INNOVATIVE SYSTEMS ENGINEERING

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Optical Communication Link Strategy

In Commercial Earth Observation

Curriculum Vitae

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Marc-André Sauvage – French (Paris) – 32 Years

- Diploma
  - 1998 : Baccalaureat Scientific
  - 2004 : Master in Computer Science
  - 2011 : Master in Space Business

- Professional
  - 2002 : ACE (Financial School) – Network engineer
  - 2003 : MeadWestvaco (Packaging) – IT Europe Dpt. – MDB Developer
  - 2004 : Faurecia (Automotive) – IT World Dpt. – Web Developer
  - 2005 – Now : Insyen (Space Business) – DLR (GSOC) sub-Contractor as a Data Services Subsystem (DaSS) Engineer for the Columbus Project (European Laboratory for the Internationnal Space Station)

Content

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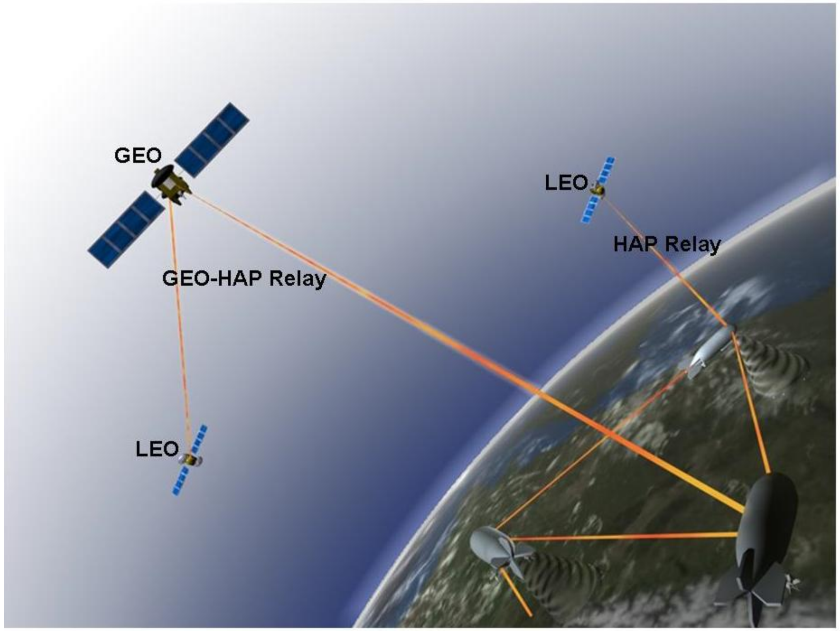

- Scope : SpaceTech Master Program
- Introduction : EO (R)Evolution
- Setting the scene
  - ST-13 CCP technical implementation
  - Communication options
- Optical Communication Links
  - Missions
  - Limitations
  - Laser Characteristics
  - Communication Phase
- Optical Link Strategy
  - Direct (Space to Ground)
  - Via Relay
    - Space to GEO to Ground
    - Space to HAP to Ground

Space Tech Master Program

www. spacetech.tudelft.nl

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From the Technological University of Deft (Netherland)

is an international Master's Degree program, designed for international mid-career professionals who wish to expand their potential by obtaining expertise in both space systems and business engineering.

- 1 Year Program (part-time)
  - 5x 2 weeks of classroom
  - 5 Attractive Session locations
    - TU, Delft (NL)
    - CNES, Toulouse (FR)
    - DLR, Munich (DE)
    - ASI, Frascati (IT)
    - ESTEC, Nordjwick (NL)
- Internationally recognized instructors
  - 4 permanent coaches (technical)
  - Multiple industry experts
  - 2 Program Officers (organization)
- Multi-disciplinary environment
  - Combining Space Syst. Eng. And Business Eng.
  - 6 competence domain
    - Business Engineering
    - Telecom
    - Earth Observation
    - System Engineering
    - Navigation
    - Personal Development
- Academic evaluation
  - Exams
  - Central Case Project (CCP)

TU Delft
Delft University of Technology

SpaceTech
MASTERING SPACE SYSTEMS

Space Tech Central Case Project

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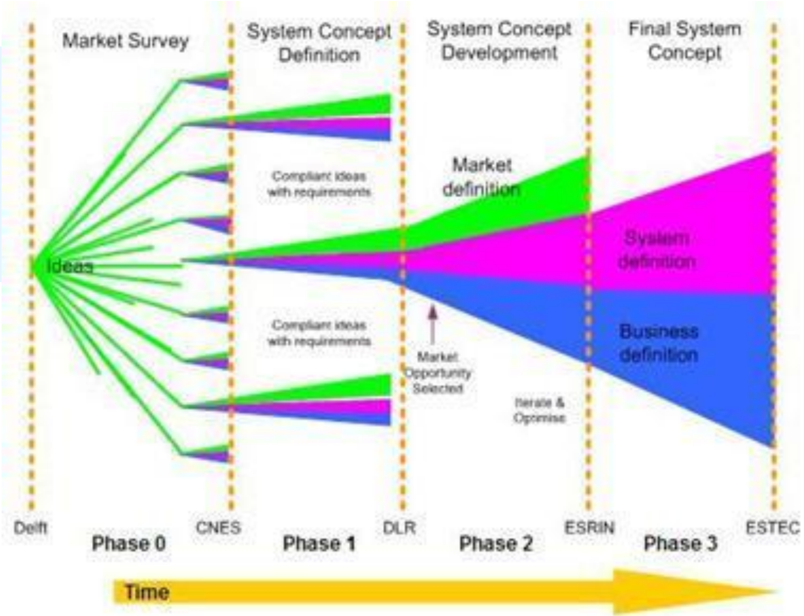
Creation of a "virtual" but credible and Financially viable space business company

