CHALLENGES AND SOLUTIONS FOR THE QB50 TELECOMMUNICATION NETWORK

Günther March

Research Master Student at von Karman Institute for Fluid Dynamics,
Rhode Saint-Genèse, Belgium.

Supervisors: Thorsten Scholz, Jan Thömel and Salvo Marcuccio.

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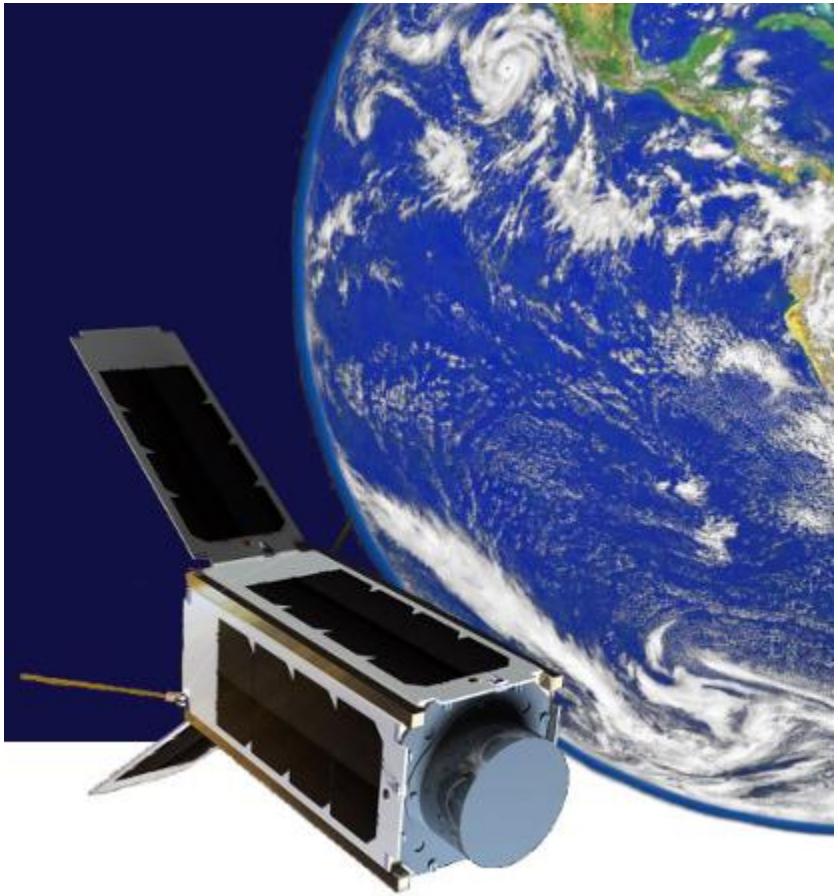
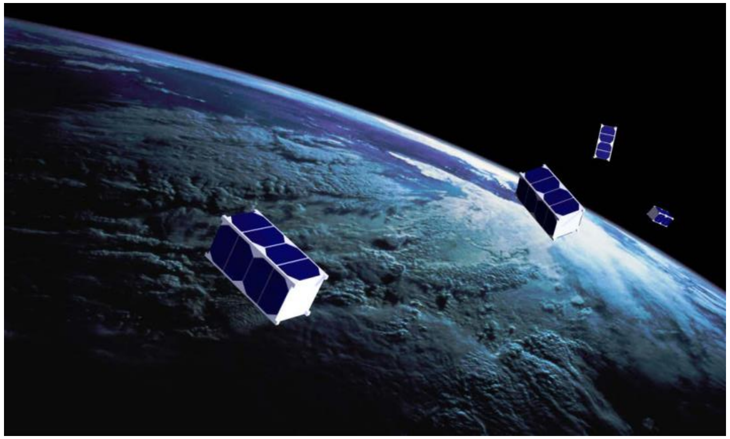


[CubeSat image courtesy of the University of New South Wales]

Introduction

QB50 Mission:

An international network of 50 CubeSats for multi-point, in-situ, long-duration measurements and in-orbit demonstration in the lower thermosphere.



- Circular initial orbit: altitude of approx. 380 km, Inclination ~98°.
- Downlink using the QB50 Network of Ground Stations.

The communication challenge:

- New kind of communication analysis (huge number of satellites);
- Achievement of mission requirements with low technologies.

Objectives & Requirements

Main Objectives:

- Find **number** and **positions** of GSs required to recover data generated.
- **Optimize communication link**.

Requirements:

- **Simple** and **high qualified technologies.**
- **2 Mb** Science data per day down to Earth for each CubeSat (**4 Mb** including Team Payload, extended to **10 Mb** for margins)

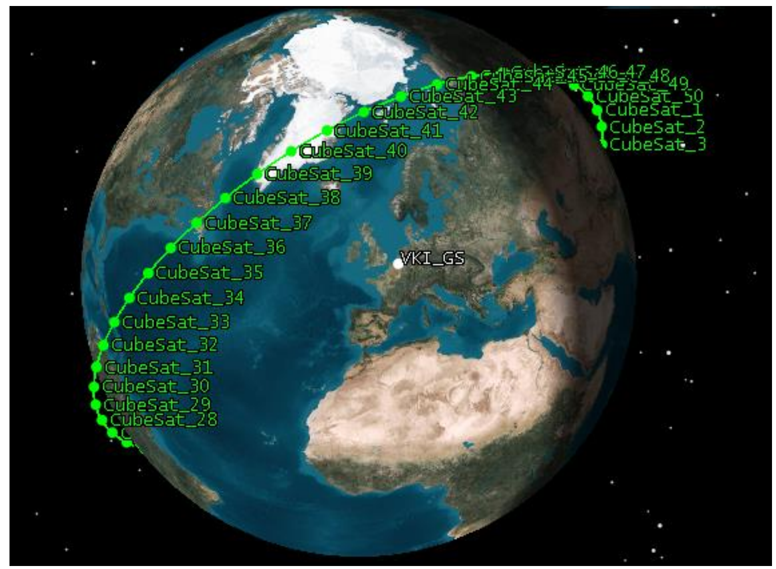
Analysis Methodology

- <u>One-to-One problem</u> (One CubeSat + One Ground station):
  - Communication system selection;
  - Orbital inclination investigation;
  - GS Latitude analysis.

- <u>Communication overlaps</u>

↓

- <u>Constellation problem</u>



Obtained by STK

Communication Solutions

- Introduction
- Objectives & Requirements
- **Communication Solutions**
- Orbital inclination Analysis
- GS Latitude Analysis
- Communication overlaps
- Constellation Problem
- Conclusions

Communication system selection:

- Analyzed comm. systems differ in frequency bands and devices for space and ground segments.

UHF/VHF system | S-Band system

- For both strategies were analyzed configurations with or without GS rotator.

- Using STK software:
  - Access time
  - Accumulated data

- Final comparison by Link Budget Analysis (signal quality).

→ SYSTEM SELECTED!

Communication Solutions

Communication systems:

UHF/VHF system:

Pro:
- Space qualified for CubeSat applications
- Low power consumption
- Wide beamwidth

Cons:
- Low data rate (9.6 kbps)

S-Band system:

Pro:
- High data rate (1 Mbps)

Cons:
- High power consumption
- Narrow beamwidth

STK Simulations:

Sim. 1: GS without rotator
Sim. 2: GS with rotator mechanism

VKI GS: 50.75 lat., 4.38 long.
Initial Orbit altitude: 380 km
Orbit inclination: 98 deg

Communication Solutions

- Introduction
- Objectives & Requirements
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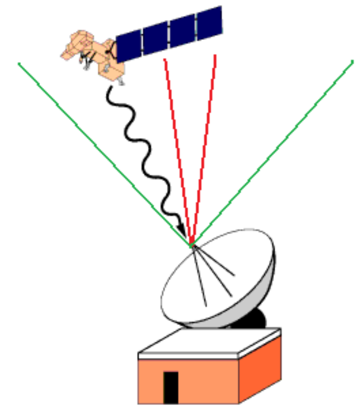
Sim.1: "No rotating GS"

Accumulated data:

UHF/VHF system: 4.09 Mb for the whole mission (~ 3 months)
S-Band system: 3.91 Mb for the whole mission (~ 3 months)

NOT FEASIBLE

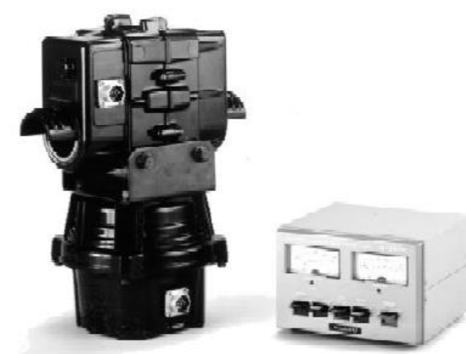


Sim.2: "GS with rotor"

Accumulated data:

UHF/VHF system: ~ 3 Mb per day
S-Band system: ~ 316 Mb per day

FEASIBLE



YAESU G-5500 Rotor

Link Budget Analysis

Signal quality investigation:

A **link budget** is the accounting of gains and losses from the transmitter, through the medium, to the receiver.

The **system link margin** is the difference between the receiver's sensitivity and the actual received power.

A system with low *link margin* requires increased system complexity.

→ Conflict with CubeSat Standards

Link Budget Analysis

UHF/VHF System:

Downlink budget:

Parameter	Value	Units
Spacecraft		
S/C Transmitter Power Output:	1,0	Watts
S/C Total Transmission Line Losses:	1,4	dB
S/C Antenna Gain:	1,5	dBi
S/C EIRP:	0,6	dBW
Downlink Path		
S/C Antenna Pointing Loss:	0,0	dB
S/C to GS Antenna Polarization Losses:	0,2	dB
Path Loss:	144,1	dB
Atmospheric Losses:	1,1	dB
Ionospheric Losses:	0,4	dB
Rain Losses:	0,0	dB

Parameter	Value	Units
Ground Station (Eb/No Method)		
GS Antenna Pointing Loss:	0,2	dB
GS Antenna Gain:	14,1	dBi
GS Total Transmission Line Losses:	3,0	dB
System Desired Data Rate:	9600	bps
Demodulation Method Selected:	QPSK	
System Allowed or Specified BER:	1,0E-05	
Telemetry System Required Eb/No:	9,6	dB
Eb/No Threshold	9,6	dB
System Link Margin:	18,9	dB

System Link Margin > 10 dB (Low cost systems)
System Link Margin > 6 dB (Professional Systems)

Link Budget Analysis

S-Band System:

Downlink budget:

Parameter	Value	Units
Spacecraft		
S/C Transmitter Power Output:	1,0	Watts
S/C Total Transmission Line Losses:	2,4	dB
S/C Antenna Gain:	6,0	dBi
S/C EIRP:	3,6	dBW
Downlink Path		
S/C Antenna Pointing Loss:	0,0	dB
S/C to GS Antenna Polarization Losses:	0,2	dB
Path Loss:	158,9	dB
Atmospheric Losses:	1,1	dB
Ionospheric Losses:	0,1	dB
Rain Losses:	0,5	dB

Parameter	Value	Units
Ground Station (Eb/No Method)		
GS Antenna Pointing Loss:	0,6	dB
GS Antenna Gain:	31,8	dBi
GS Total Transmission Line Losses:	2,0	dB
System Desired Data Rate:	1	Mbps
Demodulation Method Selected:	QPSK	
System Allowed or Specified BER:	1,0E-05	
Telemetry System Required Eb/No:	9,6	dB
Eb/No Threshold	9,6	dB
System Link Margin:	6,8	dB

System Link Margin > 10 dB (Low cost systems)
System Link Margin > 6 dB (Professional Systems)

Communication Solutions

- Introduction
- Objectives & Requirements
- **Communication Solutions**
- Orbital inclination Analysis
- GS Latitude Analysis
- Communication overlaps
- Constellation Problem
- Conclusions

Solution Selected:

