S-NET One Year in Orbit:

Verification of a Narrowband Nanosatellite Network

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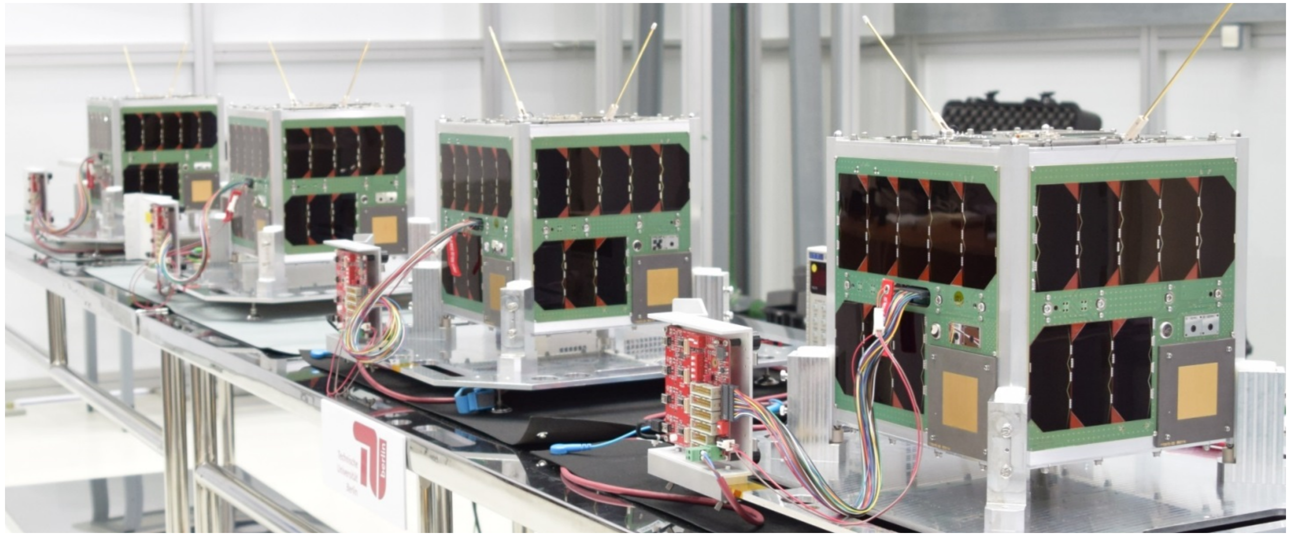
[1] German Space Administration [2] Technische Universität Berlin

Content of the presentation

- Introduction and overview of involved partners (DLR and Technische Universität Berlin)
- Nanosatellite Mission S-Net
- Possible Applications with nanosatellite networks
- Future technology developments



German Aerospace Center (DLR)

- Aeronautics
- Space Research and Technology
- Transport
- Energy
- Defence and Security
- Space Administration
- Project Management Agency

Approx. 8000 employees across 36 institutes and facilities at 20 sites. Offices in Brussels, Paris, Tokyo and Washington.

DLR's tasks as the National Space Agency (Administration)

- Defining German space planning on behalf of the federal government
- Representing German space-related interests in the international arena, in particular in ESA
- Tendering, award and support of space projects in the context of the National Space Program

- Annual budget: app. 300 M€
- Approx. 280 employees

- Annual budget in satellite communications: 35 M€
- 22 employees

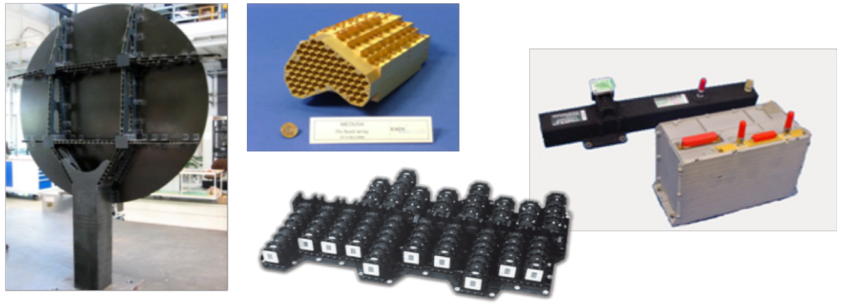
Structure of the German Space Program

	ESA	NP	DLR	Other
	ESA programs, EUMETSAT	National program	DLR / Helmholtz Association (HGF) R&D programs	EU, BMBF programs, German Research Foundation (DFG), universities, Fraunhofer Society (FhG), HGF, Max Planck Society (MPG), public bodies, industry
Application	**Satellite Communications** Navigation Earth observation			
Technology	Space transport Space station Technology of space systems			
Research	Research under space conditions Space exploration			

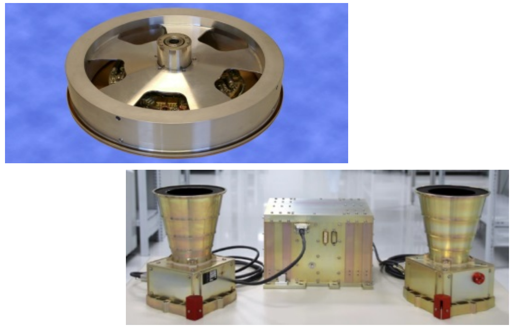
Technology Developments for Satellite Communication Communication

Multimedia Development and Demonstrations Programm COMED

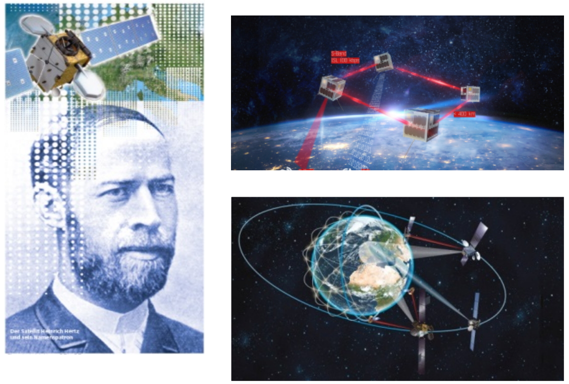
Payload technologies



Platform technologies

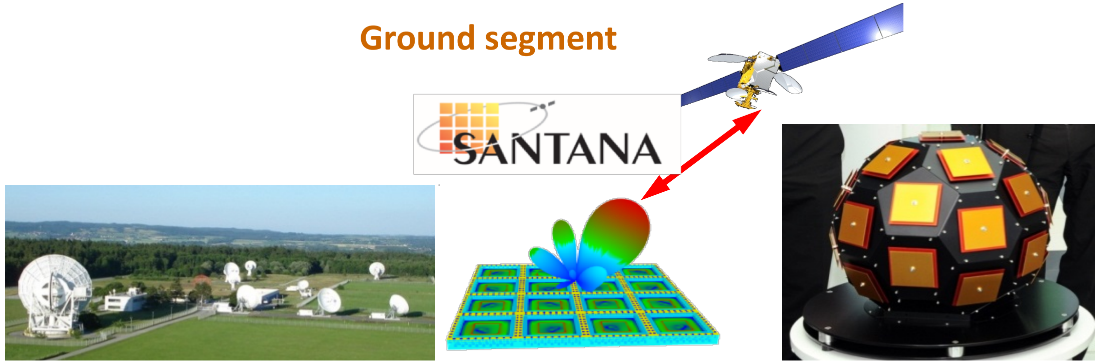


Satellite systems



COMED 1999-2004 ⇒ **COMED NG** 2004-today ⇒ **COMED IOV** 2011-2021 ⇒ **COMED EXP** 2021-2036

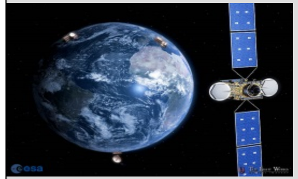
Ground segment



Services and Applications

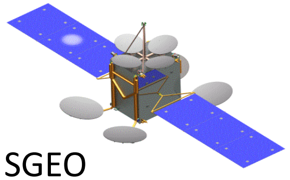
German Prime Roles in Satellite Communications

