

Connected Space Challenges and Opportunities in Satellite Computing and Networking

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Space Networking

Communications – Observation – Navigation – Disaster Support

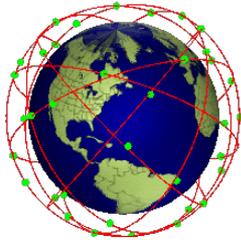


Mega-Constellations • Direct-to-Device Access • Searchable Earth
• Space Computing • Lunar and Deep Space • ...

Space Networking

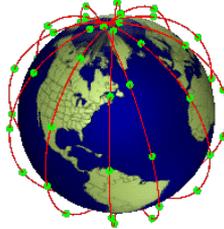
But the technology is not at all new!

Globalstar



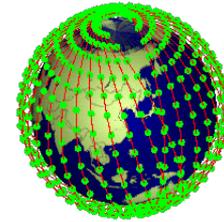
24 Satellites • Bankrupt in 2002

Iridium



66 Satellites • Bankrupt in 1999

Teledesic



288 Satellites • Cancelled in 2002

Technology was there → The **business paradigm** failed (~10\$bn losses)

Research funding frizzed for ~10y →
Meanwhile, **mobile networks** thrived



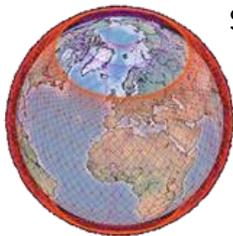
1 Images created with SaVi: <http://www.geom.uiuc.edu/~worfolk/SaVi/constellations.html>

2 Brown, Owen, et al. "Value-centric design methodologies for fractionated spacecraft." AIAA Space 2009 Conference & Exposition. 2009. © Juan Fraire

Space Networking

The renewed interest ...

Starlink



SpaceX

6k Satellites · 20k Planned

Launch

Rocket *Reusability*

Amazon LEO



Amazon

~200 Satellites · 3k Planned

Capability to

integrate with *mobile*

OneWeb



Eutelsat

648 Satellites · Partner of IRIS²

Manufacturing

Electronics *Spatialization*

Vertical Integration & Economy of Scale

[1] <https://news.mit.edu/2021/study-compares-internet-meganeetworks-0610>.

Space Networking

2024

SpaceX Starlink Gen 1	4,408
SpaceX Starlink Gen 2	29,988
OneWeb, Phase 1	718
OneWeb, Phase 2	6,372
Amazon LEO	7,774
China Guowang	12,992
Astra	13,620
Boeing	5,842
Globalstar	3,080
Lynk	2,000
Telesat Lightspeed	1,969
Spin Launch	1,190
TOTAL	89,953
E-Space	337,323



2025-26

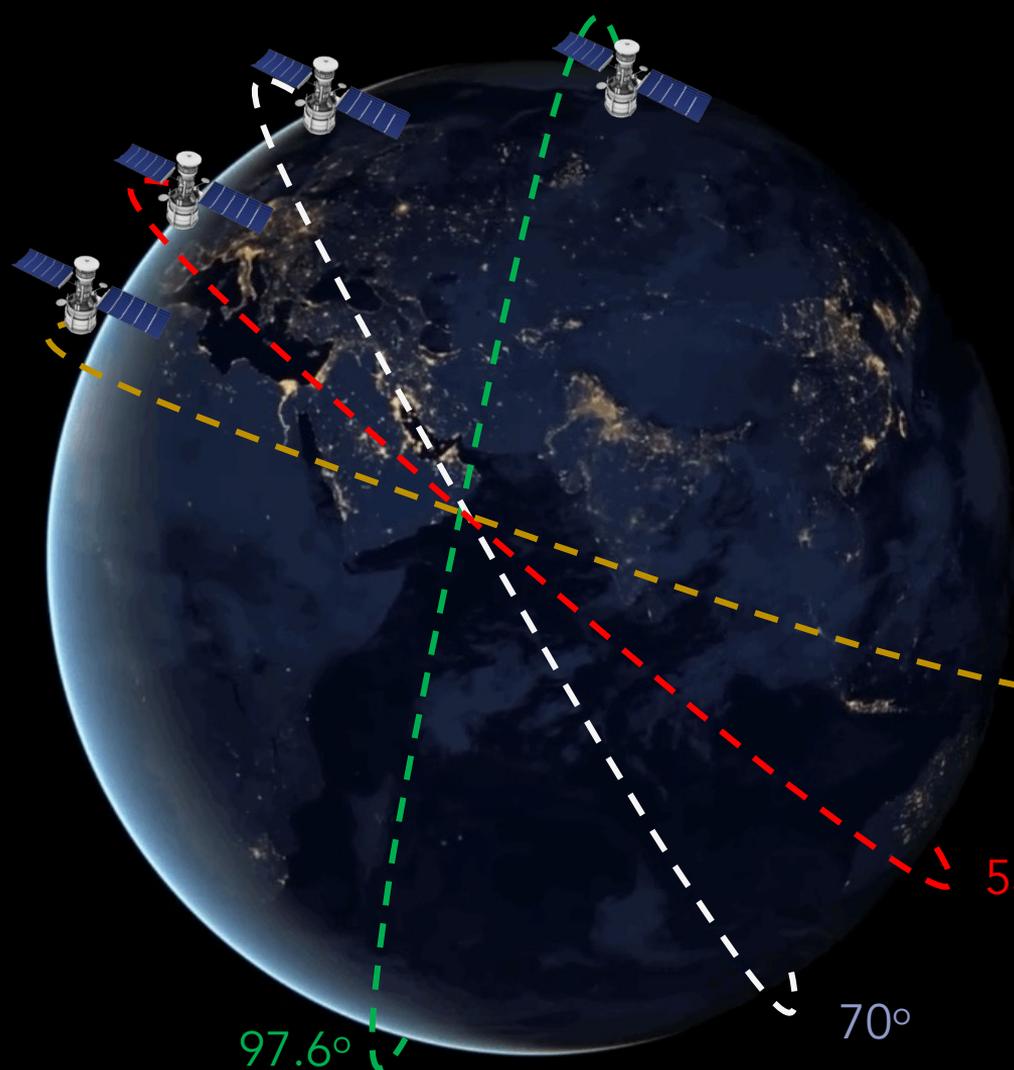
Mega-constellations (over 1,000)