- ***Ground segment***

  YAESU G-5500 Rotor

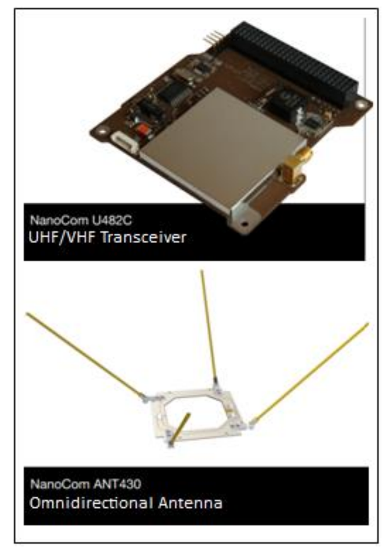
  Max El rate: 2.68 deg/s
  Max Az rate: 6.2 deg/s

  UHF/VHF Yagi Antenna (14.1 dBi)

- ***UHF/VHF system*** (Data rate: 9.6 kbps)

- ***Space segment***

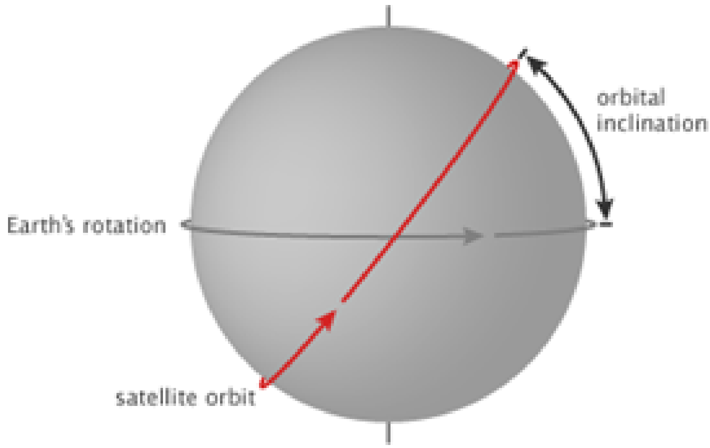
  Omnidirectional Antenna (1.5 dBi)
  UHF/VHF Transceiver



Courtesy of Gomspace.com

Orbital Inclination Analysis

Importance of orbit inclinations:



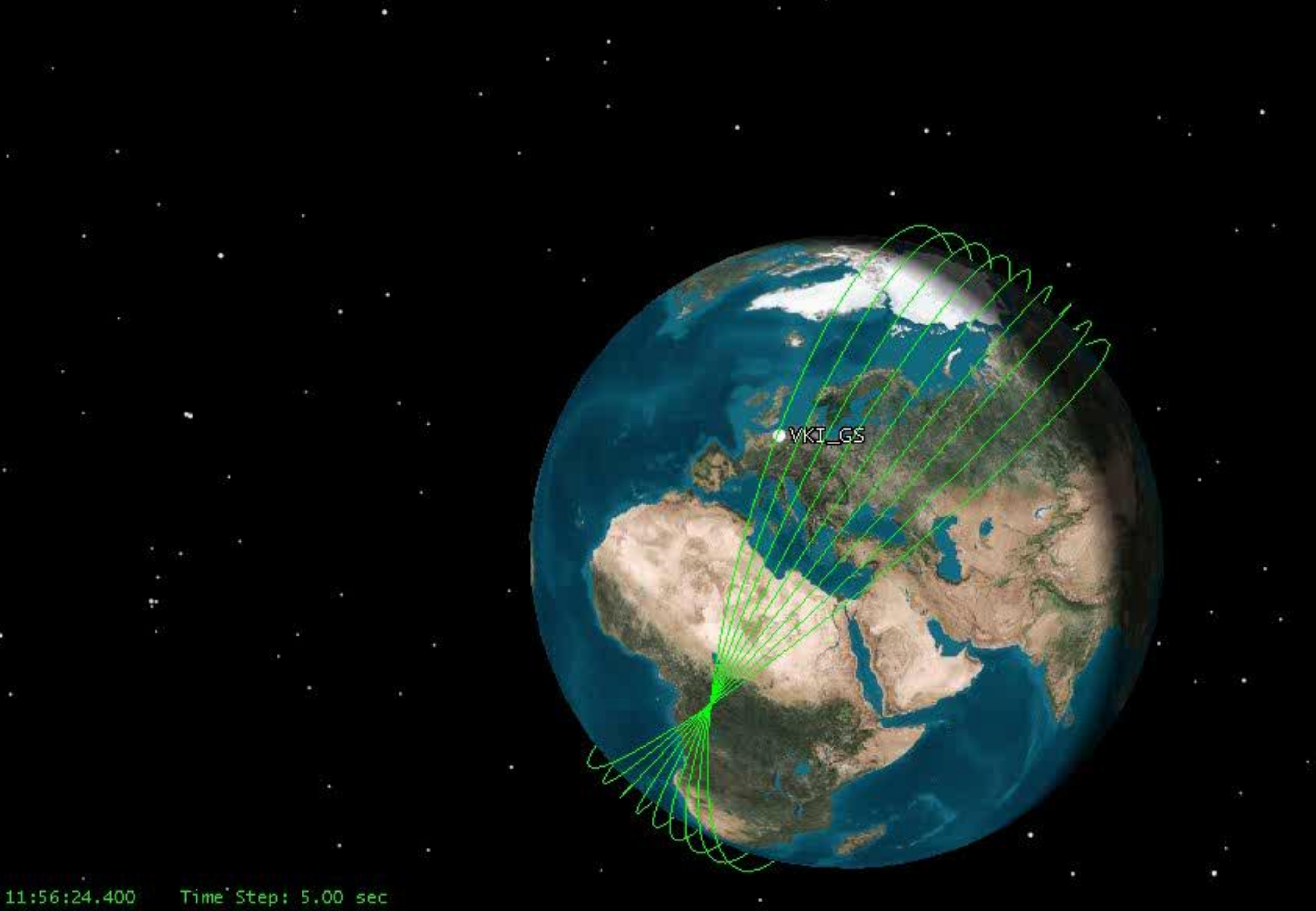
Inclination changes in function of launcher (and/or)

Variations in inclination could be due to mission modifications.

It is useful have an overview of possible performances for different inclinations!

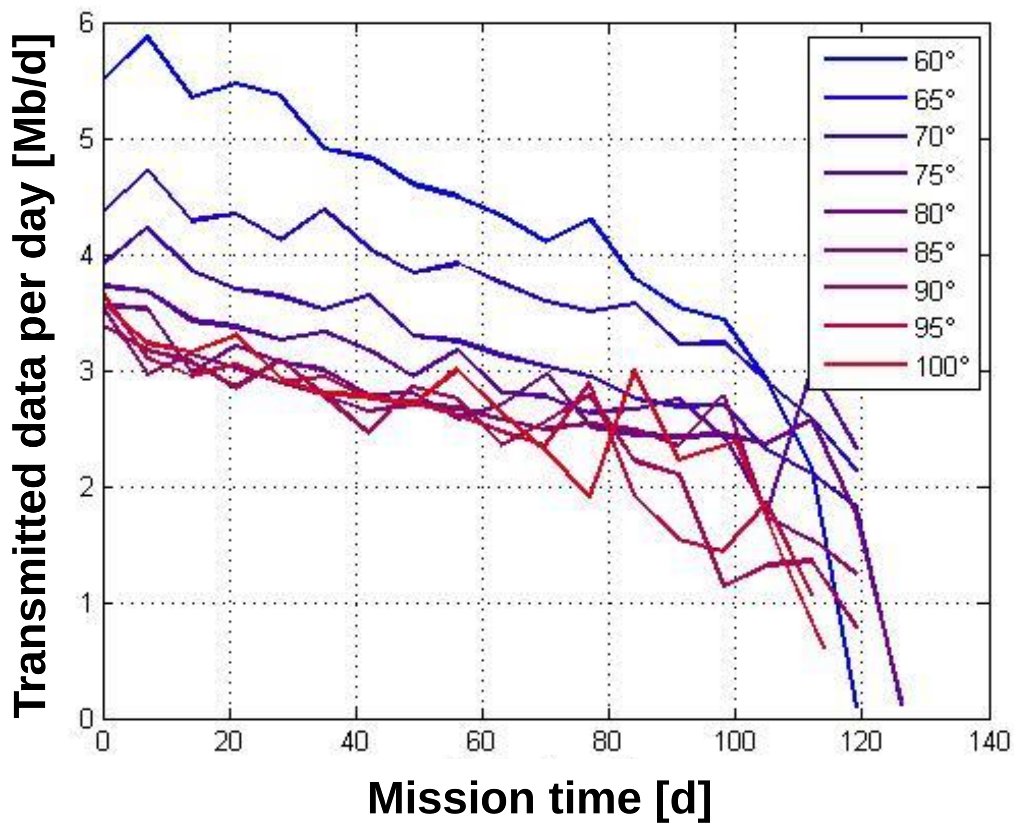
Analysis range for orbit inclinations: $60° < i < 100°$

Using …

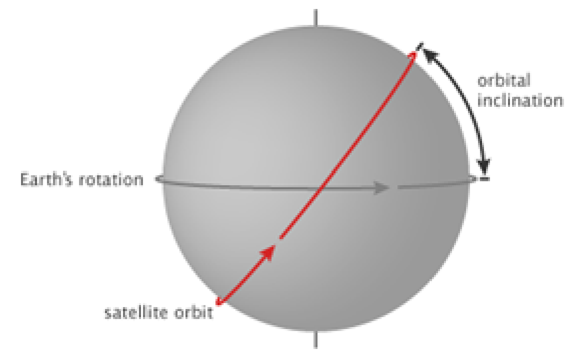

VKI_GS
11:56:24.400 Time Step: 5.00 sec

Orbital Inclination Analysis

Transmitted data per day:



VKI GS: 50.75 lat., 4.38 long.
Data rate: 9.6 kbps
Initial Orbit altitude: 380 km



60°< i < 100°

Therefore lower inclinations ensure more transmitted data.

There is a maximum increase of transmitted data above 70% for low inclinations.

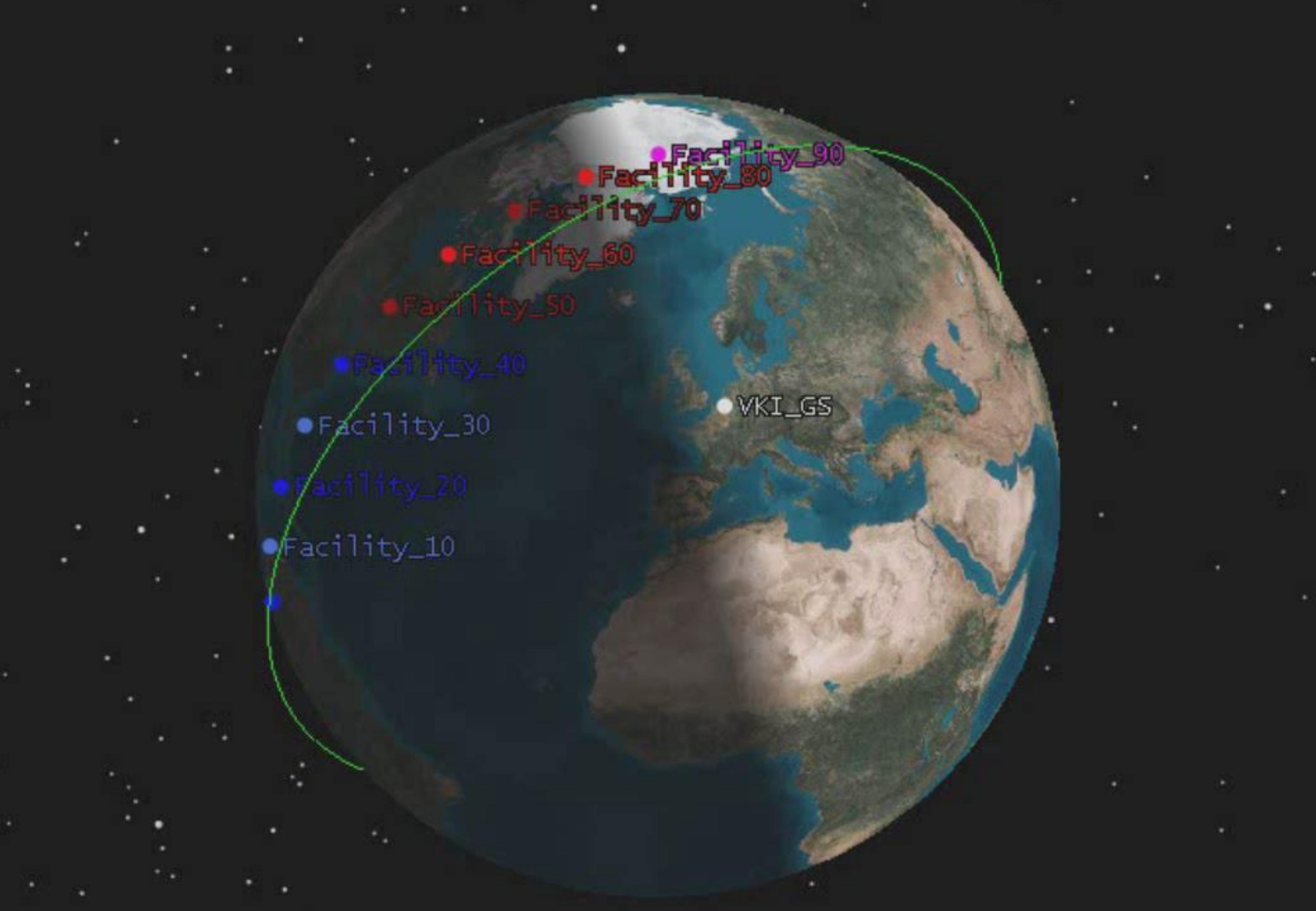
GS Latitude Analysis

Ground station position investigation:

Why should we study it?

