WHITE PAPER

G1 vs LEO Satellites

A Comparative Assessment of G1 and LEO Satellites for Large Scale FWA Networks

Low Earth orbit (LEO) satellite networks are designed to provide broadband in the most remote, hard to reach locations. While they work well for this intended application, they are less successful at delivering fixed wireless access (FWA) in mainstream markets, with unique requirements for high network capacity and spectral efficiency at scale.

This assessment examines how well satellite broadband meets the needs of FWA along the dimensions of density, interference, link rate, spectral efficiency, and capacity. We compare it to Tarana's Gigabit 1 (G1) next-generation FWA (ngFWA) platform, which was designed specifically to deliver fast, reliable broadband at large scale in mainstream markets. Our analysis finds that LEO satellite deployments will suffer degradation at densities beyond one household per square mile. In comparison, G1 offers a 300–750x improvement in density, 5x greater spectral efficiency, 4.5x more capacity, NLoS operation, and interference cancellation up to 50 dB.

This paper covers the primary architectural and operational differences between LEO satellite and G1 networks and that material gap this creates between the different platforms' ability to deliver FWA at scale and density. For the purposes of this comparison, we use Starlink as an example of the most advanced and largest satellite constellation to date, however the general conclusions apply to any LEO satellite application.

LEO Satellite Services Metrics

LEO satellite service is based a constellation of satellites that circle the earth at lower altitudes than geosynchronous satellites, typically in the range of 300–1,200 km — significantly improving latency over previous satellite broadband networks. Communications between the satellite and the terrestrial user terminal (UT) operates in the Ku band (10.7–12.7 GHz). Service is available when a satellite is in position overhead.

Coverage

Cell coverage area is a critical metric in fixed-wireless broadband networks. It determines the number of households that can be served which, in turn, affects capacity required. When calculating satellite coverage, the geographic area is divided into hexagonal cells. The area of each cell is defined by the satellite's orbital height and spot beam angular width.

In the example used on the following page, the width of the cell is 15 miles (24 km) with a total coverage area of 143 miles^2 (370 km^2).

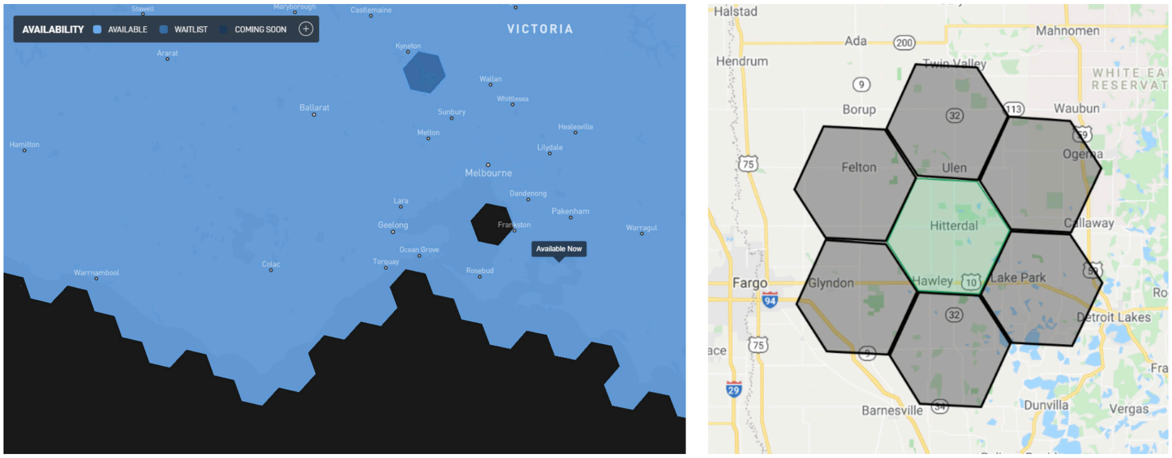

Figure 1: Starlink's cell map near Melbourne, Australia (left) and an up-close example of 7 cells (right)

Link and System Capacity

Cell capacity is the second critical metric for FWA. Capacity drives link speeds and the number of households that can be supported. The available bandwidth of Starlink's satellite system to user terminals (downlink) is 2,000 MHz and 500 MHz from the user terminal to the satellite (uplink). In normal operations, this bandwidth is shared among all satellite constellations, however for the purposes of this paper we assume a single system has all available bandwidth.

