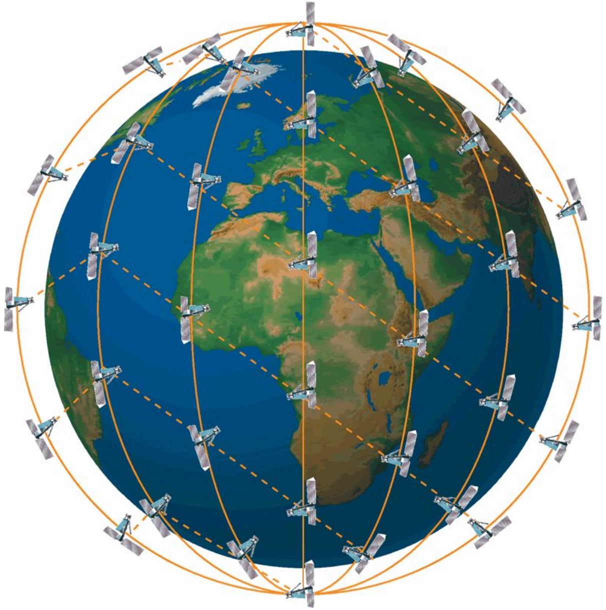
GEOSPACE Workshop 1
Nanosatellite Constellation: Design Concepts



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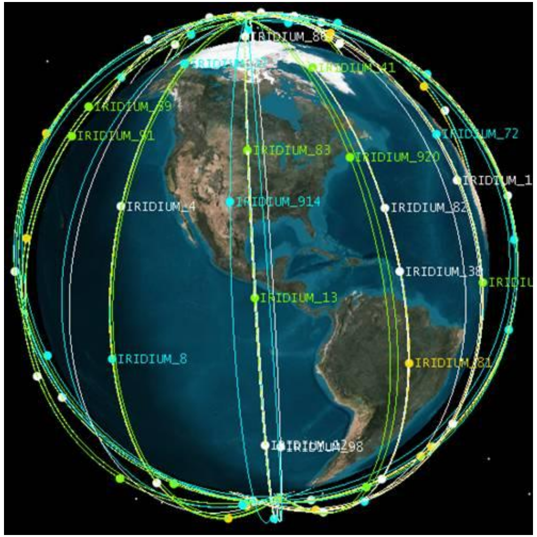
Department of Engineering, Aarhus University, Denmark - October 4th, 2017

My Background

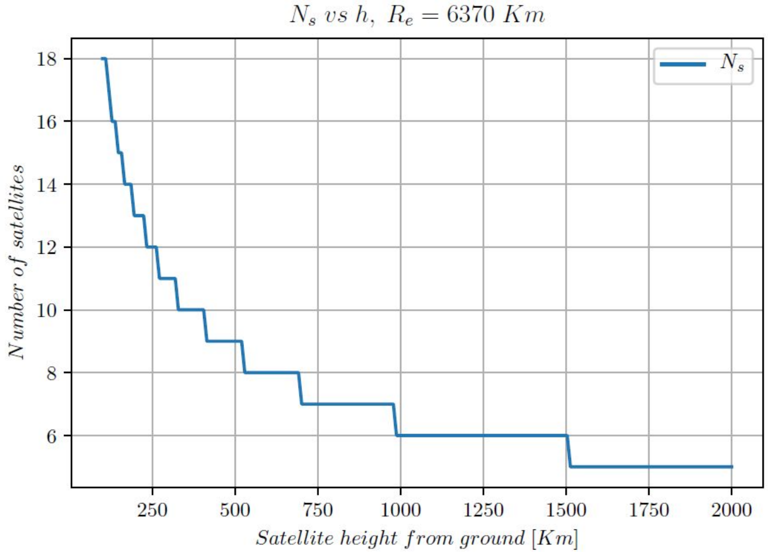
- Dipl. in Electronics Eng. → Universidad Simón Bolívar (USB), Venezuela (VE)
- MSc. in Electronics Eng. - Digital Communications → USB, VE
- Experience within academia and industry:
    - Communications and Signal Processing Teaching Assistant at USB
    - Intern at CANTV → Largest broadband and fixed telephone operator, VE
    - System engineer at Digitel → National mobile operator, VE
- Industrial PhD in Wireless Comm. → Aalborg University, DK
    - Telecommunications engineer at Steinwurf ApS, DK
- Postdoc Researcher in Nanosatellite Comm. → Aarhus University, DK

