

NTN Systems Interoperable with Terrestrial Networks

Marco Brancati

Senior Vice President at Telespazio Group

Vice-President of Space Exploration Commission at the “Ordine degli Ingegneri” of Province of Rome

Evolution of Satellite NTN Interoperable with Terrestrial Networks – Panel 2

NSE - Roma

16-17th December, 2024



Satellite systems and the new Terrestrial Network: a new alliance

Satellite technologies have always had a relationship of integration and competition with the terrestrial network which has changed profoundly over time:

- ❑ 1960s: the satellite was essential for transoceanic telecommunications in competition and integration with submarine cables;
- ❑ 1980s: the satellite was dedicated to rural and suburban connections, maritime and air communications and in general to mobile communications over large spaces;
- ❑ 1990s, where digital television distribution found satellite to be an optimal solution for business growth.

More recently, in the first ten years of the new millennium, satellite has evolved towards IP networks with the new generation of high capacity multi spot satellites (in which Italy had been a pioneer with the ITALSAT satellite), such as Eutelsat/ViaSat Ka-Sat and more recently with Eutelsat Konnect VHTS, which can cover large regions of the Earth with hundreds of spots and overall bit rates of a few hundred **Gbps**.

In parallel, with the enormous development of digital cellular telephony, which began in the early 1990s, we must remember the start of the season of constellations in low orbit, starting with **Globalstar** and **Iridium**.

The new Satellites: enormous capacity compared to the previous generation

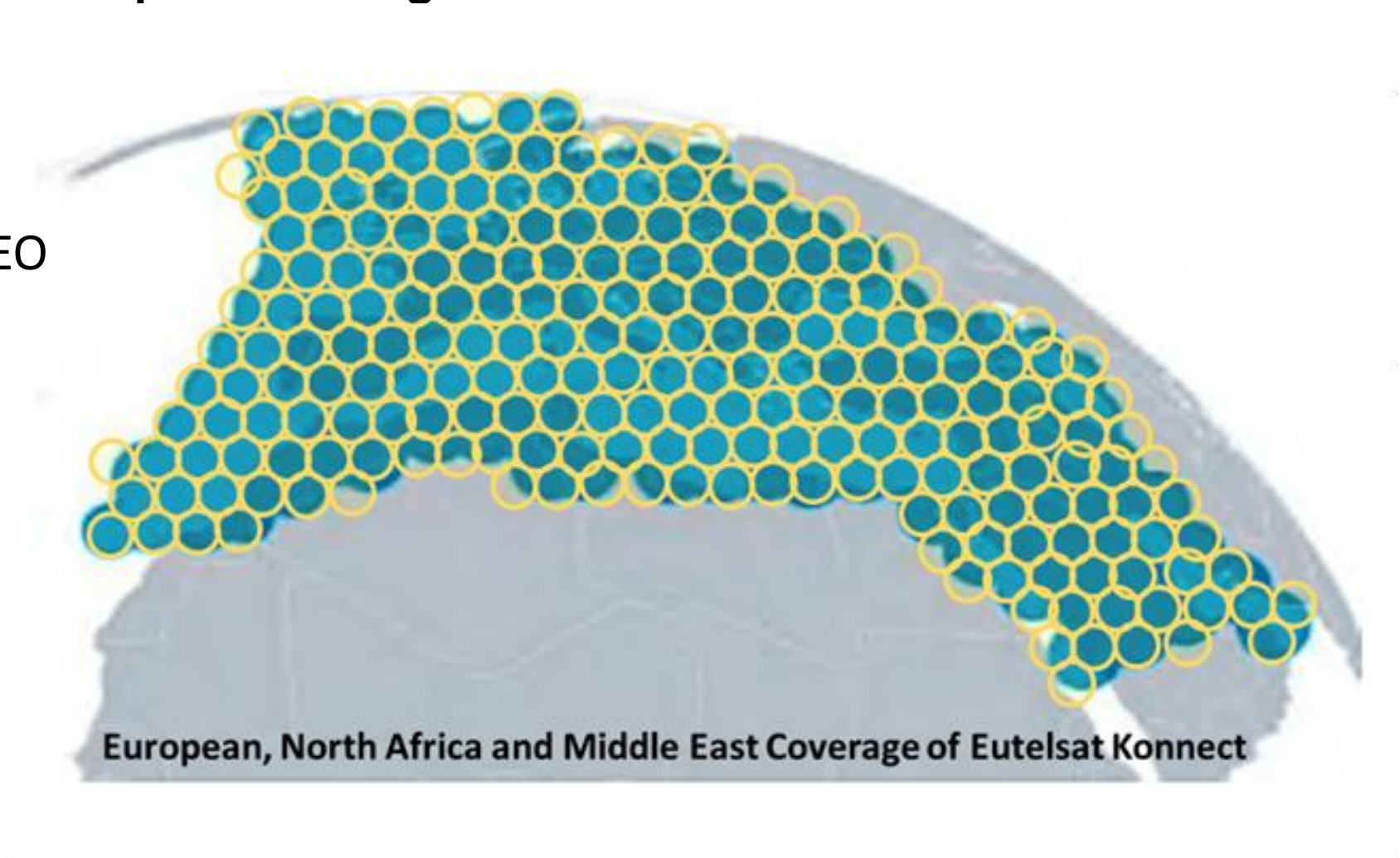
- ❑ In recent years, satellites and satellite constellations have made a big leap towards broadband and the availability of such services based on the **Full IP** paradigm.
- ❑ These large bandwidth availability can be integrated with terrestrial networks in the vision that **5G/6G** has placed as fundamental:
 - the network virtualization
 - the latency, resilience and security of the connection
 - the availability of guaranteed quality services.

The new broadband satellites are positioned in a completely new way towards the terrestrial network. Both GEO and new generation LEO satellites (VHTS and Mega Constellations satellites) are based on a large number of ground Hub stations. These stations are the key access points for new telecommunications satellites, being the necessary link between the IP network and the satellite users.

- ❑ Each Hub station is in fact assigned to a certain number of spots in the case of a GEO satellite and to cover a defined geographical area in the case of a constellation of LEO satellites.
- ❑ The connection between different points of the satellite network can only take place if the Hub stations on the ground are connected to each other with a fiber optic network which allows us to assume that from a topological point of view there is not a single logical access to the satellite network itself.

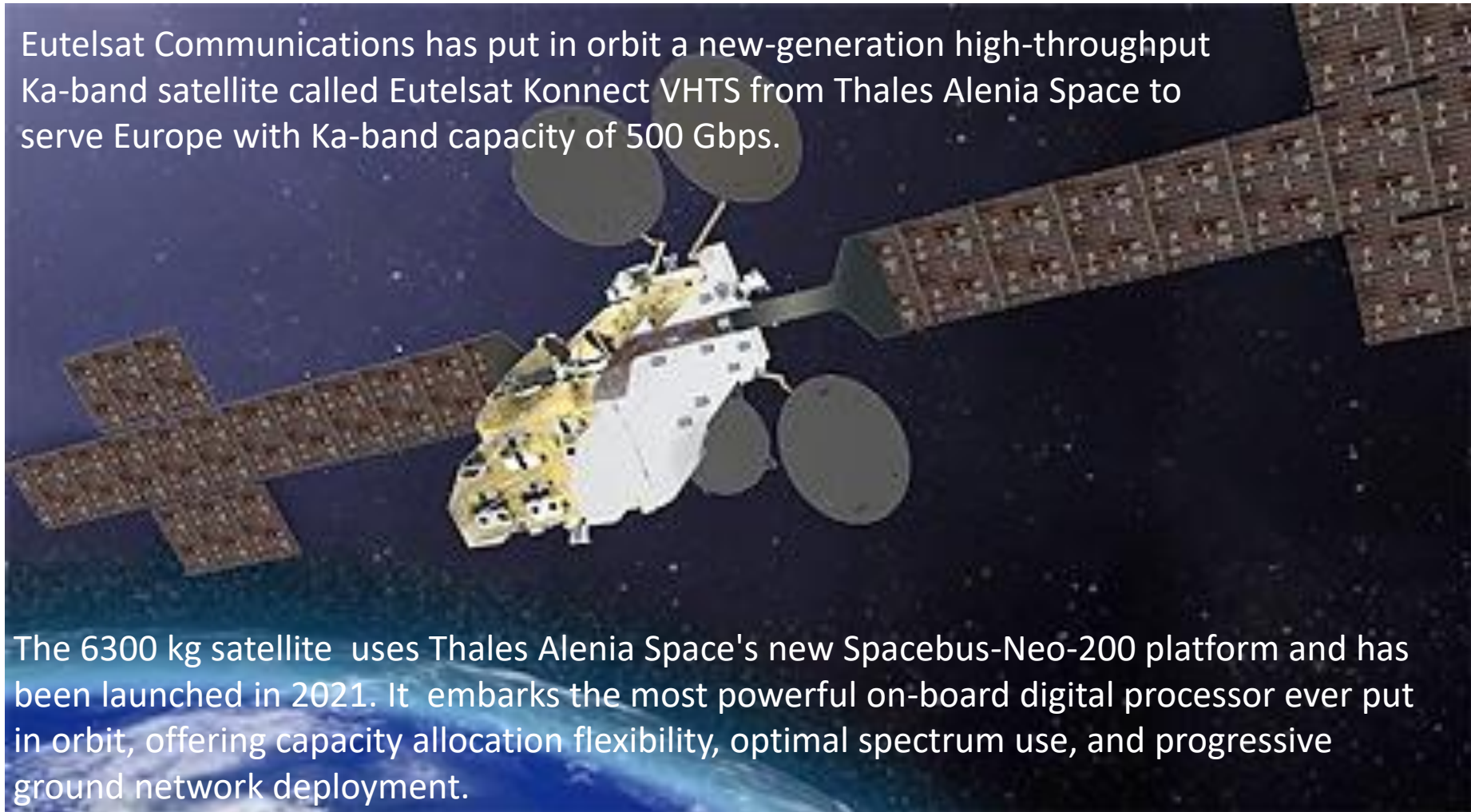
A VHTS GEO extended European Coverage

An example of VHTS GEO
Satellite Coverage
(KONNECT Satellite).
More than 200 spots;
500 Gbps Capacity



The VHTS Konnect

Eutelsat Communications has put in orbit a new-generation high-throughput Ka-band satellite called Eutelsat Konnect VHTS from Thales Alenia Space to serve Europe with Ka-band capacity of 500 Gbps.



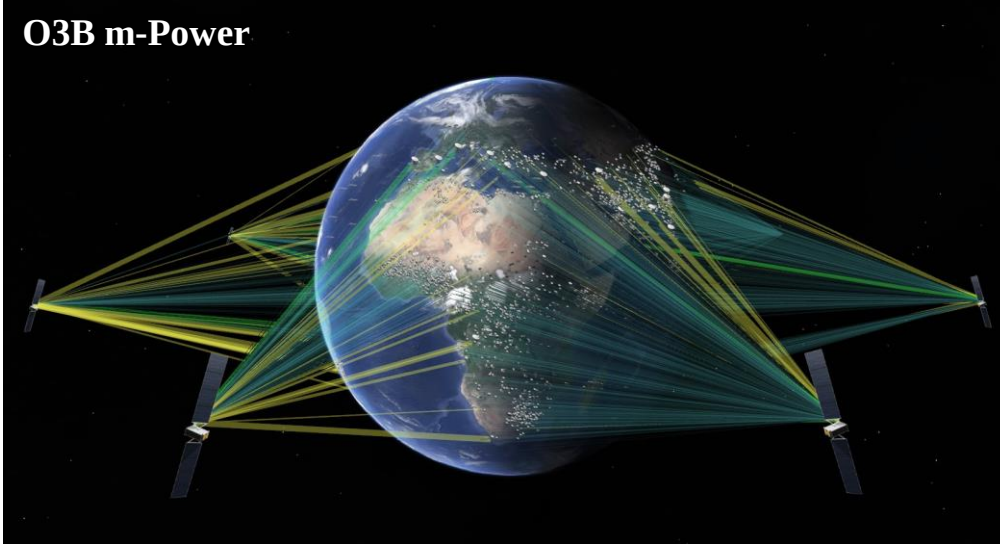
The 6300 kg satellite uses Thales Alenia Space's new Spacebus-Neo-200 platform and has been launched in 2021. It embarks the most powerful on-board digital processor ever put in orbit, offering capacity allocation flexibility, optimal spectrum use, and progressive ground network deployment.

Very High Throughput LEO Constellation network

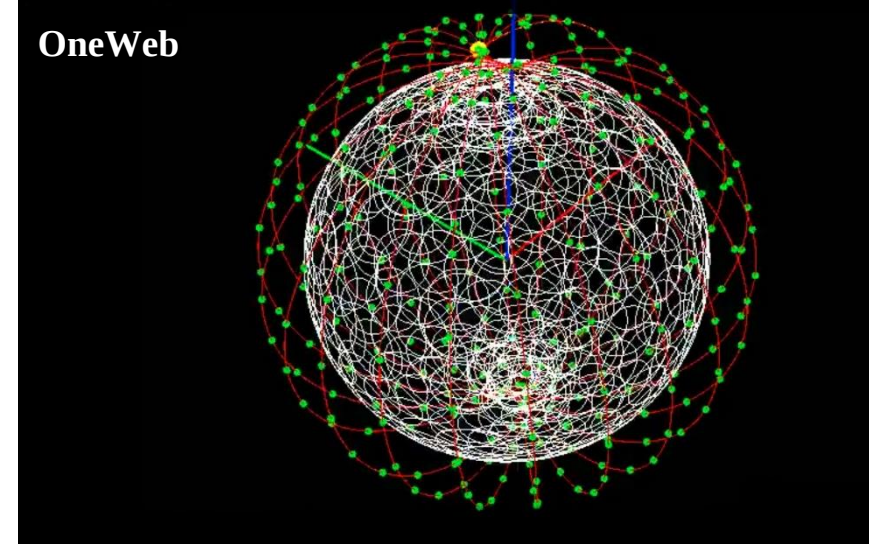
- Very High Throughput LEO satellite constellations have established themselves over the last 10 years thanks to the rapid decrease in launch costs, the introduction of innovative technologies for in-orbit control and propulsion subsystems, the availability of components for low-orbit satellites electronics closer to aeronautical technology rather than the electronic technology used for GEO. All this has facilitated access to the satellite market.
- In particular, there are some constellations (for example: STARLINK, with around 12,000 satellites in low Earth orbit for its first generation and OneWeb, with around 2,000 when fully deployed) capable of providing broadband access to a very large number high number of users.
- The flexibility of LEO constellation-based networks can increase the level of cyber protection by participating in the overall protection process; indeed:
 - cyber attackers should know the radio characteristics of the satellite used (position, doppler, range used, passage between satellites, possible use of the intersatellite connection, etc.)
 - the speed of satellite parameter changes is very difficult to emulate (the visibility window for communication typically lasts a few minutes).

MEO and LEO CONSTELLATIONS

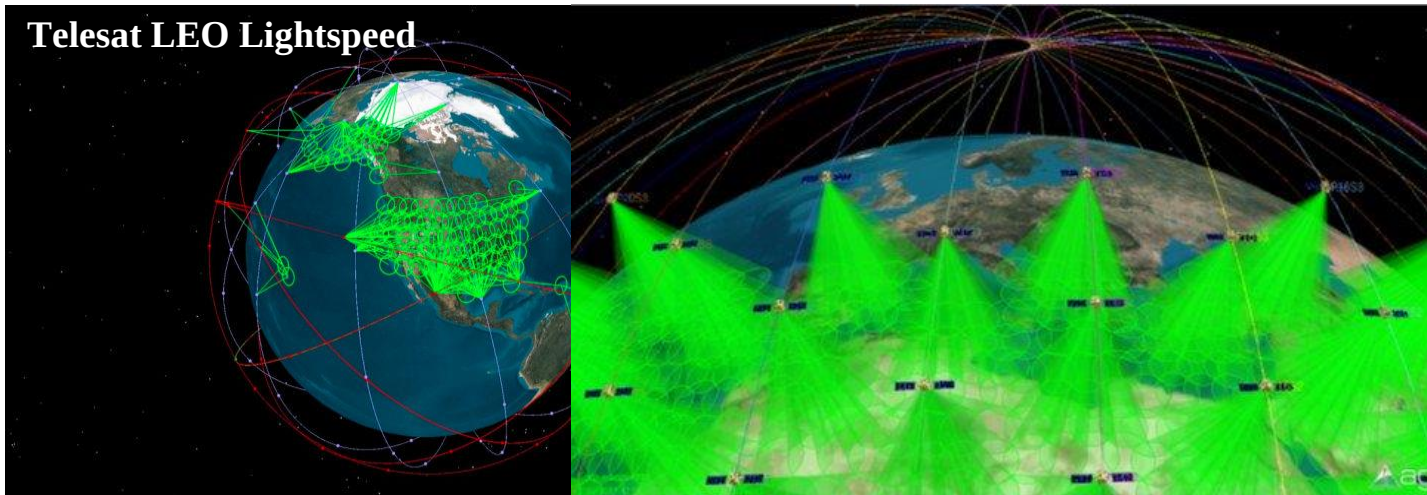
O3B m-Power



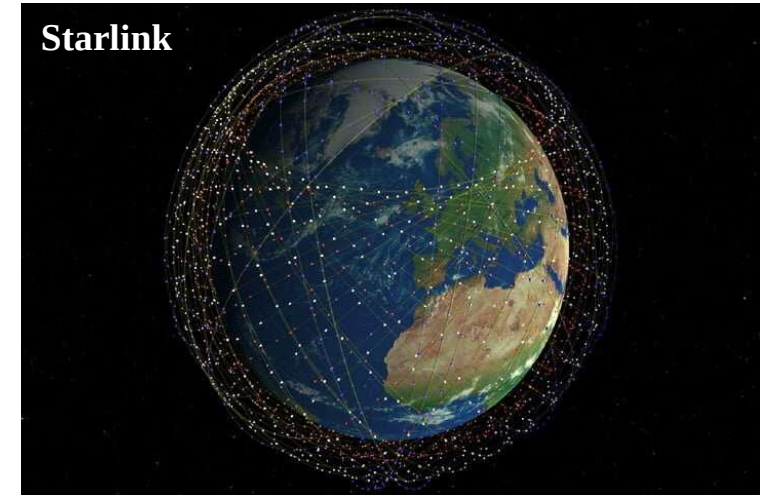
OneWeb



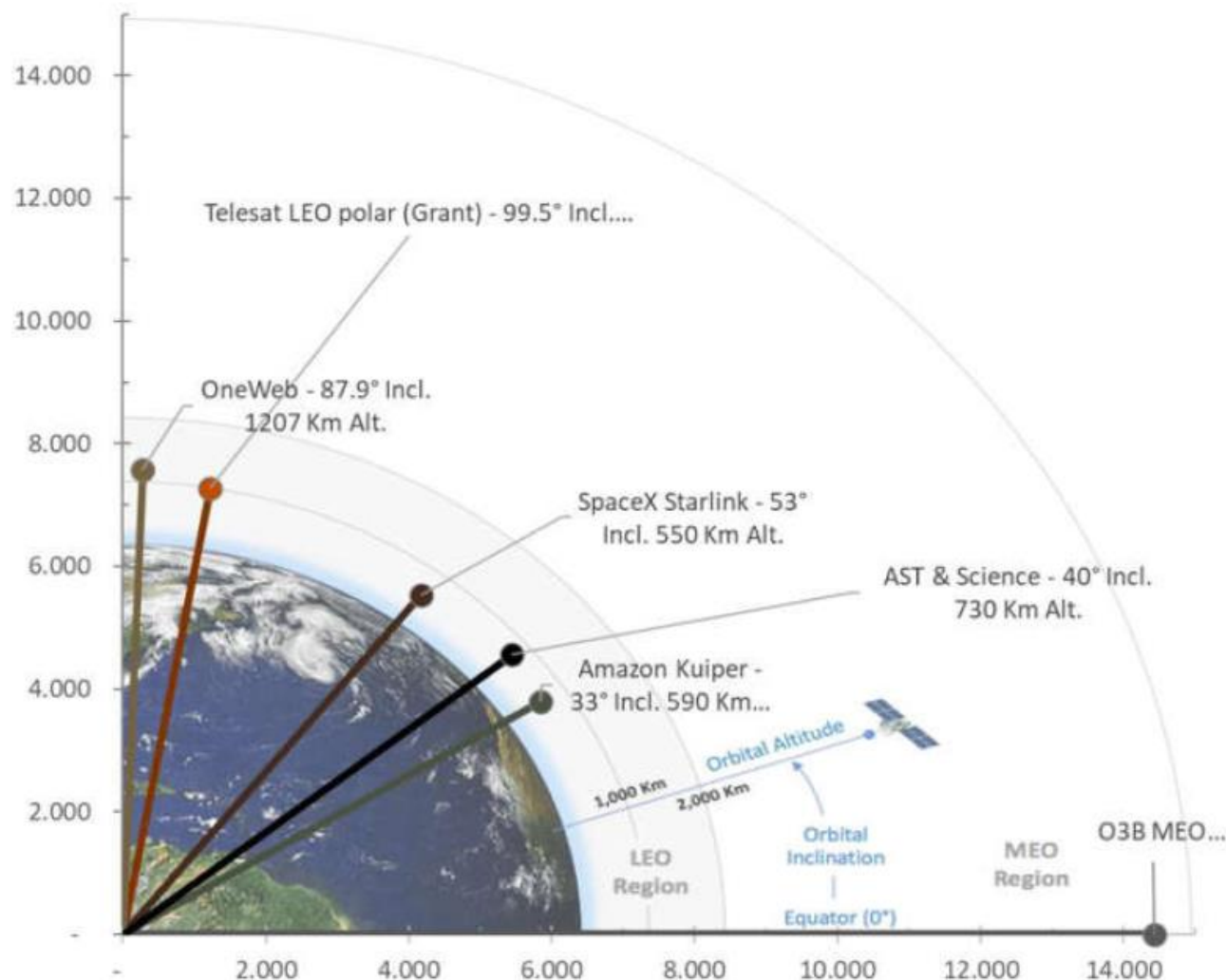
Telesat LEO Lightspeed



Starlink



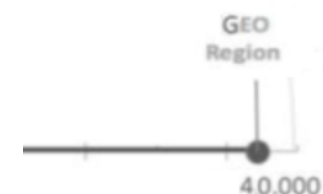
Example of a shell for some constellations, indicating altitude and inclination



A special feature of the OneWeb constellation is its use of polar orbits. Unlike Starlink or Amazon Kuiper, OneWeb satellites pass over both polar regions of the Earth with each orbit.

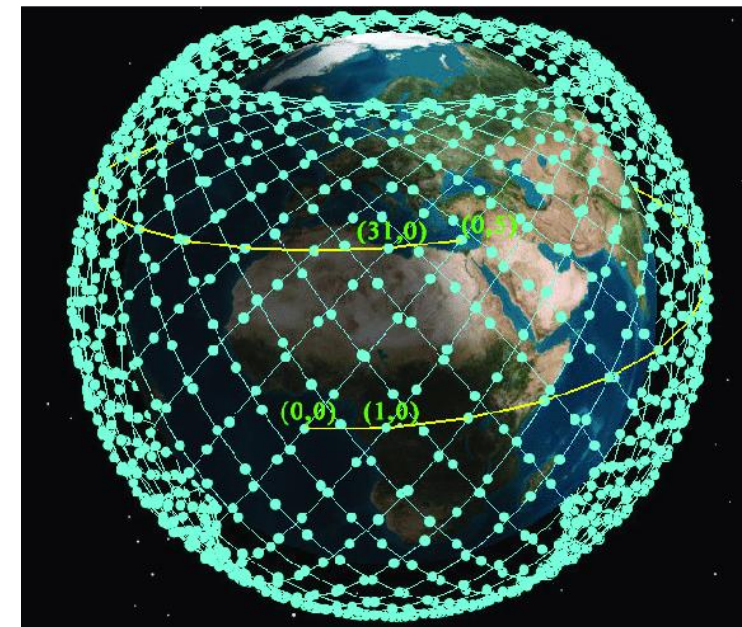
This allows coverage of the Earth's entire surface with the communication services provided by OneWeb.

However, due to the geometry of the constellation, there is a concentration of satellites over the polar regions and a sparseness over the Equator.



StarLink constellation

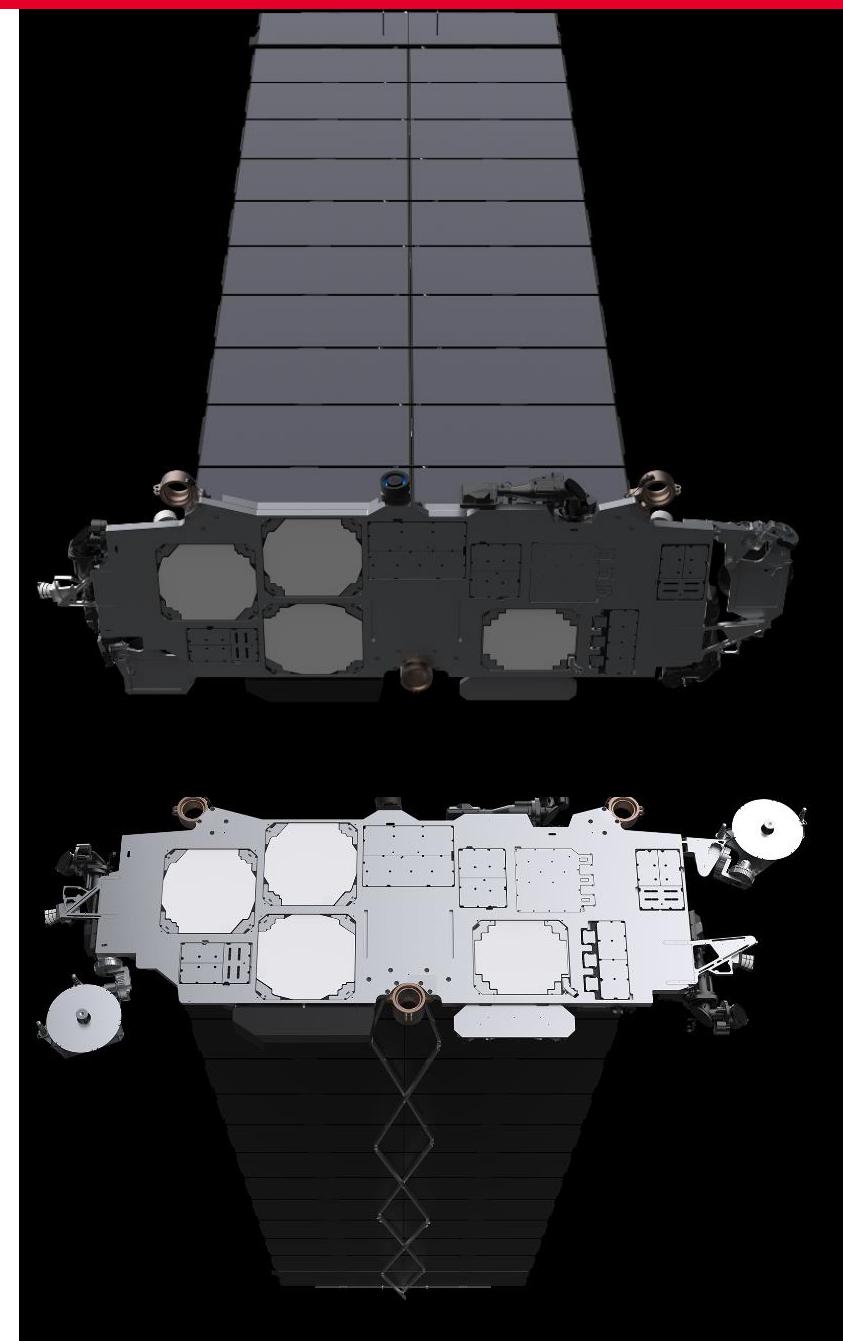
- **First Starlink constellation** was planned to consist of thousands of small LEO satellites, deployed in **three shells** (layers), dedicated to maximize broadband internet services toward global Earth coverage, and combined with ground stations (trans-receivers), to be organized as a satellite-terrestrial integrated network.
- In total, **nearly 12,000 satellites** are planned to be deployed by March 2027 and organized in three orbital shells, as follows:
 - **The first shell:** 1,584 in a 550 km altitude shell.
 - **The second shell:** 2,825 in a 1,110 / 1325 km altitude shell.
 - **The third shell:** 7,500 in a 335 / 345 km altitude shell.
- As of today, about **7,200 satellites are in orbit**
- **Second Starlink constellation** was planned to include **29,988 satellites**. To reduce impact to astronomy services as well as to prevent risks of collisions in orbit, as of today FCC provided authorization only for **7,500 satellites**, to be placed in a 335 / 345 km altitude shell.
- **First batch of 54 satellites** was launched on Feb. 3rd, 2023



