ETHER: A Sustainable 3D Architecture

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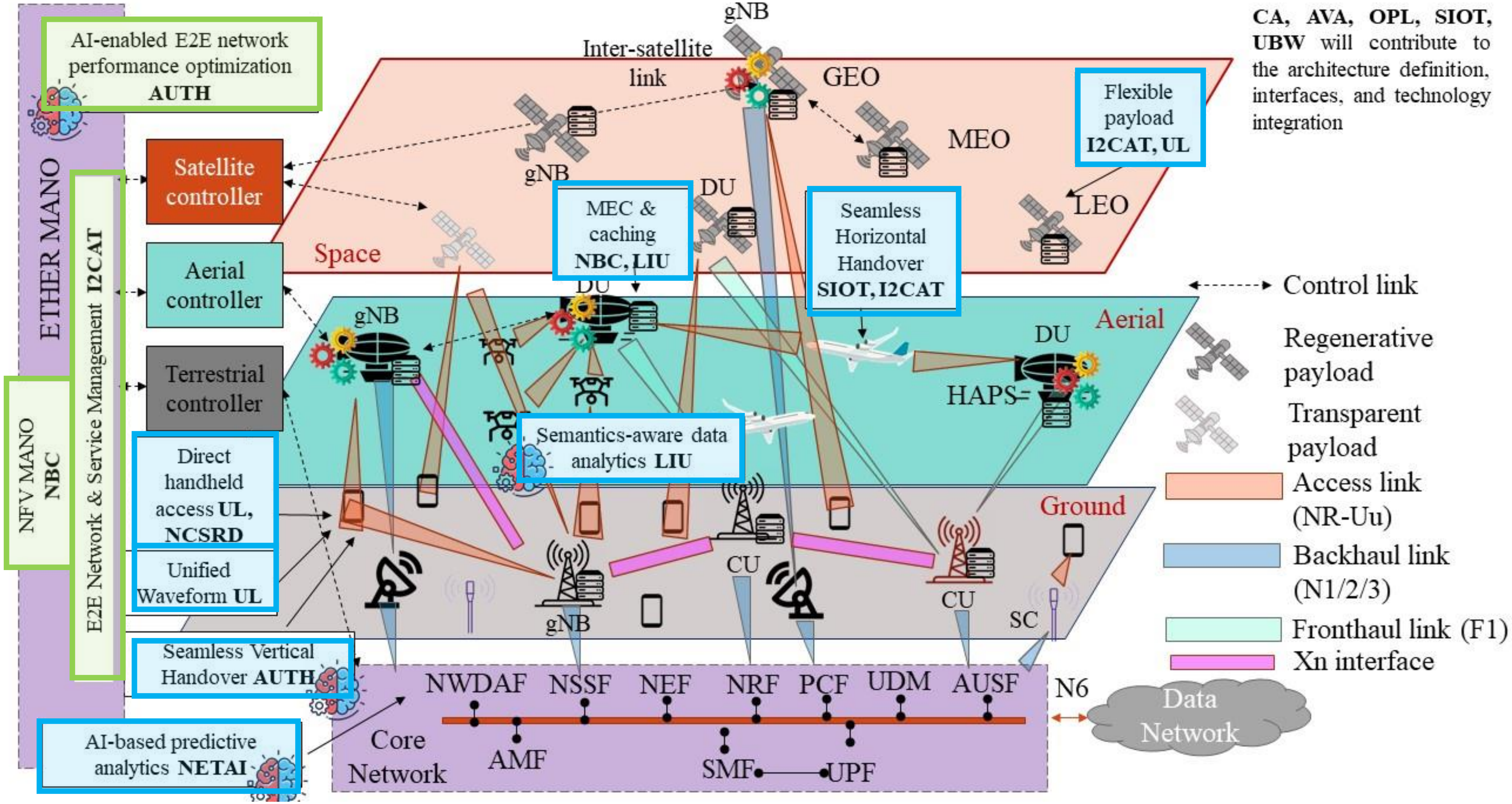
www.ether-project.eu

ETHER Vision, Use Cases, and KPIs

ETHER Vision

Higher-level technological enablers

Lower-level technological enablers



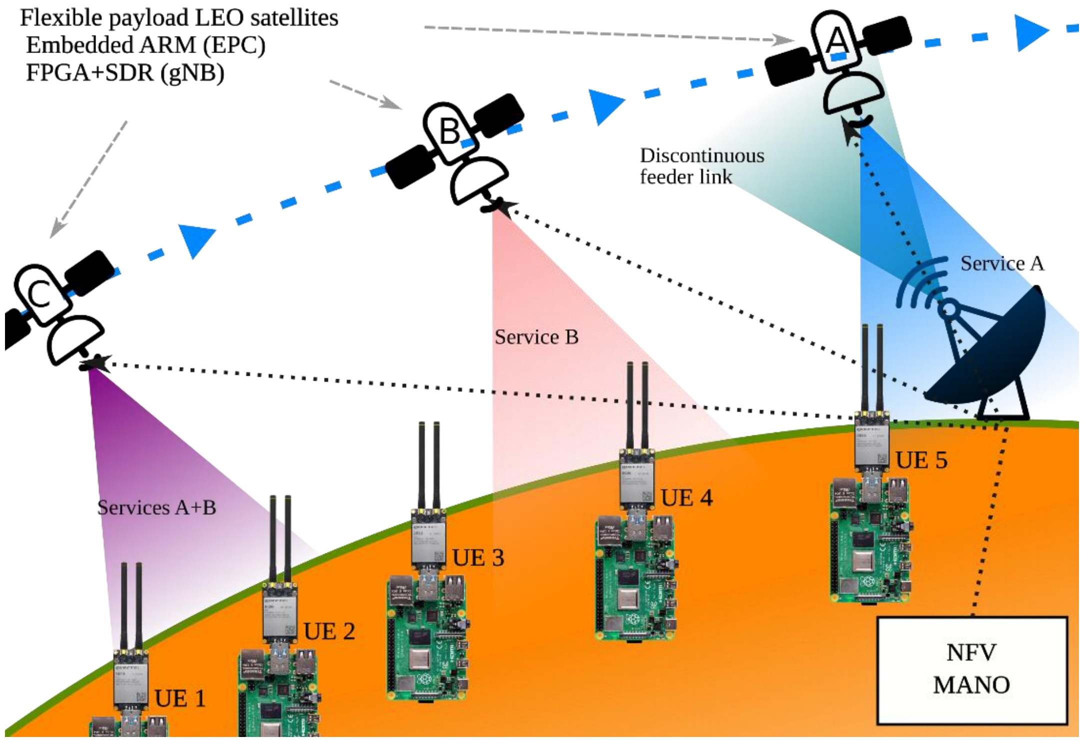
ETHER Use Case 1: Service Provision to Delay-Tolerant IoT Applications

Assumptions:

- ❑ Feeder-link discontinuity
- ❑ Satellites with store-and-forward capability
- ❑ Delay-tolerant IoT applications

Key ETHER Innovations:

- ❑ Horizontal handovers
- ❑ ETHER MANO
- ❑ Flexible payloads
- ❑ Semantics-aware information handling efficiency



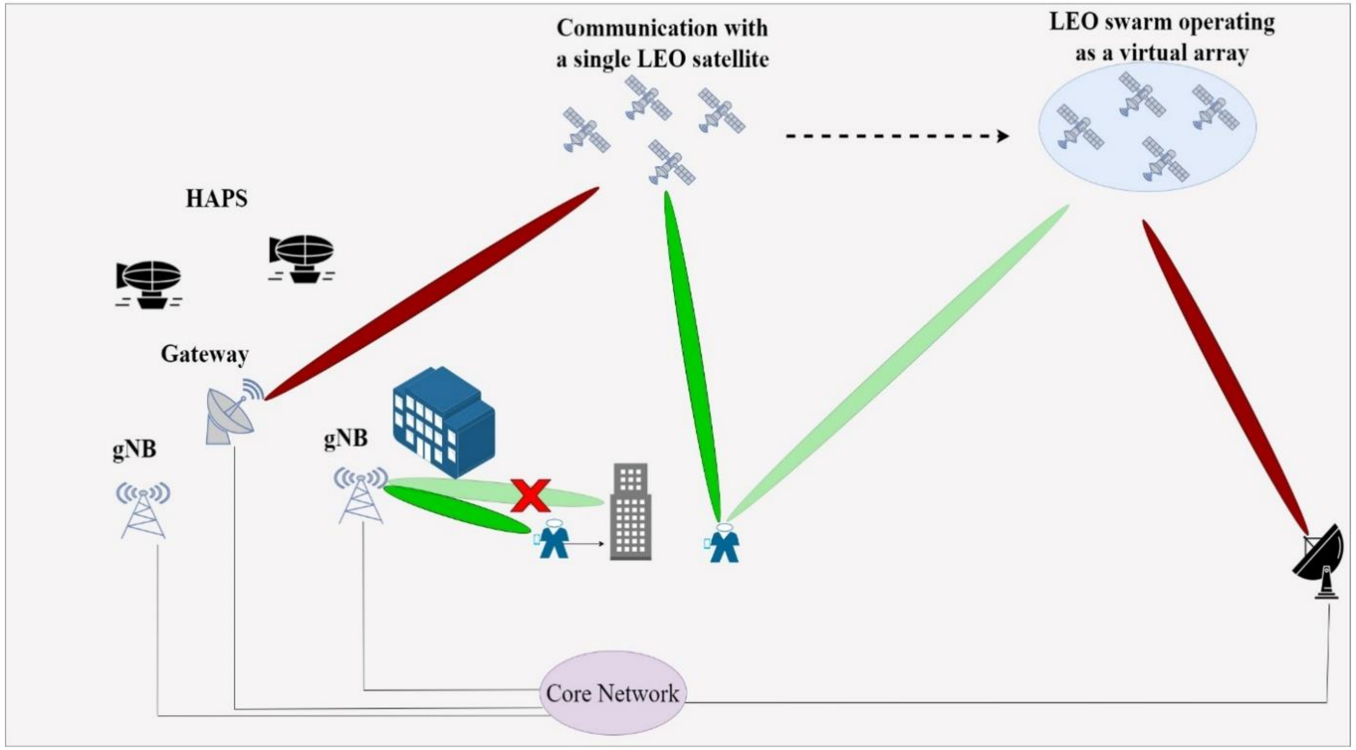
KPIs:

- ❑ > 75 % higher energy efficiency leveraging semantics-aware information handling combined with edge computing and caching

ETHER Use Case 2: Broadband Direct Handheld Device Access at the Ka Band

Assumptions:

- ❑ Communication with a terrestrial small cell infeasible either due to lack of infrastructure (remote/rural areas) or bad link/high cell traffic
- ❑ Broadband communication required for the handheld device



Key ETHER Innovations:

- ❑ Distributed beamforming from LEO-satellite swarms
- ❑ Vertical handovers across RATs
- ❑ Unified waveform design
- ❑ Terminal antenna design

KPIs:

- ❑ 100% coverage
- ❑ >70% more energy-efficient vertical handover w.r.t SOTA

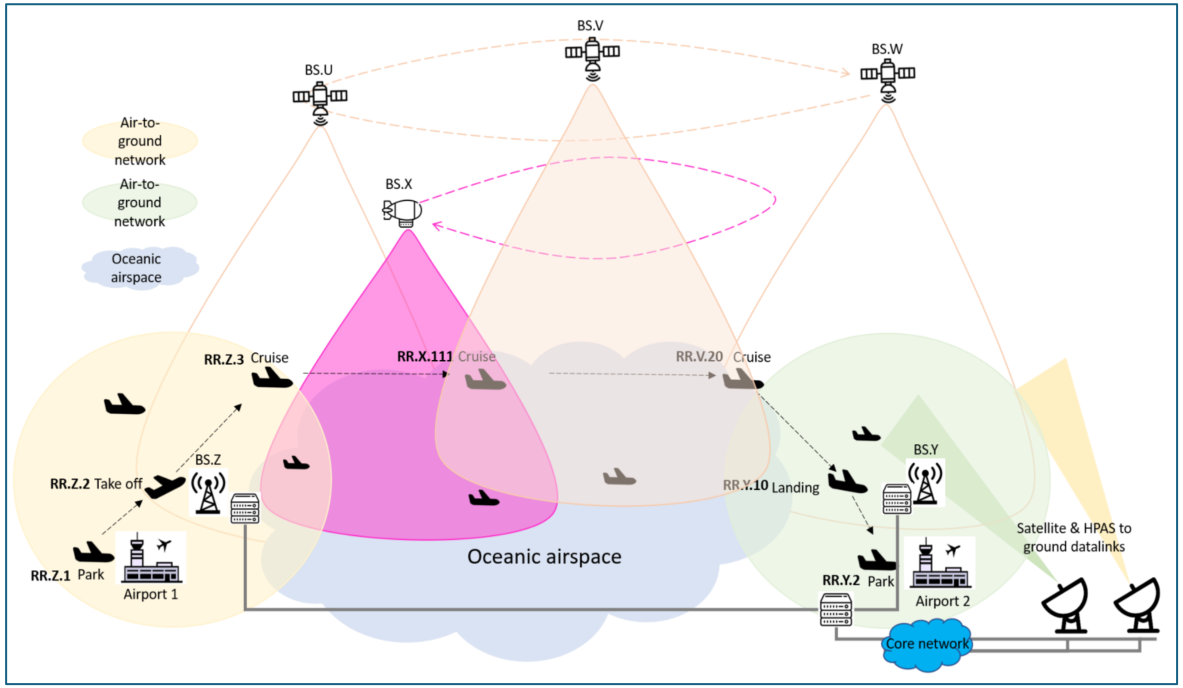
ETHER Use Case 3: Air-Space Safety Critical Operations

Assumptions:

- ❑ Aircraft moving from one airport to another
- ❑ Flight coverage via only terrestrial stations imposible throughput plane's trajectory

Key ETHER Innovations:

- ❑ Vertical handovers across RATs
- ❑ ETHER MEC orchestrator
- ❑ Unified waveform design
- ❑ Predictive analytics
- ❑ E2E network performance optimization algorithms



KPIs:

- ❑ 100% coverage
- ❑ Performance integrity 10^{-4} to 10^{-6}
- ❑ >80% more energy efficient resource allocation w.r.t. SOTA

ETHER NTN Mobility Management

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ETHER MANO Architecture (I)

Architecture

(1) Global Level

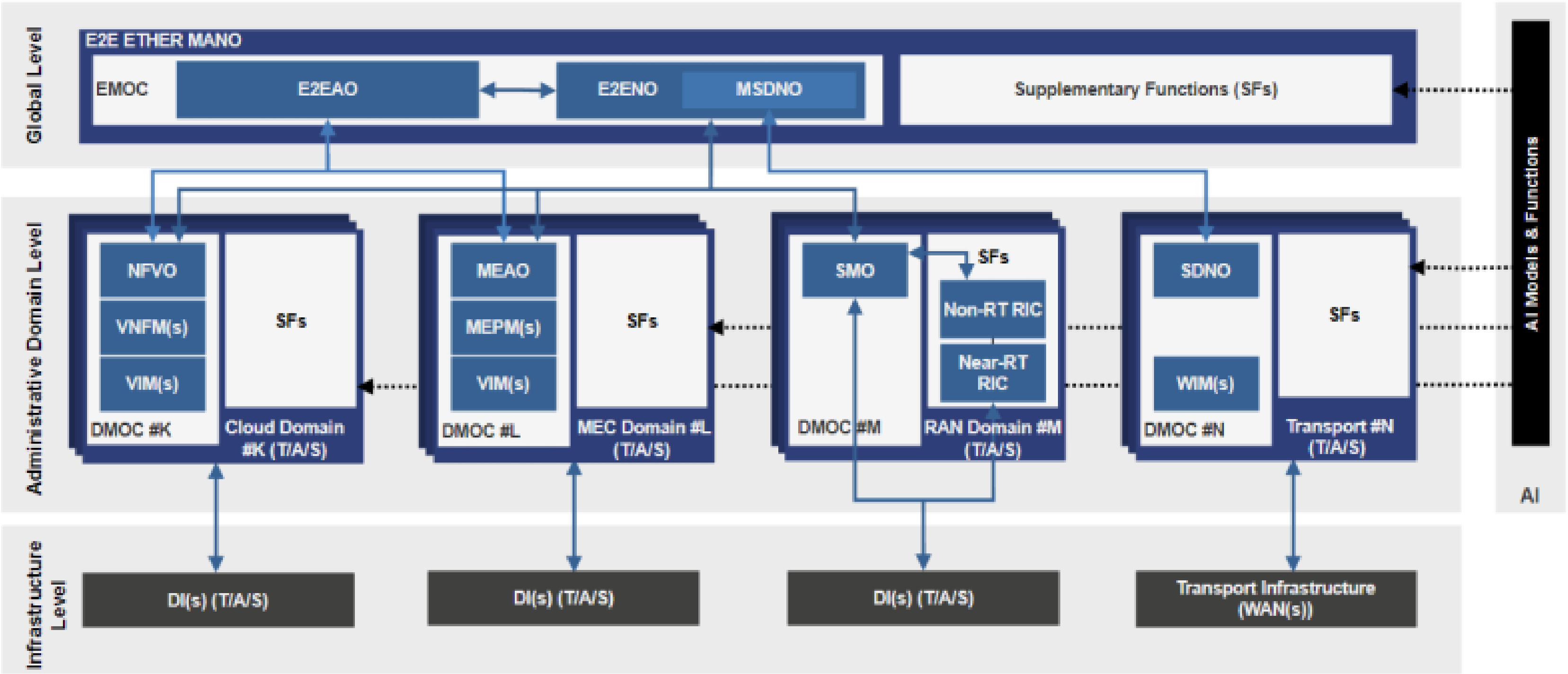
- E2E components
- E2E Application Orchestrator
- E2E Network Orchestrator

(2) Administrative Domain Level

- Multiples domains integrated
- Domain per layer (e.g., aerial)
- Domain per scope (e.g., RAN)

(3) Infrastructure and AI layers

- Presented in other sections



Domain-specific per scope

- Specific orchestrator per domain
- Connection between orchestrators
- Dedicated infrastructure

Supplementary functions

- Complement orchestration (e.g., AI modules)

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ETHER MANO Architecture (II)

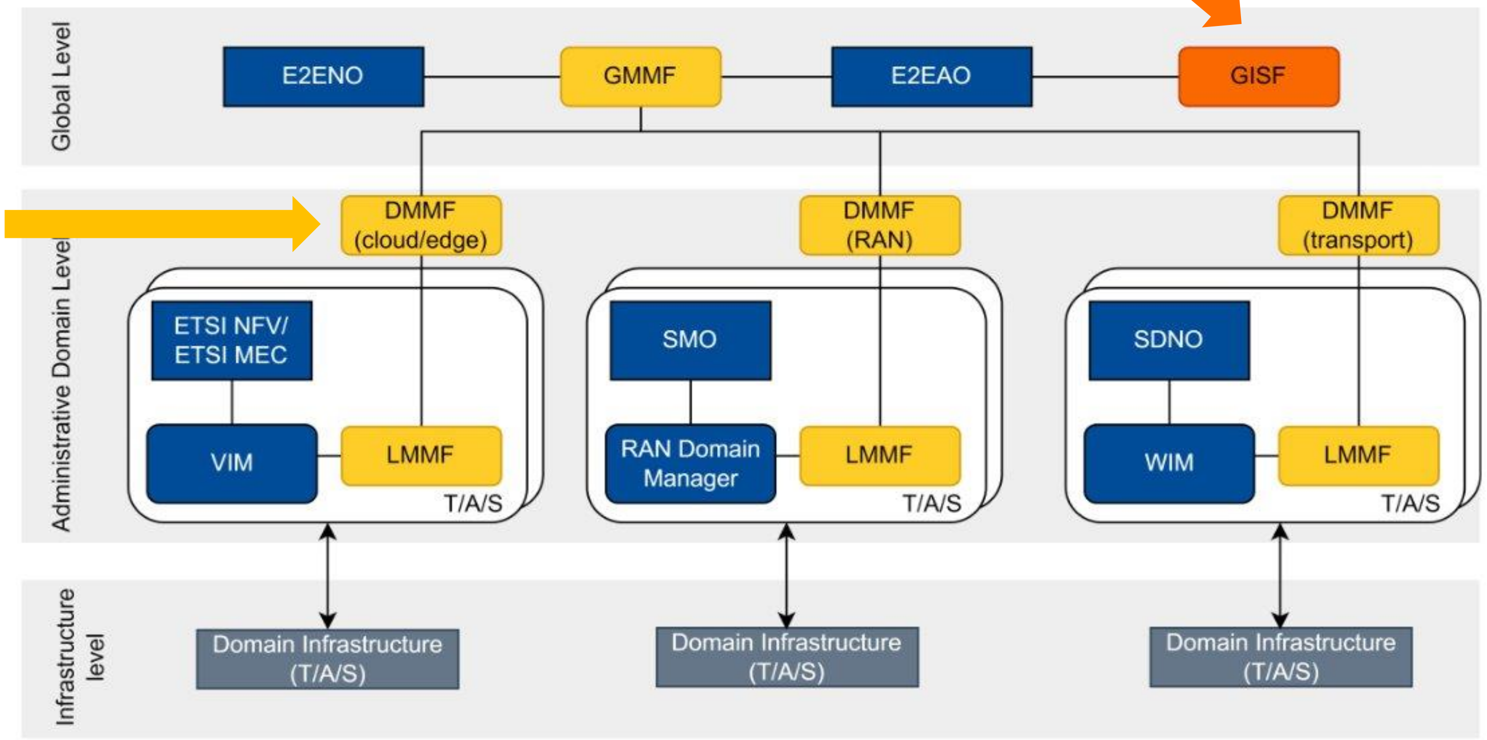
Challenges & Approach

Challenge #1: Execution on geographical location

- Current technologies do not differentiate between countries
- Deployments done by different clouds domains
- Multiple implications (e.g., legal aspects, etc.)

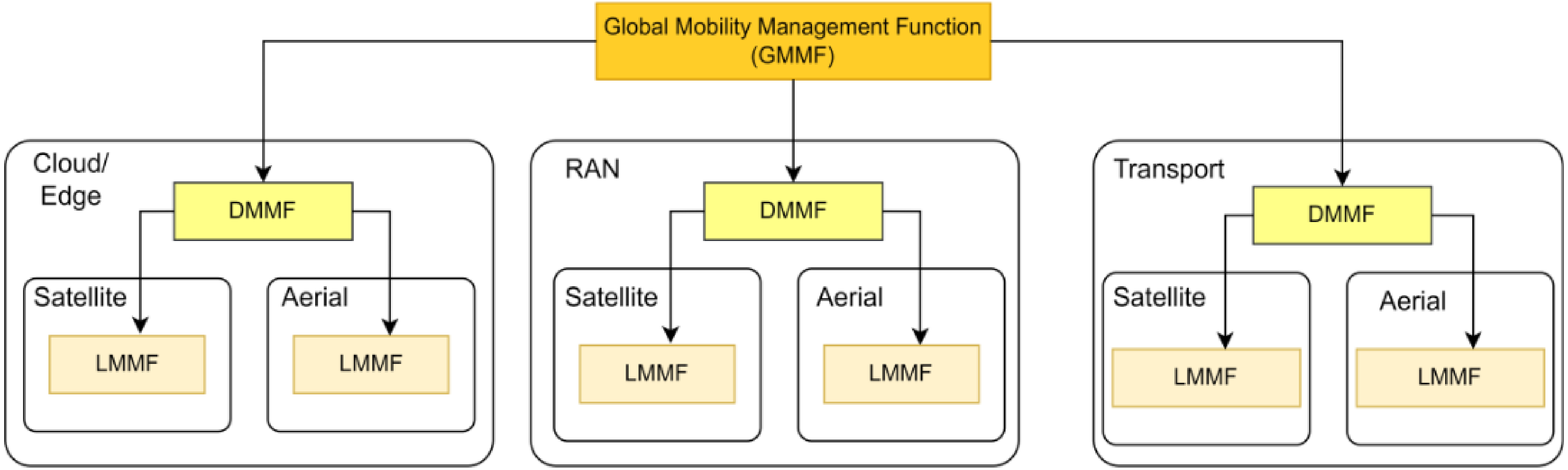
Challenge #2: Seamless management of node mobility

- Current technologies do not integrate mobile infrastructure
- Predictive mechanisms may help to anticipate changes
- Seamless integration with current architectures



ETHER MANO Architecture (III)

Mobility Management



Global Mobility Management Function (GMMF)
- Primary point of contact the mobility management framework
- Registering and discovering available domains

Domain MMF (DMMF)
- Identifying the domains that the physical infrastructure traverses within the target area
- Managing LMMFs

Local MMF (LMMF)
- Managing the mobility of physical infrastructure
- Discovery of the location of physical infrastructure
- Maintenance and update of node location

3GPP management plane stack interconnected hierarchically with the ETHER xMMF stack

Implementation of Mobility and Geolocalization Management

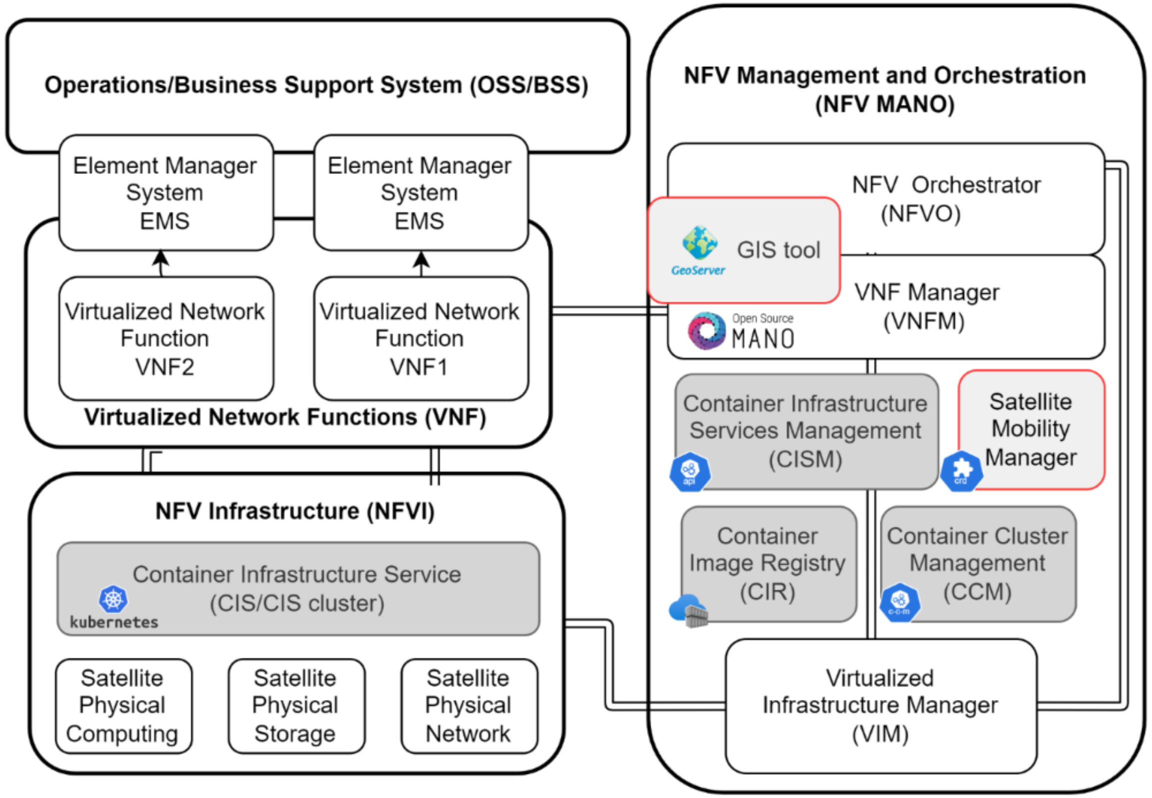
Problem and Proposed Innovation

Problem:

- **Dynamic and resource-constrained** infrastructure
- SDN-based solutions overlooking of infrastructure **geolocation**
- **Ad-hoc** satellite operations solutions

Proposed Innovation:

- Integration of **Geographical Information System** (GIS) and **mobility manager** into standardized **MANO framework**

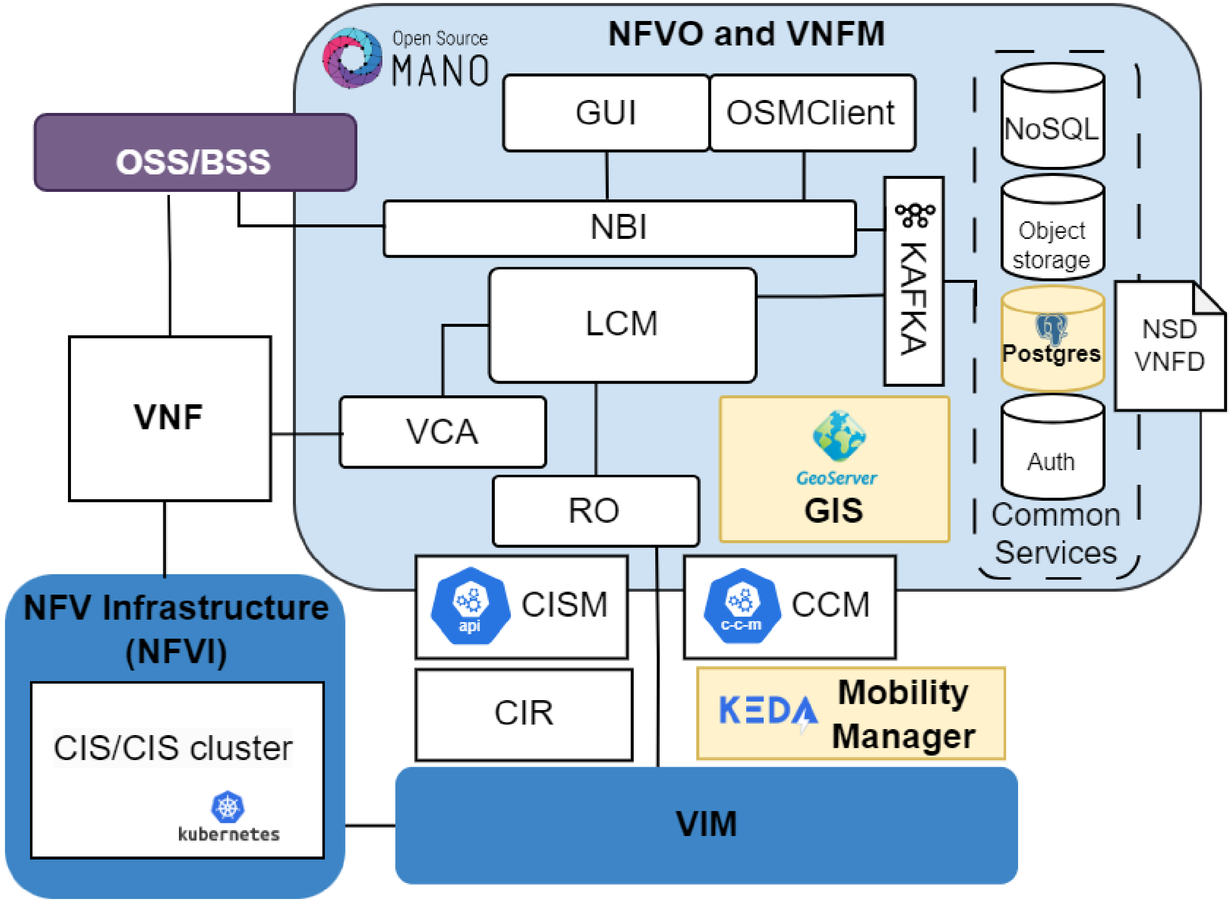


Design of Geolocalization Management

- **GIS Function**
  - Storage and query of spatial information
  - Management of target areas, and visualization of satellite infrastructure
  - Integration with external GIS

- **GIS Backend**
  - Data storage and querying.
  - Spatial data processing and management.
  - GIS server engine for publishing data in various formats.

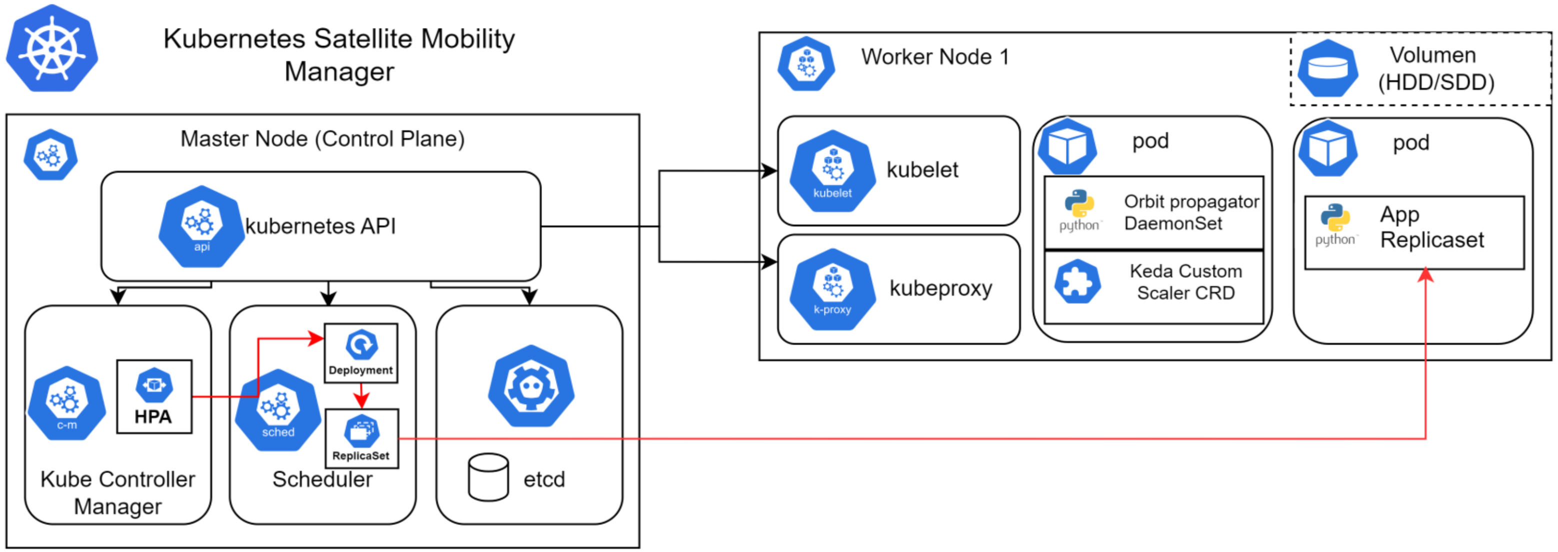
- **GIS Frontend**
  - User Interface
  - Visualization
  - Target Area Selection



Design of Mobility Management

Satellite Mobility Manager to obtain (or propagate) the position of satellite nodes and implement changes in services based on this position.

- Dynamic VNF Scaling
- Distance-based migration
- Propagated position
- Dynamic reconfiguration

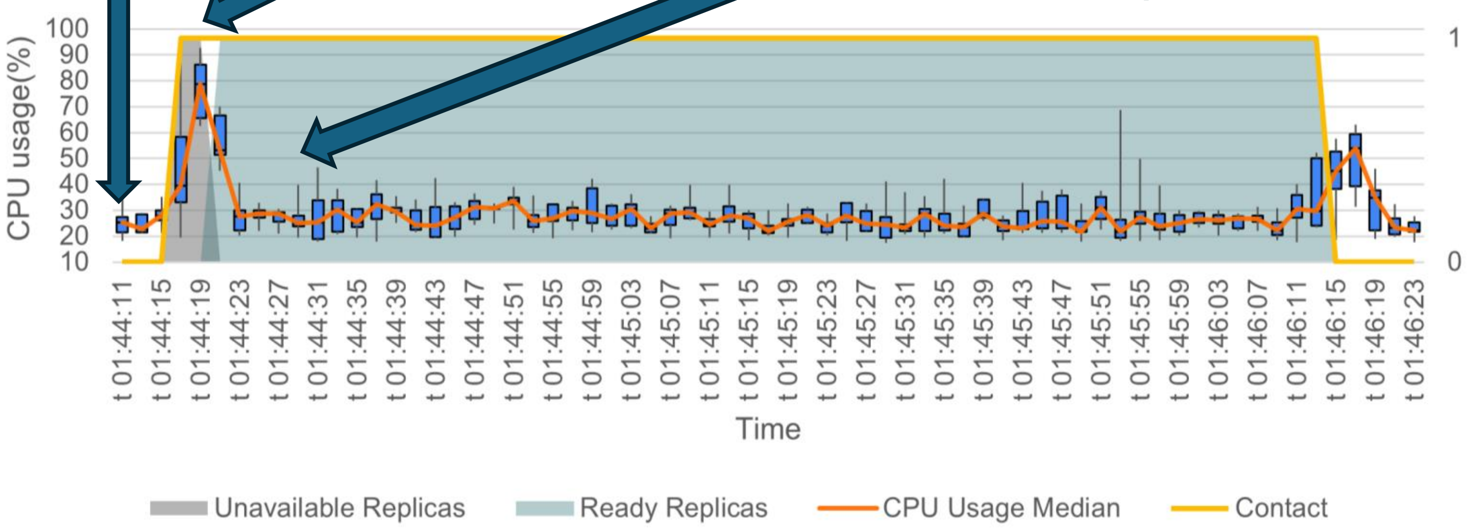


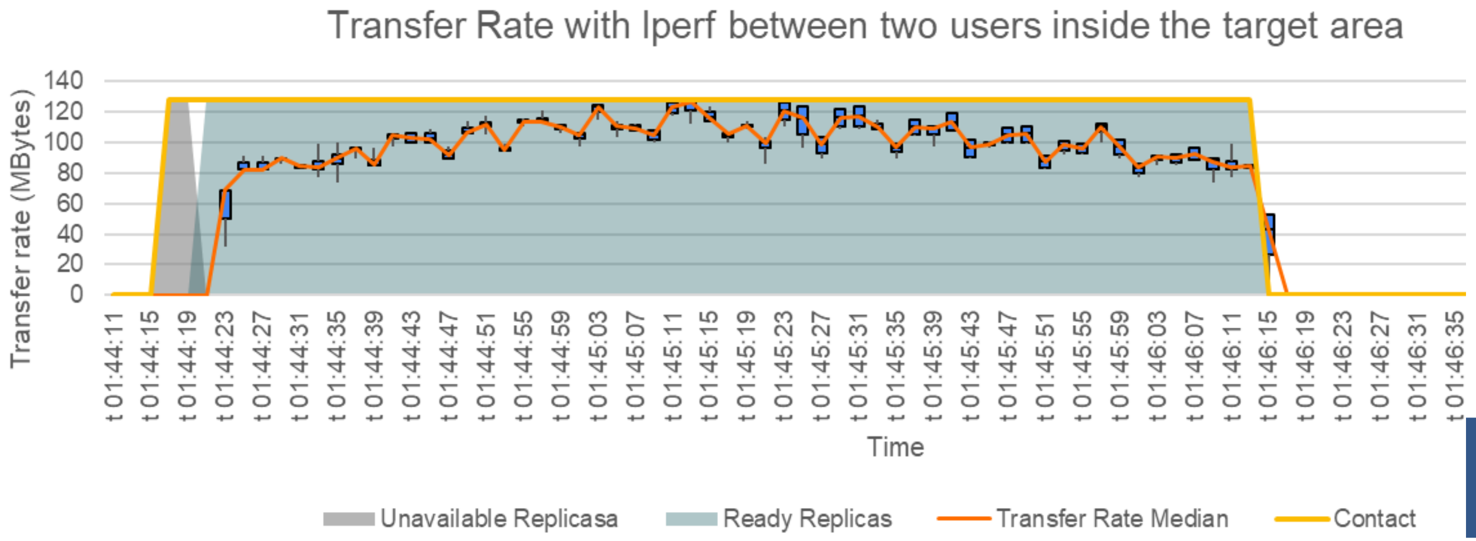
Preliminary results

Increase in CPU usage during deployment

Delay from start of deployment to effective deployment

Kubernetes scheduler accesses resources and instantiates a new pod





- **From OSM GIS plugin we selected the target area.**
- **The channel emulator propagates the orbit**
- **Custom scalers activate the service**
- **Relay service enables connection**

A Sustainable ETHER Architecture

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ETHER Techno-economic analysis and architecture evaluation

Employed models

- Channel modelling (SINR, EIRP, C/N_0, Path Loss)

- Path Loss (Link distance) [ITU-R P.618-13]
  - Rain attenuation [ITU-R P.837, P. 838-3]
  - Gas attenuation [ITU-R P.835-6, P.676-13]
  - Fog attenuation [ITU-R P.840-9]
  - Scintillation attenuation [ITU-R P.453-14]

$$EE = \frac{Data\ rate}{Power\ Consumption}\left[\frac{bps}{W}\right] = \left[\frac{bits}{J}\right]$$

- Metrics
  - Spectral Efficiency (**bps/Hz**)
  - Maximum capacity (**bps**)
  - Energy efficiency (EE) (**bits/J**)
  - Cost efficiency (CE) (**bps/EUR/year**)

$$CE = \frac{Data\ rate}{TCO\ in\ EUR\ per\ year}\left[\frac{\frac{bps}{EUR}}{year}\right]$$

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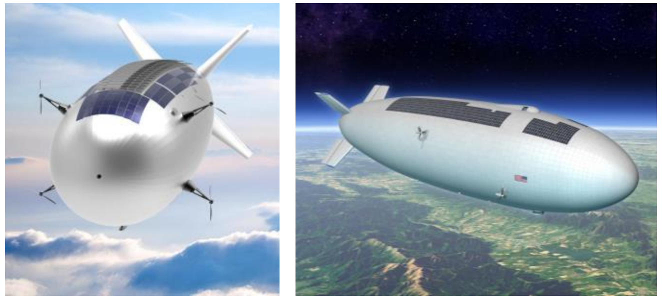
ETHER Techno-economic analysis of different BSs (1/5)

Different types of HAPS and UAVs

Aerostatic balloons



Airships (aerostatic)

Aerodynamic fixed-wing

UAVs with rotary wing

UAVs with fixed wing

Fixed-wing hybrid UAVs

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ETHER Techno-economic analysis of different BSs (2/5)

Comparison of different BS types [1], [2]

	Terrestrial BSs	Fixed-Wing UAVs	Hybrid UAVs	Aerostatic HAPS	Aerodynamic HAPS	Satelllites
Height	0-0.3 km	1-10 km	1-10 km	18-22 km	18-22 km	300-35786 km
Fllight duration	N/A	6-12 hours	6-12 hours	5-10 y (airships)	6-12 months	**LEO**: 5-10 years [3] **GEO**: 15-30 years [4]
Autonomy	No	No	No	Yes	Yes	Yes
Max. coverage (radius)	Up to 1-2 km	Up to 10 km	Up to 10 km	Up to 500 km per platform [5]	Up to 50 km per platform [6]	**LEO**: up to 5400 km **GEO**: up to 8400 km (~1/3 of Earth's surface)
Cell radius [7]	0.1-1 km	0.1-5 km	0.1-5 km	>10 km	>10 km	**LEO**: 25 km **GEO:** >200 km
Two-way delay	<<1 ms	<1 ms	<1 ms	<10 ms	<10 ms	**LEO**: <40 ms **GEO:** 238-278 ms
Payload	N/A	5-15 kg	~10 kg	<500 kg	5-20 kg [8]	**Avg. weight: LEO**: ~500 kg [9] **GEO**: 1000-6500 kg [10], [11]
TCO per BS (EUR/year)[9]	**gNB**: 168k [12], [13] **SC**: 30k [14]	200k [15], [16]	N/A	500k (airship) [13], [17]	1m-2m [18]	**LEO**: 155k [19], **MEO**: 4.15M [20], **GEO**: 7.9M [21]

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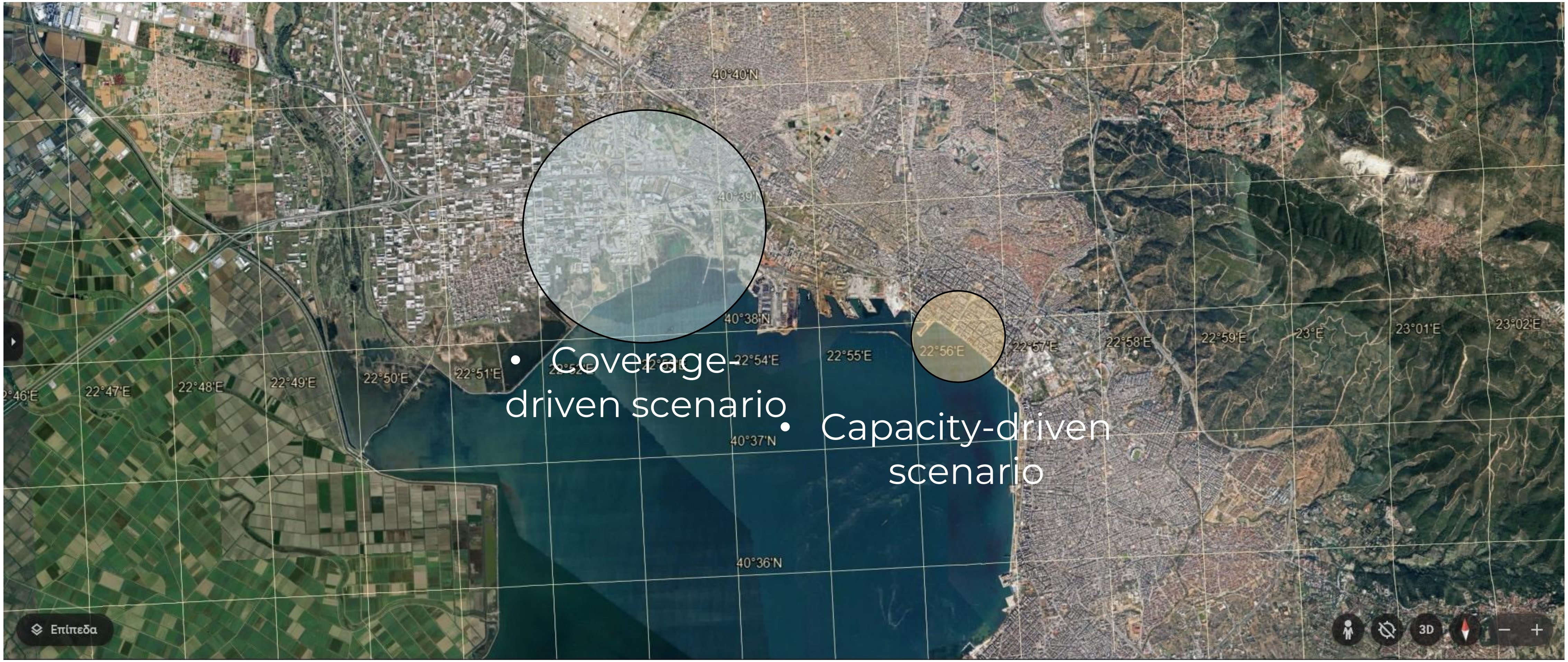
ETHER Techno-economic analysis of different BSs (3/5)

Different Scenarios

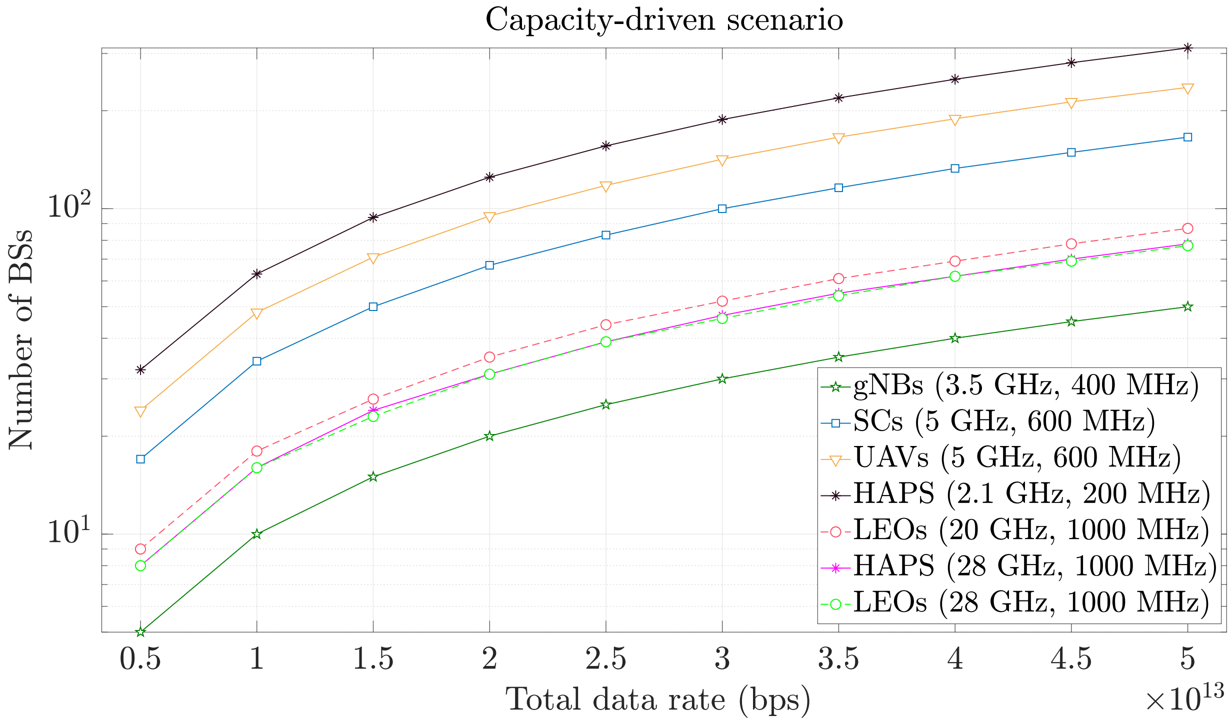
- Matlab

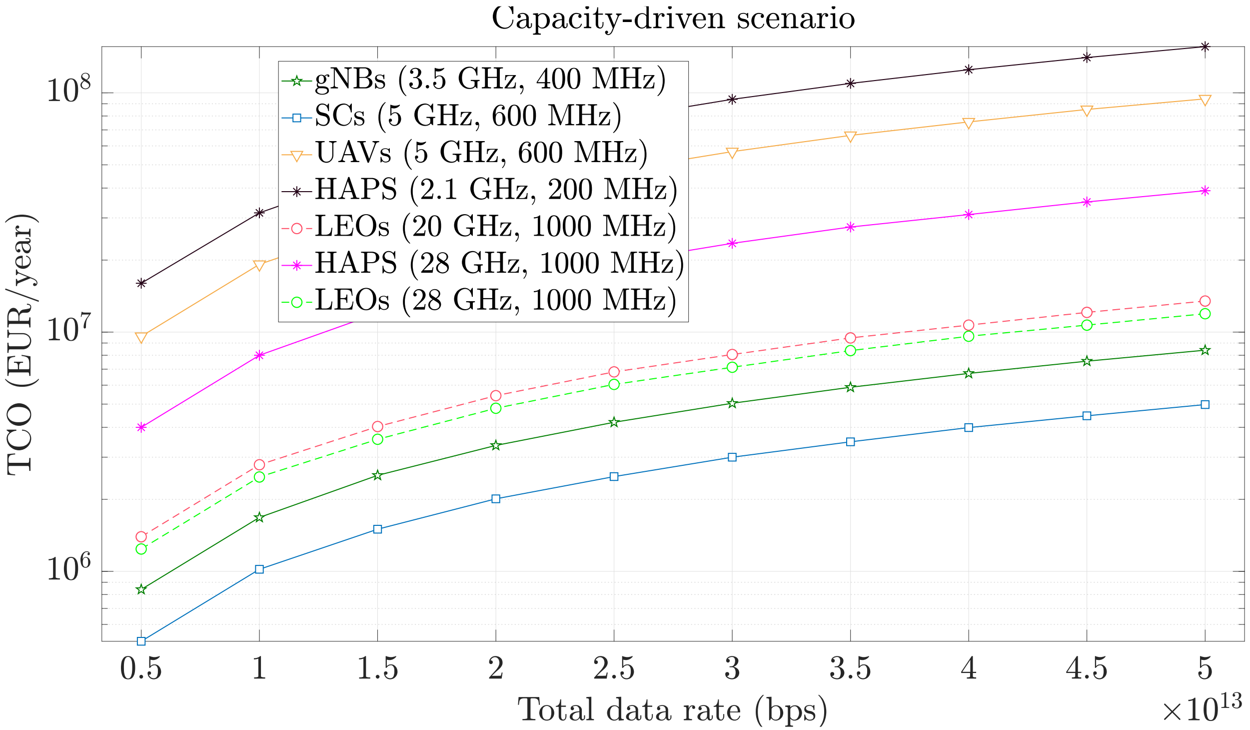


- Coverage-driven scenario
- Capacity-driven scenario

ETHER Techno-economic analysis of different BSs (4/5)

Simulation results – Capacity-driven scenario



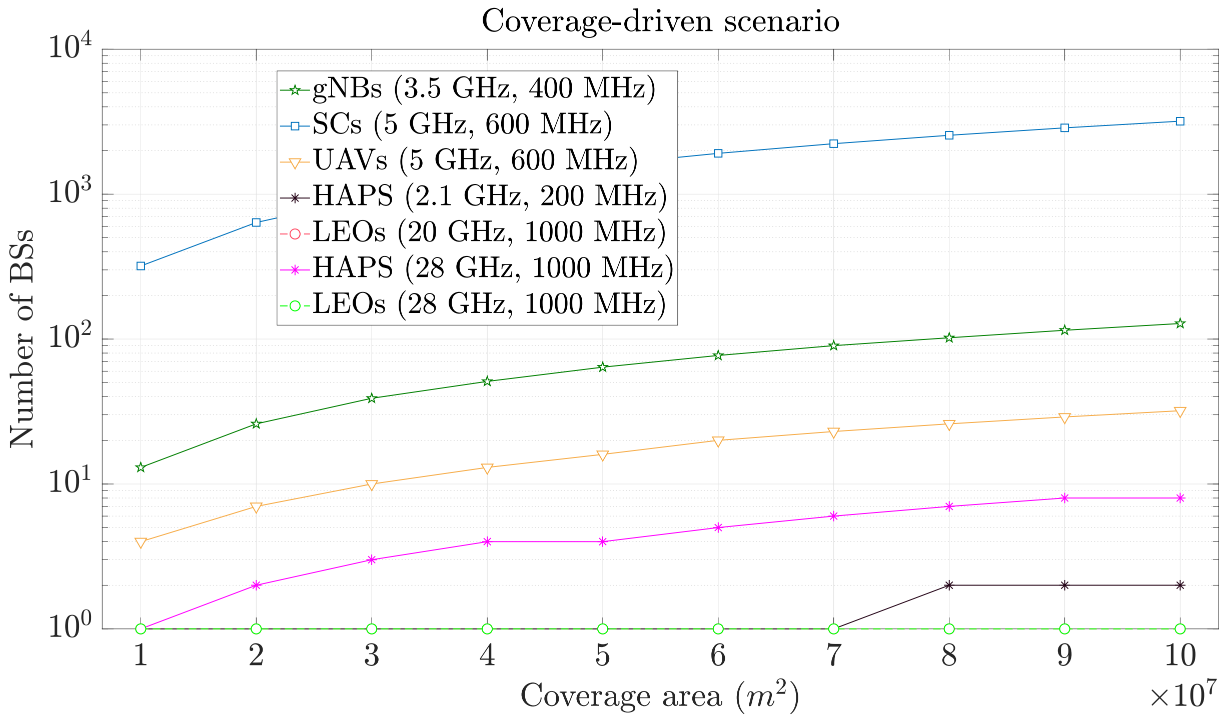


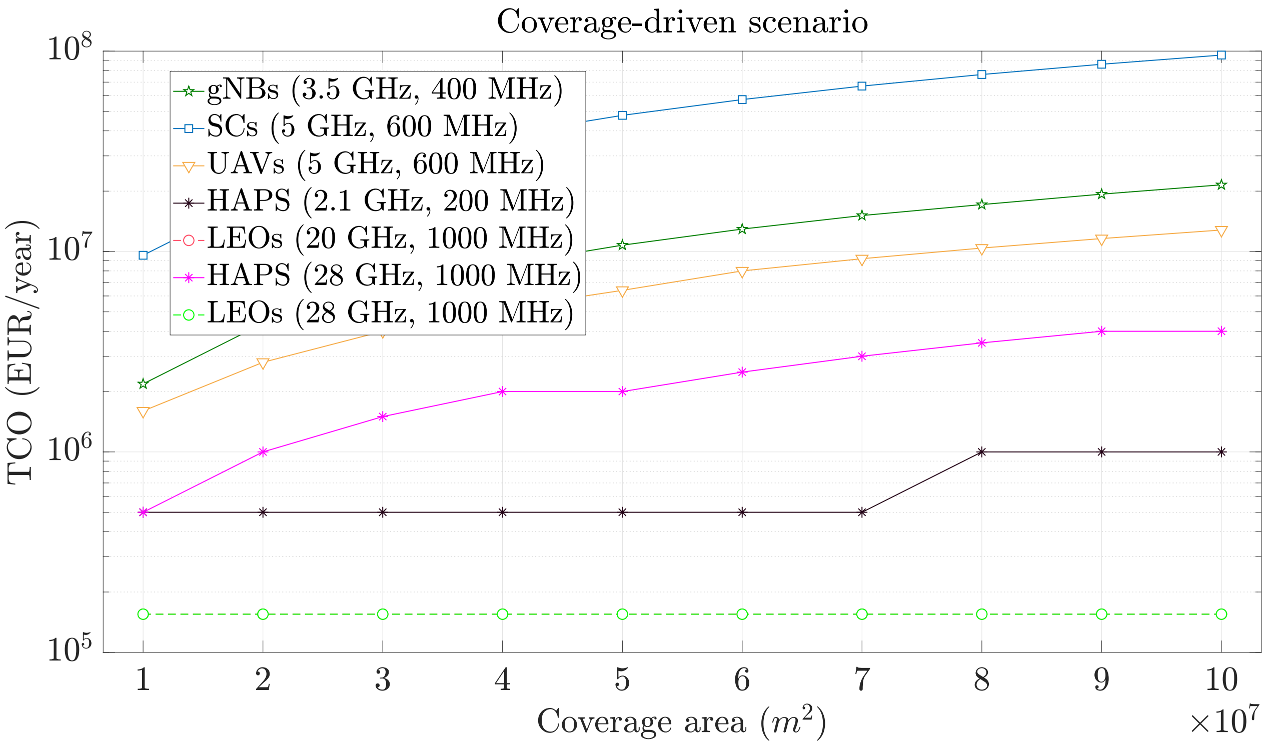
- gNBs (3.5 GHz) → require the min. number of BSs due to high capacity per gNB
- Higher frequencies → higher capacity
  - ✓ High gains compensate for the higher path loss
  - ✓ High BW → High SE

- Best choice → Terrestrial BSs involve the lowest TCO
- **Densification of densely populated areas with SCs (involve the lowest TCO)**

ETHER Techno-economic analysis of different BSs (5/5)

Simulation results – Coverage-driven scenario





- LEOs → only 1 is sufficient
- HAPS → only 1 for large areas up to 70 km^2
- Aerial and space BSs → higher coverage due to their altitude
- Higher frequencies → lower coverage

- Best choice (lowest TCO) → LEOs (28 GHz)
- 2nd best choice → HAPS (2.1 GHz)

- **Hybrid TN-NTN solutions are expected for sustainable 6G networks!**

ETHER architecture evaluation (1/2)

Simulation scenario

- Matlab
- **Proposed**: user association & traffic routing (min. power), xNF placement (centrality, computational capacity, CPU load)
- **SotA**: xNF placement (centrality) and then traffic routing (min. delay)

	SFC Type	Rate (Mbps)	Latency (ms)	Share (%)
UC2	Web	0.6-1	500	15
UC2	VoIP	0.384-0.64	100	15
UC2	Streaming	5-24	100	30
UC2	Gaming	0.24-0.5	60	10
UC2	Ultra RT AI/ML	15-25	1	10
UC1	IoT Applications	0.1-0.5	400	10
UC3	TT&C Applications	1-5	250	10

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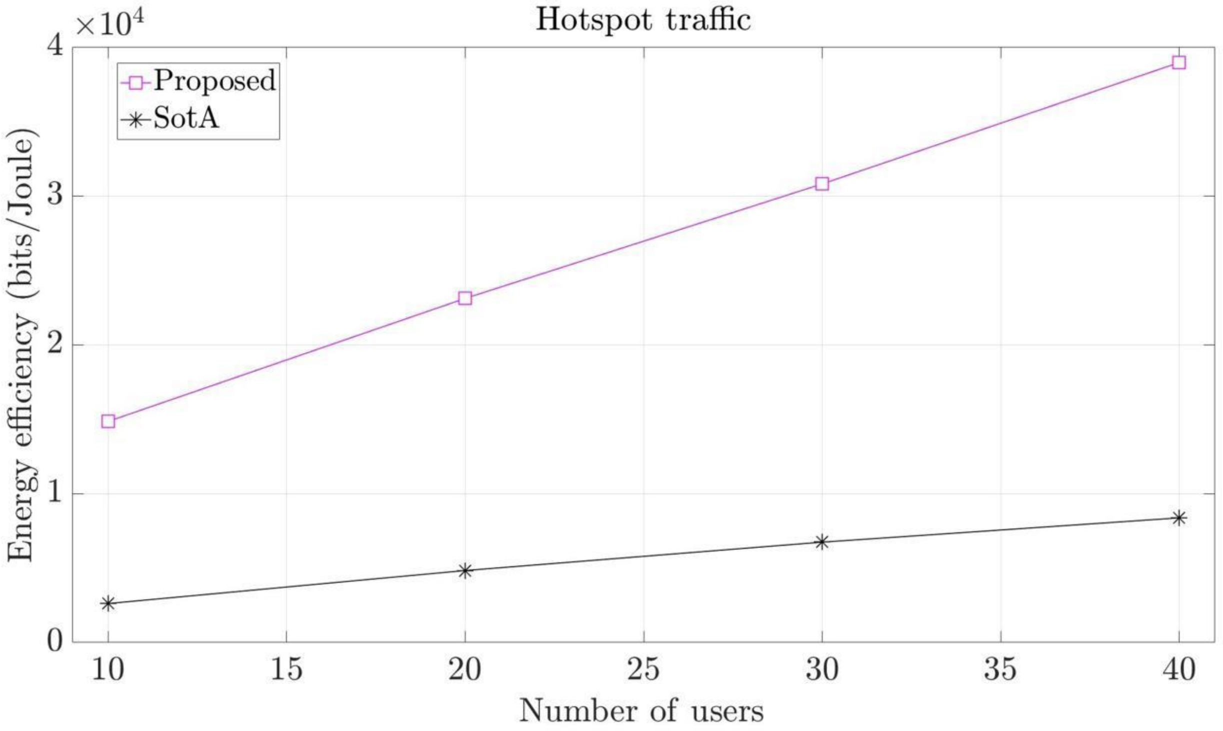
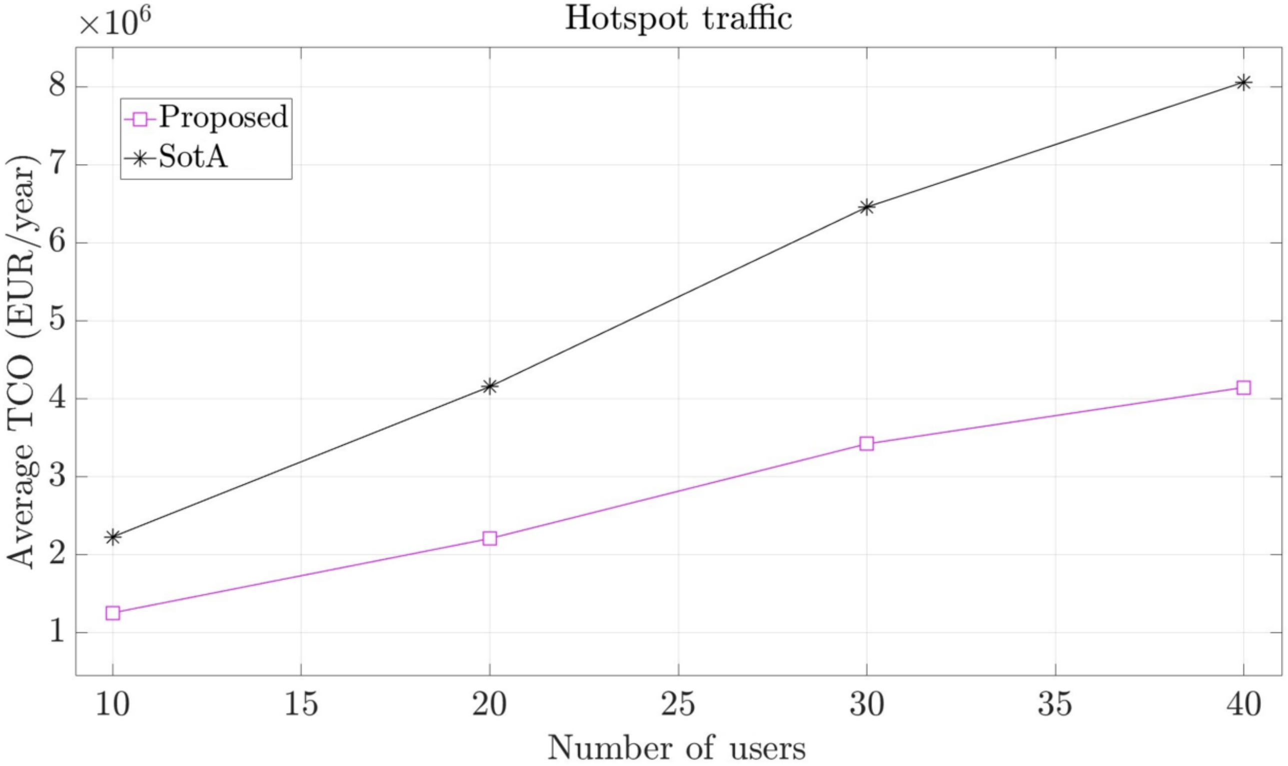
ETHER architecture evaluation (2/2)

Results – Energy efficiency (EE) and Total Cost of Ownership (TCO)





- Proposed
  - ✓ **Up to 82% higher EE** (low traffic)
  - ✓ Higher flexibility but slightly higher complexity
  - ✓ **Up to 94% lower TCO** (high traffic)
  - ✓ Fewer PMs & BSs → less OPEX & CAPEX

- Both algorithms → 100% user acceptance ratio
- **ETHER 3D architecture achieves very high energy- and cost-efficiency performance!**

Conclusions

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Main takeaways

- ETHER architecture has been defined with the required features
- MANO adaptation has been proposed and addressed
- Current results demonstrate that the first prototype allows the satellite-based NTN orchestration
- Further developments are still on-going
  - Multi-satellite scenario to manage service migration
  - Multi-service provision and dynamic reconfiguration
  - Standardization activities

- Capacity-driven scenarios will rely mainly on terrestrial means.
- Coverage-driven scenarios will rely mainly on non-terrestrial means.

✓ **Hybrid TN-NTN solutions are expected for sustainable 6G networks!**

- ETHER 3D architecture achieves very high energy- and cost-efficiency performance!

Thanks

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