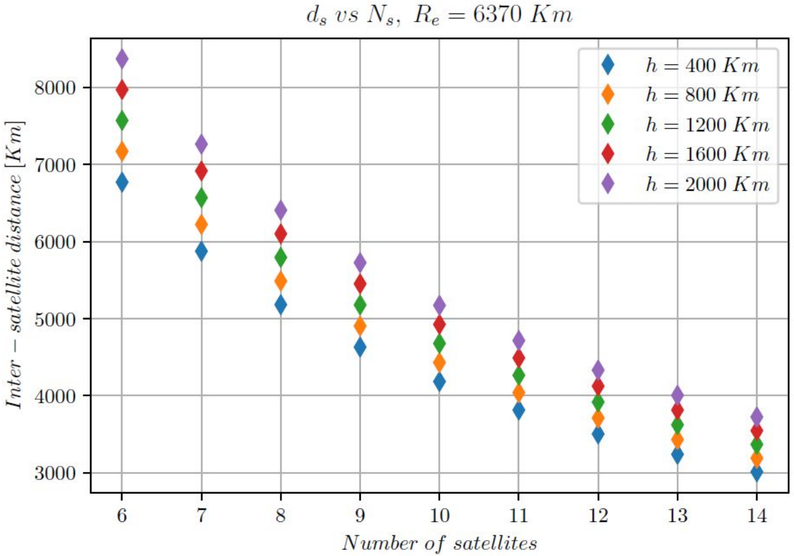
Constellations examples and Walker Delta parameters

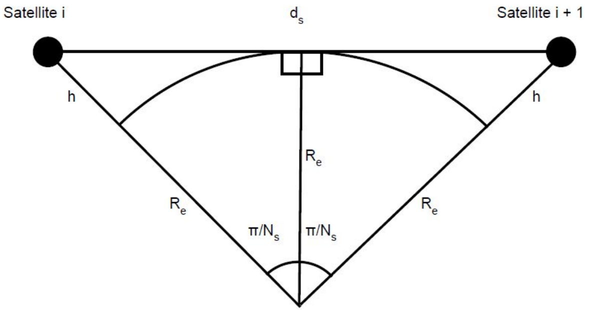
- Telecommunications
  - Iridium (voice) → 66 satellites → 11 satellites in 6 planes at i = 86.4°
  - Globalstar (voice) → 48 satellites → 6 satellites in 8 planes at i = 52°