27 : Total planned constellations
1746909 : Total planned satellites
11 : Total constellations with at least one launched sat
11055 : Total launched sats in all constellations
9453 : Total launched sats in constellation operational shells

Large constellations (50 - 1,000)

45 : Total planned constellations
8531 : Total planned satellites
39 : Total constellations with at least one launched sat
2008 : Total launched sats in all constellations
795 : Total launched sats in constellation operational shells

Starlink plans to launch 30,000+ satellites ...



LEO ISP operations are dependent on two critical infrastructural aspects

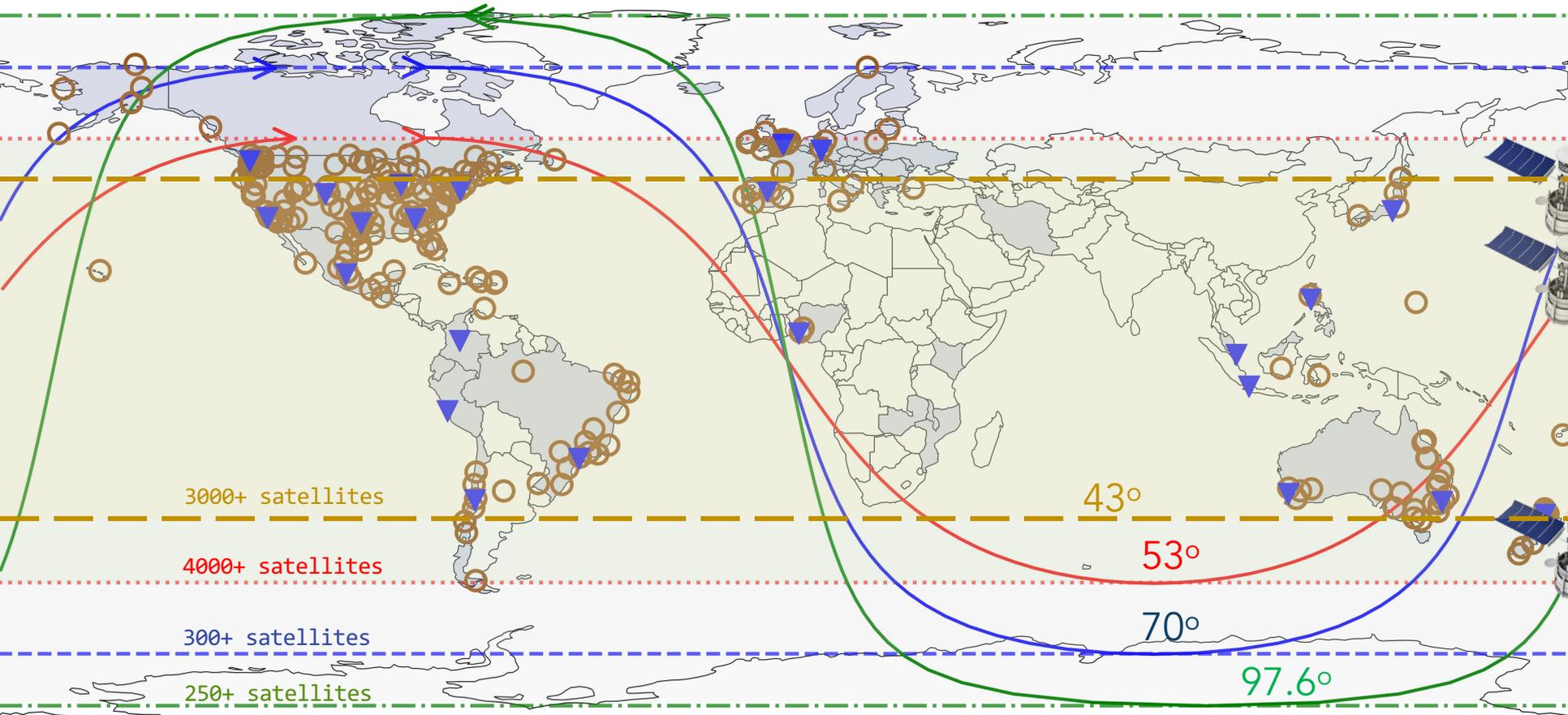
(1)

