Starlink Capacity Analysis v0.2

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Abstract

Assuming no topographical considerations or pre-existing user base, in areas where there are more than 6.66 households per square mile within a Starlink beam's coverage area, Starlink may fail to deliver the minimum service level (100/20Mbps) to qualify as a broadband service, thus failing to meet the NTIA eligibility requirements to receive federal support for broadband through programs such as the Broadband Equity, Access, and Deployment (BEAD) program.

Keywords: *Starlink; Broadband Requirements; Network Oversubscription, Network Capacity, Beam Coverage*

1 Introduction

This analysis provides an initial estimate and evaluation of the capacities and saturation limits of the Starlink satellite infrastructure. As an exploratory analysis, the goal is to provide general heuristics that relate to Starlink implementation to meet Federal requirements for "broadband" (i.e., sub-100ms latency connectivity of at least 100Mbps download speed and 20Mbps upload speed).

It should be noted preliminary that full technical specifications for Starlink are not publicly available and the assumptions utilized to produce this analysis are explicitly conditional as stated. Overall, these analyses underscore the need for comprehensive capacity analyses prior to allocation of Federal funding for satellite connectivity and that a failure to take into account fundamental real-world limits to Starlink capacity will result in the allocation of Federal funding to support connectivity that may not meet the eligibility requirements to receive Federal funding, thus raising serious concerns over waste, fraud, and abuse.

1.1 Disclaimer

The analyses presented below are based, in part, on public information available through June 2025, and which may not accurately represent the full technical capabilities of Starlink satellites. Because Starlink does not publish thorough and detailed technical specifications for their satellites, the assumptions made in these analyses may be incorrect; however, citations to source materials, whenever available (e.g., Starlink FCC filings), are provided.

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The overarching goal of these analyses are to make transparent the need for independent verification of capacity limits to the Starlink infrastructure, and the crucial need for detailed engineering, propagation, and capacity analysis to be conducted for any area where Starlink and other satellite broadband solutions are proposed (for example, as recipients of BEAD program funding).

Given the documented capacity limitations to satellite broadband service provisioning (and that these limits are driven both by new and pre-existing customer bases), formal capacity assessments require data concerning Starlink's existing user base; and, new user base limits must be independently verified prior to funding allocations to avoid harmful network congestion that could degrade services to Starlink users within an over-subscribed geographic area.

2 Analytical Appraoch

2.1 Satellite Characteristics

This analysis assumes the use of Starlink V2 satellites, which are, as of June 2025, the most sophisticated generation of widely-deployed Starlink satellites. However, three major iterations exist among the estimated 7,850 currently operational satellites: V1, V1.5, and V2. The current total number of V2 satellites is unknown; but since this analysis assumes that all operational satellites are V2 vintage, the estimates are a likely maximum capacity ceiling for the existing Starlink system.

Each V2 satellite offers approximately 96 Gbps of download bandwidth and 6.7 Gbps upload capacity (a roughly 14:1 ratio of download to upload capacity). Each satellite has beamforming capabilities to support up to 16 beams, with each beam capable of providing approximately 6 Gbps download throughput and 0.4 Gbps upload throughput.

2.2 Beam Coverage Area

Each beam has an estimated coverage area of approximately 63 square miles assuming a 1.5-degree beamwidth, as reported in Starlink's FCC filings. While multiple orbital shells exist for Starlink Low Earth Orbit (LEO) and Very Low Earth Orbit (VLEO) constellations, to simplify the analysis, we assume Ka/Ku-band, phased-array transceivers operating at 550 km altitude.

The Estimated Beam Coverage Area also utilizes the following estimates and formula to develop a circular/oval footprint at nadir, and we provide the formulas used to facilitate analyses predicated upon different parameters):

$$\text{Estimated Beam Coverage Area} = \pi * (\tan(1/2 * \theta * \pi/180) * h)^2$$

Where:

- h = satellite altitude [we assume 550 km].

- $\theta =$ beamwidth [we assume a 1.5 degree angular beam width].
- We assume a satellite operating at a right angle to a flat plane to estimate coverage area.

Estimated Beam Coverage Area = $\pi * (\tan(1/2 * 1.5 * \pi/180) * 550km)^2$

Assumption 1: Beamwidth Assumption

- We assume a beamwidth of 1.5 degrees, which is typical for Ka/Ku-band phased-array systems used in LEO constellations like Starlink. This is a reasonable midpoint between 1° (narrower, high-gain beams) and 2° (wider, lower-gain beams).
- This yields a half-angle for the beam of 0.75 degrees (0.013091 radians).

Assumption 2: Altitude

- We assume an altitude of 550 km. NOTE: While 550 km was the initial planned orbit height for Starlink's constellations in their 2019 FCC filings, shells as low as 340 km above the earth have subsequently been deployed.

Assumption 3: Footprint Area

- Assumptions 1 & 2 yields a circular footprint [i..e., assuming a 90 degree beam on a flat plane] of 162.8554 square kilometers (roughly 63 square miles)

Additional Known & Excluded Adjustments for Real-World Factors

- Off-Nadir Beams: Beams directed away from nadir create elliptical footprints, which can increase the coverage area but reduce signal strength and throughput due to slant range. For a beam steered at, say, 30° from nadir, the footprint becomes elliptical, potentially covering 200–300 km^2, depending on the angle.
- Overlap and Cell Size: Starlink's network design uses overlapping beams to ensure continuous coverage. Each beam's effective service area (or "cell") is likely smaller, around 100–150 km^2, to manage capacity and avoid interference. Engineering discussions and analyses suggest Starlink operationalizes cells using a hexagonal grid, with effective diameters of roughly 15 km. However, the actual beam footprint is likely smaller, with cells dynamically assigned to optimize capacity.
- Topology: Topography creates perturbations to the coverage ovals, while hills and mountains (and trees, buildings, etc.) cause "shadows" whereby coverage within a satellite's beam coverage oval can become disrupted.
- Self-Interference, Weather Attenuation, Harmful Interference, etc.: These real-world constraints all detrimentally affect wireless systems though, for simplicity's sake, are excluded from these analyses. All would further lower expected throughput/network capacity.

2.3 Oversubscription Limits

For a given beam within that footprint, we have two distinct cases to consider:

- USE CASE 1: A dedicated bandwidth use case where all Broadband-Serviceable Locations (BSLs) are simultaneously provided an allocated maximum amount; and,
- USE CASE 2: A more industry-standard, contention ratio use case where the oversubscription rate is 20:1 (i.e., meaning only 1 in 20 BSLs is actually using Satellite capacity at any given point in time).

For the analyses below, 6 Gbps is the beam download capacity, 0.419 Gbps is the beam upload capacity (and 0.1Gbps is the 100 Mbps Federal requirement for broadband download speed, and 0.02 Gbps is federal requirement to meet baseline broadband upload speed). Given federal minimum speed requirements to qualify as a "broadband" service, these two use cases would yield two distinct saturation points for the download and upload capacities of the Starlink network:

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.
- 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.

A contention ratio of 20:1 is within industry standards, and because the limiting factor for meeting Federal minimum speed requirement to qualify as a "broadband" connection is the upload capacity limit, we use the upload-capacity BSL-limit for subsequent analysis.

3 Findings

Given the upload capacity limit of Use Case 2 (with a maximum of 419 BSLs per beam) and the above assumptions leading to a beam coverage area of 62.9 square miles area, one can derive the following maximum average Broadband Service Location (BSL) density:

# of BSLs / Beam Coverage Area = Maximum BSLs per Square Mile

Where:

- # of BSLs = Maximum Number of BSLs that would saturate the throughput of each satellite beam [we assume 419 based upon the uplink BSL limit above].
- Beam Coverage Area = 62.9 square miles, as per the above analysis.

$$419/62.9 = 6.66 \text{ BSLs per square mile}$$

Meaning, that a BSL density of more than 6.66 BSLs per square mile within any given starlink beam coverage area would saturate the network to the point that Starlink could be unable to provide the minimal upload speed threshold to meet the definition of a "broadband" service. Exceeding this 6.66 BSLs per square mile threshold would yield a likely outcome where Starlink services would consistently fail to meet the NTIA's minimal performance requirements to receive Federal grant funding from initiatives such as the BEAD Program.

3.1 A Note on Beam Overlap

Starlink's design permits multiple beams to partially or totally overlap each other. And both a tighter beam coverage angle (creating a smaller beam coverage area) and/or polarized overlapping beams could increase the maximum permissible density. However, even with two overlapping 1 degree beams and no self-interference, one would anticipate oversubscription to occur with roughly 30 BSLs per square mile, which would still make large swaths of rural America untenable for Starlink broadband service. Under real world conditions, the risk of network congestion, hidden nodes, and self-interference would likely put a strain on the Starlink infrastructure before reaching this density level. However, there is inadequate public data documenting Starlink's congestion and self-interference thresholds to include such impact in this analysis.

3.2 Real World Observations

Currently available data indicate that, as of June 2025, only 17% of U.S. speedtest users with Starlink met the 100 Mbps down, 20 Mbps up speed requirement, according to the following:

- "Starlink's U.S. Performance is on the Rise, Making it a Viable Broadband Option in Some States" (June 10, 2024) `https://www.ookla.com/articles/starlink-us-performance-2025`
- "Starlink Shows Gains in Speed Test Report" Telecompetitor Article (June 11, 2025) `https://www.telecompetitor.com/starlink-shows-gains-in-speed-test-report/`

These longitudinal data suggest persistent challenges with the satellite coverage spanning years. Our analysis on BSL congestion levels also excludes a range of other limiting factors worthy of further documentation (and that would further lower the density threshold), including weather attenuation, hand-off latency spikes (and micro-outages), potential congestion of ground terminal uplink bands, and others.

Furthermore, preliminary findings by Meinrath and Karl document additional reliability concerns, including diurnal Starlink network congestion (of both upload and download throughput) across the country and across a longitudinal data collection window spanning from 2022 to 2025. These longitudinal data suggest persistent challenges with the satellite coverage spanning years, with data documenting consistent periodic latency spikes above 100ms and severe speed degradation during peak broadband usage hours – mirroring Ookla's 100+ms latency measurements of the Starlink network.

4 National Implications

Under the NTIA's latest Notice of Funding Opportunity (NOFO), State Broadband Offices are required to be technology independent. Further, they are required to take the lowest qualified bid and only consider secondary factors if the next highest bid is within 15% of the lowest bid.

Many State Offices are concerned that Starlink proposals may be the lowest bid and alternative proposals may not be within the 15% window for consideration.

What this analysis presents is that across many geographic areas Starlink may not be a qualified bidder as it may be unable to attain the required 100/20 Mbps service level (and, in deploying Starlink services, may actually degrade pre-existing users' services to the point that they no longer receive minimal broadband speeds). Even in lower population density regions, whenever the number of un- and underserved BSLs subscribing to the service is greater than 6 households per square mile within a beam's coverage area, further due diligence is essential prior to funding allocations.

5 Contact Information

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