High Speed Data Downlink for NSF Space Weather CubeSats

National Science Foundation Meeting

Monday August 31, 2009

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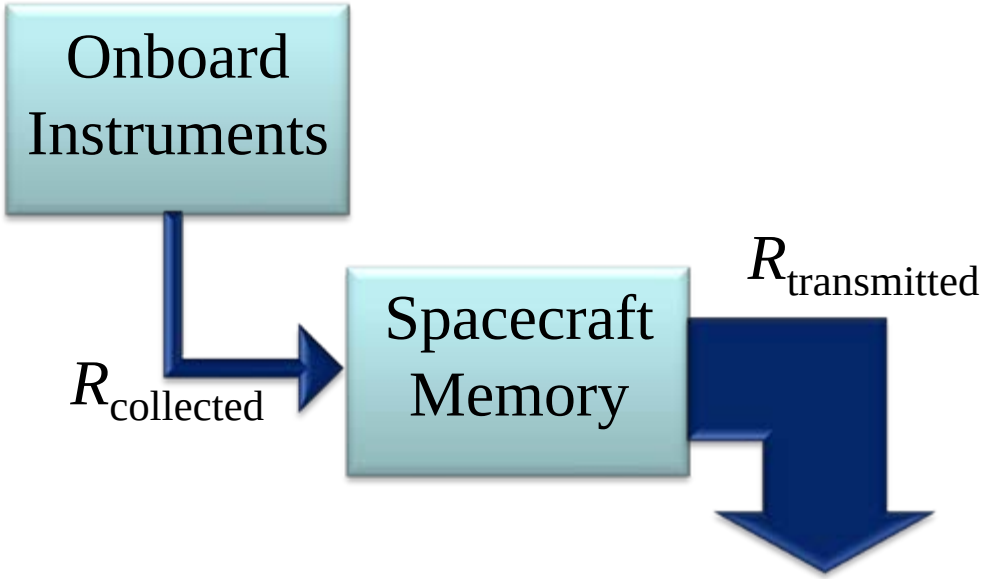
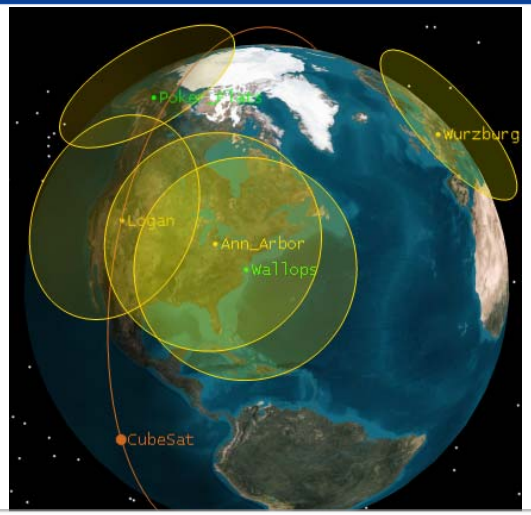
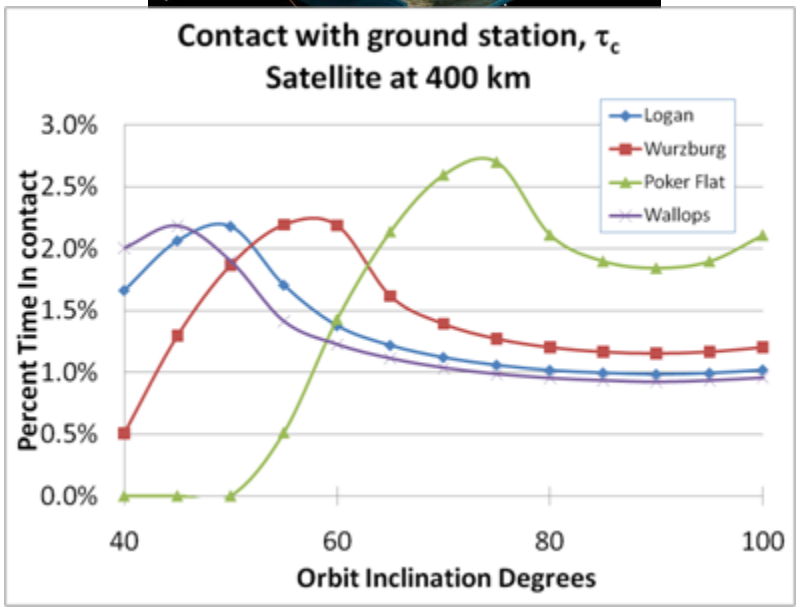
Satellite Data Flow