StarLink peculiarities (1/2)

Satellite technology

- **Antennas** – Each Starlink satellite uses 4 powerful phased array antennas and 2 parabolic antennas
- **Autonomous collision avoidance** – Starlink satellites autonomously maneuver to avoid collision with orbital debris and other spacecrafts. This capability reduces human error and provides exceptional reliability, exceeding the industry standard by an order of magnitude
- **Star tracker** – Starlink navigation sensors survey the stars to determine each satellite's location, altitude and orientation, enabling precise placement of broadband throughput
- **Optical space lasers** – Starlink is testing fully operational, optical space lasers on its satellite to provide **ISL** capabilities, which allow the spacecraft to transmit data without local ground stations, providing truly global coverage
- **Ion propulsion system** – Efficient ion thrusters, powered by krypton, enable Starlink satellites to orbit raise, maneuver in space and deorbit at the end of their useful life. Starlink is the first krypton propelled spacecraft ever flown
- **Singular solar array** – Starlink satellites feature a single solar array, significantly simplifying the system. Solar cells are standardized, and easy to integrate in the manufacturing process



StarLink peculiarities (2/2)

User Terminals

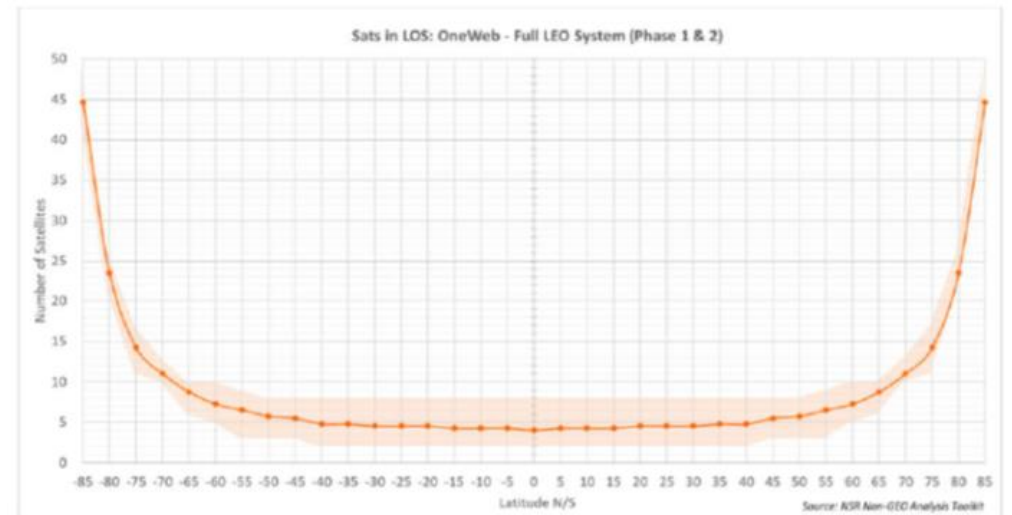
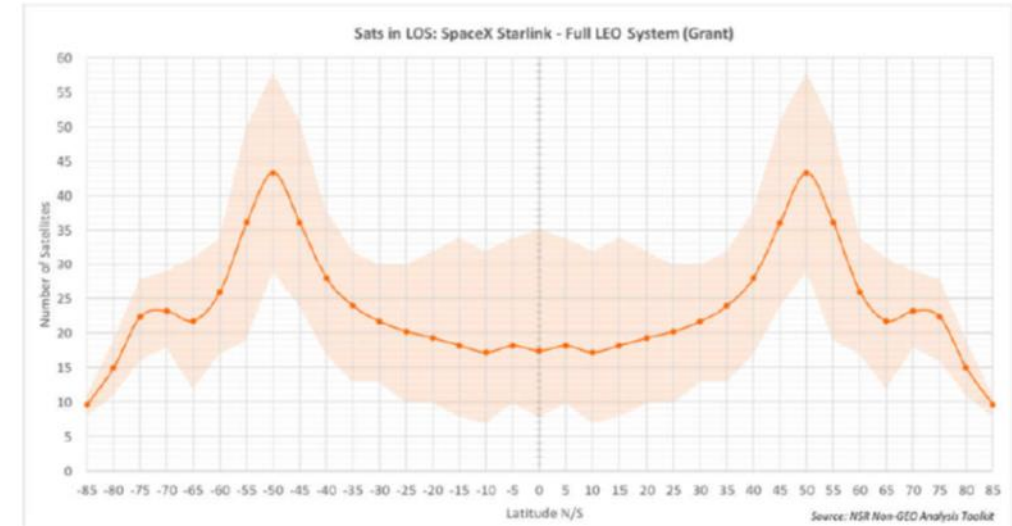
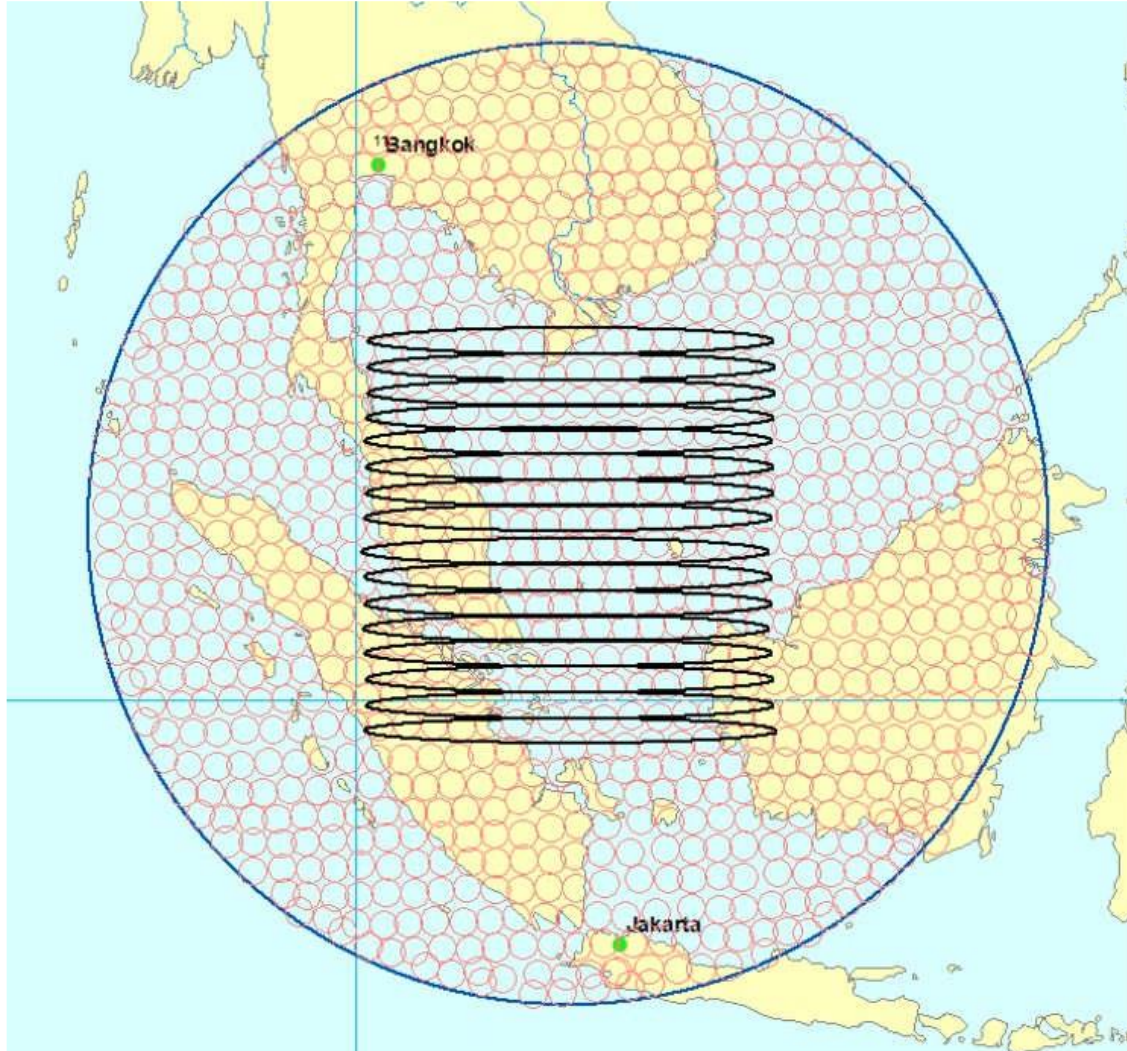
- Starlink terminals are the first commercially available phased array antennas
- They have self-orienting capabilities, therefore enabling a self-install procedure
- Available in 3 typologies:
 - **Standard – 51,3 cm dish** - Best for residential users and everyday internet applications like streaming, video calls, online gaming & more



