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Low Earth Orbit (LEO) Systems

April 26, 2023

Agenda

- Introductions
- Latest trends in the satellite industry
- LEO systems
- Project Kuiper
- The International Telecommunication Union (ITU)
- LEO regulatory challenges
- World Radiocommunication Conference (WRC) issues
- Space sustainability
- Space safety

The role of satellite in achieving the UN SDGs

Satellite internet connectivity strives to enable broadband access for unserved and underserved communities around the world and enable them to participate in the global economy.

LEOs will help bridge the Digital Divide

1 billion

Unserved households across the globe have no fixed broadband today (50% of the global total).

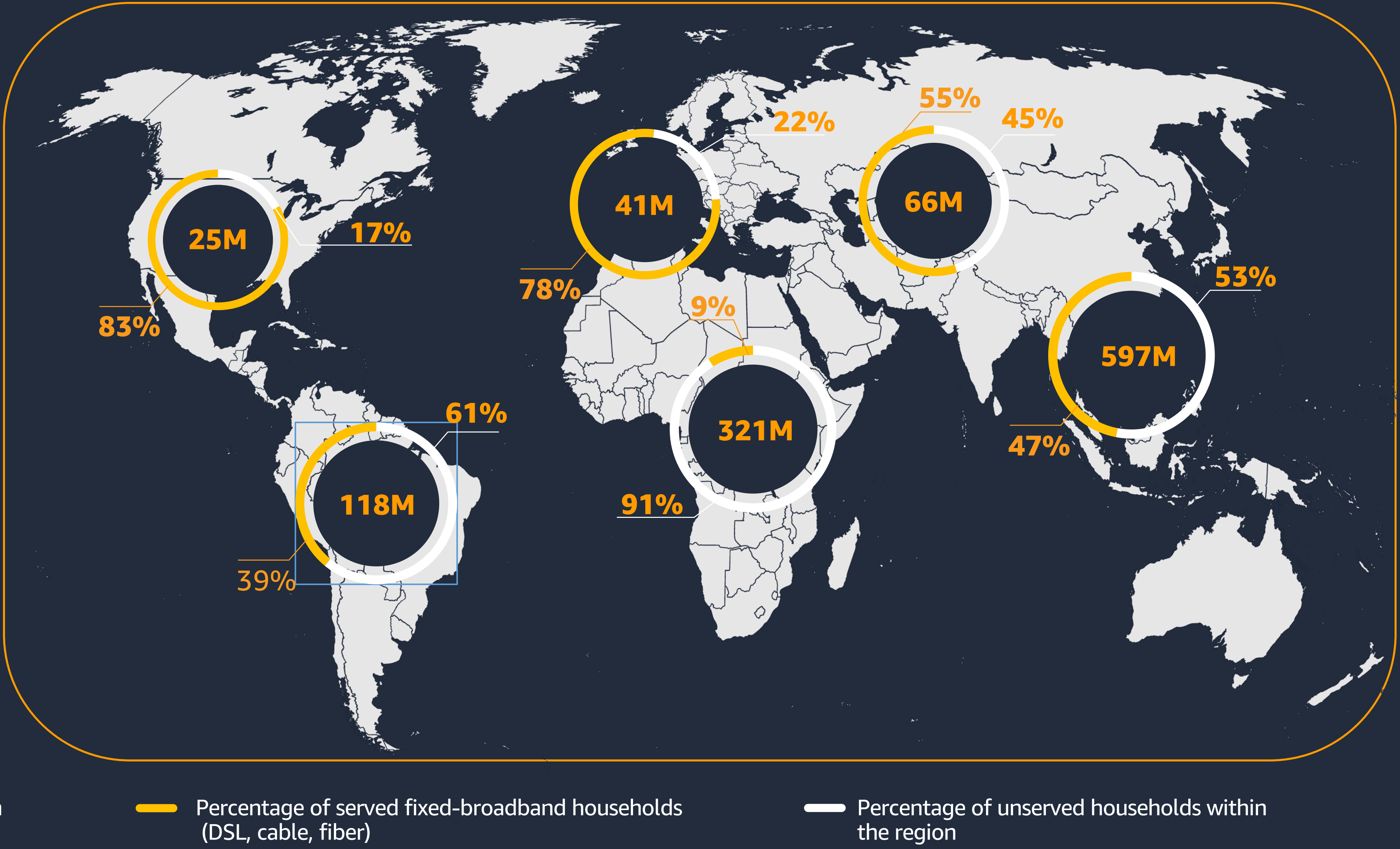
300 million

Underserved households are on legacy DSL technologies.

100 million

Business, enterprise, and public sector endpoints lack reliable connectivity.

[Source: S&P Market Intelligence]



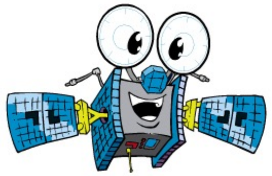
Pros and Cons of satellite broadband

Pros

- Reach
  - Ubiquitous coverage
- Bandwidth on demand
  - Provide bandwidth where and when needed
- Reliability
- Simple to implement
- Use of shared spectrum
  - Efficient use of spectrum