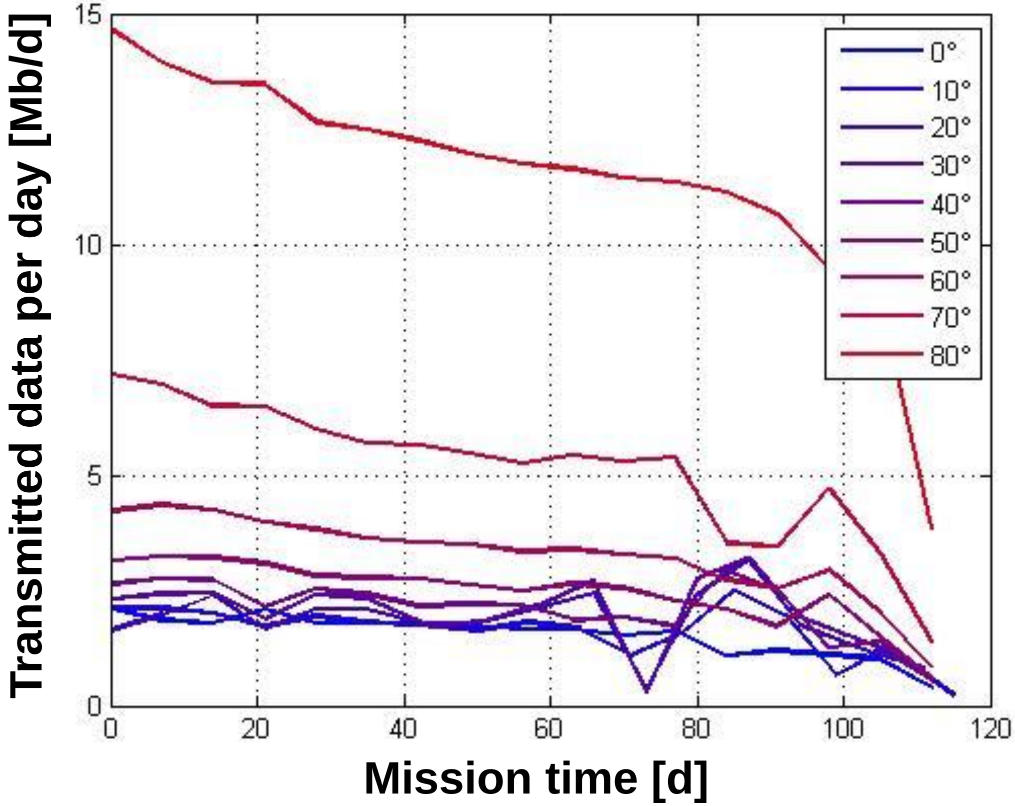
GS positions strongly influence collected data. Few stations at high latitudes could cover data like a great number of GSs at lower latitudes.

It is extremely useful have an overview of GSs performance in function of their latitudes.

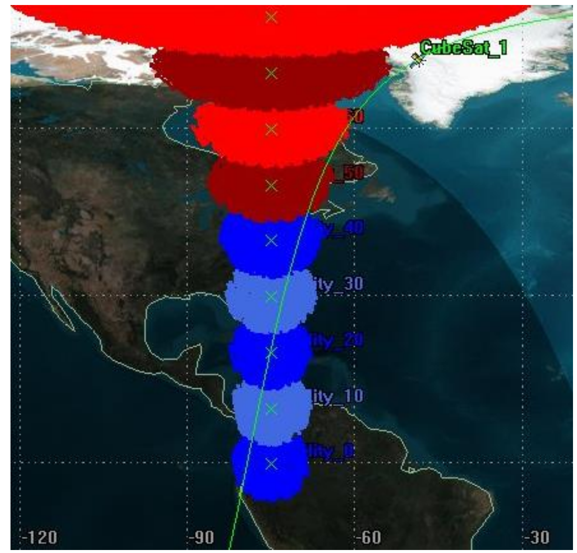

Facility_90
Facility_80
Facility_70
Facility_60
Facility_50
Facility_40
Facility_30
Facility_20
Facility_10
VKI_GS

GS Latitude Analysis

Transmitted data per day:



Orbit inclination: 98˚
Data rate: 9.6 kbps



0˚ < GS_lat < 80˚

Therefore higher latitudes ensure more transmitted data.

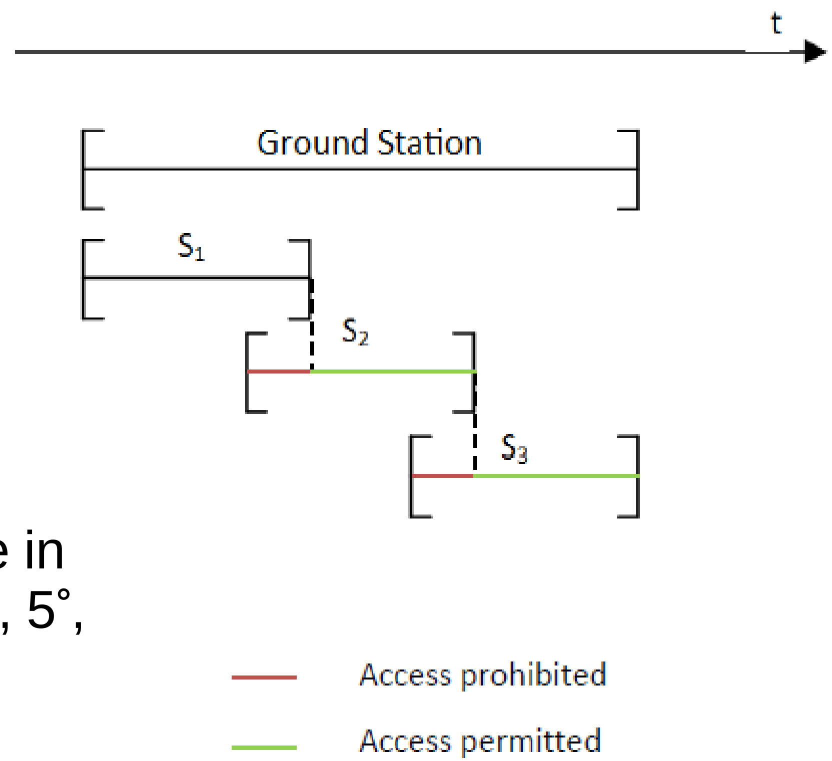
Transmitted data can be 7 times more for higher latitudes.

Communication Overlaps

The Overlap Problem:

Access Constrain:

One access per time.
ONE GS for ONE CubeSat per time.



Simulation Idea:

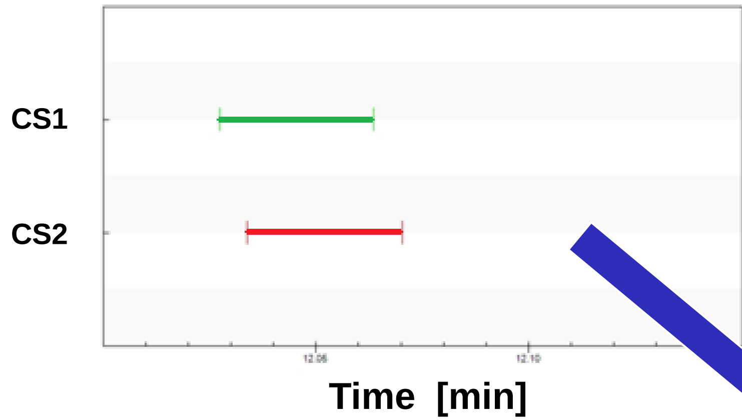
- Two CubeSats with a difference in the *True Anomaly angles* of: 2.5˚, 5˚, 7.5˚ and 10˚.

- One GS (VKI Ground Station)

Communication Overlaps

STK results:

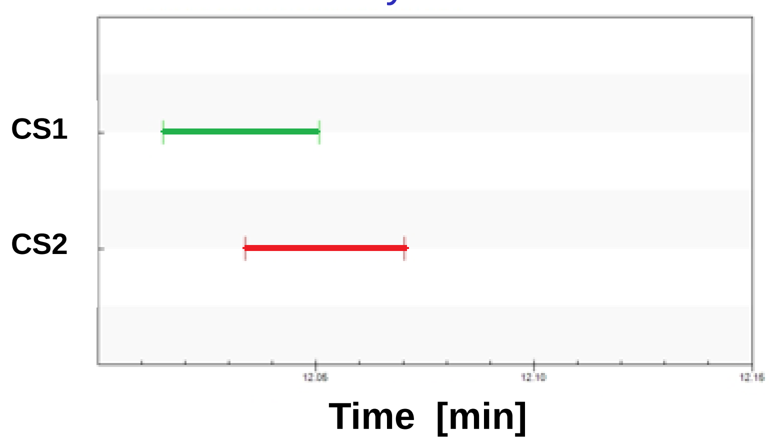
True Anomaly difference: 2.5°



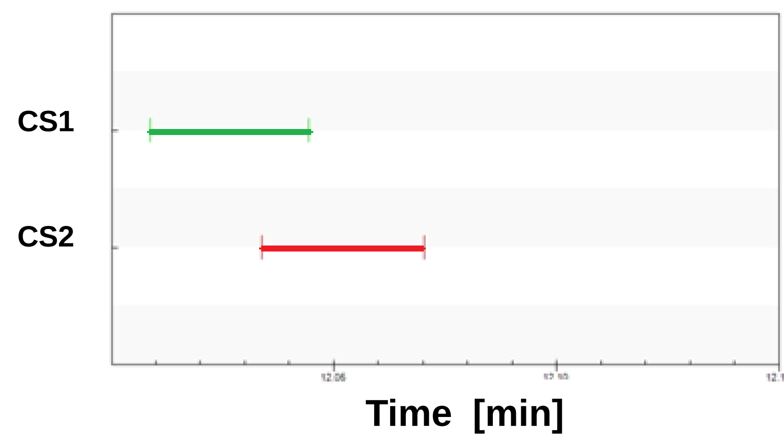
With higher angular distances overlaps are shorter.

Close CubeSats require more GSs to avoid Overlaps problem.