- **High Performance – 57,5 cm dish** - Best for power user, business, and enterprise applications. It allows better speeds at high temperatures, can connect to more satellites, and is more resilient to extreme environments.
- **Flat High Performance – 57,5 cm dish** - Designed for mobility applications and challenging environments. With a wide field of view and enhanced GPS capabilities, it can connect to more satellites, allowing for consistent connectivity while on the go. The hardware is designed for a permanent installation and is more resilient to extreme environments. Currently the only designated dish for in-motion use in approved countries.



StarLink (red) and OneWeb (black, elliptical) Beam Pattern & LOS satellites



New constellations main characteristics

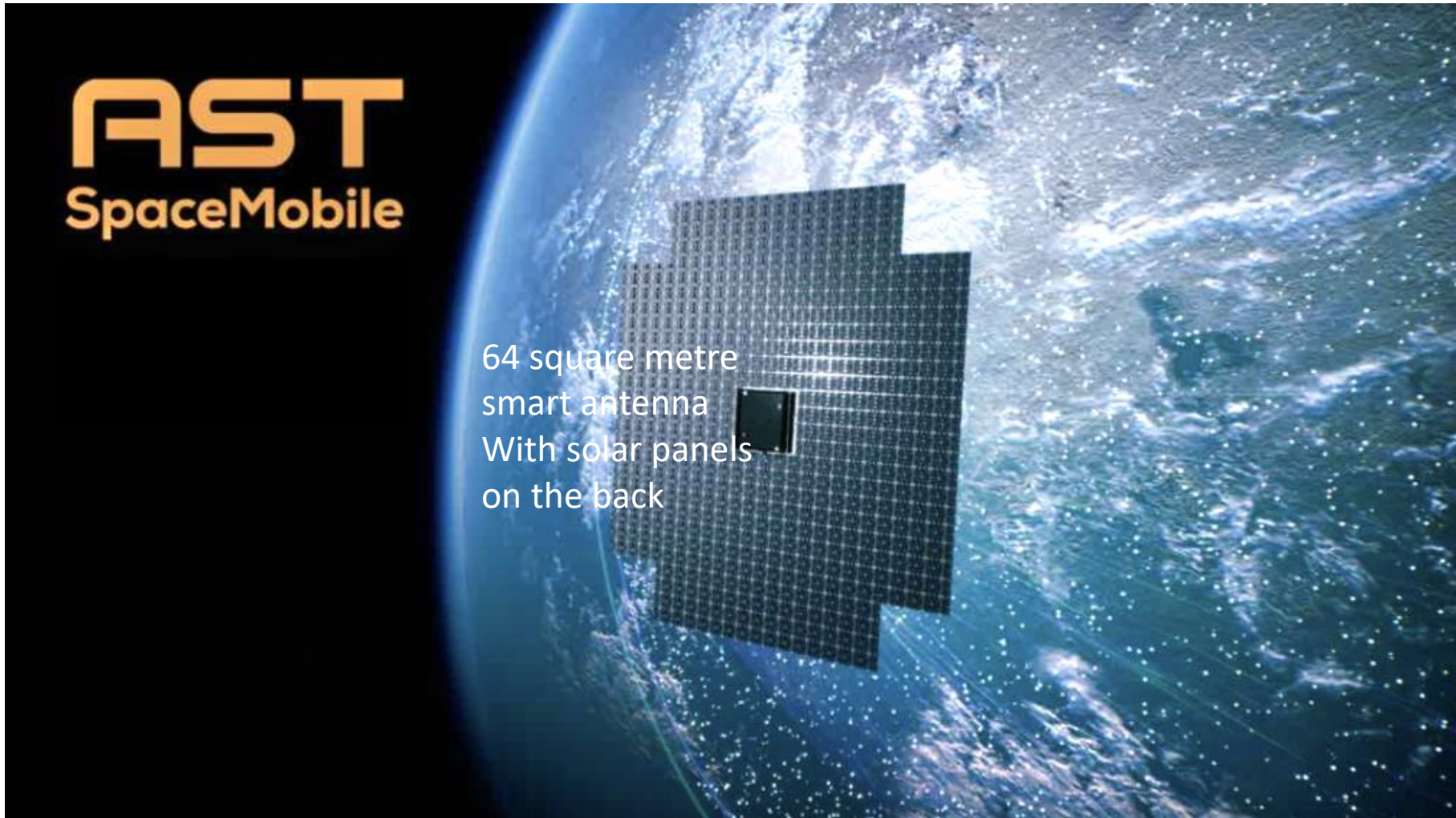
	Orbit Inclination	Orbit Altitude (Km)	Satellites per shell	Total
O3B mPower	0°	8062	10	34
	90°	8052	24	
Telesat LEO	98.98°	1015	78	298
	50.88°	1325	220	
Telesat VLEO	37.4°	1284	45	117
	99.5°	1000	72	
Kuiper	33°	590	784	3236
	42°	610	1296	
	51.9°	630	1156	
Starlink LEO	53°	550	1584	4409
	53.8°	1110	1600	
	74°	1130	400	
	81°	1275	375	
	70°	1325	450	
Starlink VLEO	53°	345,6	2550	7500
	48°	340,8	2450	
	42°	335,9	2500	
OneWeb	87.9°	1207	660	1980
	87.9°	1207	1320	

Satellite Constellation evolution towards the direct connection with smart phones

The evolution of LEO Satellite constellations towards the direct connection to smart-phones is allowed by:

- the advancements in the 3GPP form on NTN
- a few enabling technologies on board of satellite constellations:
 - new mMIMO multibeam antennas based on phased array with radiating diameters of a few meters, such as AST project
 - new RAN (Radio Access network) station capable to work on board and on ground with a suitable share of functions and SW between the space and the terrestrial segments
- the smart phone level to implement the doppler compensation aspects at reasonable costs and using proper miniaturised technologies
- 3GPP Release 17 introduces new network topologies into the 3GPP specifications that include high-altitude platforms (HAPS) and Low Earth Orbit and Geosynchronous orbit satellites. New constellations of satellite deployments and work at 3GPP have provided a possible pathway for closer integration of terrestrial and non-terrestrial network.

Artistic view of large onboard smart antenna



Space Cloud /1

Hardware limitations to solve to more fully utilize AI for space applications

Current AI models are trained and consume a large quantity of HW resources; the challenge is therefore on both side:

- Change the way models are executed by differentiating massive trainings from the actual computation
- Evolve the HW on the space / satellite platforms to cope with increasing requirements in terms of resources.

In space you have a lot of particle radiation, electrons, protons, heavy ions, as well as gamma rays and X-rays, and all of these things have a particularly harsh effect on microelectronics. Space is unfriendly to computers and getting AI-capable chips up for the task takes time and money.

Making AI chips fit for space: **computers in space die faster and don't work as reliably as those on Earth, unless they are designed to survive in the unforgiving environment.** The qualification process takes up to three years and involves rounds of testing including temperature cycling that simulates the frequent temperature changes in orbit, shaker tables that recreate the uproar of the launch and irradiation chambers that allow the engineers to verify the devices' ability to withstand radiation. Then, in addition to be robust against radiations, it shall also be resistant to wide range temperature variations.

Space Cloud /2

In November 2022 AMD released what they described as the first commercially available space-qualified chip capable of running complex AI and machine learning algorithms in real time. The company followed up on their first space-grade product in September 2023 with the Versal AI Core XQRVE2302, which is significantly smaller and about 75% less power hungry.

Implications: how do we consider information and data security in space-focused applications

The treatment of data is fundamental in space applications as they could manage heterogeneous AI datasets fusing together different level of confidentiality, from personal and sensitive data (in Europe we have GDPR regulation), to customer confidential data.

In this case the approach by **federated AI** is crucial to assure at the same time the confidentiality of a particular training dataset and the effective and efficient training of the model with no need of managing data all together at the same time.

Space Cloud /3

Data and Development: where should the data and processing reside for space-focused AI applications?

- Space system should evolve more and more towards a distributed IoT system of systems, leveraging and fully exploiting the “**on the edge**” computing. Given that there are on-going mission studies for Space Clouds (e.g.: see LDO e TPZ project), the type of AI algo running directly on the platform should be carefully selected depending on the Use case. A first approach has focused on initial task, such as detecting **and filtering images with bad quality** or cloud detection. An example of these missions are the ESA Phi Lab mission phi-sat 1 and phi-sat 2, or Loftorbital, which offers a renting of on board AI computing resources to develop new application.
- “Finally, the future could imagine a “**Semantic Communication network**” where only the interesting information is transmitted on ground, with no requirement of huge bandwidth to transfer image data.
- The data is recorded on the satellite, but we don’t have enough bandwidth to send all of it back to Earth. In many instances, important information doesn’t reach Earth at all or only with a significant delay. **Therefore, dataset through which we train on ground our algorithm are incomplete.** AI in space could make a huge difference—limit damage to the environment, save cost and possibly human lives.

Space Cloud /4

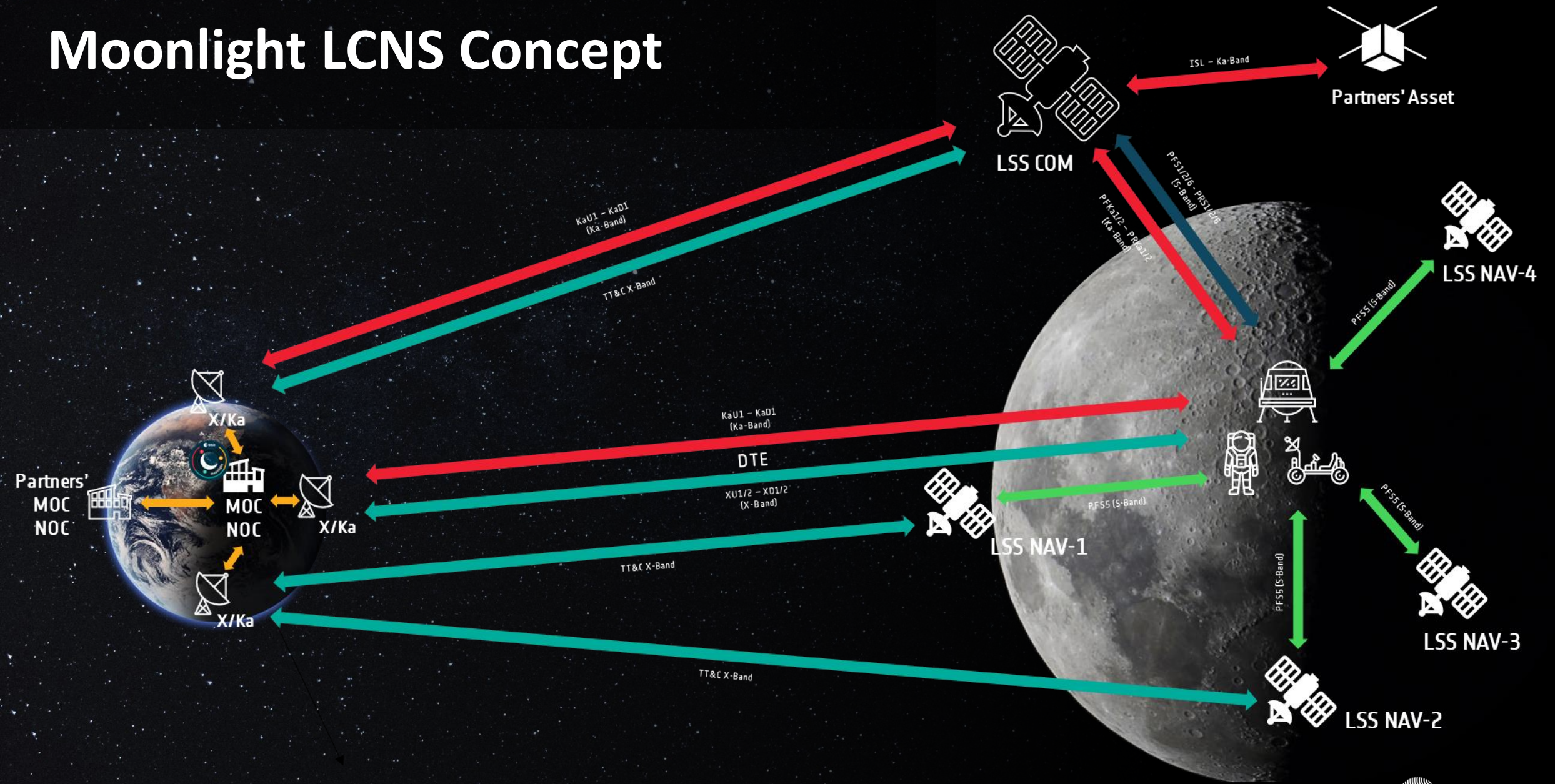
What are the existing limitations to space-based AI applications?