Basic orbit parameters in LEO







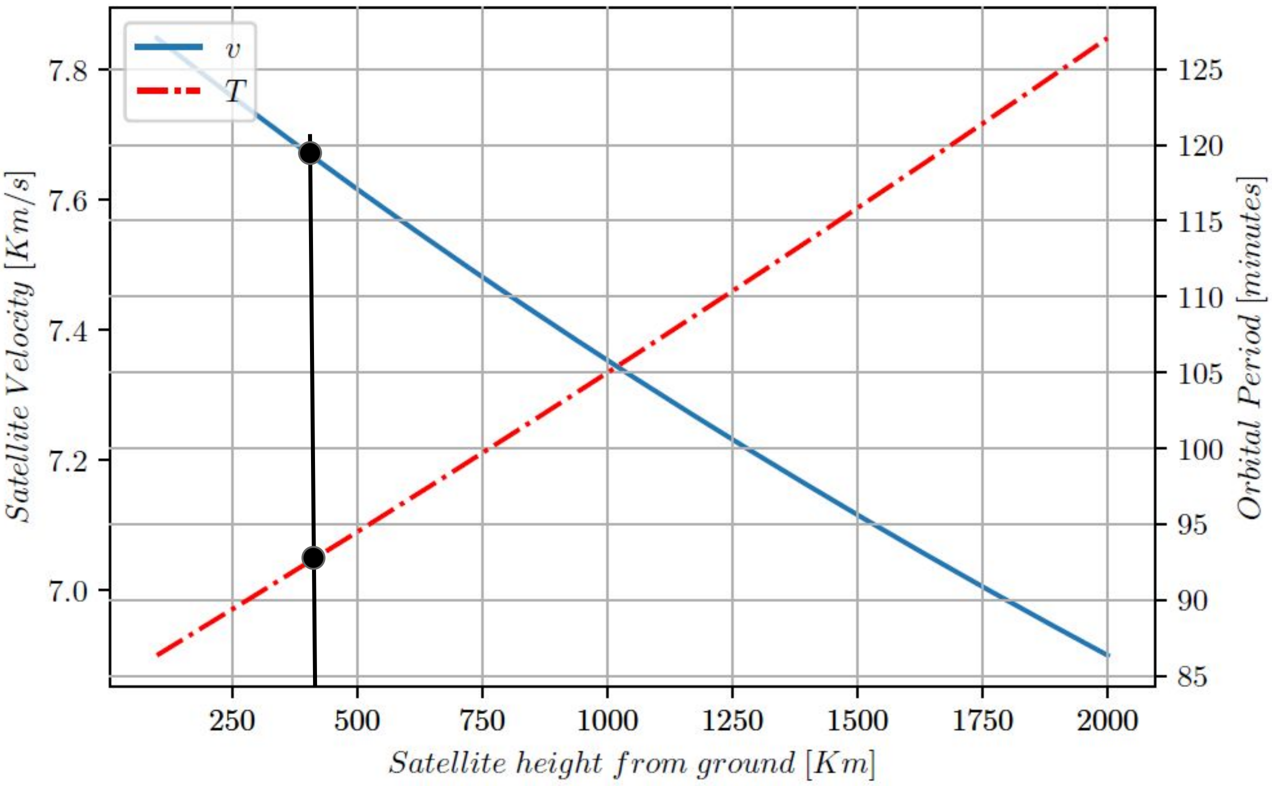
$$N_s = \left\lceil \frac{\pi}{\arccos\left(\frac{R_e}{R_e+h}\right)} \right\rceil, \quad N_s \geq 2 \qquad d_s = 2(R_e + h)\sin\left(\frac{\pi}{N_s}\right)$$

- Basic analysis for 1 plane: *i* = 51.6° & N_S nanosatellites

Satellite velocity / Orbital period in LEO

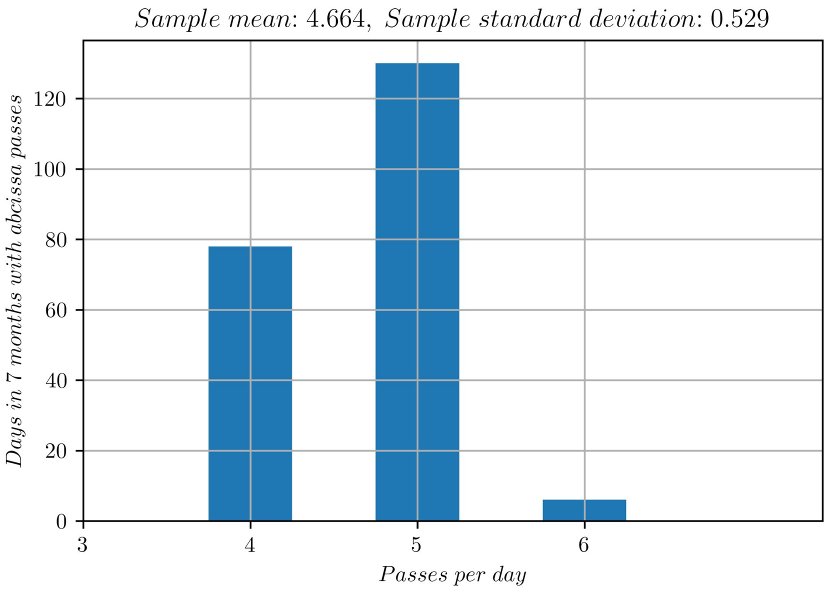
$$\frac{GM_e m}{(R_e + h)^2} = \frac{mv^2}{(R_e + h)} \implies$$

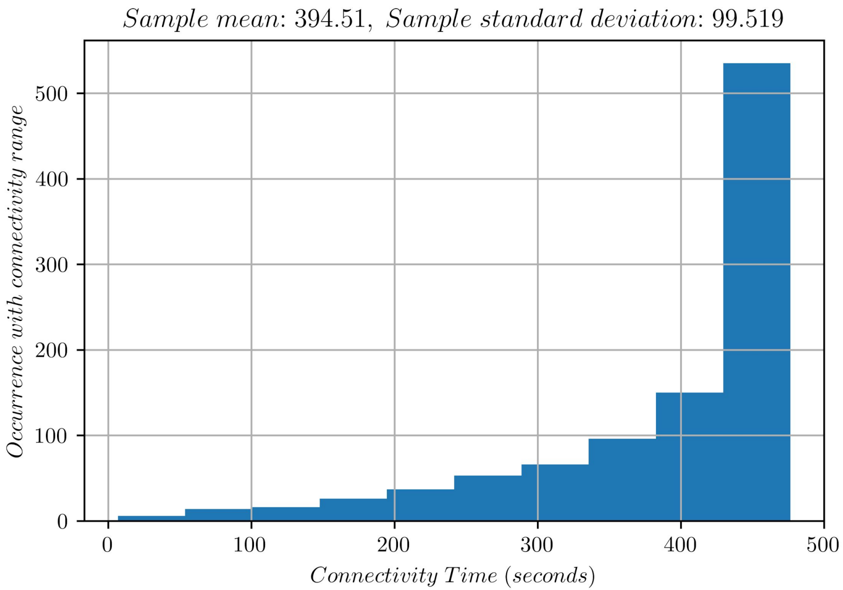
$$v = \sqrt{\frac{GM_e}{R_e + h}}$$



$$T = 2\pi\sqrt{\frac{(R_e + h)^3}{GM_e}}$$

Satellite Passes / Connectivity Time for Cubesat - AU GS

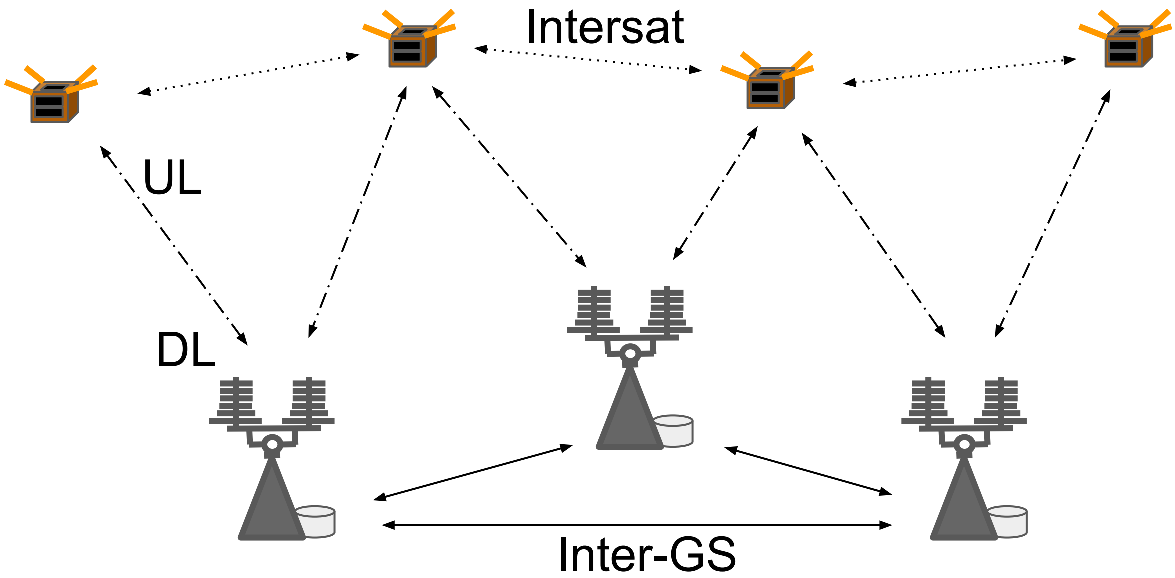




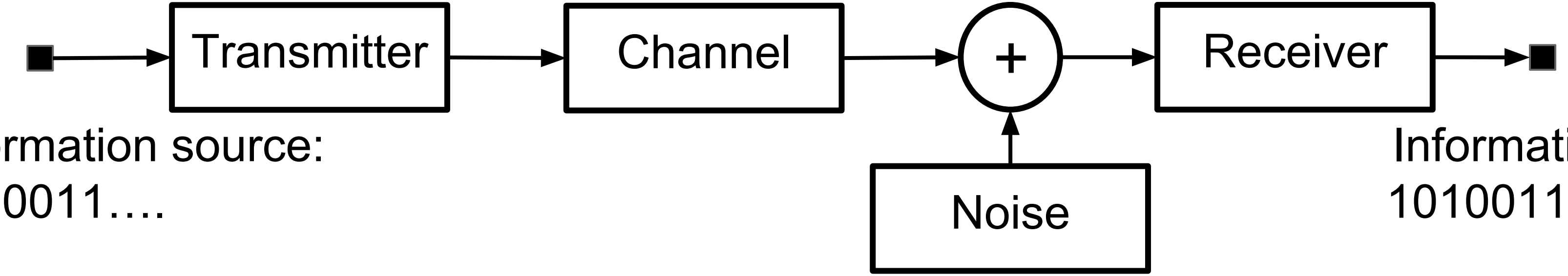
- Simulations with STK 11.02 for 7 months starting from mid-June 2018
- Based on an early proposal of the Delphini-1 orbit: 4.66 passes/day, 390 s.

System Overview

- 3 link types:
  - Uplink / Downlink
  - Intersat / Inter-GS



- AWGN models each link:



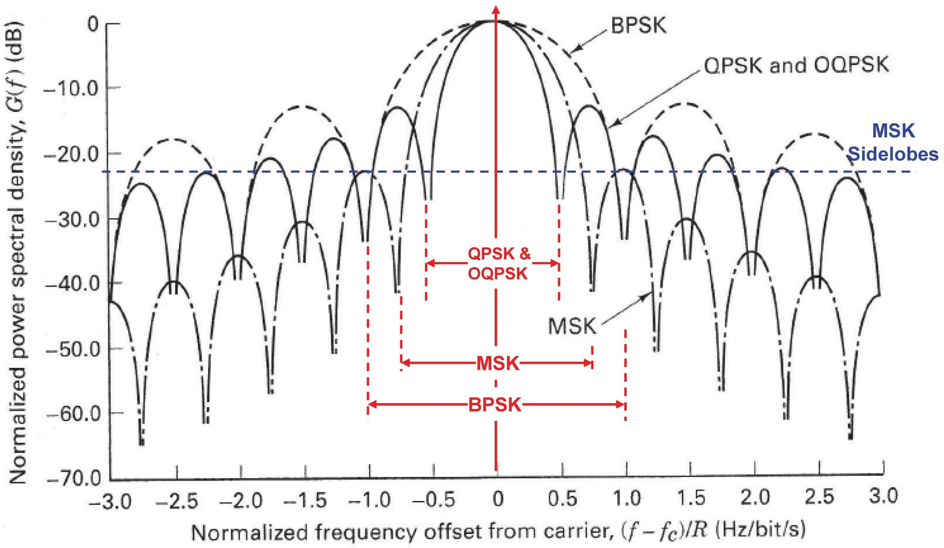
Information source:
1010011….

Information sink:
1010011….

Modulation Spectra and Bandwidth

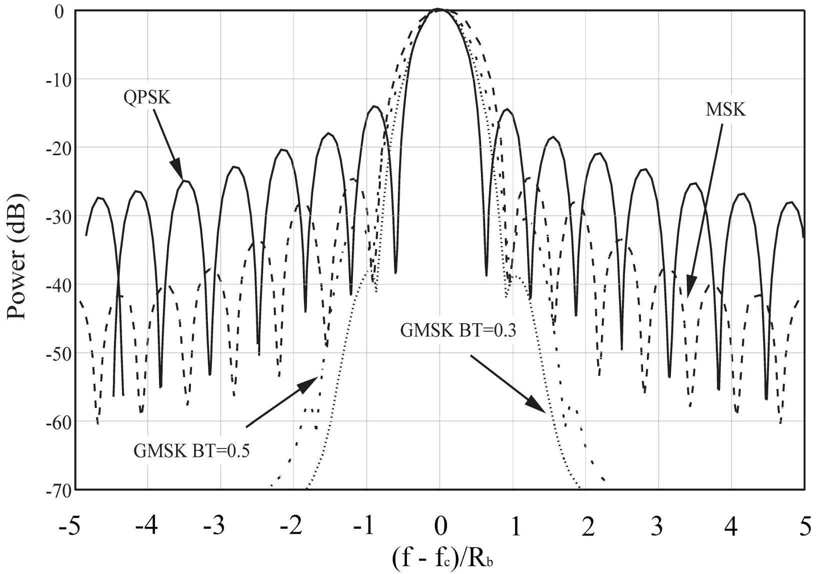
Normalized Power Spectral Density

for BPSK, QPSK, O-QPSK, and MSK



GMSK Power Spectra Comparison: Example

PSD of QPSK, MSK and GMSK modulations

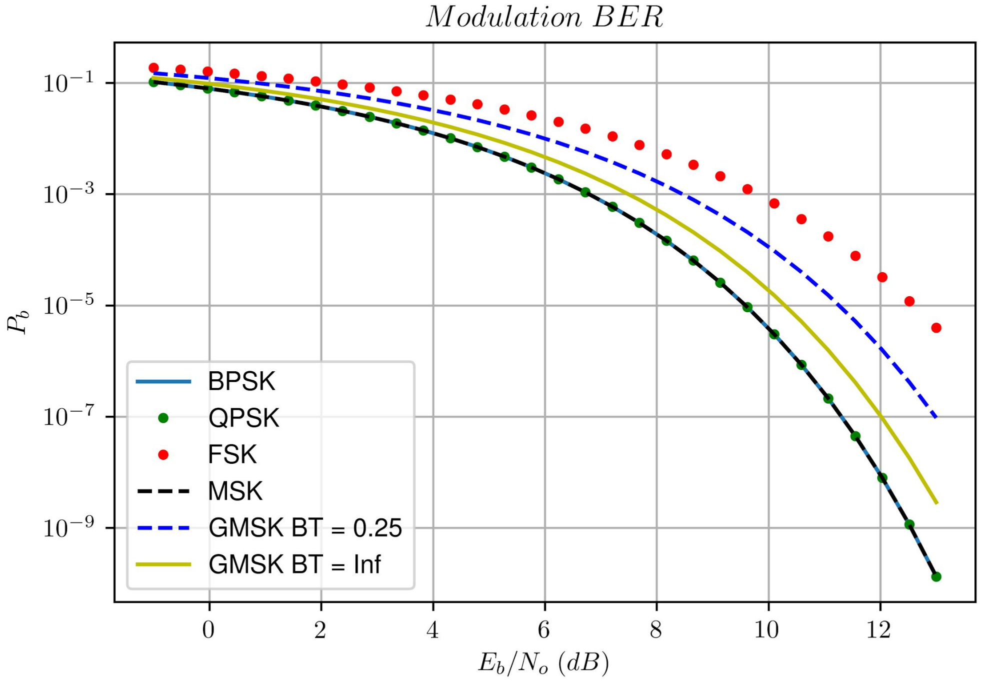


- Send random bits with bit rate R_b in a bandwidth B
- Transmitted bits control sinusoid waveform values (Amplitude, frequency, phase)

$$X_{dB} = 10\log_{10}\left(\frac{X}{X_0}\right)$$

Bit Error Probability

- Computes the probability that a decoded bit is corrupted by AWGN
- Plotted with the y-axis in log scale and x-axis in dB for E_b/N_o



QPSK: ✓✓BER, ✓✓B, ✖SL

MSK: ✓BER, ✓B, ✓SL

GMSK: ✓BER, ✓✓B, ✓✓SL

B: Bandwidth

SL: Sidelobes

Link Budget Guidelines

- Computes the SNR_{rcvd} and from proper conversions also $(E_b/N_o)_{rcvd}$
- A modulation and coding requires at least an $(E_b/N_o)_{min}$ for a target $P_{b,cod}$
- We verify if $(E_b/N_o)_{rcvd} > (E_b/N_o)_{min}$ → If ok, link works properly, otherwise adjust

$$P_{Rx} = \frac{P_{Tx} G_{Tx} G_{Rx} \lambda^2}{(4\pi d)^2} = \frac{P_{Tx} G_{Tx} G_{Rx}}{L_{FS}}$$

- We refer as free space loss to the dependence on distance and wavelength

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

- We may include other gains and losses of the system as well

Noise Temperature

- The noise power is defined as $N = N_oB$ → How to calculate N_o?
  - $N_o = k_BT_n$ with k_B is Boltzmann's constant , $k_B = 1.23 \times 10^{-19}$ J/K
  - T_n is defined as the noise temperature required to generate a thermal noise power equal to N in a bandwidth B
  - All the noise sources can be represented by a noise temperature
  - The system temperature is defined as $T_e = T_{ant} + T_{sys}$, where T_{ant} is the antenna noise temperature and T_{sys} is the equivalent system noise temperature

Link Budget Calculation - Downlink Scenario

Downlink	Value	Unit	Assumptions
Transmitter Side			
Tx Power	0	dBW	Typical satellite transmission power
Tx Cable Losses	0,2	dB	Small losses
Tx Antenna Gain	0	dBi	Close to isotropic antenna
Tx EIRP	-0,2	dBW	Equivalent radiated power with isotropic antenna
Orbit			
Height (above sea level)	400	Km	Reference height of Int. Space Station
Earth radius	6371	Km	Spherical-shaped Earth
Elevation Angle	5	°	For being above minimum Line of Sight
Link			
Carrier Frequency	438	MHz	Maximum frequency in the 70-cm UHF band
GS-satellite distance	1803,78	Km	To ensure the required elevation angle
Free-Space Loss	150,40	dB	Far-field region and effective area assumptions
Polarization Loss	3,00	dB	Max. mismatch due to uncontrolled orientation
Ionospheric Loss	0,40	dB	Typical for this medium and frequency
Atmospheric Loss	2,10	dB	Typical for this medium and frequency
Receiver Side			
Rx Antenna Gain	17	dBi	Dual Cross-Polarized Yagi-Uda Antennas
Rx Cable Losses	0,2	dB	Reception line from antenna to receiver amplifier
Rx Noise Figure	4	dB	Receiver LNA before predetection point
Noise			
Boltzmann's constant	1,38E-23	W/Hz/K	-
-	-228,60	dBW/K/Hz	Previous in dB scale
Ground Station physical temperature	290	K	IEEE Standard reference temperature
Antenna noise temperature	400	K	Sun and Earth as noise sources
Receiver noise temperature	472,78	K	Recv. transmission line + LNA front-end
System noise temperature	872,78	K	-
-	29,41	dBK	Previous in dB scale
Receiver Figure of Merit	-12,41	dB	G/T: Receiver gain - System noise temperature
Noise Spectral Density	-199,19	dBW/Hz	Boltzmann constant + System noise temp. (dB)
Carrier-to-noise-density ratio	60,09	dBHz	
Data Rate	100	Kbps	Design value
-	50,00	dBbps	Previous in dB scale
Eb/No received	10,09	dB	Pre-detection effective value
Eb/No required	5,6	dB	GMSK & BER = 10^-5 & Conv. R = 1/2 & RS(255,223)
Link Margin	4,49	dB	Link closed

- Transmitter: Antenna gain, line loss
- Orbit: Elev. angle, height → distance
- Link: Frequency, free-space loss, others
- Receiver: Antenna gain, line losses
- Receiver noise, modulation, bit prob.
- SNR, R_b, $(E_b/N_o)_{rcvd}$ and $(E_b/N_o)_{min}$
- ~ 8-11 MB / day

Link Budget Calculation - Inter-satellite Scenario

	Value	Unit	Assumptions
Transmitter Side			
Tx Power	0	dBW	1 W
Tx Cable Losses	0.2	dB	Small losses
Tx Antenna Gain	0	dBi	Close to isotropic antenna
Tx EIRP	-0.2	dBW	Equivalent radiated power with isotropic antenna
Orbit			
Height (above sea level)	400	Km	Reference height of Int. Space Station
Earth radius	6371	Km	Spherical-shaped Earth
Minimum number of satellites	11	-	For being above minimum Line of Sight (+ 1)
Link			
Carrier Frequency	436.5	MHz	Maximum frequency in the planned band
Inter-satellite distance	3815.22	Km	For C13 satellites in a ring topology
Free-Space Loss	156.88	dB	Far-field region and effective area assumptions
Polarization Loss	0.00	dB	Max. mismatch due to uncontrolled orientation
Receiver Side			
Rx Antenna Gain	0	dBi	Close to isotropic antenna
Rx Cable Losses	0.2	dB	Reception line from antenna to receiver amplifier
Rx Noise Figure	1	dB	Receiver LNA before predetection point
Noise			
Boltzmann's constant	1.38E-23	W/Hz/K	-
-	-228.60	dBW/K/Hz	Previous in dB scale
Satellite physical temperature	290	K	Verify this value
Antenna noise temperature	200	K	Sun and Earth as noise sources
Receiver noise temperature	92.29	K	Recv. transmission line + LNA front-end
System noise temperature	292.29	K	-
-	24.66	dBK	Previous in dB scale
Receiver Figure of Merit	-24.66	dB	G/T: Receiver gain - System noise temperature
Noise Spectral Density	-203.94	dBW/Hz	Boltzmann constant + System noise temp. (dB)
Carrier-to-noise-density ratio	46.86	dBHz	
Data Rate	5000	bps	Design value
-	36.99	dBbps	Previous in dB scale
Eb/No received	9.87	dB	Pre-detection effective value
Eb/No required	9.6	dB	BPSK @ BER = 10^-5, No coding
Link Margin	0.27	dB	Link closed

- Transmitter: Antenna gain, line loss
- Orbit: Number of satellites → distance
- Link: Frequency, free-space loss, others
- More stable, stationary links due to permanent connectivity
- Slower links due to the long distance

Thank you!

Questions?

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