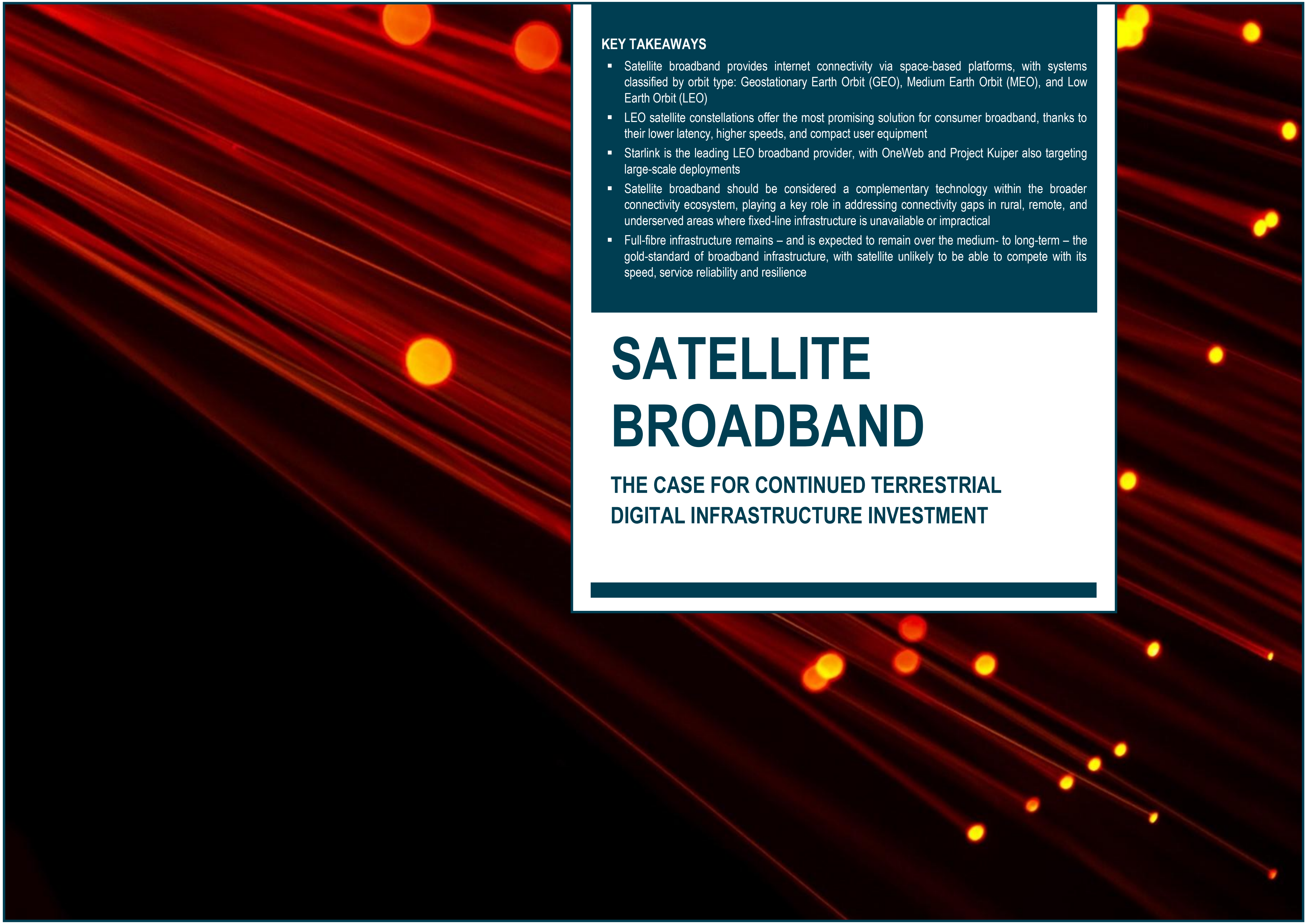


KEY TAKEAWAYS

- Satellite broadband provides internet connectivity via space-based platforms, with systems classified by orbit type: Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO), and Low Earth Orbit (LEO)
- LEO satellite constellations offer the most promising solution for consumer broadband, thanks to their lower latency, higher speeds, and compact user equipment
- Starlink is the leading LEO broadband provider, with OneWeb and Project Kuiper also targeting large-scale deployments
- Satellite broadband should be considered a complementary technology within the broader connectivity ecosystem, playing a key role in addressing connectivity gaps in rural, remote, and underserved areas where fixed-line infrastructure is unavailable or impractical
- Full-fibre infrastructure remains – and is expected to remain over the medium- to long-term – the gold-standard of broadband infrastructure, with satellite unlikely to be able to compete with its speed, service reliability and resilience

SATELLITE BROADBAND

THE CASE FOR CONTINUED TERRESTRIAL DIGITAL INFRASTRUCTURE INVESTMENT

INTRODUCTION

Satellite broadband technology has evolved substantially in recent years and is playing an expanding role in global communications. Unlike traditional fixed-line broadband infrastructure, such as Fibre to the Premises (**'FTTP'**), satellite broadband delivers internet connectivity via orbiting satellites, providing coverage to areas where terrestrial infrastructure is limited, prohibitively expensive, or technically challenging to deploy.

This paper summarises how satellite broadband technology works, outlines the three primary categories of satellites, and profiles the major market players (Starlink, OneWeb and Project Kuiper). It also compares satellite technology with fixed-line alternatives, examining its relative competitiveness, particularly in low-density rural or emerging markets.

HOW SATELLITE BROADBAND WORKS

A standard satellite system includes three core components:

1. **Satellite constellation** – A network of satellites in low, medium, or geostationary orbit
2. **Ground gateway** – Terrestrial stations that link satellites to the internet backhaul
3. **User terminal** – End-user antennas and modems, such as small parabolic dishes (20-50cm) or flat-panel phased-array antennas

Data from a user's modem is transmitted to a satellite dish, relayed through an orbiting satellite, and then routed to a ground gateway connected to the internet via a fibre backbone. The return path follows the inverse sequence, ultimately delivering data back to the user.

Modern satellite systems typically operate in high-frequency bands – such as Ku, Ka, and V – to transmit data. They often employ focused coverage areas, known as spot beams, to enhance capacity and performance.

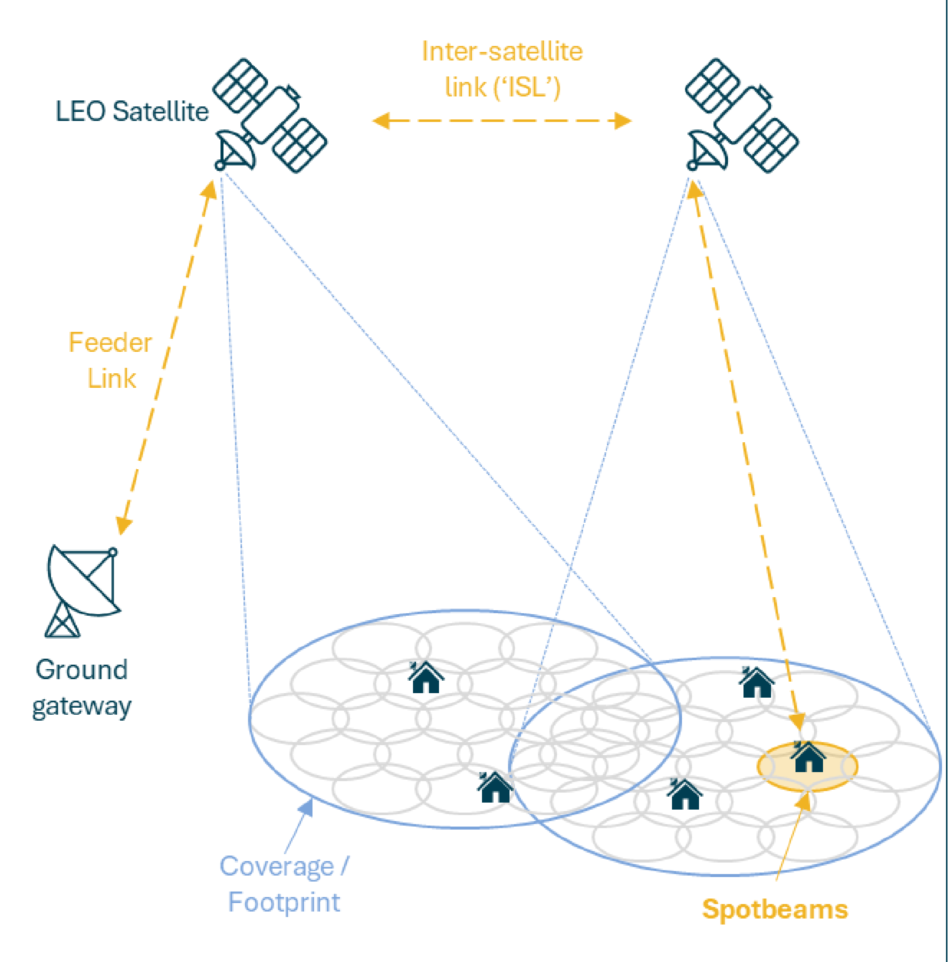
Some systems also connect directly with other satellites in orbit, known as an inter-satellite link ('**ISL**'). This enables satellites to communicate directly with each other in space, bypassing ground gateways. This shortens the signal path and enables faster, more efficient routing of data, especially in areas with limited ground infrastructure.

Key factors that determine satellite performance include:

- **Satellite density** – Higher numbers of satellites reduces bandwidth congestion and improves availability
- **Orbital altitude** – Lower orbits (e.g., Low Earth Orbit, or LEO) reduces latency compared to higher orbits
- **Technology capabilities** – Including throughput per transponder, capacity of ground infrastructure, and use of ISLs

Together, these elements determine the quality, speed, and reliability of satellite broadband services.

FIGURE 1: SATELLITE SYSTEM ILLUSTRATION



Source: Desktop research, Amber Infrastructure

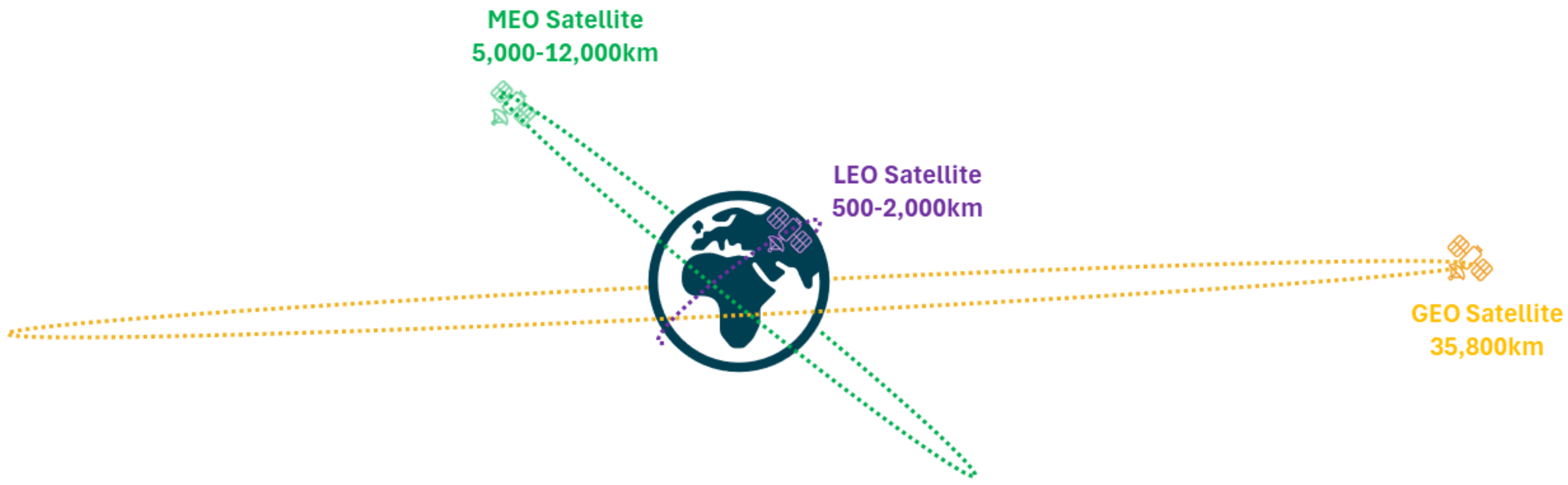
TYPES OF SATELLITE TECHNOLOGY

Satellite systems used for communications and broadband services are deployed across a range of orbital regimes, each with distinct technical characteristics and use cases. The three main categories are:

GEOSTATIONARY EARTH ORBIT ('GEO')	MEDIUM EARTH ORBIT ('MEO')	LOW EARTH ORBIT ('LEO')
GEO satellites remain static over a fixed point on the equator, providing consistent coverage over large areas. GEO satellites are commonly used for TV broadcasting and weather services. The long distance from Earth introduces high latency, limiting their use for interactive applications.	MEO satellites occupy the space between LEO and GEO satellites and are mainly used for navigation systems (e.g., GPS, Galileo). MEO satellites offer moderate latency and require fewer satellites than LEO for regional or global coverage.	LEO satellites operate closest to Earth, supporting lower latency broadband more suitable for real-time applications. Lower altitude however means a more limited coverage area, requiring large constellations to maintain continuous coverage.

Beyond these three primary regimes, several alternative orbital configurations serve more specialised roles. For example, Highly Elliptical Orbits ('HEO') provide extended coverage over high latitudes (e.g. polar regions) where GEO satellites have more limited visibility. These orbits allow satellites to linger over northern or southern regions during the peak of their elliptical path, making them well-suited for meteorological observation, Arctic communications, etc.

FIGURE 2: SATELLITE ORBITS ILLUSTRATION



Source: Desktop research, Amber Infrastructure

CATEGORY	GEO SATELLITES	MEO SATELLITES	LEO SATELLITES
Orbital Altitude	c.35,800km	2,000 - 20,000km	500 - 2,000km
Coverage Footprint	Large footprint (1/3 of Earth's surface per satellite)	Moderate footprint (several thousand km footprint radius per satellite)	Small footprint (c.500-1,500km footprint radius per satellite)
Signal Latency (Appendix 1)	500-600ms round-trip	100-150ms round-trip	25-50ms round-trip
Use Cases	▪ Weather monitoring ▪ Broadcast television and radio ▪ Government / military / disaster recovery comms. ▪ Consumer broadband	▪ Maritime and aviation services ▪ Navigation systems (e.g., GPS, Galileo System, GNSS) ▪ Consumer broadband	▪ Consumer broadband ▪ Earth observation / remote sensing / imaging ▪ IoT networks
Key Player(s)	VIAsAT (ViaSat-2), Eutelsat Konnect, HughsNet (Jupiter)	SES (O3b, O3b mPOWER)	Starlink, OneWeb, Kuiper, Telesat Lightspeed
Advantages	▪ Long satellite lifespan (15+ years), with mature operational standards ▪ Stable, persistent coverage over large regions with minimal infrastructure ▪ Economically efficient for delivering content to many users simultaneously (e.g., broadcast)	▪ Useful middle ground for balancing cost, performance, and complexity ▪ Well-suited for medium-scale high-bandwidth services (e.g., cruise ships, remote enterprises, etc.)	▪ Low latency enables near real-time communications ▪ Lower launch costs per satellite due to smaller size and mass ▪ Rapid deployment and scalability with modular constellation expansion
Limitations	▪ High latency limits suitability for interactive or real-time applications (e.g., online gaming, video calls) ▪ Limited performance in polar and high-latitude regions due to low elevation angles ▪ Larger, more expensive satellites and launch costs	▪ Moderate orbital lifespan (10-15 years) ▪ Fewer operators and active deployments than GEO or LEO, limiting ecosystem maturity	▪ High frequency of satellite replacement due to shorter orbital lifespan[1] (5-7 years) ▪ Requires large constellations and seamless handover mechanisms due to high satellite velocity ▪ Potential space debris concerns due to volume of deployed satellites

[1] Closer proximity to Earth means LEO satellites are exposed to higher atmospheric drag compared to satellites in higher orbits, which gradually slows the satellite down, causing its orbit to decay over time. LEO satellites also impacted by thermal cycling, which is the repeated heating and cooling experienced as they move in and out of direct sunlight each orbit, along with radiation exposure that can damage sensitive components (also impacts MEO and GEO satellites).; Source: Desktop research, Amber Infrastructure

LEO SATELLITE DEEP-DIVE: KEY MARKET PLAYERS

LEO satellites are currently considered the most promising for consumer broadband due to their lower latency, higher speeds, and smaller user terminals. This section profiles the leading players, including Starlink, OneWeb, and Project Kuiper:

		STARLINK	OneWeb	amazon | project kuiper
OWNERSHIP		SpaceX	Bharti Global, Eutelsat, UK Gov., Softbank	Amazon
CONSTELLATION SIZE	DEPLOYED	c.8.0k	c.0.6k	c.30
	PLANNED/TARGET	c.42k FCC[2] approved (target by 2027)	c.2k FCC approved	c.3.2k FCC approved
CURRENT STATUS		Operational	Operational	Trial phase (targeted launch 2026)
COVERAGE FOCUS		Global	Global (incl. polar regions)	Global (initial in US, Europe)
ORBITAL ALTITUDE		c.550km	c.1,200km	n.a.
ACTIVE SUBSCRIBERS		c.5.4m (Mar-25)	Not publicly disclosed	n.a.
TARGET LATENCY		25-60ms	50ms	30-50ms projected
PEAK DOWNLOAD SPEEDS		250Mbps, with 1Gpbs in development	195Mbps	400Mbps projected
DIFFERENTIATOR(S)		▪ Aggressive capacity rollout and vertical integration. By building its own satellites and launch vehicles, SpaceX keeps costs per bit low and can rapidly scale ▪ Has won government contracts to supply connectivity in remote operations	▪ High-latitude performance (i.e., polar regions) ▪ Commercial focus on telcos, enterprises, and governments, leveraging partnerships with national carriers (e.g., BT (UK), Bharti (India), and GlobalData (Japan) ▪ Merger with Eutelsat in 2023 combines GEO and LEO assets, expanding reach ▪ Enterprise-grade SLAs	▪ Amazon-backed cloud integration (AWS); custom silicon chips used ▪ Future access to space through Blue Origins launch vehicles, enabling capacity roll-out. Looking to use SpaceX in the interim

Other emerging projects to note include Telesat Lightspeed and Airbus-backed LeoSat. Notably, Chinese companies (E.g., CASIC) and Russian firms have satellite projects focused on domestic markets but are not yet significant global players.

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[2] U.S. Federal Communications Commission (FCC); Source: Desktop research, Amber Infrastructure

SATELLITE VS. TERRESTRIAL BROADBAND COMPARISON

Satellite broadband services have historically been attractive only where fixed-line infrastructure is unavailable, however, as the technology has evolved, it is increasingly being seen as a potential competitor. This section compares these technologies across several key metrics:

METRIC	SATELLITE (LEO)	FULL FIBRE ('FTTP')	CABLE ('HFC')	xDSL (ADSL/VDSL)
Typical Download Speeds	up to 250 Mbps	150 Mbps to 1 Gbps+	Up to 1 Gbps	ADSL: up to 24 Mbps; VDSL: up to 80 Mbps
Typical Upload Speeds	up to 50 Mbps	100 Mbps to 1 Gbps (symmetrical)	Typically 10–50 Mbps; varies by provider	ADSL: up to 1 Mbps; VDSL: up to 20 Mbps
Signal Latency	25–50 ms	4–8 ms	12–15 ms	ADSL: 24–28 ms; VDSL: 10–14 ms
Upfront Cost[3]	£0 (typically £299)	£0-50 (often waived with contracts; typically limited to rural areas)	Typically £0	Typically £0
Monthly Cost[3]	£75 (standard)	£20-60	£25-40	£15-30
Coverage / Availability	Nationwide, including remote areas	Expanding in urban and suburban areas; more limited in rural regions	Widely available in urban areas; limited in rural regions	Extensive, including rural areas
Quality of Service	Susceptible to weather disruptions; higher latency affects real-time applications	High reliability and consistency	Generally reliable; performance may degrade during peak times	Variable; affected by line quality and distance from exchange
Best Use Cases	Remote or rural areas lacking wired infrastructure	High-bandwidth applications like 4K streaming, gaming, and remote work	General household use, including streaming and browsing	Basic internet usage like emailing and web browsing
Notable Limitations	High latency affects gaming and VoIP; weather can disrupt service	Limited availability in rural areas; higher installation costs	Shared bandwidth can lead to slower speeds during peak times	Slower speeds; performance degrades with distance from exchange

[3] Costs as of Jun-25 and are based on UK pricing; Satellite (Starlink), HFC, FTTP, xDSL pricing based on typical range; Source: Desktop research, ISPreview, Arthur D. Little, Amber Infrastructure

- **Speed**: Full-fibre and cable generally deliver higher peak speeds (hundreds of Mbps to Gbps) than current satellite systems, although noting that modern LEO satellites (Starlink, OneWeb) have closed the gap significantly, now offering up to 200-300Mbps to users and with further speed upgrades understood to be in development.
- **Signal latency**: Satellite systems have much higher latency. While LEO satellites have the lowest latency (c.30ms), this is comparable to legacy xDSL technologies but remains significantly higher than full-fibre (see Appendix 1 for further details on signal latency).
- **Cost**: Monthly costs have been historically much higher for satellite, however have been trending down and are now more comparable with fixed technologies, although noting satellite broadband often requires a more expensive user terminal. Further declines in costs in hardware are expected.
- **Service quality and reliability**: fixed-line broadband generally delivers the highest reliability and most consistent throughput. Terrestrial networks can degrade if overused or damaged (e.g., construction cuts) but are largely unaffected by weather. Satellite signals, by contrast, may be disrupted by heavy rain or snow ("rain fade" and dish obstruction). However, satellite connectivity can play a critical role in emergency scenarios – such as natural disasters – where terrestrial networks are disrupted, serving as a vital backup to maintain connectivity.
- **Accessibility**: Satellite internet can reach locations that terrestrial networks cannot (e.g., ultra-rural areas, maritime, airborne, or disaster-stricken areas). Full fibre and cable infrastructure is largely absent in many rural regions and developing countries. Satellite technology therefore plays an important role in bridging the "digital divide" in underserved communities.

FUTURE DEVELOPMENTS IN SATELLITE BROADBAND

The satellite broadband industry is rapidly evolving, driven by technology and policy developments. This section outlines key trends and advances shaping its future:

- **Constellation growth:** Thousands more satellites are being launched. This is led by Starlink who are targeting up to 42,000 total. This abundance will increase capacity (reducing cost per bit) and enable improved coverage. However, the crowded LEO environment raises space debris and coordination concerns, leading regulators to mandate end-of-life deorbiting and collision avoidance systems.
- **Higher throughput and new bands:** Next-generation satellites will use even higher frequency bands (V and Q bands) to unlock more spectrum. They will incorporate digital payloads and beam-forming arrays to dynamically allocate bandwidth. LEOs will refine inter-satellite optical links and onboard routing to reduce latency and ground gateway dependency.
    - Note, Starlink is developing its 'V3' satellite, which is understood to have 10x the capacity of its existing V2 satellites (up to 500Gbps per satellite) and forecast to launch in 2026. Given the short lifespan of LEO satellites, once available, V3 satellites will replace existing V2 satellites over time. While the increased capacity is expected to enable Starlink to offer consumer broadband speeds up to 1Gbps, Starlink is expected to prioritise this increased capacity to: (i) increase the number of users it can serve per satellite (i.e., to remove its waitlist), and (ii) realise its ambitions to move more into the B2B market, which typically requires much higher bandwidth services.
- **Regulatory and policy shifts:** Governments are recognising that there is a role for satellite in national broadband plans. For example, the U.S. Federal Communications Commission (FCC) now considers satellite bids in rural broadband grants, which previously only included fibre / FWA. The UK and EU have also provided funding or regulatory support for OneWeb and ESA's satellite broadband initiatives. Spectrum allocations continue to set aside bands for satellite. The strategic importance of European ownership and control over satellite technology may also become a geopolitical consideration for the UK and EU, in part driven by recent threats made by Elon Musk to withhold Starlink services to the Ukrainian army[4].

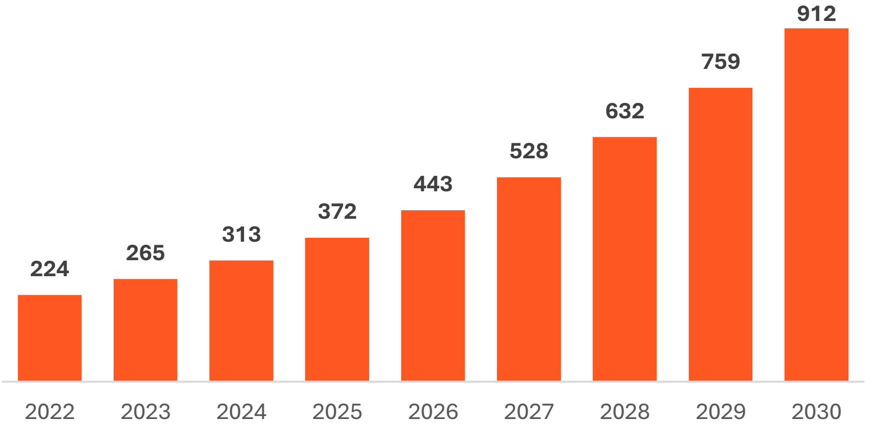
[4] Musk ordered shutdown of Starlink satellite service as Ukraine retook territory from Russia; Source: Desktop research, Amber Infrastructure

WHAT DOES THIS MEAN FOR FULL-FIBRE ('FTTP') INVESTMENTS IN RURAL AREAS?

Satellite broadband has evolved considerably in recent years, significantly narrowing the performance gap with legacy fixed-line technologies such as xDSL. Driven by advancements in LEO constellations, led by Starlink, satellite services now offer a credible alternative for residential consumers in remote and underserved regions, particularly where traditional broadband infrastructure is either absent or cost-prohibitive to deploy. Its ability to deliver relatively high-speed internet quickly and at scale makes it an important stop-gap – and in some cases a long-term solution – for remote and sparsely populated areas.

However, satellite technology is not without limitations. Despite advances in throughput and coverage, challenges such as higher latency, susceptibility to weather interference and bandwidth capacity constraints persist. These issues restrict its ability to support latency-sensitive applications like cloud-based collaboration, real-time video conferencing and online gaming (see Appendix 2). Moreover, as household data consumption is expected to increase significantly over the coming years (see figure 3) – driven by trends like 4K/8K streaming, connected homes, and remote work – there are concerns around satellite capacity and contention, particularly in densely clustered rural areas.

FIGURE 3: FIXED DATA CONSUMPTION FORECAST, '22-30 (GB/home/month)



Source: Arthur D. Little

By contrast, FTTP broadband offers a far more robust and future-proof solution. Once the physical infrastructure is in place, it can scale to meet growing bandwidth demands simply by upgrading end-point electronics. Technologies such as XGS-PON (10Gbps symmetrical) and the emerging 50G-PON (50Gbps symmetrical) standards underscore the long-term potential of full-fibre infrastructure, both in performance and cost-efficiency over time. Furthermore, FTTP provides lower latency, greater service reliability, and higher resilience to environmental factors, making it the preferred platform for advanced digital services. This is especially relevant for next-generation artificial intelligence ('**AI**'), where fibre is expected to remain the only technology able to deliver the bandwidth, scalability, and resilience required to support such services.

WHAT DOES THIS MEAN FOR FULL-FIBRE ('FTTP') INVESTMENTS IN URBAN and SEMI-URBAN AREAS?

Satellite services are not considered a competitive threat in urban and semi-urban areas due to widespread availability of high-performance FBB technologies, particularly FTTP. Satellite services also tend to operate less effectively in these environments. Performance can be impacted by physical obstructions (e.g., high rise buildings, dense infrastructure), as well as signal interference from dense mobile and WiFi networks. Higher population density also leads to greater bandwidth contention within satellite beams, potentially reducing service quality. Furthermore, installation can be more complex in urban areas where mounting dishes may be subject to space constraints.

CONCLUSION

Overall, we consider that satellite broadband should not be viewed as a direct competitor to FTTP, but rather as a complementary technology within the broader connectivity ecosystem. In areas where FTTP cannot feasibly reach in the near- to medium-term, satellite offers an essential solution that can bridge the digital divide and enable basic digital inclusion. It also has an important use case as a vital back-up in emergency scenarios, such as natural disasters, where terrestrial networks are disrupted.

FTTP deployment, including in rural areas, should therefore continue to be viewed as a strategic investment. However, this must be balanced against deployment costs, particularly in low-density regions where FTTP may remain commercially unviable without public subsidies.

Source: Desktop research, Amber Infrastructure

APPENDIX 1 – SIGNAL LATENCY

What is Signal Latency?

Signal latency refers to the time delay between when a data signal is sent and when it is received at its destination. In the context of satellite broadband, latency specifically measures how long it takes for data to travel from a user's device to a satellite, down to a ground gateway and then back through the satellite to the user. It is typically measured in milliseconds (ms).

Why does it matter?

Latency is one of the most important factors in a user's perceived experience when using the internet. For example, Starlink noted that testing showed that increasing bandwidth beyond 10Mbps does not increase web-page load time, but a reduction in latency results in substantially lower load times [5]. Minimising latency is therefore critical for delivering a smooth and responsive internet experience, especially for real-time or interactive applications. High latency can affect the performance of:

- **Video calls and conferencing** (delays and talk-over)
- **Online gaming** (lag)
- **VoIP services** (speech interactions)
- **Cloud applications** (slower response times)

What does this mean for satellite services?

For satellite technology, signal latency is, in part, influenced by the distance the signal must travel and the number of hops it encounters. Since satellite services orbiting the Earth are located thousands of kilometres away, latency can be significantly higher than with fixed-line broadband technologies like full-fibre (4-8ms):

- **LEO satellite latency is usually 20–50 ms**
- **MEO latency ranges between 100–150 ms, and**
- **GEO latency can exceed 500–600 ms**

For LEO satellites (e.g., Starlink), latency is driven by several factors, including:

- Physical speed-of-light propagation from the user to the satellite and back to the ground, which is under 10ms for the round-trip. If traffic flows between satellites via ISLs, this can introduce additional latency.
- Ground latency between the ground gateway sites and the internet connection point
- Fronthaul scheduling latency driven by the network topology and number of users served by a given beam from a satellite.

Noted that Starlink is targeting a goal of delivering a service with a stable 20ms median latency during peak usage, achieving this by increasing the number of internet connection points, optimising fronthaul scheduling latency, and minimising the impacts of non-physical limitations in the process[5].

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[5] Starlink – Improving Starlink's Latency ; Source: Desktop research, Amber Infrastructure

APPENDIX 2 – FUTURE DEVELOPMENTS DRIVING HIGHER BANDWIDTH and LOWER LATENCY REQUIREMENTS

As shown in Figure 3, greater adoption of existing technology, alongside new and emerging technological developments, are forecast to increase household data consumption significantly over the coming years, putting greater importance on high bandwidth and low latency connectivity:

HIGH RESOLUTION VIDEO STREAMING

The growing popularity of 4K and 8K televisions is driving higher demand for ultra-HD streaming services. Platforms such as Netflix and YouTube already offer content in these formats, with 8K streams requiring significantly more bandwidth than previous standards. As adoption widens, it is expected that the impact on household data usage will continue to grow.

CLOUD-BASED GAMING AND GAME STREAMING

Services like Xbox Cloud Gaming, NVIDIA GeForce NOW, and PlayStation Now allow users to stream games over the internet rather than running them locally. These platforms rely on low-latency, high-bandwidth connections – particularly as games move toward higher resolutions and more intensive graphics.

VIRTUAL AND AUGMENTED REALITY ADOPTION

The rollout of new VR and AR technologies for gaming, education, remote work, and social interaction in turn is expected to place additional demands on home networks. Many of these applications require continuous data transfer and low latency, especially when graphics processing is offloaded to the cloud.

REMOTE WORK AND DIGITAL COLLABORATION TOOLS

Hybrid and remote working models have normalised the daily use of video conferencing, cloud-based productivity suites, and large file sharing. In households where multiple people work or study from home, these tools can substantially increase both bandwidth consumption and the need for reliable, low-latency connectivity.

AI-ENABLED TOOLS AND DEVICES

An emerging category of data demand comes from AI-driven consumer technologies, such as smart speakers, home assistants and connected appliances. These systems often rely on cloud-based processing and real-time updates, contributing to ongoing background data usage.

SMART HOMES AND IOT DEVICES

Households are increasingly integrating smart devices – from cameras and lighting systems to appliances and sensors. While the data requirements of individual devices are modest, the cumulative effect of dozens of devices connected simultaneously can significantly increase baseline data usage.[7]

Source: Desktop research, Amber Infrastructure

Important Information