The Central Case Project (CCP) provides a learning laboratory environement to explore and use the competencies learned in the SpaceTech program in space related markets, space systems engineering, inter-personal skills, business engineering and space applications.
It is an activity aimed at the creation of a credible and financially viable business opportunity in commercial space-related business.



During the CCP, a market analysis is performed to identify a commercially oriented, space-related product or service. Developing a business concept that is then translated into mission objectives and an appropriate technical system concept including the investors expectations .

ST-13 CCP : Find an innovative, credible, business concept to deliver accurate, up to date and relevant geo-information to the mobile mass market

Better, Higher, Faster …

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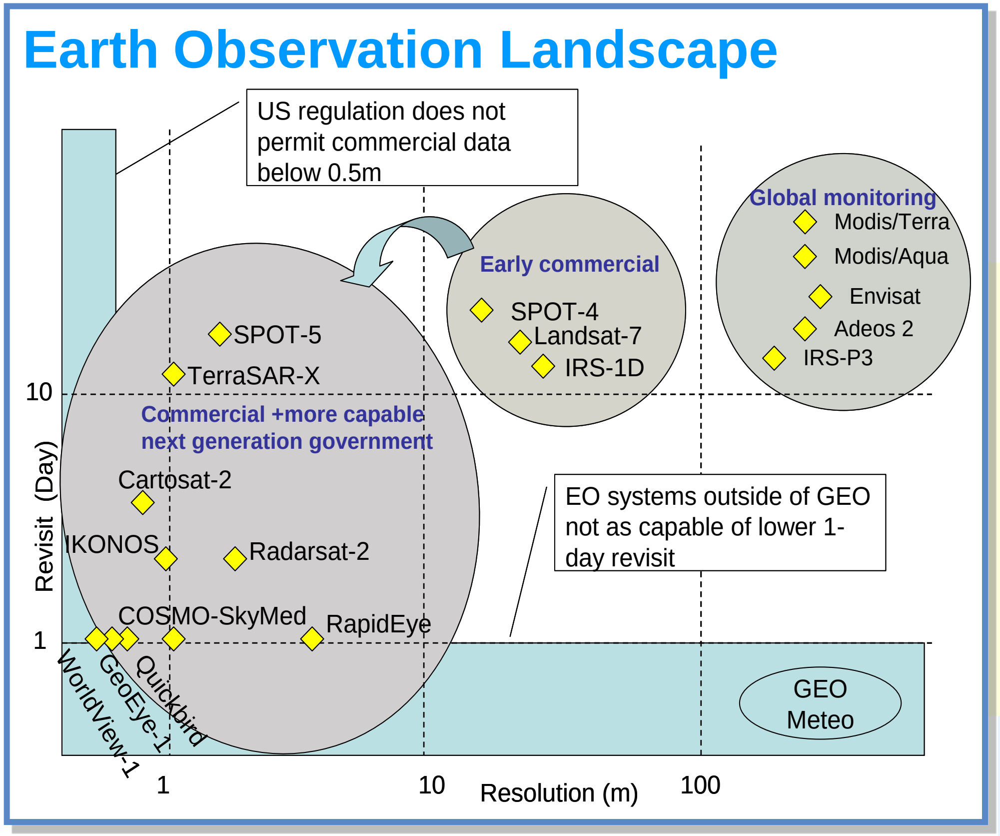


- Better: Revisit time
  - Move from 15 to 1 day
- Higher: Resolution
  - Move from 100 to <1m
- Faster: downlink
  - Move from X to Ka Band
- Better: optimization
  - Move from Bent-pipe to OBP
- Higher: data volume
  - Move from Gbits to Tbits

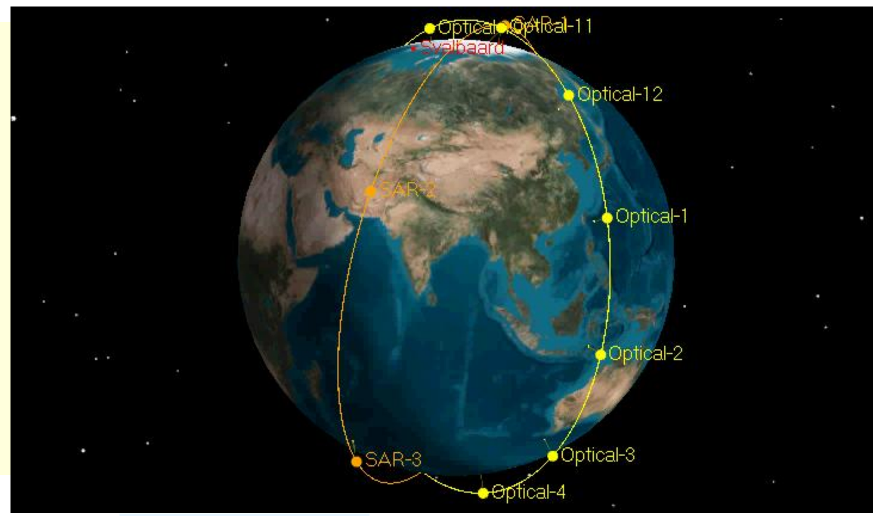
Data transfer needs to go faster …

SpaceTech-13 CCP Design

ST-13 CCP : Find an innovative, credible, business concept to deliver accurate, up to date and relevant geo-information to the mobile mass market