Further parameters refine the available bandwidth for satellites, specifically polarization, frequency division among beams, number of beams, and modulations.

Starlink satellites are ultimately expected to use 2 orthogonal polarizations, increasing capacity, however at this time only one polarization is supported by existing user terminals (UT-1). The total bandwidth is divided into 8 frequency pairs, each consisting of 240 MHz down and 62 MHz up. Each beam utilizes one polarization in each of the 8 channels. Thus, a satellite supports a total of 8 simultaneous beams (16 when 2 polarizations are supported). Each beam can be steered independently to cover a different cell or scheduled to sweep between multiple cells.

To calculate the maximum capacity of a single beam, we use the highest supported modulation (with a spectral efficiency of 5.55 bps/Hz) times the total bandwidth (240 MHz):

- 240 MHz x 5.5 bps/Hz = 1,332 Mbps maximum theoretical downlink capacity

For the entire satellite, capacity is calculated as:

- 8 beams x 1,332 Mbps = 10.6 Gbps maximum theoretical capacity for a satellite (8 beams)
- 16 beams x 1,332 Mbps = 21.2 Gbps maximum theoretical capacity (16 beams)

These numbers represent peak available throughput under ideal conditions. To determine a more realistic number, other factors must be considered: impact of weather, impact of interference, achievable signal-to-interference-and-noise ratio (SINR), distribution of user terminals, and coverage area.

Weather is an important consideration for satellite. Due to the propagation properties of the Ku band, precipitation can reduce or fully block all throughput. User terminals also require clear line-of-sight from the user terminal to the sky (satellite). Non-line-of-sight (NLoS) operation is not supported.

Ideal capacity also assumes all users are spaced in a grid many kilometers apart to prevent self-interference between terminals. It also assumes the satellites (which are both power and thermally constrained) are operating at peak power, electronics temperatures are regulated within nominal values and without draining available power, and there are no other satellite operators on the same frequency (the entire Ku band is available for use).

The SINR required to achieve maximum modulation (64-QAM) is 17 dB. Currently, the SINR recorded on UT-1 terminals is between 11 to 12.5 dB which corresponds to 16-32 APSK (Amplitude and Phase-Shift Keying) modulation and a spectral efficiency of 3.5 bps/Hz. Using these numbers yields a maximum of 63% of theoretical capacity.

- 10.6 Gbps x 63% = 6.7 Gbps theoretical capacity based on maximum achievable modulation (8 beams)
- 21.2 Gbps x 63% = 13.3 Gbps theoretical capacity (16 beams)

When looking at network capacity, it should be noted that, given 71% of the Earth's surface is covered by water. **Satellites will provide virtually no terrestrial service 71% of the time** as they orbit the planet.

Given the above parameters (weather, interference, achievable SINR, distribution of user terminals, and coverage area), **an optimistic real-world delivered satellite capacity is 1–2 Gbps with a peak capacity that will not exceed 10 Gbps**. **This corresponds to a peak beam capacity of about 625 Mbps**.

Subscriber Density

Given the capacity estimation, we can now determine the number of subscribers that can be supported in the cell coverage area. The number of supported subscribers is a key metric for any FWA network as it drives profitability (more subscribers generate more revenue). It is also important from a system dimensioning point of view to ensure capacity can meet demand.

The key parameter for satellite-delivered FWA is the size of the spot beam. As discussed earlier, each beam covers an area of 143 square miles (370 km^2) and can deliver a peak of 625 Mbps.

It should be noted that 625 Mbps represents the upper bound of link rate. According to one speed testing site, measured Starlink broadband provides an average of 54 Mbps / 5 Mbps.[1] Other speed test sites report speeds of 91 Mbps / 12 Mbps[2]. User-reported speeds on Starlink forums fluctuate widely between very low, single digit speeds and multi-hundred Mbps. Users also report performance slowdowns as more users join a cell. All of this is consistent with our analysis here.

A typical developed-country household consumes roughly 4 Mbps of downlink traffic at peak hour. This yields the following (assuming 1 beam per cell):

- 625 Mbps / 4 Mbps = 156 subscribers per cell

These estimates are confirmed by published guidelines that recommend no more than 125-130 subscribers in one cell, and yields **a low density of 1.1 HH/mile^2 (0.4 HH/km^2) per cell**. Going forward, assuming a 20% year-over-year growth (an assumption that has held steady in the last 10 years), the peak hour demand will grow to 10 Mbps by 2027 when the Starlink constellation of 12,000 satellites is expected to be completed.

- 625 Mbps / 10 Mbps peak hour = 62 subscribers per cell

This yields an **even lower density of 0.4 HH/mile^2 (0.16 HH/km^2) per cell**. This means that in a typical rural density of 50 HH/mile^2 (19 HH/km2), only 0.8% of the households can be served assuming one beam per cell. These numbers are why satellite broadband is largely considered a solution for very remote areas and is not suitable for denser deployments such as the higher end of rural areas, small towns, suburban, and urban environments.

When calculating the total number of subscribers supported on an entire satellite using 16 beams, we find the following:

- 156 subscribers x 16 beams = 2,500 total subscribers per satellite (4 Mbps peak hour)
- 62 subscribers x 16 beams = 1,000 total subscribers per satellite (10 Mbps peak hour)

Although not covered in this document, a similar exercise can be performed for other locales (suburban, urban, metro), however the results will be much worse than the rural best-case scenario presented here.

It should be noted that there is an expectation that the satellite capacity metrics will continuously improve over time. For example, Starlink has announced a plan to double satellite capacity over the next several years. However, even if supported capacity increases 10x, that is still only 1.5% of households served.

1 https://testmy.net/list?q=starlink
2 https://www.pcmag.com/news/starlink-internet-speeds-see-slight-slowdown-in-us-canada

G1 Next-Generation FWA (ngFWA)

In contrast, Tarana's technology and the G1 platform have been purpose-built from the ground up specifically to address the unique requirements and challenges in ngFWA networks:

- High data tonnage per user, typically 30 to 50x higher than mobile service, driving the need for much higher aggregate network capacity compared to a mobile network.
- Support for density at any population point: rural, suburban, urban, and metro.
- Reliable, multi-hundred Mbps service to each user, even in the face of significant challenges such as non-line-of-sight (NLoS) propagation, dynamic and multipath-rich propagation channels, self-interference at the edge of the cell, and severe interference from other uncontrolled sources in unlicensed deployments.

Coverage

G1 is typically used at ranges from 1 mile (1.5 km) at the highest modulation to 12+ miles (20 km) at the lowest modulation with 90° sectors. Assuming 360° coverage (4 sectors) at full rate (highest modulation), the coverage area is 3 square miles (8 km^2). As we will see later, this makes G1 far more suitable for denser deployments which is a critical component of large-scale fixed wireless access.

Link and System Capacity

G1 supports two 40 MHz carriers and up to 4 simultaneous 2-stream remote nodes (CPE) with a maximum achievable spectral efficiency of 10 bps/Hz per link. Maximum theoretical throughput for G1 is calculated as:

- 80 MHz x 10 bps / Hz = 800 Mbps maximum theoretical link capacity
- 800 Mbps x 4 RNs = 3.2 Gbps maximum theoretical sector capacity
- 4-sector cell = 12.8 Gbps maximum theoretical tower (cell) capacity

Assuming non-line-of-sight (NLoS) conditions, which are likely at any distance beyond 0.2 miles (350 m), distance, and other impairments, a fair estimate of capacity would be:

- 800 Mbps x 70% = 560 Mbps realistic link rate
- 3.2 Gbps x 70% = 2.25 Gbps realistic sector capacity
- 2,250 Mbps / 80 MHz = 28 bps / Hz spectral efficiency
- 2.25 Gbps x 4 sectors = 9 Gbps realistic tower capacity

These numbers are based on real-world operation of G1 in a multi-sector, multi-cell deployment. It should be noted that these numbers are conservative and take into consideration impacts such as NLoS. If we assume similar clear line-of-sight such as required by satellite, the numbers only increase towards the maximum of 800 Mbps link rate and 3.2 Gbps sector capacity.

G1's advanced interference cancellation techniques can remove up to 50 dB of self-interference and up to 40 dB of interference from other transmitters. This greatly increases G1's ability to achieve maximum link rates regardless of self or outside interference. This is particularly useful in dense deployments where interference is the norm. Interference is one of the single largest factors when determining the overall capacity of a cell and one of the reasons G1 was architected to handle it so well. This is in contrast to satellite which has no capability to cancel or mitigate interference other than changing frequencies — which is unlikely to help in an environment with thousands of other satellites and many terrestrial terminals.

Obstacles (NLoS) are the second most significant challenge to wireless links. With precise digital Tx and Rx beamforming and complete multipath integration, G1 offers unparalleled NLoS performance with no requirements for clear line-of-sight.

Subscriber Capacity

When calculating capacity for G1, we use the 9 Gbps realistic capacity for a single tower (4 sectors). Using 4 Mbps for peak hour:

- 9 Gbps / 4 Mbps = 2,250 subscribers per cell

We adjust this number to 1,024 as this represents the maximum supported subscribers by G1 (256 per BN).

In 2027, when peak usage is estimated to be 10 Mbps, the number goes to:

- 9 Gbps / 10 Mbps = 900 subscribers per cell

Assuming the same rural density (50 HH/mile^2 or 19 HH/ km^2), G1's capacity is 1,024 / 3 mile^2 = 340 HH/mile^2 (130 HH / km^2) in 2022 and 900 / 3 mile^2 = 300 HH/mile^2 (115 HH / km^2) in 2027 (10 Mbps peak hour). **G1 supports 100% of all households at either peak hour usage.**

Summary

Satellite networks are well-suited for delivering broadband in the sparsest, most remote settings where natural terrain features make other technologies difficult to implement. This advantage quickly dissipates however when even modest density and capacity requirements are added to the equation. G1, in contrast, can deliver high capacity, high link speed, and interference cancellation across a wide range of densities, from rural to urban locales.

When compared side by side, G1 beats satellite-delivered broadband in almost every metric:

	Satellite	G1
Bandwidth	240 MHz	80 MHz
Spectral efficiency	5.55 bps/Hz	28 bps/Hz
Peak link rate	1,332 Mbps	800 Mbps
Realistic link rate	625 Mbps	560 Mbps
Satellite/tower capacity	2 Gbps	9 Gbps
NLoS operation	No	Yes
Interference cancellation	None	Yes
Satellite / tower coverage	143 miles^2 (370 km^2)	3 miles^2 (8 km^2)
Density @ 4 Mbps peak (1 beam/cell)	1.1 HH/mile^2 (0.4 HH/km^2)	340 HH/mile^2 (130 HH/km^2)
Density @10 Mbps peak (1 beam/cell)	0.4 HH/mile^2 (0.15 HH/km^2)	300 HH/mile^2 (115 HH/km^2)

Density and system capacity are crucial factors when determining if an FWA system can meet both current and future needs as broadband demands continue to grow. One of the primary limiting factors for satellite broadband is the need to keep density low due to overall capacity limitations as well as to reduce the impact of interference, both self-interference and that from other satellite constellations. While capacity improvements can modestly improve the total number of subscribers supported per satellite, the technology has very little ability to reduce interference, so this will continue to be an additional factor limiting overall capacity.

G1 is purpose-built from the ground up for next-generation FWA requirements (ngFWA) at scale, capacity, and density. It was designed from the beginning to cancel unwanted interference, both self and outside transmitters, boosting overall capacity and density. This allows G1 to support far more subscribers per square mile/kilometer while maintaining high link speeds and overall capacity when compared to other wireless broadband technologies such as satellite.

- 5x spectral efficiency
- 4.5x capacity
- NLoS operation
- Interference cancellation
- 300–750x higher density

When combined, these factors clearly show the impact of architecture design and choice. G1's ability to effectively and efficiently deliver high-performance next-generation FWA at scale and density is key to bridging the digital divide with reliable, carrier-class FWA. Both this analysis and real-world reports bear this out.

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Tarana is on a mission to accelerate the deployment of fast, affordable internet access around the world. With a decade of research and more than $400M of investment, the Tarana engineering team has created a unique next-generation fixed wireless access (ngFWA) technology instantiated in its first commercial platform, Gigabit 1 (G1). G1 delivers a game-changing advance in broadband economics in both mainstream and underserved markets, using both licensed and unlicensed spectrum. G1 started production in mid-2021 and has been sold to more than 200 service providers globally. Tarana is headquartered in Milpitas, California, with additional research and development in Pune, India.
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