Satellite Internet From Space
The Basics

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- Introduction.
  - Start with some basic definitions and concepts.
  - Then provide some of the major Players in Satellite Internet providers and some of the specifications.
  - Then a little more detail wrt Starlink's system.
    - At least what has been made public and what can be deduced from the public data.
    - Lots of speculation so be wary..
  - I'm by no means claiming to be a Satellite Communications Expert.. Just curious wrt how things work!!

Satellite Internet From Space - The Basics

- **Basic Definitions:**
  - GEO Synchronous Orbit.
    - is a circular geosynchronous orbit 35,786 km (22,236 mi) in altitude above Earth's equator, 42,164 km (26,199 mi) in radius from Earth's center, and following the direction of Earth's rotation. Think stationary!!
  - LEO Orbit.
    - is an orbit around Earth with a period of 128 minutes or less (making at least 11.25 orbits per day) . A region of space that is relatively close to Earth, typically ranging from 160 to 2,000 kilometers above the Earth's surface.

Satellite Internet From Space - The Basics

- **Basic Definitions:**
  - Power Flux Density
    - Any satellite emitting RF energy towards Earth must comply with power limits as received on the ground, measured as Equivalent Power Flux Density (EPFD), set primarily by the ITU.
    - *The power from spot beams whose footprints overlap, and share the same frequency, is additive, thus, to comply with the limits, the transmit power of each beam must be reduced.* *"Modeling Starlink Capacity" – Mike Puchol.*

  – Starting in July 2024, SpaceX began conducting tests on Starlink in cooperation with the Romanian Ministry of National Defense and National Authority for Communications Administration and Regulation (ANCOM). These tests aim at demonstrating that the Equivalent Power Flux Density (EPFD) limit can be safely increased, thus improving the speed and coverage area of Starlink, without affecting classic, geostationary satellites. The results of these tests will be used to help change a rule set by the International Telecommunication Union in the 1990s regarding the limits of non-geostationary satellites.

- Basic Definitions:
  - Adaptive coding and modulation
    - dynamic technique used in modern communication systems to optimize data transmission by adjusting modulation schemes and coding rates based on real-time channel conditions. This approach enhances spectral efficiency, reliability, and data throughput, making it a cornerstone of technologies like LTE, 5G, and satellite communications.

Satellite Internet From Space - The Basics

- Some of the Players:
  - Iridium
    - Originally 66 satellites. 82 operational
    - Orbit 781 km (485 mi) Inclination 86.5 (Polar Orbit)
    - 6 orbits, 11 Satellites per orbit, period 100 minutes
    - L-band Spectrum 1,616 and 1,626.5 MHz,
      - Channel BW = 7.775 MHz.
    - 48 spot beams, 16 beams in three sectors.
    - Original 11 ground stations. 5 left
    - Used to provide mainly global satellite Voice services.
  - Eutelsat OneWeb
    - 648 Satellites at full deployment?? ~598 launched to date.
    - Orbit 1200 Km (~745 mi), 12 orbital planes, inclination 87.4^{o}
    - Throughput per satellite 7.2 Gbps, 100 ms delay

Satellite Internet From Space - The Basics

- Some of the Players:
  - Eutelsat OneWeb Cont'd
    - Gen1 weighs about 150 kg. Gen2 weighs 500kg
    - Uses Ku/Ka bands and V-band (40-75 GHz)
    - Russia Controversy. Russia wanted assurances they wouldn't be used for military purposes.
    - Kept 36 satellites. Didn't launch them. Eutelsat paid for but never given back. Cost eventually covered by insurance.
    - Positions itself more as an Enterprise-grade Network.
    - Testing has achieved ~195 Mbps DL, ~32 Mbps UL with 70ms delay. *"STARLINK VS ONEWEB: THE ULTIMATE 2025 SATELLITE INTERNET SHOWDOWN"*
    - Need onboard fuel to de-orbit.
    - 32 Steerable Ku beams.
    - Eutelsat also operates Geo Satellites.