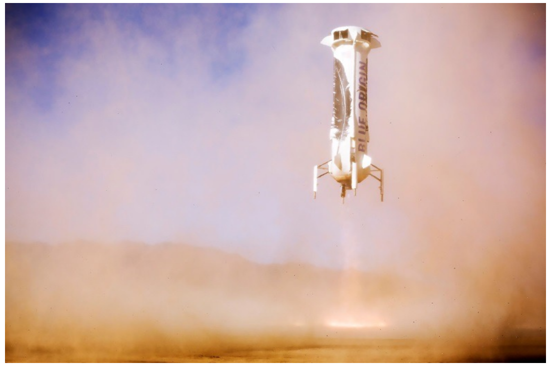
Cons

- Latency
- Cost
  - Technology of last resort

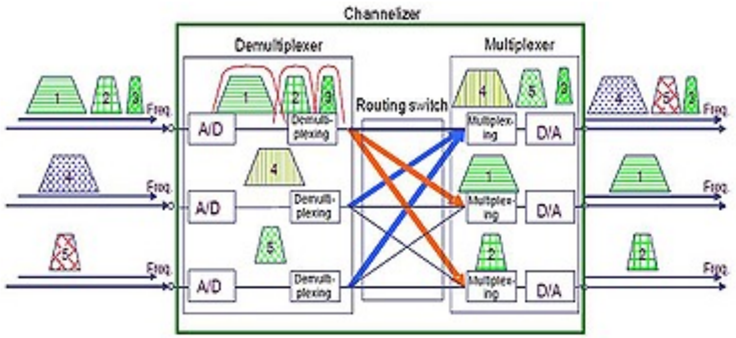


LEO HTS can effectively address the issues of latency and affordability

Latest trends in the satellite industry

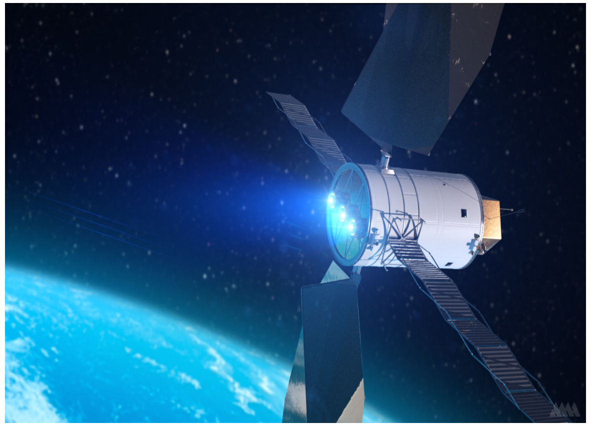


Re-useable rockets

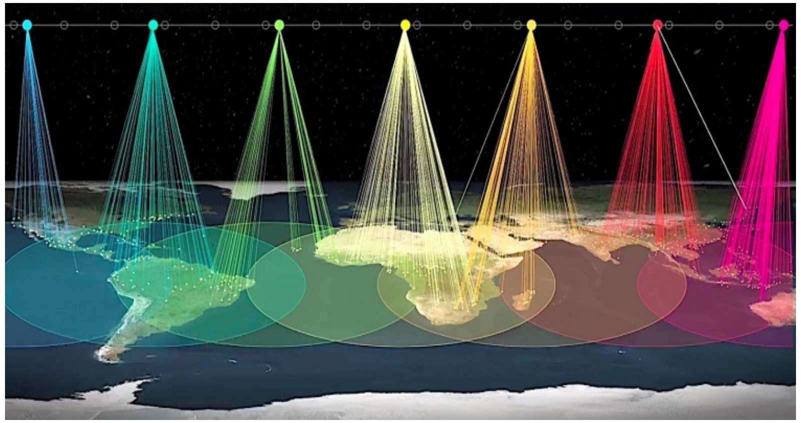


Digital payload technology

Software defined satellites



Electric propulsion



Ground based beam forming

Low vs. Medium vs. Geostationary Earth orbits

LEO

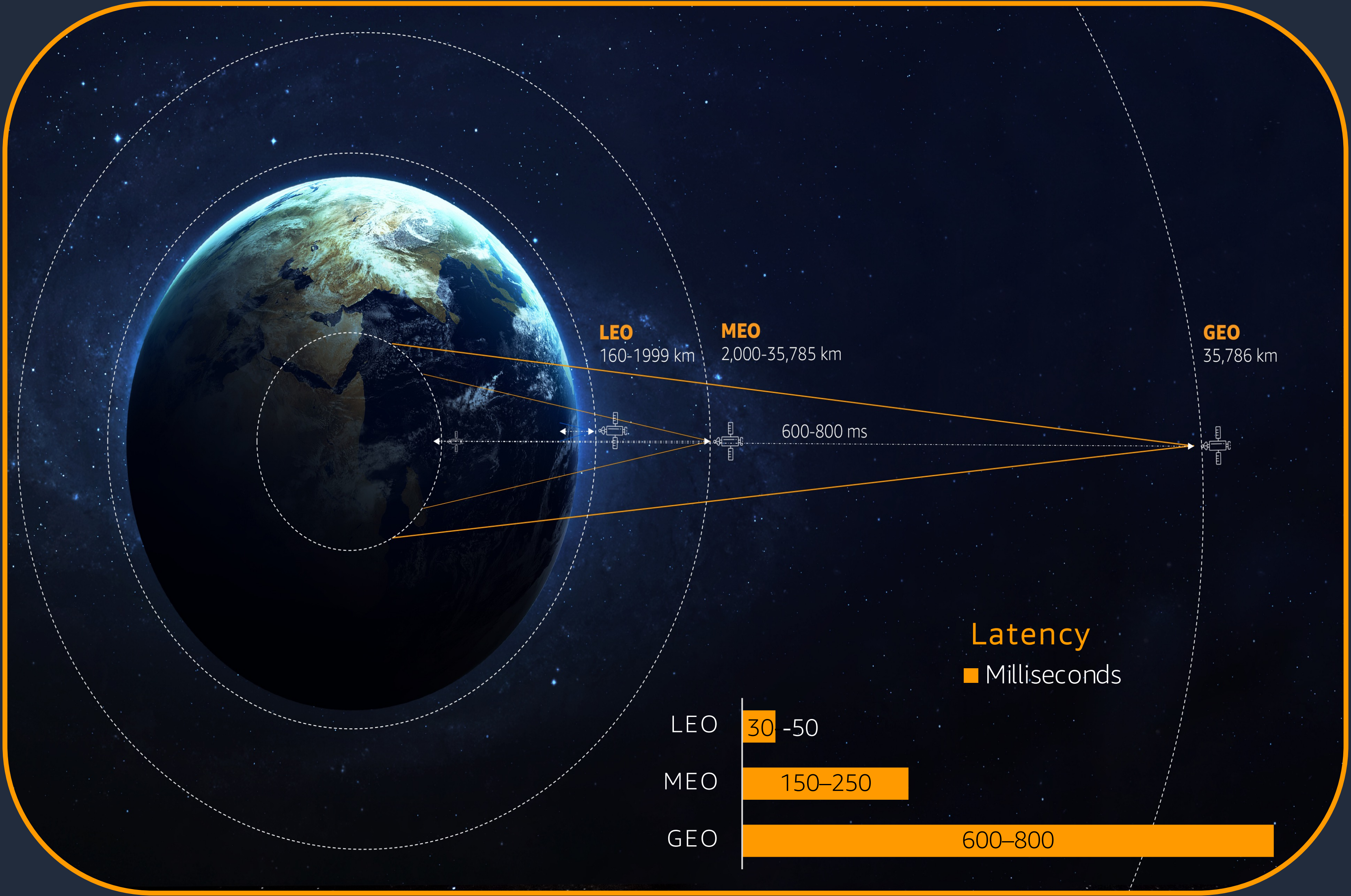
- 30–50 ms roundtrip latency
- Continuous, near-global coverage
- Steerable and shapeable beams
- Small spot beam and higher signal strength
- Resilient and persistent