$$\tau = \frac{T_{contact}}{T_{period}} = \alpha \frac{R_{collected}}{R_{transmitted}}$$

Simulate for 1 year in STK and report contact and gap times.



Straw Man Telemetry

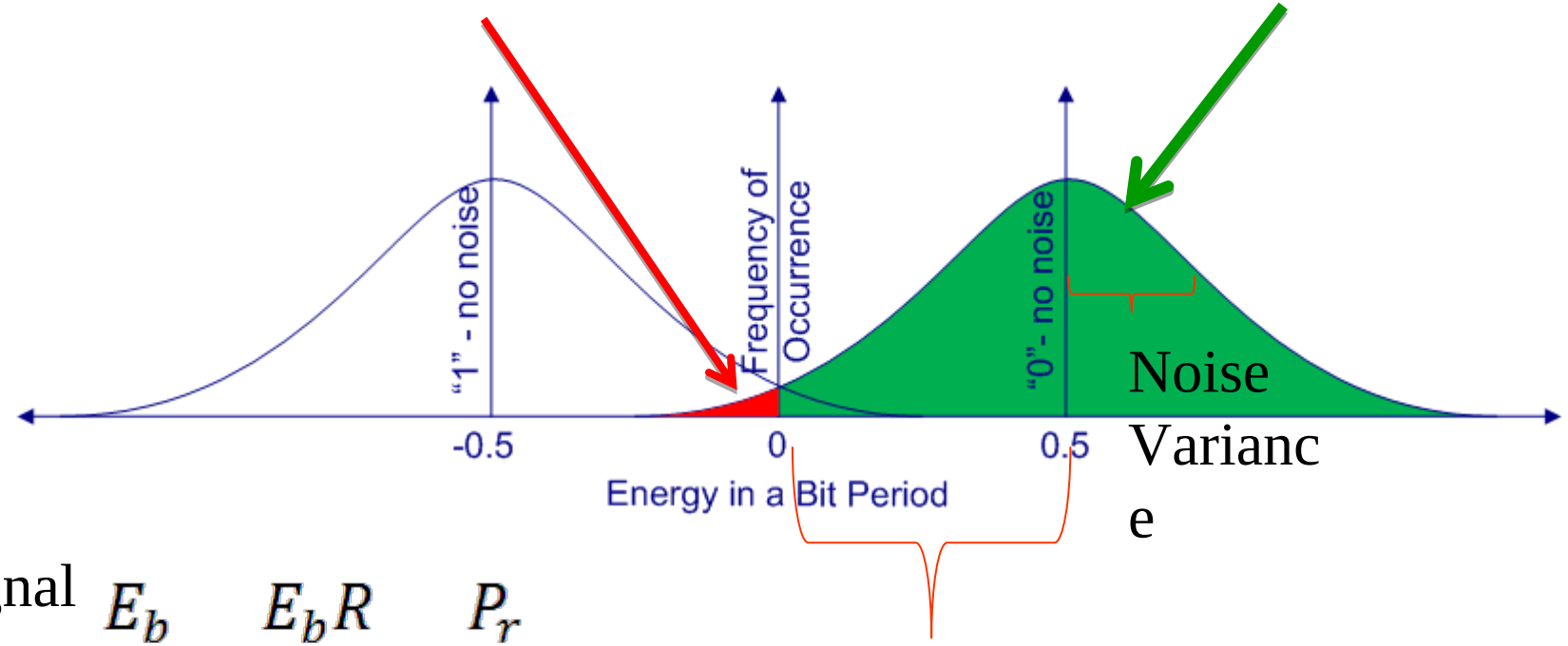
Quantity	Symbol	Value	Units
Factor of Safety	α	1.05	Unitless
Contact Time Percent	τ	1.00%	Unitless
Packet Overhead		7%	Unitless
Velocity		7.5	km/s
Word Size		16	bits

