectives

- The Deep Space Network is planning an era of very large arrays of small antennas to economically achieve much greater receiving capability.
- New uplink capability will be needed in the era of large arrays:
  - More uplinks to support more missions simultaneously
  - High EIRP for high rate uplinks, and for emergency command into spacecraft low gain antennas at great distances from Earth
  - To achieve the lowest life cycle costs
- The objectives of this presentation are:
  - To discuss the principles and technical challenges of uplink arraying, and the plan for resolving the technical challenges in the next year,
  - To establish an approach to comparing the life cycle costs of different approaches for uplinks: large antennas, arrays, or a combination,
  - To show that uplink arrays have a large potential cost advantage over building new 34-m and 70-m antennas.

Approaches for Uplinks

- There are several credible approaches for the types of antennas to be used for uplinks.
- Among all approaches shown to be technically feasible, the approach with the lowest life cycle cost (LCC) should be chosen.
- Four main approaches are considered:
  - In all approaches, the current antennas are retained as long as economical
  - Large antennas for the uplinks; no uplink arraying
    - Add new 34-m and 70-m (or similar size) antennas for additional capacity and to replace antennas that are no longer economical
  - 34-m antennas, with uplink arraying
    - Add new 34-m antennas, but not new 70-m antennas
    - Meet high EIRP requirements by uplink arraying of 34-m antennas
  - Use arrays of small (12-m class) antennas for uplinks
    - Use arrays for all new uplinks
    - Note: If the uplink arrays have substantially lower operations costs than large antennas, it may be economical to replace the large antennas sooner than the end of their otherwise useful lives
  - Use arrays for X-band and 34-m antennas for Ka-band
    - Due to difficulty of arraying at Ka-band

Uplink Array Principles

- For receive arrays, the effective G/T is proportional to the number of antennas (for identical antennas).
- For uplink arrays, the EIRP is proportional to the square of the number of antennas (for identical antennas).
  - When the far-field signals from each antenna are in phase, the signals add in the voltage sense, so the power adds quadratically in the number of signals.
  - Another way to view this is that an array of N identical antennas has N times the aperture and N times the power of one antenna, and all power is in phase. This is equivalent to one antenna with N times the power and N times the area, or N^2 times the EIRP of one antenna.
- One proposal is to build uplink arrays of 12-m antennas with 3.2 kW radiated power. Then

8x12m	is equivalent to	34m with 20 kW
16x12m	is equivalent to	70m with 20 kW
80x12m	is equivalent to	70m with 500 kW
		or one 70m plus eight 34m, with 20 kW

(Array Systems also need approximately 10 percent spares)