Satellite fleet which is deployed in multiple orbits

Starlink deploys majority in 43° and 53° orbital shell

○ Ground Station

▼ Point of Presence



Different regions globally will observe different satellite coverage and frequency

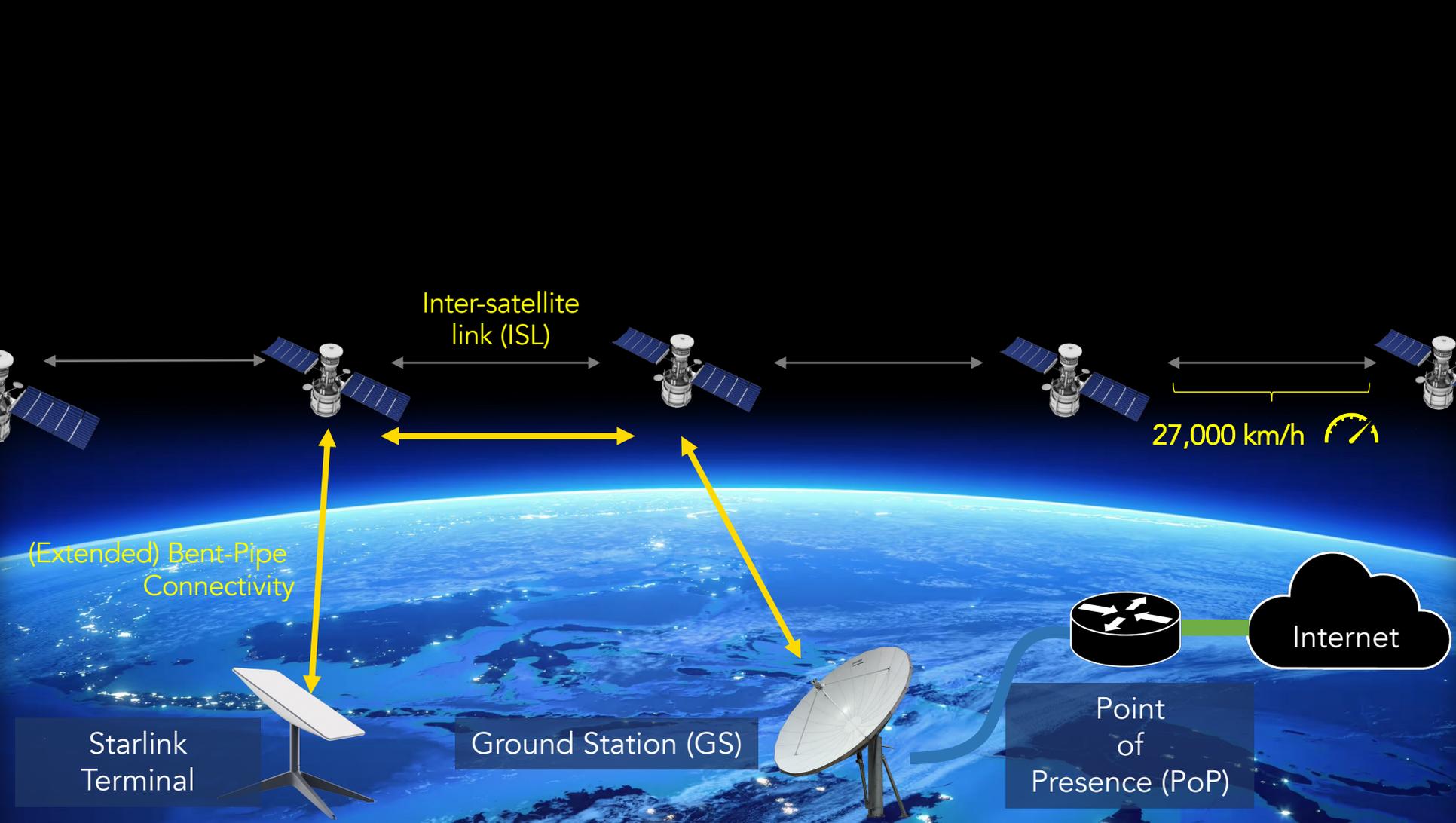


LEO ISP operations are dependent on two critical infrastructural aspects

(2)

LEO ISPs follows a "bent-pipe" connectivity

Satellites connect user terminals to Ground Stations



Inter-satellite link (ISL)