Transmitted Rate kbits/s	Collection Rate kbits/s	Data Samples Hz	Spatial Sampling m
1.2	0.01	0.66	**11290.32**
9.6	0.09	5.31	**1411.29**
115.2	1.02	63.77	**117.61**
256	2.27	141.71	**52.92**
1000	8.86	553.57	**13.55**
2000	17.71	1107.14	**6.77**
10000	88.57	5535.71	**1.35**

Matched Filter Digital Communications

Transmission of a “0” detected as a “1”

Transmission of a “0” detected as a “0”



Noise Variance

Signal to Noise $\frac{E_b}{N_0} = \frac{E_b R}{N_0 B} = \frac{P_r}{P_n}$

Energy in one bit for a given signal wave form

Required Signal to Noise Ratio

- **Noise Spectral Density**

$$N_0 = k_b T_s$$

- **Energy in bit**

$$E_b = \frac{P_t G_t G_r}{R L_s L_o}$$

  – Where Space Loss is:

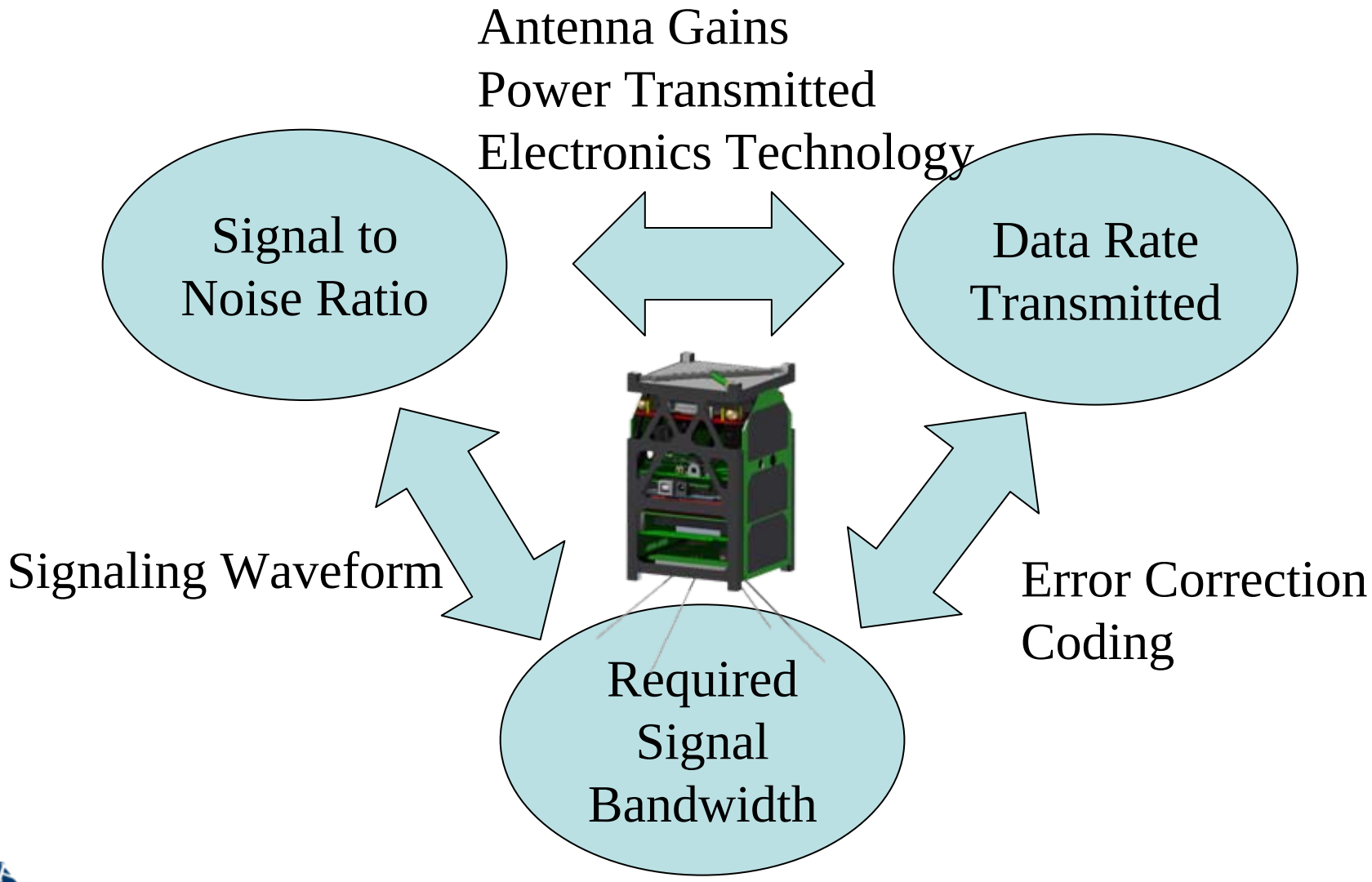
$$L_s = \left(\frac{4\pi d}{\lambda}\right)^2$$