- Optical Constellation:
  - 12 co-planar satellites
  - 530 km SSO 10:00 LTDN
  - 24 km swath payload Nadir pointing
  - Resolution: 1 m PAN – 3 m MS (pushbroom + TDI)
  - Revisit time < 6 days: 98.0%
- SAR Constellation:
  - 5 co-planar satellites
  - 510 km SSO 06:00 LTDN
  - 40 km swath payload 30° pointing
  - Resolution: 3 m resolution (continuous stripmap mode)
  - Revisit time < 6 days: 99.1%

Optical: 380 Gbits/sats/orbits

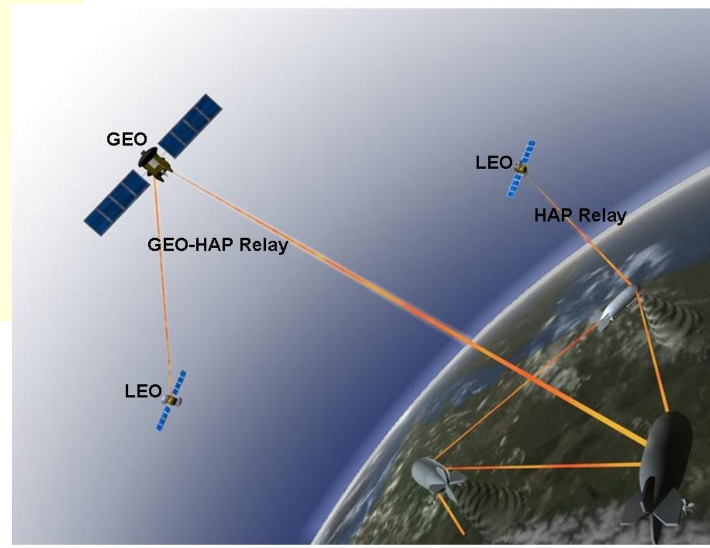


SAR: 1350 Gbits/sats/orbits

Communication options

- Microwave link:
  - Dedicated antenna on existing ground facility
  - Location: high latitude for higher revisit
  - Ka-Band at 2.5 Gbps
    - High gain antenna – high rain attenuation

- Optical link:
  - Direct optical link: Space to Ground
  - GEO Inter-Orbital optical link relay:
    - LEO to GEO optic
    - GEO to Ground Ka-Band (27.5 GHz)
  - HAP inter-orbital optical link relay
    - LEO to HAP optic
    - HAP to Ground V-Band (50-75 GHz)



Optical Link: Missions

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- KIODO [JAXA-DLR] in 2007
  - Kirari Optical Downlink to Oberpfaffenhoffen
- KODEN [JAXA-NICT] in 2007
  - Kirari Optical communication Demonstration Experiment with the NICT
- SILEX [CNES-ESA] in 2007
  - Semi-conductor Inter-satellite Link EXperiment
- OTOOLE [NASA-JAXA] in 2011
  - OCTL-To-OICETS Optical Link Experiment
- TERRASAR-X [DLR]
- …

Optical Communication is mature

Pictures: http://www.binary-space.com/

Optical Com. Architecture

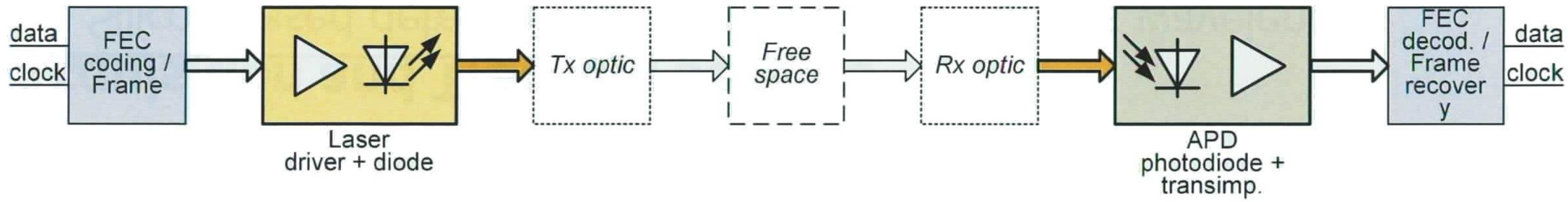
- Main factor driving optical communication payload are :
  - The transmitted wavelength which drive
  - The detection method
  - The transmission channel

- Detection :
  - Direct : distinguish 2 type of signal (0 or 1) by comparing the value to a threshold.
  - Coherent : comparing 2 quasi-coherent optical signal at Frequency F(s) and local reference Frequency F(lo)
    - Homodyne : $F(s) = F(lo)$
    - Heterodyne : $F(s) = F(lo)+\alpha$

