Enabling Affordable Communications for the Burgeoning Deep Space Cubesat Fleet

Douglas S. Abraham, Bruce E. MacNeal, and David P. Heckman
Jet Propulsion Laboratory, California Institute of Technology

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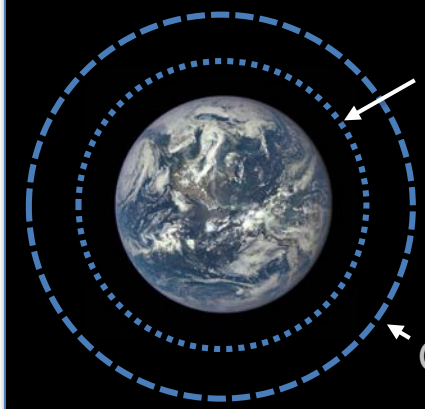
The Deep Space Challenge

$$P_r = \frac{P_t G_t A_e}{4\pi R^2}$$

Received power is inversely proportional to the square of the distance.



LEO: ~400 km

GEO: ~35,786 km

P_r = ~1 ten thousandth P_r from LEO

Lunar Distance: ~382,500 km

P_r = ~1 millionth P_r from LEO

Mars Distance: ~225,000,000 km

P_r = ~3 trillionths P_r from LEO

Communicating beyond GEO takes large antennas, low-noise receivers, and powerful transmitters.

The Scaling Problem

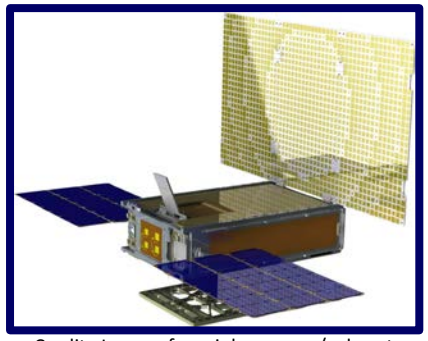
Mars Reconnaissance Orbiter

Credit: Images from mars.jpl.nasa.gov/MRO.

Smaller spacecraft are generally cheaper to build and launch. But,

Mars Cubesat One

Smaller solar arrays mean less available transmitter power.

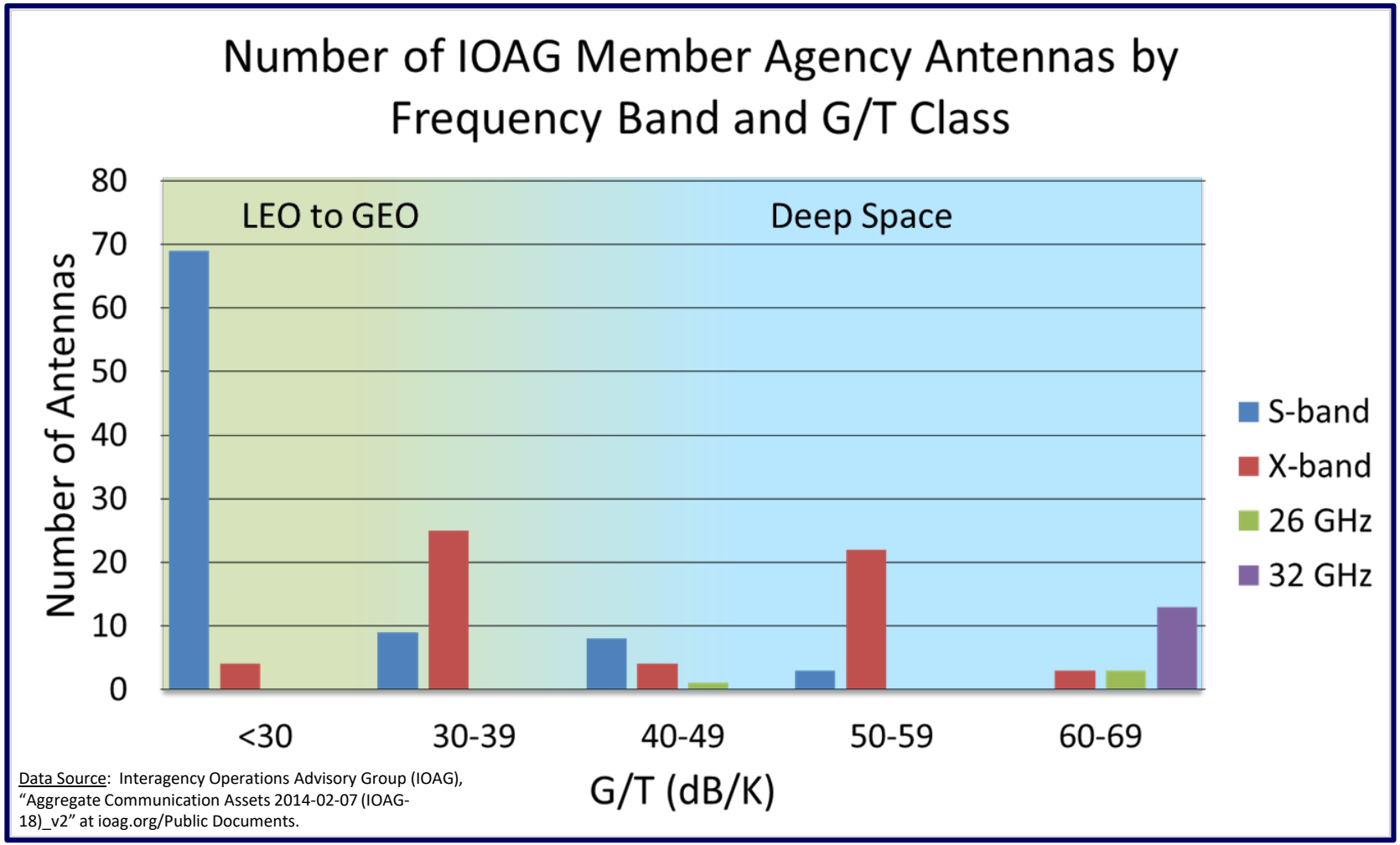


Smaller spacecraft have less area to devote to antennas.

Credit: Images from jpl.nasa.gov/cubesats.

The ground-side communications burden must increase to compensate.

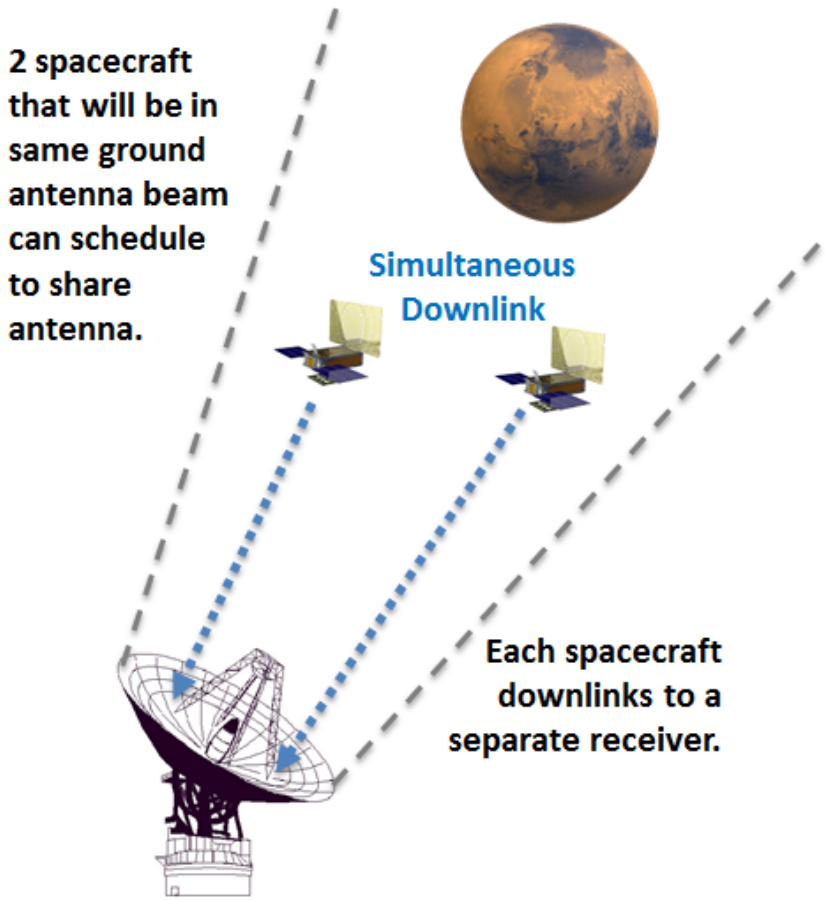
Ground Antenna Supply



The world's supply of deep-space-capable antennas is limited. We need to make efficient use of what we have.

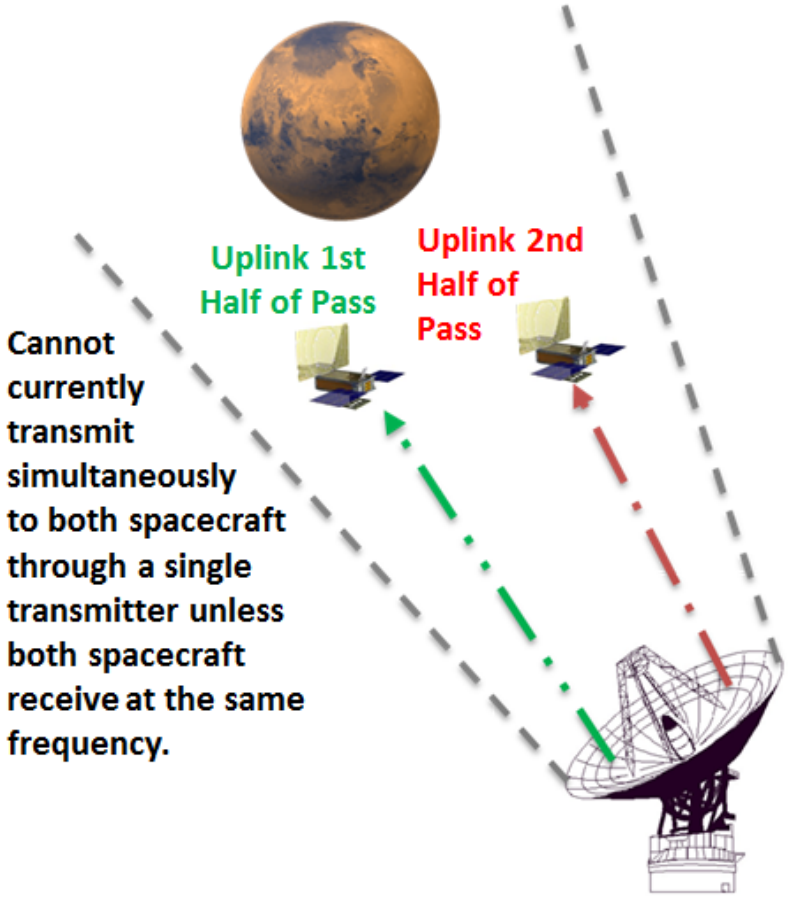
Multiple Spacecraft Per Antenna

2-MSPA



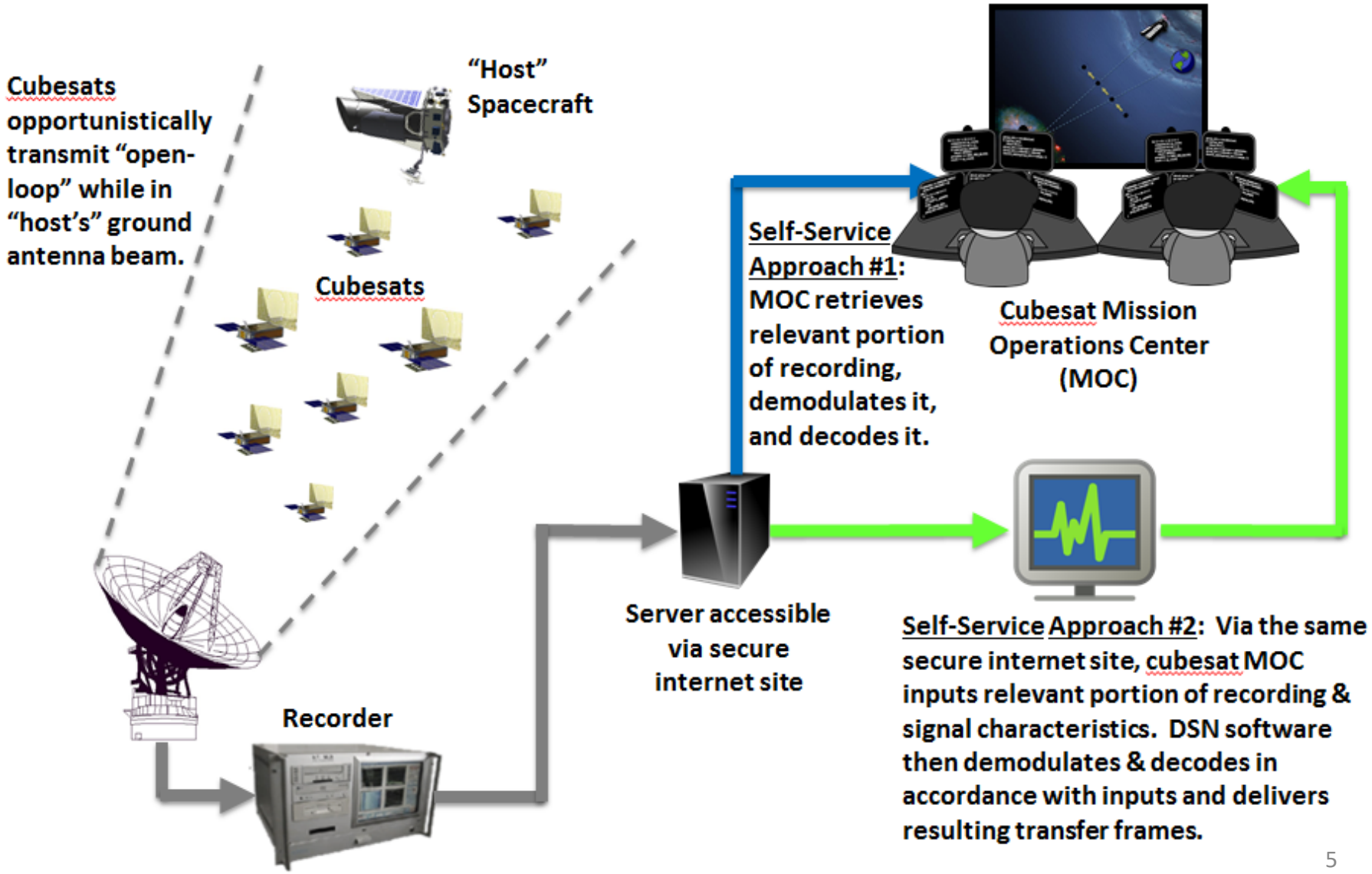
Currently, 2 receivers per antenna, allowing 2-MSPA. DSN moving to 4-MSPA capability on selected antennas.

Serial Uplink Swapping



Instead, while in 2-MSPA mode for the downlink, each spacecraft shares half the pass for the uplink.

Opportunistic MSPA



The Value Proposition

Why are MSPA and OMSPA important from the user missions' perspective?

1) Enhanced Antenna Availability

- 4-MSPA for critical events where low-latency is important.
- OMSPA for routine science downlink.

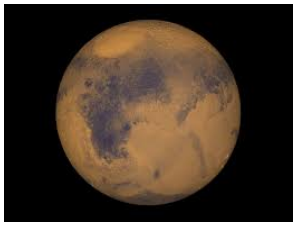
2) Reduced Antenna Scheduling Coordination

- OMSPA occurs outside the scheduling system; depends only on being in the beam of a scheduled spacecraft.
- No scheduling contention with other missions during OMSPA.

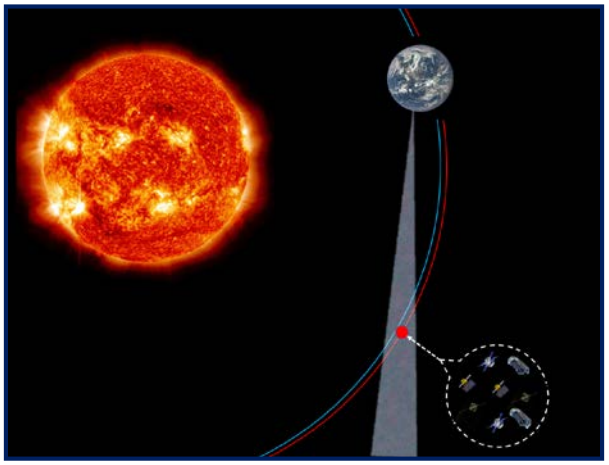
3) Reduced Aperture Fees

- While NASA missions do not actually pay these fees, they do factor into a mission's bottom-line cost during the proposal phase.
- While not yet decided, 4-MSPA will likely enable downlink-only at ¼ the base fee.
- While not yet decided, OMSPA might ultimately involve a nominal, flat monthly charge to recover the costs of the recorders, secure internet server, and their maintenance.

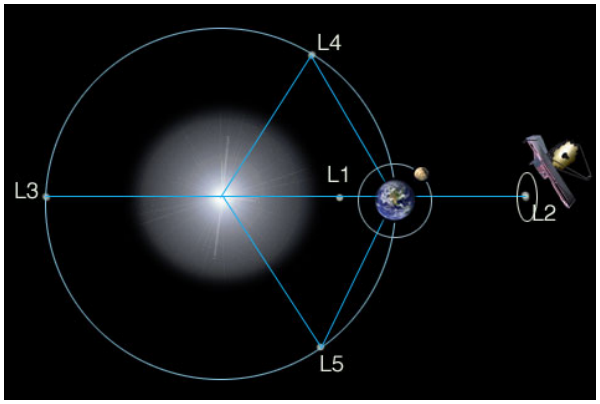
Example In-Beam Destinations



Cubesats at Mars or Venus are always in the beam of other spacecraft at these locations.



A constellation or “flotilla” of cubesats deployed into an Earth Trailing Orbit (ETO) will remain in beam of one-another with few maneuvers and little navigation.



Credit: http://jwst.nasa.gov/orbit.html

Very low-energy trajectories can take cubesats into SEL1 or SEL2 halo orbits timed to reside in proximity with (and in beam with) large observatory spacecraft.

Data Rate & In-Beam Range

Assumed Spacecraft Telecom Design	Transmitter Power(W)	Antenna Gain (dBi)	Band (Frequency, GHz)	Location	Earth→SC Range (AU, average)	Earth→SC Range (km, average)	Supportable Downlink Data Rate (bps)	Max Range from OMSPA Host (km)
Lunar Flashlight (earlier design)	1	5	X-Band (8.48)	Moon	0.0026	388,954	280,000	224
Lunar Flashlight (earlier design)	1	5	X-Band (8.48)	SEL 1,2	0.01	1,495,979	19,000	862
Lunar Flashlight (earlier design)	1	5	X-Band (8.48)	ETO	0.1	14,959,787	100	8,616
MarCO	4.5	28	X-Band (8.43)	Mars	1.7	254,316,380	1000	146,476
MarCO	4.5	28	X-Band (8.43)	Venus	1.1	164,557,658	2200	94,778
MarCO	4.5	28	X-Band (8.43)	ETO	0.1	14,959,787	318,000	8,616
MarCO	4.5	28	X-Band (8.43)	SEL 1,2	0.01	1,495,979	31,000,000*	862
MarCO	4.5	28	X-Band (8.48)	Moon	0.0026	388,954	480,000,000*	224
Mars Reconnaissance Orbiter	100	46	X-Band (8.43)	Mars	1.7	254,316,380	1,300,00	146,476

Calculations assume a DSN 34m ground antenna.
*Of course, the spacecraft electronics won't support this rate.

Cubesats at the example destinations are capable of quite useful data rates and can still stay reasonably far from other spacecraft sharing the beam.

Conclusions

- 4-MSPA and OMSPA minimize the requirement for building expensive new antennas while potentially offering prospective user missions enhanced antenna availability and reduced attributed aperture fees.
- OMSPA also potentially offers prospective user missions freedom from antenna scheduling contention over the time periods that it is applied.
- Cubesat mission designers can realize these benefits by selecting destinations that maximize their in-beam time with other spacecraft.
- For the example destinations in this study, cubesats can achieve very useful data rates and remain reasonably far from the other in-beam spacecraft.