Trend and Perspective of Distributed Space Systems

분산형 우주시스템의 동향 및 개발전망

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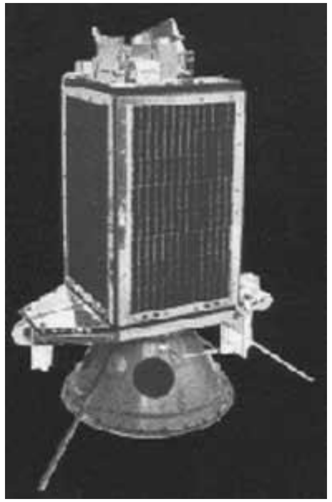
Q: 초소형위성의 미래는?

80‘s	90‘s	2000‘s	2010‘s	2020‘s
Active reconfiguration	**Application** **New avionics**	**Distribution** **Miniaturization**	**Commercializing**	**?**

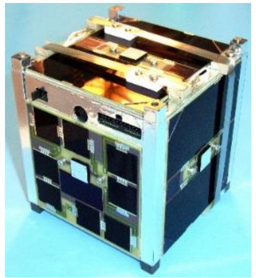


UOSAT-1 (54 kg, 1981)
U.of Surrey
2 x 8bit μC, 16k DRAM

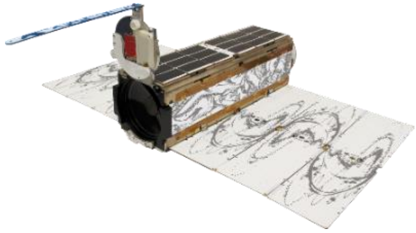
S-Band, CCD Kamera
(DLR TubSat)

CAN Bus (FASat)
Formation (Snap-1)
Training (LapanTubsat)

Cubesat & PPOD, 1999
1/2/3 U



3-axis control
(Beesat-1)



Spin-off:
Gom Space, Clyde Space
ISIS +400
6/12 U, Komplettlösungen

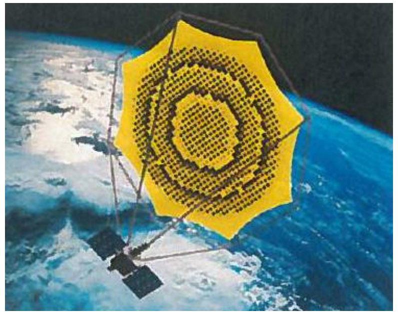
Q: 초소형위성의 미래는?

a) Femto Satellites < 1 kg
b) Micro Satellites > 100 kg
c) Distributed systems (swarm / constellation)
d) Moon / Mars mission

초소형위성의 미래

2020‘s

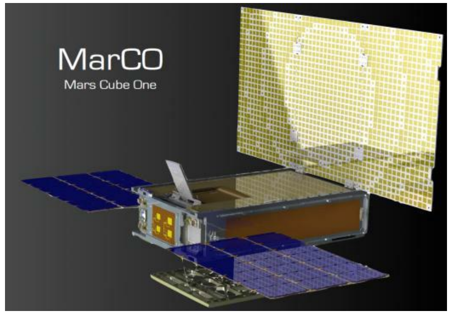
distributed (cooperative) systems



Application of future small satellite constellations [1]

1. LEO Communication (23)
2. M2M Communication (20)
3. Hires EO (19)

Beyond LEO



Deployable mechanism
- Solar panels
- Antenna
- De-Orbit device

High performance density
- Multifunctional components
- Highly integrated design
- MEMS technology

Communication technology
- X, Ka, Ku Band
- Optical communication
- Antenna
- Protocol

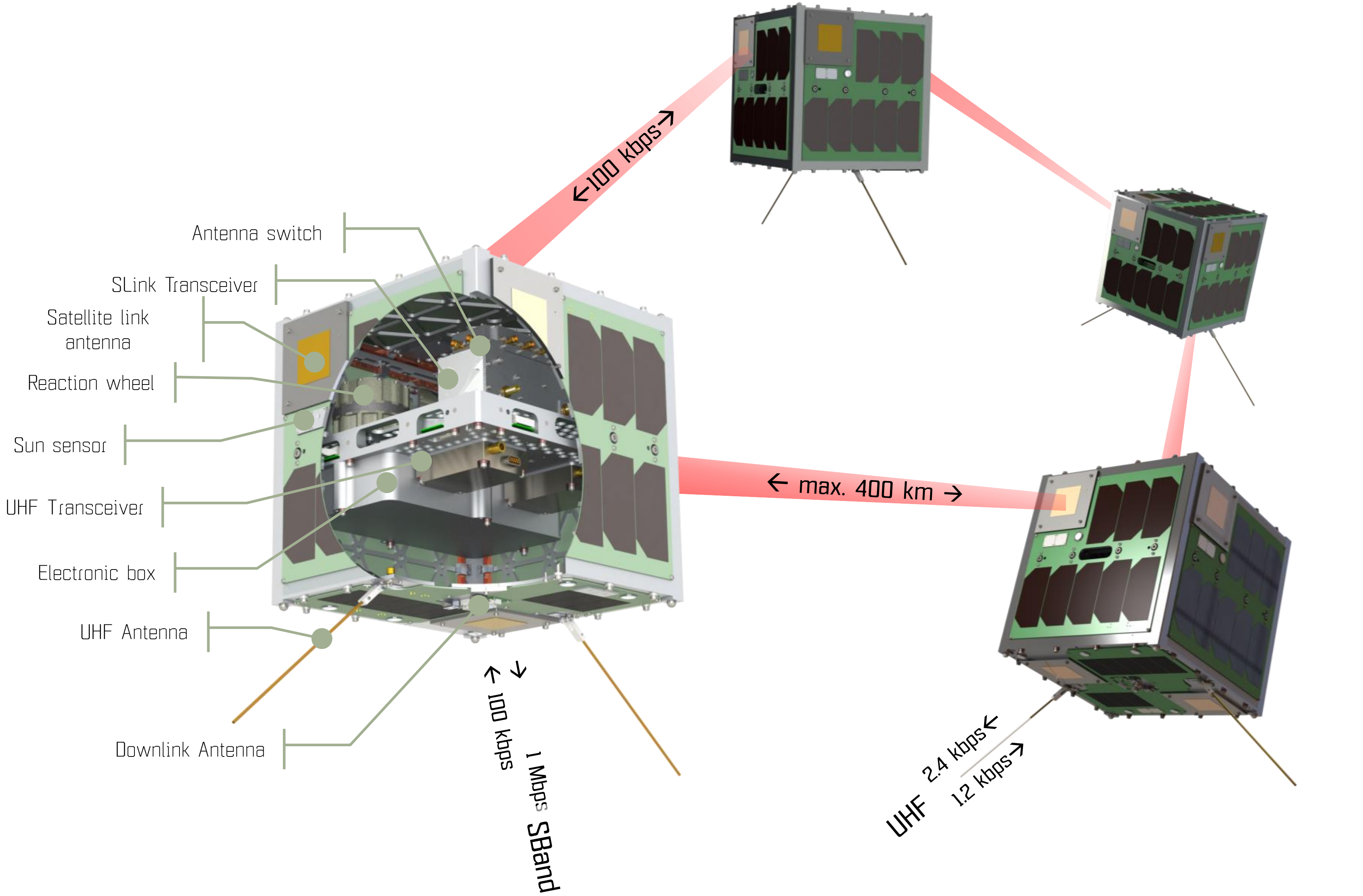
Onboard Autonomy
- FDIR
- AI

!

Increased system complexity

[1] Sweeting, Modern small satellites – changing the economy of space, Proceedings of the IEEE, Vol. 106, No. 3, 2018

“Worldwide first Multihop Nanosat Network” S-NET



Satellites	4
Satellite mass	< 9 kg
Satellite size	24 x 24 x 24.5 cm
Energy reserve (SSO)	5.6 W
Orbit	SSO < 650 km
Launch	Soyuz Fregat via Dispenser
Payload	ISL S-band transceiver Laser reflector
Launch	1. Feb. 2018
Designed lifetime	> 1 year

ISL Applications

Rapid S/C commanding and response

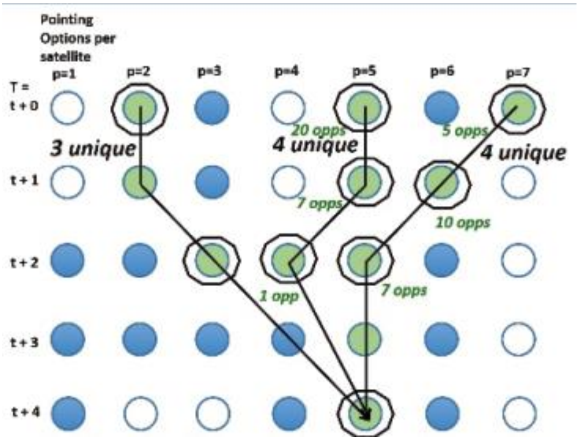
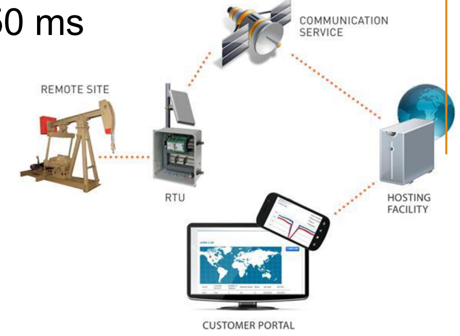


Figure: Constellation optimization of Earth observation by „Rapid Response Imaging“

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

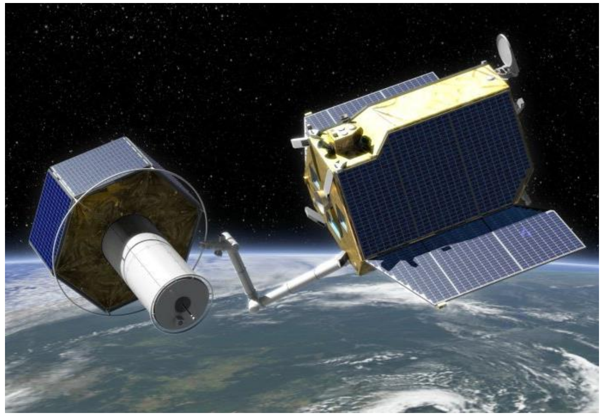
M2M / IOT communication

- 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



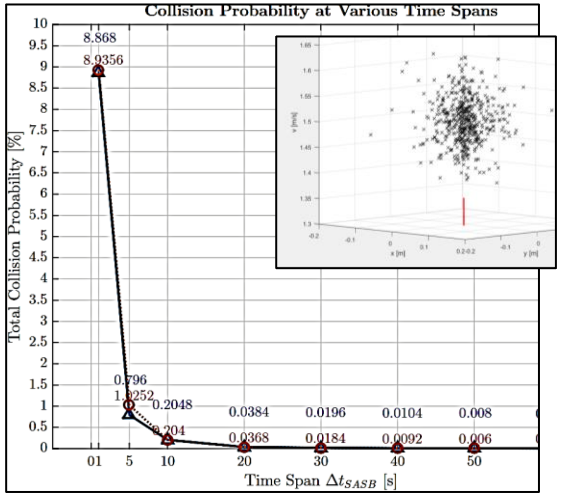
artist impression of DEOS [DLR 2010]

Research | Formation and Constellation

Req: closed network topology of 400km for 6 month!

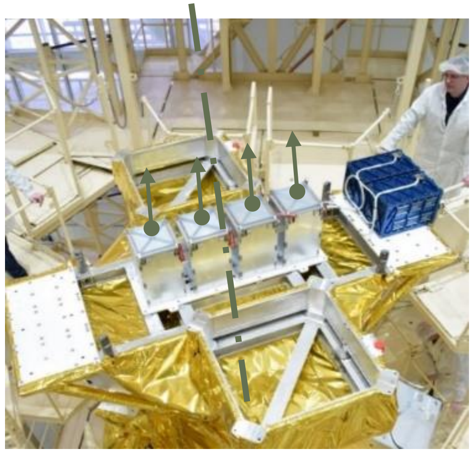
Parametric Motion Analysis

1. Perturbation analysis
2. Collision vs. Drift



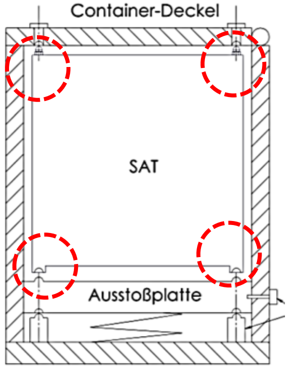
Precise Upper Stage control

1. Pointing < **1°** in cross/radial
2. Drift < 10 arcmin / 30s



Precise Dispenser Ejection

$$\vec{v}_{eject} = 1.5\frac{m}{s} \pm 3\%$$

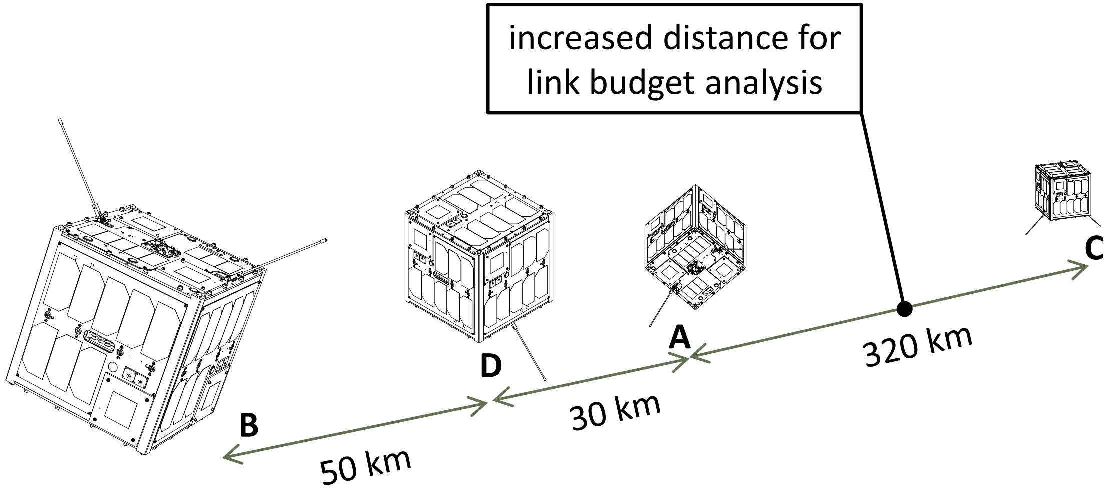


Guarding pins for zero friction ejection

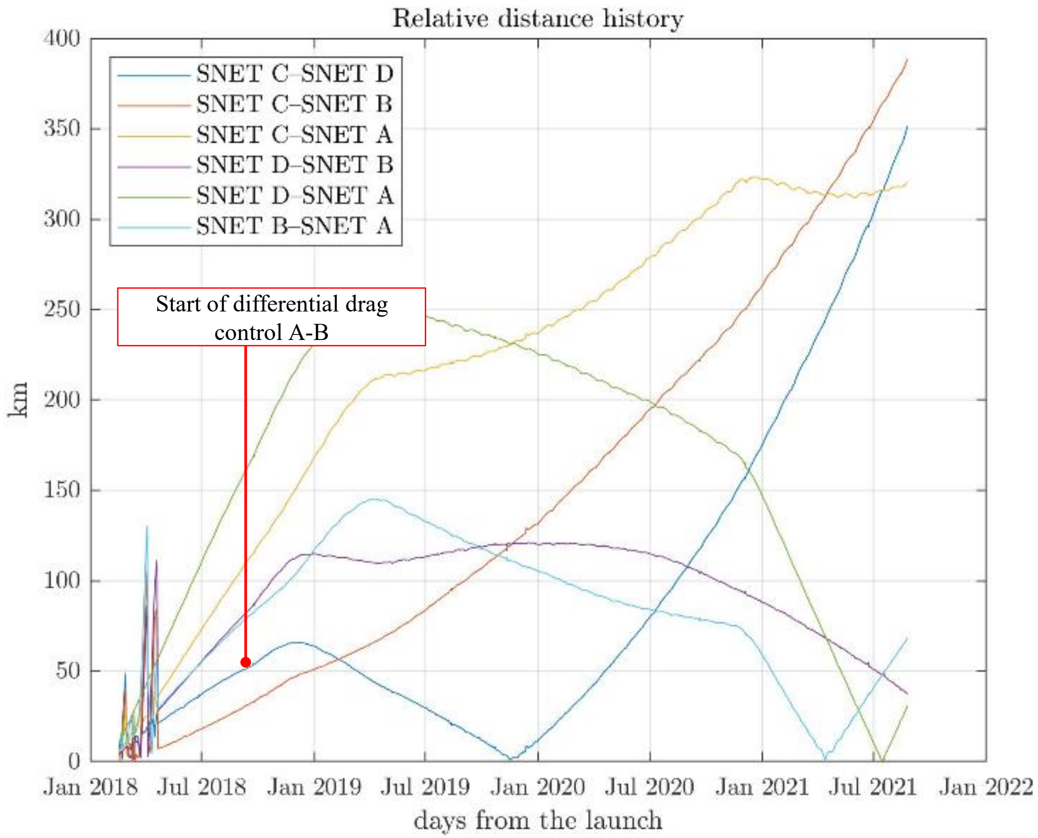
Yoon, Z., Lim, Y., Grau, S. et al. Orbit deployment and drag control strategy for formation flight while minimizing collision probability and drift. CEAS Space J 12, 397–410 (2020)

Research | Formation and Constellation

- Ultra precise in-orbit insertion
- Formation flight using atmospheric drag
- Relative distance after 2 years< 300 km
- Excellent system trade-off complexity vs. performance



▲**In-line formation 2021.08.01 (42 month after launch)**



Yoon, Z., Lim, Y., Grau, S. *et al.* Orbit deployment and drag control strategy for formation flight while minimizing collision probability and drift. *CEAS Space J* **12,** 397–410 (2020)

Promoting Next Generation

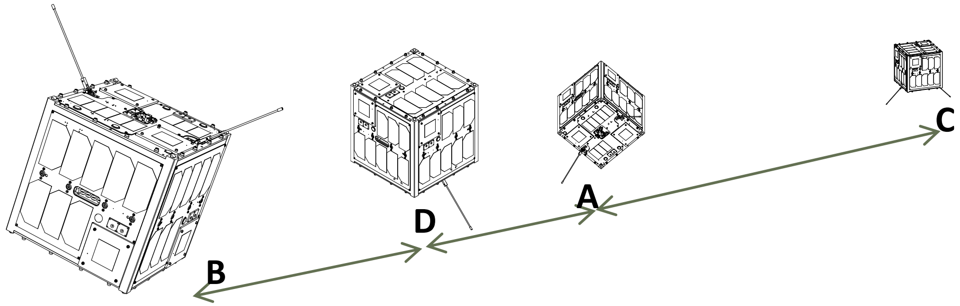
From 2014,
+160 international master students graduated

Workshop with high school students on satellite communication

S-NET
5 research fellows
10 students

R&D Plan @ KAU

Distributed Satellite Operation



UHF Station

- Standard TMTC
- (432…438 MHz) – Amateuer radio freq
- Pointing antenna with approx. 14 dBi
- Datarate 4.8 kbps (tbc) brutto (UL & DL)
- Paketbased protokol, GMSK

Mission Control Center

S-Band Station

- Experiment, S/W-Updates, Images
- 3 m antenna
- Developed for operation of TUBSAT series
- SGP4-based tracking
- Signal strength tracking under development

Complexity Optimization for DSS

$$C(n,m,A) = \sum_{i=1}^{n} \alpha_i + \left(\sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} A_{ij} \right) \cdot \frac{E(A)}{n}$$

Matrix Energy / Graph Energy

Scaling

Components

Interfaces

DSM

Components

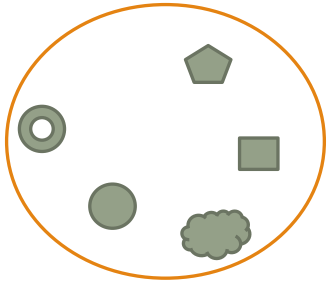
Interfaces

Topologie

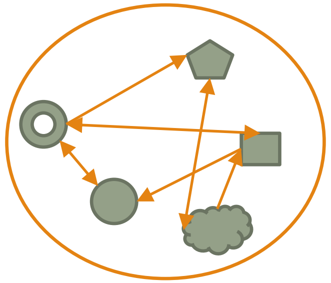
Component development & testing

Interface management

Architecture (Distribution of connections) → System integration

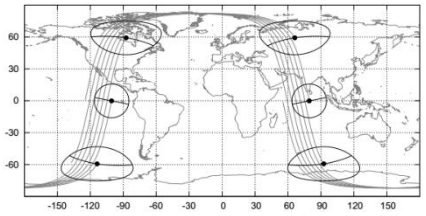


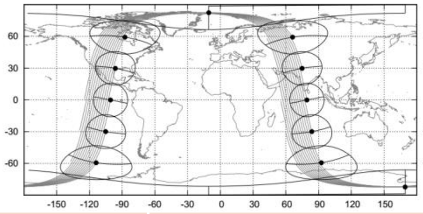
	Controll	Actuator	Dynamics	Sensors	Filter
Controller	X	1	0	0	0
Actuator	0	X	2	0	0
Dynamics	0	0	X	3	0
Sensors	0	0	0	X	1
Filter	1	0	0	1	X

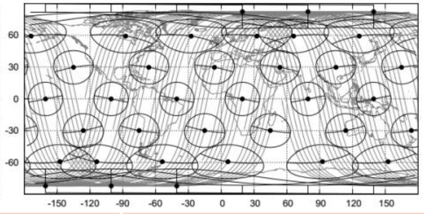


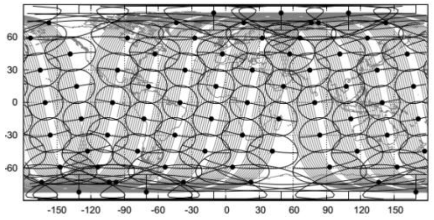
Kaushik Sinha, Structural complexity and its implications for design of cyber-physical systems, MIT 2014

Satellite Constellation and Application









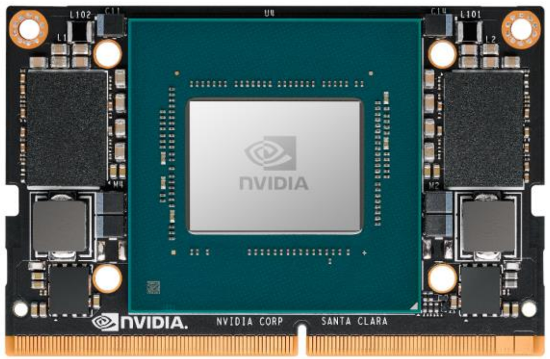
Constellation	**6 Satellites** Walker Star 97.78: 6/1/1	**12 Satellites** Walker Star 97.78: 12/1/1	**36 Satellites** Walker Star 97.78: 36/6/2	**72 Satellites** Walker Star 97.78: 72/6/2
User terminal Tx rate (service A)	max. 3.3 KB/24h	max. 13.4 KB/24h	max. 20.3 KB/24h	max. 39.1 KB/24h
System throughput (Service B)	max. 2.4 GB/24h	max. 4.8 GB/24h	max. 14.4 GB/24h	max. 28.9 GB/24h
Gap time	10h	10h @ 20°N/S	10min @ 20°N/S	real time
#max. user terminals (service B) in each cell @ 20°N/S	17	34	103	200
Application	Animal tracking Animal behavior Visual IoT Messaging Logistics tracking **Store-and-forward**	Animal tracking Animal behavior Visual IoT Messaging Logistics tracking **Store-and-forward**	Animal tracking Animal behavior Visual IoT Messaging Logistics tracking Disaster monitoring **Near real time**	Animal tracking Animal behavior Visual IoT Messaging Logistics tracking Disaster monitoring Cooperative driving **Real time**

Space AI

Efficient onboard processing is the key for smart airborne systems

- autonomous real-time decision making
- Relieve downlink channel bottleneck

Onboard computer with high reliability and high performance AI processor

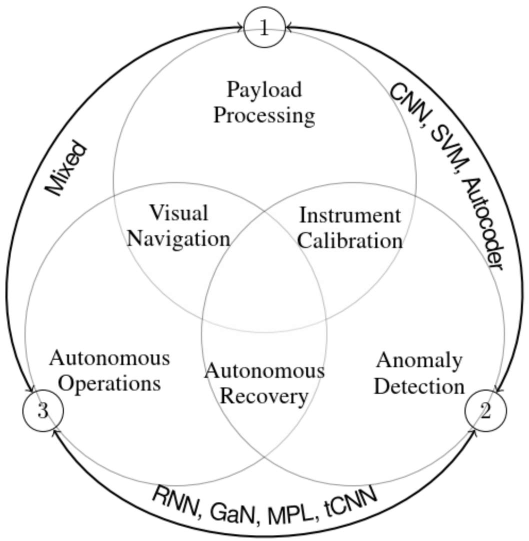


Jetson Xavier NX

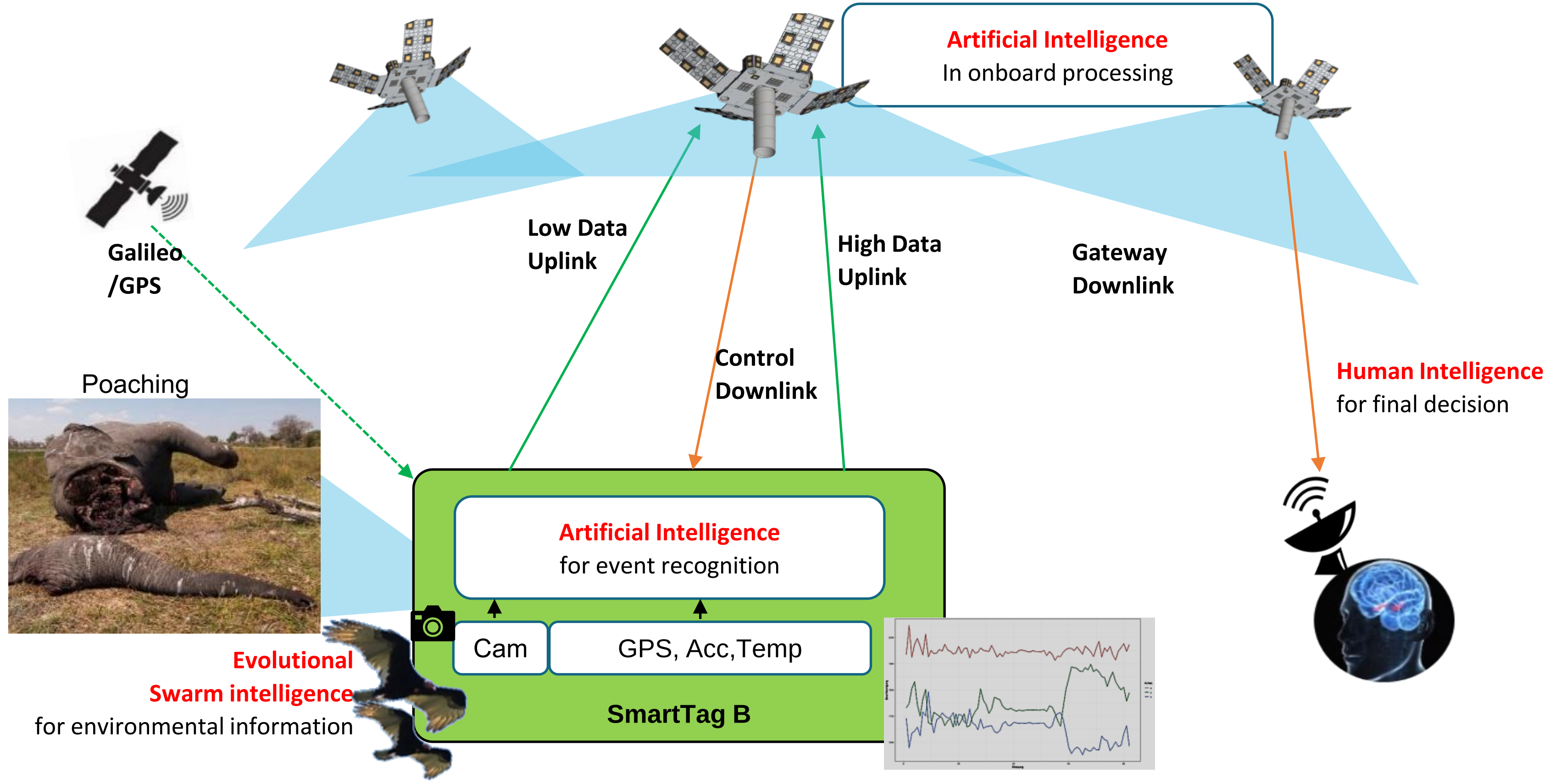
- AI Accelerator max. 21 TOPS
- 6-core NVIDIA Carmel ARM®v8.2 CPU
- 384-core GPU with 48 Tensor Cores

Google Coral Dev Board Mini

- TPU max. 4 TOPS (int8),
- High efficiency: 2 TOPS/Watt
- 4x Cortex-A53 1,8 GHz



Internet of Life



Research for societal benefit

Collaboration with experts

Future ist not a promise, but a **joint venture!**

Cooperation with excellent
Science and Industry

Promoting next generation
talents