Satellite Internet From Space - The Basics

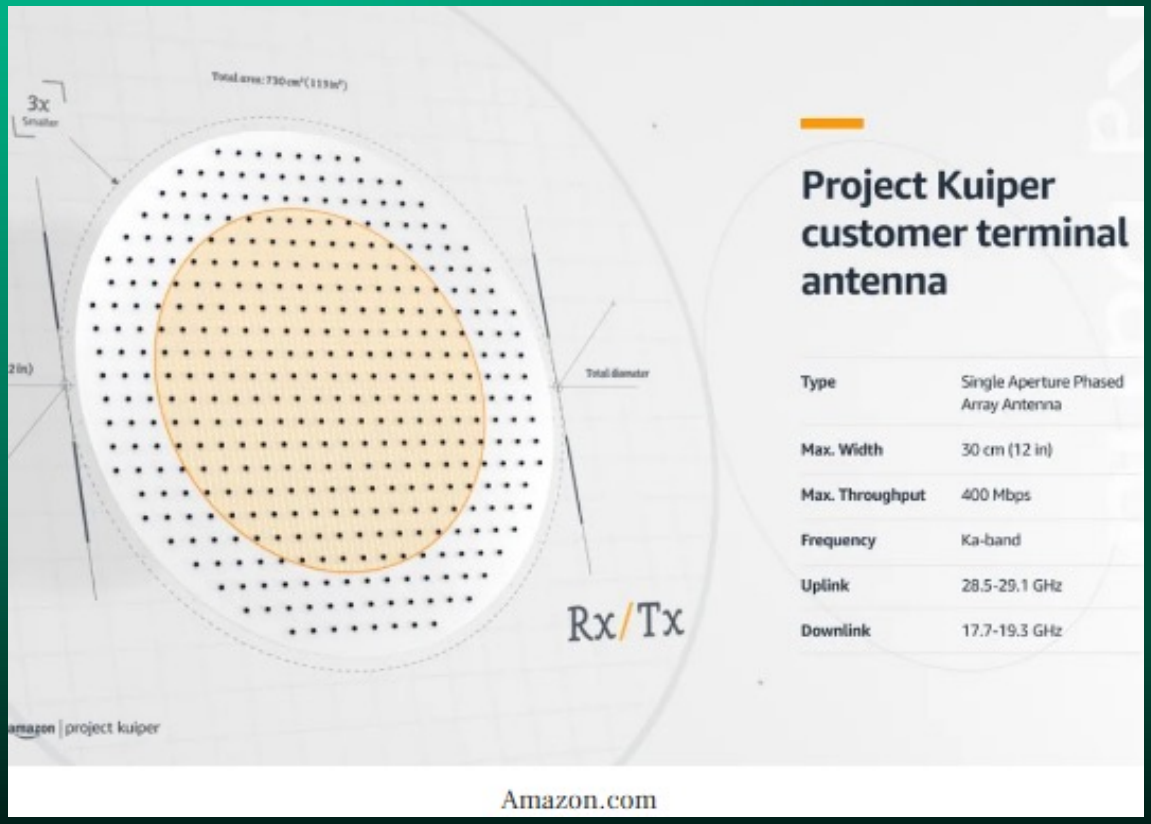
- Some of the Players:
  - HughesNet
    - Geosynchronous orbit, over 600 ms delay
    - Data plans from 25 Mbps up to 100 Mbps
    - Has a low latency plan but satellite is combined with terrestrial wireless connection. What's the point of the satellite connection.
  - ViaSat Internet (aka Exede, Wildblue)
    - Geosynchronous orbit, over 600 ms delay
    - 1.5 Mbps up to 25 Mbps.

- Some of the Players:
  - Telesat - Lightspeed.
    - Initial LEO constellation will have 198 satellites
      - 78 Polar Satellites at 1,015 km
      - 120 Inclined Satellites at 1,325 km
    - Focus on providing internet access for government, aeronautical, and maritime use and industries like oil and gas that work in remote locations.
    - In 2022 using the lightspeed prototype satellite currently in orbit. This test saw download speeds of 100Mbps, upload speeds of 96Mbps, and a latency of 26.5ms.
    - Telesat has contracted 14 launches from SpaceX starting in mid-2026 to deploy all 198 Lightspeed satellites within a year.
  - Other than a couple of Test Satellites, I don't think their network is fully operational.

Satellite Internet From Space - The Basics

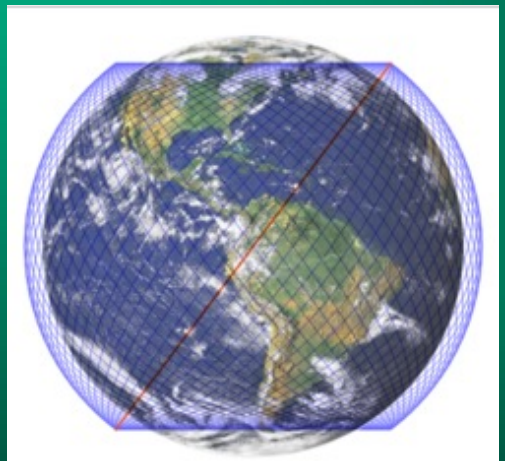
- Some of the Players:
  - Kuiper (Amazon's)
    - Initial LEO constellation will have 3236 satellites
      - 98 orbital planes, 3 orbital shells (590 km, 610 km, 630 km)
      - Phase 1: 578 satellites at 630 km, inclination 51.9°
      - Will weigh roughly 600-700 kilograms (1,300-1,540 pounds).
      - To date ~129 + 2 test satellites launched.
      - OISL (optical inter-satellite link). These lasers are capable of maintaining 100 Gbps over distances up to 2,600 km. Beats current best of 100 Gbps at 1,000 km
    - User Terminal (UT)
      - Uses Ka-band (17-30 GHz) *StarLink uses Ku ESA at 12-14GHz*
      - 12" Flat phase array antenna.
      - Expected to support 400 Mbps.

- Some of the Players:
  - Kuiper (Amazon's) Cont'd
    - User Terminal (UT)



Amazon.com

- Some of the Players:
  - Starlink
    - LEO Satellites: ~7400 active but you will see ~8500 number. I think this includes Decaying/deorbited satellites.
    - Phase 1: consisted of the 72 orbits with 22 satellites each at 550 km. 1548 satellites.



The Starlink constellation, phase 1, first orbital shell: 72 orbits with 22 each, therefore 1584 satellites at 550 km (340 mi) altitude

- Some of the Players:
  - Starlink
    - Uses Ku-band for satellite to user terminal communication.
      - 12 – 14 GHz. Via ESA's (Electronic steerable Arrays), ie Phased Array.
      - 3 ESA's for Downlink and 1 ESA for Uplink.
      - 8 Beams per ESA with 2 polarizations with 8 channels of 250 MHz results in 48 DL satellite beams with 2 GHz of BW available.
      - Given the 2 GHz *2 polarizations and 64QAM with 5.11 bits/hz
        - one gets a DL satellite capacity of ~20 Gbps.
      - UL ESA 8 x 62.5 MHz channel = 500MHz
        - *I've seen it mentioned that the UT can only Tx/Rx in one polarization. I'm not sure if this is still true, but could halve the throughput on both UL/DL capacity of the Satellite.*

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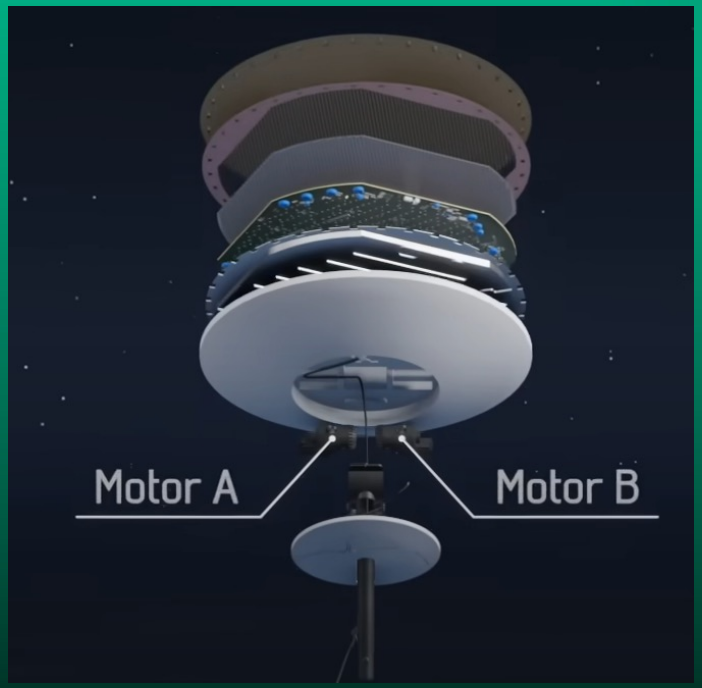
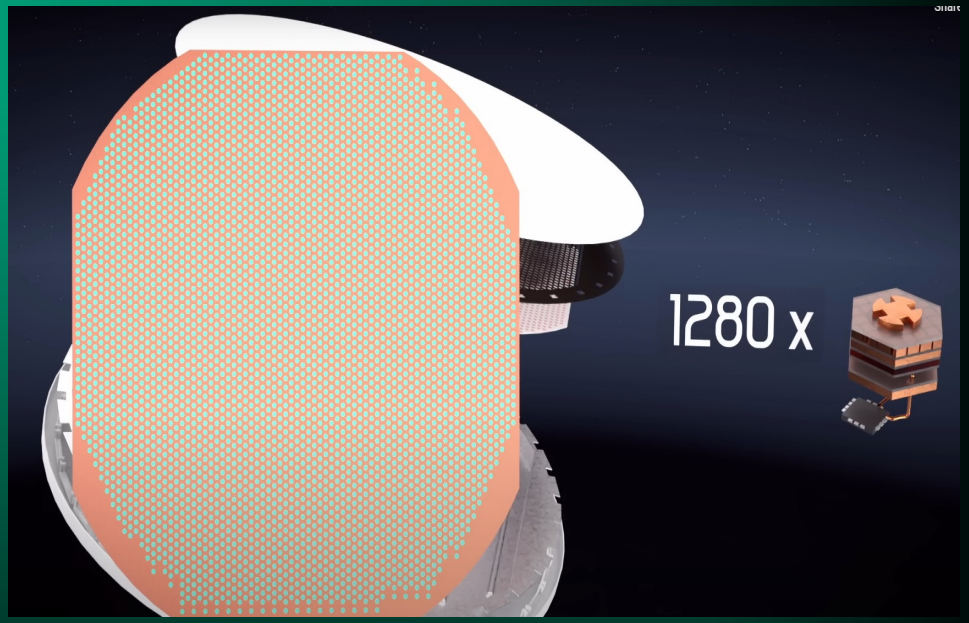
- Some of the Players:
  - Starlink
    - User Terminal:.
      - Use Ku-band: DL = 10.7 GHz – 12.7 GHz; UL 14.0 GHz – 14.5 GHz
      - UT only has one polarization and can use only one of the 8 channels at a time. So BW is restricted to a DL/UL BW of 250/62 Mhz.
      - Flat panel configured in an ESA (electronically steerable phase array)
    - UT Dishy:
      - Has 1280 individual antennas used in beam forming.
      - Has two motors for initial setup.

- Some of the Players:
  - Starlink User Terminal





Youtube: “How does Starlink Satellite Internet Work?” by Branch Education.

Satellite Internet From Space - The Basics

- Some of the Players:
  - Starlink User Terminal
    - Starlink's UT Service Plans

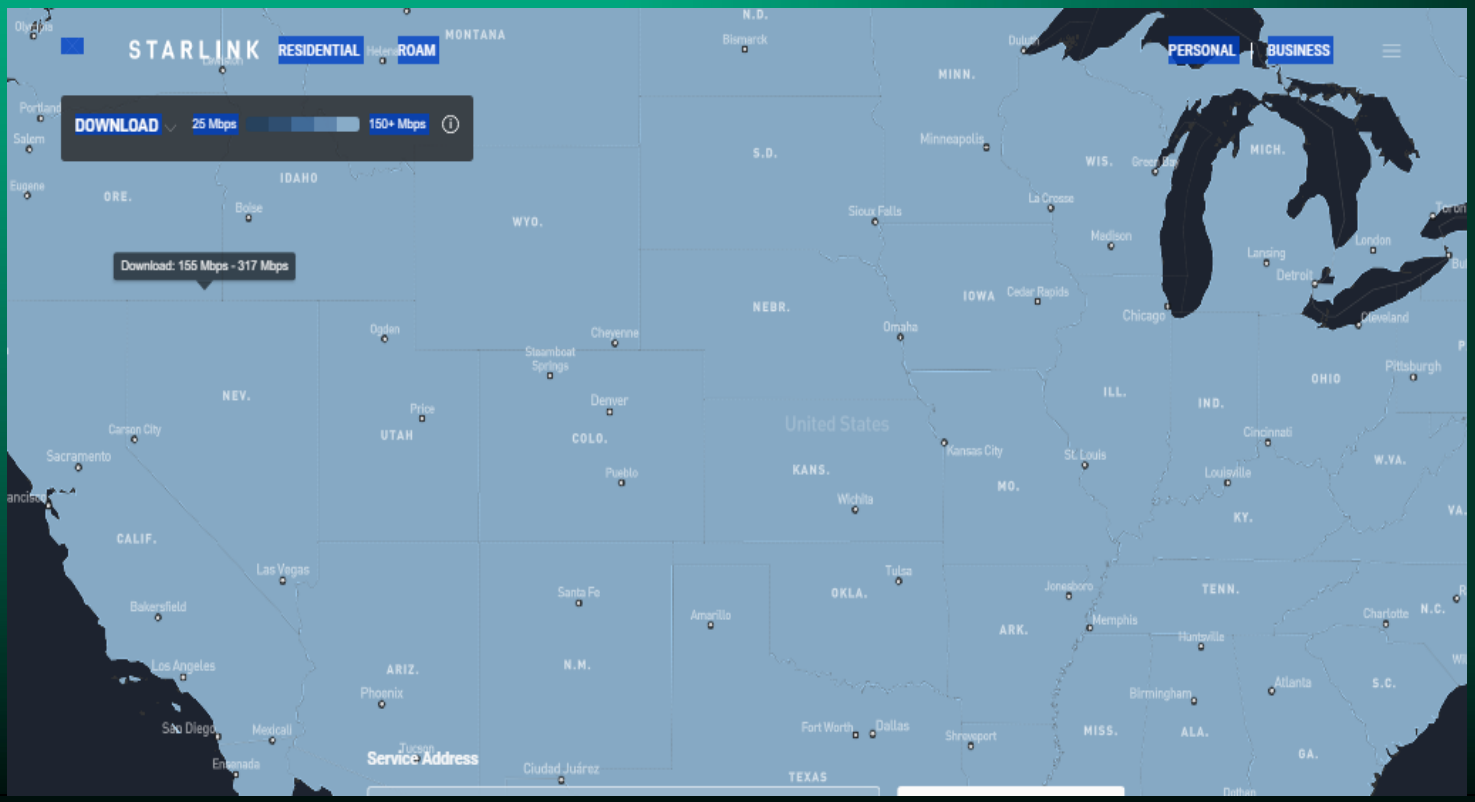
SERVICE PLAN	RESIDENTIAL LITE (FIXED)	RESIDENTIAL (FIXED)	RESIDENTIAL 50GB (FIXED)	PRIORITY	ROAM 50GB (MOBILITY)	ROAM UNLIMITED (MOBILITY)	ROAM 10GB (MOBILITY)
AVAILABILITY	≥99%	≥99%	≥99%	≥99%	≥99%	≥99%	≥99%
DOWNLOAD	97-265 Mbps	*Click For Download Speeds*	*Click For Download Speeds*	104-282 Mbps	48-232 Mbps	48-232 Mbps	48-232 Mbps
UPLOAD	11-26 Mbps	*Click For Upload Speeds*	*Click For Upload Speeds*	14-30 Mbps	10-25 Mbps	10-25 Mbps	10-25 Mbps

    - Notice the two 9's. 99.999

Daily: 14m 24s		Daily: 0.86s
Weekly: 1h 40m 48s		Weekly: 6s
Monthly: 7h 18m 17s		Monthly: 26s
Quarterly: 21h 54m 52s		Quarterly: 1m 19s
Yearly: 3d 15h 39m 30s		Yearly: 5m 16s

Satellite Internet From Space - The Basics

- Some of the Players:
  - Starlink User Termial [Starlink Specifications - Starlink]
    - Starlink users typically experience download speeds between 25 and 220 Mbps, with a majority of users experiencing speeds over 100 Mbps. Upload speeds are typically between 5 and 20 Mbps. Latency ranges between 25 and 60 ms on land, and 100+ ms in certain remote locations. https://www.starlink.com/legal/documents/DOC-1723-29826-76
    - Starlink | Availability Map https://www.starlink.com/map?view=download

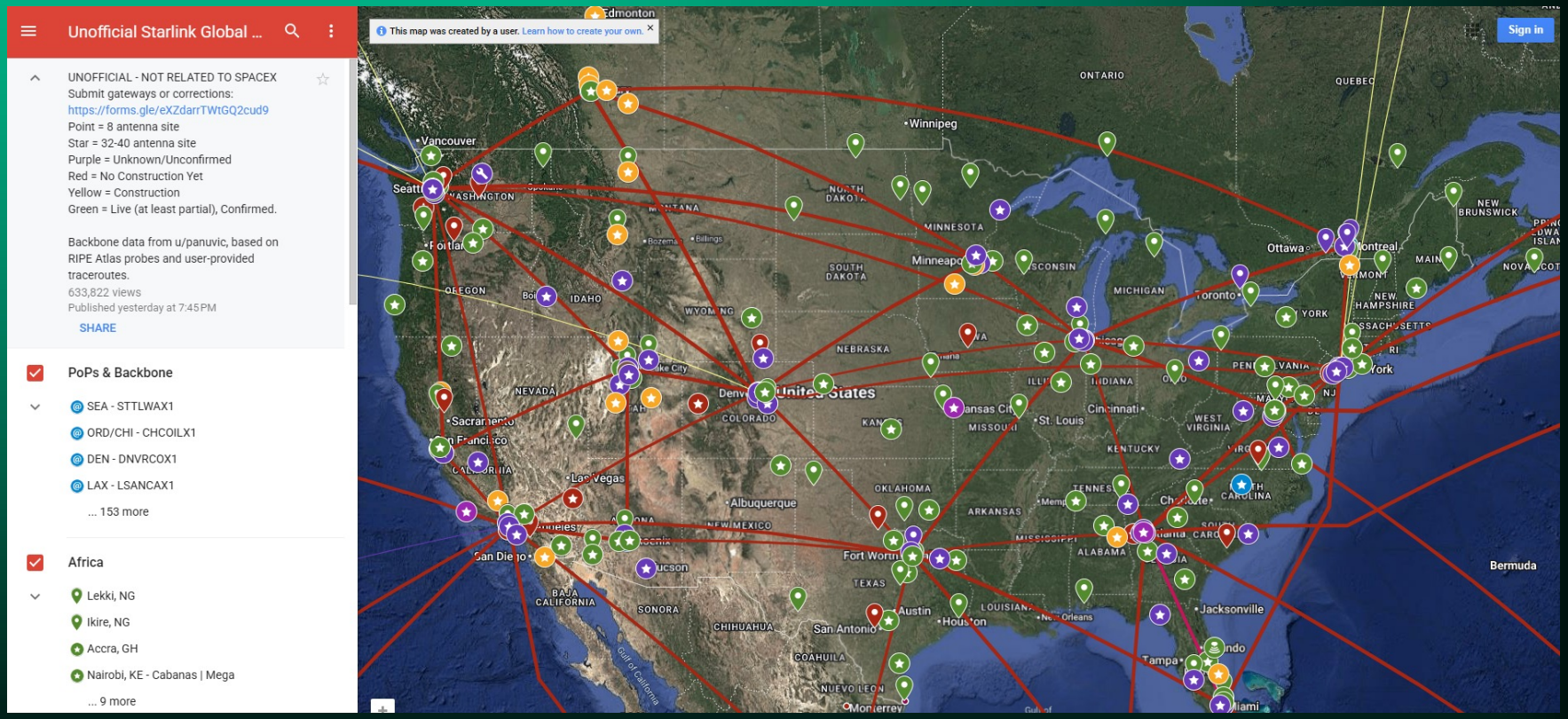


Satellite Internet From Space - The Basics

- Some of the Players:
  - Starlink
    - Uses Ka-band for satellite to gateway communication.
      - 27- 40 GHz Via two parabolic dishes.
      - Satellite has two Ka parabolic antennas that combined can provide a throughput of 20 Gbps to a ground station gateway.
      - ~ 100 ground station gateways planned in the US with ~ 64 live in the US.
      - US has the most by a large margin. Most countries/continents have only a handful, up to 10 to 15 gateways.
        - https://starlinkinsider.com/starlink-gateway-locations/

Satellite Internet From Space - The Basics

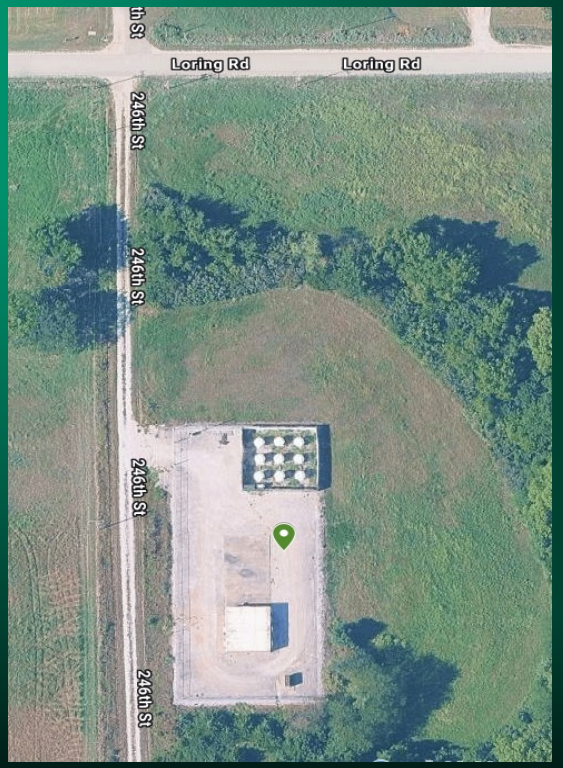
- Some of the Players:
  - Starlink – Gateways
    - https://starlinkinsider.com/starlink-gateway-locations/



Satellite Internet From Space - The Basics

- Some of the Players:
  - Starlink – Gateways
    - https://starlinkinsider.com/starlink-gateway-locations/
    - Each Gateway station can communicate with 8 satellites. The 9th dome is for support communication.
  - North of Benkelman, NE

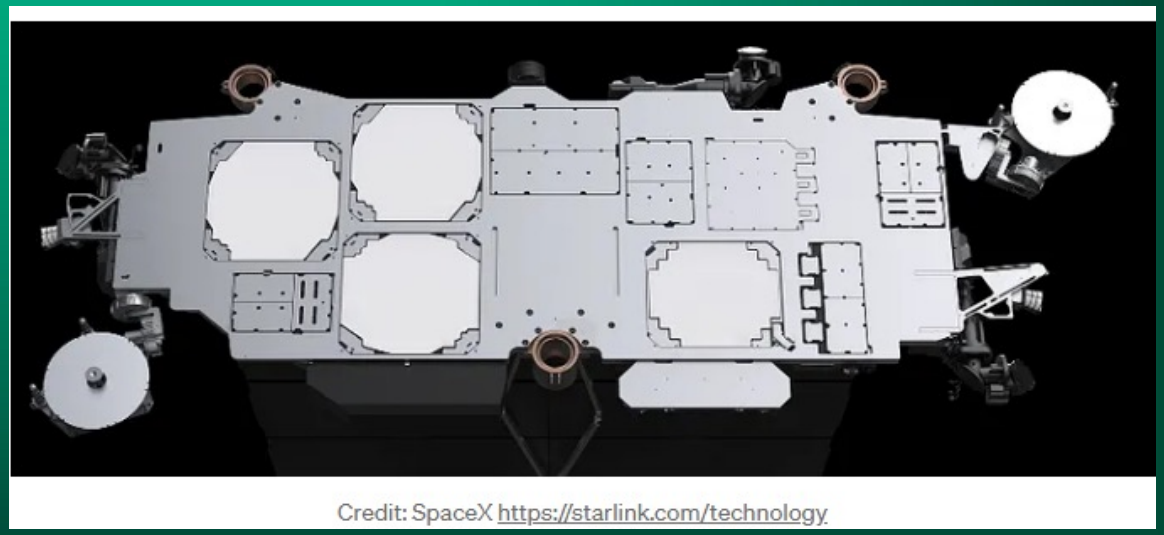
Northeast of Lawerence, KS



- Some of the Players:
  - Starlink – Individual Specifications wrt Satellite.
    - V0.9: mass 227 Kg (500 lb), krypton thrusters, 550 km(340mi).
      - 95% of components designed to burn-up upon reentry.
    - V1.0: mass 260kg (570 lb), Ka-band added, one had special coating to reduce glare. Abandoned due to thermal issues and IR reflectivity. Visors added to block sunlight reflection.
    - V1.5: mass 295kg (650 lb), Lasers added for inter-satellite communication (100 Gbps). Visors removed since Sept. 2021. What are they using now? Bus = 2.8m x 1.3m
    - Starshield: derived from v1.5 and v2.0 and host classified gov. and military payloads.
    - V2 mini: mass 800kg (1800 lb), addition of 2 solar panels, 4x the backhaul capacity (20 Gbps to 80 Gbps). I do believe this for backhaul and due to the addition of E-band. Bus = 4.1m x 2.7m

- Some of the Players:
  - Starlink Satellite.
  - V2 mini with DtC: Direct to Cellular, mass 970kg (2140 lb), Bus = 7.4m x 2.7m , launched Jan. 2, 2024

    This may be V1.5 or V2 mini?

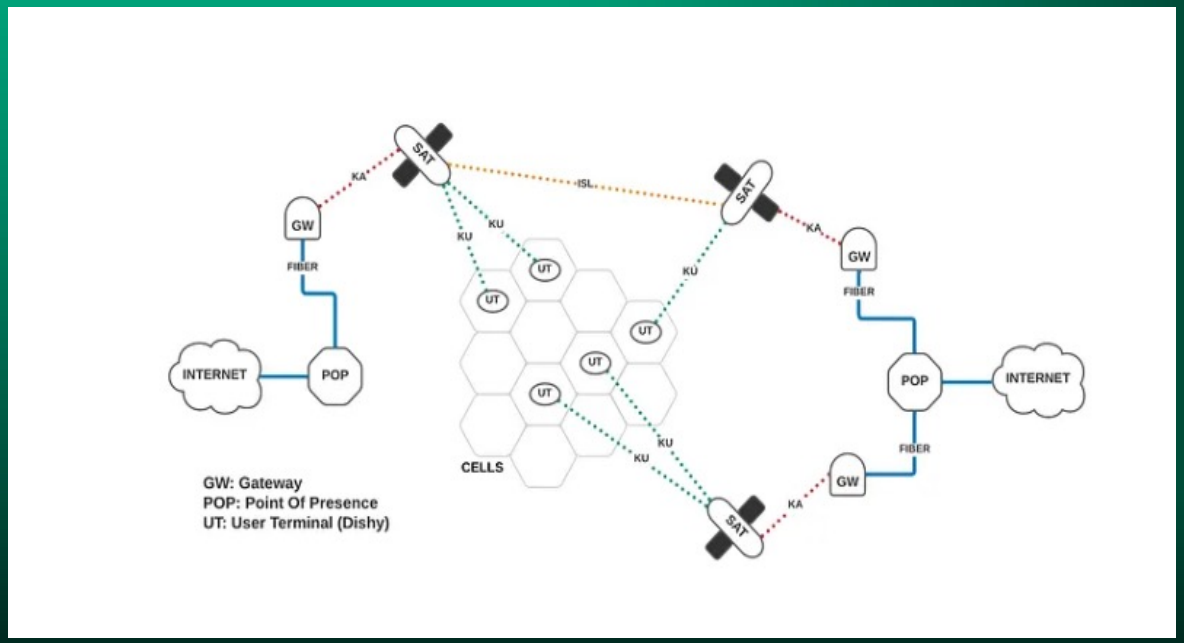


Credit: SpaceX https://starlink.com/technology

V2 Starship1: mass 2000kg (4400 lb), Bus = 6.4m x 2.7m

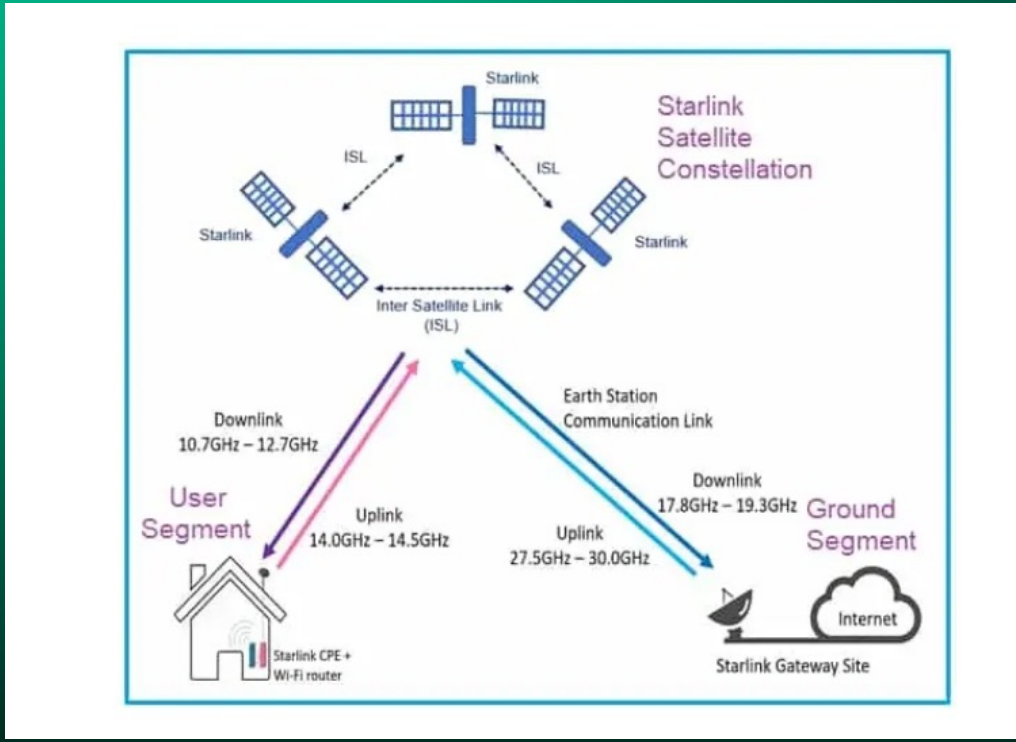
V2 Starship2 DtC: Bus = 10.1m x 2.7m

- Satellite Communications
  - Essentially 3 Networks acting as one.
    - 1) Satellite to User.
    - 2) Satellite to Ground station/Gateway.
    - 3) Inter Satellite.

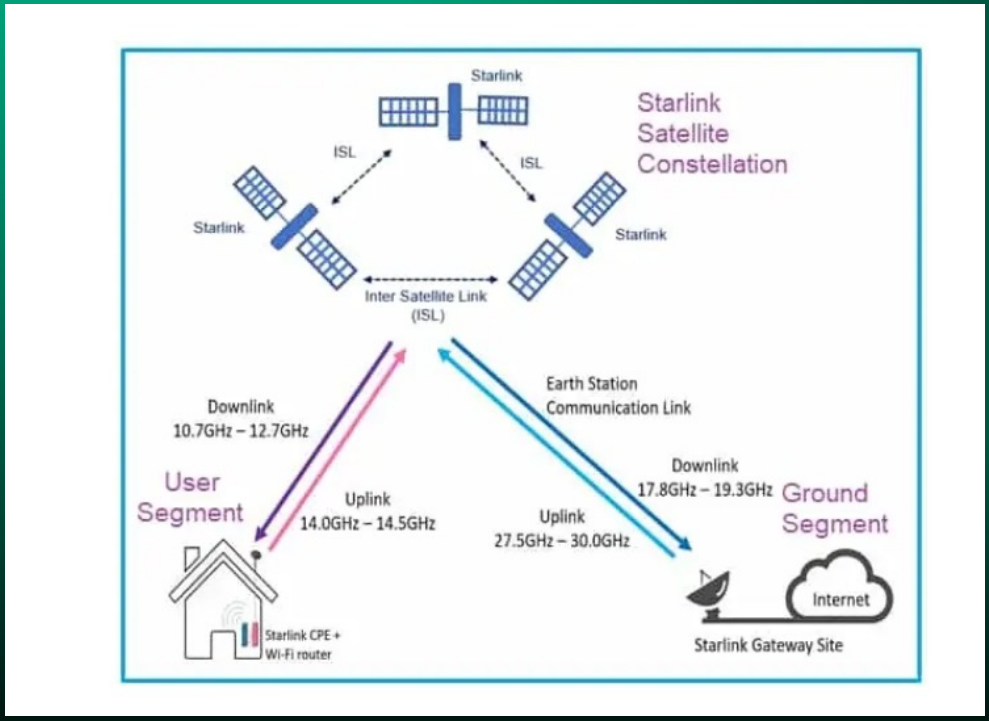


"Modeling Starlink Capacity" – Mike Puchol.

- Satellite Communications
  - Diagram with the frequency bands used by Starlink
  - Not shown is the newly added E-Band between the Gateway and satellite.



- Satellite Communications
  - Some other useful facts.
  - The Starlink UT will have a new satellite in FOV about every 4 minutes.
  - A Ground station will be contact with ~8 satellites



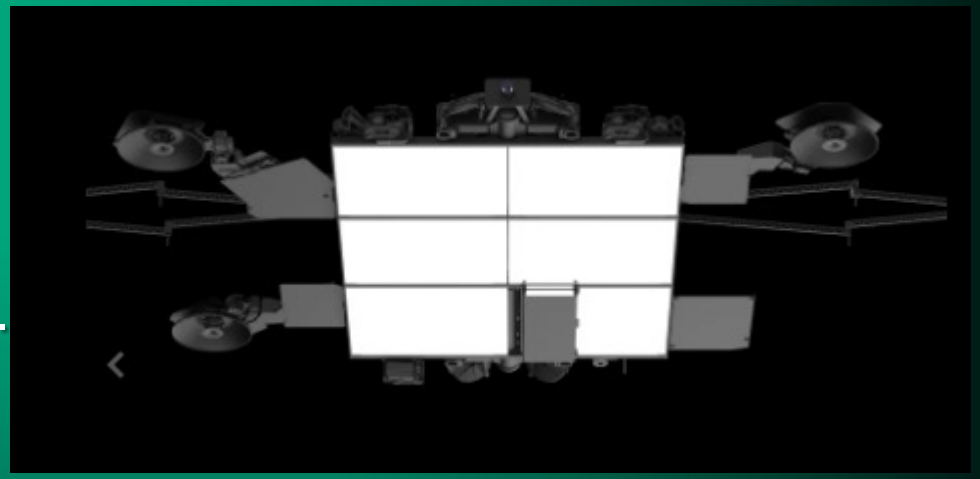
- Satellite Communications
  - Some other useful Starlink facts.
  - Having lots of Ground stations, especially in the United States, is a huge benefit to Starlink capacity.
  - Having lots of Ground stations reduces the amount of traffic that has to be backhauled between satellites and reduces the number of satellites that are being as the conduits to the gateway.
    - This will help minimize delay and help manage satellite capacity restraints over a large regional area (could be a country) with a lot of users or the potential for a lot of users. Like the United States.
  - I'm not going to get into the overall capacity of the Starlink system.
  - There's just too many unknowns to comfortably predict the capacity of each of the 3 mini communication systems that make up the System. Specifically, the public doesn't exactly know the mechanics of the schedulers that are being used by the Satellites or the ground stations.

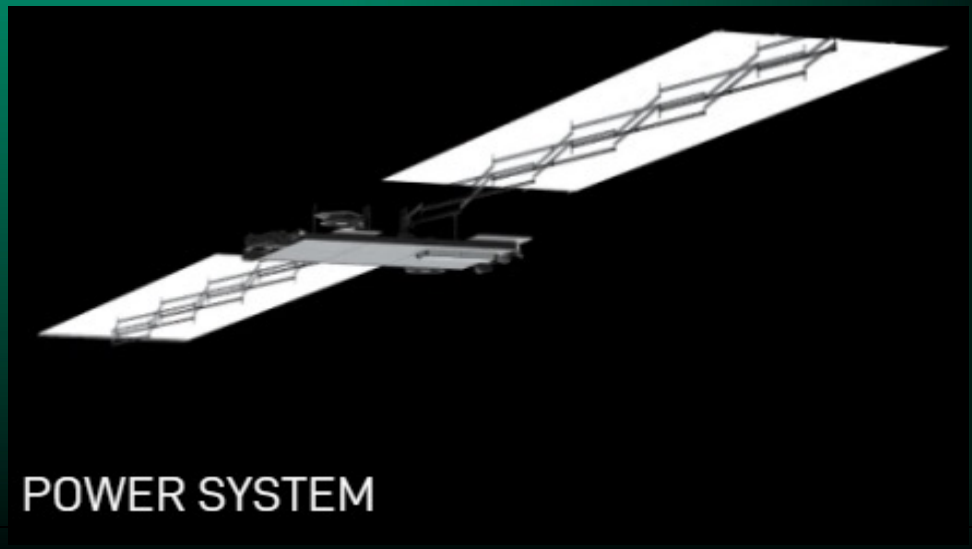
- Satellite Communications - Bonus Slides
  - New V2 satellites have 5 – Ku-band ESA's and 3 dual Ka-band and E-band attennas.

https://www.starlink.com
/us/technology

Off of the Starlink web site.

So hopefully it's accurate.





- # Satellite Communications - Bonus Slides
  - Where the 419 BSLs number is coming from?
  - Assume 6 Gbps is the beam download capacity, 0.419 Gbps is the beam upload capacity (100/20 Mbps Federal requirement for broadband speed).
    - Author of paper contended an industry-standard over subscription of 20:1
      - A little rosy in my opinion.

- **Per Beam BSL Limit (Download Speed):**
  - USE CASE 1: If all BSLs are simultaneously downloading, then the maximum # of BSLs per beam is 6 Gbps/0.1 Gbps, or 60 BSLs.
  - USE CASE 2: If only 1 in 20 BSLs are downloading at any given time, then each beam could serve 60 X 20, or 1,200 BSLs.

- **Per Beam BSL Limit (Upload Speed):**
  - USE CASE 1: If all BSLs are uploading simultaneously, then the maximum # of BSLs per beam is 0.419 Gbps / 0.02Gbps, or roughly 21 BSLs. (actually 20.95)
  - USE CASE 2: If only 1 in 20 BSLs are uploading at any given time, then each beam could serve 20.95 X 20, or 419 BSLs.

"Starlink Capacity Analysis v0.2"

- Satellite Communications - Bonus Slides
  - # of BSLs / Beam Coverage Area = Maximum BSLs per Square Mile
  - Beam Coverage Area = 62.9 square miles, ~ equal to a circle beam with a diameter of 15 miles.
  - 419/62.9 = 6.66 BSLs per square mile
    - **Remember this assumes a over subscription of 20:1**
  - If we assume a 10:1 over subscription ratio
    - 10*20.95 = ~210 BSLs .
    - 210/62.9 = 3.33 BSLs per square mile

"Starlink Capacity Analysis v0.2"

- Starlink's U.S. Performance is on the Rise, Making it a Viable Broadband Option in Some States https://www.ookla.com/articles/starlink-us-performance-2025tates | Ookla®

- # Satellite Communications - Bonus Slides
  - As of Q1, 2025, only 17.4% of U.S. Starlink Speedtest users nationwide were able to get broadband speeds consistent with the FCC's minimum requirement for broadband of 100 Mbps download speeds and 20 Mbps upload speeds.
  - Much of this is due to Starlink's low upload speeds, which are on the uptick but with a combined overall median upload speed of 14.84 Mbps in Q1 2025 there is still room for improvement.

States With the Highest % of Starlink Users that Receive 100/20 Mbps Broadband Speeds

State	% of Starlink users that receive 100/20 Mbps
South Dakota	42.3
Rhode Island	39.0
Wyoming	38.5
Maine	36.5
Massachusetts	35.1

Data as of Q1 2025

States with the Lowest % of Starlink Users that Receive 100/20 Mbps Broadband Speeds

State	% of Starlink users that receive 100/20 Mbps
Alaska	5.3
Mississippi	8.4
Louisiana	9.0
Arkansas	9.6
Florida	9.8

Data as of Q1 2025

– Starlink's U.S. Performance is on the Rise, Making it a Viable Broadband Option in Some States, Sue Marek https://www.ookla.com/articles/starlink-us-performance-2025tates | Ookla®

Any Questions?

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