Power generation and computer resources being core themes so far.

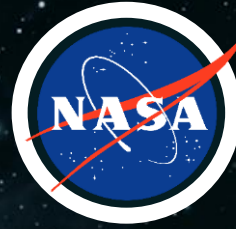
At the moment, the AI models are eager to consume resources, and this is leading to a disruptive spiral with respect to resources consumptions also in terms of environment sustainability.

- Development of Frugal AI techniques.
- HW manufacturers are designing new way of running AI, not only by mean of GPU, but on simple and smaller CPUs with less power consumption.
- We can imagine that on the medium-long term the HW manufacturers on one side and the data science community on the other side will find a way to have lightweight models already pre-trained and capable to run on smaller HW.

Moonlight LCNS Concept



**GNSS
satellite**



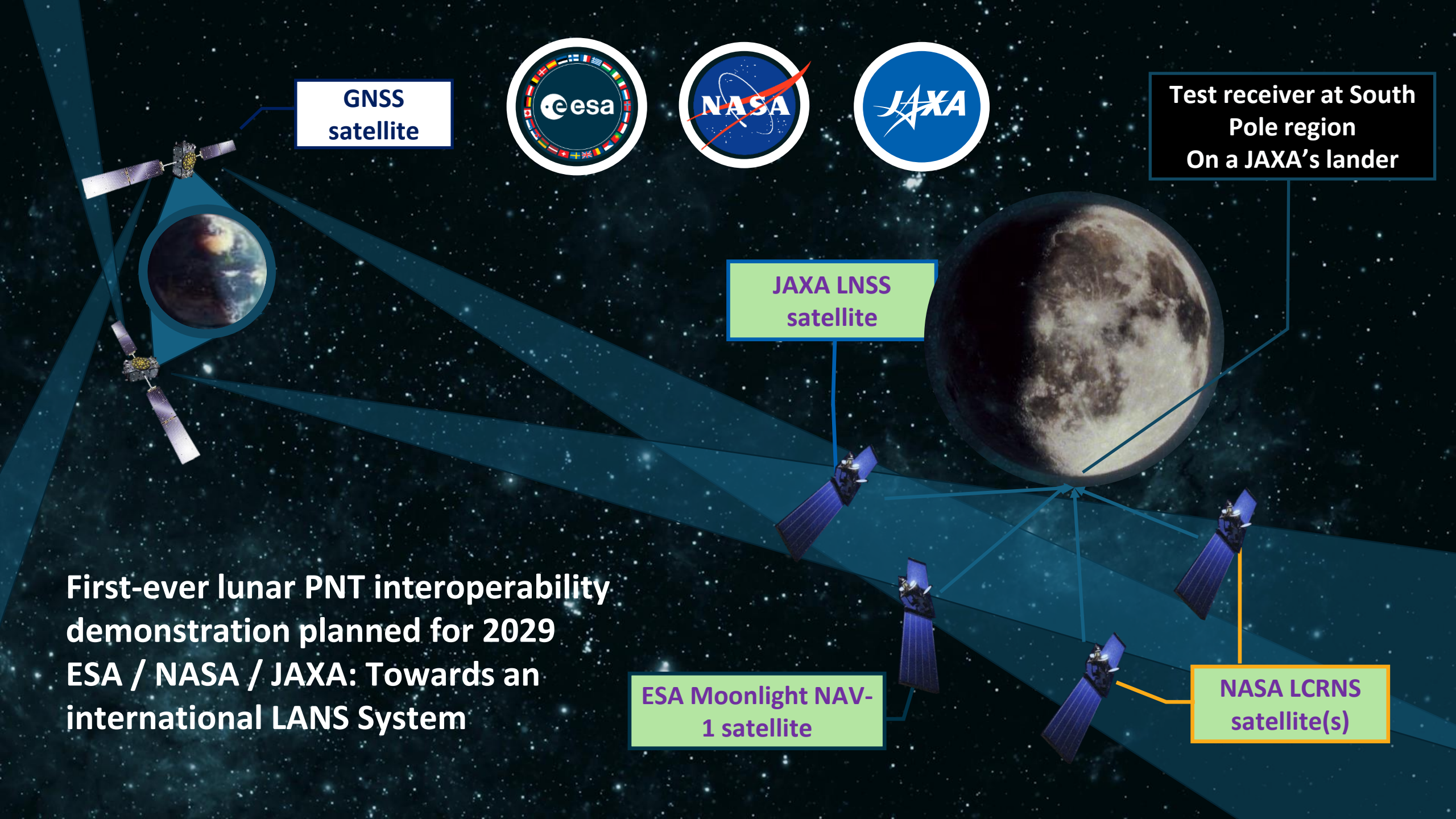
**Test receiver at South
Pole region
On a JAXA's lander**

**JAXA LNSS
satellite**

**ESA Moonlight NAV-
1 satellite**

**NASA LCRNS
satellite(s)**

**First-ever lunar PNT interoperability
demonstration planned for 2029
ESA / NASA / JAXA: Towards an
international LANS System**



Conclusions (1/2)

The integration model between satellite networks and terrestrial networks before the introduction of VHTS satellites and LEO Mega constellations was essentially based on the satellite as an access network to the terrestrial network, based on a single Hub to manage the entire satellite network.

- Advantage: management simplicity
- Disadvantage: The satellite network configured in this way is a delay element for the overall performance of the hybrid network.

With the introduction of the new architectures of the new very large capacity satellites, the presence of a significant presence of **fiber optic network** as an integral part of the architecture allows:

- position the intelligent elements to manage satellite capacity in accordance with the resources of the terrestrial network (**Orchestration**)
- configure network resources by integrating resources in accordance with the required performance (**Slicing**)
- structure a **virtual network** in which satellite and terrestrial capabilities are managed in a technology-agnostic manner
- the access points to the satellite network, thanks to the significant availability of bandwidth, can be used as **network nodes** and not just as access points for a single user.

Conclusions (2/2)

Satellite capacity is much lower than that of the terrestrial network but is characterized by great flexibility and territorial coverage.

It can support **better quality, coverage of more sparsely populated areas** that are expensive to cover with broadband with terrestrial technologies, build **resilient networks** and in addition can more efficiently provide specific services such as:

- **IOT Services**
- **Cryptographic key distribution services**
- **Broadcasting services for streaming** (especially "live" for shows, sporting events, etc.)
- **Network configuration and communication protocol management services**

The key points obtained through the intelligent integration (based on Edge Points) of the satellite network with the terrestrial network are:

- **Latency optimization** (guides the proximity of Edge Points to network access points)
- **Broadband availability** (is compromised if the smart element is far from the access point)
- **Optimization of the number and positioning of Hub stations**
- **Overall improvement in network performance** (better efficiency and performance, greater resilience of services, less local interference, better customer experience, greater flexibility and scalability, greater information security).



Thank You