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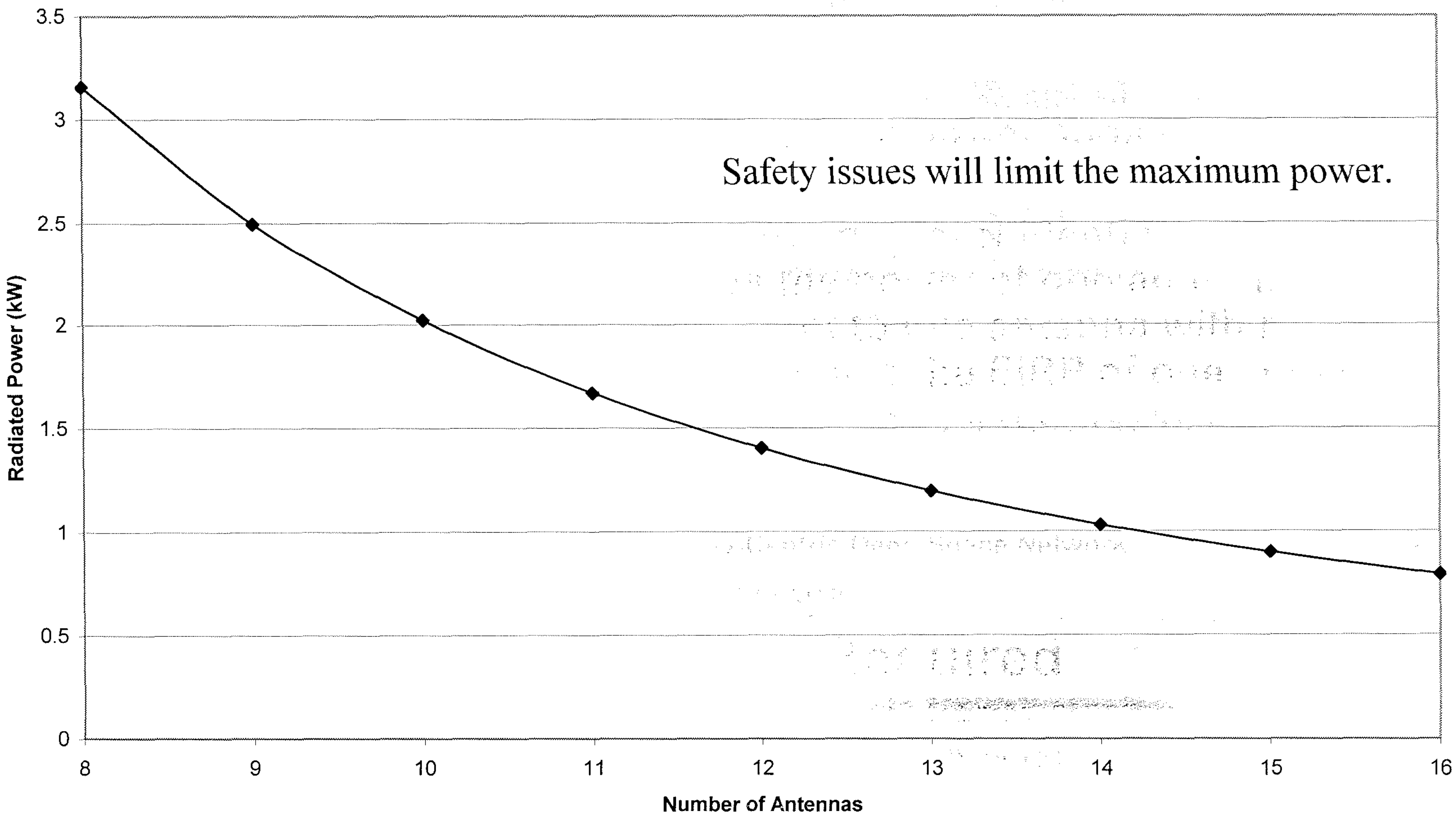
Uplink Arrays