MEO

- 150-ms roundtrip latency
- Flexible, shapeable beams
- Higher throughput versus GEO

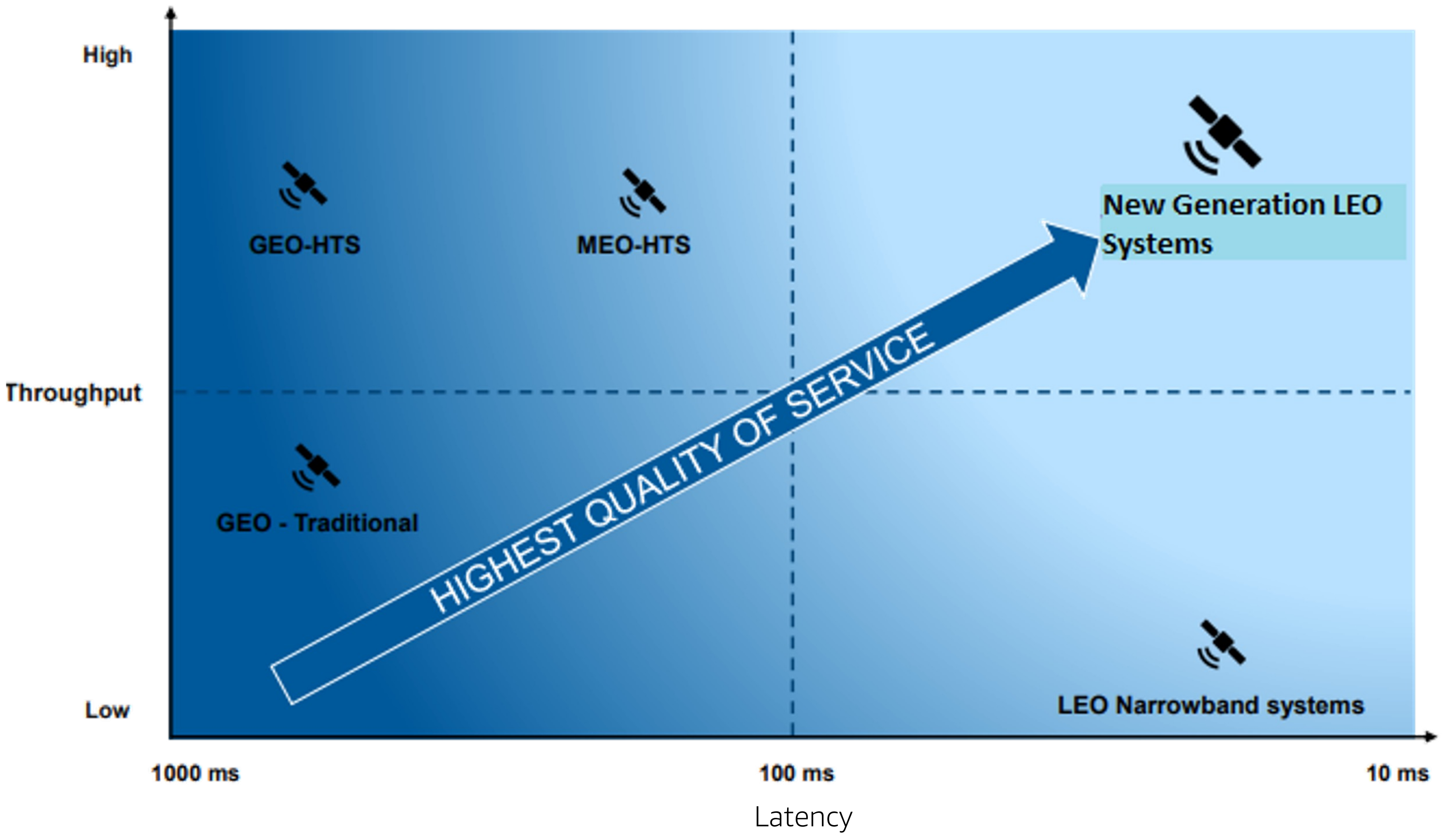
GEO

- 600–800 ms roundtrip latency
- Few satellites
- Large coverage areas (85,000 km^2)
- Equatorial position
- No polar coverage possible