27,000 km/h

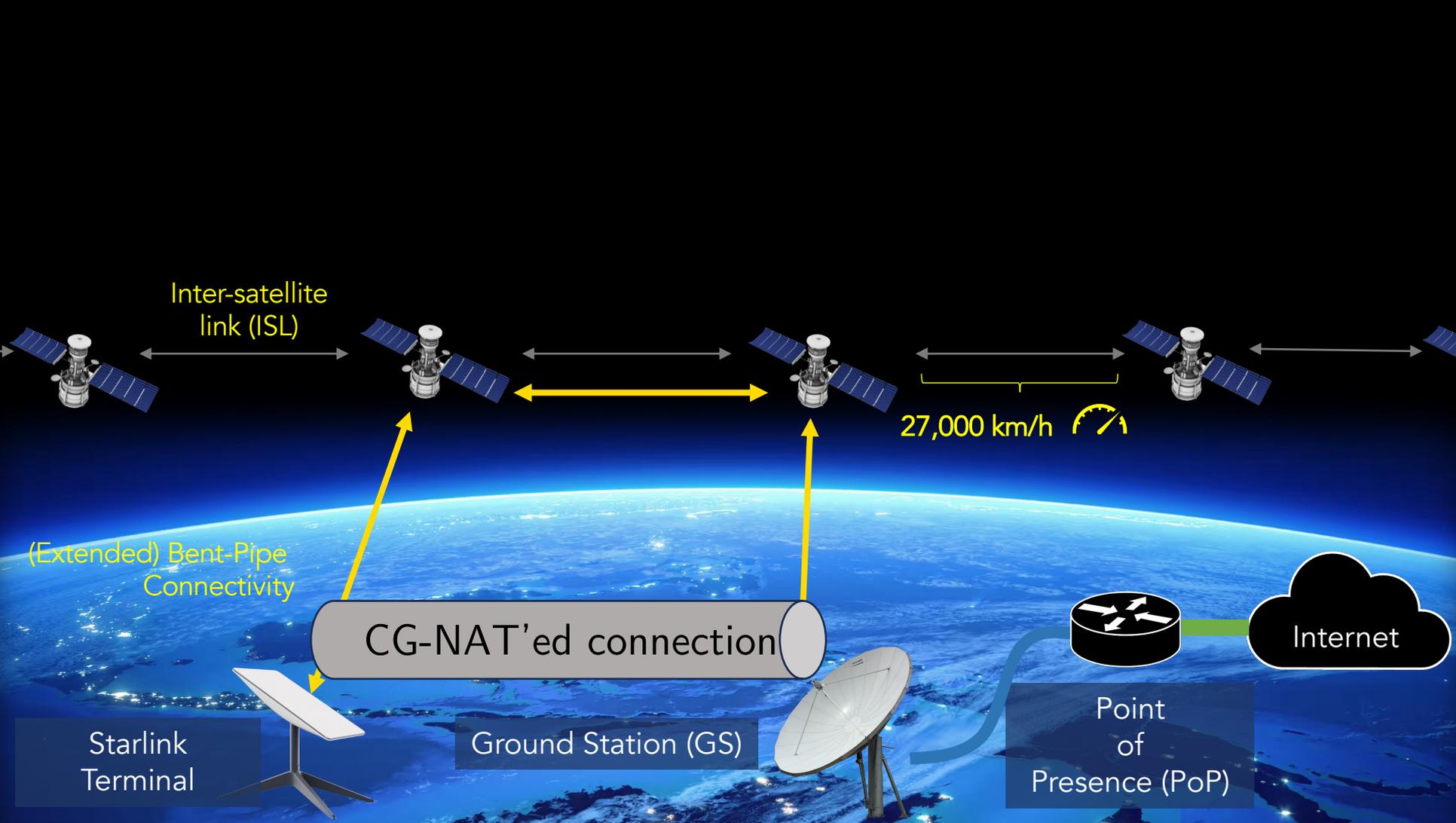
(Extended) Bent-Pipe Connectivity

Starlink Terminal

Ground Station (GS)

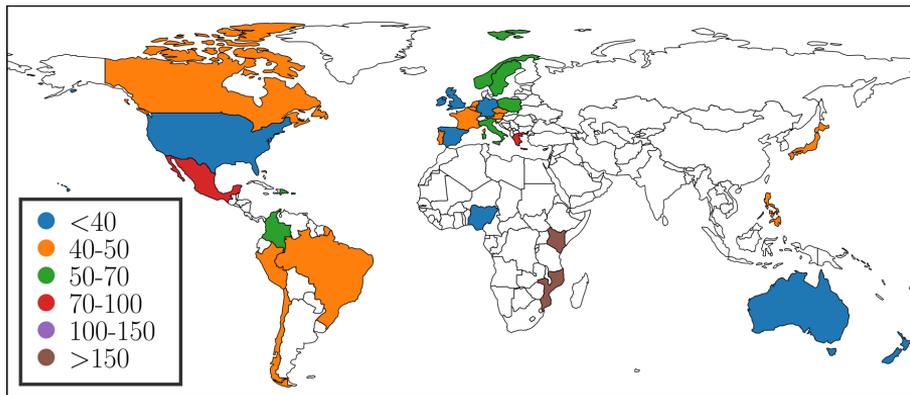
Point of Presence (PoP)