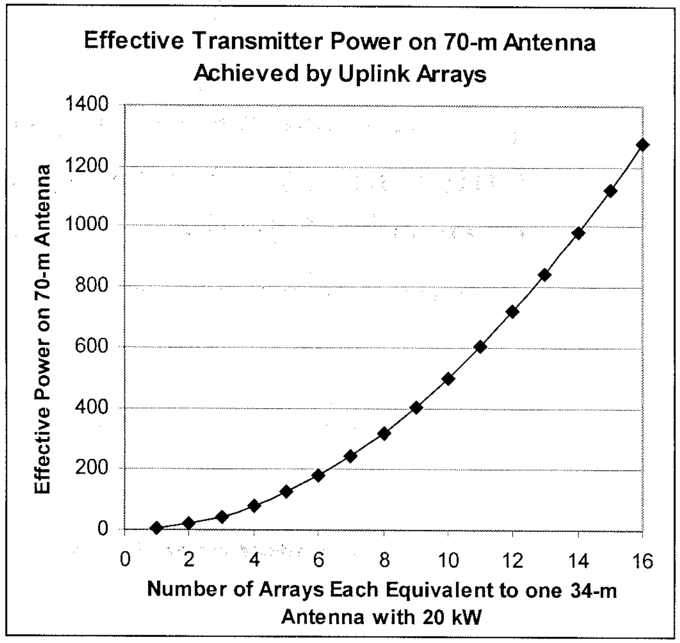
Radiated Power Required

Radiated Power Required for Array to be Equivalent to 20 kW on a 34-m Antenna

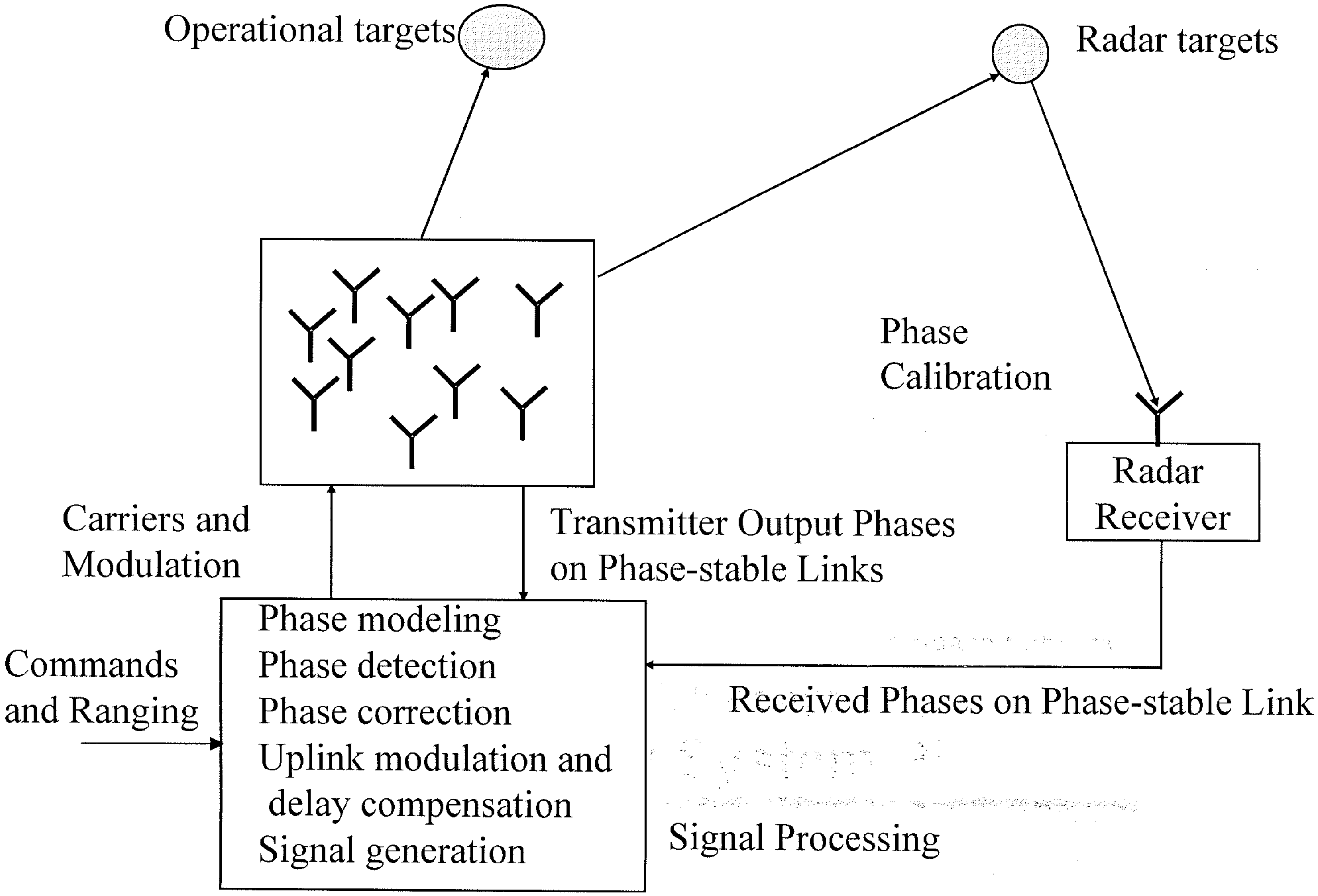


Achieving High EIRP

- The same antennas can be used both for many low EIRP uplinks and for one uplink with very high EIRP.
- For example:
  - To achieve the equivalent of the 400 kW we have today on a 70-m antenna (at S-band) takes the equivalent of nine 34-m antennas.
  - The equivalent of 1.28 MW on a 70-m antenna would take the equivalent of 16, 34m antennas.



Uplink Array System Pictorial



Uplink Arrays

Technical Challenges and Resolution Plan

- The main technical challenges in uplink arraying are:
- Initial calibration of the phases of the transmitted signal
  - The main approach is to use radar with Earth satellites for targets.
  - Feasibility will be assessed by surveying available targets, analyzing link budgets and errors due to target orbit uncertainties, reviewing past JPL work, and using outside help
- Maintaining phasing for different target positions, and for the time between calibrations (hours to days)
  - The main error sources are antenna mechanical stability, system electronic stability, and atmospheric stability.
  - These error sources are analogous to corresponding error sources for downlink interferometry.
  - Interferometry data from the three BWG antennas at Goldstone will be used to assess these error sources.
  - Uplink-unique instrument effects will be assessed for current systems.
- Resolution of these issues is planned by the end of CY2004.