Modulation (notes) For BER of 10^{-5}	E_b/N_o	Bandwidth
FSK	13.3	2 R
FSK-4		
FSK-8	9.2	2.6 R
BPSK	9.6	R
DPSK	10.3	R
QPSK	9.6	0.5 R
Convolutionally Coded PSK	4.4	

- **Ideal Data Encoding**

$$R_{max} = B \log_2(1 + \frac{E_b}{N_o})$$

Link Budget Trades



High Gain Ground Stations

Image courtesy of http://si.smugmug.com/gallery/1674201_UxZmP/1/457184513_4s3Ag

We are limited by regulations and not technology for CubeSat downlinks.

NTIA “Red Book” Table on 460-470 MHz

Table of Frequency Allocations			410-698 MHz (UHF)		
International Table			United States Table		FCC Rule Part(s)
Region 1 Table	Region 2 Table	Region 3 Table	Federal Table	Non-Federal Table	
460-470 FIXED MOBILE Meteorological-satellite (space-to-Earth)			460-470 Meteorological-satellite (space-to-Earth)	460-462.5375 FIXED LAND MOBILE 5.289 US201 US209 NG124	Private Land Mobile (90)
				462.5375-462.7375 LAND MOBILE 5.289 US201	Personal Radio (95)
				462.7375-467.5375 FIXED LAND MOBILE 5.287 5.289 US201 US209 US216 NG124	Private Land Mobile (90)
				467.5375-467.7375 LAND MOBILE 5.287 5.289 US201	Personal Radio (95)
5.287 5.288 5.289 5.290			5.287 5.288 5.289 US201 US209 US216	467.7375-470 FIXED LAND MOBILE 5.288 5.289 US201 US216 NG124	Private Land Mobile (90)