Internet

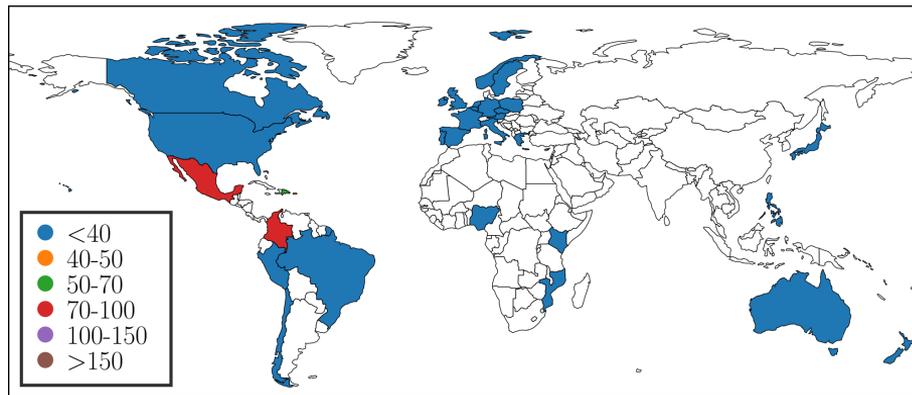


Global Performance

World View of Latencies



Starlink

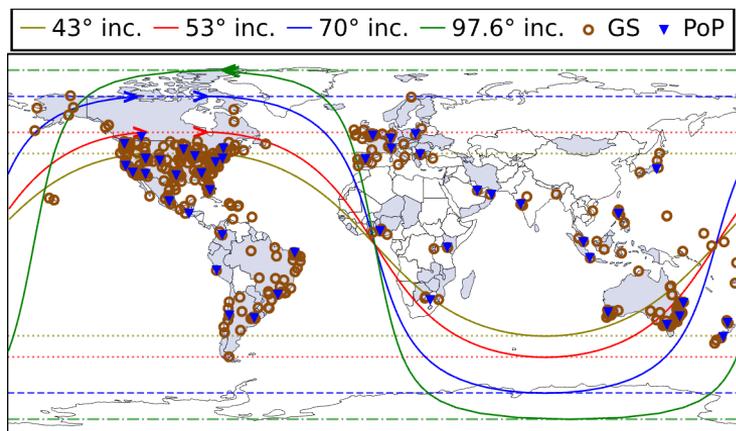


Top-3 mobile network operators

- Median latencies for Starlink is ~40-50 ms while mobile network latencies are ~30 ms
- Well-provisioned regions (such as NA and EU) enjoy the best Starlink latencies
- Starlink performs poorly in several regions with long tail latencies, e.g. Africa
- Not many regions where Starlink currently outperforms cellular

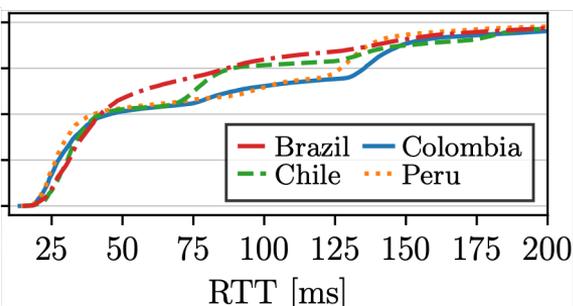
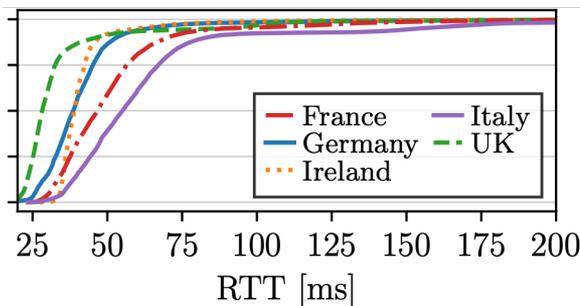
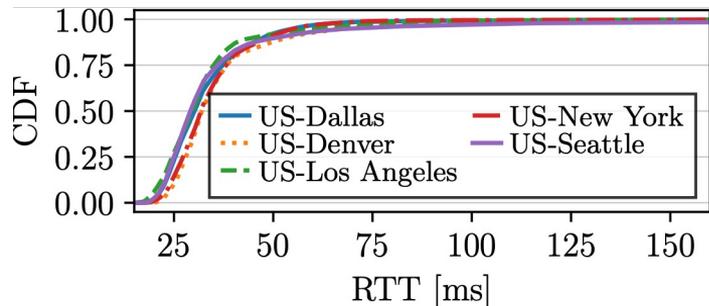
Global Performance

A Digital Divide?



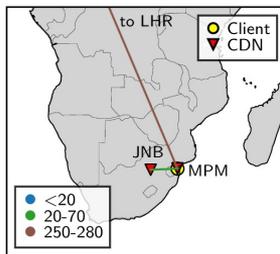
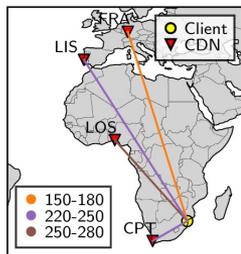
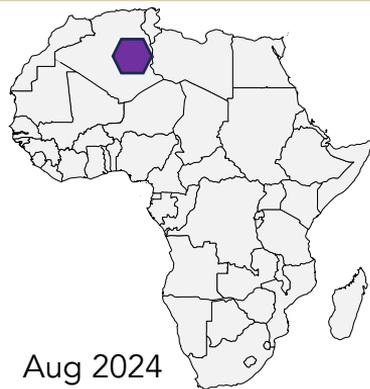
Clear impact of ground station infrastructure