Hispasat-AG1

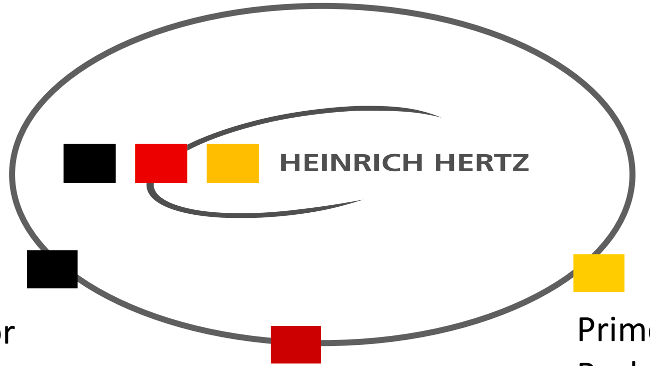


EDRS

MTG



SGEO



Prime for
Satellite Platform

Competence
Ground Stations & Antennas

Prime for
Payload

Integration of German Technolog

2021

In Orbit Verification
Communication Experiments

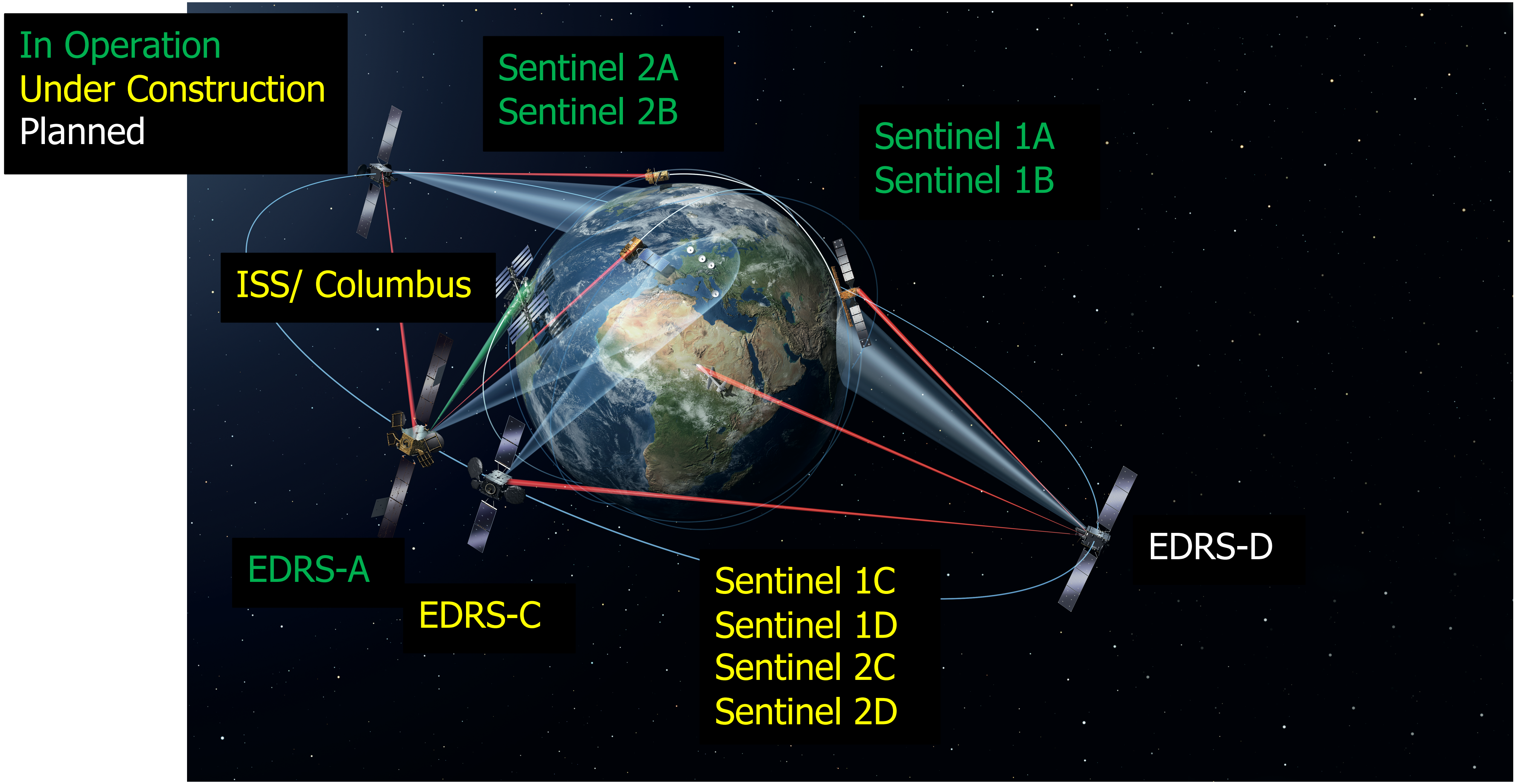
Ka-Band:
Transmit/ Receive
of large Data Rates

New Services

Ground Terminals
(SANTANA et.al.)
Satellite Control (TM/TC)
Mission Control
(Network)

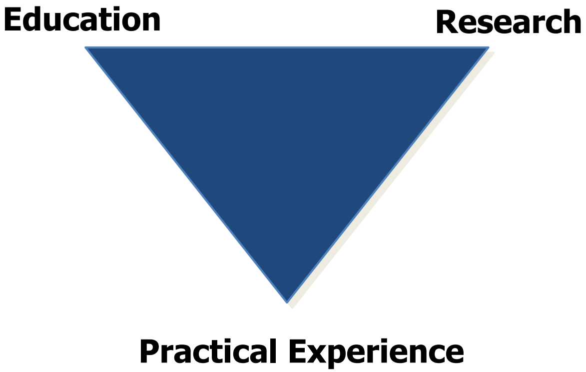
DLR

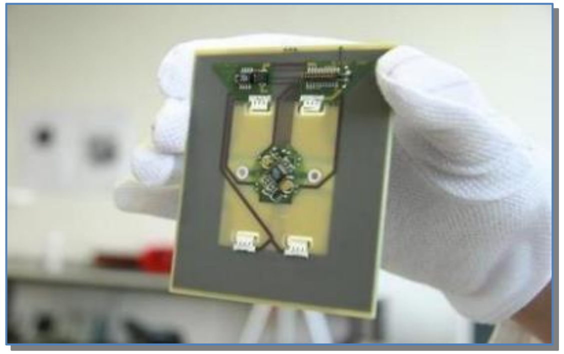
Commercial EDRS Service (European Data Relay Satellite)



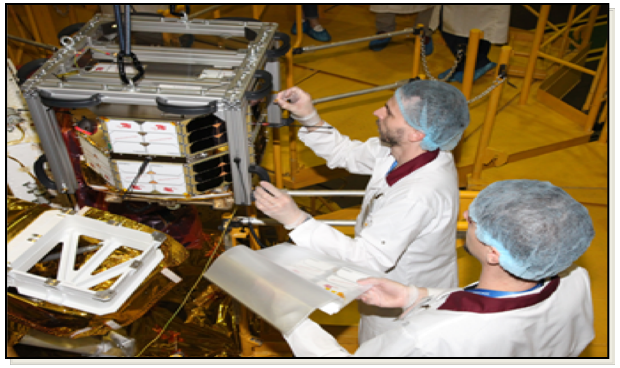
Space Technology at Technische Universität Berlin


Education in space technology




Miniaturization and Standardization


Theory and “Hands-on”
in space robotics


Theory and “Hands-on”
in satellite technology


Theory and “Hands-on”
in space propulsion systems

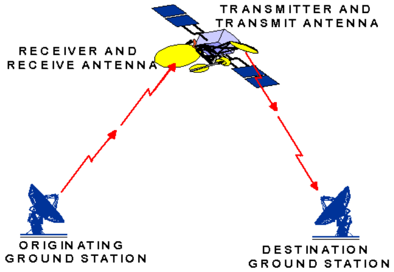
Small Satellites at Technische Universität Berlin

The Chair of Space Technology at TU Berlin currently **operates 9 satellites**

Small Satellite History at TU Berlin

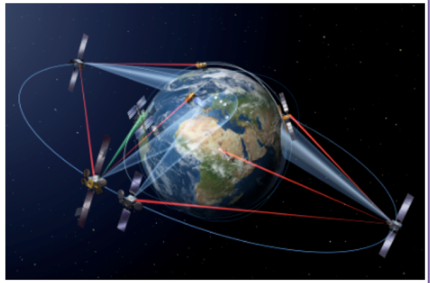
SatCom Network

Traditional GEO ComSat



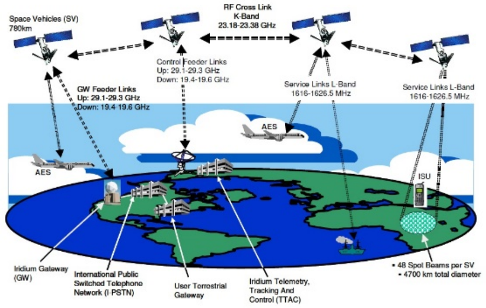
Broadcast, Internet, Phone
Ka, Ku-Band downstream
Inmarsat, Intelsat,
Eutelsat, SES

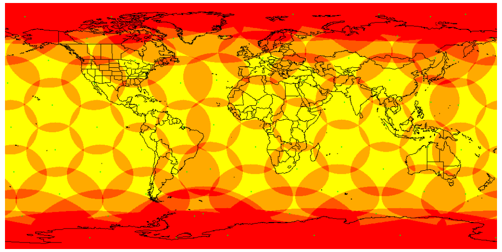
LEO-GEO Data Relay



Data relay
LCT ISL
Ka Downlink
1.8 Gbps 45000 km
EDRS: 3 x GEO

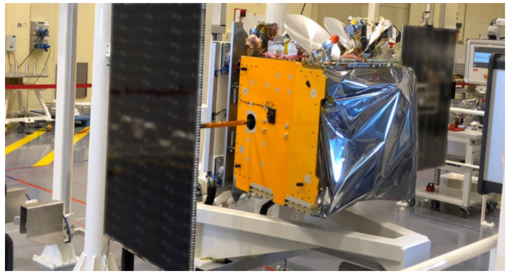
LEO data service





Internet, Phone, M2M
Iridium:
66 x Iridium NEXT (860 kg)
L-Band: 128 kbps / 1.5 Mbps
latency 50 ms

LEO Broadband



Broadband data
OneWeb:
900 +1260 LEO + MEO satellites
á 145 kg (1G)
Ku, Ka-band 500 Mbps?,
Latency 50ms

LEO Narrowband

M2M

S-NET
S-band ISL
100 kbps
Medium latency

Intersatellitelink (ISL) Applications

Rapid S/C commanding and response

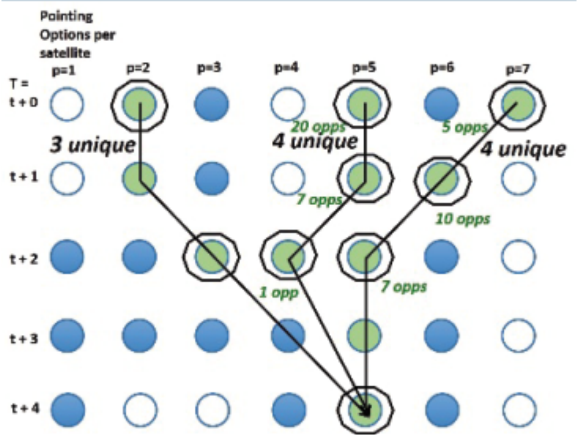
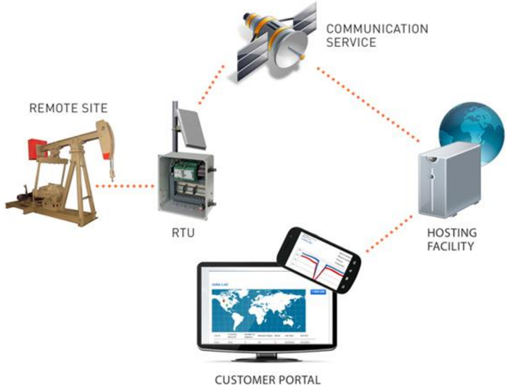


Figure: Constellation optimization of Earth observation by „Rapid Response Imaging“

Source: Nag. S,, Scheduling for rapid response imaging using agile, small satellite constellations, IAA 2017 Berlin

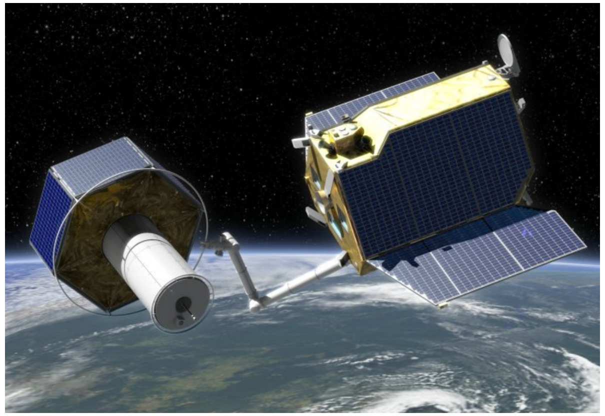
M2M / IoT communication

- Low latency (LEO 30ms vs GEO 550 ms)
  - Autonomous driving
  - Road trains
- Low-rate applications
  - Tracking of mobile targets (railroad)
  - Monitoring of remote sites (off-shore wind farms)
- Global internet
  - OneWeb: Ku / Ka, 50 Mbps, 30 ms
  - Starlink: Ku / Ka, 1 Gbps, 25 ms
  - LTE: 300 Mbps, 50 ms



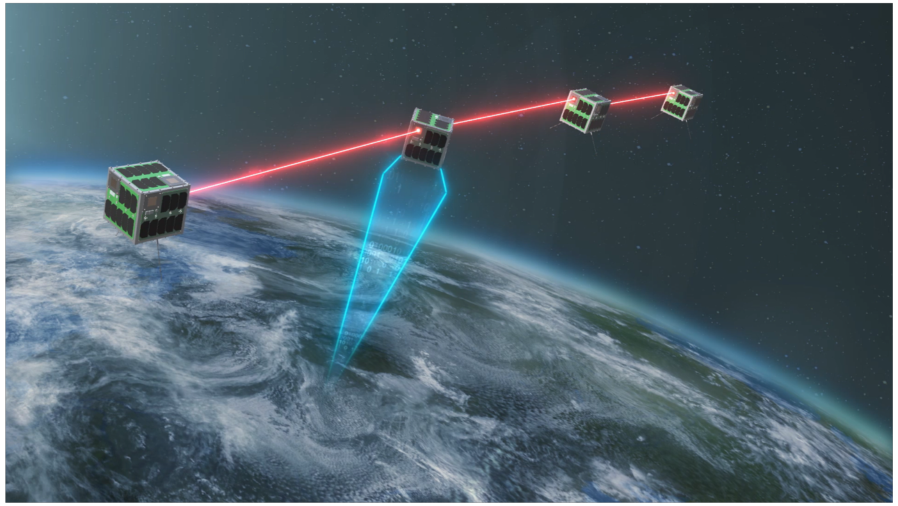
On-Orbit Servicing / proximity operations

- Communication between servicer (roboter) and target
- Repairing and refueling of commerical satellites
- Space debris removal at EoL



artist impression of DEOS [DLR 2010]

S-NET Objectives

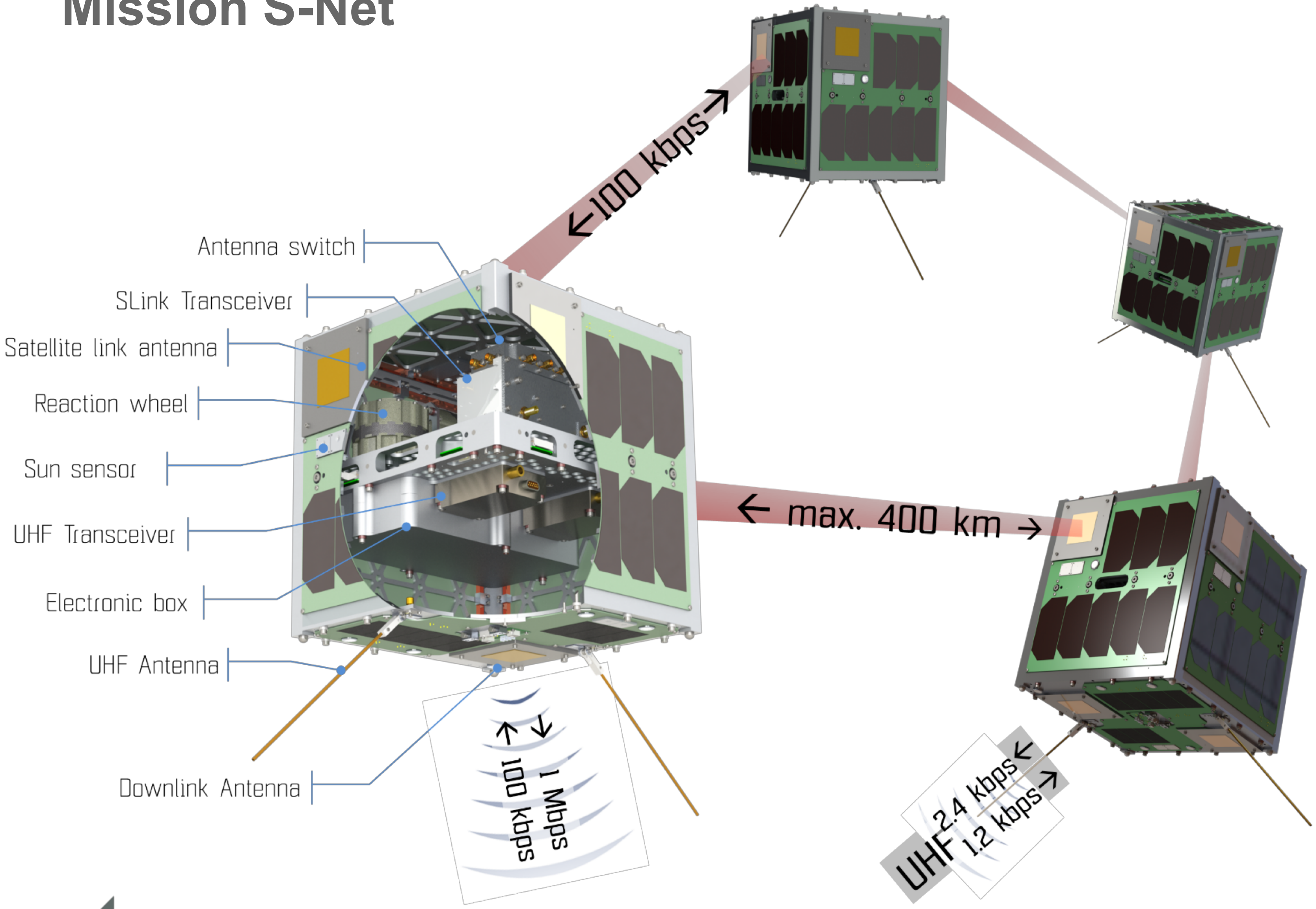


Mission statement:

„Demonstration of inter satellite communication within a nanosatellite network“

- demonstrate multipoint ISL with S-band transceiver
- verify the newly developed / optimized ISL communication protocols
- analyze the stability of a nanosatellite formation
- demonstrate the feasibility of nanosatellites as a base for demanding communication missions

Mission S-Net



Satellites	4
Satellite mass	8.7 kg
Satellite size	25 x 25 x 25 cm3
Power (nominal)	< 4.5 W
Orbit	SSO < 600 km
Launch	Soyuz / Fregat via Dispenser
Payload	S-band transceiver, Laser reflector
Launch	Feb. 1st 2018
Design lifetime	1 year

SLink Radio (S Band)

Parameter	Value
Range ISL	100 km nominal, up to 800 km
Bit rate DL	0.674 . . . 3.394 Mbps
Bit rate UL	30.8 . . . 252 kbps
Bit rate ISL	8.8. . . 126.55 kbps (DBPSK, 800 km / 8-ADPSK, 100 km)
Symbol rate ISL	80 kHz
Multiplexing	TDD / P2P, store and forward M2M
Modulation ISL	DBPSK, DQPSK, 8-ADPSK, 16-ADPSK (option) Adaptive modulation and coding
Modulation UL/DL	BPSK, QPSK, 8-PSK, 16-QAM
Doppler correction	>50 kHz
Coding	convolutional r = 1/2, r = 3/4
Decoder	Viterbi, soft decision
RF output / Power	27 dBm / <12 W
Mass	< 450 gramm with housing
Volume	140×80×65 mm3

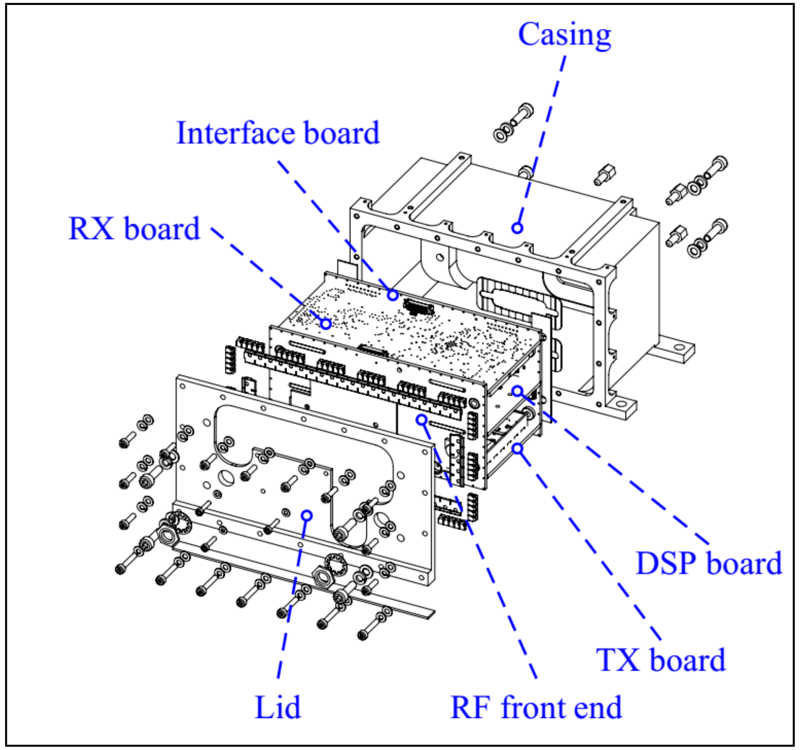


Figure: Components. Modular PCB design.

Figure: SLink has been developed in cooperation with IQ wireless Ltd.

Antenna Configuration

- 1 x circular polarized planar S-band antenna on each side of the satellite with ~6 dBi gain
- Signal can be transmitted to every direction independent of satellite's orientation

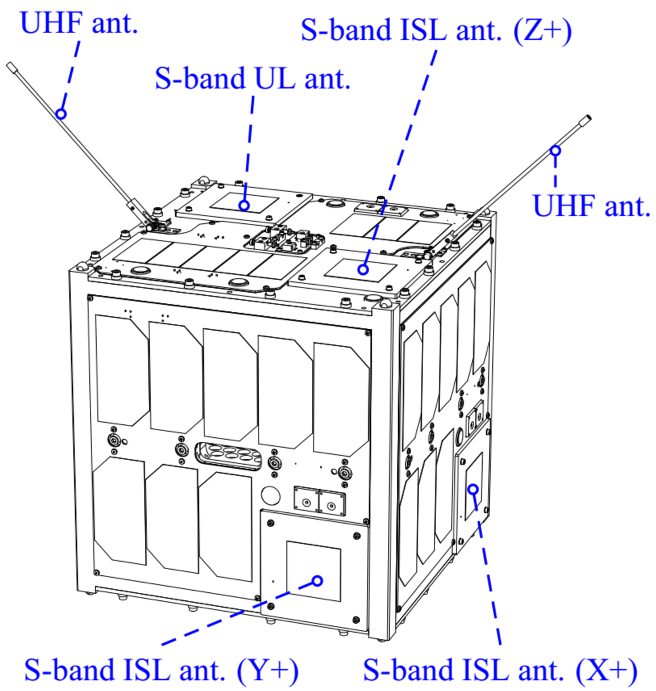


Figure: Antenna configuration

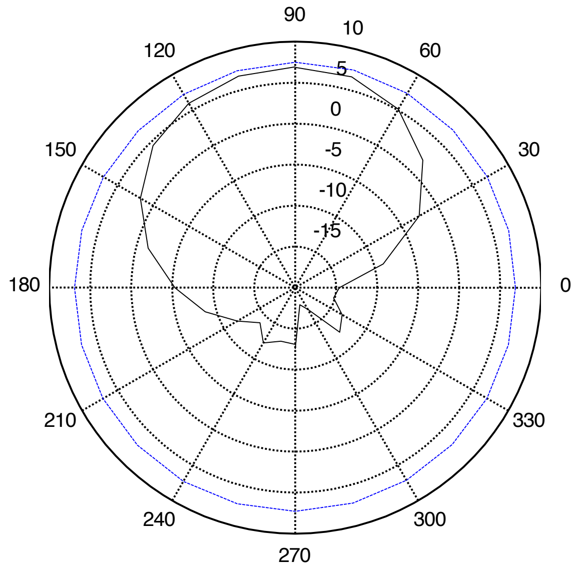


Figure: Antenna gain in azimuth (dashed) and elevation

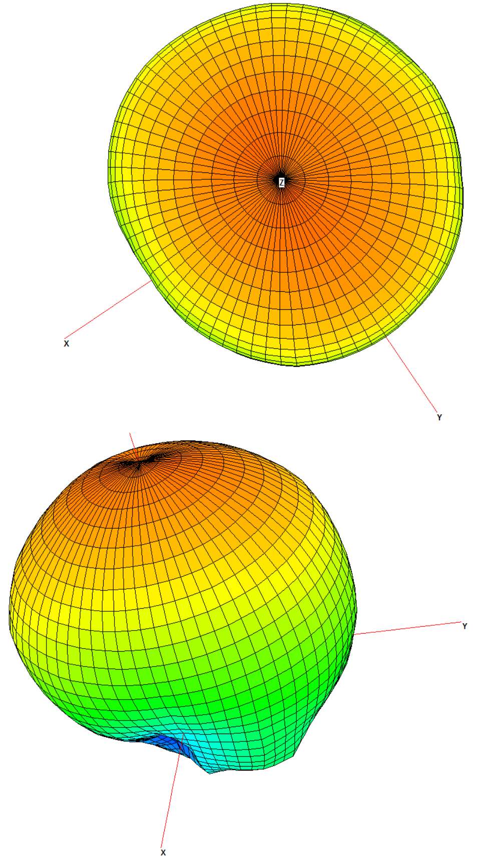
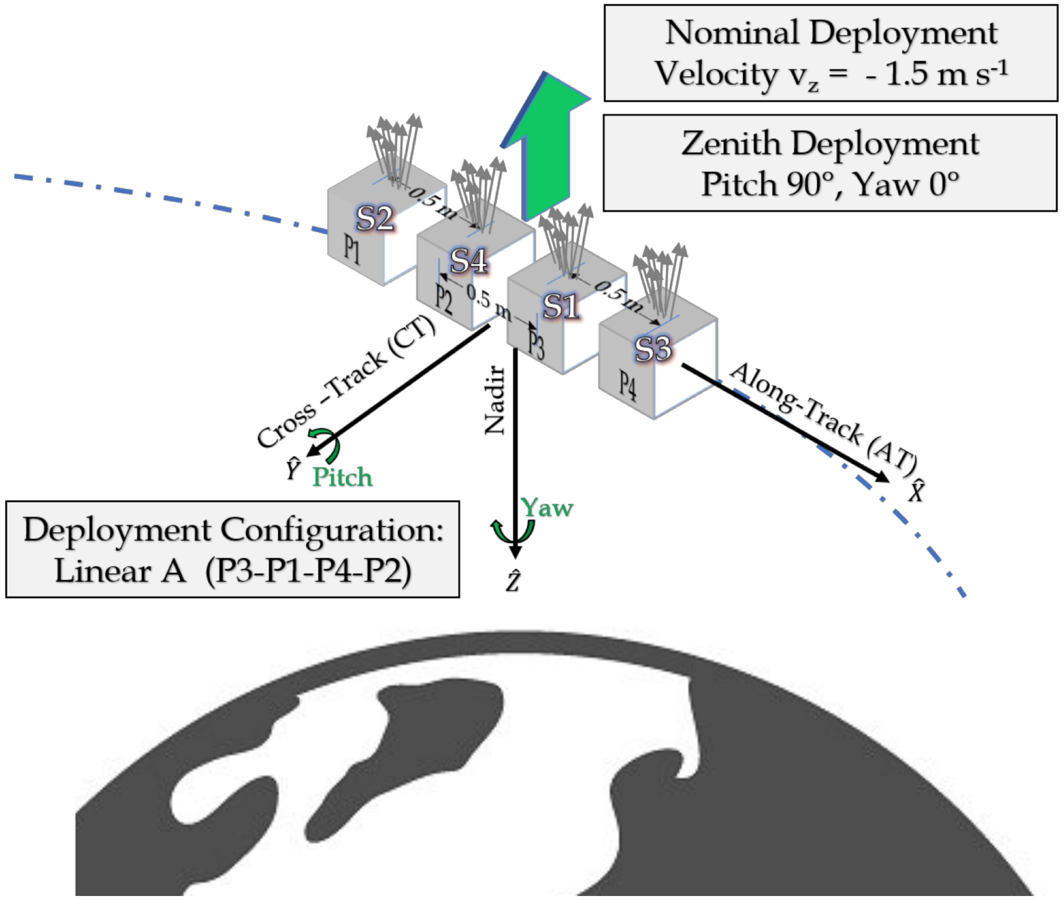


Figure: 3 D view of Antenna diagram in azimuth and elevation

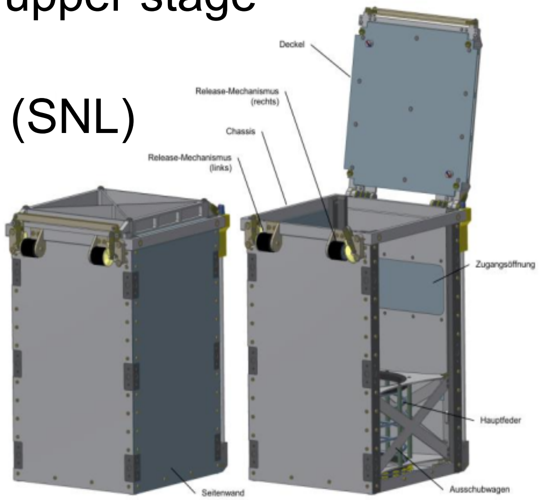
Deployment Sequence

- S-Net is a demonstration mission
- Relatively short ISL experiment times were required (few months); **a passive orbit control** was selected:
  - Reduces mission costs,
  - Faster development process,
  - Reduces requirements on attitude determination and control
- Relative distance drift during mission depends on separation parameters from upper stage



Single Nanosatellite Launcher (SNL)

Astro- und Feinwerktechnik Adlershof GmbH

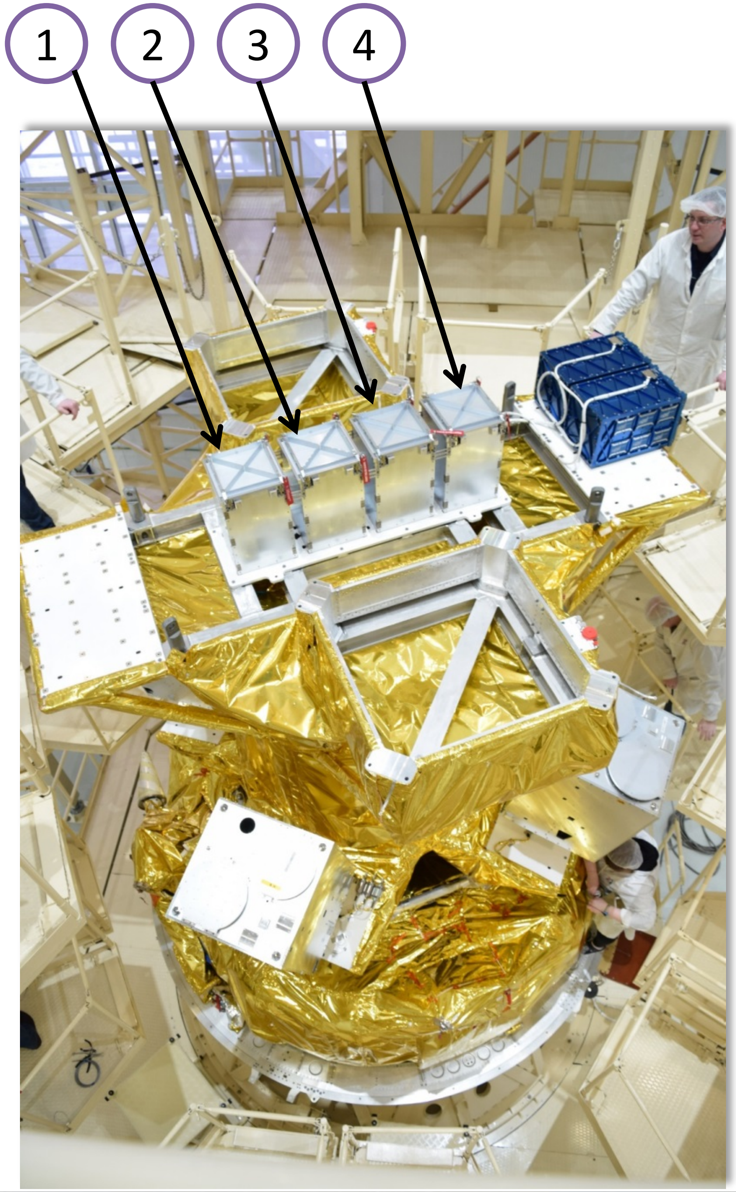


Deployment Sequence

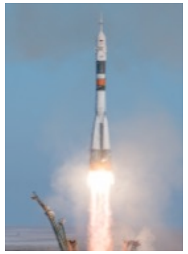
- Launcher (Soyuz/Fregat) requirements:
  - Cross-track deployment,
  - 3-axis stabilization of the upper stage during separation within 0.5°,
  - 10 s between separation pulses
  - Separation sequence #1, #3, #2, #4 for mitigation of collision probability.

- Dispenser requirement (by Astrofein Ltd):
  - Angular misalignment: <1°,
  - Differences in magnitude of separation vectors < 4.5 cm/s (1σ) @ 1.4 m/s

- Collision probability: 0.2%



Status Mission Operation



Orbit insertion 2018.02.01

Component level functionality check-out

- Standard-TM during first passes
- Function test of extended components (PDH, SLink, RW, MAT)
- Download & validation of basic component's historical TM

Subsystem and system level functionality check-out

- Check-out Detumbling via magnetorquer
- Check-out Detumbling via reaction wheels
- Check-out Nadir Pointing
- Validation of power budget, temp. Ranges, communication, redundancy

Payload operation

- Long-term analysis of SLink payload
- ISL experiments
- SLink Downlink experiments
- SLink Uplink experiments
- Performing laser ranging
  Relative drift measurement and analysis
- Check-out Target Pointing

LEOP
2 weeks

Commissioning Phase
5 weeks

Experiment Phase

Relative Distances

- Requirement for ISL: < 400 km for 4 month
- Status:
  - < 235 km after 350 days
  - Sufficient SNR to perform ISL in 2019

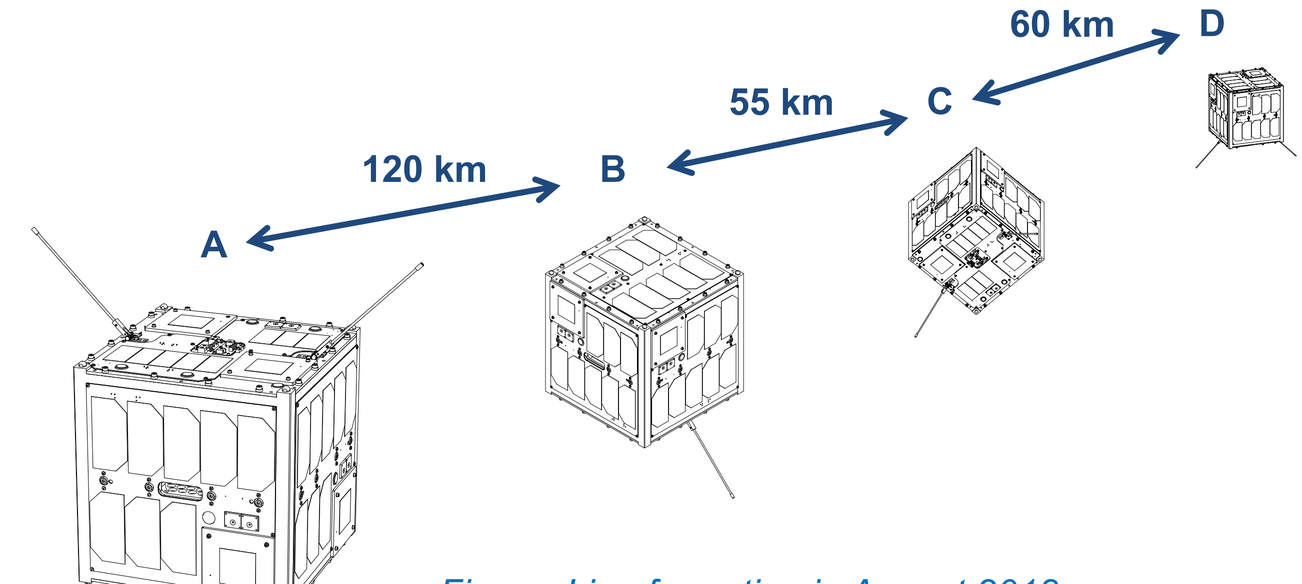


Figure: Line formation in August 2018

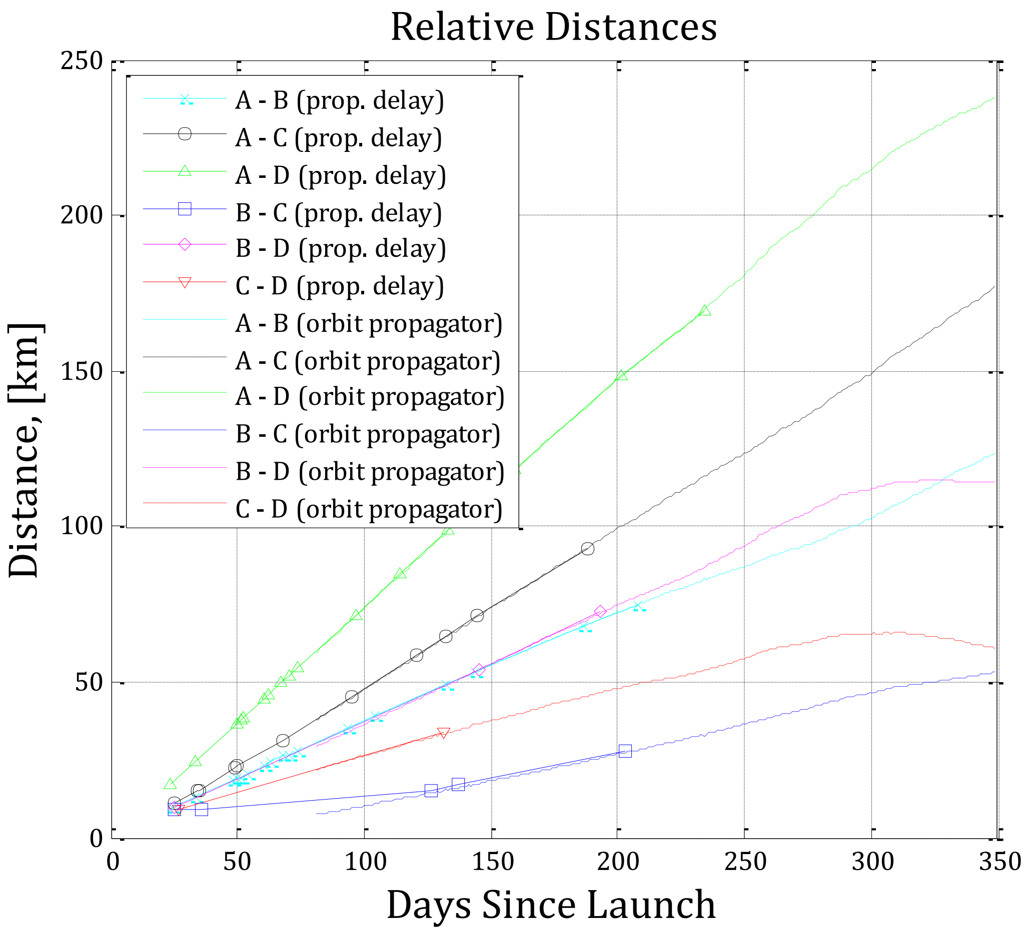
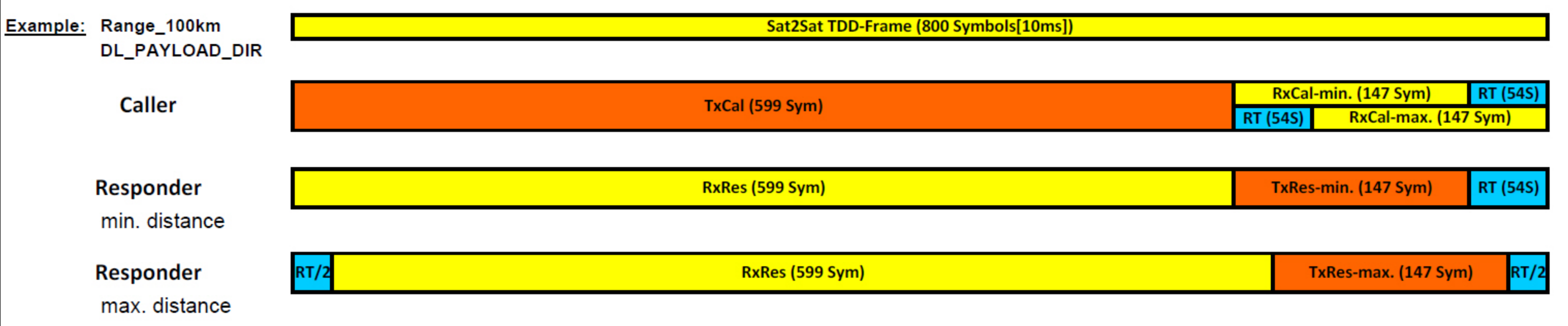


Figure: Measured (signal propagation) and propagated (space radar) distances between satellites

TDD Frame Structure

- Symbol frequency: 80 kHz
- Frame length: 10 milliseconds
- Assumed BER: 10e-5
- User data packets (CCSDS' Proximity-1 PLTUs) being partitioned on the Data link layer, acknowledged and combined to PLTUs again
- TDD packet lengths and AMC thresholds optimized for a BER of 10e-5 because of ARQ



Num Symbols in different Modes; Callers view

	DL_PAYLOAD_DIR			UL_PAYLOAD_DIR		
	Tx	Rx	RT	Tx	Rx	RT
Range_100km	599	147	54	147	599	54
Range_200km	546	147	107	147	546	107
Range_400km	439	147	214	147	439	214
Range_800km	225	147	428	147	192	428

Figure: TDD packet structure

Synchronization

- Both transceivers involved in a P2P session must be synchronized before any user (payload) data can be exchanged
- Automatic gain control (AGC)
  - Responder increases RX gain setting (AGC sweep) and tries to detect the preambles sent by the caller, if a preamble is detected it begins to transmit answers to the caller module,
  - Caller increases RX gain setting (AGC sweep) and tries to find the preambles sent by the responder module,
  - After a SYNC is achieved, few further TDD frames needed to set modulation and coding (ACM) and to switch the RF channel (optional); after this data services can be performed
- Antenna search algorithm (ANS)
  - Additionally to the RX gain setting the six antennas will be switched
- TDD frame length: 10 milliseconds
- Caller's AGC sweep time: ~320 milliseconds
- Responder's AGC sweep time: ~800 milliseconds
- **AGC synchronization time in 90% of the cases: < 1.5 seconds**
- **AGC+ANS synchronization time in 90% of the cases: < 3.5 seconds**

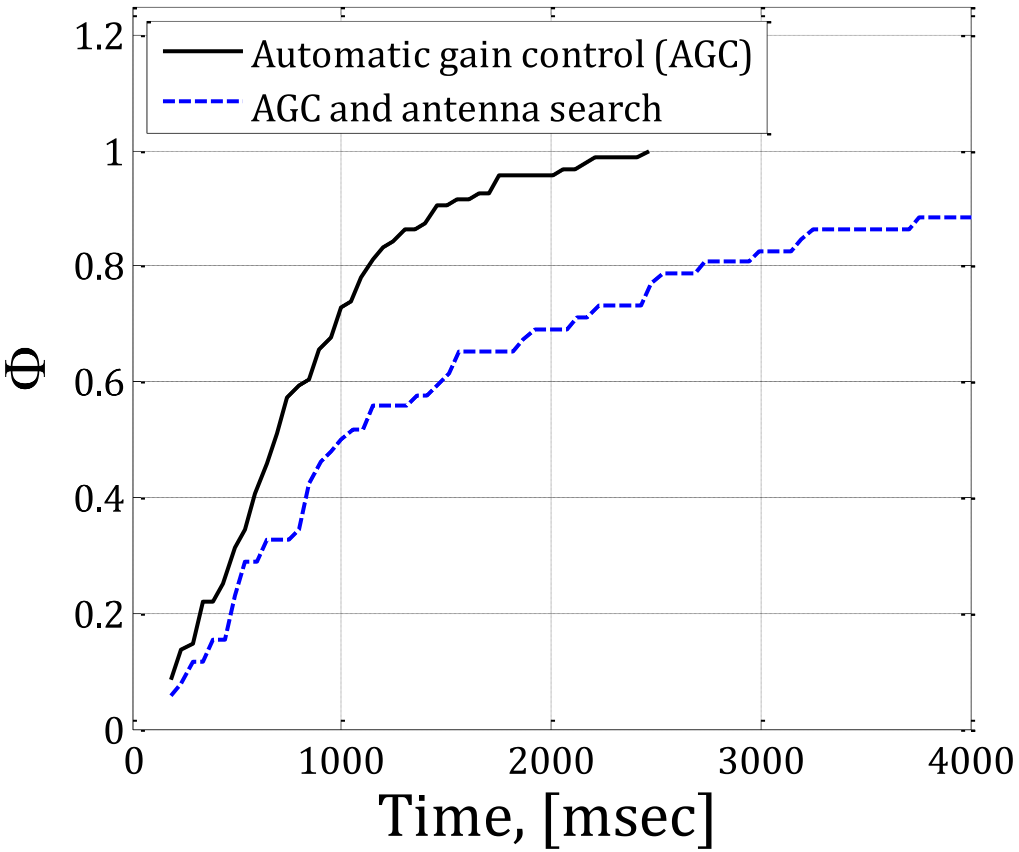


Figure: Cumulative distribution function for the synchronization time

Session Timing

1. Caller starts transmitting (hailing).: TX on flag (TxOn)
2. Both modules get synchronized: Session established flag (SesEst), modulation, coding and channel are selected.
3. Data transfer begins (payload bytes only shown: 4096)
4. All bytes are transmitted (caller), received (responder) and acknowledged (responder). RX complete flag (RxCmpl)
5. Session is closed (handshaking by both modules)

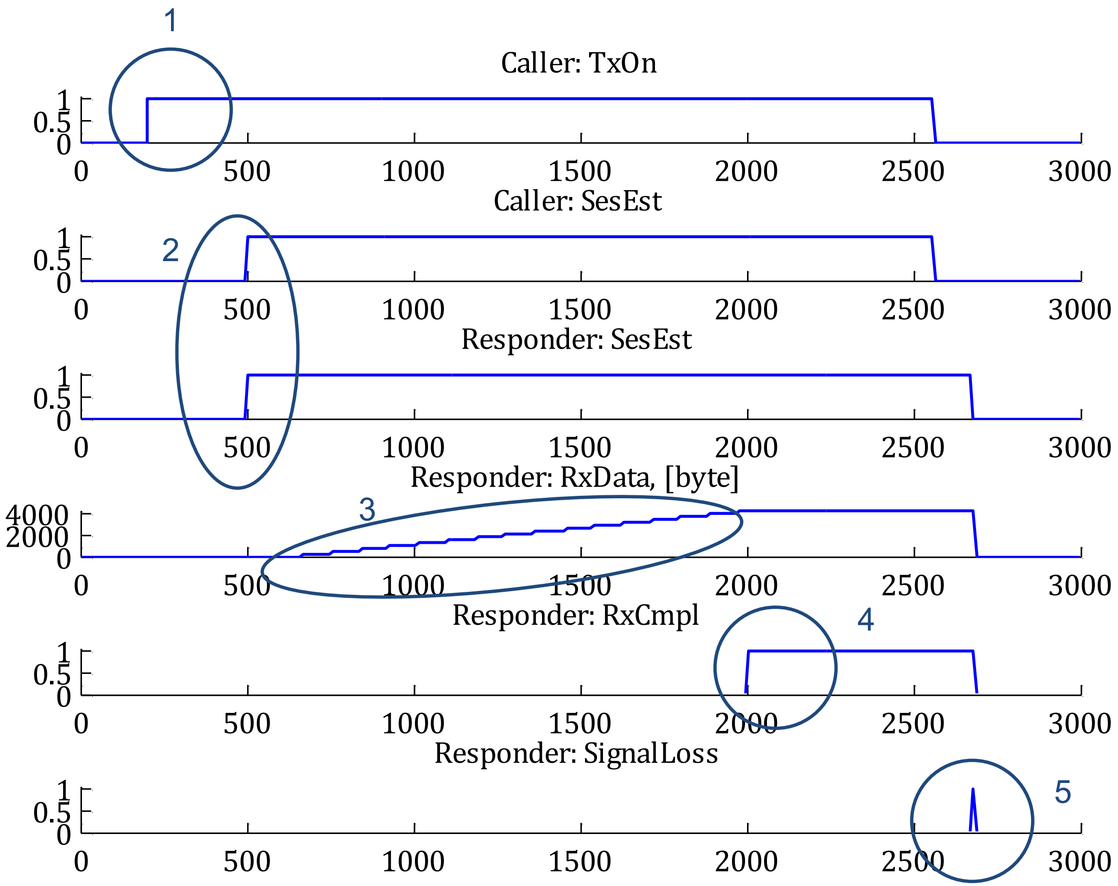


Figure: Session timing. Time in milliseconds. DBPSK, r=0.5. Data rate: 27.5 kbps

ISL Link Budget

Parameter	#1	#2	#3
Frequency (MHz)	2266	2266	2266
TX power output (dBm)	27	27	27
TX losses (dB)	1.5	1.5	1.5
TX antenna gain (dBi)	0	0	5
Distance (km)	10	65	148
RX antenna gain (dBi)	0	0	5
RX losses (dB)	1.5	1.5	1.5
RX sensitivity (dBm)	-116.50	-116.50	-116.50
Roll-off faktor	0.25	0.25	0.25
Symbol rate (kbit/s)	80	80	80
RX noise factor (dB)	3.5	3.5	3.5
Link budget (dB)	140.50	140.50	150.50
Free space path loss (dB)	119.55	135.81	142.95
Margin C/N (dB)	**20.96**	**4.69**	**7.56**

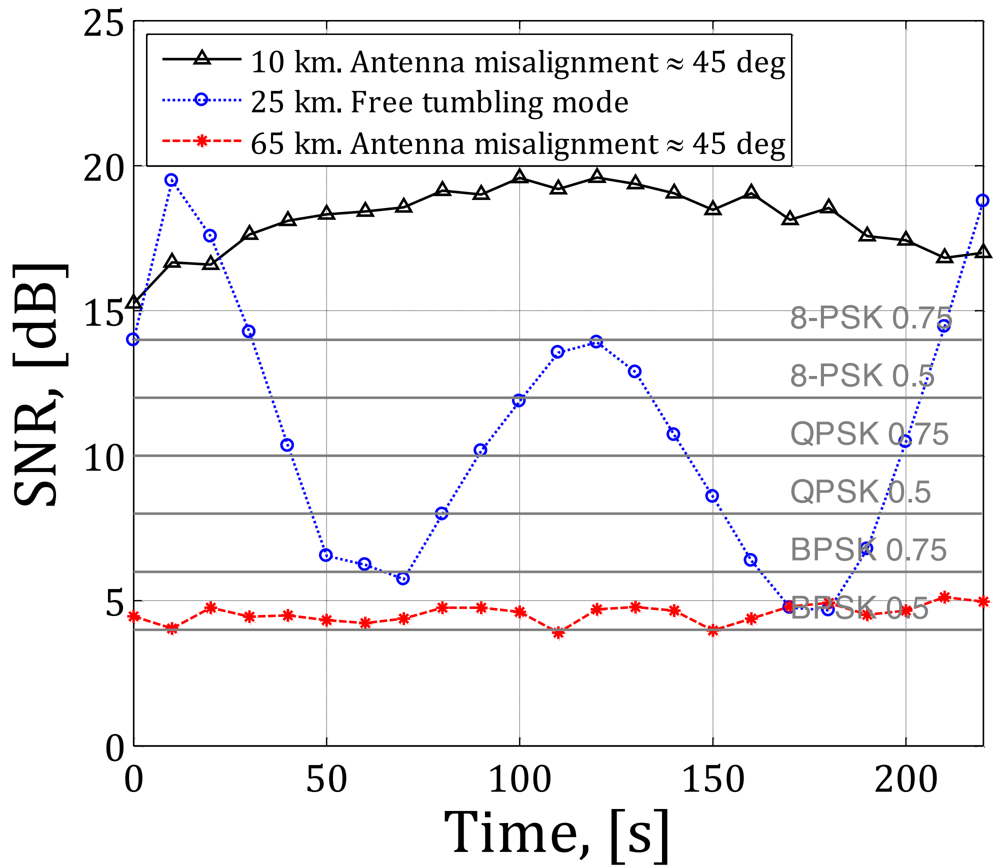


Figure: Measured signal-to-noise ratio.
Black: case #1. Red: case #2.

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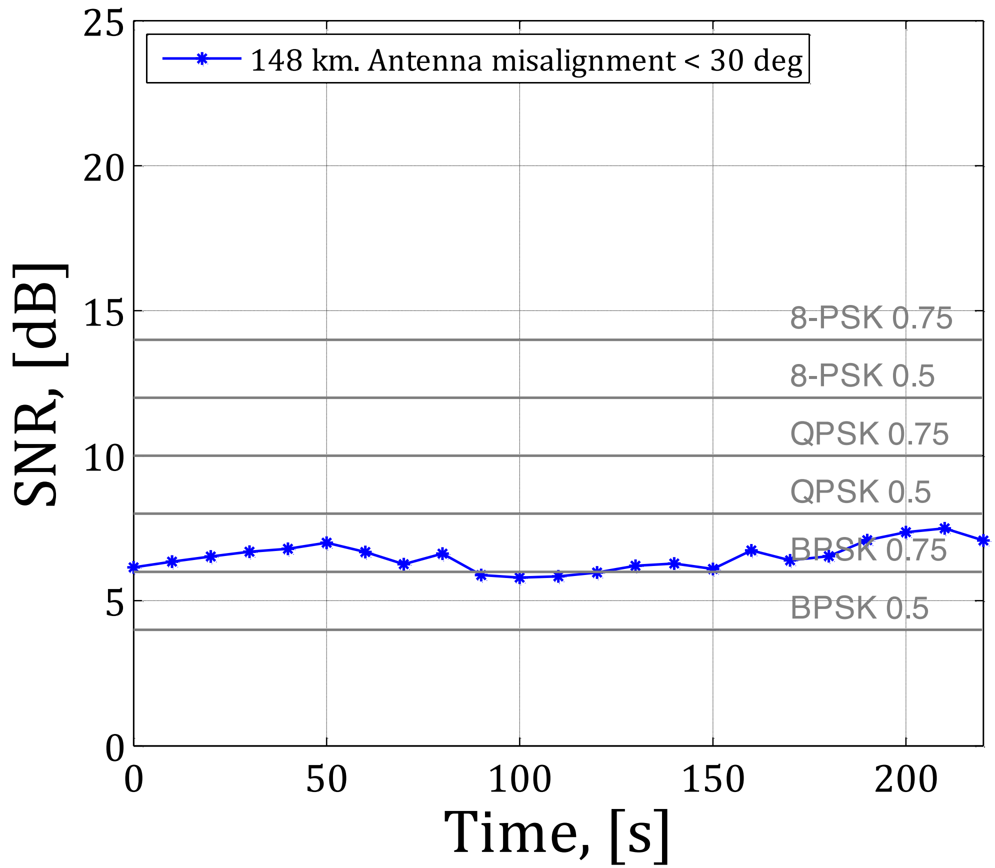


Figure: Measured signal-to-noise ratio.

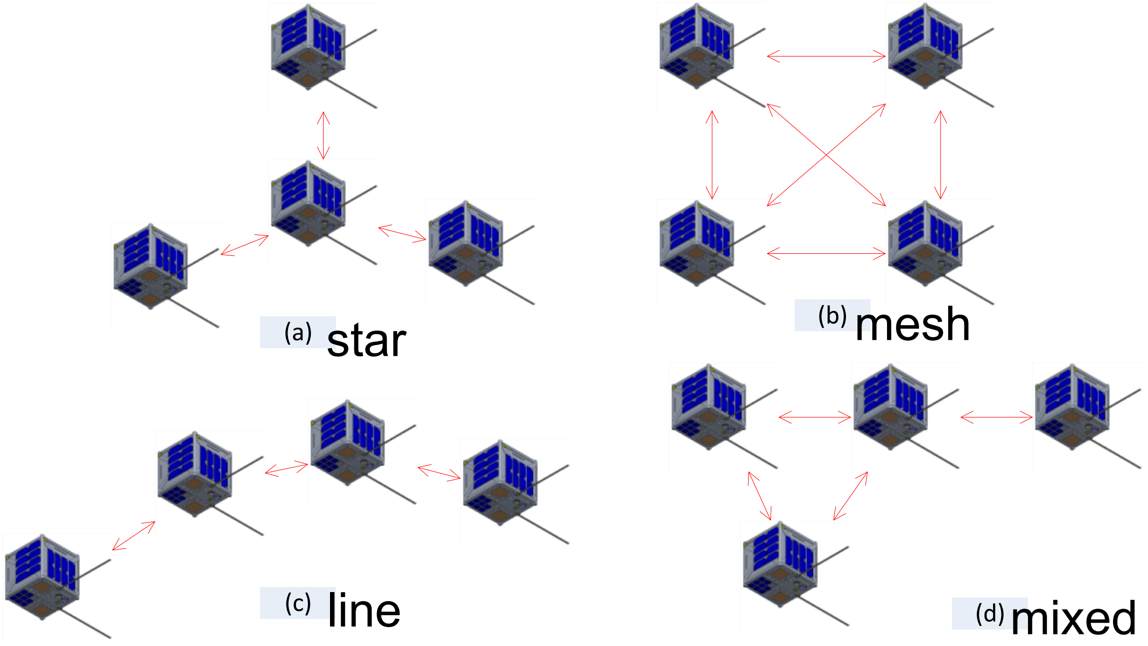
Operational Scenarios

- Network topology is determined by orbital configuration

1) Access via competition
- ALOHA protocol

2) Access via allocation
- Token passing (decentralized)
- Polling (centralized)

3) Access via reservation
- TDMA



- ISL communication in short P2P sessions organized
- Multi-Hop: Store-and-Forward principle
- Proactive Routing

•ISL protocol successful verified

S-NET for M2M use case demonstration

Precision GPS

Banking ATM

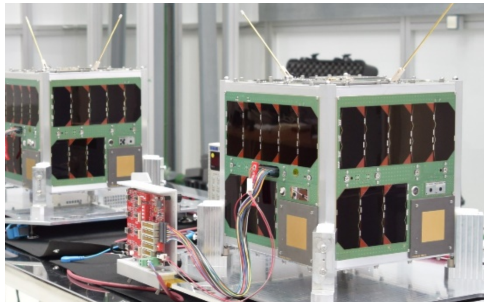
Election Polling

Maritime Containers Tracking

Oil & Gas

Water Irrigation Management

LEO Narrowband



M2M

S-NET
S-band ISL
100 kbps
Medium latency

Applications for Nanosatellite Networks

- Advantages using small satellites:
  1) Cheaper (low cost) to build and launch
  2) Low power and smaller antennas (due to LEO)
- Disadvantage: only one or two contacts per day, constellation of more than 40 up to several hundred satellites necessary
- S-Band with 30 MHz bandwidth enables transmitters in the size of a credit card
- (Global) Connectivity (from „always-on“ to „one time per day“) depends on the applications
- Internet of Space (satellite networks) can bring the Internet of Things everywhere on earth

Small Satellite technology serves as a key enabler for new services
to transform IoT connectivity across industry sites
and geographical and political borders

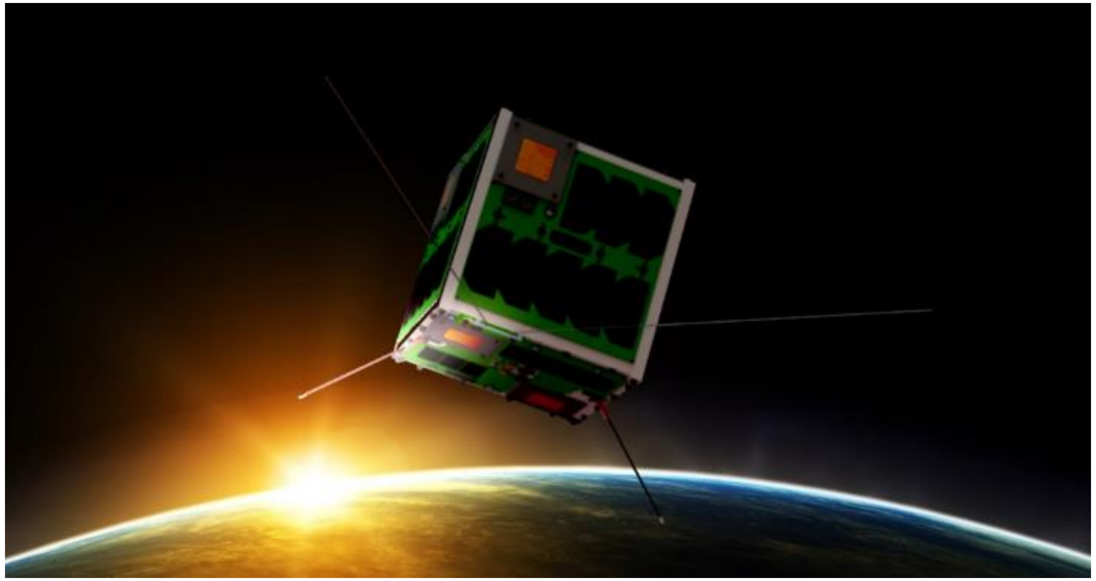
SALSAT (Spectrometer Analysis Satellite)

Mission objectives:

- Spectrum Analysis (VHF, UHF; S band)
- Creation of a global heatmap for spectrum use
- Detection and location of interferences

Mission parameter:

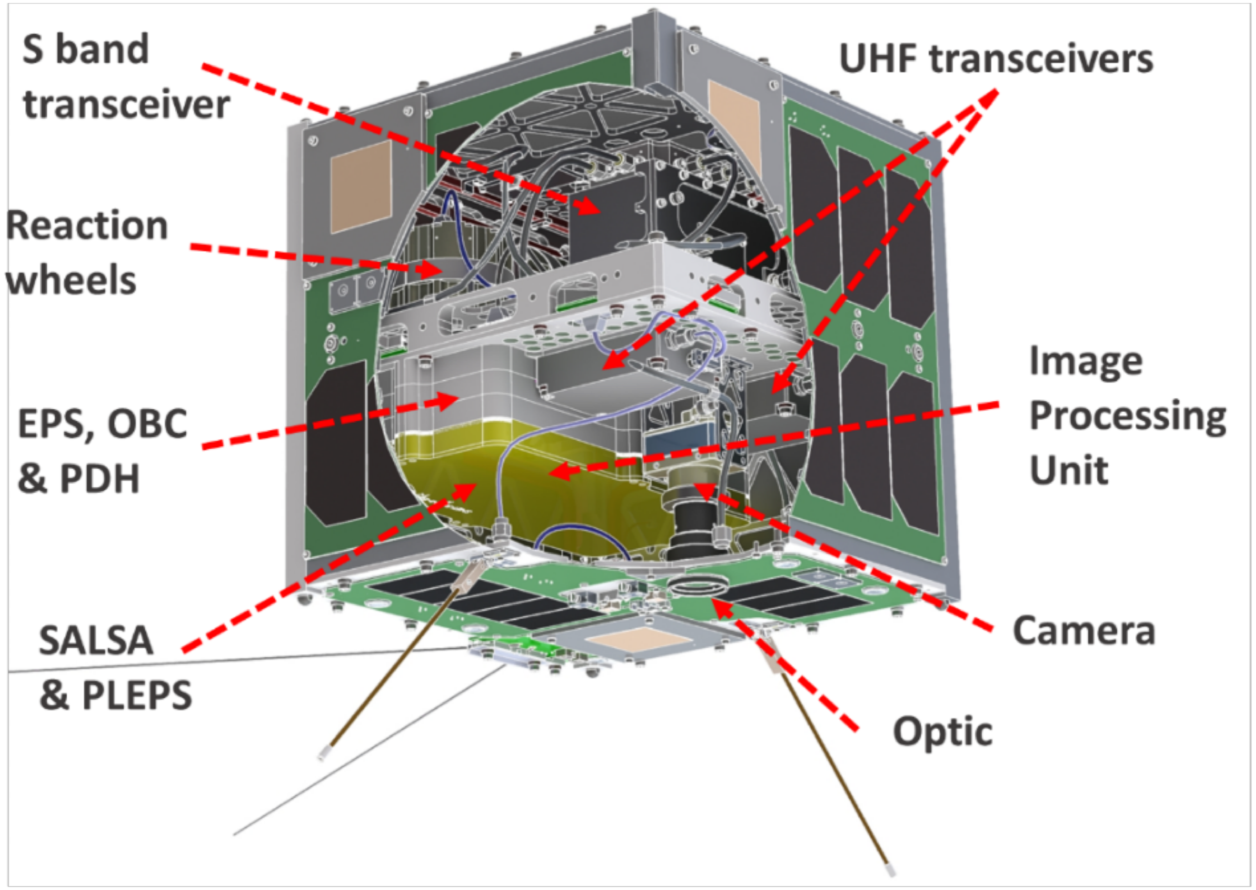
- TUBiX10 Bus & SNL
- Mass: approx. 18 kg
- Orbit: 410 – 630 km
- Type: Non-SSO, inclination > 60°
- Lifetime: > 1 year



SALSAT (Spectrometer Analysis Satellite)

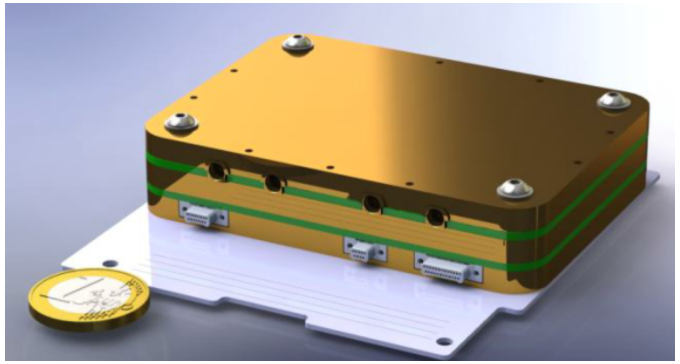
Current status:

- Mission concept
- PDR (10/2018)
- Launch contract signed
- Payload development
- Subsystem testing 2019
- CDR 2019
- Launch in 2020



From S Link to X Link

S Band ISL Transceiver

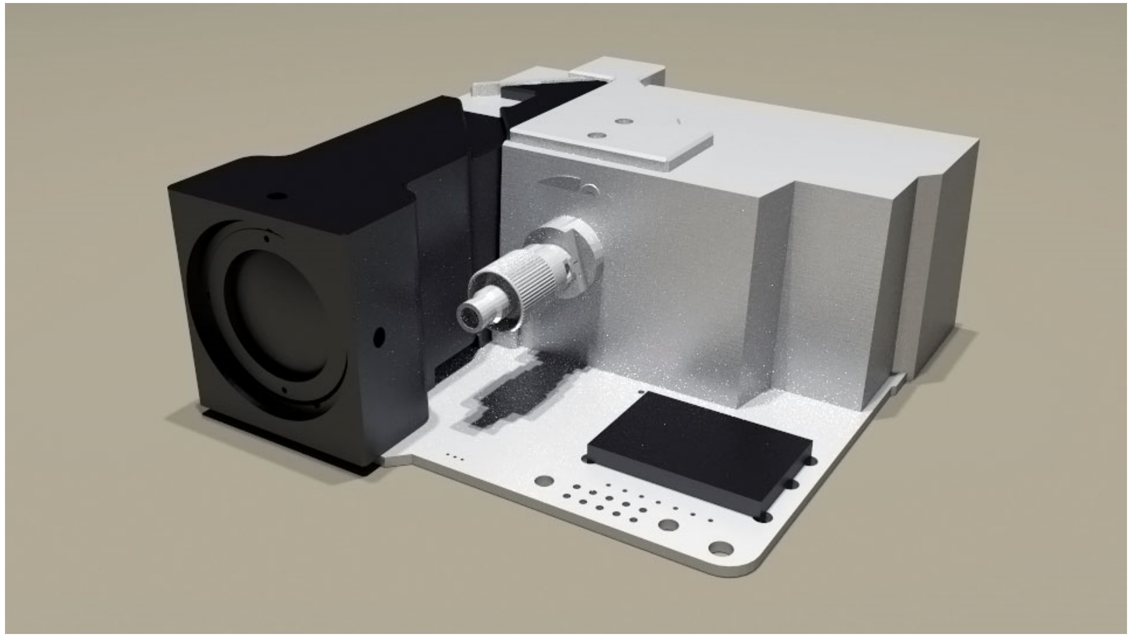


X Band ISL Transceiver

X Link
X Band (8 GHz)
SDR high speed data links
FDD, full duplex
BPSK, QPSK, FEC
Down: 25 Mbps (to 100 Mbps)
Up: 64 kpbs

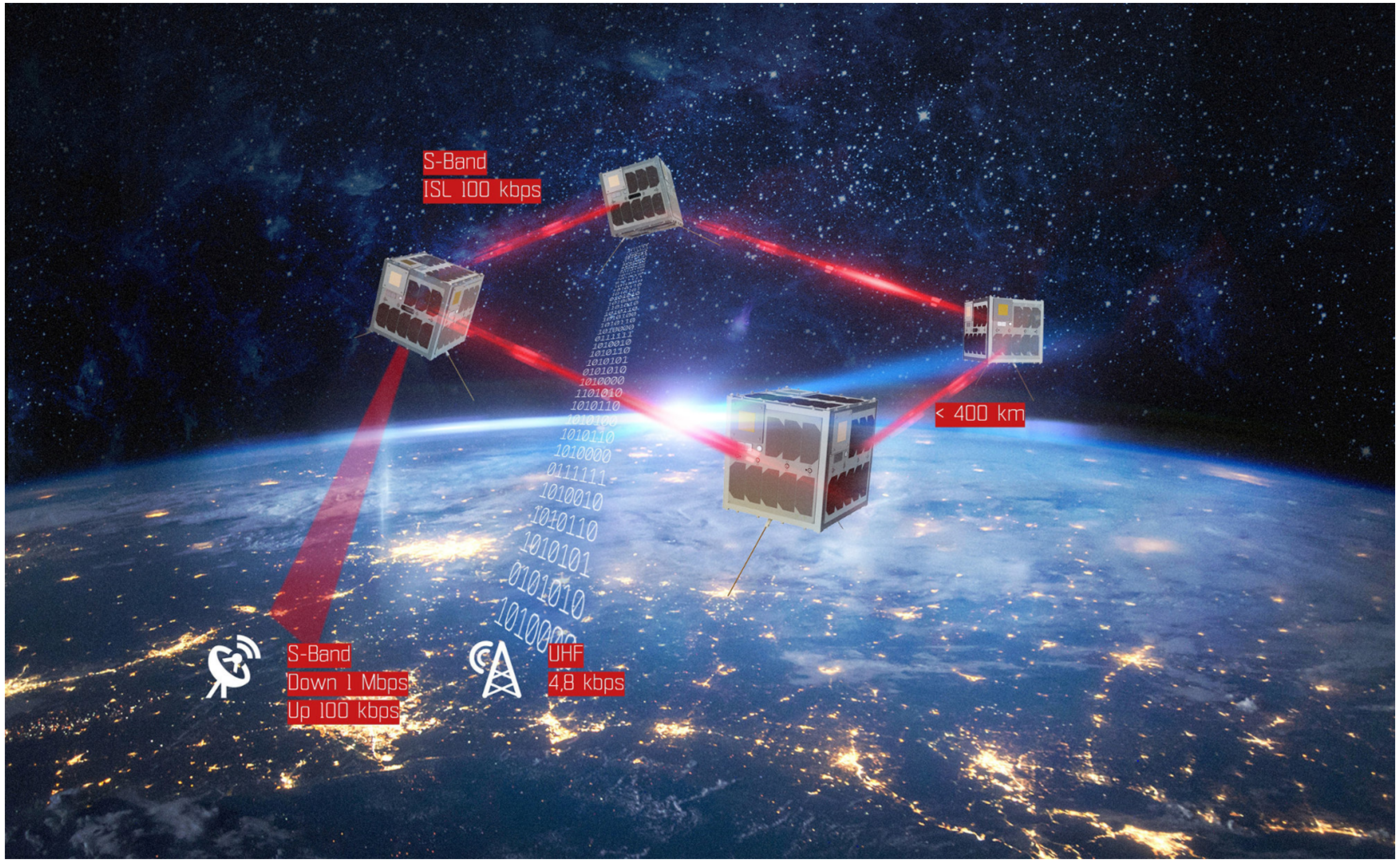
From RF to Optical Communication

- World's smallest Laser Communication Terminal
- Laser Communication Terminal for CubeSats
- Size of only 1x1x0.3U (~10x10x3cm³)
- Mass of about 350 gram
- Data rate of 100 Mbit/s
- Successful CDR für CubeL
- In-Orbit Verification planned in 2019



CubeL @ TESAT

Thank you for your attention!



Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag