Communication Systems for Future Airborne/Spaceborne Networks

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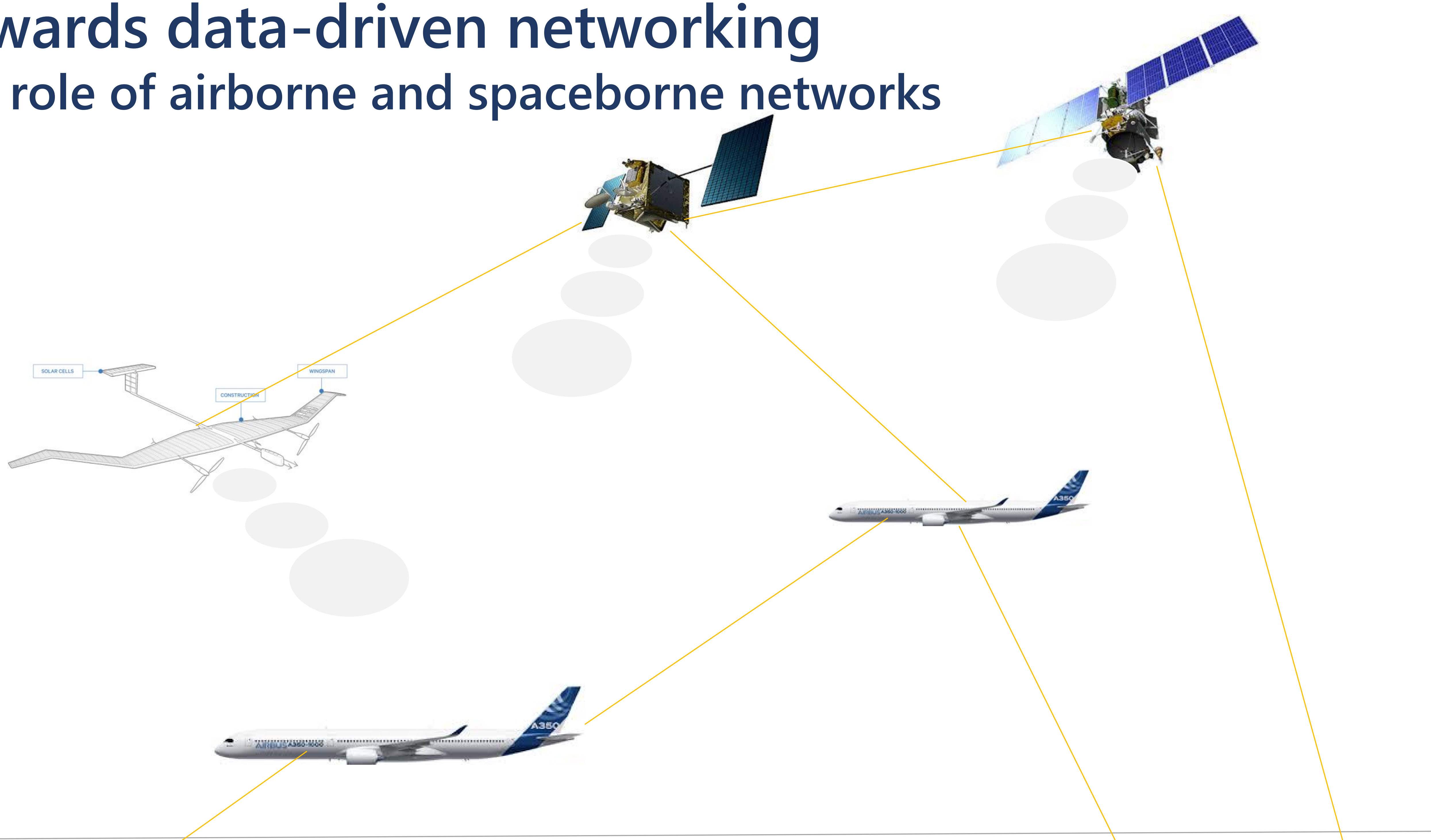
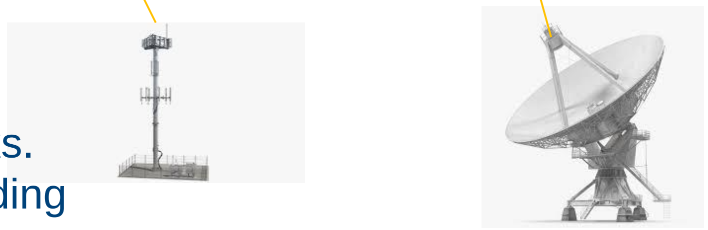
The World is getting more… data-driven

It is widely recognized that the **world** is increasingly **data-driven, cloud-based** and **transnational**, creating an increasing demand to move large quantities of data quickly and securely around the globe.

- Data usage has drastically increased in the last 10 years
- More data created in the past two years than ever before
- 2015: barrier of 1 Zeta Byte of global traffic undertaken.
- Forecast: data demand to grown exponentially

Towards data-driven networking
The role of airborne and spaceborne networks



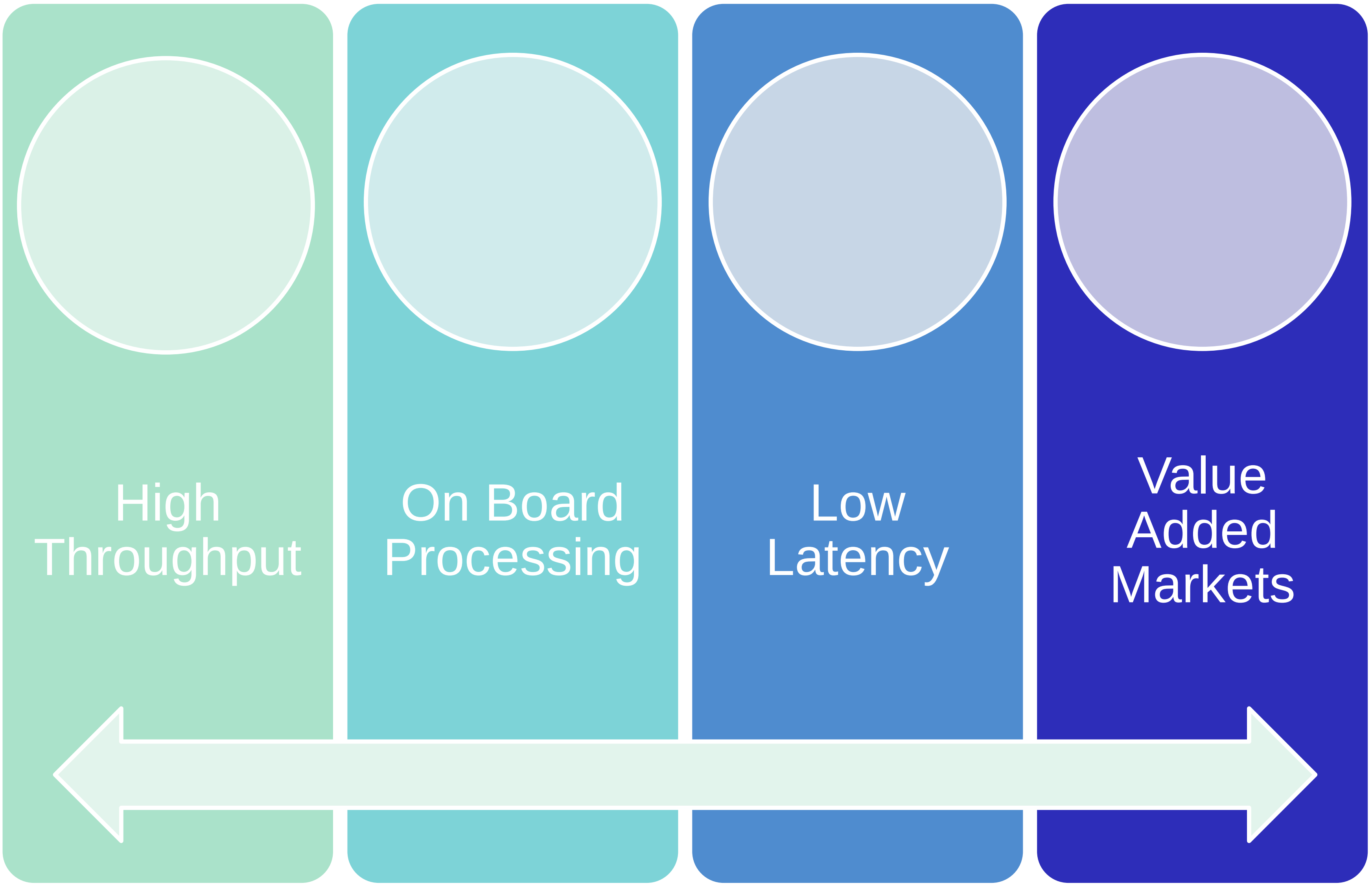


Airborne/Spaceborne networks:

- Aircraft within communication range connect with each other using laser links.
- Aircraft density is sufficiently high → mesh networks between aircrafts including High-altitude platform stations (HAPS), and communication satellites.
- Access to online content available via multi-hop transmission.
- Data sharing between aircraft, even without internet access.

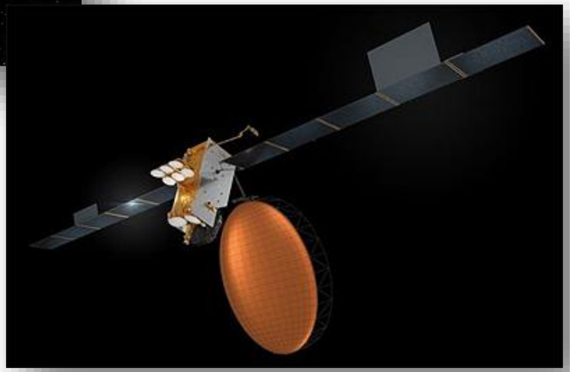
Airborne and Spaceborne Internet

Drivers for global data services



On-board routing and switching + multi-beam technology + free space optics

Airborne and Spaceborne Internet
On board processing



Example:
•Eutelsat Quantum
•Inmarsat-6

Regenerative Payloads

- Signal is demodulated, decoded, re-encoded and modulated aboard the satellite.
- On-board processing: e.g. switching packets based on MPLS or IP routing.
- In-orbit data caching may also be considered.
- Advantages: efficient channelization, routing capabilities.
- Disadvantages: more complex; use power also to process signals.

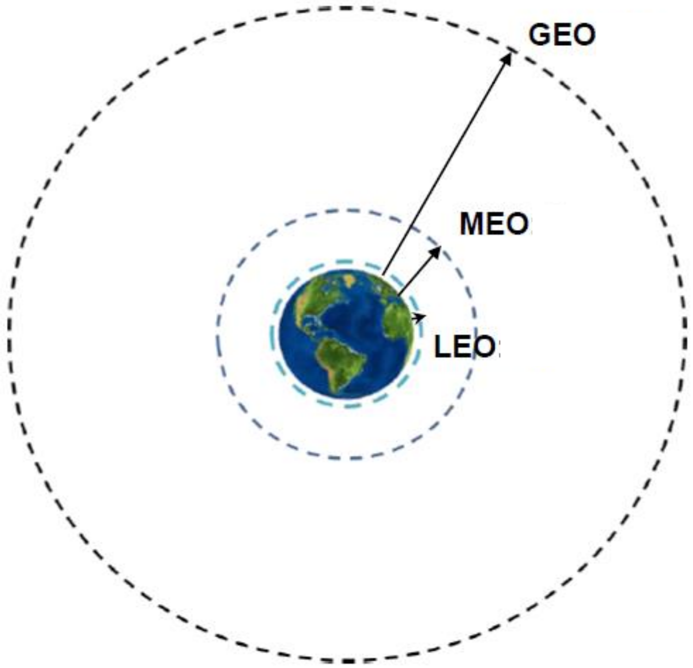
Software Defined Flexible Payloads

- Reprogrammable features to address dynamic markets.
- Dynamic beam shaping and tracking capabilities.
- Design for wide-area networks and dynamic traffic shaping.
- Rapid response for public protection and disaster recovery.

Perspective for the integration with terrestrial networks:

- Higher flexibility on resource allocation.
- Possibility to embed a 5G gNB or gNB DU into a satellite.
- SDN and NFV will significantly reduce the risk of updated orbiting systems.

Airborne and Spaceborne Internet
Latency matters



- Satellite networks:
  - The closer to earth, the less latency there is.
  - LEO satellites orbiting the earth at around 1,500km → 25 times closer than GEO satellites (36,000km) and 5 times closer than MEO satellites (8,000km)
  - *Case: LEO for data networking becomes compelling, bring latency to value around 12 ms.*

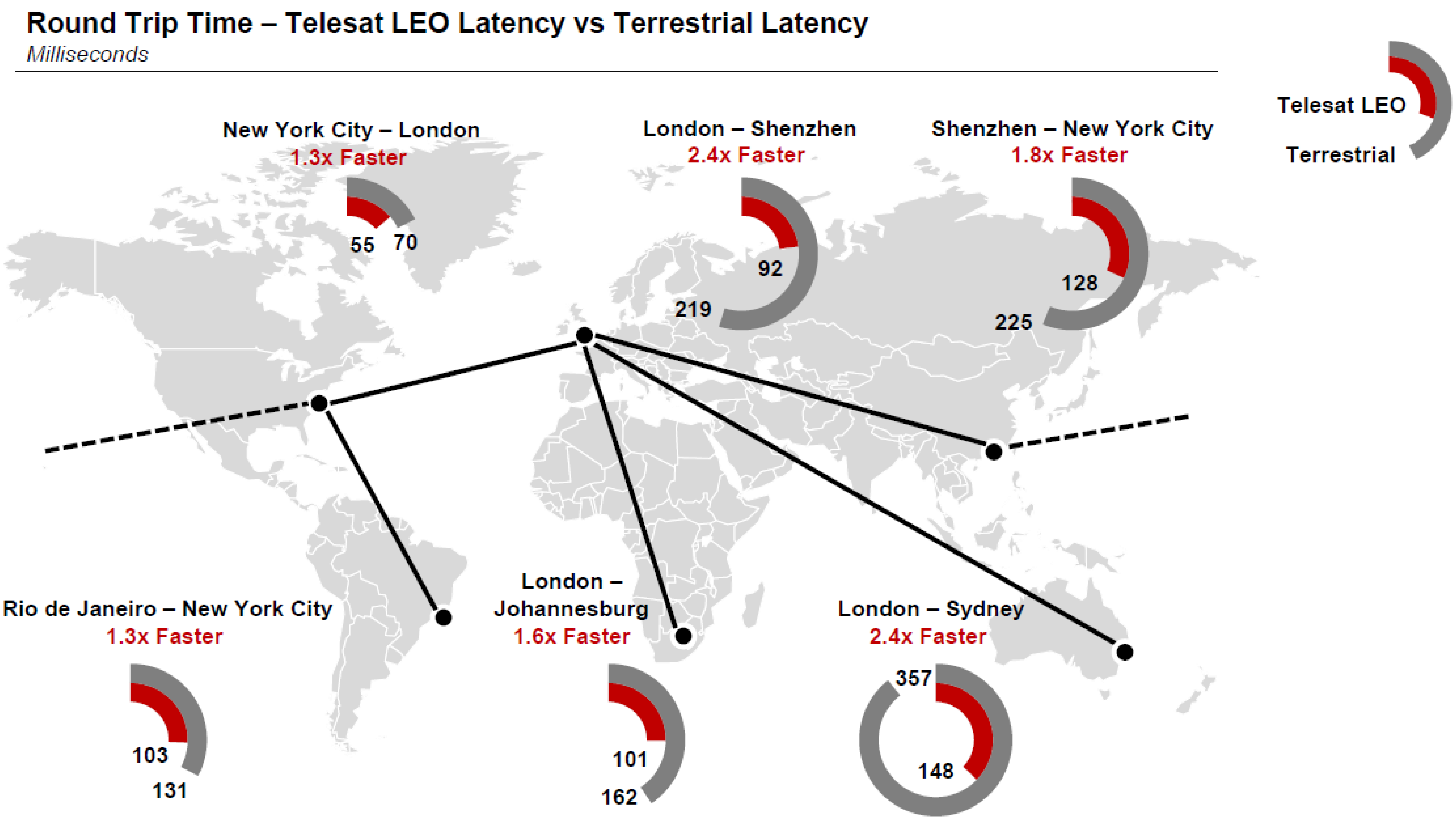
    → 5 ms when the satellite is in a 90 degree angle.

		LEO at 600 km		LEO at 1500 km		MEO at 10000 km	
Elevation angle	Path	Distance D (km)	Delay (ms)	Distance D (km)	Delay (ms)	Distance D (km)	Delay (ms)
UE: 10˚	satellite - UE	1932.24	6,440	3647.5	12,158	14018.16	46.727
GW: 5˚	satellite - gateway	2329.01	7.763	4101.6	13.672	14539.4	48.464
90˚	satellite - UE	600	2	1500	5	10000	33.333
Bent pipe satellite							
One way delay	Gateway-satellite_UE	4261.2	14.204	7749.2	25.83	28557.6	95.192
Round Trip Delay	Twice	8522.5	28.408	15498.4	51.661	57115.2	190.38
Regenerative satellite							
One way delay	Satellite -UE	1932.24	6.44	3647.5	12.16	14018.16	46.73
Round Trip Delay	Satellite-UE-Satellite	3864.48	12.88	7295	24.32	28036.32	93.45

3GPP TR 38.811 V15.0.0 – Study for New Radio (NR) to support non terrestrial networks (Release 15)

Typical LEO attitudes on range of (600-1200) km at low elevation of (0-10) º → fraction of Earth covered = 1.69% to 7.95%.

Airborne and Spaceborne Internet
Leveraging inter-satellite links



Telesat LEO simulations of traffic moving over only inter-satellite links
Round-trip time at the network layer including processing latency for system and inter-satellite links.

Airborne and Spaceborne Internet
Value added markets

- Standard-based approach → LEOs, HAPS, aircrafts becoming / may become a core component in the telecommunication infrastructure.
- Integration into cellular networks will increase role in core markets such as IoT and M2M, while fulfilling the 5G Vision.

Cellular

Backhauling and Fronthauling

Government Enterprise

Secure communications

- Security and resilience are key attributes with a 'touchless airborne network'.
- Carrying traffic between any points on earth without touching the earth's surface (isolated from any terrestrial infrastructure).

- Narrowband services means bi-directional communication (e.g. for firmware updates, monitoring).
- As IoT visions such as "smart cities" become more widely deployed, high performing LEO constellations will be a cost-effective way to connect devices.

Industry 4.0

Monitoring and operating remote equipment

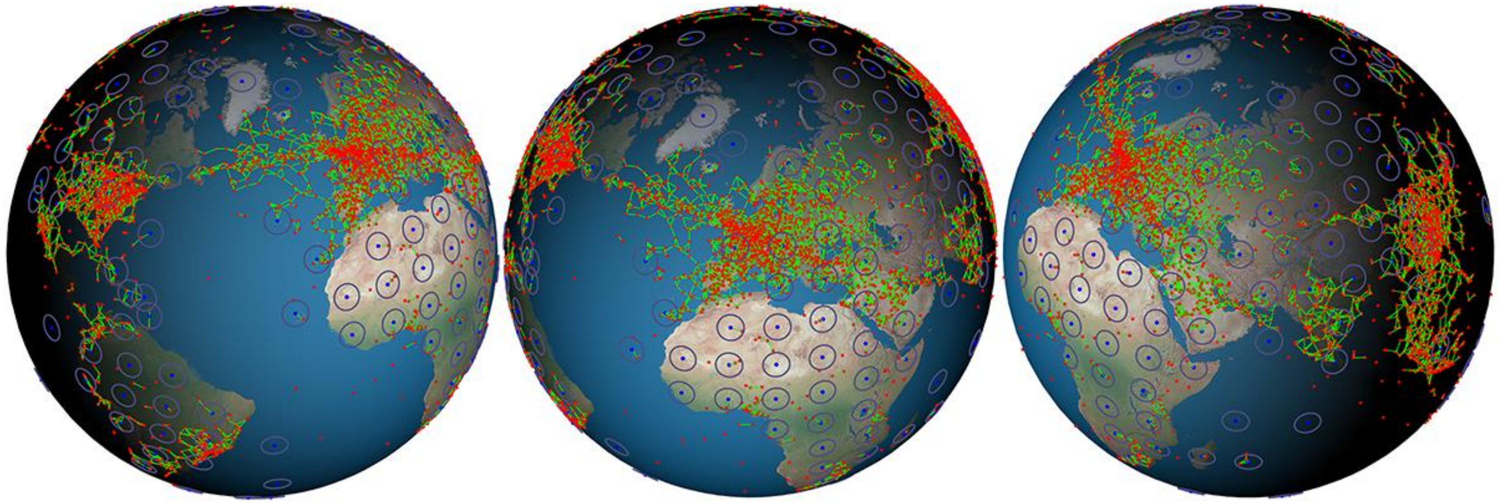
Connected Mobility

Connected

Vehicles

Autonomous vehicles

- Airlines, and cruise lines are demanding for more bandwidth for consumer devices and for Internet access anywhere.
- Autonomous vehicles require frequent upgrades independently of their location.

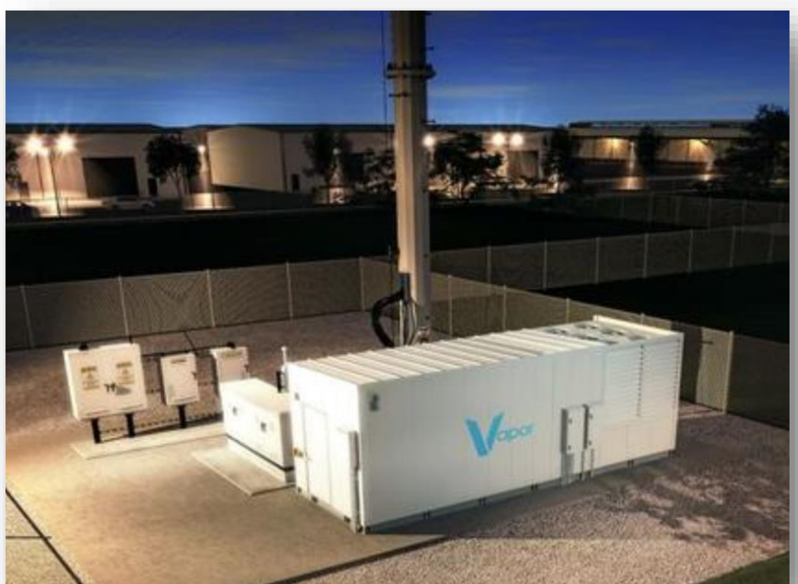


Airborne and Spaceborne Internet

Support for efficient Edge Computing

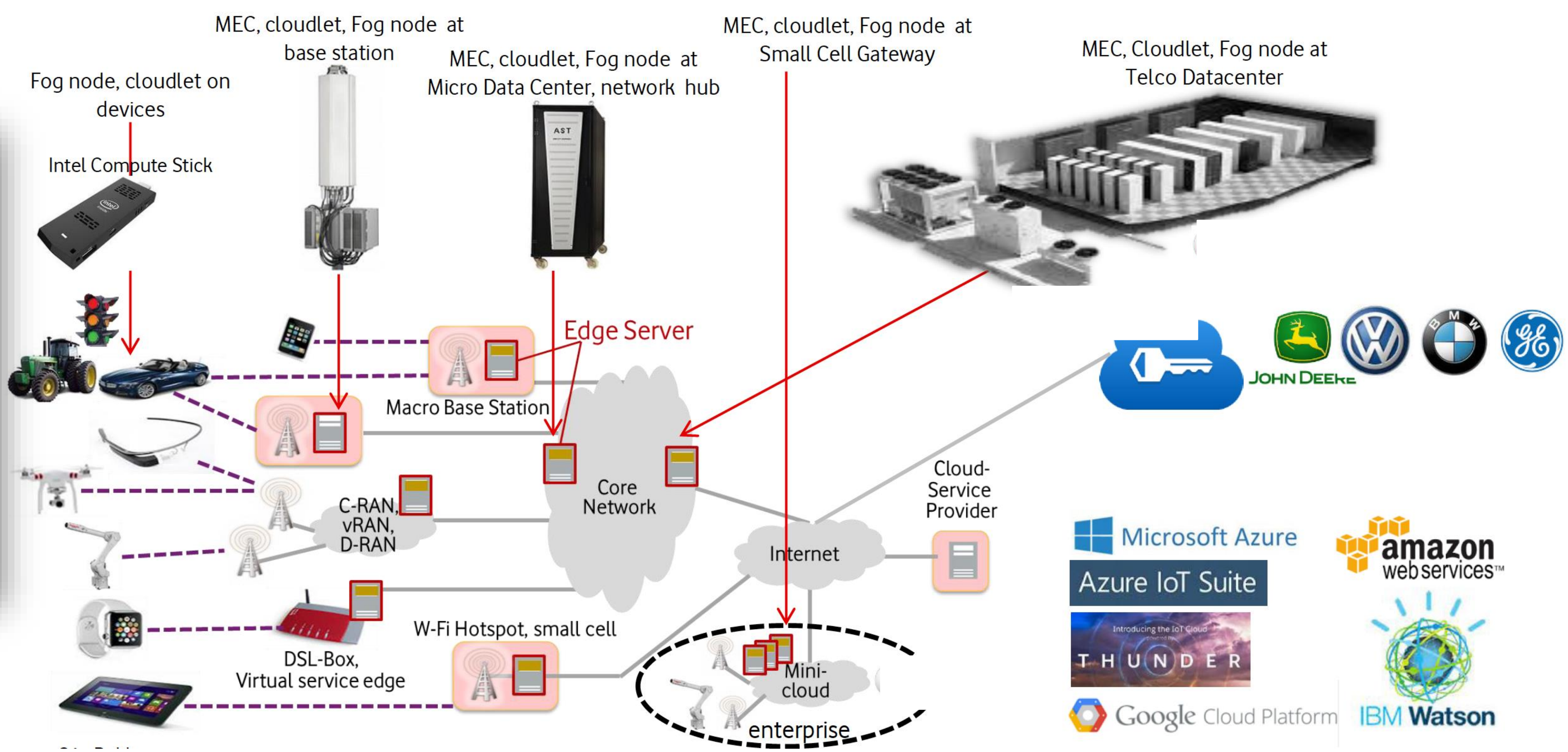
Where is the Edge?

The edge is a (set of) networked nodes
where computational and storage resources may be
accessed in the short time frame.



by Vapor IO

Kinetic Edge micro data center operating alongside a cellular tower.

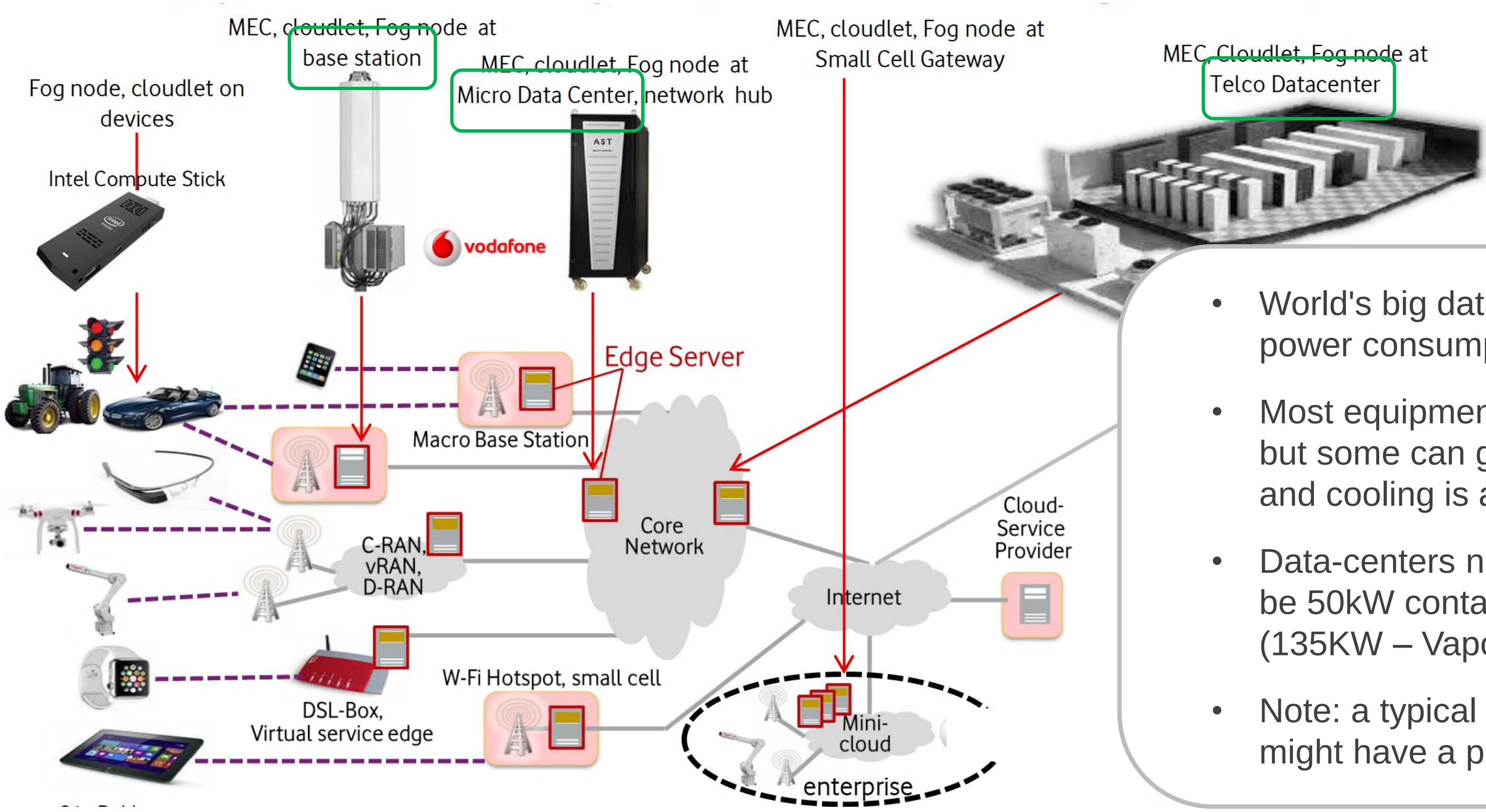


by Vodafone

Airborne and Spaceborne Internet
Support for efficient Edge Computing

Edge Capacity: Power perspective

Milliwatts at one end of distributed computing (devices), and gigawatts at the other (cloud).



- World's big data centres have a total power consumption of about 100GW.
- Most equipment racks use 3-5kW, but some can go to 20kW if power and cooling is available.
- Data-centers near cell towers might be 50kW container sized units (135KW – Vapor IO).
- Note: a typical macro-cell tower might have a power supply of 1-2kW.

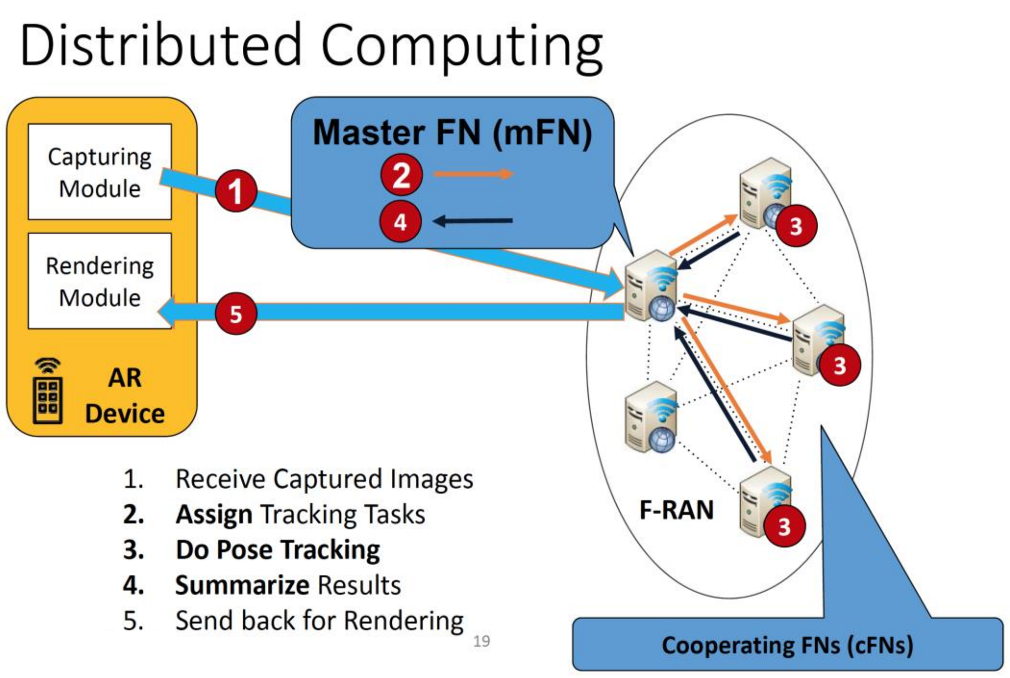
Rough calculation:

Total realistic "network edge" will account for less than 1% of total aggregate computational capability.

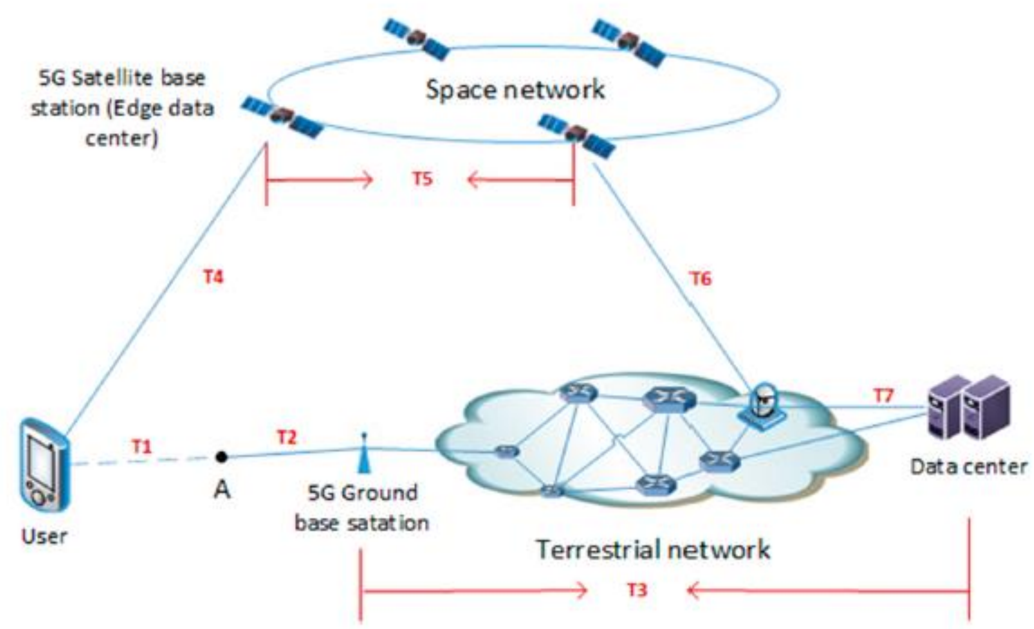
Airborne and Spaceborne Internet
Support for efficient Edge Computing

Mitigate the low capacity at the edge

Orchestration of a large number of edges (at base stations)



Rely on a lower number of higher power edges (at micro data centers)

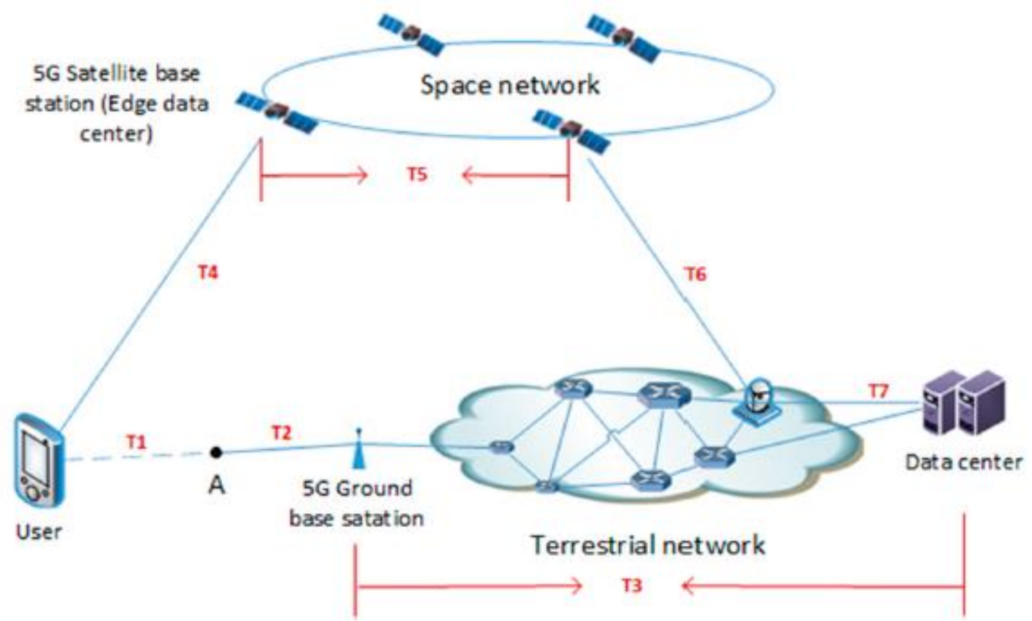


Airborne and Spaceborne Internet

Support for efficient Edge Computing

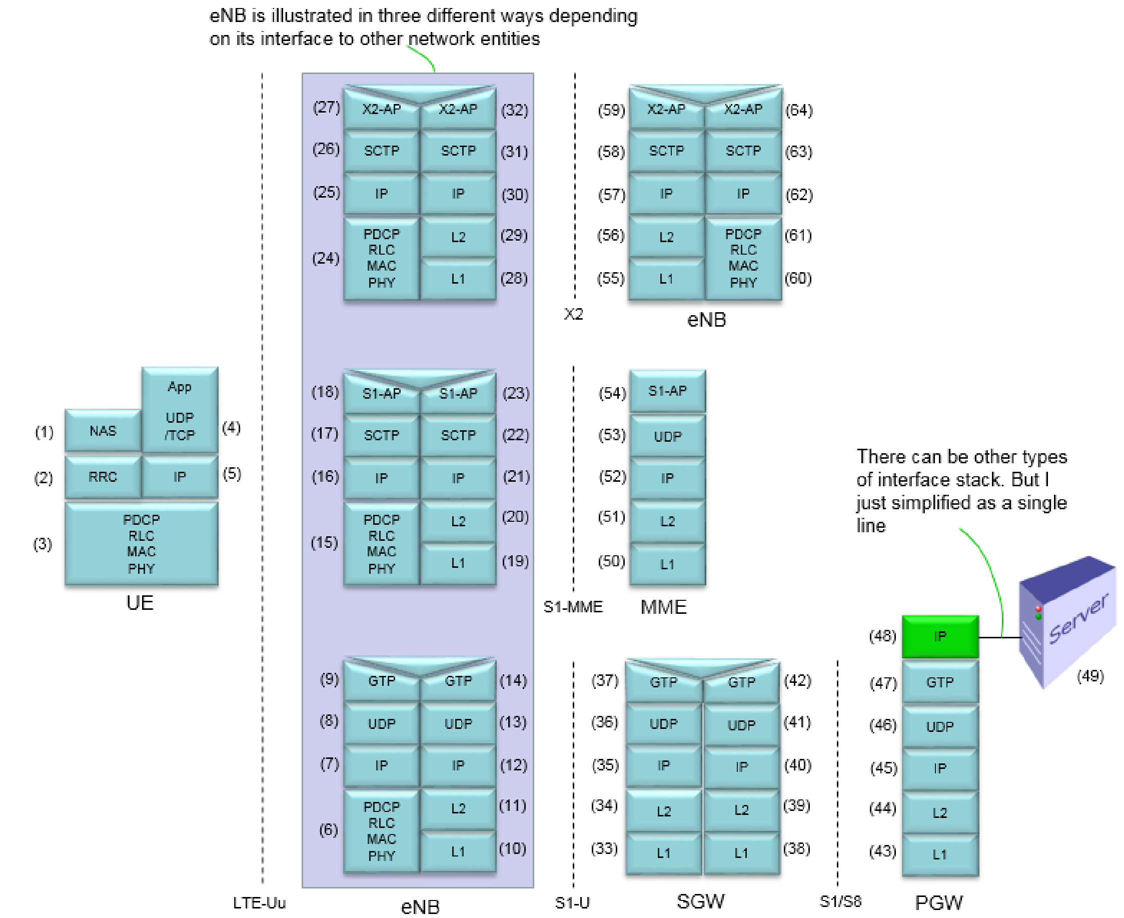
Mitigate the low capacity at the edge

Higher distance between network equipment, but potentially lower processing delay



Delay values may be in the order of 50ms, with single LEO satellite

Lower distances between network equipment, but potentially higher processing delay



In live network test, the delay value may be easily reach 50 ms and even 100 ms.

Difference can be higher in a edge-to-cloud scenario

Latency over larger distances (>3000Km) towards cloud centers < than terrestrial fiber optics

Airborne and Spaceborne Internet
Support for efficient Edge Computing

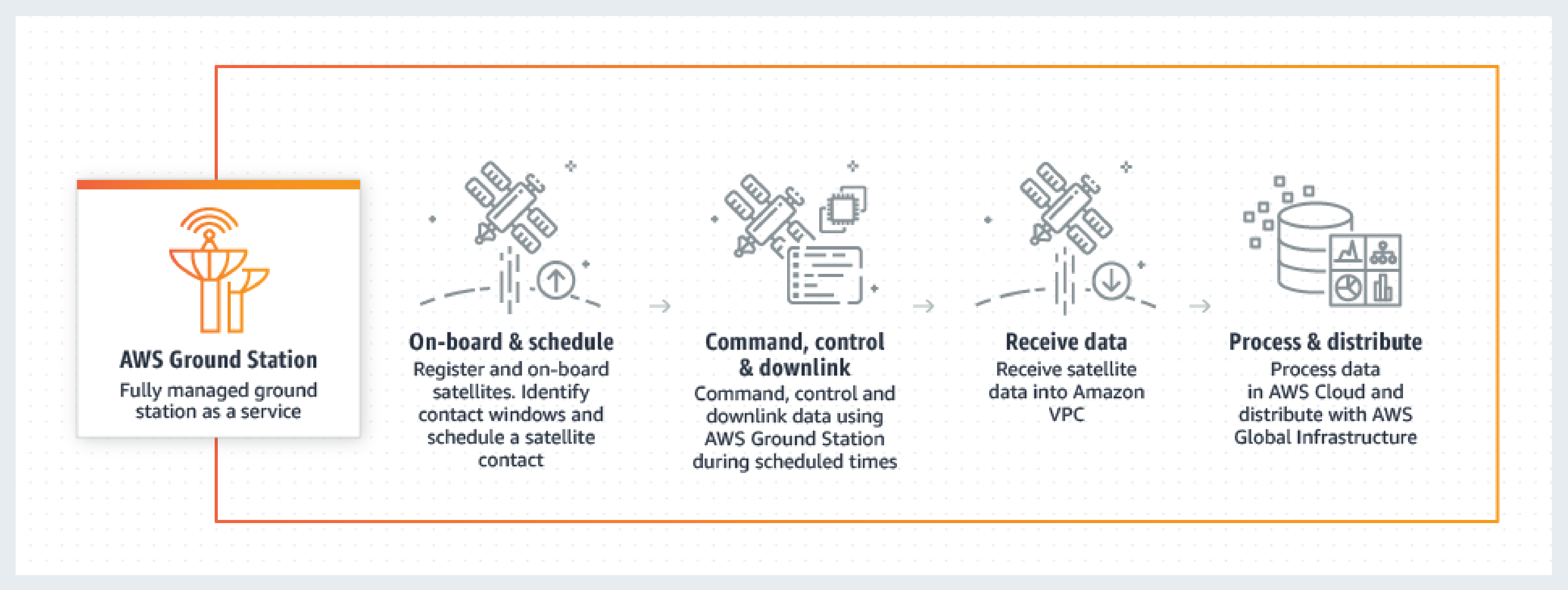
Amazon

- AWS Ground Stations: 12 parabolic antennas installed at Amazon's global regions.
- Plus lower-cost antennas spread across other areas:

•Allows for more connectivity and more opportunities to downlink data.

•Repaves the playing field for sorting out edge computing problems.

- All of this is available to customers as a service, so you're only paying for it when you're using it.

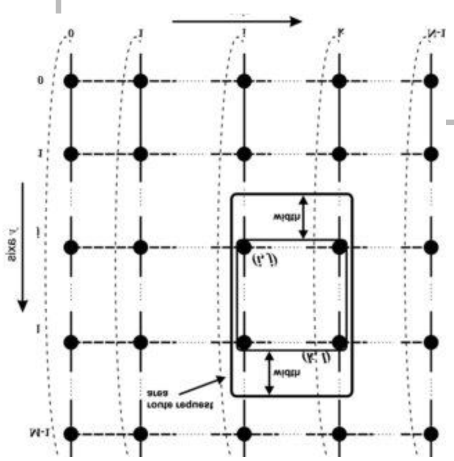


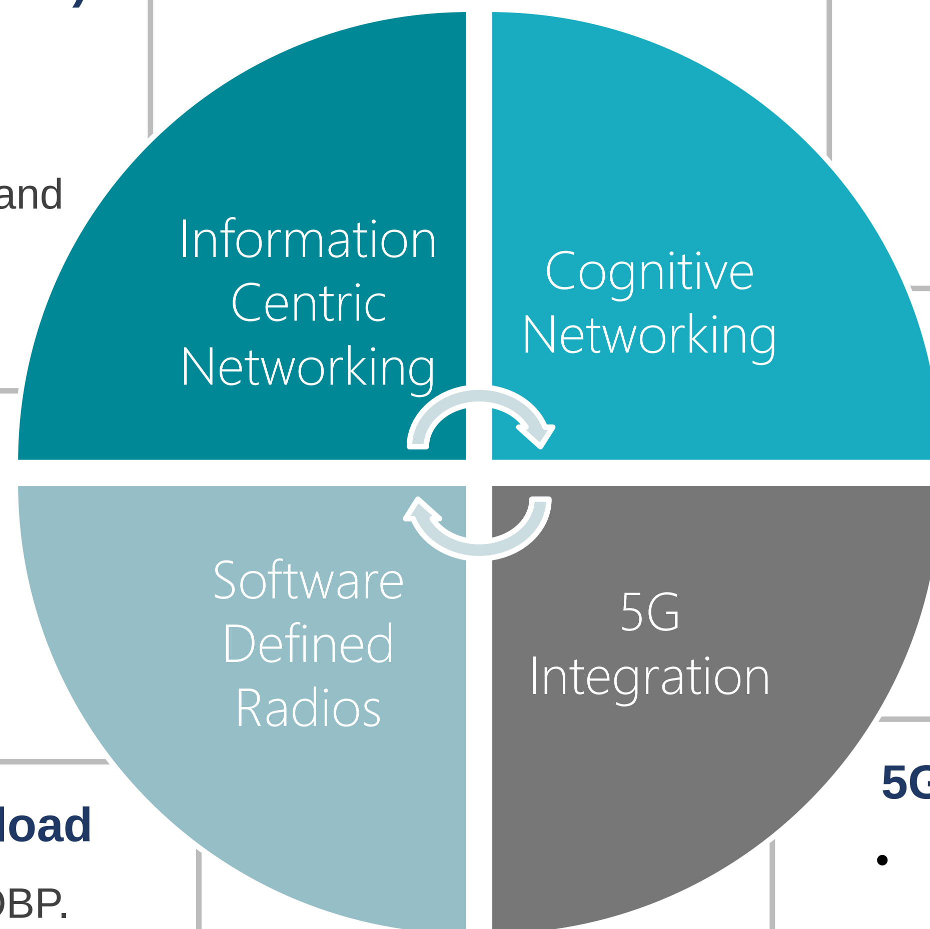
Airborne and Spaceborne Internet

Core technology

Information-Centric Networking (ICN)

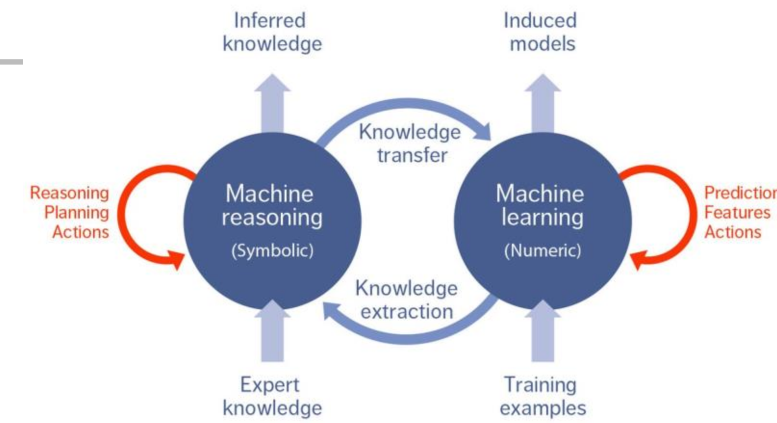
- Reduces communication latency.
- Supports intermittent connectivity.
- Embedded packet authentication and robustness against DoS attacks.





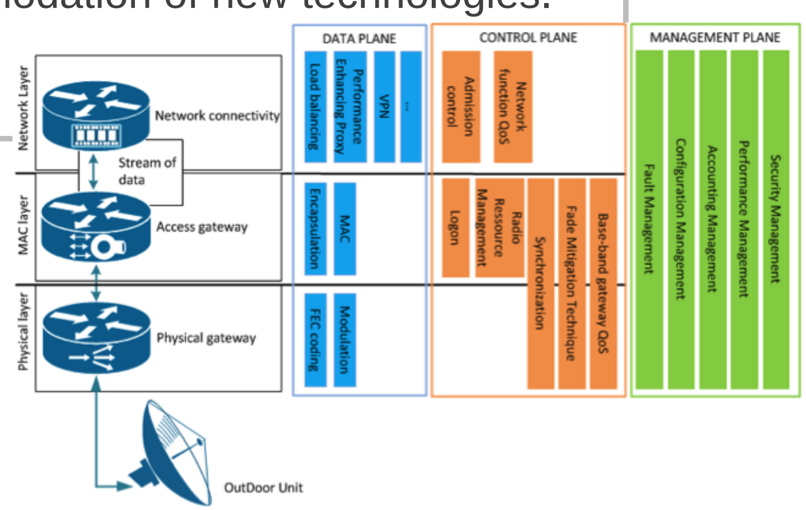
Cognitive Networking

- Automation of the network operation
- Prediction of changes through context awareness.
- Developing new services meeting current/future business needs.



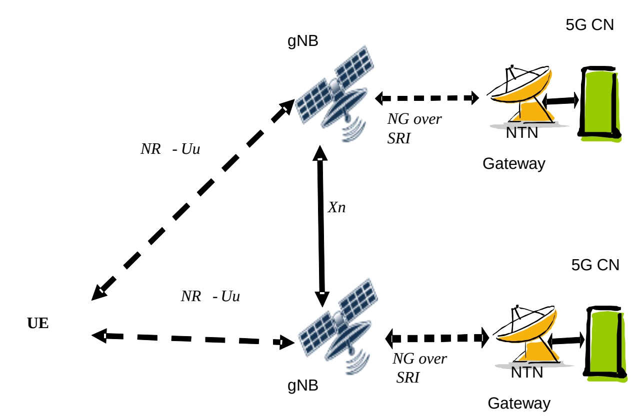
Software Defined Radios / Payload

- Reduces operational risks of OBP.
- Reduces product design cycles.
- Extends live expectation by accommodation of new technologies.



5G Integration (standardization)

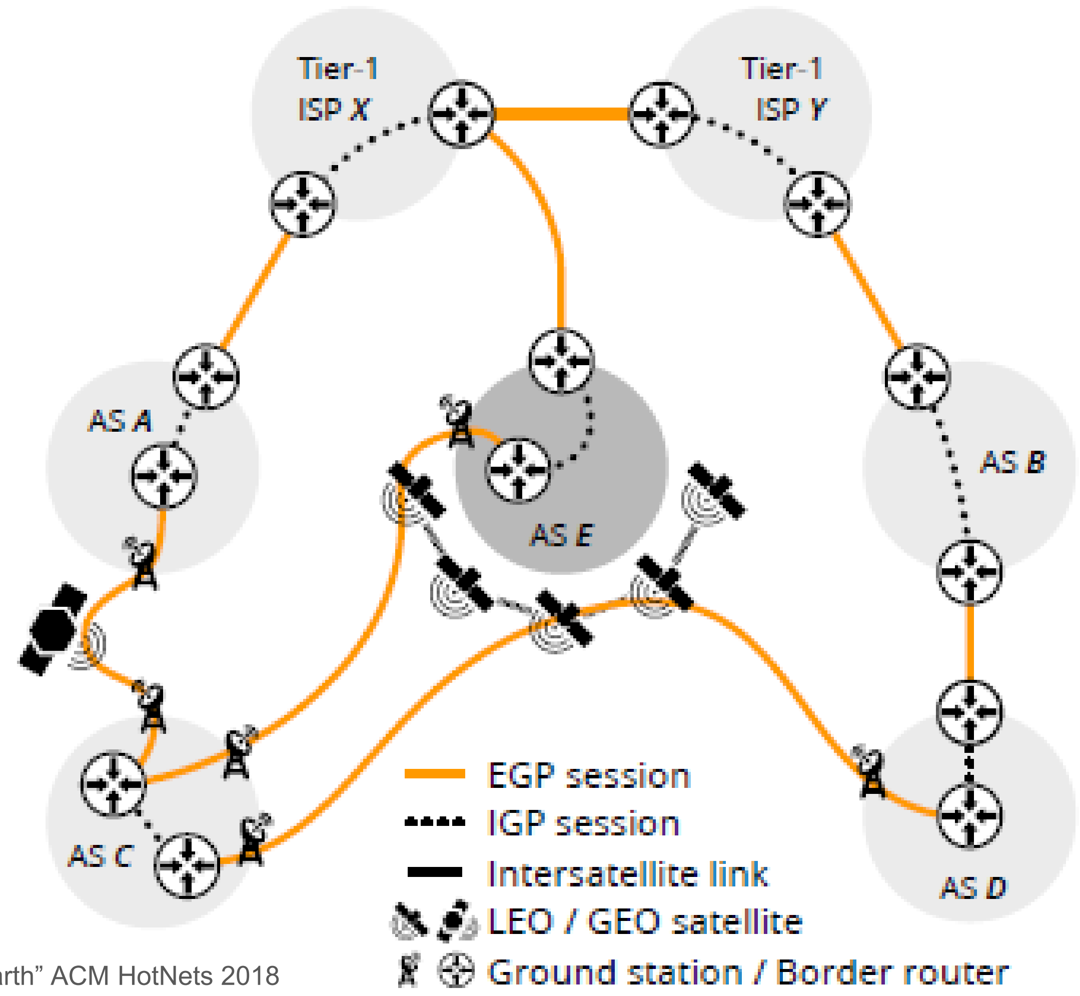
- Integration of gNB (full or DU) in satellites.
- Handover management for mobile base stations.
- Routing/forwarding solutions for inter-gNB communications.



Airborne and Spaceborne Internet
Final thought: Space-enabled interconnection market

Idea

- Integrate Airborne/ Spaceborne networks (e.g. satellite constellations) into the Internet backbone as a global point of exchange.
- Space networks (e.g. OneWeb) sell connectivity to terrestrial Internet Service Providers.



T. Klenze et al. “Networking in Heaven as on Earth” ACM HotNets 2018

Challenges

- Suitable Interconnection models, including transit providers.
- Relative movement of satellites in different orbits → customized inter-satellite routing protocols for optimal path discovery.
- LEO connectivity is intermittent with short disconnection bursts → may be a problem if exposed to inter-domain traffic (may increase BGP stability problem).
- Bandwidth fluctuations, due to bursty Internet traffic and oscillation of satellite link capacity due to natural phenomena.

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