- Consistent performance across USA due to dense ground infrastructure
- In EU, closeness to PoP means shorter latencies (e.g. Italy connects to PoP in Spain)
- Significantly higher latencies in SA, long distances between GSs and limited PoPs in the region



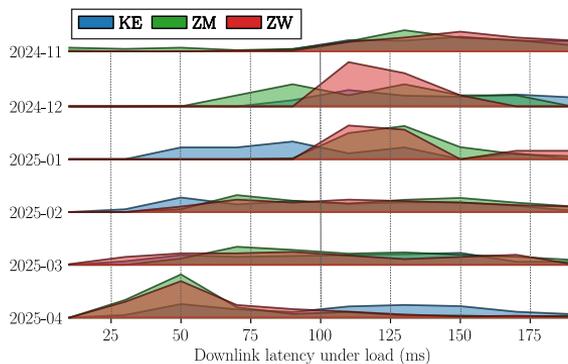
CDN Performance

Impact of terrestrial infrastructure



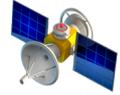
Several new PoPs and GS deployments in Africa that started becoming active starting Jan 2025

- Before new deployments, most of the CDN server mappings were in EU (DE and PT) compared to local fetches in terrestrial
- The majority of users were reassigned to Nairobi and Johannesburg PoPs from Jan 2025
 - DL loaded latencies reduced by almost 3x ($\cong 50 - 60$ ms)





Towards Space-Friendly Internet Future



Several open challenges as the ecosystem evolves and new market opportunities become evident

?

Dichotomy between satellite and terrestrial network operations

?

Democratizing space connectivity

?

Space computing:
Coming reality or
Pipe dream?

?

Beyond Earth-centric applications

?

Regulations, policies
and sustainability

?

Next steps for the
different
stakeholders

Dagstuhl Seminar 26062

Connected Space: Challenges and Opportunities in Satellite Computing and Networking

