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SmallSat Communications in Deep Space: A Novel Architecture

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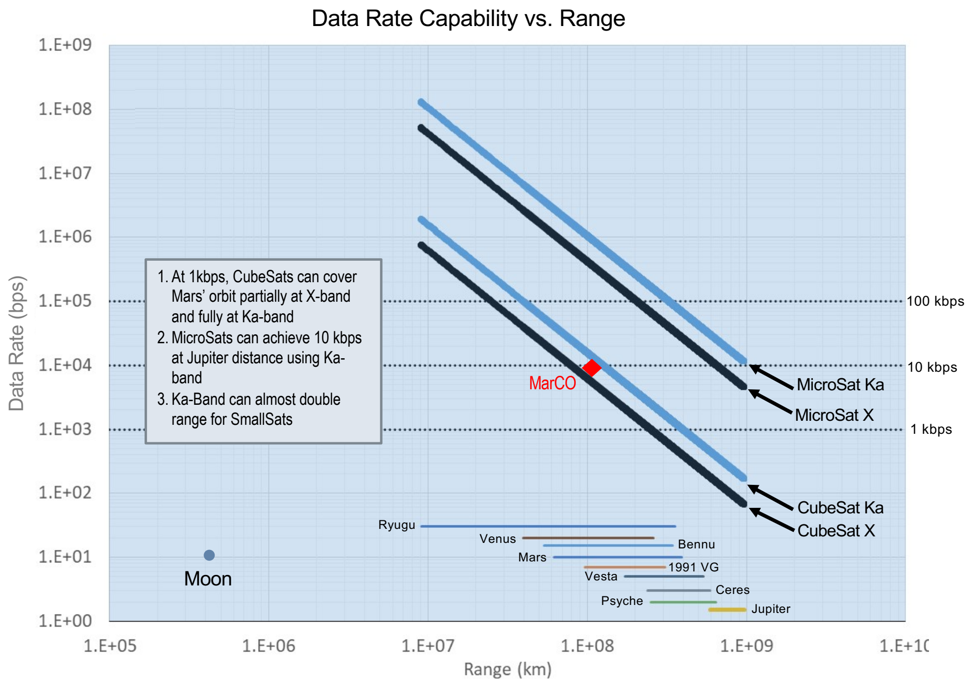
Background

- A NASA multiagency study in 2018 investigated improvements to SmallSat communications systems to allow SmallSats play a greater role in deep space science endeavors
- The space segment and the ground network were treated as a whole to provide for improvements not only via investments in technology, but also via improvements in operational procedures
  - In this study the ground network is assumed to be NASA's Deep Space Network (DSN)
- The study product was a set of recommendations (or guidelines) to space agencies and the planetary SmallSat community.
- The adoption of some or all of the guidelines is expected to result in an enhanced communications capability for the deep space SmallSat missions.

Type	Transmit Power	Antenna Size	Dry Mass	Comment
CubeSat	4 W (SSPA)	0.5 m	N/A	6U CubeSat
MicroSat	30 W (TWTA)	1.5 m	$\leq$ 100 kg	

Recommendations

1. SmallSats are encouraged to baseline their downlink at Ka-band to benefit from more spectrum availability, less competition for spectrum and increased antenna gain at Ka frequencies relative to lower bands

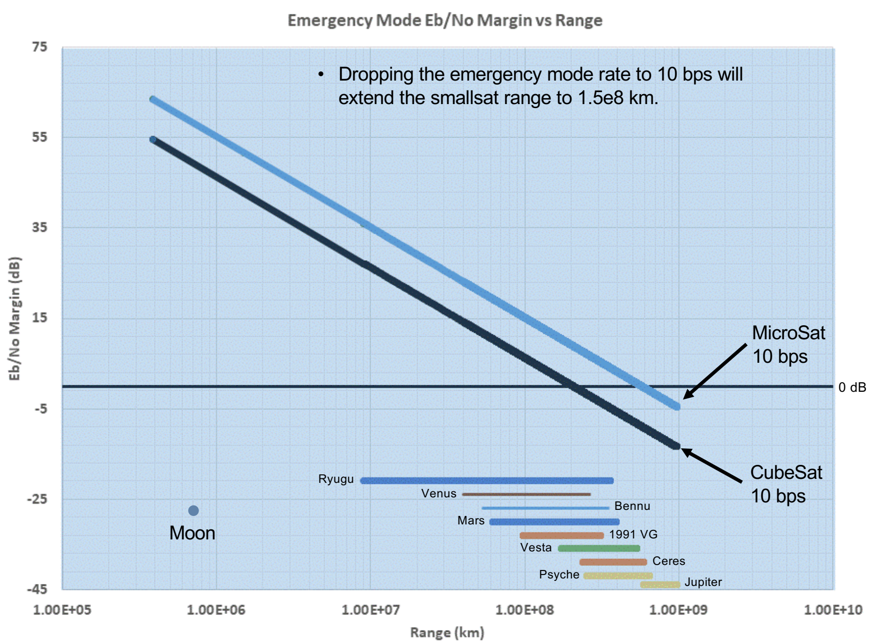


Data Related to Figure

Spacecraft	CubeSat (6U)	MicroSat (~100 kg)
Spacecraft Transmitter Power	4 W	30 W
Spacecraft Antenna Size	0.5 m	1.5 m
Ground		
Elevation	20 deg	20 deg
DSN antenna size	34 m	34 m
Receiver	Cryocooled	Cryocooled
Transmitter	N/A	N/A
Link		
Frequency X	8415 MHz	8415 MHz
Frequency K	26000 MHz	26000 MHz
Frequency Ka	32000 MHz	32000 MHz
Modulation	BPSK	BPSK
Coding	LDPC (1024, ½)	LDPC (1024, ½)
Weather	90%	90%
Margin (dB)	3	3

Recommendations, cont.

2. A study needs to be performed to investigate options for emergency mode communications. This might include evaluating the use of directional antennas, diversity antennas, lower data rates, etc.”



Spacecraft	Small SmallSat (6U)	Large SmallSat (~100 kg)
Spacecraft Transmitter Power	4 W	30 W
Spacecraft Antenna (single patch array)	8 dBi	8 dBi
Ground		
Elevation	20 deg	20 deg
DSN station (31-m antenna, 20 kW amplifier)	DSS34	DSS34
Link		
Telemetry Modulation Index	46 deg	46 deg
Telemetry Datarate	10 bps	10 bps
Frequency X	8415 MHz	8415 MHz
Modulation	BPSK	BPSK
Coding	Turbo (1784, 1/6)	Turbo (1784, 1/6)
Weather	90%	90%
Margin (dB)	3	3

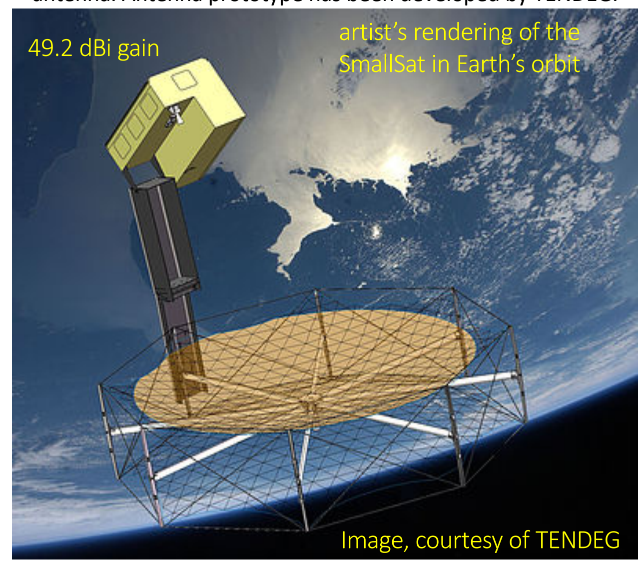
Recommendations, cont.

3. Deep space optical communication has the potential of providing many benefits for large primary missions that produce volumes of science data. However, because at this point the technology is not developed far enough and that a low-cost optical ground structure does not yet exist, it is recommended that the planetary SmallSat community to continue the evaluation of this technology for further maturation.
4. A study should be conducted to reduce SWaP of radios to free up SmallSat resources to be applied to primary mission goals. The study should include both DTE and proximity applications.
   - Example, combine DTE and proximity radios in one
5. SmallSats that use range observations for their navigation should employ PN regenerative ranging to improve range SNR and reduce interference effect on the range signal, improving communications efficiency.
6. SmallSats that intend to use DDOR for navigation should spread their DOR tone in order to improve their navigation accuracy without added operational cost.

Recommendations, cont.

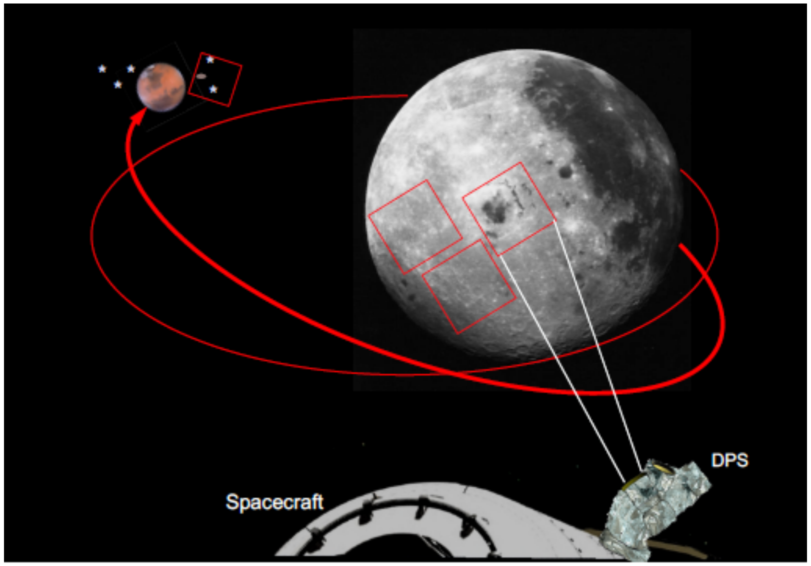
7. Because efficient, powerful SSPAs are needed to increase the range and transmission rate of SmallSats, investment should be made in Ka-band SSPAs with at least 40% power efficiency and an RF output exceeding 10 W. Similarly, at X-band SSPAs are needed with at least 40% power efficiency and greater than 15 W RF output.
8. Make investment in large aperture CubeSat deployable antennas focusing on two areas: (1) productize and improve reliability of the new technologies, such as mesh reflector and folded panel reflectarrays that have been developed in the past few years, and (2) fund R&D on higher risk new technologies that have better stowage efficiency / compaction ratio and/or lower mass density (see figure).

KaTENna: One-meter, Ka-band, deployable mesh reflector antenna. Antenna prototype has been developed by TENDEG.



Recommendations, cont.

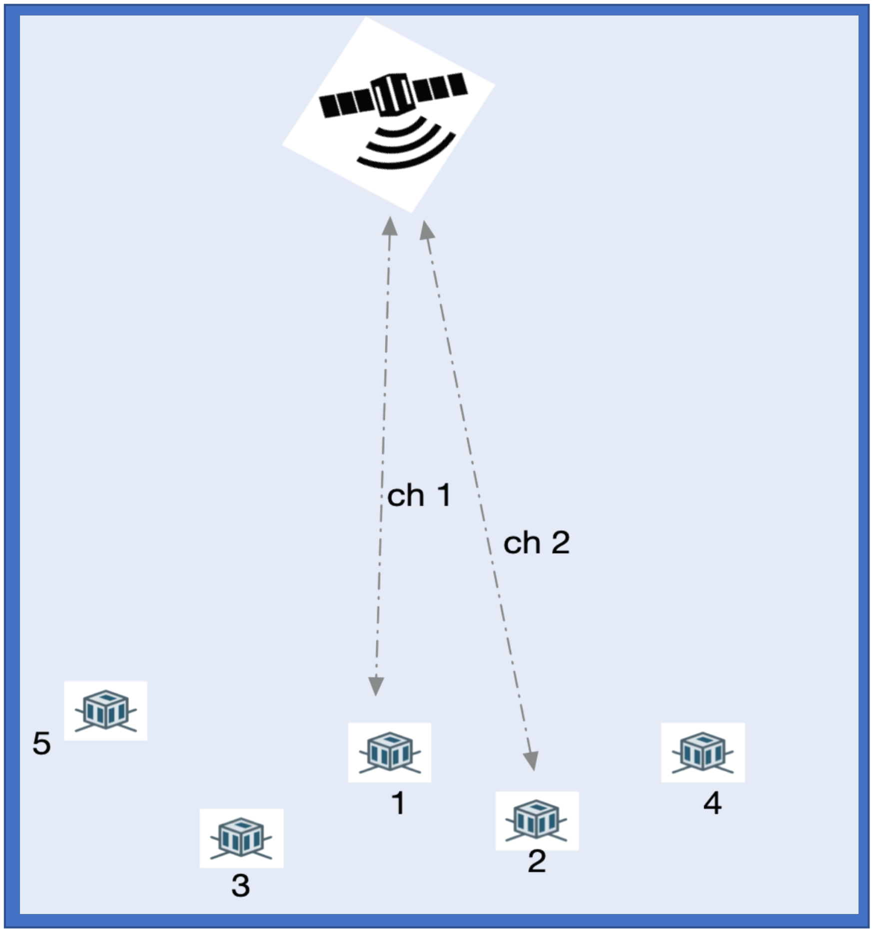
9. Optical navigation may offer great benefits to SmallSats with complex navigation requirements because it streamlines operations and enables new capabilities, such as autonomous navigation, rendezvous, and formation flying, that are not easily achievable with conventional approaches. NASA should invest in advancing the technology through development and flight demonstration efforts, with focus on low-cost Deep Space Positioning Systems (DPS) that would be suitable for use by SmallSats.



Credit: Division 39, JPL

Recommendations, cont.

10. Missions are recommended to consider Disruption Tolerant Networing (DTN) as a solution to data flow reliability and mission operations cost savings.
11. Implement multiple instantiations of Proximity-1 protocol with a radio supporting multiple frequency channels (see figure)
12. Implement the Demand Assignment Multiple Access (DAMA) feature of Proximity-1 protocol



Recommendations, cont.

13. Due to the fast pace of SmallSat development, it is often not practical to develop a new proximity flight antenna as part of the mission. Consequently, it would be beneficial for space agencies to identify the range of likely antenna requirements and fund developments in those areas.
14. Depending on range and data rate requirements, guidelines on frequency preference and antenna directivity for proximity applications are provided in the Table:

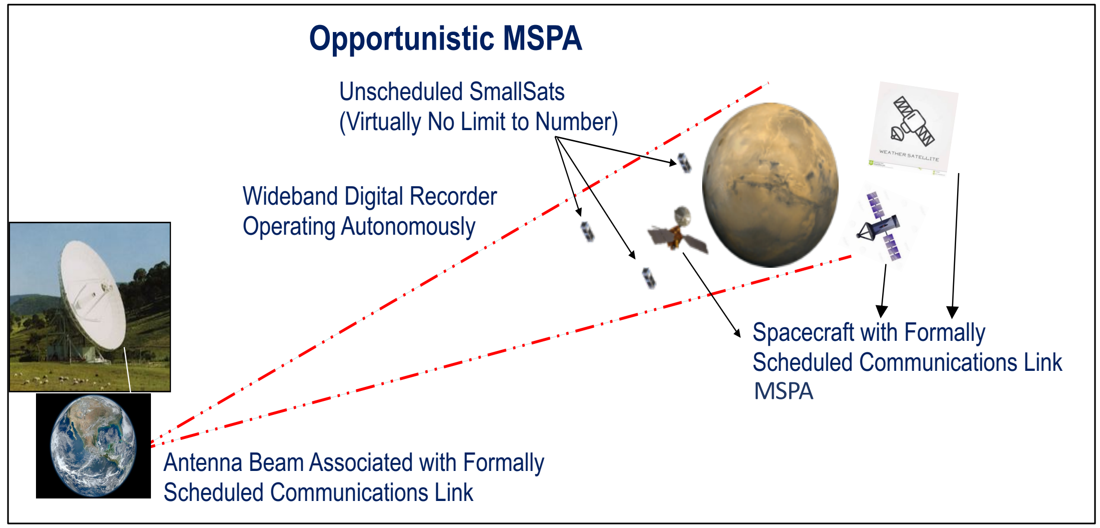
Scenario	Antenna Type	Pointing Requirement	Notes
Close Range	LGA to LGA	No pointing	UHF is preferred
Mars Orbiter Distance	LGA to LGA	No pointing	UHF is preferred
	LGA to MGA or HGA	Pointing at one end	
Long Distance (~50,000 km)	LGA to MGA or HGA	Pointing at one end	
Very Long Distance (>50,000 km, such as Saturnian moon to moon)	HGA to HGA	Pointing at both ends	Ka-band outperforms lower frequencies

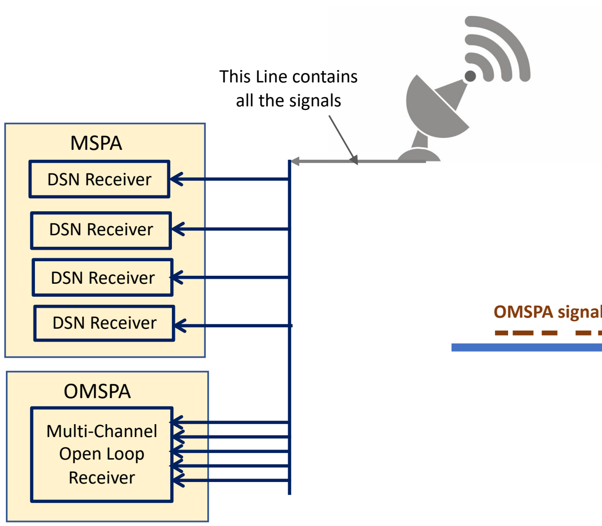
Recommendations, cont.

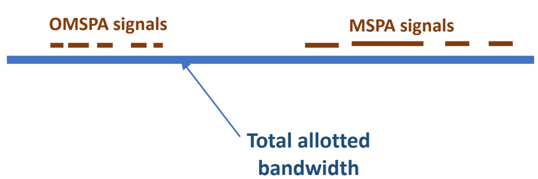
15. One-way proximity navigation is attractive because it allows simultaneous exchange between multiple satellites. Therefore, the merits of different one-way proximity navigation techniques should be examined via analysis, laboratory tests and flight implementation in order to determine the effectiveness of proposed one-way proximity navigation schemes.
16. Because Radio Science investigations typically require phase measurements, SmallSat radios that plan to support Radio Science should be able to accept an external frequency input. The external source is expected to offer the desired frequency stability that is needed for science observations.
17. SmallSats that plan to support Radio Science observations may be required to support dual band communication links, with a wide frequency band separation, in order to observe radio-wave propagation effects through a frequency-dependent medium and/or mitigate the effects of propagation through an ionized medium

Recommendations, cont.

18. It is recommended that the DSN to continue the advancement and implementation of beam-sharing techniques (OMSPA, and MUPA) to allow more efficient utilization of the DSN's antennas in situations where multiple spacecraft all reside within the beamwidth of a single ground antenna.







MSPA:	Multiple Spacecraft per Aperture
OMSPA:	Opportunistic MSPA
MUPA:	Multiple Uplink per Antenna

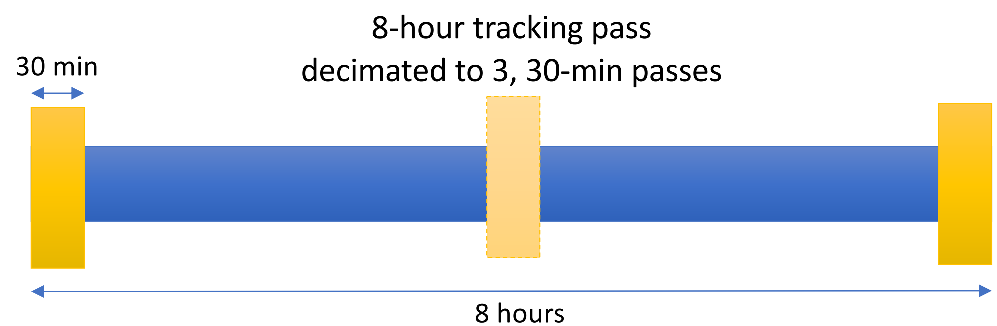
Recommendations, cont.

19. The DSN is recommended to increase the number of potentially available DSN-affiliated antenna assets by pursuing antenna cross-support arrangements with other agencies and non-profit entities. One example of this is the affiliation of Morehead State University's 21-m antenna with the DSN.

21-m DSN Affiliate Antenna at Morehead State University

Recommendations, cont.

20. It is recommended that the DSN continue to investigate the feasibility of reducing setup/tear-down times for ground antenna passes to free up more antenna time for SmallSats, as well as other DSN customers.
21. The Doppler Pass Sub-Sampling (DPSS) concept for reducing Doppler measurement time has been shown in NASA-funded studies to save DSN antenna time. This technology should be field tested and validated using a spacecraft of opportunity. Also, contingent on the successful validation of the DPSS technology, SmallSat missions should be designed to employ the DPSS concept for reducing Doppler measurement time, particularly when sequentially sharing the uplink during an MSPA pass.



Recommendations, cont.

22. A greater SmallSat mission reliance on a combination of one-way tracking (enabled by CSACs and MSPA), monthly DDORs and/or occasional two-way tracking should be encouraged. This approach could enable sufficient navigation performance to allow greater reliance on the downlink-only nature of n-MSPA and OMSPA. Note: this approach may impose a clock stability requirement on the spacecraft.
23. Simultaneous Multiple Uplinks Per Antenna (MUPA) capability has the potential to reduce the use of DSN antenna time by enabling simultaneous 2-way Doppler and ranging for multiple in-beam spacecraft across the full duration of an MSPA pass. To realize this potential, spacecraft software and the radio should be enhanced to allow 1) for variable turnaround ratios and 2) for receiver acquisition in high Doppler environments.
24. SmallSat mission planners and designers should note that developing a mission with considerations given to beam sharing opportunities has the potential to save money and/or enable greater ground antenna access than might otherwise be the case.
25. While the DSN investigates User Initiated Services (UIS), it should also develop UIS guidelines for a beacon system for SmallSats. Such development will need to proceed hand-in-hand with mission advancements in onboard autonomy.