Lower case means secondary user

Must read the notes

Definitions

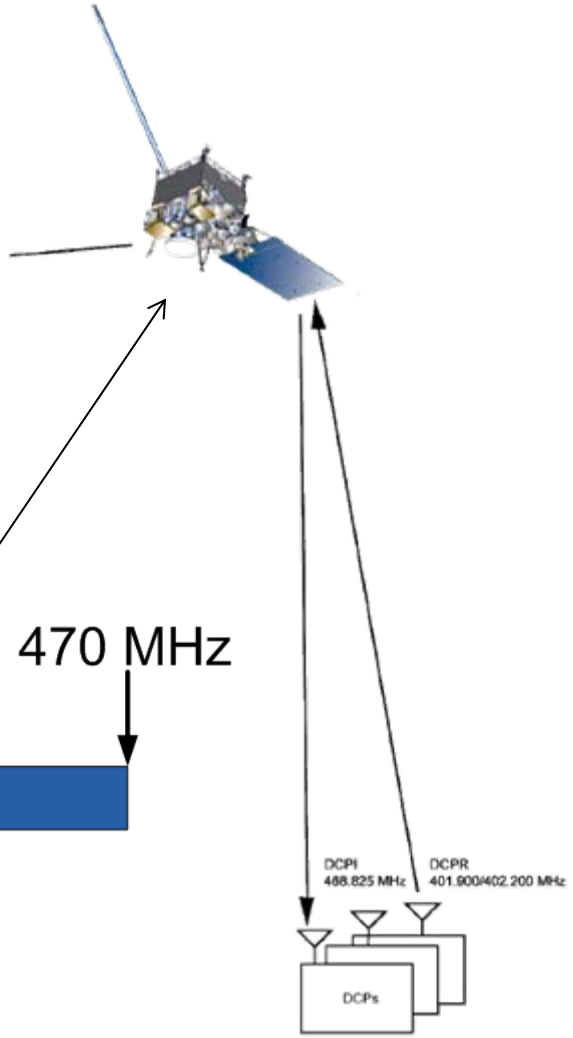
- **Earth Exploration-Satellite Service:**
  A radio communication service between earth stations and one or more space stations, which may include links between space stations, in which:
  - information relating to the characteristics of the Earth and its natural phenomena including data relating to the state of the environment is obtained from active sensors or passive sensors on earth satellites; similar information is collected from active sensors or passive sensors on Earth satellites:
  - airborne or earth-based platforms; such information may be distributed to earth stations within the system concerned; platform interrogation may be included. This service may also include feeder links necessary for its operation.
- **Meteorological-Satellite Service:**
  An Earth exploration-satellite service for meteorological purposes.