Feb 01 – Feb 04, 2026

Organizers ▷



Nitinder Mohan



Nishanth Sastry



Paulo Mendes



Brandon Lucia



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Tanya Shreedhar

Elif Uysal

Dan York



Seminar Structure



Academic

Industry

Policymakers

Participants from three key stakeholders of the ecosystem

Discussions across the following themes

NTN-TN
Architecture

Space-based
Use Cases

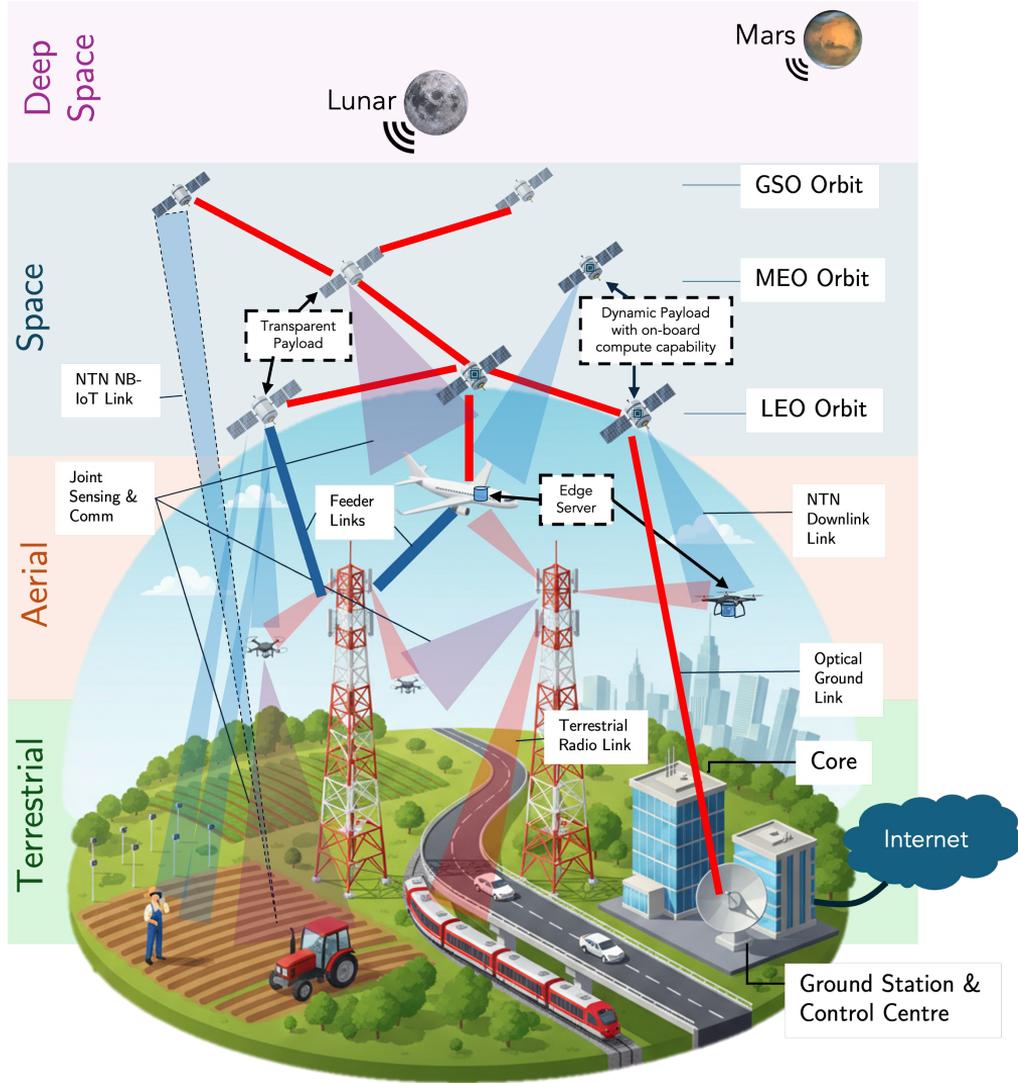
Interoperability
& Regulations

Space
computing

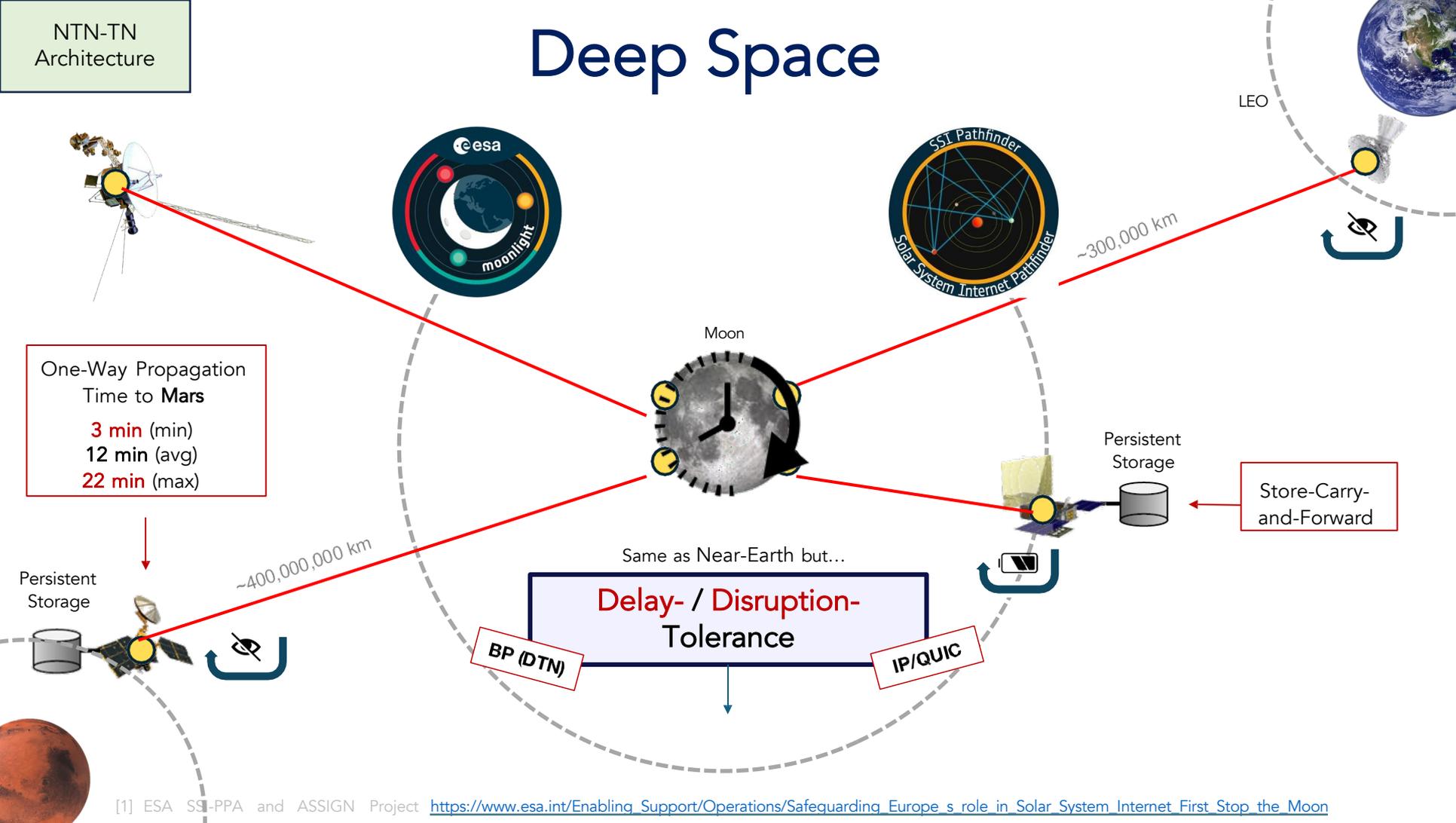
Security and
Resilience

NTN-TN Architecture

- The **3D-Network** is a dynamic network with changing topology
- Each Domain (space, air, ground) has its own characteristics
- Variety of communication technologies can be strung together to connect the ecosystem
- Protocol mismatch between space and ground networks
- Flexible solutions are required for transmission optimization



Deep Space



One-Way Propagation
Time to **Mars**

3 min (min)
12 min (avg)
22 min (max)

Persistent
Storage

Persistent
Storage

Store-Carry-
and-Forward

Same as Near-Earth but...