True Anomaly difference: 7.5°



True Anomaly difference: 10°

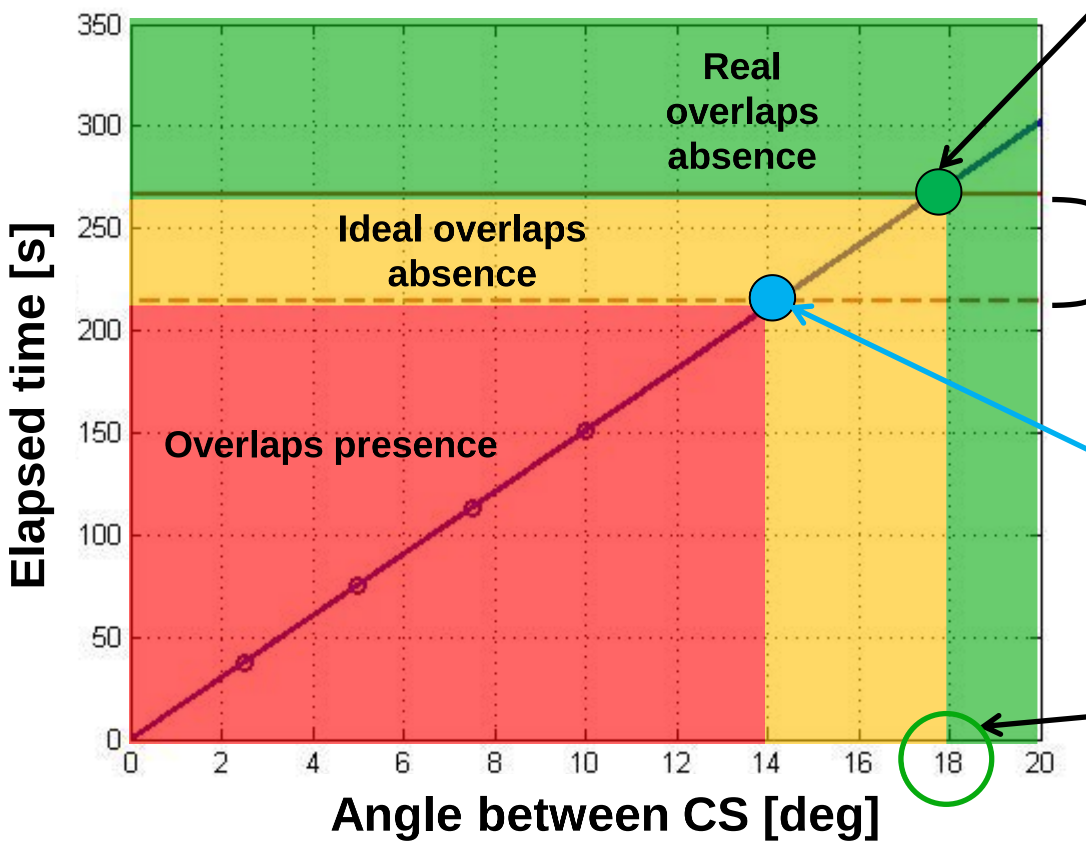


Communication Overlaps

- Introduction
- Objectives & Requirements
- Communication Solutions
- Orbital inclination Analysis
- GS Latitude Analysis
- **Communication overlaps**
- Constellation Problem
- Conclusions

Evaluation of minimum angle between CS to avoid overlaps:

Interpolating results…



Minimum condition to don’t miss contacts due to overlaps.

Time required to rotate antenna to the starting position.

Overlaps end condition, corresponding to the average access time.

Minimum angle difference to avoid overlaps.
(18˚ ↔ 20 CubeSats for one GS)

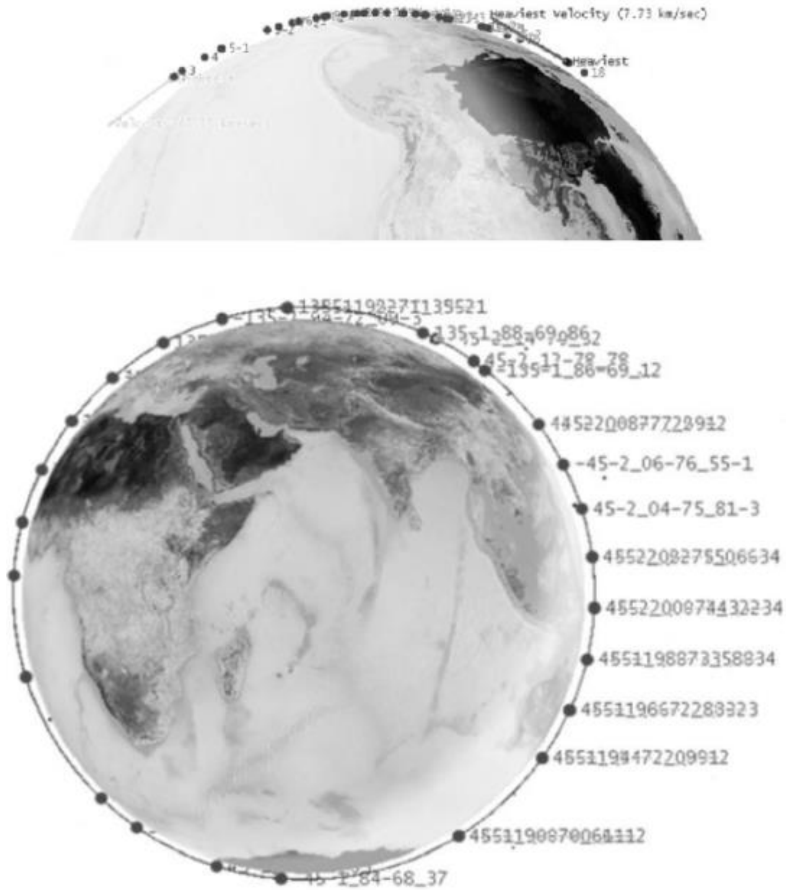
Constellation Problem

- Introduction
- Objectives & Requirements
- Communication Solutions
- Orbital inclination Analysis
- GS Latitude Analysis
- Communication overlaps
- **Constellation Problem**
- Conclusions

Constellation Issues:

- Only one CS can communicate with one GS per time and vice versa;

- Constellation geometry varies with time.



After deployment (up), after 1 month (down)

Constellation Problem

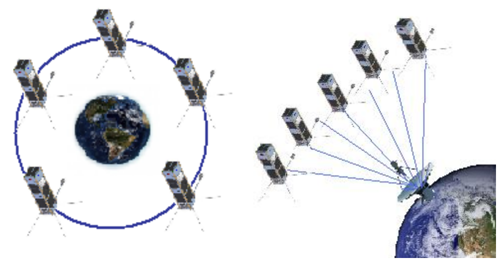
Analyzed CubeSat configurations:

- 5 CSs with large angular distance *(Group 1)*

  (72 deg of difference in True Anomaly angles)

- First 5 CSs of distributed configuration *(Group 2)*

  (7.2 deg of difference in True Anomaly angles)

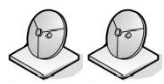
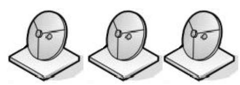
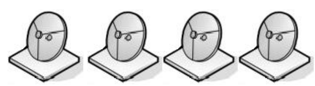
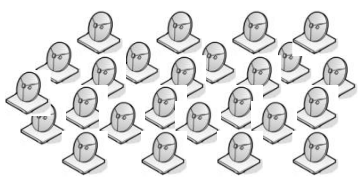


Post-processing STK results by… MATLAB

Constellation Problem

1 to 25 GS combinations analysis:

Analyze some possible combinations with ground segments including from 1 to 25 GSs.

Case 1	1				1 GS
Case 2	6				
Case 3	13				
Case 4	20				
Case 5	1	13			2 GSs
Case 6	28	3			
Case 7	7	21			
Case 8	13	17			
Case 9	7	13	3		3 GSs
Case 10	12	17	2		
Case 11	25	9	1		
Case 12	24	7	2		
Case 13	6	13	23	21	4 GSs
Case 14	25	20	9	1	
Case 15	28	1	13	3	
Case 16	7	3	18	24	
…	…	…	…	…	…
Case 97	…	…	…	…	25 GSs
Case 98	…	…	…	…	
Case 99	…	…	…	…	
Case 100	…	…	…	…	

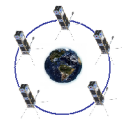
Constellation Problem

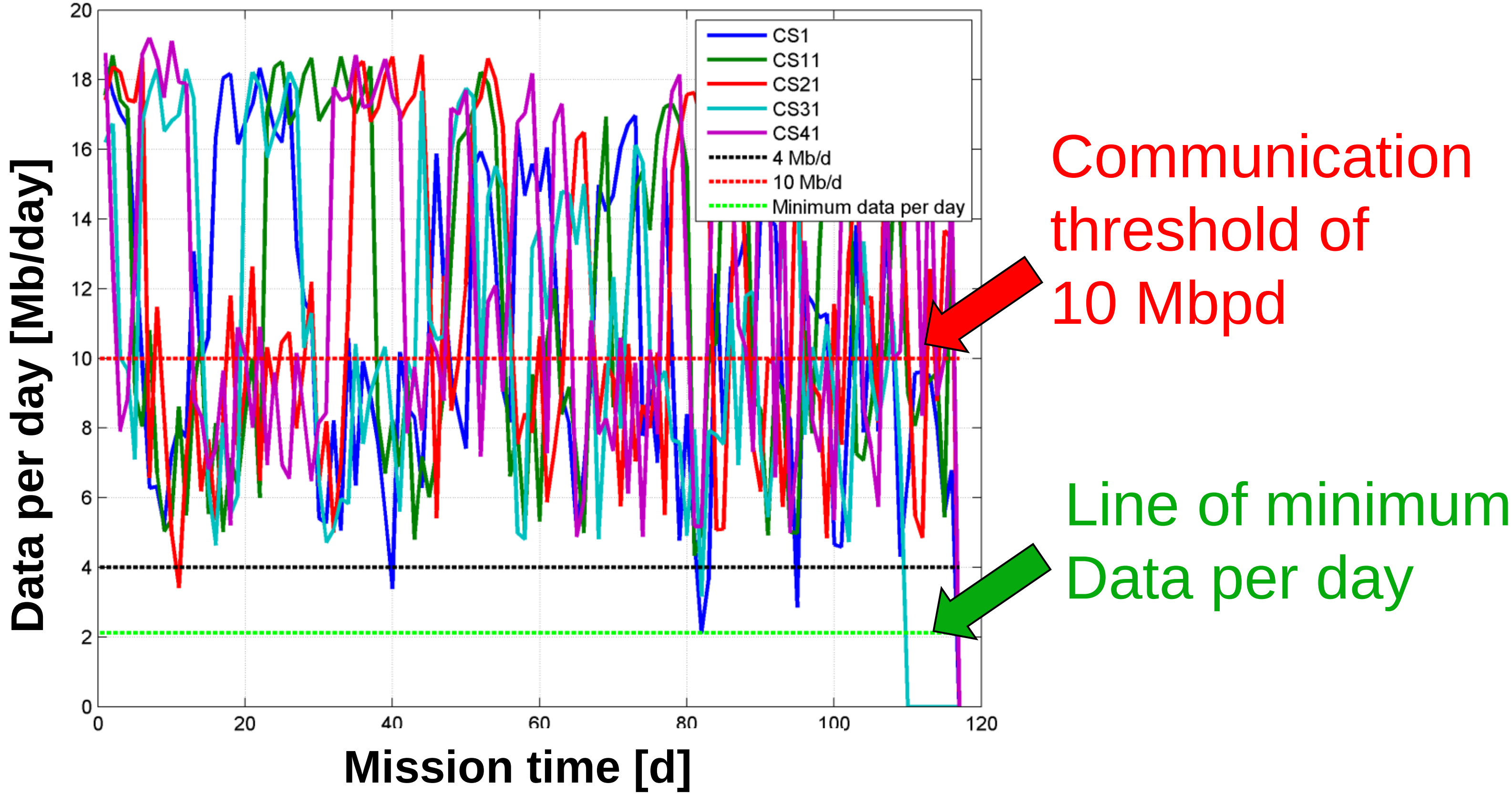
- Introduction
- Objectives & Requirements
- Communication Solutions
- Orbital inclination Analysis
- GS Latitude Analysis
- Communication overlaps
- **Constellation Problem**
- Conclusions

1 to 25 GS combinations analysis:

CS Group 1

Results for 1 GS





Constellation Problem

1 to 25 GS combinations analysis:

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- **Constellation Problem**
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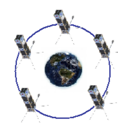
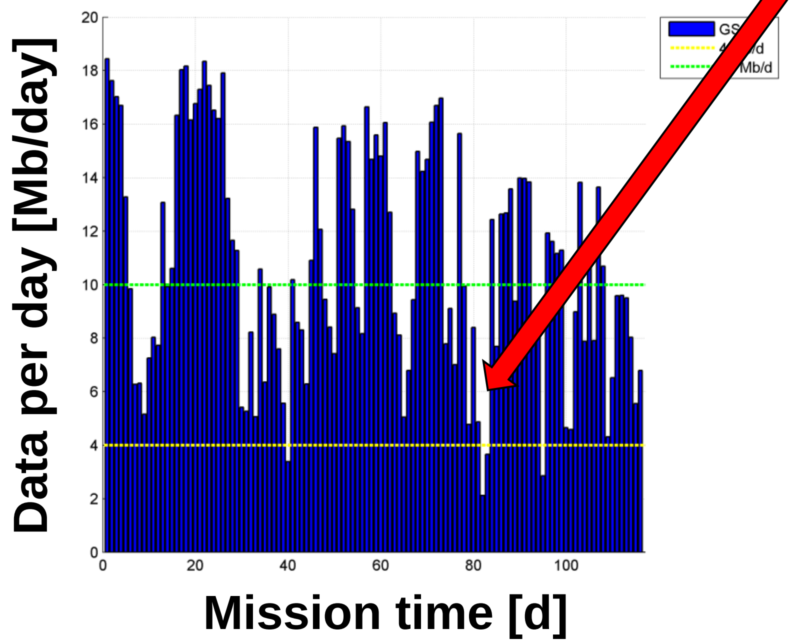
CS Group 1

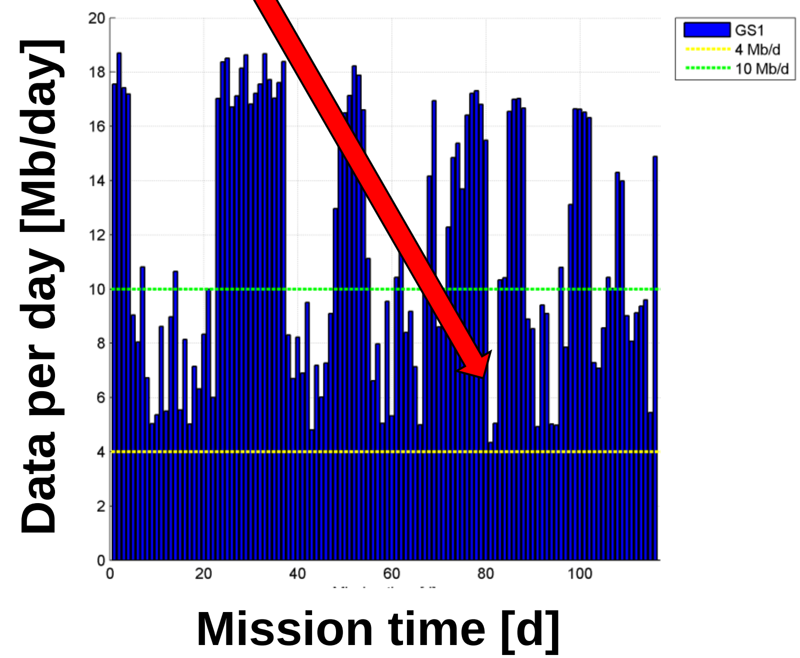
Results for 1 GS



Low peaks under 10 Mbpd lines



Ex. CS 1



Ex. CS 11

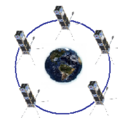
Constellation Problem

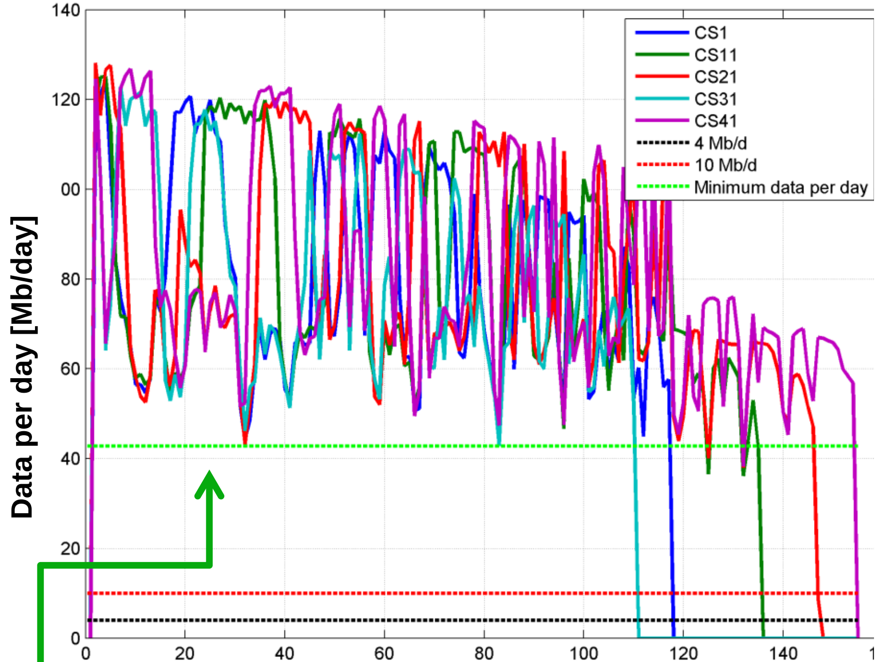
- Introduction
- Objectives & Requirements
- Communication Solutions
- Orbital inclination Analysis
- GS Latitude Analysis
- Communication overlaps
- **Constellation Problem**
- Conclusions

1 to 25 GS combinations analysis:

CS Group 1

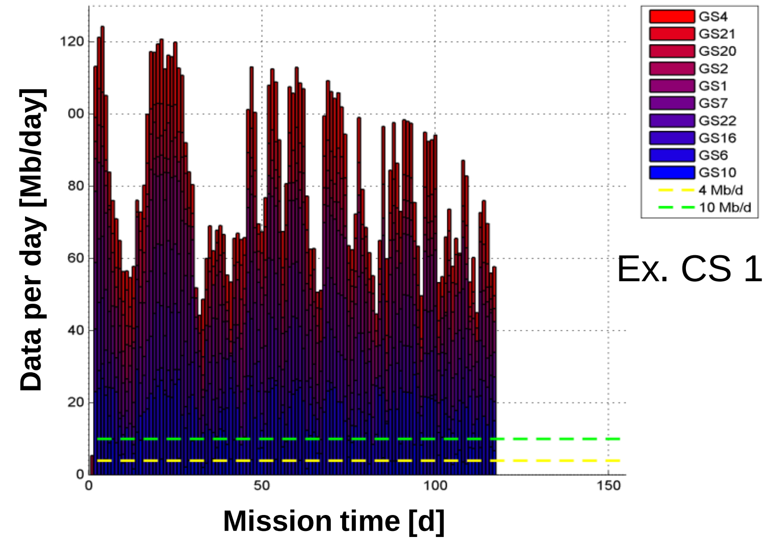
Results for 10 GSs



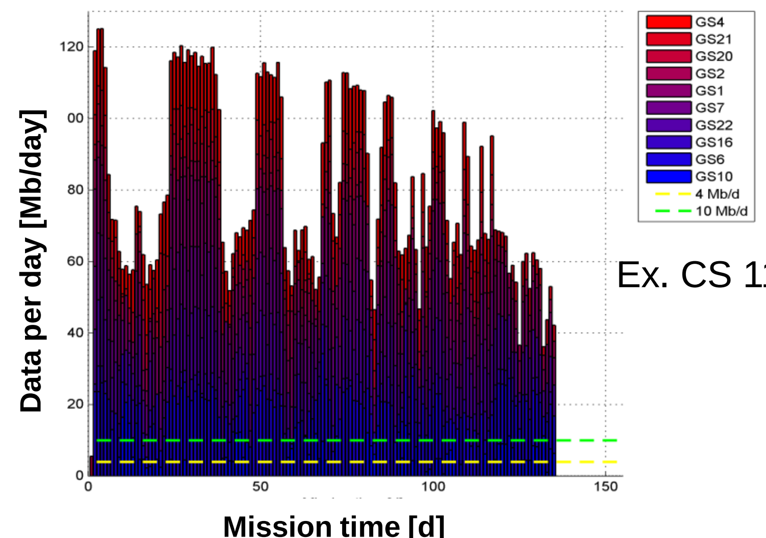


Above 10 Mbpd line!

Resources excess



Ex. CS 1



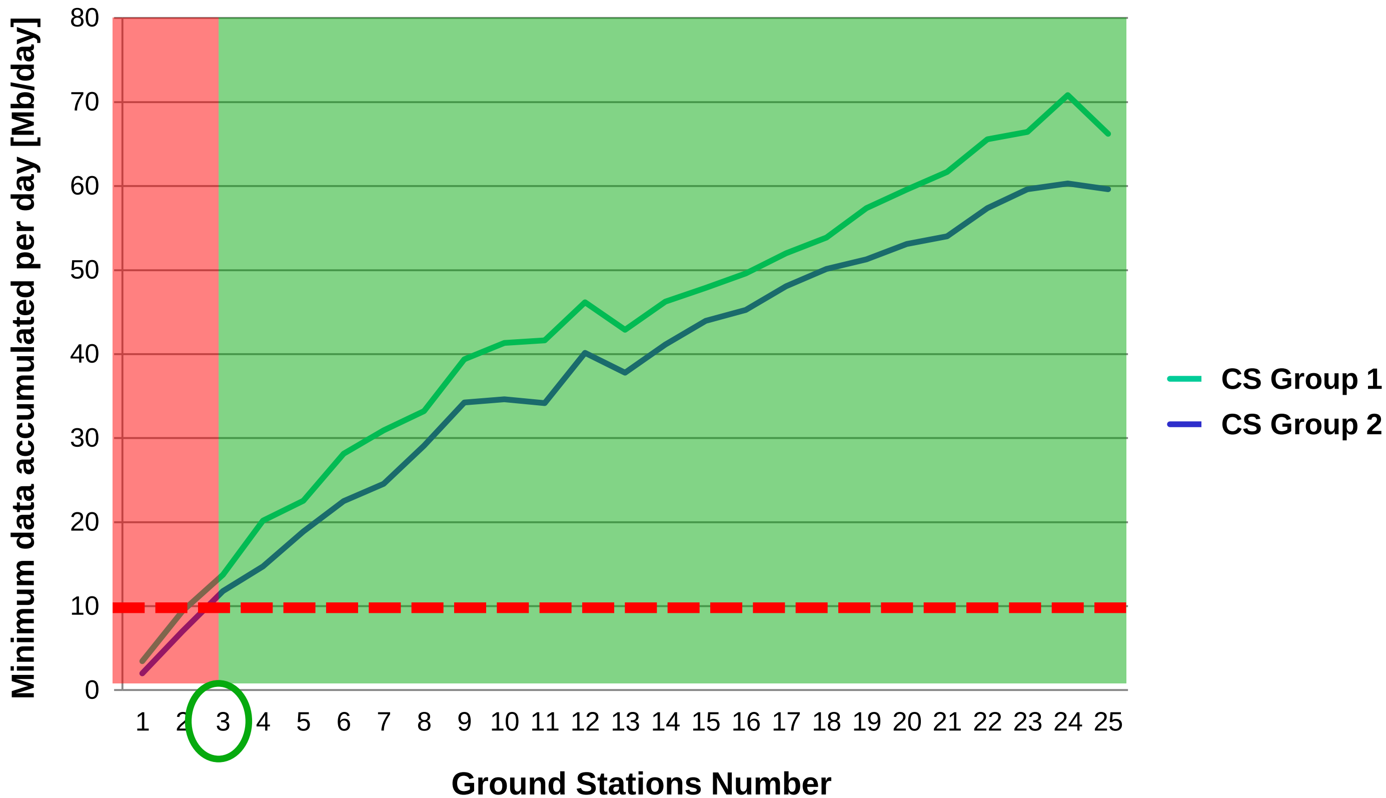
Ex. CS 11

Constellation Problem

1 to 25 GS combinations analysis:

Results comparison between CS Group 1 and 2.