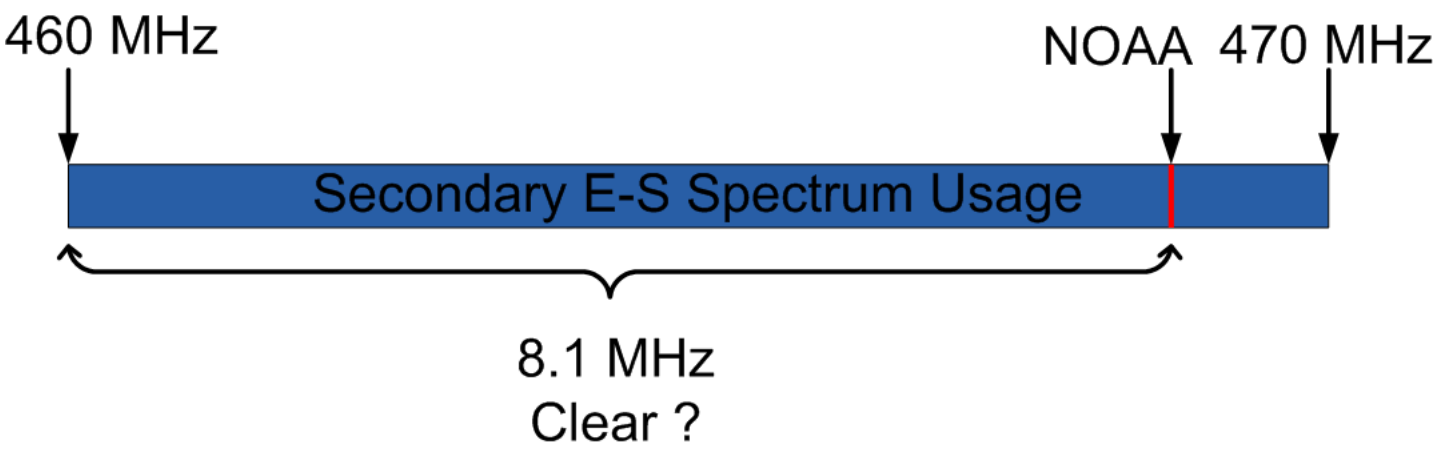
Regulations on 460 to 470 MHz

- **5.289 Earth exploration-satellite service applications, other than the meteorological-satellite service, may also be used in the bands 460-470 MHz and 1690-1710 MHz for space-to-Earth transmissions subject to not causing harmful interference to stations operating in accordance with the Table.**
- **US201 In the band 460-470 MHz, space stations in the Earth exploration-satellite service may be authorized for space-to-Earth transmissions on a secondary basis with respect to the fixed and mobile services. When operating in the meteorological-satellite service, such stations shall be protected from harmful interference from other applications of the Earth exploration-satellite service. The power flux-density produced at the Earth's surface by any space station in this band shall not exceed -152 dBW/m²/4 kHz.**

Existing E-S Users in this band

- **GOES Data Collection Platform Interrogation (DCPI) Systems**
  - Provides a Control link to weather stations around the world
  - Conforms to -152 dBW/m²/4 kHz flux limit
- **Need to identify other users**





Straw Man Concept

- **Power on ground limited**
  - -152 dBW/m²/4 kHz
  - -158 dBW / m² kHz
- **CubeSat at reentry**
  - 250 km altitude
- **Available bandwidth,**
  - 8 MHz.
- **Isotropic antenna on CubeSat**
- **Max Power Tx**
  - 1-watt RF

Design Element	Symbol	Units	250 Reg
Link Frequency	f	GHz	0.465
Transmitter Power	P_{tx}	Watts	1
Transmitter Power	P_{tx}	dBW	0.00
Transmitter			
Antenna Gain	G_{tx}	dB	0.00
Antenna Transmitter Losses	L_{tx}	dB	-0.5
Antenna Beam width	θ_{tx}	Deg	180.0
Antenna Misalignment	α_{tx}	Deg	15
Alignment Loss	$L_{\theta tx}$	dB	-0.08
Equivalent Isotropic Radiated Power	EIRP	dBW	-0.58
Losses			
Propagation Path Length	S	Km	250.0
Space Loss	L_s	dB	-133.76
Atmospheric	L_a	dB	-0.1
Polarization Loss	L_n	dB	-3
Total Losses	L	dB	-136.86
Receiver			
Antenna Gain	G_r	dB	35.9
Antenna Receiver Loss	L_r	dB	-0.5
Antenna Beam width	θ_r	Deg	2.5
Antenna Misalignment	α_r	Deg	1
Alignment Loss	$L_{\theta r}$	dB	-1.91
Total Receiver	G	dB	33.44
Sky (Antenna) Noise Temperature	T_a	K	60
Receiver Temperature	T_r	K	120.00
System Noise Temperature	T_s	K	180.00
Receiver Merit	G/T	DB(1/K)	10.89
Powers			
Power Flux Density	ϕ	dB(W/m²)	-119.53
Power Flux Spectral Density	ϕ_f	dB(W/m²/kHz)	-158.57
Power Flux Spectral Density Limit	ϕ_f	dB(W/m²/kHz)	-158.02
Carrier Power Received	P_{rx}	dBW	-103.99
Noise Spectral Density	N_o	dB(W/Hz)	-206.05
Carrier to Noise Density	P_{rx}/N_o	dB(Hz)	102.05
Rates			
Data Rate	R	Bps	8.00E+06
Eb/No	E_b/N_o	dB	33.02
Required Eb/No		dB	9.6
Required Margin		dB	3
Margin		dB	20.42

What can you do with 1-Watt Tx

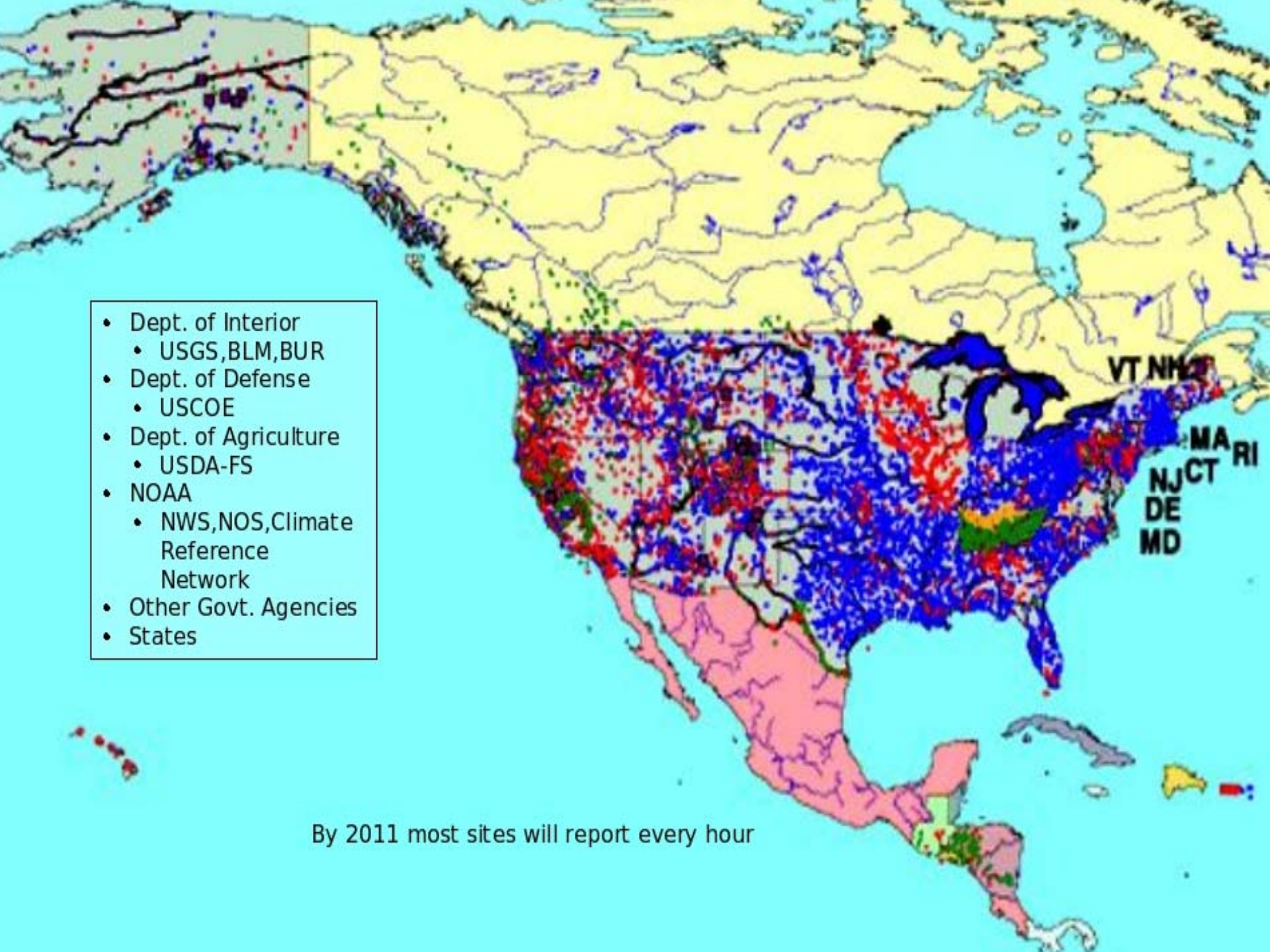
- **Assumptions**
  - 36 dBi ground station gain (18 meter dish)
  - 600 km circular orbit
  - Spacecraft 5º above the horizon (2329 km)
  - 464 MHz center frequency
  - Isotropic antenna's on CubeSat
  - 1 Watt RF power (~40mW orbit average power)
  - 180 K Receiver system noise temperature
- **Results**
  - Channel Capacity 36 Mbits/s $R_{max} = B \log_2(1 + \frac{E_b}{N_o})$
  - 8 Mbits/s with BPSK signaling
- **Conclusion**
  - Lots of capability

Design Element	Symbol	Units	600 5 deg
Link Frequency	f	GHz	0.464
Transmitter Power	P_{tx}	Watts	1
Transmitter Power	P_{tx}	dBW	0.00
Transmitter			
Antenna Gain	G_{tx}	dB	0.00
Antenna Transmitter Losses	L_{tx}	dB	-0.5
Antenna Beam width	θ_{tx}	Deg	180.0
Antenna Misalignment	α_{tx}	Deg	15
Alignment Loss	L_{atx}	dB	-0.08
Equivalent Isotropic Radiated Power	EIRP	dBW	-0.58
Losses			
Propagation Path Length	S	Km	2329.0
Space Loss	L_s	dB	-153.12
Atmospheric	L_a	dB	-0.1
Polarization Loss	L_n	dB	-3
Total Losses	L	dB	-156.22
Receiver			
Antenna Gain	G_r	dB	35.8
Antenna Receiver Loss	L_r	dB	-0.5
Antenna Beam width	θ_r	Deg	2.5
Antenna Misalignment	α_r	Deg	1
Alignment Loss	L_{ar}	dB	-1.90
Total Receiver	G	dB	33.43
Sky (Antenna) Noise Temperature	T_a	K	60
Receiver Temperature	T_r	K	120.00
System Noise Temperature	T_s	K	180.00
Receiver Merit	G/T	DB(1/K)	10.88
Powers			
Power Flux Density	ϕ	dB(W/m^2)	-138.92
Power Flux Spectral Density	ϕ_f	dB(W/m^2/kHz)	-177.95
Power Flux Spectral Density Limit	ϕ_f	dB(W/m^2/kHz)	-158.02
Carrier Power Received	P_{rx}	dBW	-123.37
Noise Spectral Density	N_o	dB(W/Hz)	-206.05
Carrier to Noise Density	P_{rx}/N_o	dB(Hz)	82.68
Rates			
Data Rate	R	Bps	8.00E+06
Eb/No	E_b/N_o	dB	13.64
Required Eb/No		dB	9.6
Required Margin		dB	3
Margin		dB	1.04

Thoughts

- **Dishes**
  - 18 Meter at Wallops
  - 20 Meter at SRI and MoreHead University
  - Develop an array of antennas and create multiple sites.
- **Code division Multiple Access**
  - Give each satellite their own spread spectrum code
  - Develop Custom ASIC for CubeSats
- **Some engineering at this point would be useful**
- **The big advantage an “Isotropic antenna” on CubeSat**
  - Low impact on spacecraft.

Backup Slide


• Dept. of Interior
• USGS,BLM,BUR
• Dept. of Defense
• USCOE
• Dept. of Agriculture
• USDA-FS
• NOAA
• NWS,NOS,Climate Reference Network
• Other Govt. Agencies
• States
VT
NH
MA
RI
CT
NJ
DE
MD
By 2011 most sites will report every hour