JPL

Array Phasing Accuracy and Ka-band

- To keep degradation in EIRP to acceptable levels, it is necessary to keep the phasing between the array antennas to on the order of 10 to 15 degrees.
- In terms of time delay, the required accuracy is on the order of 1 mm for X-band, and 0.25 mm for Ka-band.
- These accuracies are very challenging, especially at Ka-band.
  - At Ka-band, real time atmospheric and instrument calibrations may be necessary, and/or only small, closely packed arrays may be feasible.
  - Real time calibration using downlink array signals is probably feasible when there is a downlink from the same spacecraft that is the uplink target.
- Uplink arraying may be feasible at X-band, but not at Ka-band.
  - Arrays might be used for X-band, and 34-m BWG antennas for Ka-band.
  - It might be most economical to use only large antennas for uplinks, with no uplink arraying. This may depend on the relative demand for X-band and Ka-band uplinks.

Basis for Life Cycle Cost Trades

- Assuming that uplink arrays are feasible with both 12-m and 34-m antennas, we observe that all needed capability can be built out of two "Baseline Building Blocks":
  - A " Full 34-m equivalent"
    - Downlink equivalent to a 34-m antenna
    - Uplink equivalent to a 34-m antenna with 20 kW radiated power
  - A "Receive-only 34-m equivalent", or "RO 34-m equivalent"
- The equivalent of a 70-m antenna with 20 kW can be achieved using two "Full 34-m equivalents", plus two "RO 34-m equivalents".
- Four "Full 34-m equivalents" would combine to equal a 70-m with 80 kW.

Basis for Cost Trades

Full and RO 34-m Equivalents

- RO 34-m Equivalent
  - The Prototype Array Task plans 12-m antennas with T=30K, plus 30K typical atmospheric noise (at Ka-band).
  - A "RO 34-m equivalent" takes 9 of these antennas (plus one spare).
- Full 34-m equivalent
  - If 3.2 kW transmitters are used, it takes 8 to achieve the EIRP of a 34-m antenna with 20 kW.
  - These antennas will probably have a higher system temperature than receive-only antennas.
  - Enough RO antennas need to be added to achieve G/T equivalent to a 34-m antenna
  - The paper discusses this and presents some curves.

Next Steps in Costing

- To estimate the life cycle cost of uplink arrays, the next steps are:
  - Complete system-level block diagram,
  - Complete operations concept,
  - Estimate the costs of key elements: transmitters, two-way feed system, phase control system, radar system, signal processing, power system,
  - Update estimates of performance and number of antennas needed,
  - Complete implementation cost estimate using cost data from receive-only Demonstration Array System task,
  - Estimate operations, maintenance and life cycle costs.
- For existing and potential new 34-m and 70-m antennas, obtain estimates of (future) life cycle costs. Include costs for uplink arraying of 34-m antennas, as appropriate.
- Compare results for different levels of DSN capability.

Initial ROM Implementation Cost Estimate

The purpose of this estimate is to establish that uplink arrays are worth further investigation, from a cost point of view. This is an initial Rough-Order-of-Magnitude cost estimate for implementation of "Full 34-m equivalent": 9 uplink plus 4 RO antennas. The estimate is for recurring cost assuming several will be implemented, and does not include non-recurring engineering.

Thirteen antennas and all other elements of downlink array, based on Prototype Array Task estimate of approximately $400K per antenna.	$5200K
9 transmitters and power @ $250K	$2250K
9 feed and microwave upgrades @ $50K	$450K
Uplink signal processing, including exciters, @ $100K	$900K
Phase-stable feedback of transmitter phase to signal processing @ $50K	$450K
Radar antenna system, facilities and links, shared with two uplink arrays	$1000K
Miscellaneous	$900K
Total ROM estimate for "Full 34-m equivalent" (Plus or minus 50 percent)	$11150K
ROM estimate for 70-m equivalent: Two "Full 34-m equivalents" @ $11150K plus 2 "RO 34-m equivalents" at 10x400=$4000K	$30300K

These estimates compare to roughly $35M for a 34-m antenna, and $100M for a 70-m antenna.