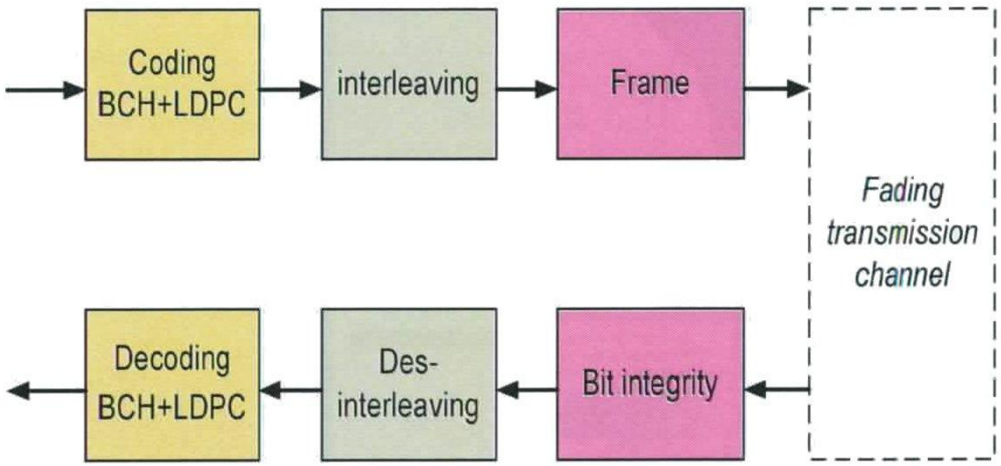
- Wavelength :
  - 0.85 µm
    - Direct detection
  - 1.06 µm
    - Coherent detection
  - 1.55 µm
    - Direct detection
    - Coherent detection

- Transmission Channel :
  - Distance between partners
  - Atmospheric constraints
    - Clouds
    - Turbulence
    - Aerodynamic perturbation

Laser Characteristics and coding



- Architecture:
  - Avalanche Photodiode (APD)
  - Aluminium Gallium Arsenide (AlGaAs)
  - 0.85 µm
  - Direct detection
- Coding Scheme
  - BCH+LDPC
  - Interleaving
  - Frame synchronization



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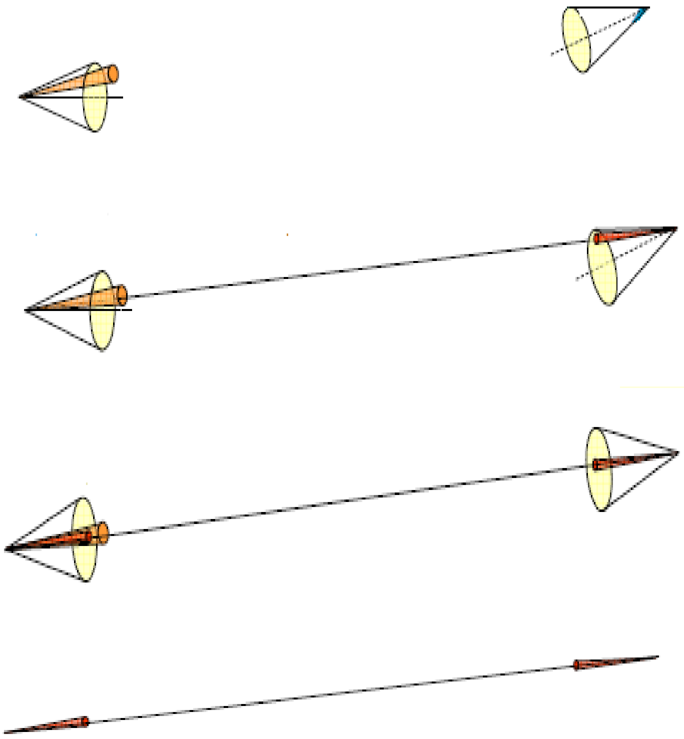
Communication Phases



- Pre-Pointing
  - Open loop
  - From orbital data base
  - Using beacon
- Acquisition /Alignment
  - Cooperative sequence
  - From open to close loop
  - Reduction of uncertainty cone
  - Slave transmit communication signal
  - Alignment of the telescope axis
- Communication
  - Master switch beacon off
  - Data transmission in close loop
- Canonical position
  - Back to open loop

