JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

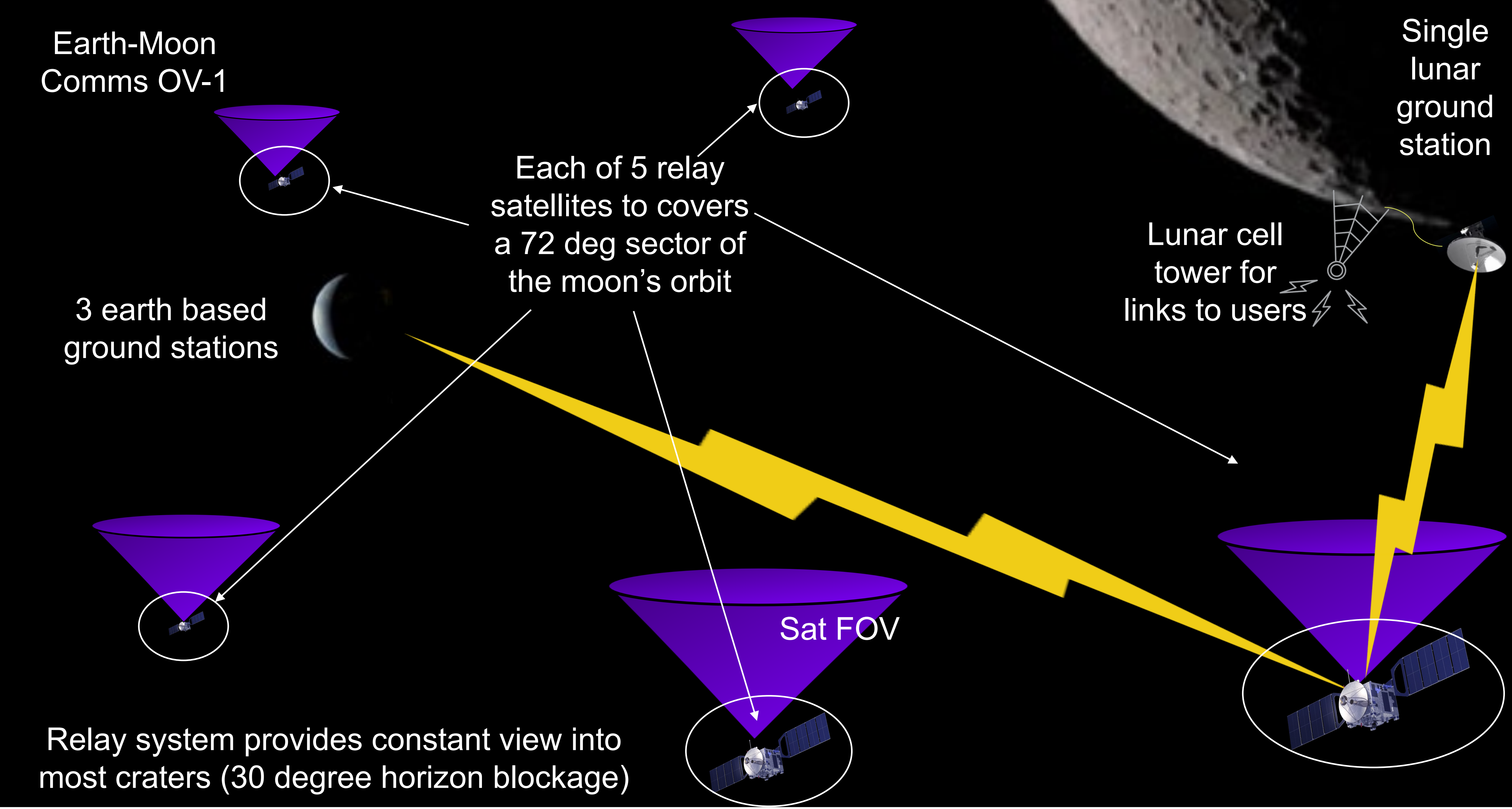
11100 Johns Hopkins Road
Laurel, MD 20723-6099

Conceptual Design for Communications Network for Earth-Lunar Communications

JHU-APL IRAD

FPS-KVG

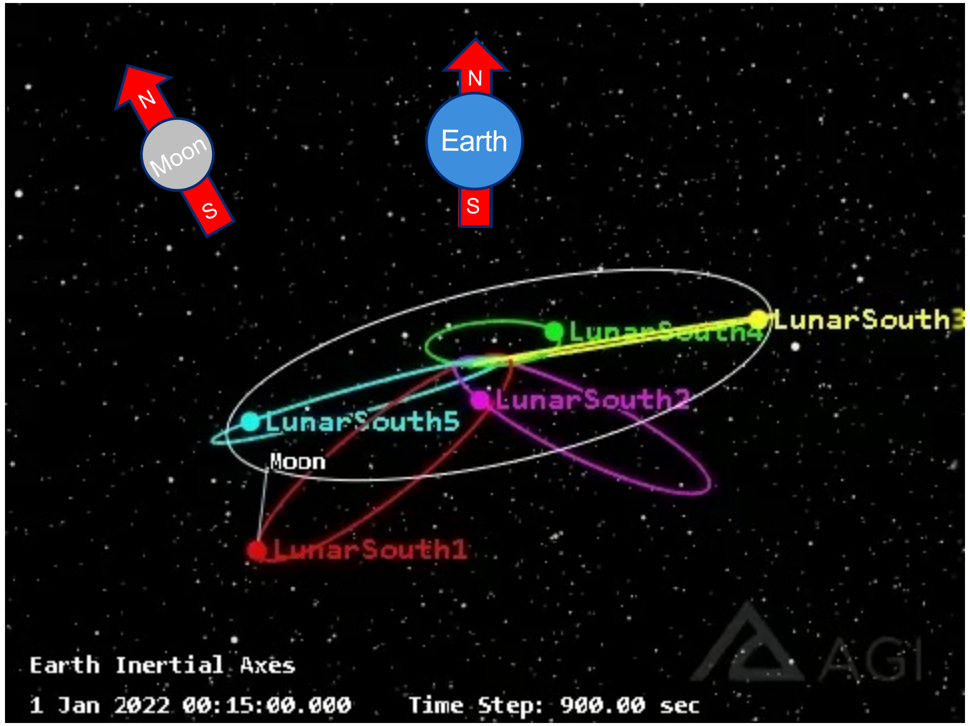
Chuck Quintero
Senior Professional Staff II
Chuck.Quintero@jhuapl.edu
301-820-5577

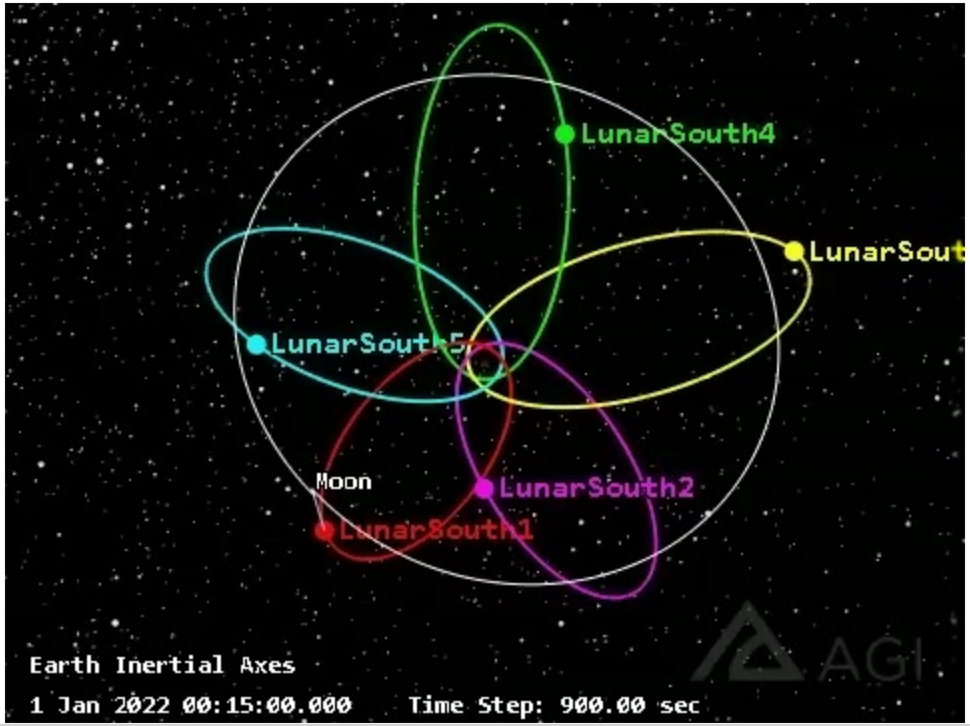

Earth-Moon
Comms OV-1
Each of 5 relay
satellites to covers
a 72 deg sector of
the moon’s orbit
Single
lunar
ground
station
Lunar cell
tower for
links to users
3 earth based
ground stations
Sat FOV
Relay system provides constant view into
most craters (30 degree horizon blockage)

Starfish Constellation Design

- Lunar relay support broken up into 5 segments per month, each covers 72 deg
- Relay orbital parameters:
  - Period = 13.66 days
  - Apogee = 452264 km
  - Eccentricity = 0.9
  - SMA = 241390 km
  - Perigee = 17761 km
- Each relay inclined to match a segment of the lunar inclination (28.6 deg), so each has a different inclination:

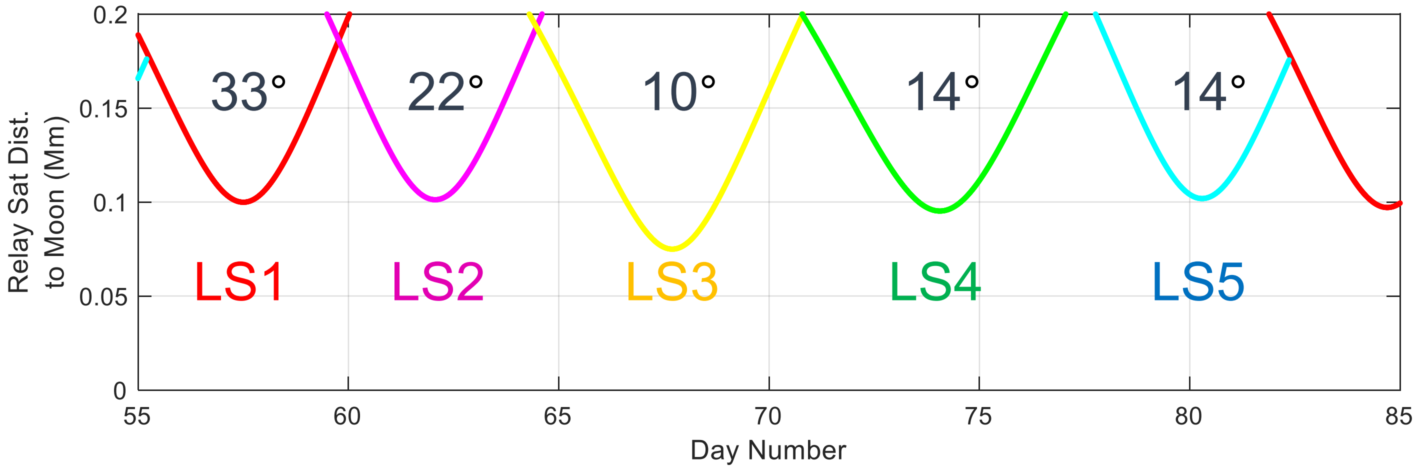
Relay Sat No.	Inclination	Argument of Perigee	RAAN	Mean Anomaly
1	33	90	0	330
2	22	90	72	216
3	10	270	324	42
4	14	270	36	258
5	14	90	288	114

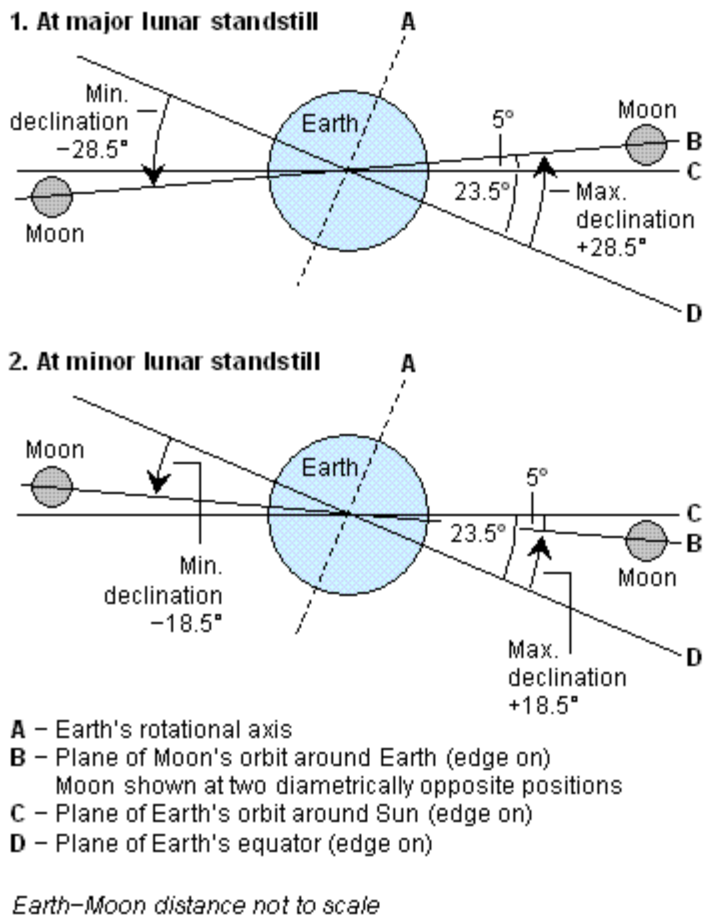




Lunar inclination drives max relay sat ranges

- Each relay satellite orbits directly below the moon (LOS to Scott Crater) for 6 days
- 452264 km apogee inclined to maintain ~100,000 km positioning South of the moon during close approach (100,000 min distance to moon greatly reduces lunar perturbations to orbit stability)
- Perigee altitude of 18,000 km (<GPS altitude) facilitates orbit corrections for station keeping, including inclination shifts to follow lunar precession (18.6 year cycle)
- Results of iterative matching of inclinations to lunar inclination as shown below, (inclinations are w.r.t. earth equator):





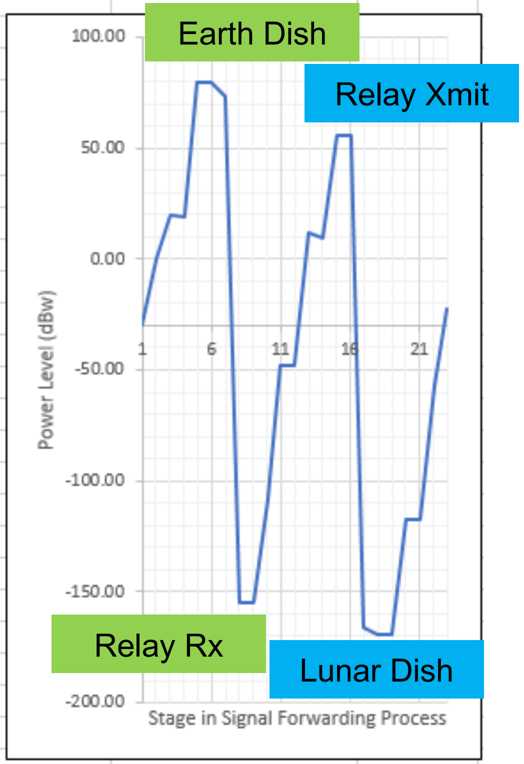
Earth to Moon Relay Link Budget

- Ku-band comms for earth relay selected for:
  - Large bandwidth availability
  - Similarity to existing space qualified X-band hardware
  - Reduced size for antenna dishes
- Results:
  - Design supports 100 simultaneous users, each with 4.8 Mbit connections (recommended datarate for 720p High Efficiency Video Coding (HEVC H.265) @30fps) with 2.12 dB of margin
  - Link budget to the right shows the signal level in the relay link, and the final signal level above the targeted -30 dBm signal level
  - Increases to the number of users and the datarate can be achieved by increasing the power in the transmitter and relay, as well as by increasing the size of the dishes used

Uplink Frequency (GHz)	19.5	Downlink Frequency (GHz)	18.5		
Uplink Lambda (m)	0.015374	Downlink Lambda (m)	0.016205		
Originating Earth Station		Satellite Relay		Receiving Lunar Station	
Antenna diameter (m)	5	Antenna diameter (m)	1	Antenna diameter (m)	2
		Slant Range (km)	300000	Slant Range (km)	150000

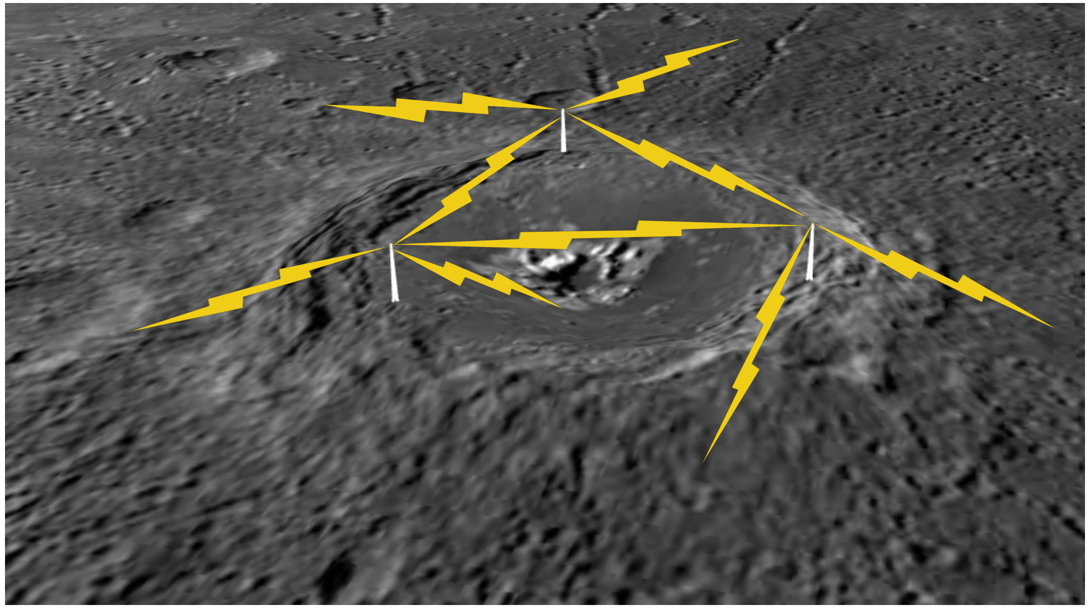
	Gain (dB)	Signal Level (dBw)
Earth station transmitter		
Output signal from modulator		-30.00
Driver (preamplifier) amplifier gain	30	0.00
HPA gain	20	20.00
Line loss to antenna	-1	19.00
Transmitter antenna gain	60.186676	79.19
Uplink path		
Rain attenuation and other losses	-6	73.19
Free space loss	-227.7909	-154.60
Satellite receiver		
Antenna gain	46.207276	-108.40
Satellite receiver amplifer gain	60	-48.40
Satellite transmitter		
TWT amplifier gain	60	11.60
Output losses	-2	9.60
Antenna gain	45.750018	55.35
Downlink path		
Free space loss	-221.313	-165.96
Rain attenuation and other losses	-3	-168.96
Earth station receiver		
Receiver antenna gain	51.770618	-117.19
Line loss from antenna	-0.5	-117.69
LNA gain	60	-57.69
Down converter & IF amplifier gain	35	-22.69
Datarate Analysis		
System Temp	50	
Bandwidth	5.00E+08	
Carrier to Noise	3.45E-13	101.93
Number of Users	100	81.93
Required Datarate	4.80E+06	15.12
Eb/No	13	2.12

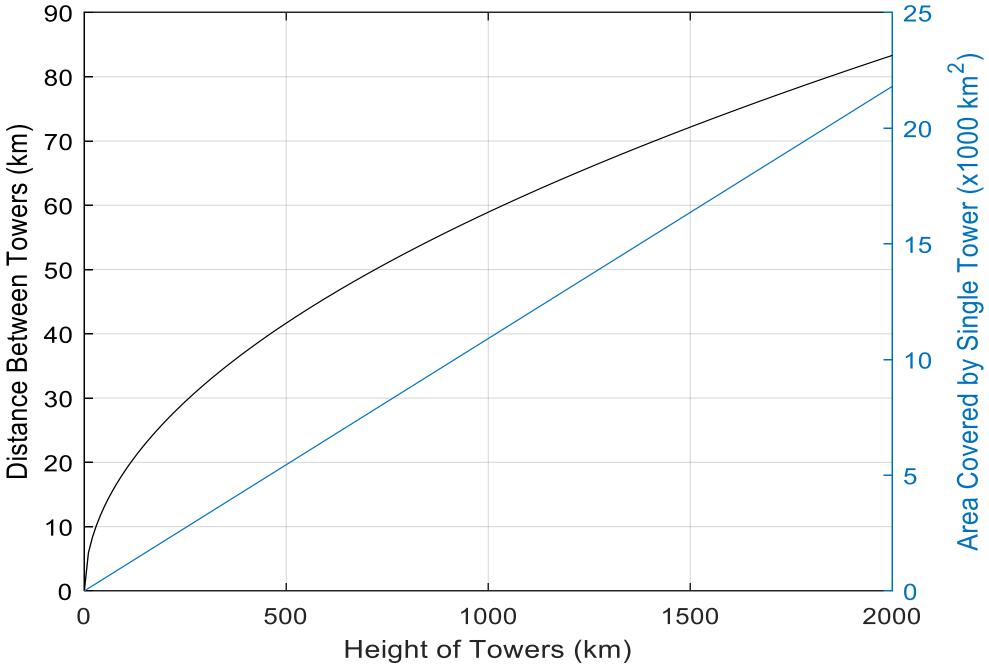
<--- Link Margin



Signal Distribution on Lunar Surface

- Nokia is working on cell HW, but need towers:
- The Lunar surface is abundant in minerals containing anorthite in both polar and other highland areas, and various other compounds in lava-flooded lowlands which can be processed on site for aluminum metal
- As shown to the right, towers on edges of craters eliminate shadowed zones and can be used as lunar navigation beacons
- Cross-links between towers can be handled using free space optical (FSO) communication, typically 780-1600 nm bands
- Much of the message traffic is expected to be between users, and doesn't require the Starfish constellation relay
- Each tower can connect to the relay satellite assigned for that 6 day period, routing to correct tower using internet DNS routing
- As shown to the right, each tower covers 5,000-20,000 square km, with 3 towers per crater are recommended for coverage, and for navigation





JOHNS HOPKINS
APPLIED PHYSICS LABORATORY