**Delay- / Disruption-
Tolerance**

BP (DTN)

IP/QUIC

Architecture Opportunities

- Clusters-as-AS: treating satellite clusters as autonomous systems unifies routing, security, and orchestration
- MEO/GEO as backbone eliminates ground-based controller dependency
- Ground Station as a Service (GSaaS) enables shared infrastructure
- Two-layer routing: interior (OSPF-like within cluster) and exterior (BGP-like between operators)
- Build simulation and emulation tools with accurate link dynamics
- Deep space as a natural extension

Link Optimization · Routing/Congestion handling · Function Placement

Space computing

There is a growing hype around datacenters in space

However, putting compute in space is hard

Are the use cases worth it?



Graphic Credit: Chuck Carter

How Starcloud Is Bringing Data Centers to Outer Space

The NVIDIA Inception startup projects that space-based data centers will offer 10x lower energy costs and 10x lower energy consumption on Earth.

Data centers are racing to space — and regulation can't keep up

Experts warn the move could shift critical infrastructure beyond national laws — deepening digital dependence for much of the developed world.



Musk vows to put data centers in space and run them on solar power but experts have their doubts

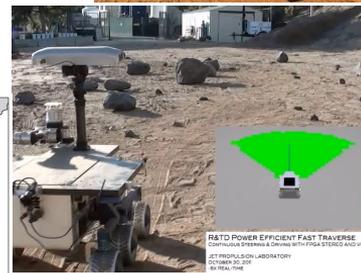
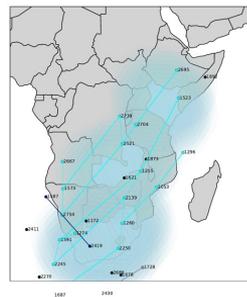
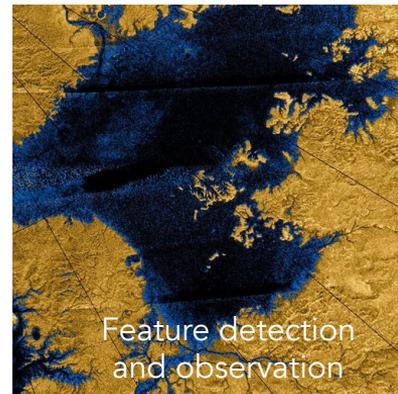
If Datacenters Go to Space, Heat Becomes the Hardest Problem

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*.

Opportunities

- Think beyond earth-based applications
 - Computing may make more sense for space-generated and consumed data
- Increasing Radiation Hardened Computing Capability Onboard
 - Voyager (8,000 instructions/sec and kilobytes of memory)
 - Curiosity (200 MFLOPS BAE RAD750)
 - Terrestrial Datacenter?
- Compute in Deep Space has clear advantages
- Compute coupled with content store?



Security Opportunities

- New security threats due to advancement of technology (e.g. quantum) that render corresponding solutions in space more challenging to implement (e.g. *Post Quantum Crypto in Space*).
- Increased interconnectivity => *increased attack surface*
- Adoption of terrestrial protocols in space may bring *new vulnerabilities on-board* that may have a bigger impact than in terrestrial implementations (e.g. 5G bootstrapping).
- Big constellations => other terrestrial security problems in space (e.g. secure routing)
- *Solutions that may not be available in space* (e.g. PKI) may limit use cases (e.g. federated systems).
- High-speed networks in space => fog/edge computing of user data => *confidential computing* in space
- *Key management* in missions with several nodes and high constraints (e.g. DTN), and not only.
- *(multi)Payload-as-a-service* => need for internal spacecraft segregation
- ...and combine

Policy Challenges

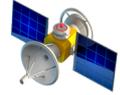
- Affordability
- Interoperability
- Vendor lock-in and e-waste
- Security
- Privacy
- Resilience
- Open standards
- Space debris
- Success of business models – financial sustainability
- Environment / climate sustainability
- Reliability
- Spectrum sharing
- Gateway/Ground Stations
- Consolidation
- Competition
- Control by US corporations (and billionaires in particular)
- Space weather
- Impact on astronomy

Standards as ecosystem enablers: reduce CAPEX/OPEX,
enable innovation and technology transfer





Towards Space-Friendly Internet Future



Keep a look out for the full report!

- There is plenty of pressing problems in the field that requires attention
- The stars are aligning – market needs are matching the technological requirements for space networking
- Several concerns and challenges on policy, regulation, standardization need immediate attention

<https://leo-net-workshop.github.io/>

LEO-NET 2026

The 4th ACM Workshop on LEO Networking and Communication

Denver, Colorado, USA

August 17th, 2026
Submission deadline: 1 May



This week

Systems and Protocol Aspects for
Circumstellar Environments Research
Group SPACERG