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Optical Link: Limitations

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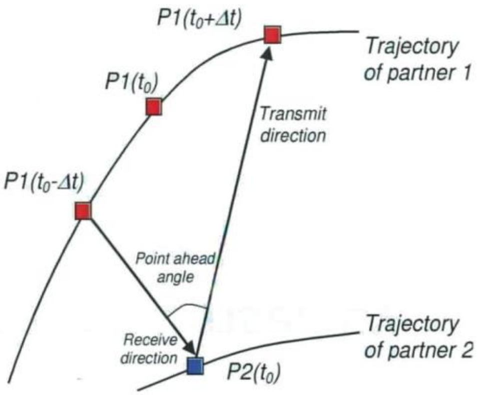
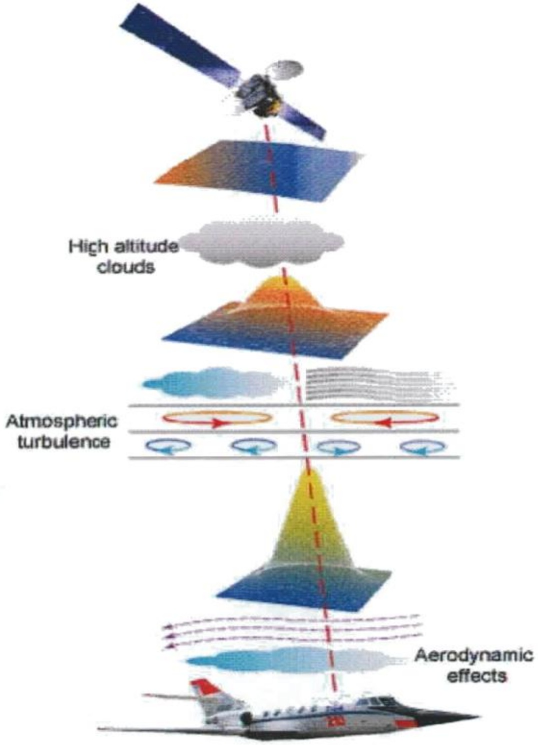
Atmosphere is not uniform, and varies over time and location which causes density fluctuation that can disturbed the propagated signal.



- Atmospheric disturbance
  - Clouds
  - Turbulences
  - Aerodynamic effects
  - Diffractions
- Narrow beam constraints
  - Pointing accuracy
  - High antenna Gain
  - Satellites motions



Reliable propagation channel modeling mandatory

Narrow beam

- High Gain antenna in optical wavelength
  - small transmitted power : 100 mW (~60 W)
  - small antenna size : 250 mm (>1m)
  - small wavelength : 0.85 µm (10 mm)
    - –> G(tx) > 100 dB (~35 dB)
  - Very narrow beam
    - beam width from GEO to Earth ~296 m (6500 km at Ka-Band)

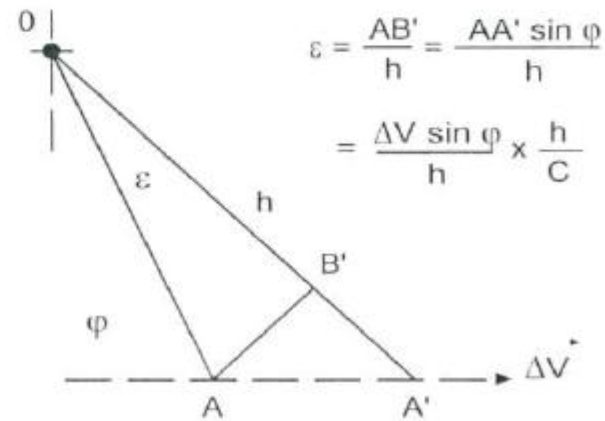
$$G_T(x) \approx \left[\frac{\pi D_T}{\lambda}\right]^2 * \left[\frac{2J_1(x)}{x}\right]^2$$

$$x = \frac{\pi D_T}{\lambda}\sin\theta$$

$$D = 2.44 * \frac{\lambda L}{Diameter}$$

- Satellite motion
  - pointing ahead mechanism
- Pointing accuracy
  - main transmission lobe : 6-8 µrad
  - for each µrad deviation : illumination drop

Pointing error +/- x µradian	0	0.1	0.5	1	2	3	4
% drop in illumination	0	5	22	40	63	78	87



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Optical Space to Ground Strategy

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In Optical

- Sensing: increasing satellite number
  - Increase your revisit time
  - Increase probability of good picture
- Communication: increasing OGS number
  - Increase your downlink capability
  - Increase probability of good optical link

Direct Communication

- Optimize OGS Number / Location
- Optimize Link Quality / Coding
- Optimize Data Storage / Quantity

Indirect Communication

- Optimize Relay Number / Location
- Optimize Link Optical / Microwave
- Optimize Data Storage / Bandwidth

Where and How to be cost efficient ?

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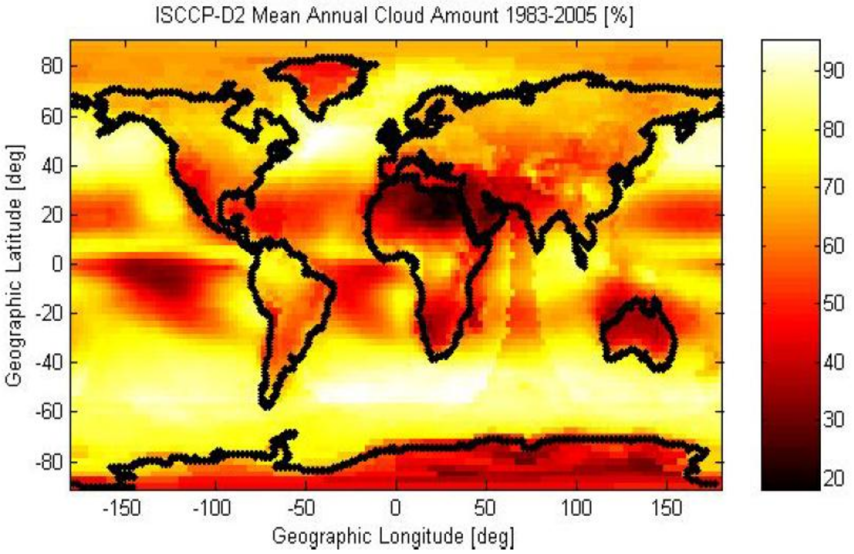
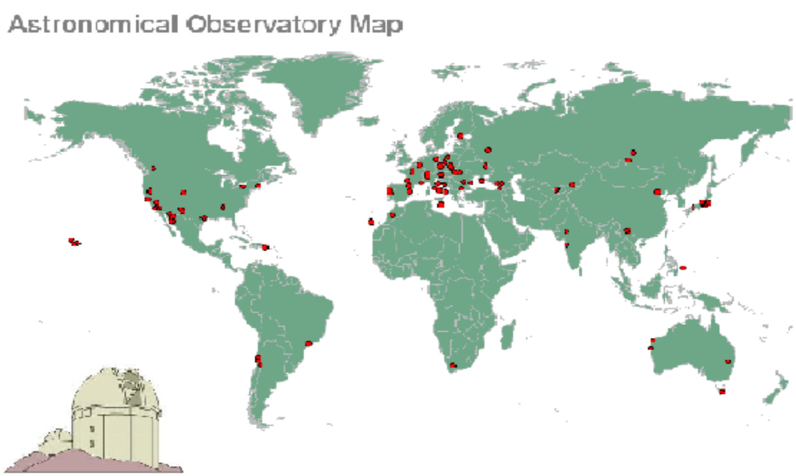
Weather statistics vs. local climate

- Area between +/- 20° latitude
  - – Long revisit time (6 days)
  - – Short link duration
  - + Multiple possible location
- Area around -80° latitude
  - + Short revisit time (<1 day)
  - + Long link duration

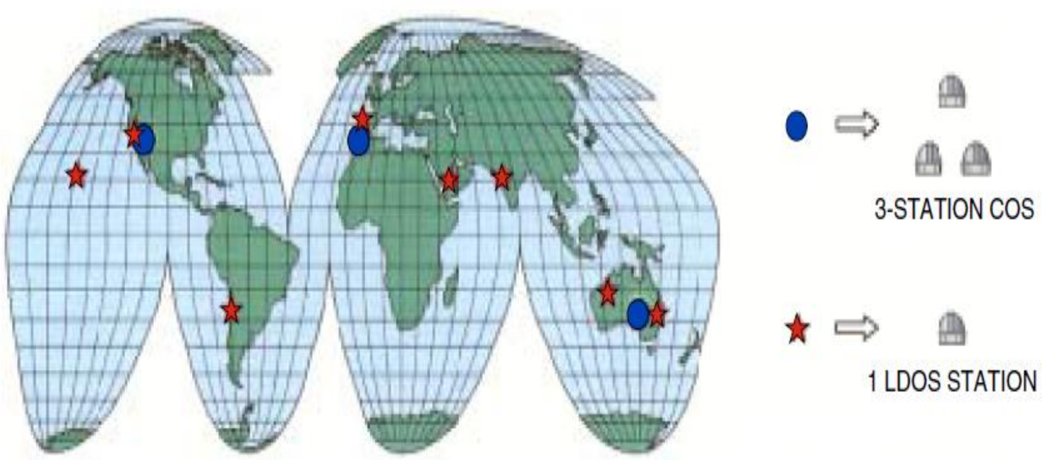




- Astronomical observatories
  - + Better local weather condition
  - + Multiple locations possible

OGS subnet deployment

- 3*3 Cluster Optical Subnet
  - 120° longitude separation between cluster
  - 700 km separation between stations
- 8 Linear Dispersed Optical Subnet
  - 45° longitude separation between stations
  - 700 km separation between stations



- LDOS
  - 97% availability when 3 OGS simultaneously visible
  - 66% availability when 2 OGS simultaneously visible
  - 100% coverage for telemetry line at 30° elevation
- COS
  - 97% availability if clear sky condition 70% of the time
  - 79% coverage for telemetry line at 30° elevation
  - 100% coverage for telemetry line at 30° elevation if 4 * 3 COS

GEO relay: advantages / constraints

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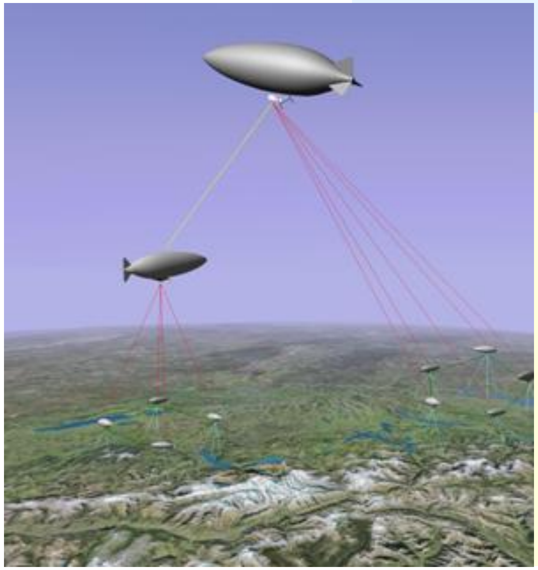
- Advantages
  - Space proven hardware
  - Mature technique as already operationally used
  - No atmospheric constraint and disturbance (Optical)
  - Link quality even over long distance (Optical)
  - High data rate / Low power consumption (optical)
  - Long duration link
  - Possibility to rent Ka-Band bandwidth

- Disadvantages
  - Asymmetric data rate (Optical Versus Ka-Band)
  - High Ka-Band antenna power
  - High Gain Ka-Band antenna
  - Rain attenuation on Ka-Band frequencies.
  - Several LEO satellite in line of sight simultaneously
  - On-board storage require
  - 3 GEO satellites require for continuous data stream.

Stratospheric HAP

High Altitude Platforms (HAPs) are quasi—stationary Unmanned Aerial Vehicle (UAV) That provide services to a large area while staying at very high altitude (17-22 km) for a long period of time. At This altitude, clear sky conditions are meet.

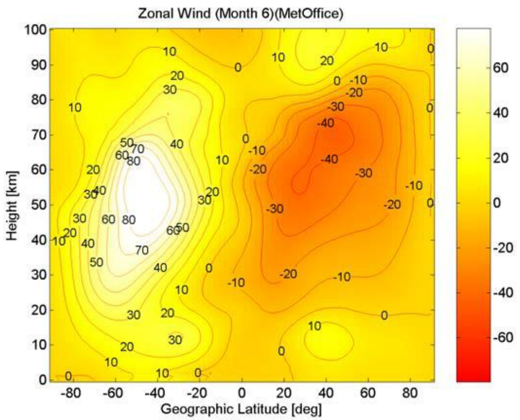


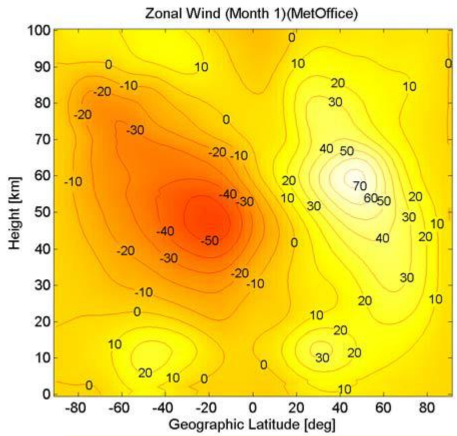
Category	Mass (Kg)	Range (Km)	Altitude (m)	Endurance (h)
Micro	< 5	< 10	250	1
Mini	< 25	< 10	150–300	< 2
Close Range	25– 50	10 – 30	3000	2 – 4
Short Range	50–250	30 – 70	3000	3 – 6
Medium Range	150 –500	70 – 200	5000	6 – 10
MR Endurance	500 – 1500	> 500	8000	10 – 18
LADP	250 2500	> 500	50 – 9000	0.5 – 1
LALE	15 – 25	> 500	3000	> 24
MALE	1000 – 1500	> 500	5/8000	24 – 48
HALE	2500 – 5000	> 500	20000	24 – 48
Stratospheric	> 2500	> 500	> 20000	> 48

Solar panel arrays can be deploy on the HAP, to improve all power requirement for station keeping and communication payload functionality.

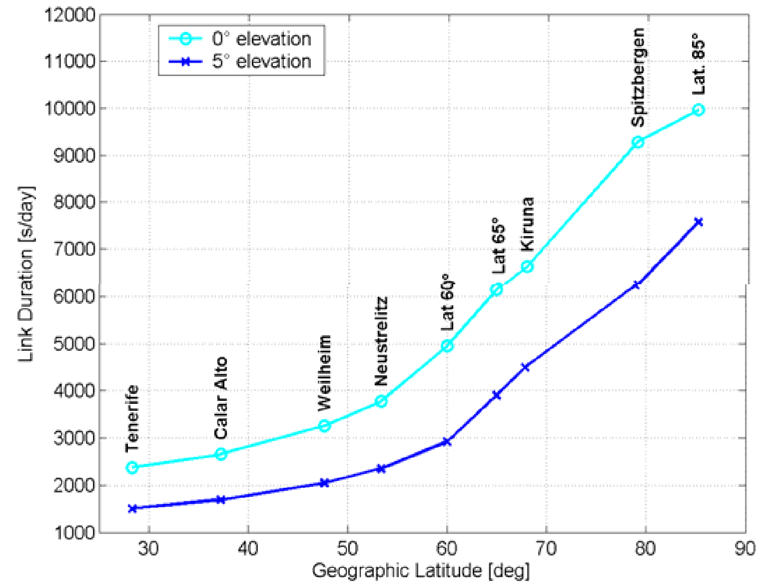
HAP : Altitude selection

- Wind : zonal wind speed (along latitude circle) model provides good estimate of favorable height and latitude for HAP position in respect to average wind speed. (22 km)





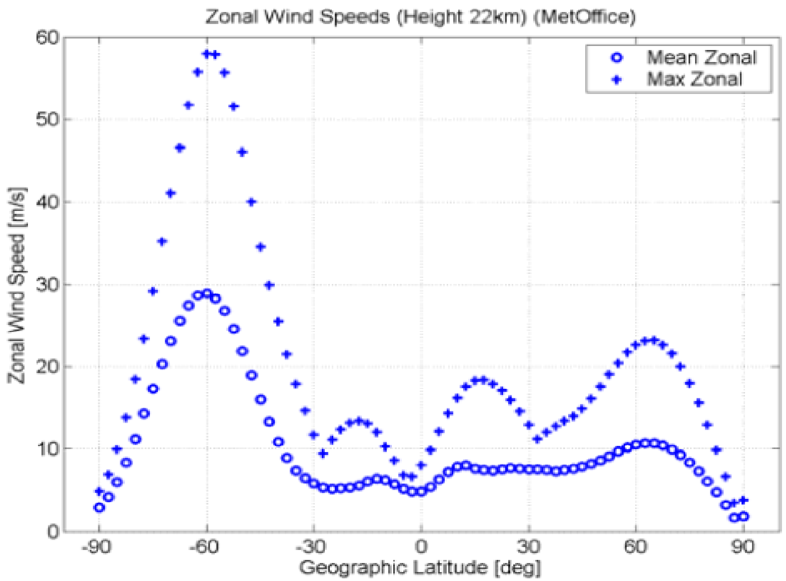
- Link contact :
  - Link contact depends on HAP latitude
  - 3 contacts per day at low latitude
  - 15 contacts per day at high latitude
- Link duration
  - Depends on minimum elevation angle
  - 8 minutes at 10° - 13 minutes at -2° (due to elevated position of the HAP)



Stratospheric HAP relay

- Advantages
  - Above clouds: Optical link LEO -> HAP possible
  - High Endurance (>48h)
  - No space proven hardware required
  - Easy to deploy and maintain
  - Can carry on-board storage and heavy communication payload
  - HAP Network possible
  - High data rate HAP to Ground with V-Band frequencies

- Disadvantages
  - High rain attenuation
  - Subject to air access control
  - Needs a license to fly over certain territories
  - Significant wind speed affecting station keeping



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Conclusion: data rate

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Some scenarios were studies about the data downlink rate via relay stations (HAP and GEO) using different technologies (Optical and Micro Wave)

D: mean amount of data per day
f : effective data rate
T: link duration
λ: Latitude Position

$$D = f_{eff} \cdot T(\lambda, \alpha) \cdot \left[1 - p_{clouds}(\lambda, t)\right]$$

α : minimum elevation angle
p : probability of clouds blocking
t: period of the year

Scenario	1 LEO-HAP-GND	2 LEO-HAP-GND	3 LEO-HAP-GND buffered	4 LEO-GEO-HAP-GND	5 LEO-GEO-HAP-GND	
Link to GND	OPT	MW	MW	OPT	MW	
LEO-HAP	5,6	5,6	5,6			Gbps
LEO-GEO				2,8	2,8	Gbps
GEO-HAP				2,8	2,8	Gbps
HAP-GND	5,6	0.8	0,8	5,6	0,8	Gbps
Effective Data Rate	5,6	0,8	5,6 buffered	2,8	0,8	Gbps
Typ. Link Duration	40-166	40-166	40-166	720	720	min./day
Cloud Coverage (blockage)	37-80	NA	NA	37-80	NA	Percent
Data Transmission per Day for One Satellite	7.3-14.0	1,9-8,0	13,3-55,8	24.2-76.6	34,6	Tbit/day
Data Transmission per Day Full Utilization	96.8-306.3	69.1	69,1	48.4-153.1	69.1	Tbit/day

Optical Link
Microwave Link

Optical: 380 Gbits/sats/orbits **SAR: 1350 Gbits/sats/orbits**

Conclusion: Costing

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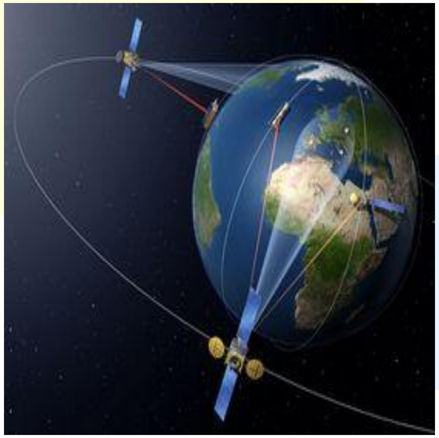
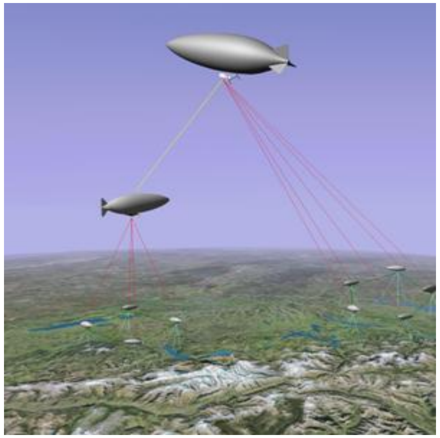
- OGS
  - \+ $10-15 M / OGS
  - * 8-12 OGS
  - = $100-150 M

- GEO
  - \+ $100 M / GEO
  - * 3 Satellites
  - \+ $72 M Launch
  - * 3 Launch
  - = $516



- HAP
  - \+ $400 000 / HAPs
  - * 400 HAPs
  - = $160



Acknowledgment

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Questions ?

Any Question ?