Emergence of LEO systems

Low latency + high throughput = highest quality of service



Why low latency matters

Video conferencing

Fast fluid applications for information workers

Industrial

Real time, critical traffic for industrial scenarios

Gaming

Super fast gameplay and rendering for whatever you play

Enterprise & transportation

High frequency trading, remote customer service and high bandwidth apps

Search and rescue

When lives are at stake, every second counts

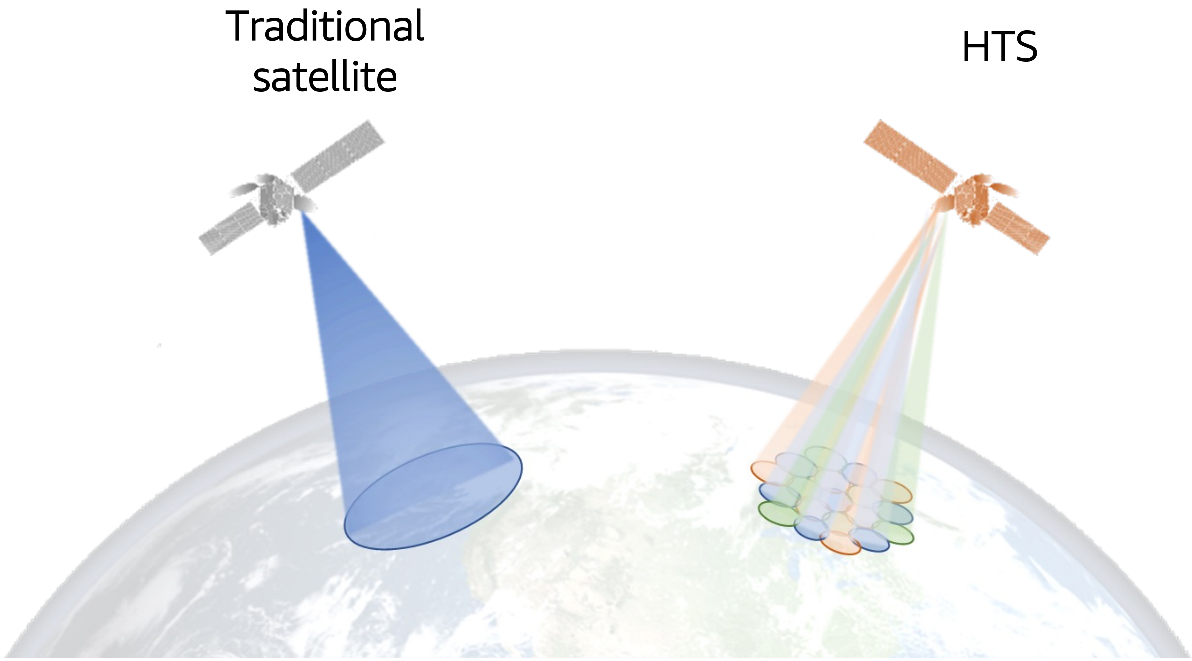
Metaverse

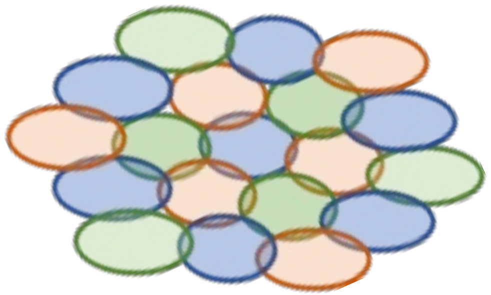
Immersive, high bandwidth teaching, learning, gaming and world building.

NGSO - new efficient spectrum use approaches

NGSO technology enables delivery of greater capacity with new spectrum sharing approaches

- Frequency re-use and smaller beams in next generation satellites allow greater capacity to be delivered by the same satellite.
  - This allows more customers to be served at faster speeds.
- NGSO systems provides for greater spectrum sharing and more efficient use of spectrum.
  - The availability of multiple satellites from any earth station enables sharing between NGSO systems, and protection of geostationary satellite orbit (GSO) systems.





- Dynamic frequency changing
- Dynamic channel bandwidth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OUR MISSION

Project Kuiper is an initiative to increase global broadband access through a constellation of satellites in low Earth orbit (LEO). Our mission is to deliver fast, affordable broadband to unserved and underserved communities around the world.

Overview

Project Kuiper is built around the Kuiper System. Designed and operated by Amazon, Project Kuiper will provide fast, affordable broadband on a global scale.

Performance

The Kuiper System is a flexible, high-performance broadband system that combines satellites with customer terminals, gateway stations, and global networking and infrastructure.

Scale

We will deploy satellites at several altitudes and multiple orbital inclinations, allowing the system to reach a majority of the world's population.

Impact

Project Kuiper will serve residential households, as well as schools, hospitals, businesses, governments, and other organizations operating in places without reliable broadband.

Our customers

Residential

High-speed, low-latency service for individual households.

Small Businesses

Bringing small businesses into the digital age.

Public Services

Increasing access to information, education and healthcare.

Enterprise and Transportation

Flexible, secure broadband to connect remote assets across land, sea and air.