Min. data collected per day for different number of GSs



Constellation Problem

- Introduction
- Objectives & Requirements
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- Orbital inclination Analysis
- GS Latitude Analysis
- Communication overlaps
- **Constellation Problem**
- Conclusions

1 to 25 GS combinations analysis:

3 GSs results

CS Group 1	CS Group 2
Average data collected: 13,7 Mb/d	*Average data collected*: 11,8 Mb/d

Requirements satisfied!

Minimum number of GSs results to be 3.

What happens if we select only one GS at very high latitude?!

Constellation Problem

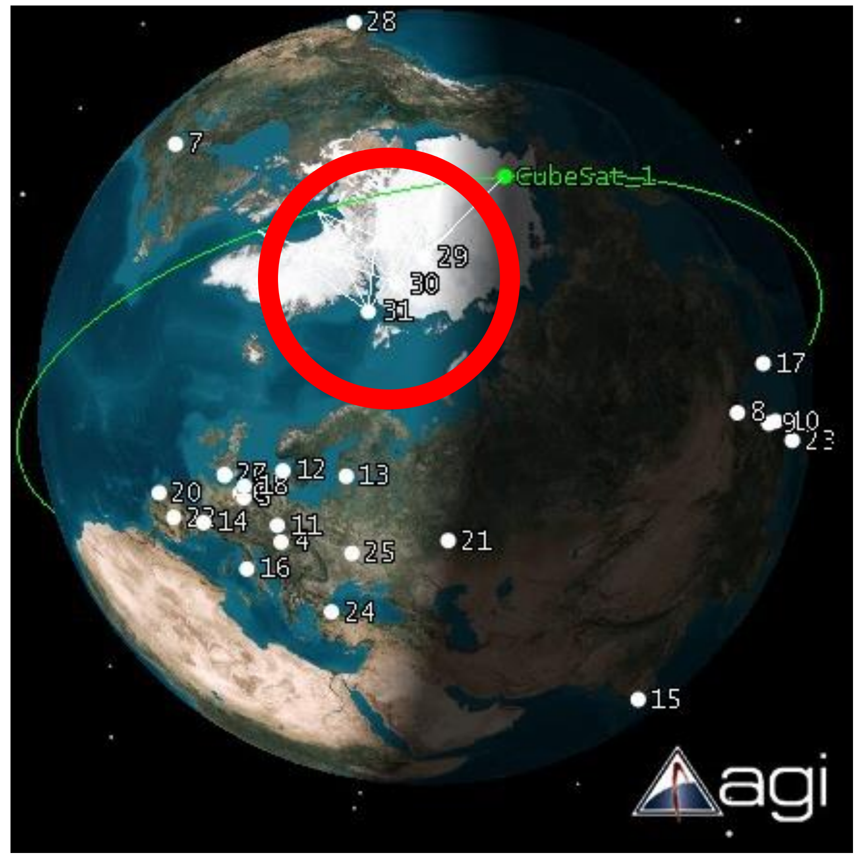
Use of a single GS at high latitude:

Three different GSs, characterized by 3 different latitudes:

- GS 29: 0˚ long., 90˚ lat.
- GS 30: 0˚ long., 85˚ lat.
- GS 31: 0˚ long., 80˚ lat.

The orbital characteristics and mission requirements are the same.

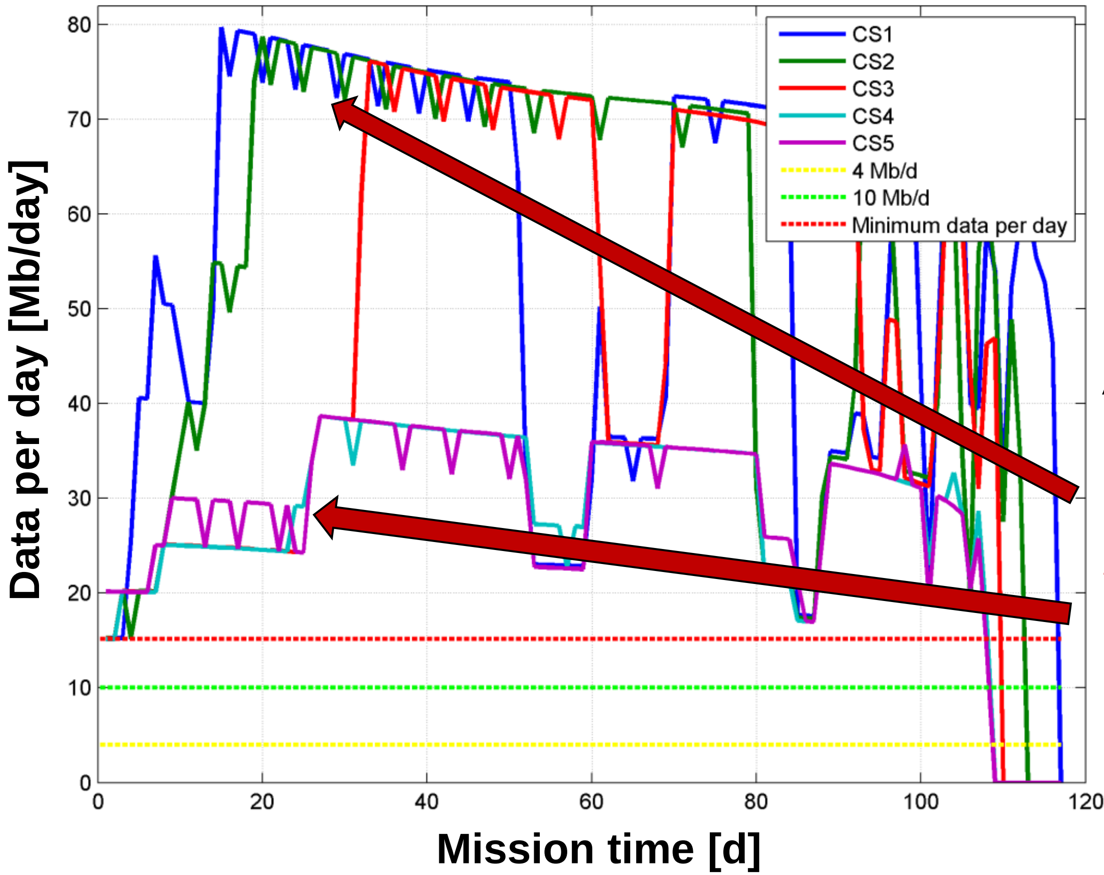
Two different CS groups (CS Group 1 and CS Group 2).

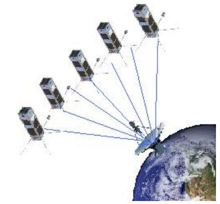


Constellation Problem

Use of a single GS at high latitude:

CubeSat Group 2





Feasible results

Above 10 Mb/day

Large differences in *Data per day* between CSs (Strong overlaps presence).

Conclusions

Results:

- *UHF-VHF System*, which ensures better signal quality;

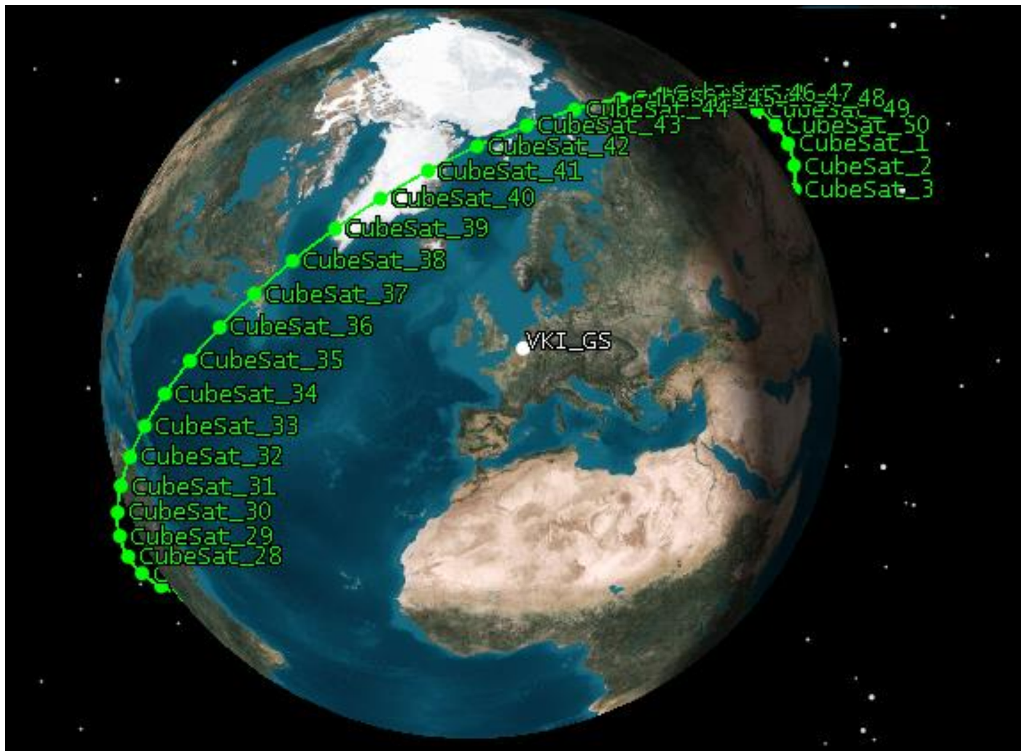
- In-depth study of *overlaps*, *GS position* and *orbital inclination* influence;

- The use of a *single GS* could be an effective alternative, but there are relevant downsides as the *strong overlaps effects*, *difficult accessibility* and *maintenance*, which requires high costs to guarantee a high reliability.

- By *Combination Analysis* the minimum number of GSs turns out to be 3 (between GSs of QB50 partners).

Thanks to: VKI QB50 Team and ESA for sponsorship

Thank you for your attention



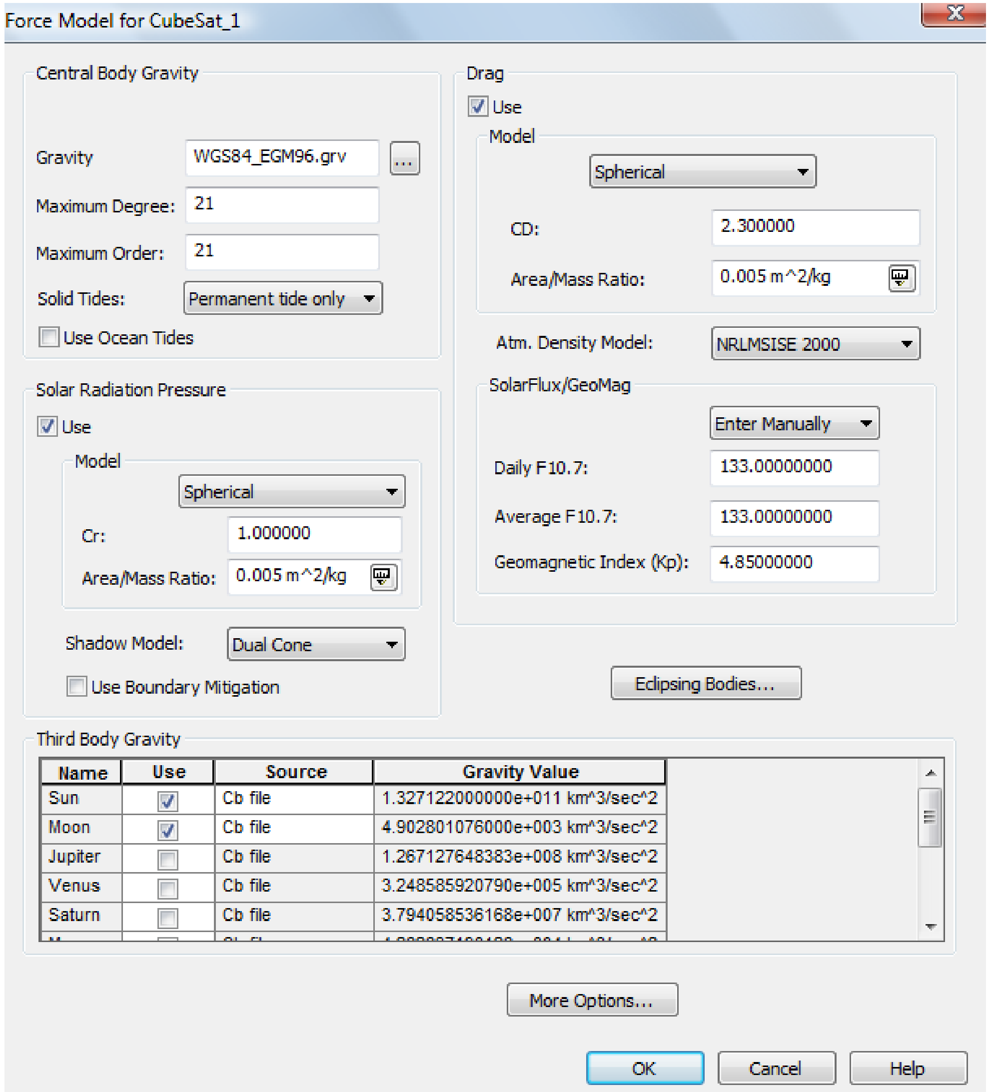
Günther March

Postgraduate Research Master Student
Von Karman Institute for Fluid Dynamics
Rhode Saint-Genèse, Belgium.