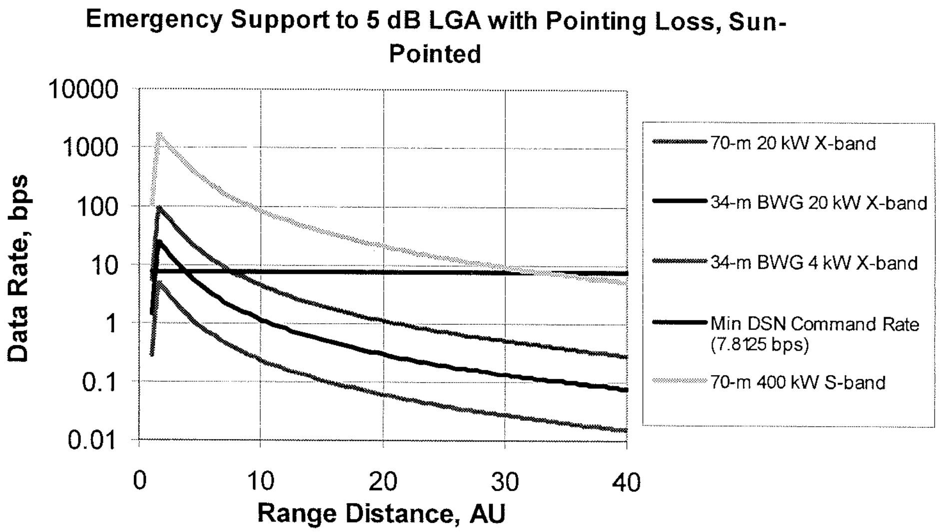
Concluding Remarks

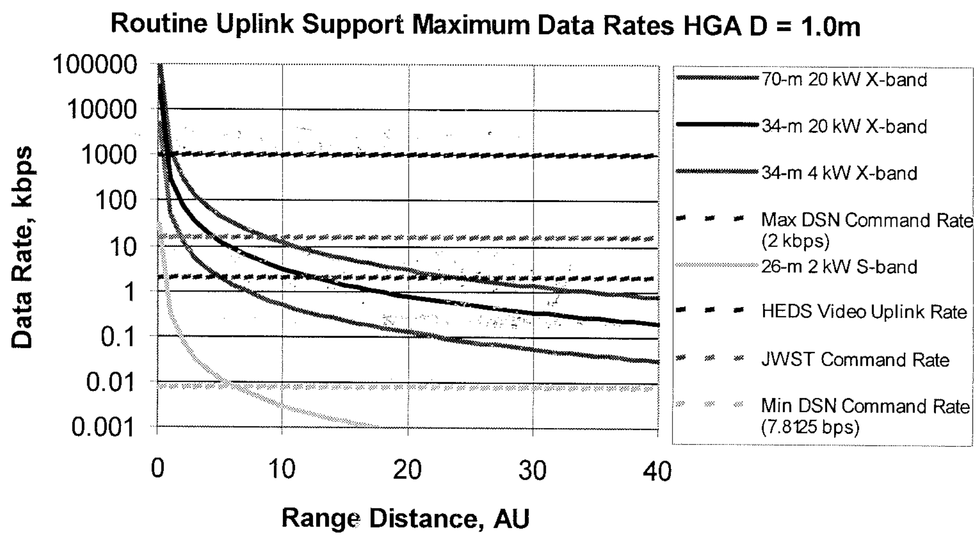
- There are mission-set drivers for increased DSN uplink capability.
- Life-cycle cost is a key driver on the technical approach.
- The principles and technical challenges of uplink arrays are well understood. There is a plan to resolve the technical feasibility by the end of CY2004, to the extent that resolution can be made without actual demonstration.
- A basis for comparing the costs of uplink arrays to large DSN antennas has been formulated.
- Uplink arrays appear to have cost benefits over 34-m and 70-m antennas. Initial ROM cost estimates for uplink arrays are less than one-third the cost of 34-m and 70-m antennas, for the same capability.

Backups

Drivers for Uplink Capability

- **Emergency Command:**
  - Need equivalent of 70-m antenna with 20 kW at Jupiter (6 AU).
  - Need equivalent of 70-m antenna with 400 kW at 30 AU.
- **High Rate Uplinks**
  - Future missions are anticipated to want command rates of 20 kbps to 1 Mbps.
  - A 70-m antenna with 20 kW supports only about 150 kb/s at Mars and 25 kb/s at Jupiter. (Coding or larger spacecraft antennas could increase these.)
- **Larger Mission Set**
  - The DSN will have to support more spacecraft in the future. Example: clusters of spacecraft, and numerous Mars missions.
  - Approximately 10 uplinks per complex may be needed, compared to 5 at Goldstone today, but this need is not yet well established.





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Uplink-Downlink Arrays

System Temperature and Numbers of Antennas