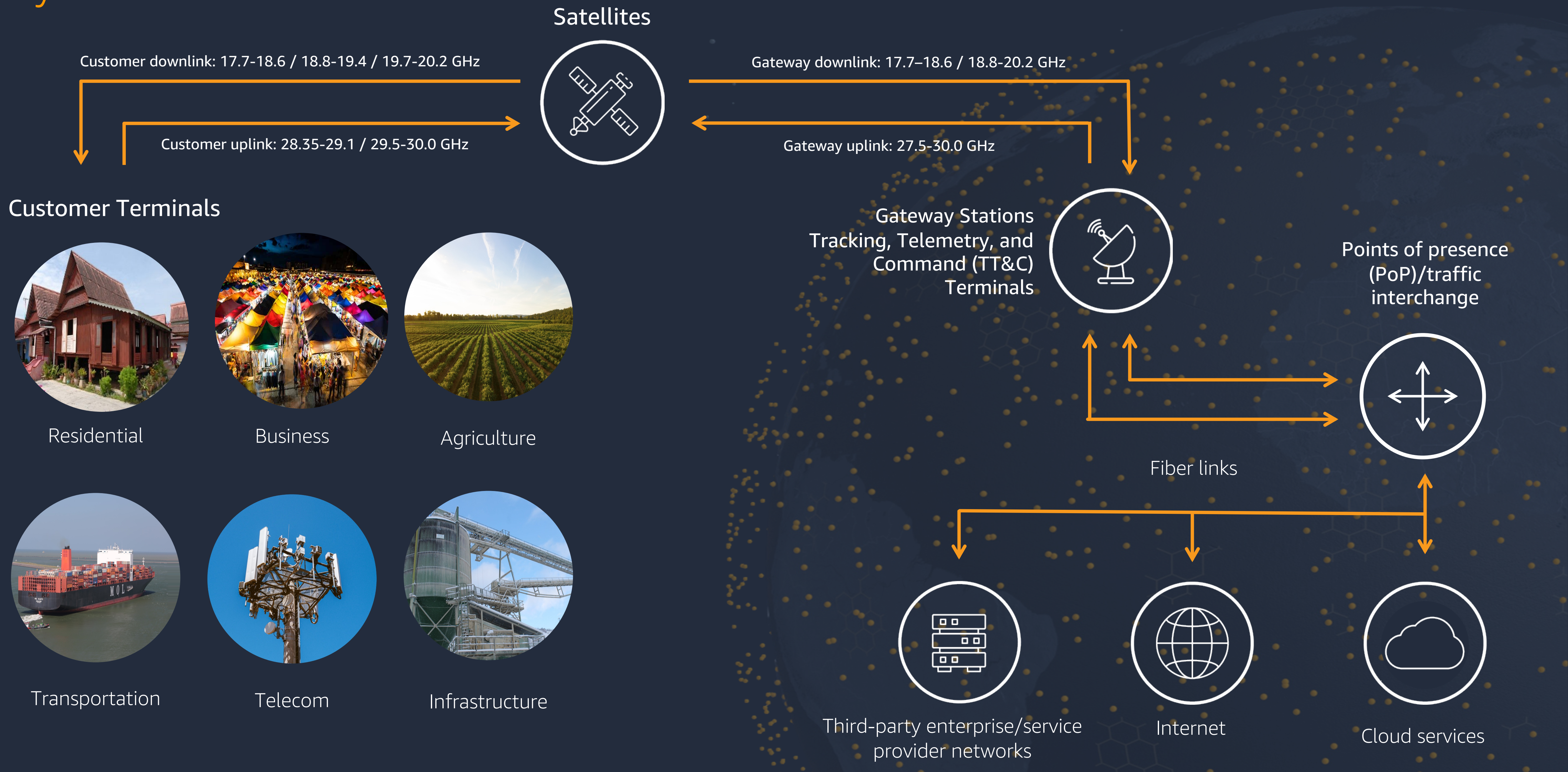
Emergency Services

Reliable broadband to support emergency and disaster relief efforts.

Telecommunications

Expanding wireless and mobile networks to new regions.

System architecture



Networking & infrastructure

Project Kuiper includes a distributed network of gateway stations, as well as the terrestrial networking and infrastructure required to deliver service on a global scale.

Gateway Stations

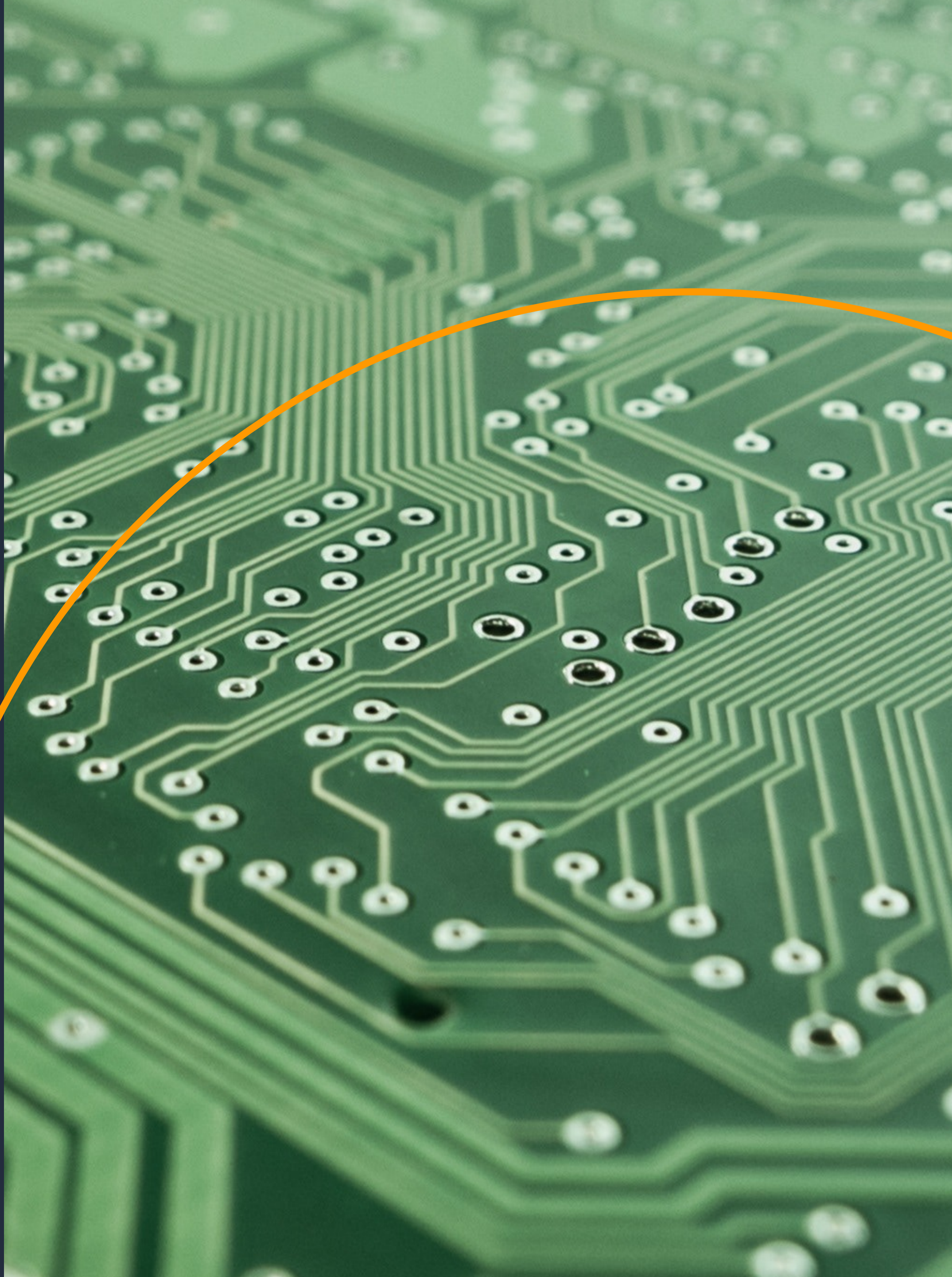
Our global network of gateway stations will provide secure data uplink and downlink with the satellite constellation, and route traffic to Internet exchange points (IXPs) and points of presence (PoP) around the world.