Contacts:
gunther.march@vki.ac.be
g.march@hotmail.it

Appendix

Force Model for STK:



CubeSat force model for STK scenarios

Link Budget Analysis

Communication Link Losses:

Free-Space Path Loss:

Attenuation of an electromagnetic wave as it propagates through space, is also the major component in the link budget analysis.

$$\mathrm{FSPL(dB)} = 10\log_{10}\left(\left(\frac{4\pi}{c}df\right)^2\right)$$

Rain Loss:

Attenuation due to the rain presence. This loss varies much with frequency.

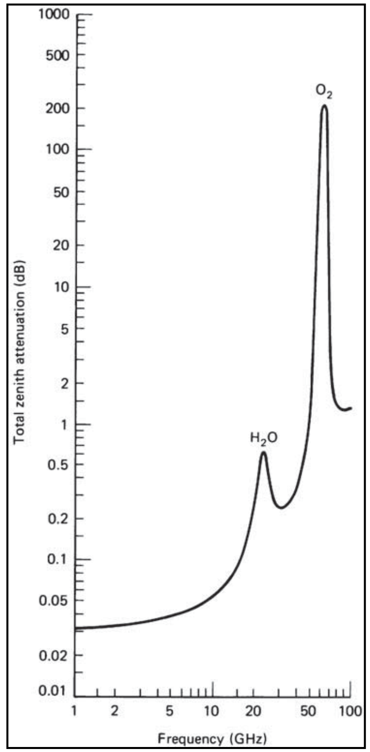
$$A_p = aR_p^b L_S r_p \quad \text{, [dB]}$$

Ionospheric Loss:

Clouds of electrons may travel through the ionosphere and give rise to fluctuations in the signal.

Atmospheric Loss:

Energy absorption by the atmospheric gases. The atmospheric absorption loss varies with frequency.



Link Budget Analysis

UHF/VHF System:

Uplink budget:

Parameter	Value	Units
Ground Station		
GS Transmitter Power Output:	10,0	Watts
GS Total Transmission Line Losses:	4,0	dB
Antenna Gain:	16,3	dBi
GS EIRP:	22,3	dBW
Uplink Path		
GS Antenna Pointing Loss:	0,3	dB
GS-to-S/C Antenna Polarization Losses:	0,2	dB
Path Loss:	134,6	dB
Atmospheric Losses:	1,1	dB
Ionospheric Losses:	0,7	dB
Rain Losses:	0,0	dB

Parameter	Value	Units
Spacecraft (Eb/No Method)		
S/C Antenna Pointing Loss:	0,0	dB
S/C Antenna Gain:	2,0	dBi
S/C Total Transmission Line Losses:	1,9	dB
System Desired Data Rate:	1200	bps
Demodulation Method Selected:	AFSK/FM	
System Allowed or Specified BER:	1,0E-05	
Telemetry System Required Eb/No:	23,2	dB
Eb/No Threshold	24,2	dB
System Link Margin:	33,6	dB

System Link Margin > 10 dB (Low cost systems)
System Link Margin > 6 dB (Professional Systems)

Link Budget Analysis

S-Band System:

Uplink budget:

Parameter	Value	Units
Ground Station		
GS Transmitter Power Output:	35,0	Watts
GS Total Transmission Line Losses:	4,0	dB
Antenna Gain:	30,6	dBi
GS EIRP:	42,1	dBW
Uplink Path		
GS Antenna Pointing Loss:	0,5	dB
GS-to-S/C Antenna Polarization Losses:	0,2	dB
Path Loss:	157,3	dB
Atmospheric Losses:	1,1	dB
Ionospheric Losses:	0,4	dB
Rain Losses:	0,5	dB

Parameter	Value	Units
Spacecraft (Eb/No Method)		
S/C Antenna Pointing Loss:	0,0	dB
S/C Antenna Gain:	6,0	dBi
S/C Total Transmission Line Losses:	0,4	dB
System Desired Data Rate:	1	Mbps
Demodulation Method Selected:	QPSK	
System Allowed or Specified BER:	1,0E-05	
Telemetry System Required Eb/No:	9,6	dB
Eb/No Threshold	9,6	dB
System Link Margin:	20,4	dB

System Link Margin > 10 dB (Low cost systems)
System Link Margin > 6 dB (Professional Systems)

Link Budget Analysis

Link Budget Results:

For low cost systems there is a *Minimum Required Link Margin* of 10 dB.

UHF/VHF system:

Uplink :
System Link Margin = 33,6 dB

Downlink :
System Link Margin = 18,9 dB

S-Band system:

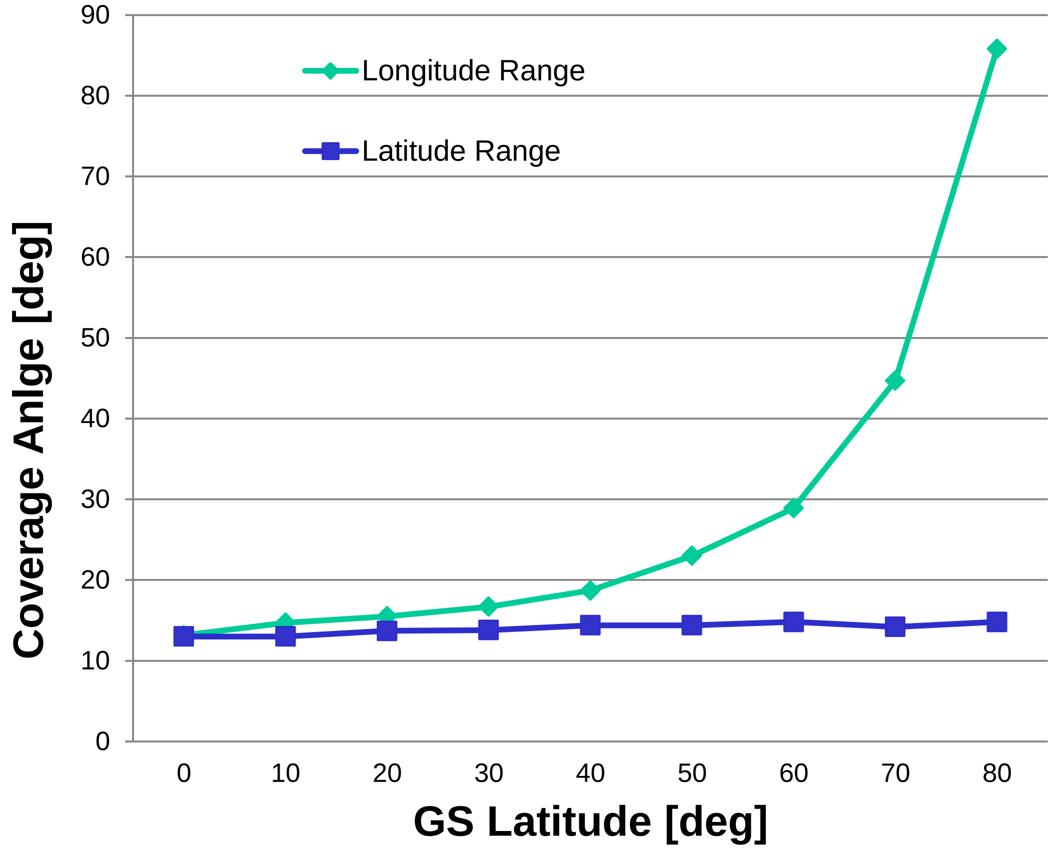
Uplink :
System Link Margin = 20,4 dB

Downlink :
System Link Margin = 6,8 dB

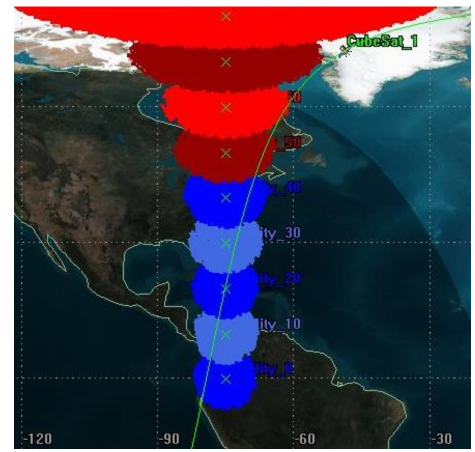
GS Latitude Analysis

- Introduction
- Objectives & Requirements
- Communication Solutions
- Orbital inclination Analysis
- **GS Latitude Analysis**
- Communication overlaps
- Constellation Problem

GS coverage range angle:



Orbit inclination: 98°



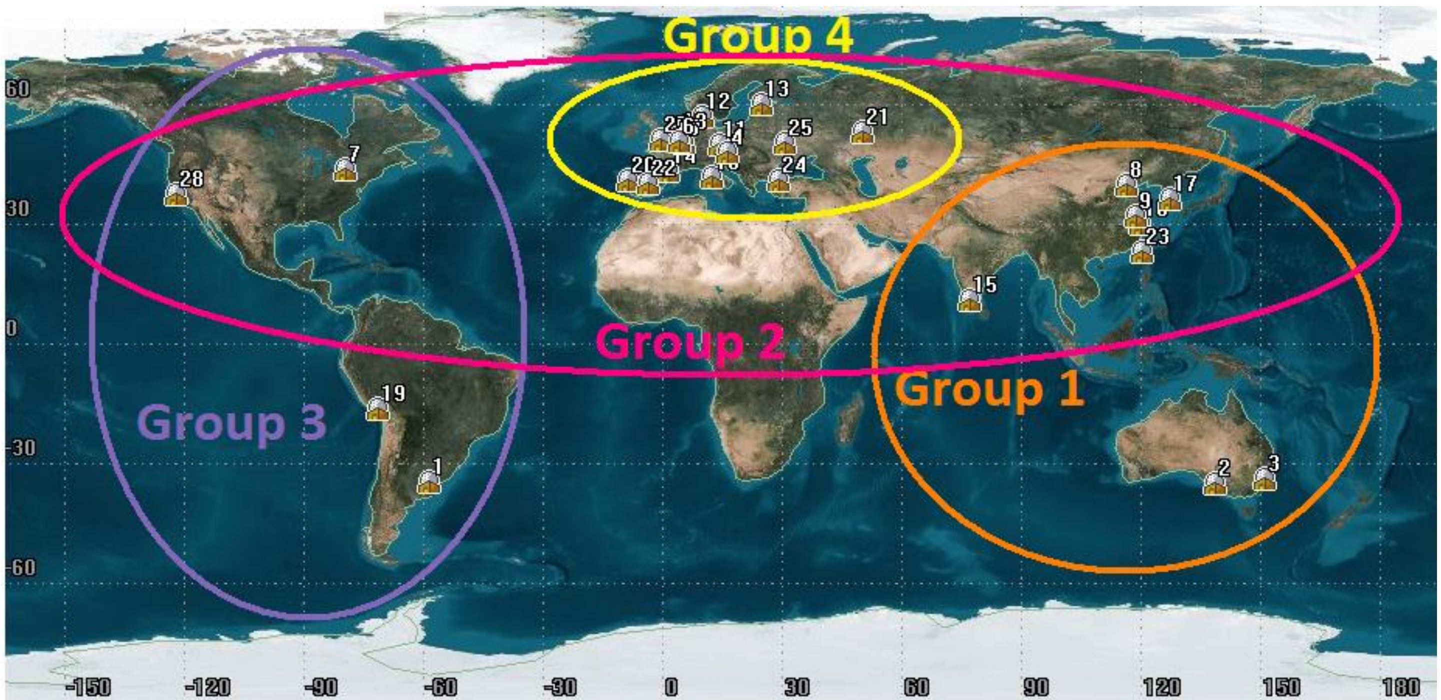
Higher GS latitudes lead to greater longitude range angles. Latitude range angle is nearly constant.

