

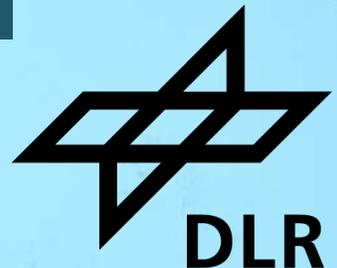
FROM GROUND TO SPACE AND BACK: NEXT FRONTIER OF EDGE- CLOUD CONTINUUM

Dr. Tomaso de Cola (DLR)

one6G Open Lecture 11

Online, January 22nd 2026

(one6G)



Few Words about DLR – German Aerospace Center

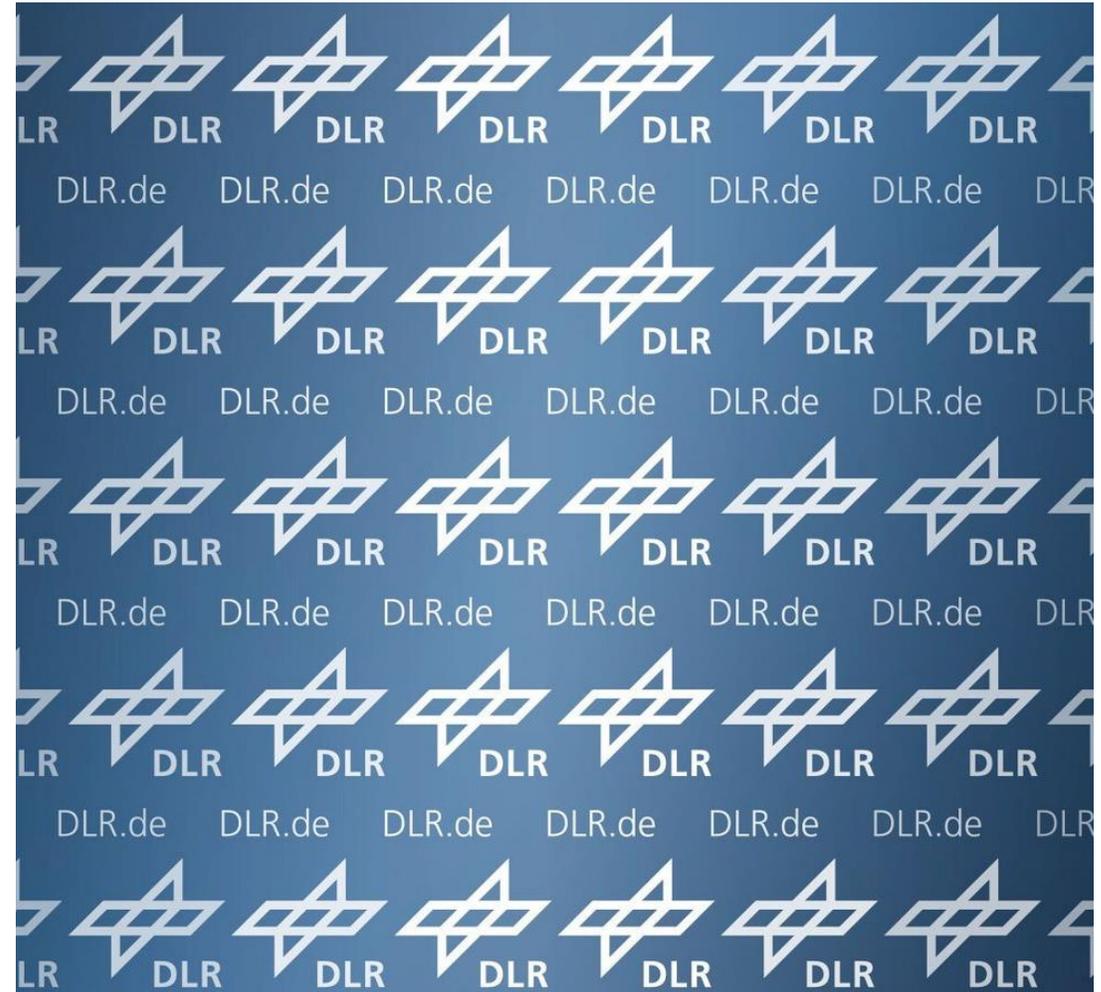


Research & Technology Center

- DLR develops technologies for
 - Aeronautics
 - Space
 - Energy
 - Transport
 - Security
 - Defence

National Space Agency

- Implements the space strategy of the Federal Government
- Develops and manage the national space programme
- Represents the interests of the Federal Republic of Germany in space-related international bodies
- Advises the Federal Government
- Develops initiatives and strategic approaches for space policy



Credit: © [DLR](https://www.dlr.de/)

DLR Institute of Communications and Navigation



Satellite Networks

The Satellite Networks department plays since many years a leading role in Europe in the conception and investigation of novel system concepts, transmission techniques, protocols and applications for Satellite Communications.



Optical Satellite Links

The department Optical Satellite Links deals with the application of optical technologies in satellite communication and related topics.



Communications Systems

The focus of the department Communications Systems is on aeronautical, car-to-car and train-to-train communications, on multisensor navigation, and swarm exploration.



Navigation

The department of Navigation aims for a significant role in the realization of the European Global Navigation Satellite System (Galileo) with a focus on ground systems and user terminals.



Nautical Systems

The department of Nautical Systems is working on research topics in the field of maritime PNT (Position, Navigation and Time) sensors and dedicated satellite based as well as terrestrial augmentation systems and services.



Institute Project Management and Administration

The department Institute Project Management and Institute Administration is responsible for the main cross-sectional tasks and functions in the Institute.



GLOBAL CONNECTIVITY FOR PEOPLE AND MACHINES

Global Connectivity for People and Machines

Setting Standards in Communications



GLOBAL POSITIONING FOR FUTURE APPLICATIONS

Global Positioning in Future Applications

Taking Accuracy, Reliability and Robustness to the next Level



AUTONOMY AND COOPERATION FOR TRANSPORTATION AND EXPLORATION

Autonomy and Cooperation

Creating Solutions for Transportation and Exploration



CYBERSECURITY FOR RADIO SYSTEMS

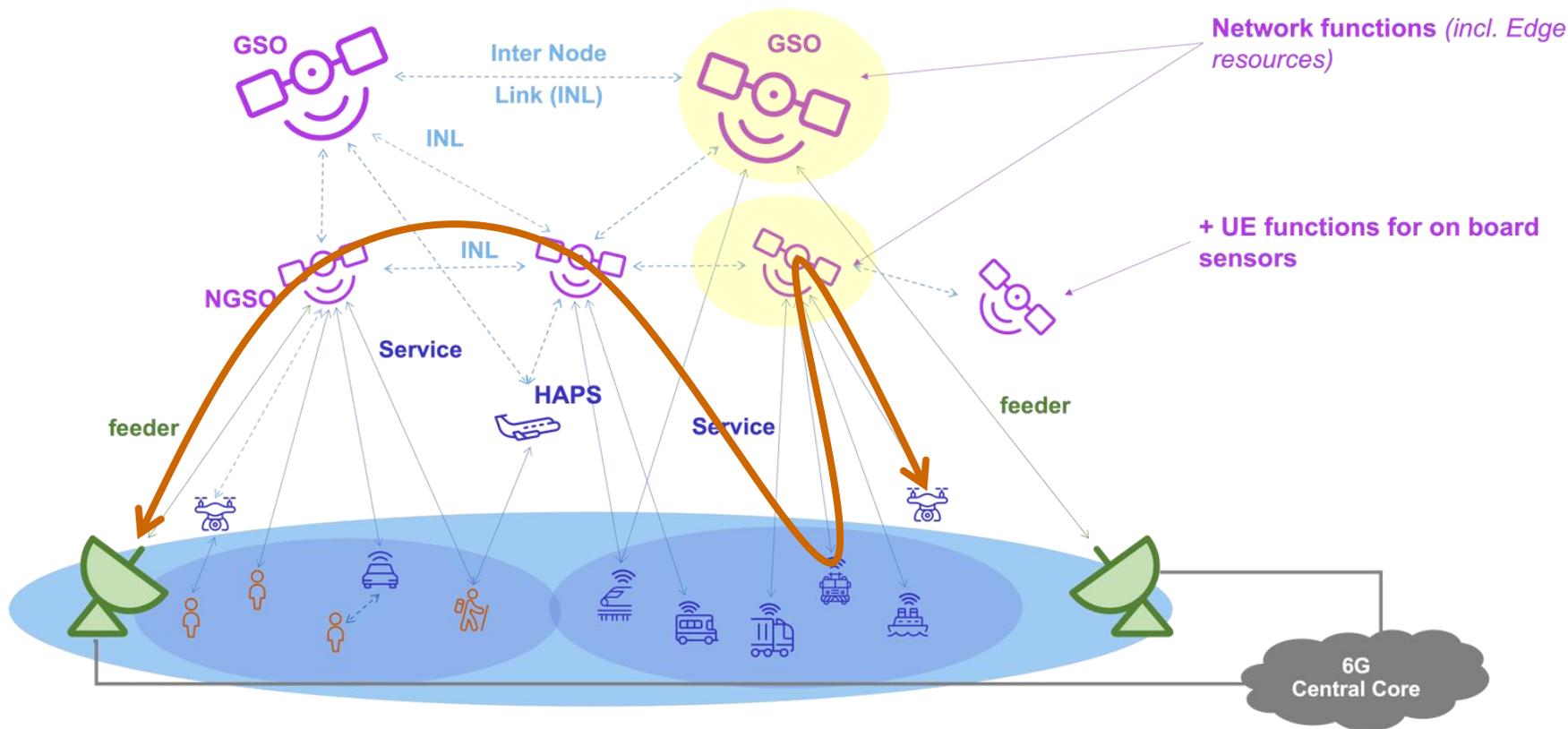
Cyber Security for Radio Systems

Protecting Society in the Digital Age

Satellite Networks Department – Our Vision



Multi-Orbit & Multi-Frequency Architecture



Space Segment

- Regenerative → Intelligent Software-Defined Payloads
- Edge computing in Space

Networking and Protocols

- Routing (for large constellations with optical ISLs)
 - AI / ML based
 - Extension to **resilient and secure** routing
- Network Slicing and Orchestration
- Handover TN / NTN

NTN (Related) Projects Overview



Systems / Architectural Studies

5G stardust

NEXASPHERE 6G

6GNTN

unity-6G

Agrarian
Farming on the Edge

European Commission | 6GSNS

6G-TakeOff

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Technology Developments

- **RoPRO**
Routing for Megaconstellations  European Space Agency
- **EDGECOLB**
Edge computing in space
- **QUICOPSAT**
QUIC protocol adaptations for SatCom
- **AIComS**
Develop AI/ML-based SW/HW for future NTN payloads
- **TRACK / 5G-InRail**
SatCom Component for FMRCS

Demonstrations

- **MIXELS – DEMONSTRATION OF AN EXPERIMENTAL 5G gNodeB IN SPACE**



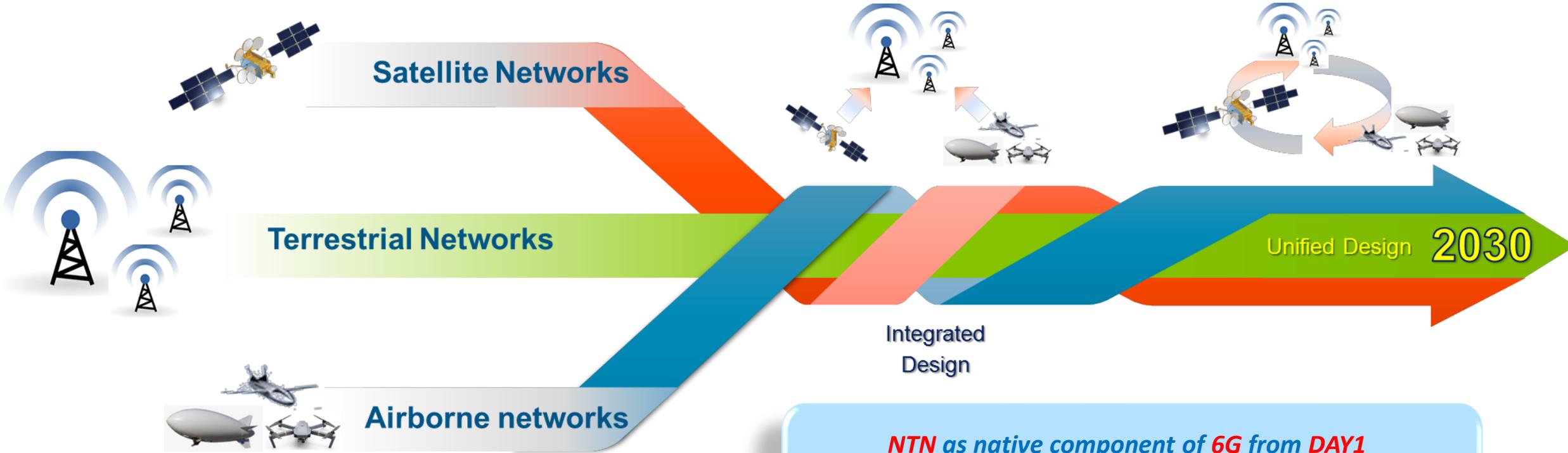
The outlook of NTN into 6G



4G & Before

5G & B5G

6G & beyond



NTN in 6G from DAY1: Way Forward



- **Service centric networking**

- Optimal placement and coordination of service function chains among different elements of the space and ground segments

- **Orchestration of space networks as an integrated part of the 6G system**

- Exploitation of Function-as-a-Service paradigms supported by AI techniques to correlate NTN-6G context data with network operations and achieve effective network orchestration

- **Edge/Cloud continuum**

- Exploitation of space assets placed in different interconnected flying systems will be an added value to guarantee diversified and QoS-proof access to distributed computing and storage resources across the whole 6G network.

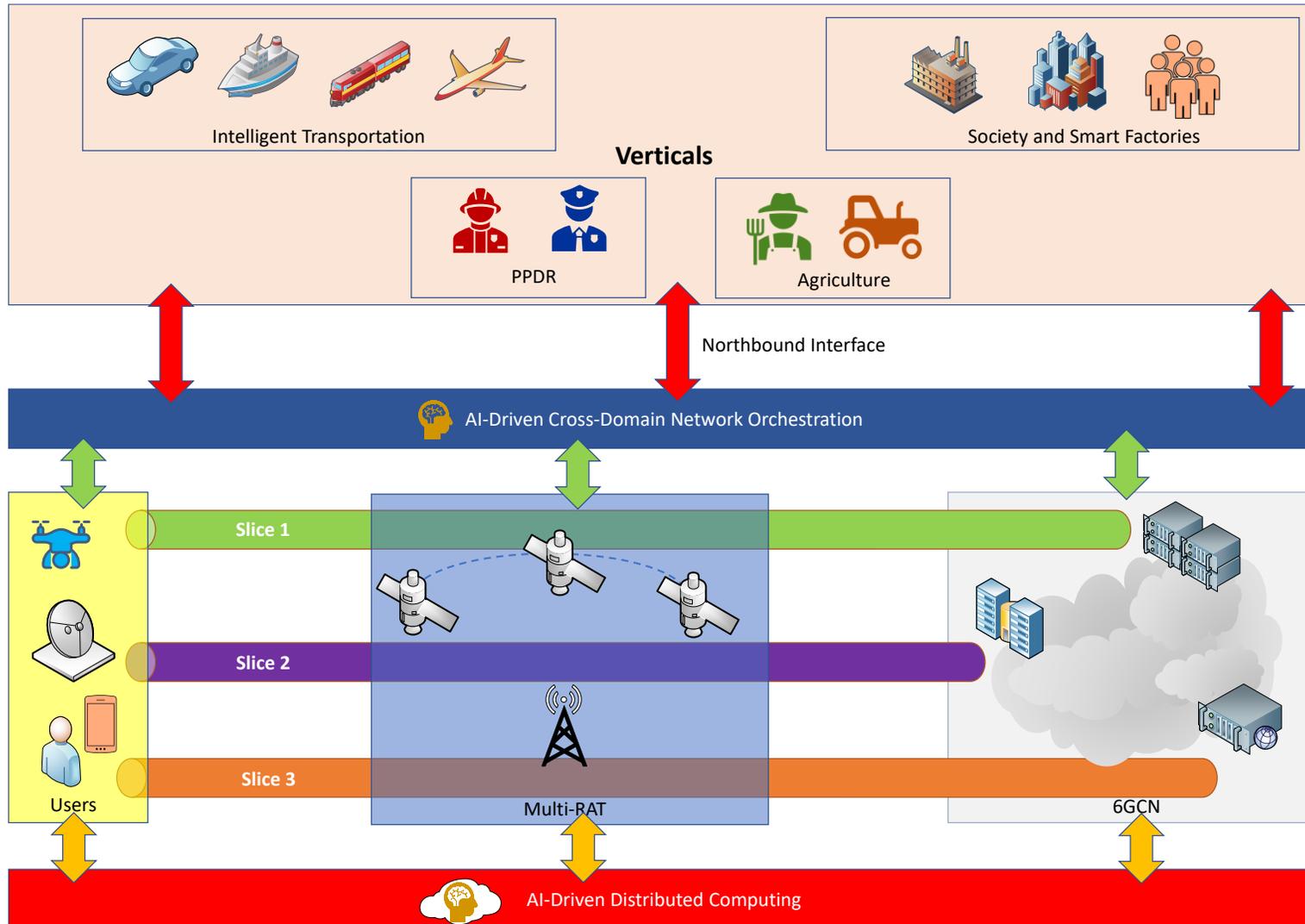
- **Dynamic end-to-end network slicing and resource allocation**

- Effective service provisioning techniques across all protocol layers in order to enable a service assurance in multi-layer multi-orbit scenarios by means of AI-based complex dynamic control strategies

- **Distributed AI techniques**

- Applied throughout the entire 6G-NTN network architecture to guarantee a flexible and effective service provisioning under the operational constraints imposed by the heterogeneity of NTN-6G network elements.

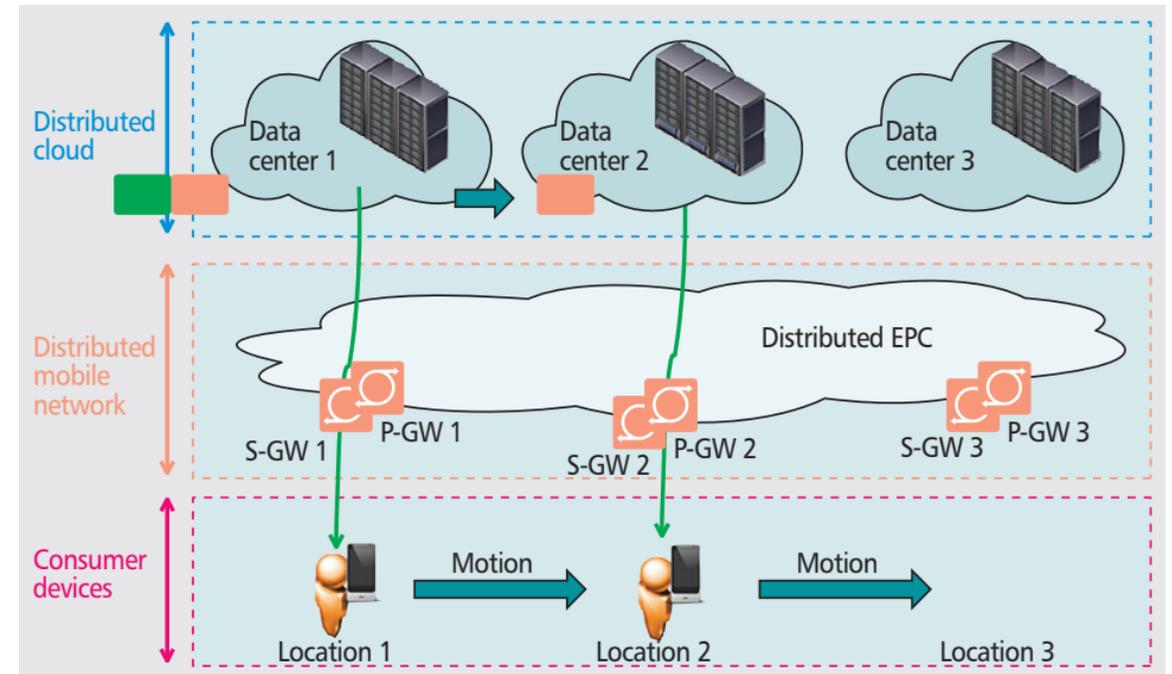
A service-oriented architecture



- Fully softwarised network architecture
- Intent-based networking paradigm
- AI based optimisation of
 - Network orchestration/slicing functions across TN and NTN segments
 - Distributed computing functionalities on ground and space towards edge-cloud continuum
- Self-organised networking architecture to cope with NTN-varying topology

An inspiring idea...

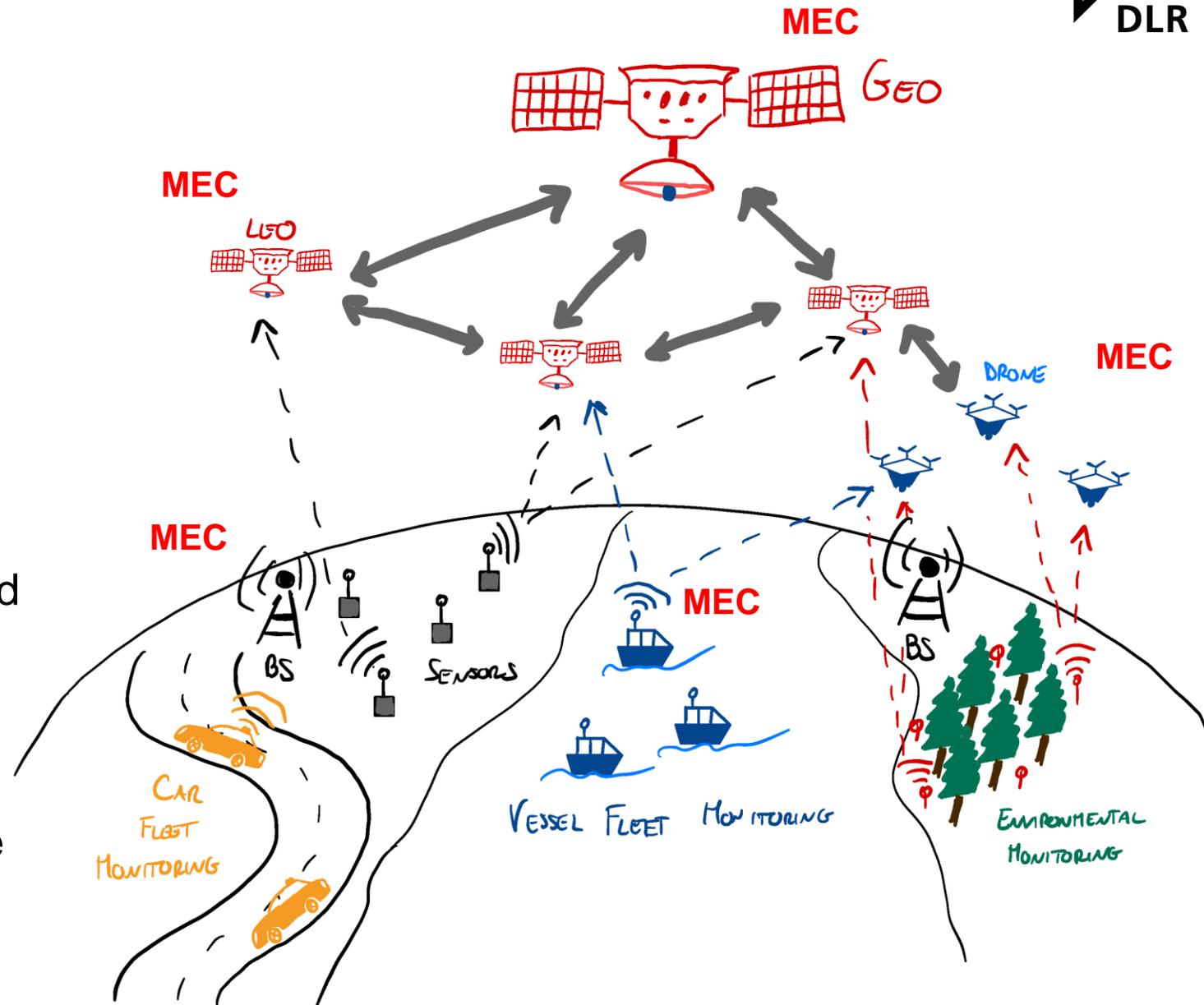
- Exploitation of LEO constellations to take advantage of low delay access
- Implementation of onboard MEC facilities to provide (mobile) users with quick access to the stored content
- Possible application of the “follow-me cloud” concept in space:
 - Data access session continuity
 - Synchronisation/coordination between multiple MEC instances
 - Distributed caching concepts
- Design of effective communication architecture in what concerns user, control, and management planes



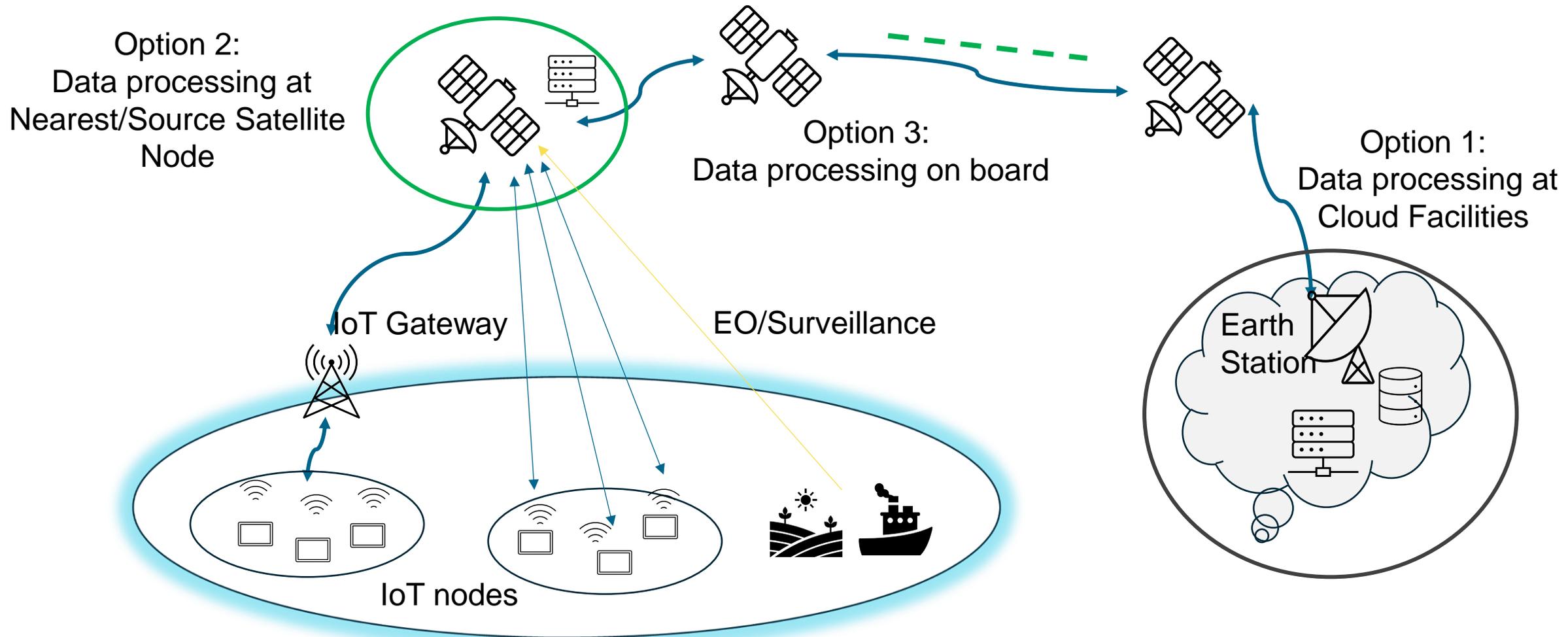
T. Taleb and A. Ksentini, "Follow me cloud: interworking federated clouds and distributed mobile networks," in IEEE Network, vol. 27, no. 5, pp. 12-19, September-October 2013.

What does mean in space?

- **The 3D-Network** is a dynamic network with changing topology
- Each Domain (space, air, ground) has its own characteristics
- for NTN this depends on the orbit (GEO, MEO, LEO)
- Highly flexibel solutions are required for transmission optimization
- Its beneficial for (high demanding) MEC Apps and its developers to be aware about expected performance



Different flavours of edge computing in space



Edge Computing in Space: Why?



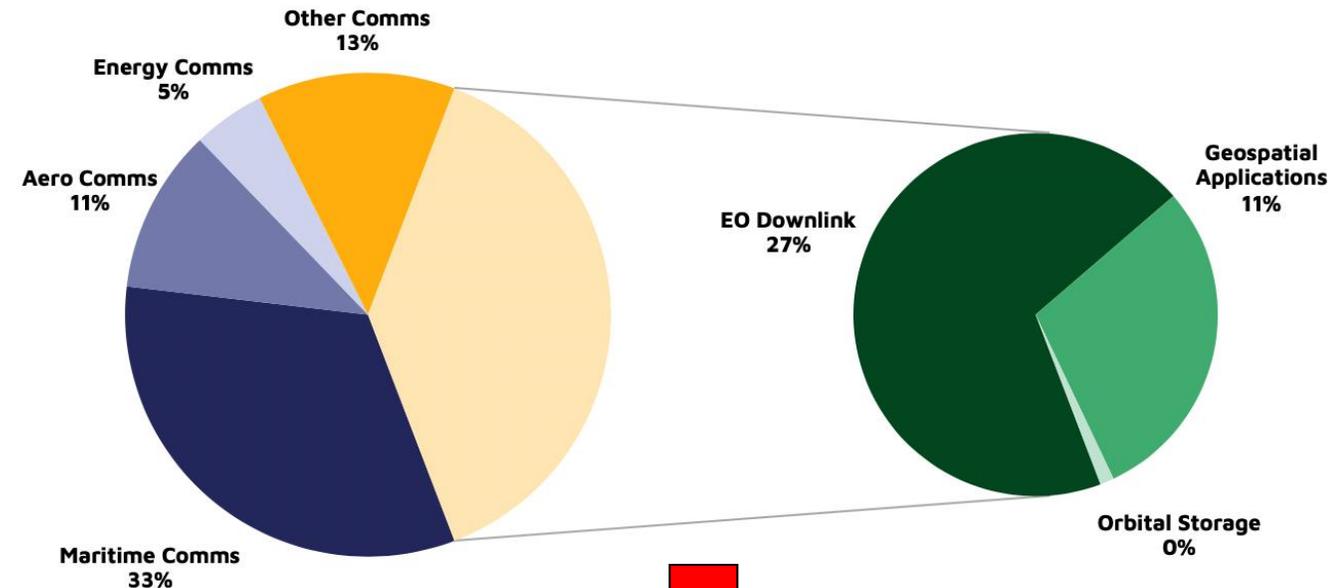
- MEC support particularly appealing to move data availability as much closer as possible to users, so as to reduce large latency typically experienced by satellite systems:
 - Combination of edge caching and intrinsic multicast capability of satellites to optimise content delay and content penetration
 - Integration of MEC functionalities directly in the satellite access segment
- MEC intended as “edge computing” to boost local computing (i.e., onboard satellite) to relief core network from excessive data distribution:
 - Support to IoT-based services by means of in-space edge computing
- MEC for possibly enabling low delay services (i.e., zero-perceived latency, relaxed uRLLC requirements) with LEO satellite constellations

Satellite Opportunities for MEC

Two Typologies of Services

- Onboard processing of IoT data:
 - Different sectors generating raw data for further processing on ground
 - Pre-processing of data to reduce the volume of data and identify the key information to be sent out
 - Data fusion across multiple data sources
 - Distributed data processing by means of federated learning
- Downlink of satellite native data:
 - EO images are typically in the order of several TB per day
 - Pre-processing for lower bandwidth usage
 - Reduction of the overall service delay in relation to the limited visibility of LEO satellites

Cumulative Satellite Cloud Service Revenues, 2019 - 2029

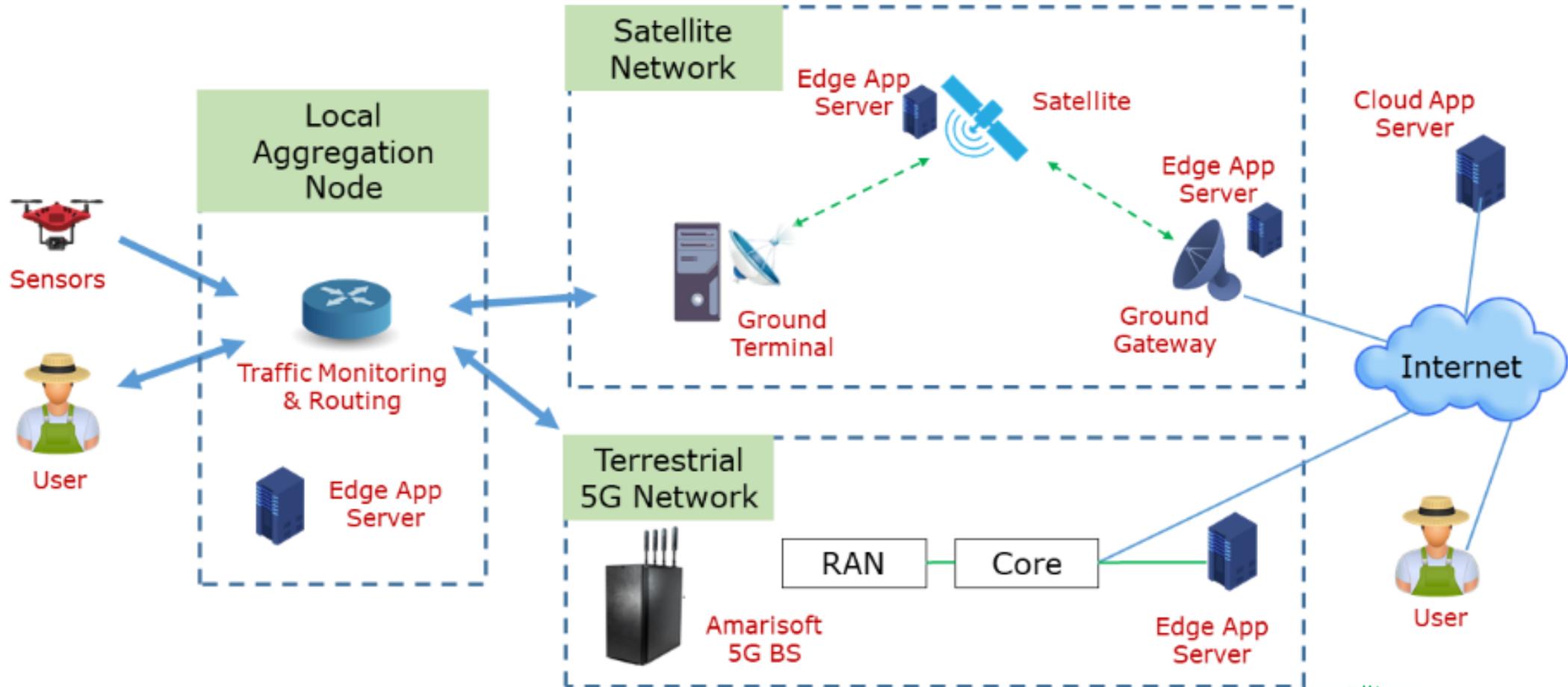


Source: NSR

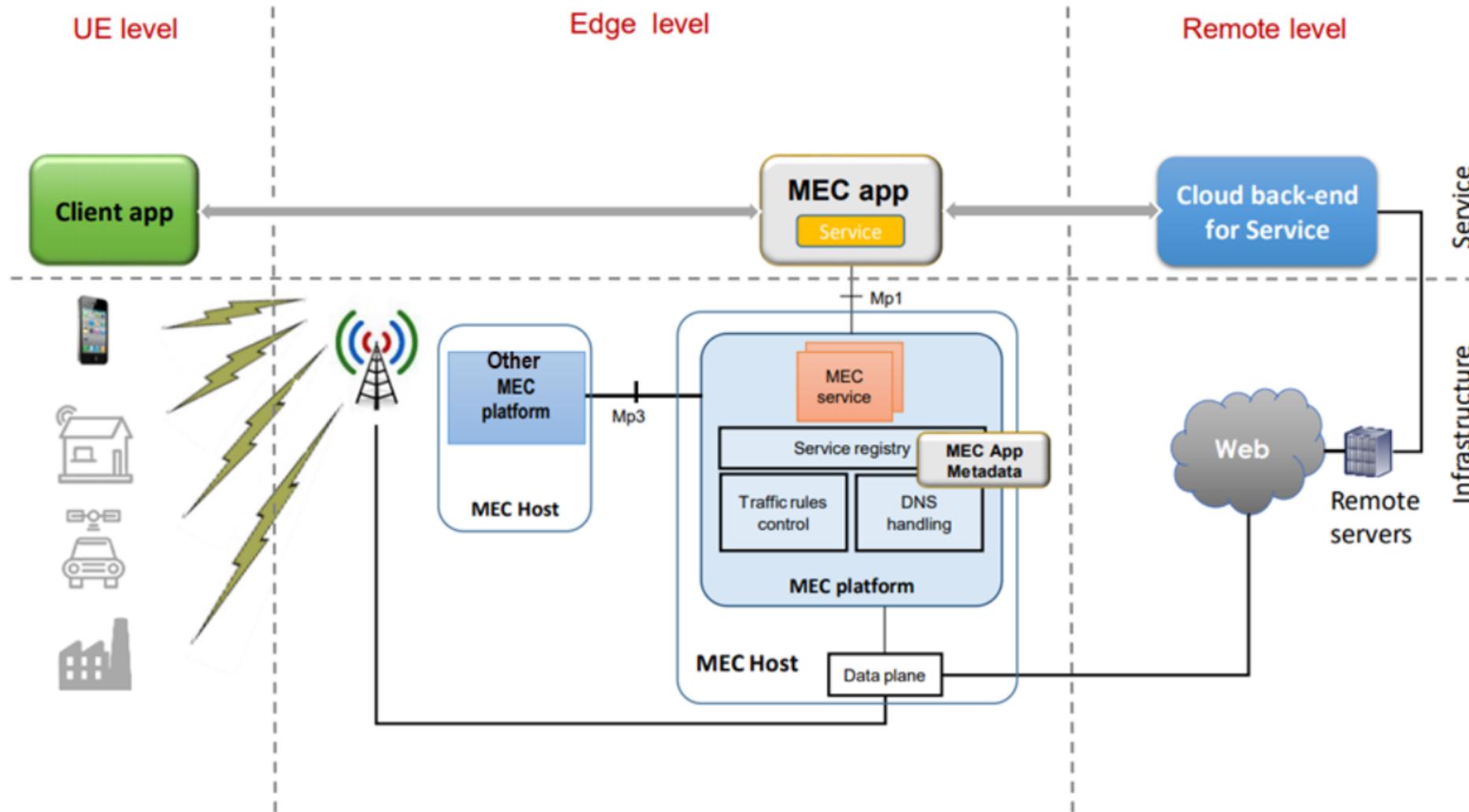
52 Exabytes cloud traffic to be transported

16 B\$ revenue expected until year 2029

A Practical Use case: smart farming

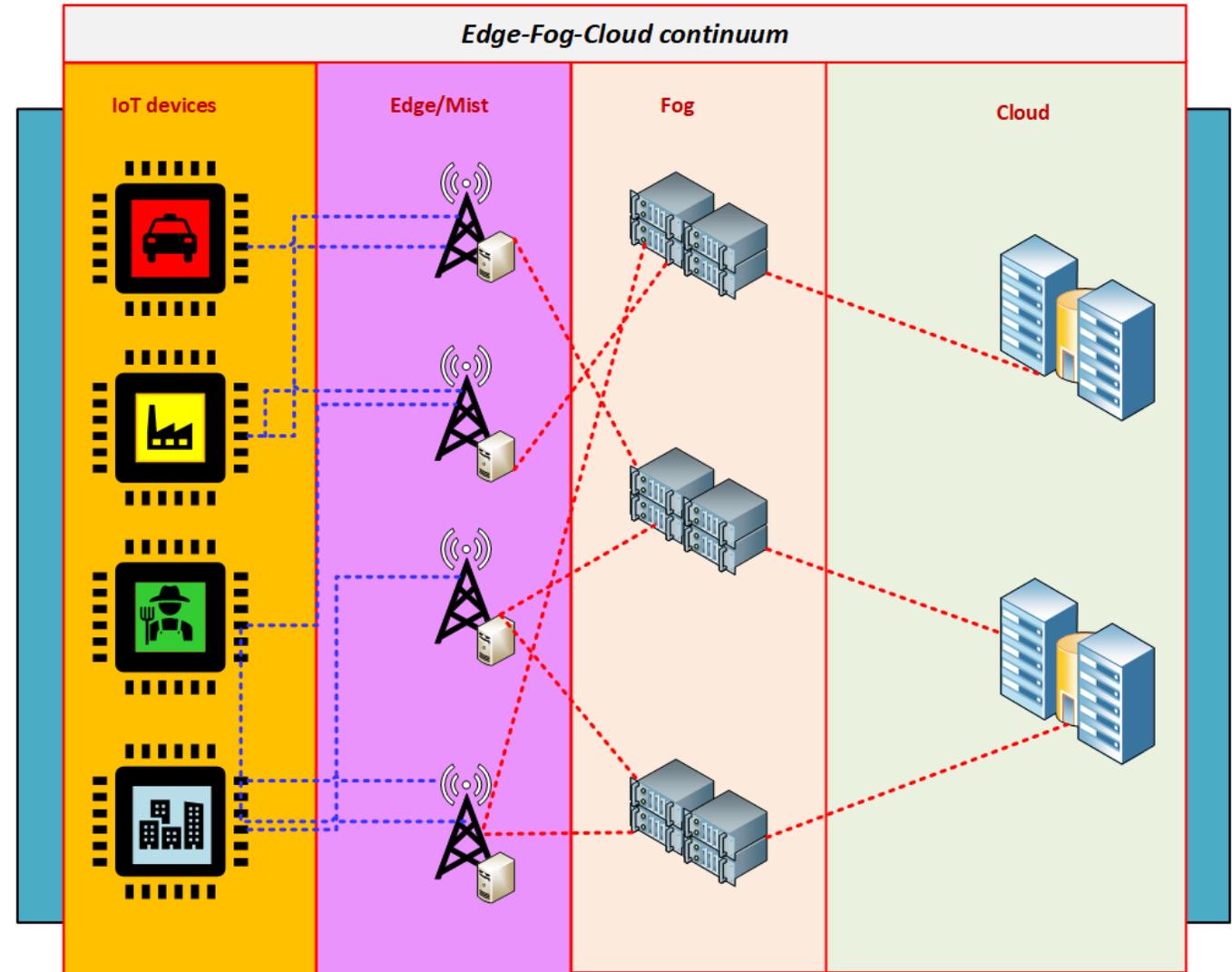


Edge Computing: The General Picture



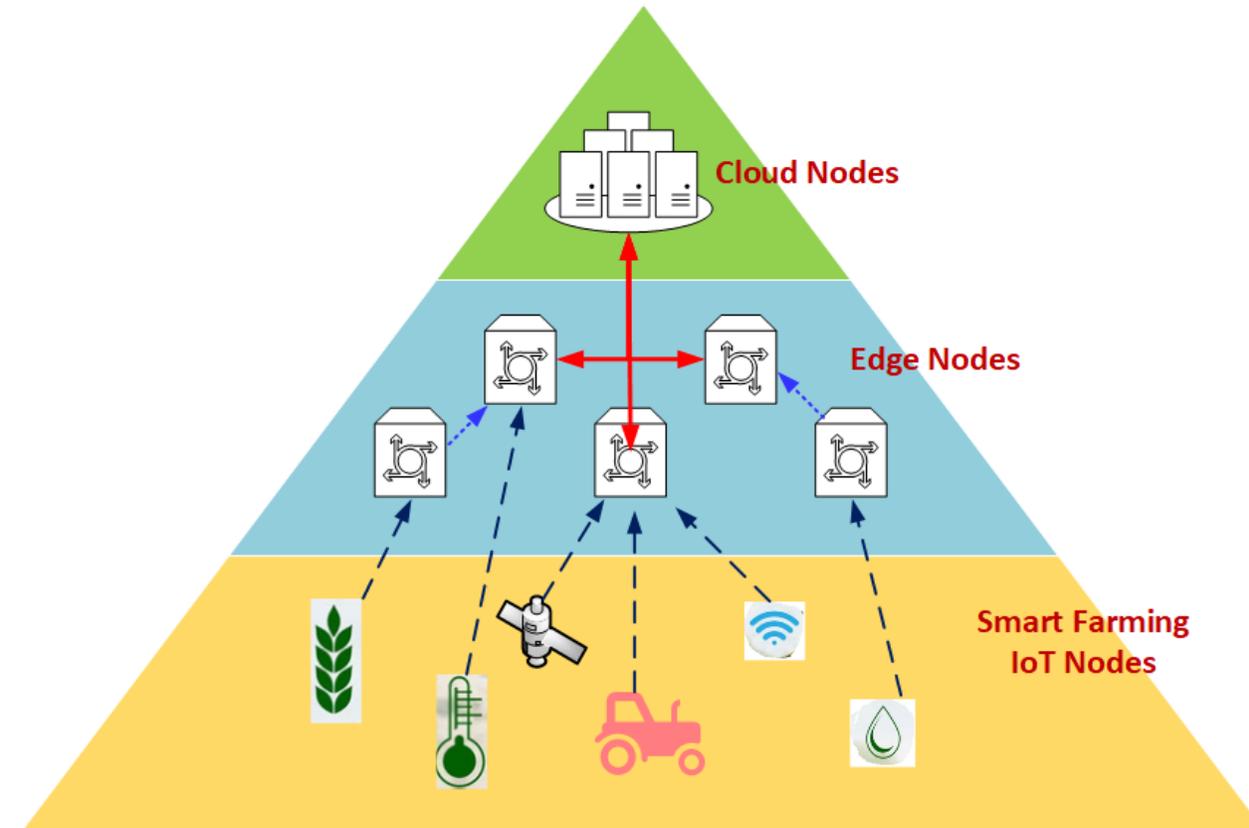
The transition to edge-cloud continuum

- Multiple verticals demanding storage and computation capabilities to the network
- Network to be intended as dense and distributed factory of services and functions
- Exploitation of edge-fog-cloud functions in a nutshell according to service availability (in time and space) and users demands

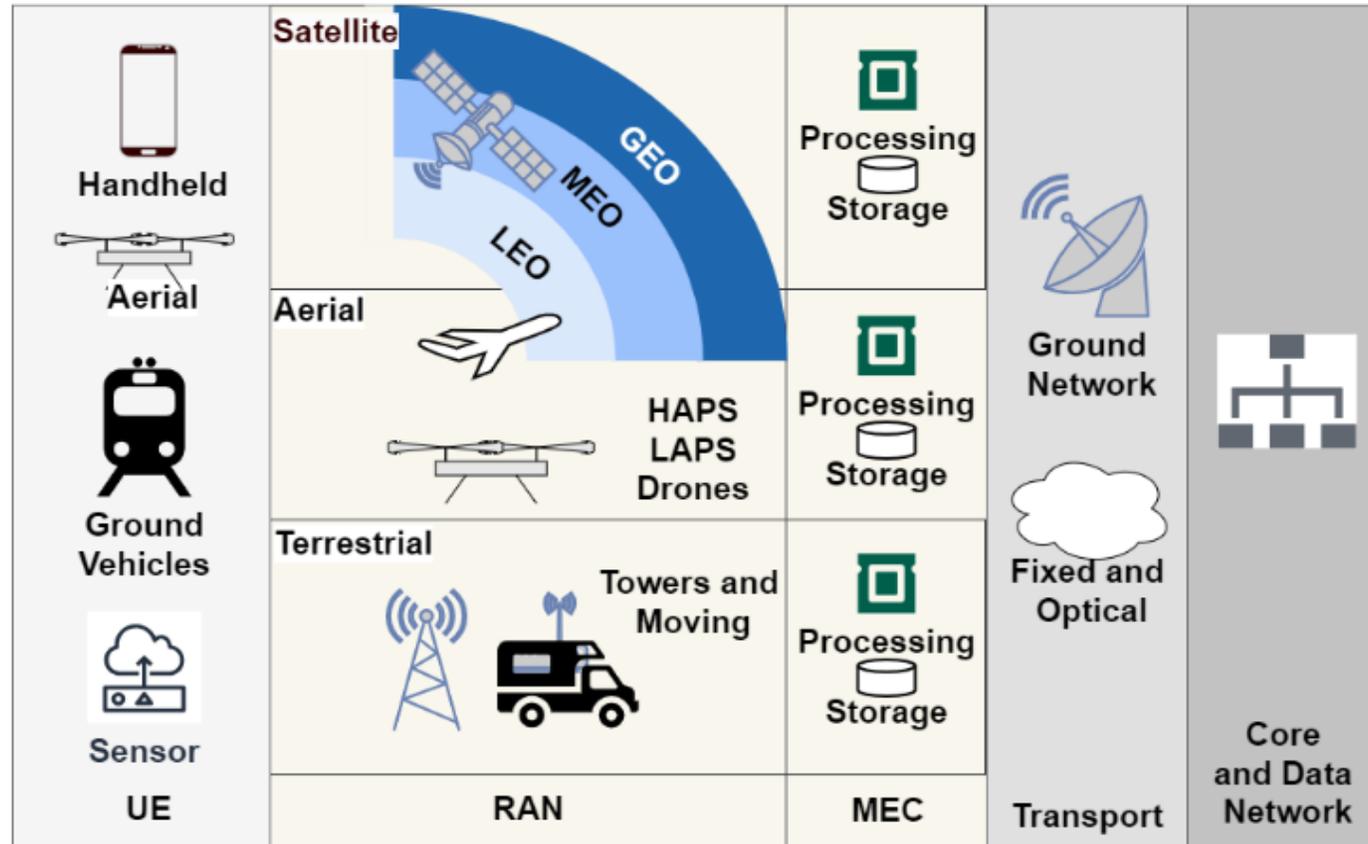


The case of NTN edge for smart farming

- Smart farming building on different assets for sensing purposes:
 - UAVs
 - On-ground sensors
 - EO satellites
- Data to be processed in smart and distributed way
 - Data filtering, fusion, processing
 - Distributed computation
 - Final results accessibility to end users themselves and to policy/decision makers acting remotely
- NTN as glue of all domains in a holistic communication and sensing distributed platform



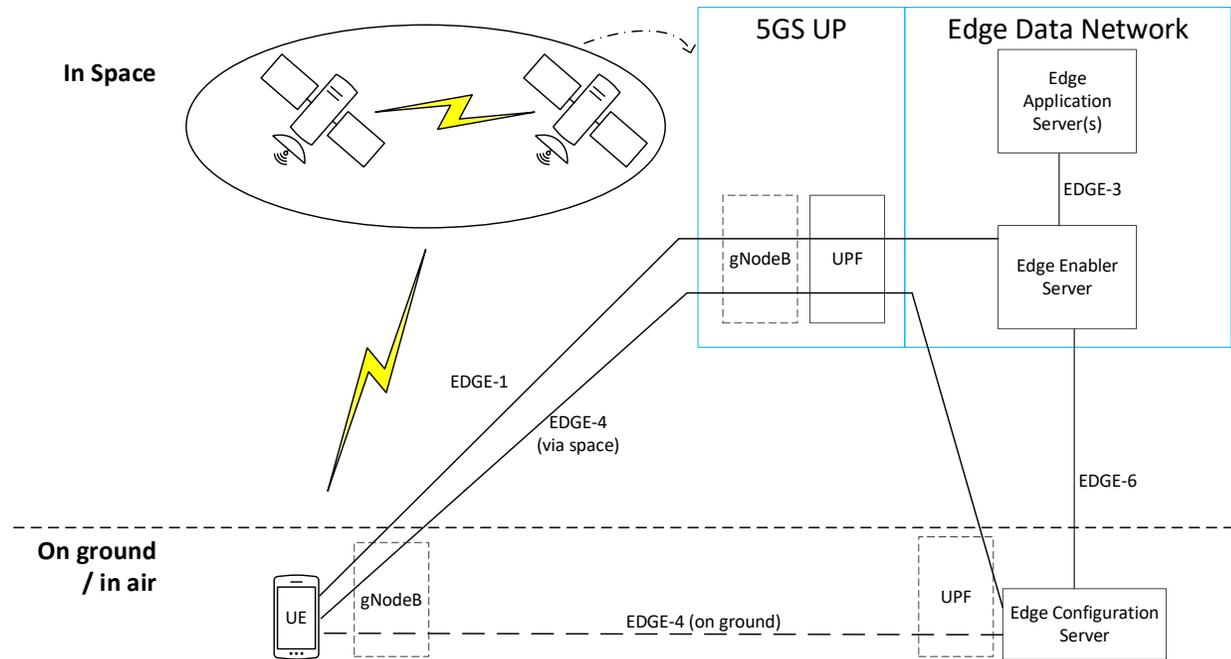
MEC-Platform Co-Located with the RAN



There are many options for MEC platform placement, we considered co-located with the gNB

Bringing services closer to the user by hosting the edge on-board flying nodes → combining benefits of NTN and MEC

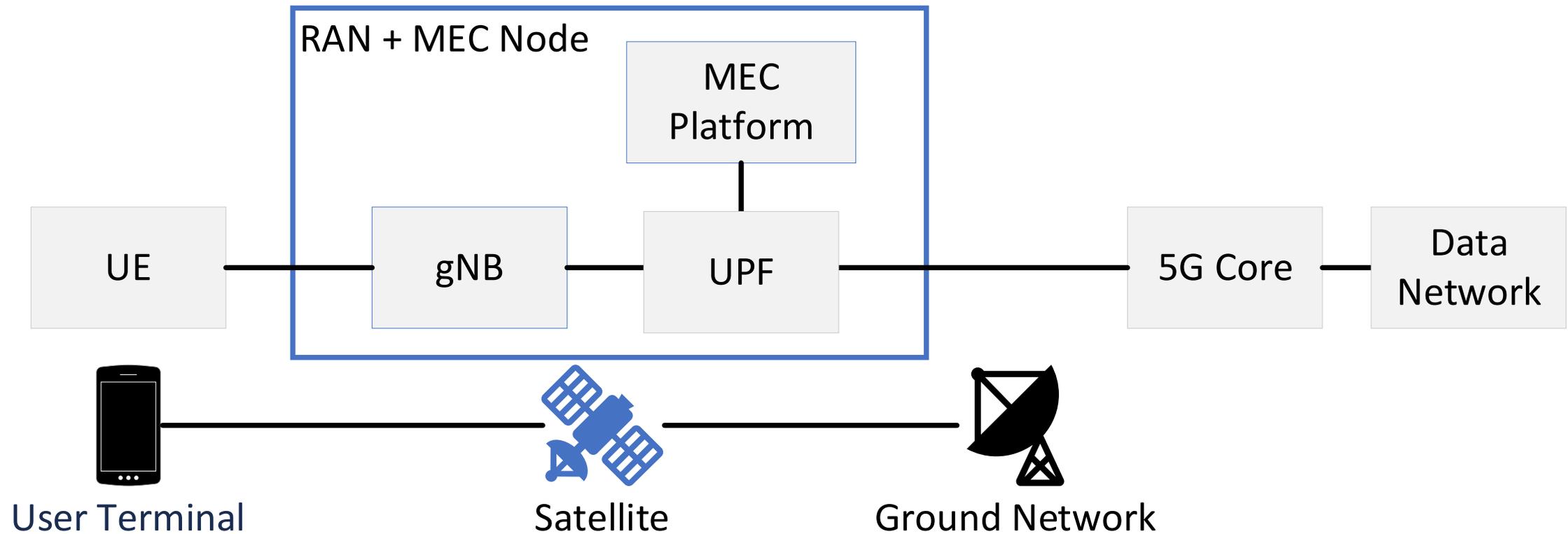
Achieving Edge Computing in 5G/6G-NTN



3GPP TR 23.700-01 Study on application enablement for satellite access enabled 5G services, Rel. 19

- Edge Application (EAS) and Enablement Servers (EES):
 - deployed in one or more satellites, constituting the Edge Data Network (EDN)
 - Multiple EESs in a satellite EDN, EEC may trigger EAS discovery towards each EES which increases delay due to EDGE-1 interactions.
 - Edge Configuration Service on ground.
- The UE can be on the ground/sea or in the air (e.g. drone).
- The UPF to access satellite EDN is deployed on satellite,
- RAN (e.g. gNB) can either be deployed on ground/sea (e.g. in a ship) and connected to satellite UPF or be deployed on regenerative satellite
- The 5GS control plane functions (e.g. AMF, SMF) are deployed on the ground

Architecture - RAN and MEC Node On-Board



Edge Computing in Space: Pros and Cons



- Though the attractive market and business opportunities, important technical challenges cannot be neglected:
 - The preferred satellite systems are LEO constellations:
 - lower delays against GEO
 - increasing appeal of mega constellations
 - Large coverage
 - Possibly lower access delays in comparison to terrestrial edge/clouds infrastructure
 - But:
 - Visibility of satellite limited to a few minutes (5-10 minutes, depending on the system geometry)
 - Terrestrial edge and cloud infrastructures are typically fixed, whereas satellites are moving assets
 - Task assignment and satellite edge state has to migrate (or has to be replicated) across multiple neighbour satellites
 - Computing, storage, and power availability onboard satellites is limited
 - Satellites resources cannot be fully dedicated to specific edge computing tasks but must be shared across multiple services

Edge Computing in Space: Networking Challenges



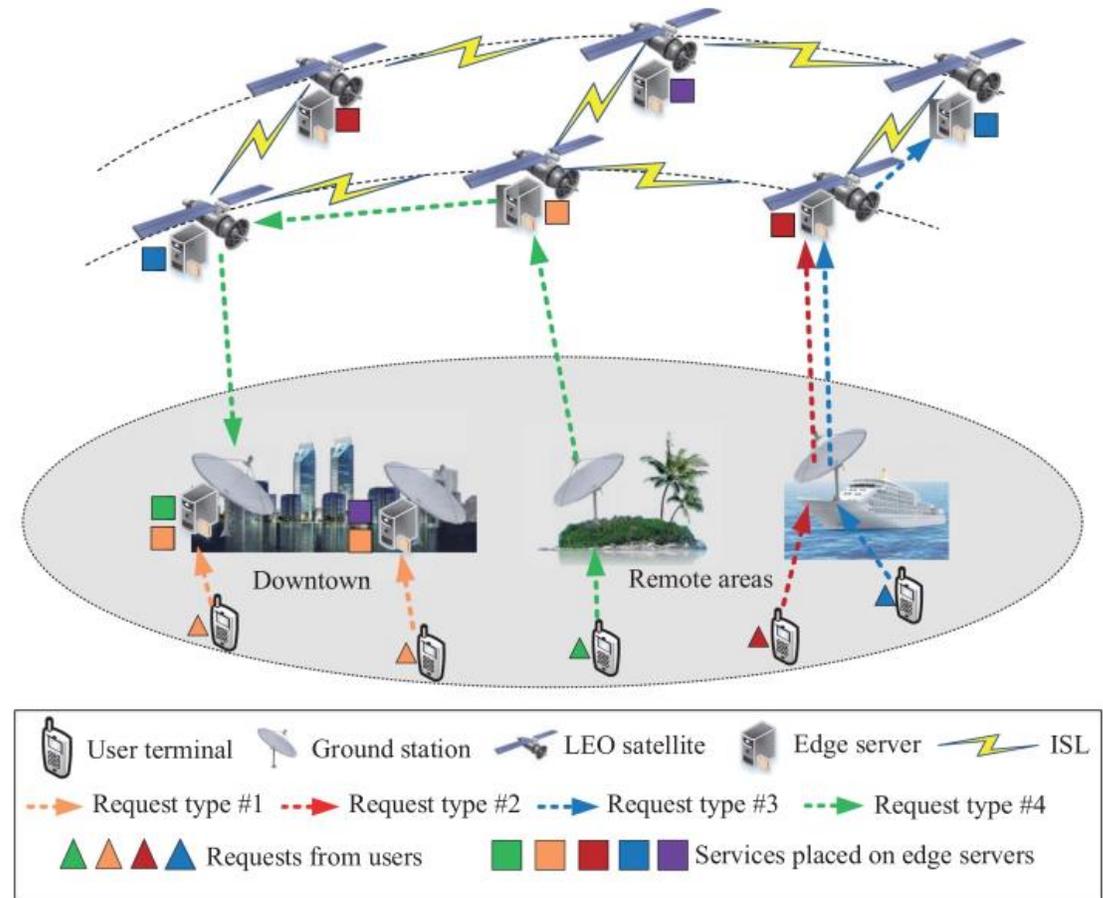
- MEC implementation in space implies:
 - Coordination between different space assets
 - Routing across the available inter-satellite links
 - Load-aware offloading processes
 - Flow and congestion control across terrestrial and space networks
 - Server assignment for task execution
 - Avoid network instability because of sudden or continuous route changes or task assignments
 - Network orchestration to interact with edge computing, which is not an easy task because of the distributed nature of LEO constellations
 - Service and MEC host discovery

- Additional considerations:
 - Satellite constellations are most of the time inactive because they traversing inhabited areas (e.g., oceans):
 - As such, this time they are idle could be exploited for edge computing functionalities or for state migration by means of inter-satellite links

D. Bhattacharjee et al., "In-orbit Computing: An Outlandish thought Experiment?" In Proceedings of the 19th ACM Workshop on Hot Topics in Networks (HotNets '20).

Service and server association in space

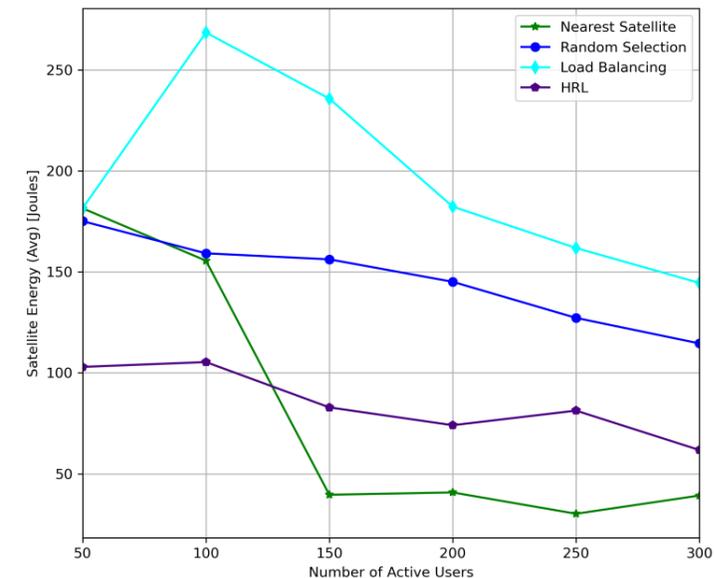
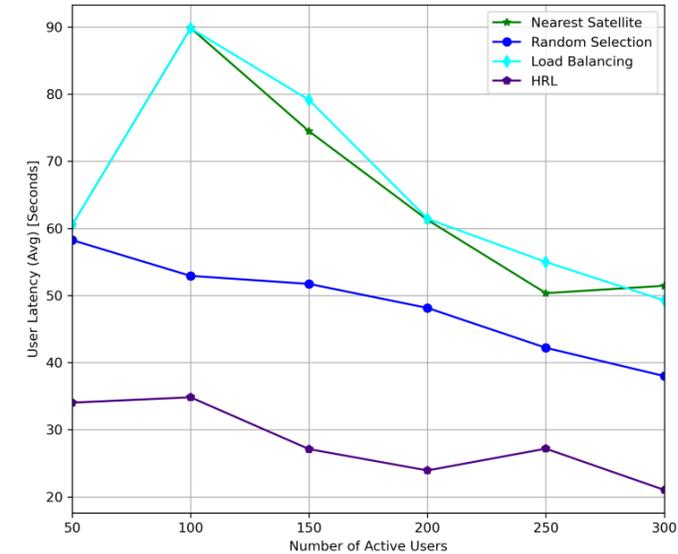
- One of the main problems is map users demands in terms of computing tasks to servers in space.
- Key aspects:
 - Several servers, but different services available in space
 - Computation and storage availability dynamically varying over time and space
 - Association between users and servers is not continuous because of satellite movement
 - Task forwarding in space through ISL appealing, either through routing or by means of MEC-to-MEC engines



T. De Cola et al., „Joint Optimization of Server and Service Selection in Satellite-Terrestrial Integrated Edge Computing Networks,“ IEEE TVT, Feb. 2024, vol. 73, no. 2, pp.2740-2754

Performance optimisation: a study case

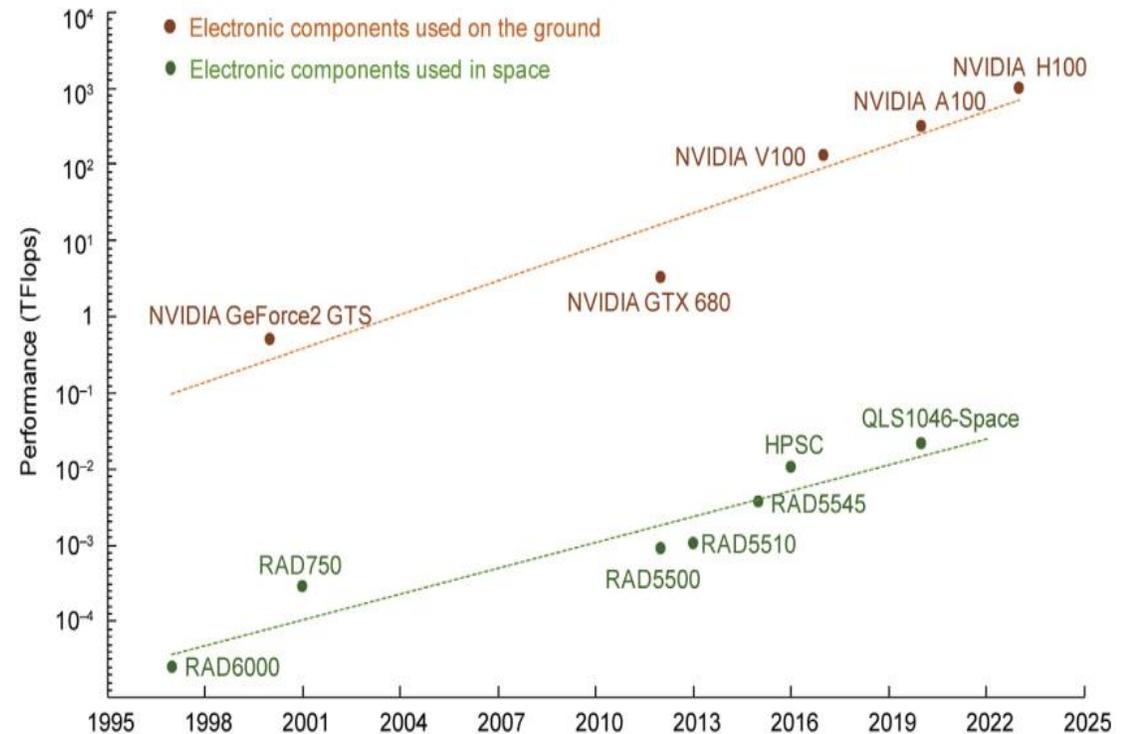
- Optimisation of service delay and energy efficiency
- Main KPI and attributes to be considered:
 - Delay components: communication and computation
 - Energy components: communication and communication
 - Limited power budget
 - Limited onboard storage capacity
- Several allocation strategies possible
 - Random user-to-server mapping
 - Nearest-satellite
 - Load balancing in space
 - Capacity achieving in space
 - Hierarchical reinforcement learning



D. Tarchi et al., „In-Space Computing for IoT Data Processing via Low Earth Orbit Satellites,“ IEEE ICC, Worskhop on Mega Constellations, Jun. 2025, Montreal, Canada

New trends and challenges

- Increasing interest towards more computation and intelligence capacity in space
- Limitation coming from space assets from power and storage capability
- Not immediate to simply transfer terrestrial deployments to space



Y. Liu, „Computing over Space: Status, Challenges, and Opportunities,“ Elsevier, Engineering 54 (2025) 20–25

But...

IEEE Spectrum

Q Type to search

NEWS COMPUTING

Nvidia Sends a Powerful GPU to Space >

The computer will serve as a test of satellite-based data centers

BY TEREZA PULTAROVA | 03 NOV 2025 | 4 MIN READ |
Tereza Pultarova is a London-based journalist

INNOVATION • GOOGLE

Google CEO Sundar Pichai says we're just a decade away from a new normal of extraterrestrial data centers

By **Sasha Rogelberg**
Reporter

December 1, 2025, 1:25 PM ET

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The New York Times

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Even the Sky May Not Be the Limit for A.I. Data Centers

Some tech leaders are concerned that the artificial intelligence race will exhaust available land and energy. The solution might lie in orbit.



Google CEO Sundar Pichai said the company will launch a prototype satellite to test AI hardware in space in 2027.

And still.....

- Despite the technical appeal, several debates on the potentials of data centers in space:
 - Really the holy-grail for cloud/edge computing?
 - Moving datacenters in space solves the problem of water-based cooling on ground, but what about heat dissipation in space?
 - Trade-off between business exploitation and general performance achievement?

If Datacenters Go to Space, Heat Becomes the Hardest Problem

by Garrett Abare | | Artificial Intelligence, Die Cutting, Electrical Insulators, Tech Blog, Thermal Pads, Waterjet Cutting

Every few years, an idea resurfaces that sounds futuristic enough to dismiss at first pass: *datacenters in space*.

The knee-jerk reaction is predictable—*space is freezing, so cooling must be easy*. But that intuition is exactly wrong. Once you strip away that misconception, the entire concept collapses into a single, unforgiving constraint:

Heat rejection.



Conclusions

- MEC is a central part of B5G ecosystems and will be pivotal towards the emergence of new services and consolidation of existing ones
- MEC is expected to be a satellite performance booster, not only in the sense of caching capabilities for eMBB services but also in terms of edge computing for mMTC services
- Extension of traditional satellite concept towards 3D-satellite systems also integrated with other aerial systems can represent the new horizon for the implementation of MEC in space:
 - Advantages: availability of satellite onboard processing capabilities and inter-space links for a distributed MEC architecture
 - Challenges: definition of new (or updated) networking strategies able to scale in-network computing capabilities over a large reach, from terrestrial infrastructure up to space systems



(courtesy of New York Times)