Network

Project Kuiper uses software-defined networking to coordinate beams and allocate bandwidth, and offers complete end-to-end encryption between customer and administrative endpoints.

Amazon Web Services

Project Kuiper leverages terrestrial fiber and networking systems from Amazon Web Services (AWS), and will use AWS to provide secure data compute, storage, processing, and analytics for customers.



Deployment schedule

Initial satellite constellation is deployed at three altitudes and multiple orbital inclinations to cover the world's most populated regions.

Constellation deployment sequence

Phase	Shell (alt/inclination)	Added planes	Satellites/ plane	Deployed satellites	Total satellites
1	630 km/51.9°	17	34	578	578
2	610 km/42.0°	18	36	648	1,226
3	630 km/51.9°	17	34	578	1,804
4 ↑	590 km/33.0°	28	28	784	2,588
5 ↑	610 km/42.0°	18	36	648	3,236

↑ Phases 4 and 5 will increase global network capacity

Customer terminals

Small, compact customer terminals allow customers to connect to the network and enjoy fast, reliable service at an affordable price.

Technical specifications

Type: Single aperture phased array antenna

Frequency: Ka-band

Compact: 17 cm in. sq, 100 Mbps

Standard: 28 cm in. sq., 400 Mbps

Enterprise: 81 x 45.7 cm in surface, 1 Gbps

The International Telecommunication Union (ITU)

- Role of the ITU
- Radio Frequency Spectrum used by NGSOs
- ITU filing basics
- Radio Regulations most important for NGSO systems
- Spectrum Sharing
- Rationale, efficient, economical and equitable use of the radio frequency spectrum and satellite orbits

Role of the ITU

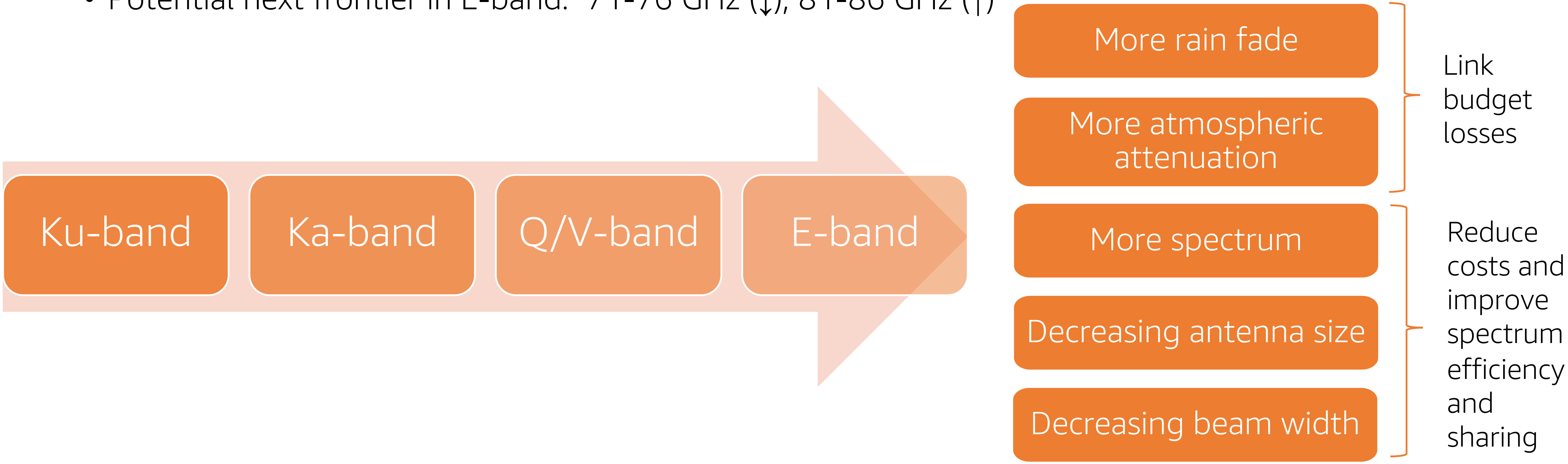
- The ITU Radiocommunication Sector (ITU-R) plays a critical role in managing the use of the radio frequency spectrum and satellite orbits.
- Allocation of spectrum for different services.
- Recording of frequency assignments and orbital positions for Geostationary Satellite Orbits (GSOs) and characteristics of satellites for NGSO systems.
- Management of terrestrial and space plans.
- Prevention and resolution of harmful interference.

- ITU Radio Regulations provide the mechanisms for spectrum sharing and the procedures for resolving harmful interference and infringements of the Constitution, Convention, or Radio Regulations.

The right to international recognition for any frequency assignment is derived from ITU filings, coordination with other operators, and ultimately recording in the ITU's Master International Frequency Register (MIFR) with a favorable finding

Radio frequency spectrum

- Modern LEO broadband systems are licensed in the following frequency bands:
  - Ku-band: 10.7-12.7 GHz (↓), 13.75-14.5 GHz (↑)
  - Ka-band: 17.7-20.2 GHz (↓), 27.5-30 GHz (↑)
  - Q/V band: 37.5-42 GHz (↓), 47.2-50.2 GHz (↑), 50.4-51.4 GHz (↑)
  - Potential next frontier in E-band: 71-76 GHz (↓), 81-86 GHz (↑)



ITU filing basics

- **RR No. 8.3** Any frequency assignment recorded in the Master Register with a favourable finding under No. **11.31** shall have the right to international recognition.
- Process starts with filing an Advance Publication or Coordination Request with the ITU.
- 14 years+ for a NGSO in the Ku-, Ka-, or Q/V-bands to finish the process.
- Date priority matters – and an unfavourable finding at any step means starting over.
- In 2022, 51 countries submitted 322 new NGSO filings totalling 1.76 M satellites. USA has the most filings and Rwanda has the most satellites. Only 12 filings were notified. Strong interest in Ku-, Ka,- and V-bands.

Year 0			Year 7	Year 9	Year 12	Year 14
Advance Publication or Coordination Request →	Resolution 49 Due Diligence Information →	Bringing into Use (1 satellite, 90 days) →	Notification (+ completed coordination) →	Milestone 1 (10%) →	Milestone 2 (50%) →	Milestone 3 (100%)

Most important Radio Regulations for NGSO systems

Volume 1: Articles	Volume 2: Appendices	Volume 3: Resolutions	Volume 4: ITU-R Recommendations incorporated by reference
• Article 5: frequency allocations • Article 9: Coordination procedures • Article 11: Notifying and recording frequency assignments • Article 21: terrestrial/space sharing • Article 22: space service sharing – equivalent power flux-density limits (EPFD)	• Appendix 4: characteristics of satellite networks and earth stations for filings • Appendix 5: identification of administrations for coordination • Appendix 7: determining the coordination area around an earth station • Appendix 8: includes earth station antenna patterns	• Resolution 35: NGSO milestones • Resolution 49: administrative due diligence • Resolution 76: aggregate EPFD limits • Resolution 85: application of Article 22 (EPFD)	• Resolution 27 (Rev. WRC-19) explains the use of incorporation by reference in the Radio Regulations • Incorporation by reference changes a Recommendation from voluntary to mandatory

Spectrum sharing in Ka-band

Band (GHz)	Coordination NGSO-NGSO (9.12)	Coordination GSO-NGSO (9.12A/9.13)	Protection of terrestrial PFD (Article 21)	Protection of GSO FSS EPFD (Article 22)
17.3-17.7	↓↑			
17.7-17.8	↓↑		↓	
17.8-18.1	↓		↓	↓ aggregate
18.1-18.6	↓		↓	↓ aggregate
18.8-19.3	↓	↓	↓	22.2 N/A
19.3-19.7	↓	↓	↓	22.2 N/A
19.7-20.2	↓			↓ aggregate
27.5-28.6	↓↑			↑
28.6-29.1	↑	↑		22.2 N/A
29.1-29.5	↑	↑		22.2 N/A
29.5-30	↑			↑

22.2 Non-geostationary-satellite systems shall not cause unacceptable interference to and, unless otherwise specified in these Regulations, shall not claim protection from geostationary-satellite networks in the fixed-satellite service and the broadcasting-satellite service operating in accordance with these Regulations. No. 5.43A does not apply in this case.

Principles of the ITU

Article **44** of the Constitution, Use of the Radio-Frequency Spectrum and of the Geostationary-Satellite and Other Satellite Orbits, contains the following two provisions:

195
PP-02

1 Member States shall endeavour to limit the number of frequencies and the spectrum used to the minimum essential to provide in a satisfactory manner the necessary services. To that end, they shall endeavour to apply the latest technical advances as soon as possible.

196
PP-98

2 In using frequency bands for radio services, Member States shall bear in mind that radio frequencies and any associated orbits, including the geostationary-satellite orbit, are limited natural resources and that they must be used rationally, efficiently and economically, in conformity with the provisions of the Radio Regulations, so that countries or groups of countries may have equitable access to those orbits and frequencies, taking into account the special needs of the developing countries and the geographical situation of particular countries.

Rational, efficient, economical, and equitable

- The ITU Radio Regulations Board (RRB) has reported on the fulfilment of these principles to the last 5 WRCs
  - Bringing into use of satellite networks
  - Extension of the time limits for bringing into use
  - Issues related to the Appendix 30/30A/30B Plans
  - Harmful interference
  - Resolution 219 (Bucharest, 2022), Sustainability of the radio-frequency spectrum and associated satellite orbit resources used by space services
- Design, deployment, operation, and post-mission disposal of satellite is conditioned by licensing authorities, informed by space situational awareness providers, and improved by operator best practices.
- The key objective of the ITU Radio Regulations is the avoidance of harmful interference. ITU addresses the use of radio frequencies – it does not regulate or manage physical objects.

LEO regulatory challenges

Enabling framework for NGSO connectivity

- NGSO systems require regulatory certainty, and a ”light touch” regulatory approach must be taken into account.
- Internationally harmonized spectrum allocations lead to predictability and facilitate deployment of innovative technologies.
- For satellite to play its role in the communications ecosystem, it must continue to have access to the spectrum in use today (Ka Band) and to new spectrum to meet future demand (Q/V Band).
- Adopt spectrum assignment methodologies that are consistent with International best practices

Characteristics of an enabling regulatory regime

- Ensures flexible and streamlined licensing procedures for domestic internet service providers and satellite broadband providers.
- Regulatory transparency is key for licensing processes.
- Online licensing processes facilitate entry and reduces costs.
- Allows for satellite provision of international internet capacity without a requirement for domestic ground stations to route traffic to and from satellites.
- Availability of licensing and spectrum planning information allows operators to plan and undertake processes in a timely manner.
- Spectrum use and allocation information facilitates spectrum management and coordination.
- Reduced license and spectrum costs/fees (administrative cost recovery) help reduce costs of connectivity to end users.
- Mutual recognition of equipment certification/homologation reduces time and complexities of introducing new services.

WRC issues

WRC-23 Agenda Items for NGSO systems

- Agenda items
  - 1.16 – Enable ESIM operations with NGSO systems
  - 1.17 - Inter-satellite links for NGSO systems
  - 1.19 – Harmonize spectrum for worldwide operations of NGSO systems
  - 7
    - Issue A – Orbital Tolerance for NGSO systems
    - Issue D2 – Address elements needed to improve the calculation of EPFD
    - Issue J – Resolution 76, NGSO systems to evaluate aggregate interference into GSO networks

NGSO sharing studies

- There have been no recommendations developed for sharing spectrum between NGSO systems
- WP4A is currently studying proposals for consideration of techniques to facilitate sharing of spectrum between NGSO systems
- Next generation of NGSO systems are greatly different than satellite systems of 20 years ago, with vastly superior spectrum sharing abilities
- These technological advancements must be considered in any new spectrum sharing techniques under development

Space sustainability

- Space treaties
- Best practices

Landscape - space treaties

- Relevant UN space treaties:
  - Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty)
    - Article VI- The activities of non-governmental shall require authorization and supervision
    - Article VIII- A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object
  - Convention on Registration of Objects Launched into Outer Space (Registration Convention)
    - When a space object is launched into earth orbit or beyond, the launching State shall register the space object
  - Convention on International Liability for Damage Caused by Space Objects (Liability Convention)
    - Outlines the liability of Launching States for damage caused by their space objects both on the Earth or in space

Landscape – standard sources and best practices

- Multilateral efforts
  - UN Committee on the Peaceful Uses of Outer Space (COPUOS): Long-Term Sustainability Guidelines
  - 1st Committee: Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviors
  - Paris Peace Forum- Net Zero Space Initiative
  - Artemis Accords

- Industry efforts
  - American Institute of Aeronautics and Astronautics (AIAA): "Satellite Orbital Safety Best Practices" Reference Guide
  - Space Safety Coalition: Best Practices for the Sustainability of Space Operations
  - The Hague Institute for Global Justice: Compact on Norms of Behavior for Commercial Space Operations
  - World Economic Forum (in collaboration with ESA): DRAFT Space Industry Debris Mitigation Recommendations

Landscape – standard sources and best practices

- Role of ITU
  - ITU has adopted a practical approach to maintaining space sustainability
  - They include mechanisms in the Radio Regulations and the ITU-R recommendations
    - Registration of satellite radio frequencies allows for transparent and sustainable use
    - Coordination procedures have a primary aim to ensure efficient use of orbits and spectrum
    - WRC-19 established the milestone mechanism for the NGSO satellite systems to strike a balance between the prevention of spectrum warehousing, the proper functioning of coordination mechanisms and the operational requirements related to the deployment of NGSO systems

Space safety

- Role of operators
- Role of government

Role of operators

The satellite industry has a vested interest in responsible operations in a safe, sustainable environment.

- Operators should:
  - Coordinate and communicate to encourage and allow safe operations, safe interaction
  - Use empirical knowledge to develop best practices and operating standards
    - Shared knowledge for current and future operators
    - Common processes across nations, across organizations
    - Help informing the developing regulatory landscape
    - AIAA Best Practices
    - Space Safety Coalition Best Practices

No one is more motivated to keep the LEO safe than the NGSO operators deploying to LEO

Role of Government

The satellite industry is rapidly changing, and satellite operators are most familiar with their technologies, systems, and how to best promote safe satellite operations.

- Governments should:
  - Identify opportunities to foster international coordination
  - Be aware and involved in encouraging the private sector to develop shared operational norms
  - Invest in advanced Space Situational Awareness technologies to promote the more efficient use of space

Space safety and sustainability

Space safety and sustainability is a core tenet for the Kuiper team, and we are committed to taking all the necessary steps to protect against orbital debris.

Constellation design

- 20 km altitude separation between shells
- In-track separation of at least 50 km
- No more than 9 km of cumulative altitude deviation

Reliability

- Comprehensive subsystem and system testing, in the factory and on orbit below ISS prior to orbit raising
- Ephemeris sharing and maneuver forecasts

Deorbit and demise

- Active deorbit within one year
- Passive deorbit of no more than nine years based on natural decay due to gravitational forces

Protecting astronomical observations

We are taking steps to minimize our impact on astronomical observations.

System design

- Project Kuiper operates at lower altitudes and includes fewer satellites, helping reduce reflectivity compared to larger constellations or those operating at higher altitudes (over 1,000 km)
- Prototype missions will help us evaluate reflectivity and test our mitigation measures.

Deployment and operations

- Maneuvering capabilities reduce Earthward reflectivity during propulsive operations (orbit raise and lower).
- Steering capabilities allow us to minimize reflections during mission operations.

Collaboration

- Amazon is committed to working with the astronomical community to find shared solutions. We will share ephemeris data throughout operations to help protect and preserve scientific research.

Thank you

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