Constellation Problem

Ground segments analysis:

- *Group 1*: Asia N/S
- *Group 2*: Northern hemisphere W/E
- *Group 3*: America N/S
- *Group 4*: Europe

- CS Orbit inclinations: 98°
- Data rate: 9.6 kbps
- 28 GSs in 4 groups
- Min. contact time for calculations: 20 s



Constellation Problem

Daily data results:

- Introduction
- Objectives & Requirements
- Communication Solutions
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- GS Latitude Analysis
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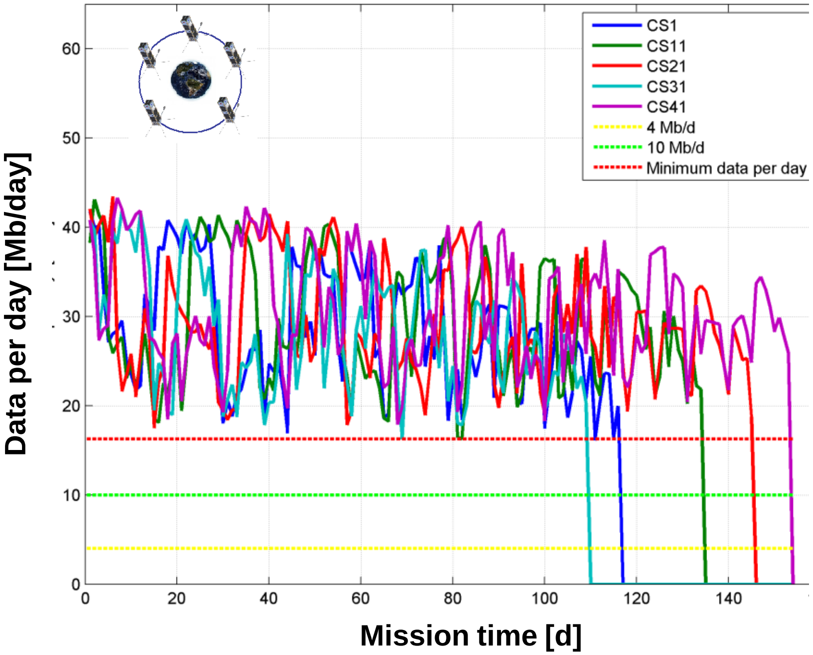
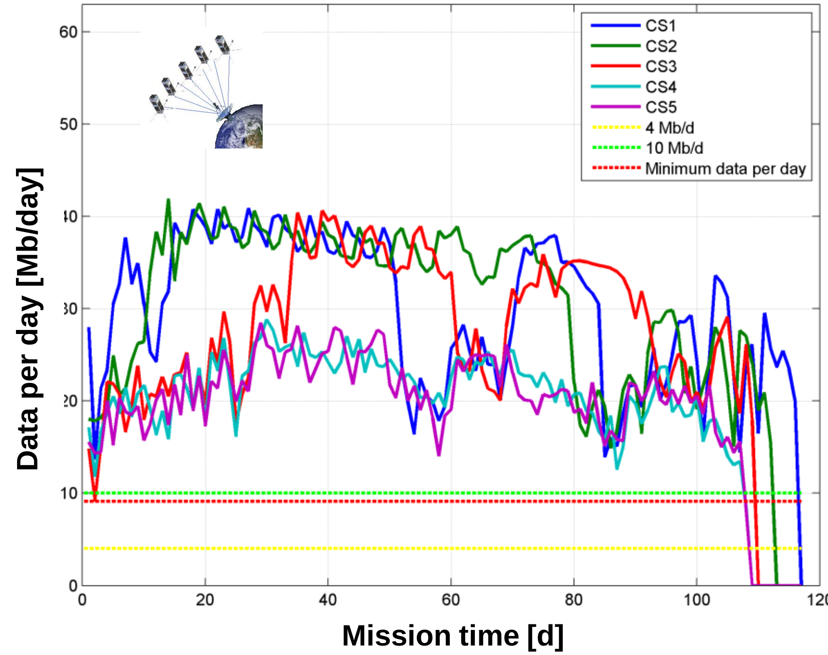
- **Constellation Problem**
- Conclusions

Asia N/S Ground Segment





Requirements reached.
Since the starting phase good amount of data collected.

Requirements are not reached.
In the starting phase low amount of data collected.

Constellation Problem

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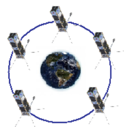
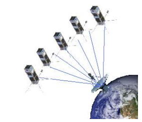
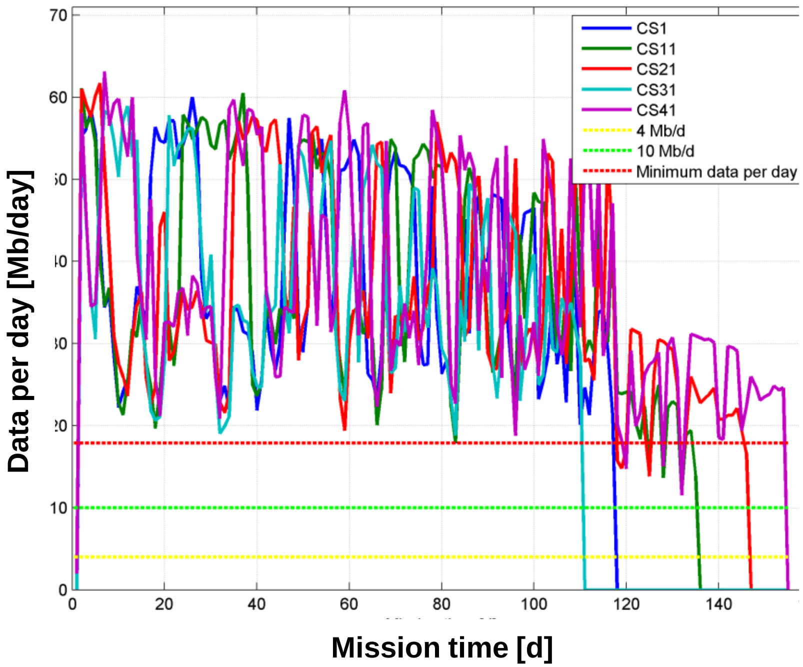
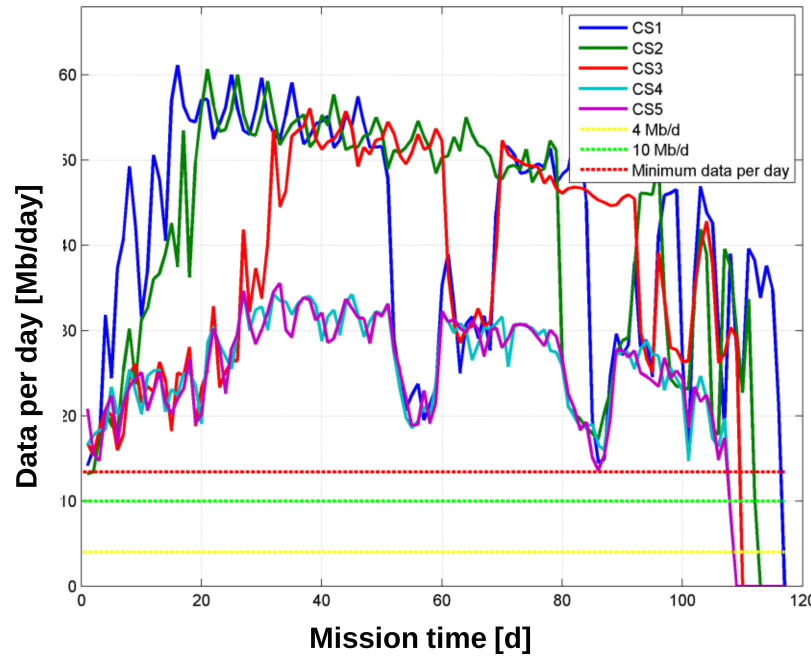
Daily data results:



America N/S Ground Segment







Requirements reached.
Since the starting phase good amount of data collected.

Requirements reached.
In the starting phase low amount of data collected.

Constellation Problem

Ground segment summary results:

1) *ASIA N/S:*

GS Group1: max >40 Mb/d, min: ~16 Mb/d
GS Group2: max >40 Mb/d, min: ~9 Mb/d

✗

2) *Northern hemisphere W/E:*

GS Group 1: max ~90 Mb/d, min > 20 Mb/d
GS Group 2: max ~90 Mb/d, min ~18 Mb/d

✓

3) *America N/S:*

GS Group 1: max ~60 Mb/d, min ~18 Mb/d
GS Group 2: max ~60 Mb/d, min ~13 Mb/d

✓

4) *Europe:*

GS Group 1: max ~30 Mb/d, min ~15 Mb/d
GS Group 2: max ~30 Mb/d, min ~14 Mb/d

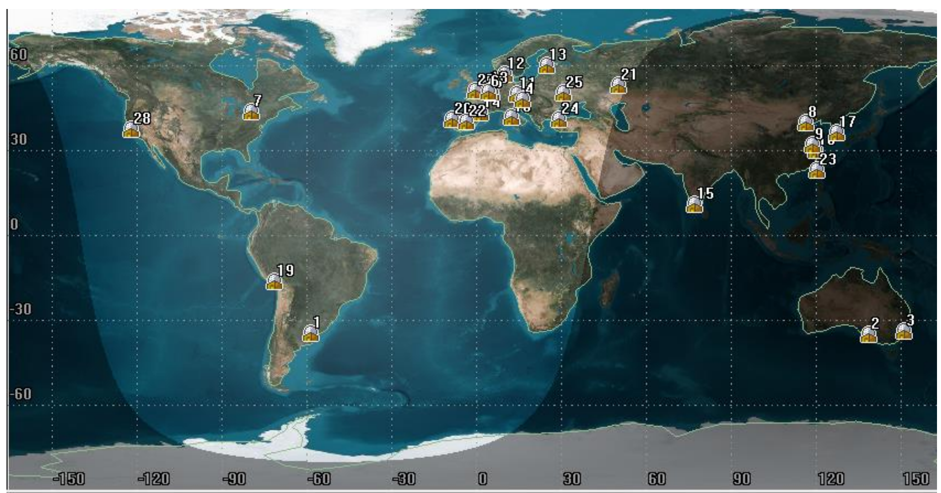
✓

Constellation Problem

1 to 25 GS combinations analysis:

GSs used for the combinations:

Universidad de Buenos Aires	1	Anna University	15
The University of Adelaide	2	University of Rome “LA SAPIENZA”	16
University of Syndey	3	Korea Advanced Institute of Science and Technology	17
University of Applied Science Technikum Wien	4	Delft University of Technology	18
University of Liège	5	PERUVIAN CONSORTIUM	19
von Karman Institute	6	University of Porto	20
York University – Toronto	7	Samara State Aerospace University	21
Beihang University	8	Universidad Politécnica de Madrid	22
Nanjing University of Science and Technology	9	National Cheng Kung University	23
Zhejiang University	10	Istanbul Technical University / Air Force Academy	24
Czech Technical University in Prague	11	National Technical University of Ukraine	25
Aalborg University	12	MSSL University College London	26
Aalto University	13	University of Surrey	27
Institut Supérieur de l’Aéronautique et de l’Espace ISAE	14	QB50 US Consortium	28



Constellation Problem

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1 to 25 GS combinations analysis: