Helios Towers

The Future of Connectivity

How networks must evolve to support exponential growth in data demand



About this white paper

This white paper has been prepared by Helios Towers, drawing on over 15 years of experience operating and investing in telecommunications infrastructure across Africa and the Middle East. It combines independent industry research with practical insight gained from supporting mobile network deployment at scale in diverse operating environments. The analysis reflects Helios Towers' perspective on how terrestrial and satellite networks can be integrated to deliver resilient, cost-effective and ubiquitous connectivity. Assumptions, calculations and methodologies are appended to this paper.

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Foreword



Tom Greenwood
Chief Executive Officer,
Helios Towers

As digital services, cloud computing and artificial intelligence continue to accelerate, demand for connectivity will only increase.

Over the past five years, data consumption across Helios Towers' markets has increased 6x. Looking ahead, independent forecasts indicate that demand across our markets could grow 12x by 2040, almost double the forecast 7x increase in global data growth. Meeting that demand will require continued innovation, investment and collaboration across the telecommunications ecosystem.

As the operator of over 15,000 telecommunication towers across our markets, we see first-hand the critical role resilient infrastructure plays in enabling our customers' growth and improving digital access and experiences for millions of mobile users. We also recognise the exciting opportunities presented by emerging technologies such as Low Earth Orbit (LEO) satellite systems to extend connectivity into areas that have traditionally been beyond the economic or physical reach of terrestrial networks.

This paper explores how these technologies will work together. Its conclusion is clear: the future of connectivity is not defined by competition between satellite and terrestrial infrastructure, but by complementarity. Satellite technology will play an important role in extending coverage to remote communities, and hard-to-reach locations, while terrestrial mobile and fibre networks will remain the primary platforms for delivering the scalable, affordable and high-capacity connectivity needed to support long-term digital growth.

Our purpose at Helios Towers is "Connecting People, Powering Growth", and through harnessing complementary technologies, the industry has the opportunity to accelerate the socio-economic benefits that universal connectivity will bring.





Marcus Weldon
Senior Technical Advisor,
Helios Towers
Former President, Nokia Bell Labs

The emergence of direct-to-device satellite technology has generated considerable discussion about the future of mobile communications. While the potential of these technologies is significant, it is equally important that their capabilities and limitations are understood within the broader context of how wireless networks fundamentally operate. This paper seeks to provide an objective engineering perspective on that discussion.

We examine the underlying principles that determine wireless network capacity: spectrum, propagation distance and, most importantly, spatial spectrum reuse.

These are governed by the laws of physics rather than market dynamics, and they ultimately define how different technologies perform under real-world conditions.

To ensure the analysis is robust, we have deliberately adopted conservative assumptions throughout - often favouring satellite performance - to test whether modern LEO direct-to-device systems could approach the capacity density of terrestrial mobile networks. Even under these optimistic assumptions, the conclusions remain consistent.

Satellite technology will play an increasingly important role in extending connectivity to places where terrestrial networks are uneconomical or impractical, such as in deep-rural terrestrial locations or in aviation and maritime settings, as well as in strengthening network resilience and supporting a range of specialised use cases. However, our analysis demonstrates that terrestrial networks retain an inherent advantage in delivering scalable mobile broadband capacity because of the superior spectral density achievable in terrestrial cells compared to satellite beams.

The intent of the paper is not to advocate for one technology over another, but rather to outline how they can form a complementary set of technologies that together provide a complete set of economical connectivity solutions.



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Summary of key findings

Global data consumption is projected to increase nearly 7x by 2040

Driven by artificial intelligence, video and cloud-based services.

Terrestrial networks will carry 97% of all data

Independent forecasts suggest that approximately 97% of global data traffic will be delivered by terrestrial mobile and fibre networks by 2040, reinforcing their role as the backbone of global connectivity.

Satellite traffic is projected to grow from a low base, reaching approximately 3% of global data traffic by 2040.

Satellites will play a key complementary role in reducing the coverage gap

Satellite technology will extend coverage to underserved areas, helping reach the 300 million people globally who lack coverage and enabling ubiquitous coverage.

Terrestrial networks provide unmatched capacity at scale

Limitations in spectrum, beamforming and power mean satellites cannot support high-capacity, urban or indoor demand at the same scale as terrestrial infrastructure.

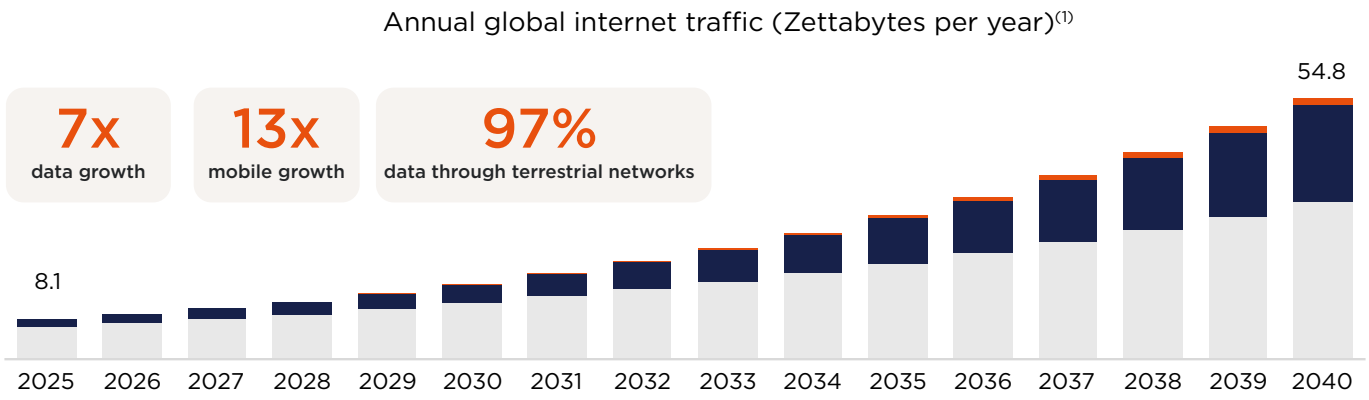
The primary barrier to digital inclusion is the usage gap

Approximately 3.1 billion people live within coverage but do not use mobile internet. Bridging the digital divide will require addressing affordability, device access and digital adoption, not just expanding coverage.

Key takeaway: Satellite and terrestrial networks will play complementary roles in the future connectivity landscape. Satellite will be most effective in hard-to-reach, low-density environments, including ultra-rural areas, as well as maritime and aviation use cases, extending the frontier of coverage.

Terrestrial mobile and fibre networks will remain the critical enabler of global connectivity, supporting the vast majority of data traffic and underpinning the expected expansion in data demand over the coming decades.

Figure 1.0 Global data traffic forecast 2025-2040



Data traffic (ZB)	2025	2040	Growth
Fixed & fibre	6.5	33.0	**5x**
Mobile	1.6	20.4	**13x**
Satellites	0.0	1.5	**N/A**
Total	**8.1**	**54.8**	**7x**

Note: Figures and growth multiples may not sum precisely due to rounding.

By 2040, global data consumption is set to increase nearly 7x, driven by artificial intelligence, cloud computing and data-intensive applications. Based on recent independent forecasts(1), global internet traffic is projected to rise from 8 zettabytes annually in 2025 to almost 55 zettabytes by 2040.

Under this trajectory, the overwhelming majority of data growth will continue to be carried by terrestrial infrastructure. Of the approximately 55 zettabytes of data traffic forecast in 2040, around 97% is expected to be supported by mobile and fixed networks. Fixed and fibre networks remain the largest carriers of data in absolute terms, increasing from approximately 7 zettabytes in 2025 to around 33 zettabytes by 2040. However, mobile traffic is expected to grow faster than fixed, rising 13x from roughly 2 zettabytes to around 20 zettabytes and capturing over 40% of incremental growth.

This trend is even more pronounced in Africa and the Middle East, with data traffic in Helios Towers' nine markets expanding by 12x by 2040(1), almost double the pace of global growth, with mobile traffic carrying the highest share due to a lower prevalence of fixed line availability.

Satellite traffic is expected to increase from a negligible amount in 2025 to around 1.5 zettabytes by 2040. This will represent a 3% share of the total incremental data growth globally.

At the same time, digital connectivity remains unevenly distributed. Around 300 million people in 2025 (roughly 4% of the global population) remain outside coverage entirely(2). Extending terrestrial infrastructure to these final areas has proven disproportionately expensive(2) despite ongoing efforts from governments and the mobile industry to extend access to all.

It is against this backdrop, and through advances in engineering and launch economics, that Low Earth Orbit (LEO) satellite systems have emerged, enabling baseline connectivity in remote and hard-to-reach locations. However, this paper demonstrates that while satellite expands reach, it does not alter the fundamental economics of high-capacity connectivity. Satellites are inherently constrained in capacity density relative to terrestrial infrastructure. Spectrum, beam geometry and power limitations restrict their ability to support dense traffic loads, indoor coverage and sustained urban demand.

The evidence therefore points to a complementary future. Satellite platforms are best suited to rural, remote, maritime, aviation and emergency response scenarios, while terrestrial infrastructure, delivered through proven mobile operator and tower company models, will continue to carry the vast majority of global data traffic.

This complementarity is particularly important in Africa and the Middle East. While coverage has expanded significantly, the region accounts for the majority of the 300 million people outside coverage globally.(2)

(1) FTI Consulting (2026) (2) GSMA (2026), The Limits of D2D: Modelling the Extent of Direct-to-Device Connectivity, GSMA Intelligence

Introduction

As demand for data continues to accelerate, the challenge is no longer coverage alone, but how to deliver scalable, affordable and high-capacity connectivity across diverse environments.

Despite significant progress in expanding network infrastructure, over 3.4 billion people remain unconnected to mobile internet services, representing approximately 42%[1] of the global population. This reflects two distinct but related challenges:

- The usage gap: approximately 3.1 billion people live within network coverage but do not use mobile internet services, due to barriers such as affordability, device access, digital skills and perceived relevance.
- The coverage gap: around 300 million people still live outside the footprint of mobile broadband networks entirely, primarily in remote and low-income regions where deployment is complex and uneconomic.

The significantly larger usage gap highlights that extending coverage alone will not be sufficient to achieve universal connectivity and a holistic approach is needed.

While advances in satellite technology, particularly Low Earth Orbit (LEO) systems, are expanding the reach of networks into previously unserved areas, they do not change the fundamental dynamics of how connectivity is delivered at scale. Terrestrial infrastructure remains uniquely positioned to support high-capacity, high-density and indoor demand, while satellite plays a targeted role in extending coverage and enhancing resilience.

The future of connectivity is therefore not defined by substitution, but by complementarity. Satellite and terrestrial networks will operate together, with distinct roles shaped by technical, economic and geographic realities.

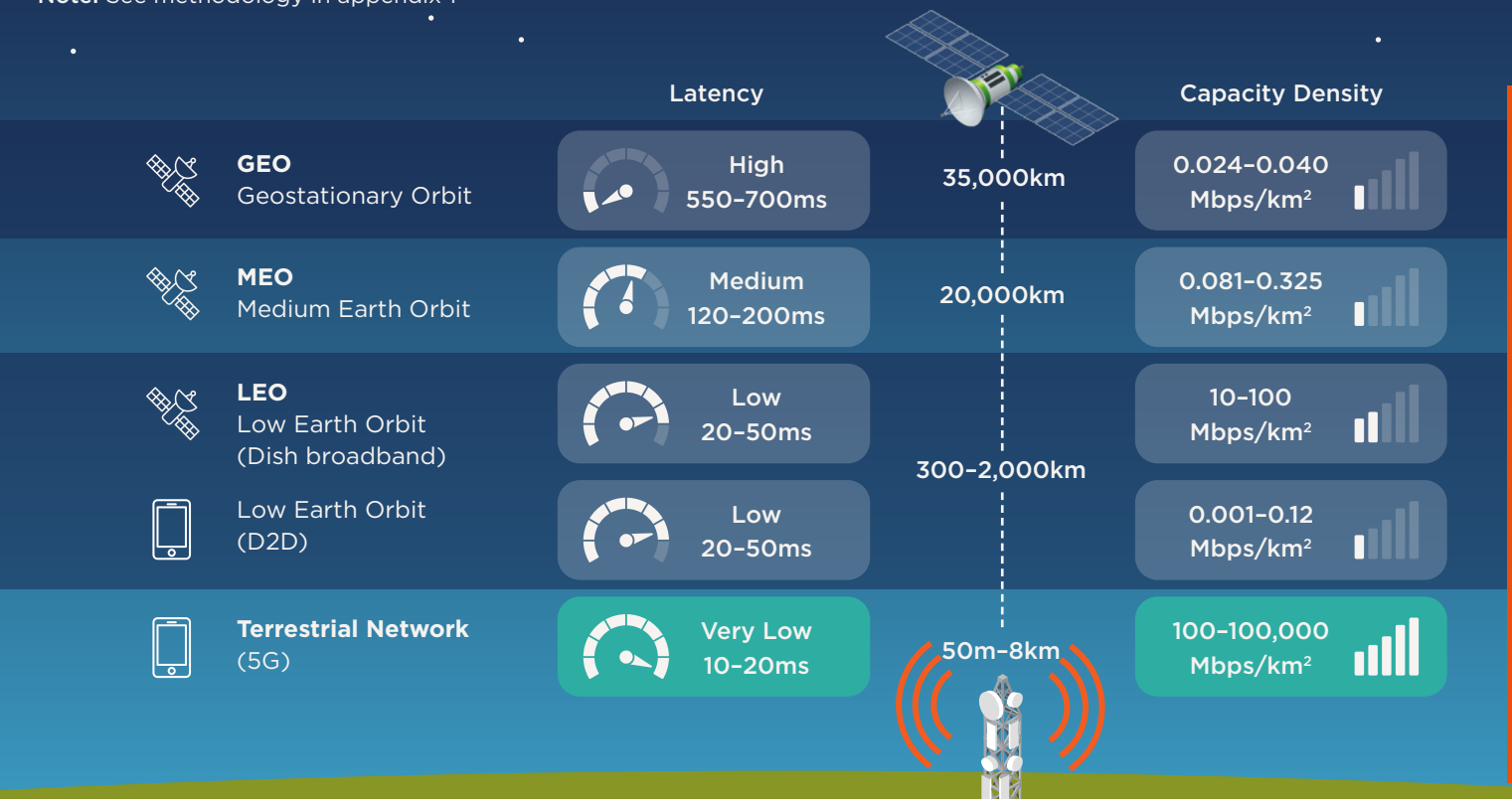
This distinction is particularly important in Africa and the Middle East, where significant progress in network coverage has been achieved, yet large segments of the population remain offline. Closing this gap will require solutions that balance reach, affordability and long-term scalability.

Against this backdrop, this paper examines the evolving role of satellite connectivity within the broader ecosystem, focusing on its capabilities, limitations and interaction with terrestrial networks across different environments.

[1] GSMA (2025), The State of Mobile Internet Connectivity 2025: Trends in Mobile Internet Connectivity



Figure 1.1 A comparison of LEO, MEO and GEO satellite constellations
Note: See methodology in appendix 1



Technical primer: Understanding satellite networks

Satellite systems are commonly grouped into three categories:

1. Geostationary Earth Orbit (GEO)
2. Medium Earth Orbit (MEO)
3. Low Earth Orbit (LEO)[1]

Each of these satellite systems has various advantages and disadvantages, which are a function of:

1. Coverage area

The geographic area of the Earth's surface where the satellite's signal can be utilised. Measured in km².

2. Latency

The time it takes for data to travel to the satellite and back. Highly influenced by distance.

3. Data capacity

The total data throughput of the satellite is measured in bits per second. This is closely linked to spectrum.

4. Spectrum (Frequency)

The range of radio frequencies used to transmit data between network infrastructure and devices. It is a finite resource, licensed and regulated at the national level.

5. Number of satellites in the constellation

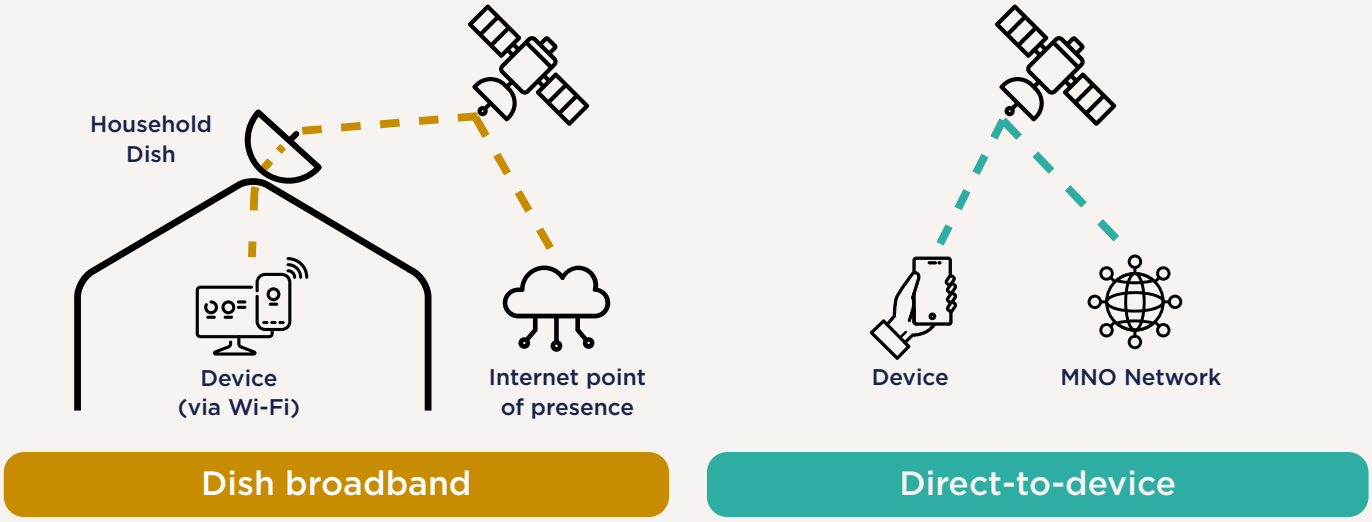
More satellites can improve geographic coverage, increase aggregate network capacity and reduce service gaps by increasing the number of satellites visible to users at any given time. However, constellation size is not unlimited. It is constrained by orbital capacity, spectrum rights, collision-avoidance and debris-mitigation requirements, regulatory approvals, satellite replacement cycles, launch economics, ground-segment capacity and the complexity of managing handovers and interference across the network.

LEO satellites orbit at altitudes of roughly 300–2,000km creating latency of c.20–50ms, significantly less than the c.500ms or more of GEO satellites. Although MEO satellites provide a compromise between GEO and LEO, their latency remains higher and less suitable for real-time mobile services[2,3].

Given the growing number of mobile network operator partnerships announced globally for direct-to-device, LEO satellite services remain the most appropriate focus for this paper.

[1] ITU (2023), Non-geostationary Satellite Systems www.itu.int/en/mediacentre/backgrounders/Pages/Non-geostationary-satellite-systems.aspx [2] ESA – Types of Orbits www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits [3] SES (2024), O3b mPOWER Factsheet

Figure 1.2 Dish broadband vs Direct-to-device



LEO satellite technical capabilities

LEO satellite constellations form networks that orbit the Earth approximately every 90 to 120 minutes, enabling continuous global coverage[1]. Each LEO satellite typically provides a practical coverage footprint on the order of c.1–2 million km², depending on orbital altitude and minimum elevation angle constraints. For example, a satellite at c.500–550km altitude can cover approximately 2 million km² under typical operating conditions. This coverage area is further subdivided into spotbeams (or cells), each typically covering on the order of c.160–2,000km², corresponding to beam diameters of roughly c.14–50km, depending on system design[2] and frequency band.

Service models

LEO satellite telecommunications are currently implemented through two main service models: dish-based broadband services and direct-to-device (D2D) communications, as illustrated in Figure 1.2. Both models serve distinct user requirements and application environments but remain subject to the same physical limitations.

Dish-based broadband services

Dish-based broadband systems use a fixed terminal that requires an unobstructed view of the sky to establish a link to the satellite constellation. The user terminal connects to a local Wi-Fi router to distribute connectivity within a home, business, or site network. These systems provide broadband speeds of up to 100–200Mbps per household, although the number of users able to achieve these speeds simultaneously is limited. They are typically powered by the local electrical grid.[3]

Direct-to-device (D2D) communications

D2D services allow smartphones to communicate directly with LEO satellites using existing mobile network spectrum bands in partnership with mobile operators[4]. This approach enables network operators to extend mobile coverage to areas where typical terrestrial solutions cannot reach, although it also requires a clear line of sight to the sky to work effectively and cannot be reliably used indoors.

Partnerships between satellite operators and mobile network operators, such as Starlink with T-Mobile, and AST SpaceMobile with AT&T and Verizon, are driving early deployments of D2D capability.

However, current D2D satellite deployments remain modest in scale, with constellation sizes still significantly smaller than conventional LEO broadband networks, constraining near-term capacity.

[1] ESA, Types of Orbits, www.esa.int [2] SES (2024), O3b mPOWER Factsheet [3] Nokia (2025), Satellite Communication Benchmarking with Terrestrial 5G Networks White Paper [4] Garcia-Cabeza, J., et al. (2025). Direct-to-Cell: A First Look into Starlink's Direct Satellite-to-Device Radio Access Network through Crowdsourced Measurements.

Key differences of satellite operators versus terrestrial networks

D2D satellite connectivity faces different physical and engineering limitations from those of terrestrial mobile networks. These limits arise from:

- LEO geometry and beam footprint.
- Urban propagation and indoor penetration.
- Spacecraft power, thermal and compute ceilings in orbit.
- Spectrum and regulation.
- Constellation scale and cost required to meet mainstream service levels.

LEO geometry and beam footprint (capacity per km^2)

From altitudes of roughly 300–2,000km, LEO satellite beams cover far larger areas than terrestrial mobile cells. This is particularly limiting for direct-to-device services, where satellites must communicate with standard handsets using limited antenna gain and transmit power. Even with beamforming, a D2D beam may cover a footprint measured in tens of kilometres in diameter, equivalent to hundreds or thousands of square kilometres. The available spectrum and satellite capacity must therefore be shared across a large geographic area, reducing capacity density and limiting per-user throughput where demand is concentrated. Narrowing beams further is theoretically possible, but rapidly becomes impractical and uneconomical for commercial deployment due to the need for substantially larger antenna arrays, higher power, tighter thermal management and more demanding interference coordination.[1]

Capacity-density analysis shows the scale of this constraint clearly. Field-test analysis of Starlink's early LEO D2D network estimates current outdoor mobile-data performance of 3.1Mbps per beam under the current 2×5MHz PCS G Block configuration.[2] Even before accounting for user sharing, this capacity is distributed across a wide footprint. As a result, achievable capacity per square kilometre is extremely low, typically in the thousandths to hundredths of a megabit per second per km^2, and remains orders of magnitude below modern terrestrial mobile networks.

Urban propagation and indoor penetration

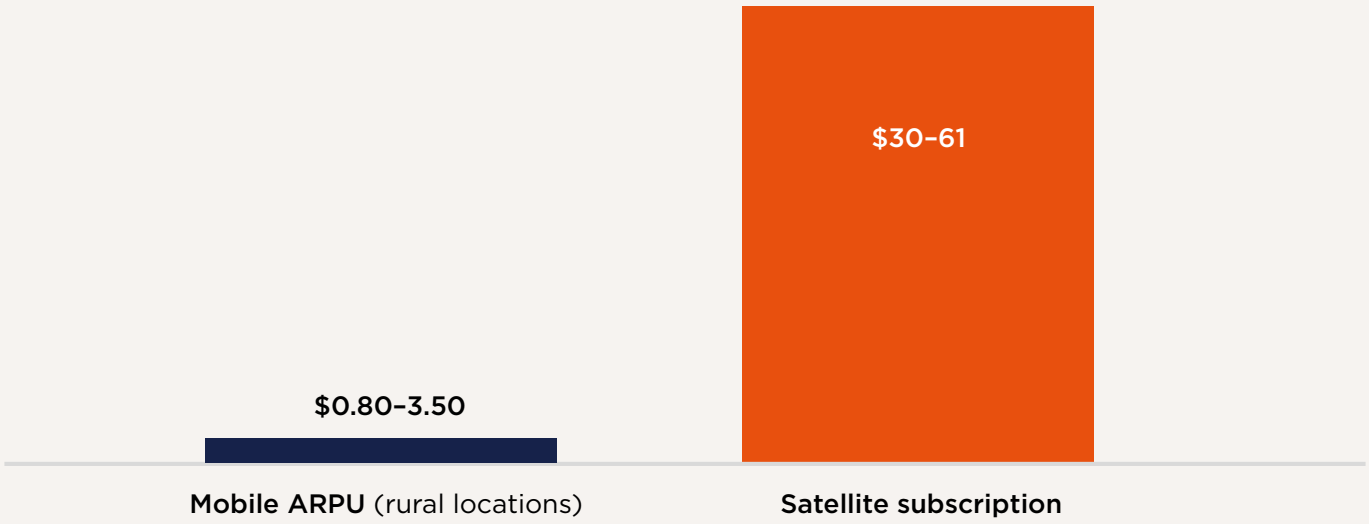
In urban environments, end-to-end path loss can exceed 170 dB, meaning the signal reaching a device is approximately 10^{17} times weaker than the transmitted signal. In practical terms, this is an extremely faint signal that requires highly sensitive receivers and favourable conditions to maintain stability.

Conventional smartphones are designed for terrestrial cellular networks, using compact, low-gain antennas and limited transmit power that further constrain direct satellite communications, particularly indoors and in obstructed environments.

When buildings and foliage are introduced, additional attenuation further reduces signal strength, making reliable indoor connectivity challenging. Terrestrial networks mitigate this through denser site grids and in-building solutions, enabling stronger and more consistent indoor performance than LEO direct-to-device systems can typically support.

[1] Xu et al. (2023), Enhancement of Direct LEO Satellite-to-Smartphone Communications by Distributed Beamforming [2] Garcia-Cabeza, J., et al. (2025). Direct-to-Cell: A First Look into Starlink's Direct Satellite-to-Device Radio Access Network through Crowdsourced Measurements

Figure 1.3 Average rural mobile ARPU vs cost of satellite per month across a sample of SSA countries[4]



Spacecraft power, thermal and compute limits in orbit

Satellite performance is relatively constrained by power, thermal, and processing capacity. As demand increases, driven by higher throughput, onboard processing, and inter-satellite connectivity, these limits become more pronounced. This caps the number of users each satellite can serve at any one time and creates challenges in scaling to dense, urban-level demand.[1]

Spectrum and regulation

LEO satellite systems must coexist with terrestrial licensees in prime mobile spectrum bands, often operating within relatively narrow channel allocations in early direct-to-device deployments. Moving to higher-frequency bands can increase available bandwidth but introduces greater atmospheric attenuation and reduces signal penetration, particularly in challenging environments. In practice, spectrum sharing frameworks, national licensing regimes, and interference coordination requirements constrain the usable bandwidth and transmission power available to satellite systems more than physics alone, particularly in proximity to dense urban networks.[1],[2],[3]

Affordability and economics

In addition to physics and regulatory constraints, affordability will limit adoption. Affordability ultimately determines scalability. In many African markets, mobile connectivity is priced for mass adoption, supported by low-cost prepaid models and shared infrastructure economics.

Across a sample of Sub-Saharan African countries, mobile ARPU typically ranges between $1.30 and $5.40 per month, with ARPUs in rural locations even lower and ranging between $0.80 and $3.50 per month. This reflects affordability constraints and the prevalence of prepaid business models.

By comparison, LEO satellite services are priced significantly higher, with typical monthly service costs in the range of $30–61, representing a significant premium over mobile connectivity, excluding upfront hardware costs.

Key takeaway: Fundamental physical, regulatory and economic constraints mean that terrestrial networks will continue to be the core technology for mobile users.

[1] Barros, S. (2025), From Cell Towers to Satellites: A 2040 Blueprint for Urban-Grade Direct-to-Device Mobile Networks. [2] Garcia-Cabeza, J. (2025), Direct-to-Cell: A First Look into Starlink's Direct Satellite-to-Device Radio Access Network through Crowdsourced Measurements. [3] ITU-R (2025), Recommendation P.619-6: Propagation data required for the evaluation of interference between stations in space and those on the surface of the Earth, International Telecommunication Union. [4] FTI Consulting, 2026 broadband packages benchmark.

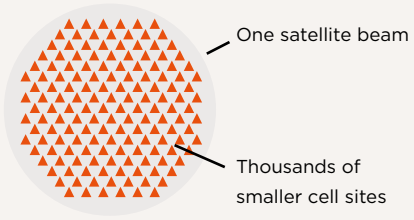
The capacity challenge

With global data demand projected to grow 7x by 2040, meeting this demand will depend on the three fundamental drivers of wireless network capacity.

Capacity Density (Mbps/km²)	=	Beam density (Beams per km²)	x	Spectrum (MHz)	x	Spectral efficiency (Bits/s/Hz)
Terrestrial		Ability to continuously densify capacity through spatial spectrum reuse by increasing cell sites		Spectrum is finite		High
Satellite		Distance from Earth means beam footprint cannot densify beyond certain limits (e.g. one beam per 160km²)		Spectrum is finite		Low, due to longer distances, power constraints and handset limitations

Beam density

Wireless network capacity depends on spatial spectrum reuse. In satellite networks, multiple beams using the same frequency generally cannot be directed at the same location without causing interference. Terrestrial networks divide coverage into thousands of small cells, allowing the same licensed spectrum to be reused repeatedly, densifying the network. Satellite D2D systems serve much larger beam footprints, meaning all users must share the same spectrum resource across a large area. This fundamental difference is why terrestrial networks deliver dramatically higher capacity density.



Spectrum

Current LEO D2D deployments typically use only a small proportion of an operator's licensed mobile spectrum, whereas terrestrial networks operate with much larger spectrum holdings. To isolate the impact of network architecture, in the following case study we have illustrated a scenario where both technologies have access to the same 100MHz of licensed spectrum. This conservative assumption removes spectrum quantity as a differentiating factor, allowing the analysis to focus on spatial spectrum reuse. Using representative D2D spectrum allocations would further increase the throughput density advantage of terrestrial networks, without changing the overall conclusions.

Spectral efficiency

Spectral efficiency is the amount of data that can be transmitted over a given amount of radio spectrum, typically measured in bits per second per hertz (bit/s/Hz). In practice, terrestrial 5G networks are expected to achieve higher spectral efficiency than current LEO direct-to-device (D2D) systems due to more favourable radio conditions, shorter distances and advanced technologies such as Massive MIMO and beamforming.

However, representative commercial spectral efficiency values for LEO D2D systems are not publicly available. Accordingly, this analysis assumes an equal spectral efficiency of 3 bit/s/Hz for both terrestrial and LEO D2D networks. This deliberately conservative assumption isolates the effects of spectrum allocation and spatial spectrum reuse. Using representative terrestrial spectral efficiency values would further increase the performance advantage of terrestrial networks, without altering the overall conclusions.



Use case: Dar es Salaam, Tanzania

6m population in 2025 | 15x data growth forecast by 2040[1]

Over the following pages, we show the capacity challenge in action. Dar es Salaam is used as a representative high-growth urban market to illustrate the fundamental engineering principles that determine wireless network capacity. While the city provides the illustrative example throughout this analysis, the same methodology and conclusions apply to the vast majority of towns and cities worldwide.

	Scenario 1 Current deployment		**Scenario 2** Future lower-bound satellite footprint		**Scenario 3** Higher throughput requirement		**Scenario 4** How terrestrial capacity scales	
	In conducting the modelling, we first start with **current deployment.**		We then stretch the satellite assumptions, **reducing beam coverage area to 160km²** and **increasing allocated spectrum to 100MHz**, equivalent to the MNO in the example.		We then modelled a demand for improved user-experience - taking the **Mbps per user requirement from 2 (basic 3G) to 100 (modern 5G).**		And finally we demonstrate the scalability of the terrestrial network through cell tower densification - by **increasing the number of cell sites within the 160km² area**.	
	Satellite	Terrestrial	Satellite	Terrestrial	Satellite	Terrestrial	Satellite	Terrestrial
Comparison area diameter (km)	25	25	14	14	14	14	14	14
Coverage area (km²)	c.500	c.500	160	160	160	160	160	160
Spotbeams / cell sites	1	1,200	1	384	1	384	1	1,000
Allocated spectrum (MHz)	5	100 (3 sectors - 300MHz per site)	100	100 (3 sectors - 300MHz per site)	100	100 (3 sectors - 300MHz per site)	100	100 (3 sectors - 300MHz per site)
Service requirements (Mbps per user)	2 Basic 3G user experience	2	2 Basic 3G user experience	2	100 Modern 5G user experience	100	100 Modern 5G user experience	100
Subscriber capacity (subs / km²)	0.15	11,000	9.38	11,000	0.19	216	0.19	564
Concurrent active users[2] (per km²)	0.02	1,100	0.94	1,100	0.02	22	0.02	56
Terrestrial advantage (capacity density)	c.72,000x		c.1,200x		c.1,200x		c.3,000x	

Shading indicates a change in assumption as compared to the prior scenario

Key takeaway: Even under highly optimistic satellite assumptions, terrestrial mobile networks deliver orders of magnitude greater capacity density.

[1] FTI Consulting (2026) [2] Assumes 10% concurrency rate

Scenario 1
Current deployment

In conducting the modelling, we first start with **current deployment.**

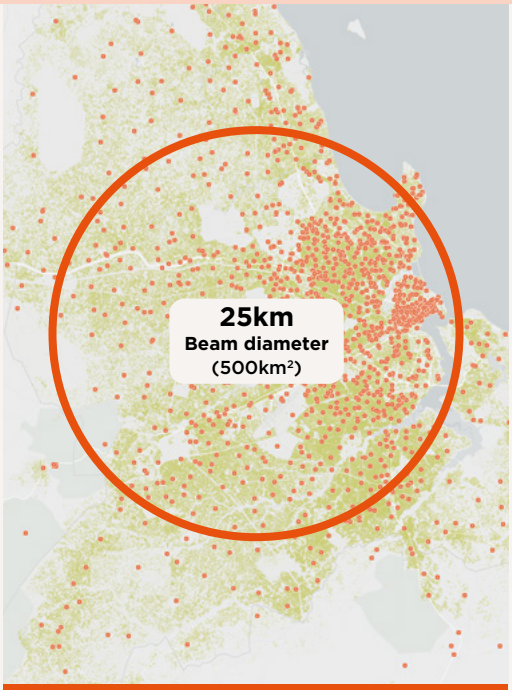
1
satellite beam

5MHz
Spectrum per beam

2Mbps
Assumed consumption per user

0.15
Subscriber capacity (subs / km²)

0.02
Concurrent active users per km²



Dar es Salaam comparison area

1,200
terrestrial sites

3 sectors @ 100MHz each
Spectrum per site

2Mbps
Assumed consumption per user

11,000
Subscriber capacity (subs / km²)

1,100
Concurrent active users per km²

c.72,000x Terrestrial advantage

This scenario compares a single LEO direct-to-device (D2D) satellite beam with an equivalent terrestrial coverage area in Dar es Salaam under today's deployment conditions.

For satellite D2D, we assume a 25km diameter beam (c.500km²), representing a typical LEO satellite footprint in 2025, with 5MHz of licensed mobile spectrum allocated to satellite services.

For the terrestrial comparison, we analyse the same 500km² area of Dar es Salaam, served by 1,200 macro sites. Each site uses 100MHz of licensed spectrum across three sectors, enabling the same spectrum to be reused repeatedly through spatial spectrum reuse.

For both technologies, we assume a 2Mbps service requirement per active user and 10% concurrent user rate, representing a basic 3G mobile broadband experience.

Under these assumptions, the terrestrial network delivers 72,000× greater capacity density than the satellite D2D system, with satellite delivering 2Mbps to approximately 10 concurrent users within the beam. While satellite can provide ubiquitous coverage, the ability to repeatedly reuse spectrum across hundreds of terrestrial sites results in orders of magnitude greater subscriber capacity.

Scenario 2
Future lower-bound satellite footprint

We then stretch the satellite assumptions, **reducing beam coverage area to 160km²** and **increasing allocated spectrum to 100MHz**, equivalent to the MNO in the example.

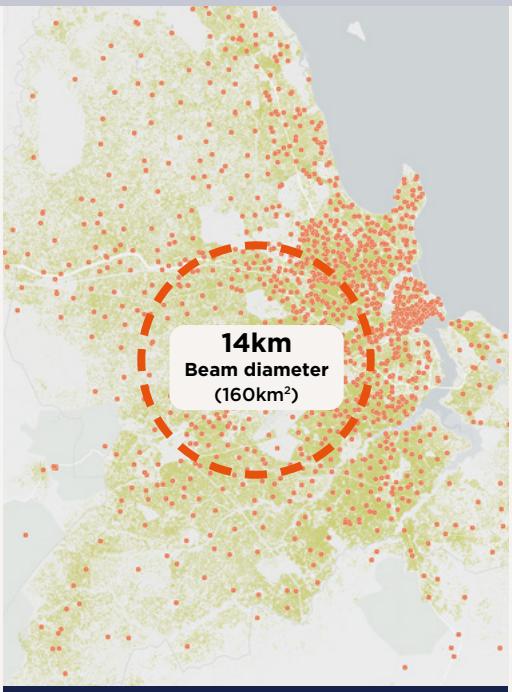
1
satellite beam

100MHz
Spectrum per beam

2Mbps
Assumed consumption per user

9.38
Subscriber capacity (subs / km²)

0.94
Concurrent active users per km²



Dar es Salaam comparison area

384
terrestrial sites

3 sectors @ 100MHz each
Spectrum per site

2Mbps
Assumed consumption per user

11,000
Subscriber capacity (subs / km²)

1,100
Concurrent active users per km²

c.1,200x Terrestrial advantage

We then examine a deliberately optimistic future lower-bound satellite footprint for D2D.

Here we assume the satellite is allocated the same 100MHz of licensed spectrum as the terrestrial operator. This assumption removes spectrum allocation as a differentiating factor, allowing the analysis to isolate the impact of spatial spectrum reuse.

To further favour satellite performance, we assume a 14km spotbeam diameter (approximately 160km²), representing a practical lower bound for commercial services for a LEO D2D system[1], and reflects the expected diameter of the next generation, V2 mobile satellites from Starlink. This assumption is intended solely to test the upper limit of achievable satellite capacity density and does not represent a typical commercial deployment.

Maintaining the same 2Mbps service requirement per simultaneous active user, the satellite D2D system supports approximately 9 subscribers per km², equivalent to approximately one simultaneously active user per km² assuming a 10% concurrent user rate.

By comparison, the terrestrial network supports approximately 11,000 subscribers per km², equivalent to around 1,100 concurrent active users per km² under the same assumptions.

Despite assumptions that substantially favour the satellite system - including equal spectrum allocation and a highly optimistic spotbeam footprint - the terrestrial network still delivers approximately c.1,200 times greater throughput density, resulting in a similar advantage in subscriber capacity. This demonstrates that, even when spectrum availability and beam size are optimised for satellite D2D, the ability of terrestrial networks to repeatedly reuse the same spectrum across hundreds of sites remains the dominant driver of capacity density.

[1] Diameter is aligned to the next generation V2 mobile satellites from Starlink.

Scenario 3

Higher throughput requirements
(through existing equipment)

We then modelled a demand for improved user-experience - taking the **Mbps per user requirement from 2 (basic 3G) to 100 (modern 5G).**

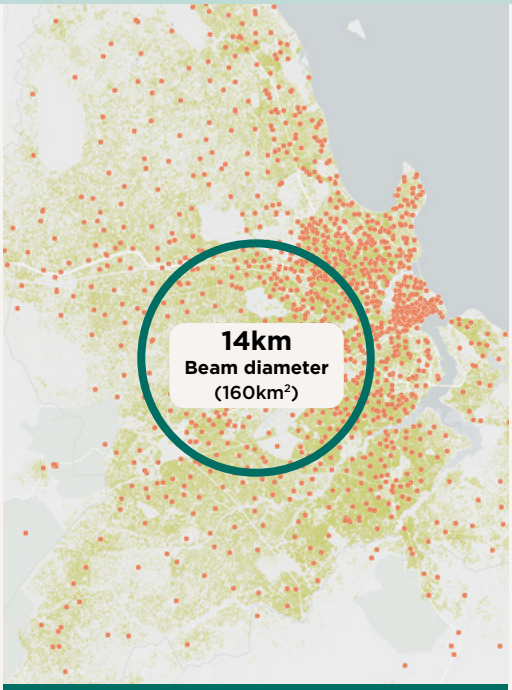
1
satellite beam

100MHz
Spectrum per beam

100Mbps
Assumed consumption per user

0.19
Subscriber capacity
(subs / km²)

0.02
Concurrent active users per km²



Dar es Salaam comparison area

384
terrestrial sites

3 sectors @ 100MHz each
Spectrum per site

100Mbps
Assumed consumption per user

216
Subscriber capacity
(subs / km²)

22
Concurrent active users per km²

c.1,200x Terrestrial advantage

We next increase the service requirement from 2Mbps (basic 3G experience) to 100Mbps (modern 5G experience) per simultaneous active user, representing a high-capacity mobile broadband service.

As expected, the subscriber capacity falls proportionally for both technologies because each active user consumes fifty times more network capacity. However, the relative advantage remains effectively unchanged because the limiting factor is spatial spectrum reuse rather than user throughput.

Under these assumptions, the satellite system supports approximately 0.19 subscribers per km², equivalent to around one simultaneously active user for every 50km², while the terrestrial network supports approximately 216 subscribers per km², equivalent to around 22 concurrent active users per km².

The terrestrial network therefore continues to deliver approximately c.1,200× greater throughput density, resulting in a similar advantage in subscriber capacity. This demonstrates that increasing per-user demand reduces the number of users both architectures can support, but it does not change the fundamental advantage created by terrestrial spatial spectrum reuse.

Scenario 4
How terrestrial capacity scales

And finally we demonstrate the scalability of the terrestrial network through cell tower densification - **by increasing the number of cell sites within the 160km² area**.

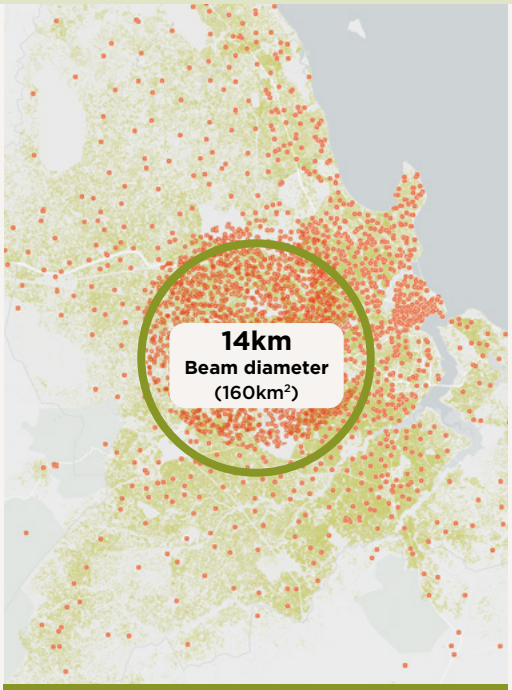
1
satellite beam

100MHz
Spectrum per beam

100Mbps
Assumed consumption per user

0.19
Subscriber capacity (subs / km²)

0.02
Concurrent active users per km²



Dar es Salaam comparison area

c.1,000
terrestrial sites

3 sectors @ 100MHz each
Spectrum per site

100Mbps
Assumed consumption per user

564
Subscriber capacity (subs / km²)

56
Concurrent active users per km²

c.3,000x Terrestrial advantage

The fundamental advantage of terrestrial mobile networks becomes even more apparent as demand increases.

Terrestrial throughput density can continue to grow through additional spatial spectrum reuse as more sites are deployed. By increasing site density, operators create progressively smaller cells, allowing the same licensed spectrum to be reused more frequently and increasing aggregate network capacity within the same geographic area. In the illustrative Dar es Salaam scenario, increasing the number of sites increases throughput density and subscriber capacity, demonstrating how terrestrial networks can incrementally increase capacity as demand grows.

LEO direct-to-device (D2D) systems cannot increase local capacity in the same manner, and are limited to serving a total of three concurrent users across a single 160km² beam. All users within a spotbeam share the same spectrum resource, and while additional satellites can increase overall constellation capacity and geographic coverage, they cannot provide the same degree of local capacity scaling through network densification. Capacity within a given location therefore remains fundamentally constrained by spotbeam footprint, available high-quality spectrum (which cannot be greater than available terrestrial spectrum) and the practical limits of spatial spectrum reuse.

Use case: Dar es Salaam, Tanzania

Conclusion

This analysis demonstrates that the principal limitation of satellite D2D is throughput density rather than coverage.

Satellite D2D is exceptionally well suited to extending basic connectivity into deep rural, remote and hard-to-reach areas where user density is low and traffic demand is modest. However, in towns and cities, where hundreds or thousands of users require broadband connectivity simultaneously, the ability of terrestrial mobile networks to repeatedly reuse the same licensed spectrum across many small cells provides an overwhelming and inherently scalable throughput density advantage. Moreover, as the traffic demands increase in rural areas, terrestrial networks will increasingly complement the satellite deployments, using lean mobile site technologies that leverage the satellite footprint for backhaul.

This advantage is a consequence of fundamental radio physics and engineering rather than implementation choices. Even under highly optimistic assumptions that favour satellite D2D, including equal spectrum allocation and a significantly reduced spotbeam footprint, terrestrial networks continue to deliver orders of magnitude greater throughput density because of their ability to densify and repeatedly reuse spectrum across a large number of sites.

As demand for mobile broadband continues to increase, terrestrial operators can further expand capacity by deploying additional sites and increasing spatial spectrum reuse. While advances in satellite technology will continue to improve coverage, latency and overall system capability, they cannot replicate the same degree of local capacity scaling over populated areas.

Satellite D2D should therefore be viewed as a complementary technology that extends coverage beyond the economic reach of terrestrial infrastructure, while terrestrial mobile networks remain the primary platform for delivering scalable mobile broadband capacity in populated environments.



Terrestrial networks

Delivers capacity

Rural & urban

Indoor & enterprise

Higher capacity demands

Economic growth & digital services



Satellite D2D

Extends reach

Deep rural & remote

Hard-to-reach communities

Maritime, aviation & lower capacity demands

Resilience & redundancy

Together they deliver universal connectivity

Terrestrial networks deliver the capacity the world depends on.
Satellite extends coverage beyond the reach of the terrestrial infrastructure.

Practical use cases
for satellite connectivity

While satellite systems cannot substitute terrestrial networks in dense, high-capacity environments, they offer highly applicable use cases where geography, economics or resilience constraints limit ground-based deployment. In these contexts, satellite provides complementary value.

Terrestrial coverage gaps – direct-to-device (D2D)

D2D services enable standard smartphones to connect directly to satellites using licensed mobile spectrum in partnership with operators. This approach is particularly suited to sparsely populated rural areas where full tower deployment is uneconomic. While D2D does not replicate urban-grade performance, it provides essential baseline connectivity, supporting services including voice, messaging and emergency access, without the capital intensity of terrestrial build-out in every location.

Satellite backhaul solutions

Where fibre or microwave backhaul is impractical, satellite dish solutions can connect remote base stations to the mobile network. This enables mobile coverage in difficult terrain, accelerating time-to-service.

Maritime connectivity

Maritime communications depend on satellite infrastructure. Commercial shipping, offshore energy and cruise operators rely on satellite systems for operational and passenger connectivity. Advances in LEO constellations have improved latency and throughput, reinforcing satellite's foundational role in environments beyond terrestrial reach.

Aviation connectivity

In the aviation sector, LEO systems are improving service quality for both passenger broadband and operational communications. Satellite connectivity remains the key in-flight broadband technology for the aviation industry.

Emergency response and network resilience

Satellite enhances network resilience during natural disasters, extreme weather events and infrastructure failures. For example, after the Tonga volcanic eruption severed undersea fibre cables, satellite services provided interim connectivity until physical infrastructure could be repaired.[1] Should terrestrial systems become disrupted, satellite provides an alternative method of communication for emergency services.

Internet of Things (IoT)

Satellite connectivity is well suited to low-bandwidth IoT applications in remote environments, including agriculture, energy, mining and environmental monitoring. It enables distributed sensor networks without requiring extensive terrestrial infrastructure. However, some technological barriers remain including the power requirements of satellite modems in IoT devices, meaning a dish-mediated service may be required.

Key takeaway: Satellite connectivity provides ubiquitous coverage and is effective where terrestrial networks are uneconomical or impractical.

[1] International Telecommunication Union (ITU) report covering the 2022 Hunga Tonga-Hunga Ha'apai volcanic eruption

Collaboration

between satellite operators and mobile network providers

Globally, mobile network operators are increasingly formalising partnerships with Low Earth Orbit (LEO) satellite providers. These arrangements are primarily structured around direct-to-device (D2D) connectivity, rural backhaul, enterprise broadband and resilience use cases.

T-Mobile (US) has partnered with SpaceX's Starlink to launch "Direct to Cell" satellite services, initially focused on messaging and basic connectivity in areas without terrestrial coverage. The emphasis is on closing residual coverage gaps rather than replacing tower infrastructure in high-demand markets.

Orange has strengthened its multi-year LEO capacity agreements with Eutelsat (OneWeb) to support enterprise services and mobile backhaul. Orange has positioned satellite as a promising complementary technology to accelerate digital inclusion in underserved regions, particularly across Africa and the Middle East.

Deutsche Telekom (Europe) is partnering with SpaceX's Starlink to trial direct-to-device services. These trials focus on connecting standard mobile phones in areas without terrestrial coverage.

MTN has publicly referenced direct-to-device trials with satellite providers including Lynk Global and AST SpaceMobile across several African markets. The focus has been on evaluating satellite as a mechanism to extend baseline coverage and enhance resilience in ultra-rural environments.

Vodacom Group, which is majority-owned by Vodafone Group, has announced collaboration with SpaceX's Starlink to expand connectivity across African markets. Separately, Vodafone Group has partnered with AST SpaceMobile to develop direct-to-device satellite connectivity capabilities.

Yas, part of AXIAN Telecom, has partnered with AST SpaceMobile to launch Africa's first direct-to-device space-based mobile broadband network. The partnership will integrate satellite connectivity with Yas' existing mobile infrastructure, enabling voice, data and internet services directly to standard smartphones in areas beyond terrestrial coverage.

Airtel Africa has announced collaborations with both SpaceX (Starlink) and OneWeb to explore satellite connectivity across its African markets. These arrangements focus on extending coverage in rural and underserved areas and supporting enterprise, D2D and backhaul use cases where terrestrial economics are constrained.

> **"**Industry shifts have opened the door for deeper collaboration among satellite operators, MNOs, carriers, spectrum owners, device manufacturers, and regulators. As satellite network performance continues to improve and these partnerships expand, satellite-to-mobile offerings—such as Starlink Mobile—are poised to evolve from a "backup" layer into a meaningful complement to terrestrial networks, extending coverage and enhancing overall network resilience and performance.**"**
>
> **SpaceX**

Implications for operators, infrastructure providers, and policymakers

The analysis in this paper points to satellite and terrestrial networks coexisting with distinct and complementary roles. This requires stakeholders across the ecosystem to adjust strategy, investment priorities and regulatory frameworks accordingly.

Mobile network operators

LEO services can support coverage expansion in remote and low-density areas, enhance network resilience, and provide redundancy during outages or emergencies. At the same time, terrestrial mobile networks will continue to underpin traffic-intensive, indoor, urban, and peri-urban use cases, where performance, scalability, and cost efficiency are critical. Hybrid strategies that integrate satellite capabilities where they are most effective, while continuing to densify terrestrial networks in high-demand environments, will deliver the greatest long-term value, including enabling wider service adoption in rural areas.



CASE STUDY

Why coverage alone is no longer enough for MNOs

For mobile network operators, the remaining connectivity gap is increasingly defined by usage rather than coverage. Despite mobile broadband networks now reaching an estimated 96% of the global population, approximately 3.1 billion people (around 38%) still live within covered areas without using mobile internet services.[1] This usage gap far exceeds the much smaller coverage gap of those without any network footprint, highlighting a fundamental shift in the nature of the connectivity challenge.

Globally, this disconnect is driven by factors that sit largely outside network availability. Affordability of internet-enabled devices and data plans, limited digital skills and low awareness of the benefits of mobile internet have emerged as the primary barriers to adoption.[1] These constraints directly affect operators' ability to convert coverage investments into sustained traffic growth and returns, particularly in lower-income and rural markets.

The challenge is most acute in Sub-Saharan Africa, the least connected region worldwide. Despite widespread network coverage and continued infrastructure expansion, only around 25–27% of the population actively uses mobile internet.[1] This gap persists even as coverage improves, reflecting the limits of coverage-led strategies in driving adoption. For the poorest 20% of households, the cost of an entry-level smartphone can represent close to one month's income[1], significantly constraining take-up even where services are available. These affordability pressures are compounded by lower levels of digital literacy, rural–urban disparities and persistent gender gaps in internet usage[1].

For MNOs, these dynamics underscore that further coverage expansion alone will not resolve the adoption challenge. While satellite and other technologies can extend baseline connectivity into the most remote locations, they do not address the underlying affordability and skills constraints that suppress usage at scale. Closing the digital divide and unlocking the associated productivity, inclusion and GDP growth benefits will therefore depend on complementary strategies that improve affordability, device access and relevance, supported by cost-efficient, high-capacity terrestrial networks.

[1] GSMA, The State of Mobile Internet Connectivity 2025.

Infrastructure providers

For infrastructure providers, the convergence of satellite and terrestrial technologies reinforces their role as the backbone of the connectivity ecosystem. Ground-based towers will remain essential for delivering high-capacity mobile services as data demand continues to grow. Satellite solutions can complement this foundation by enhancing network resilience and supporting coverage extension, particularly when integrated through backhaul or redundancy architectures. LEO satellite backhaul enables operators to bypass geographic constraints that have historically limited microwave or fibre deployment, providing connectivity to rural villages and hard-to-reach locations. Through integrating satellite connectivity with their terrestrial offering, infrastructure providers can help optimise mobile operators' coverage.

Role of towercos in rural connectivity

In rural markets, tower infrastructure plays a critical role in enabling commercially viable connectivity across dispersed populations, transport corridors and local economic centres. This is particularly important in low-density environments, where the cost of network deployment rises as population density declines, reducing the ability to recover investment and achieve sustainable returns.

Compared to wide-area satellite coverage, terrestrial tower networks provide localised connectivity that supports stronger signal strength and better indoor performance, enabling more reliable and higher-quality services. This proximity, combined with spectrum reuse, allows capacity to be delivered efficiently in areas where demand is concentrated.

Towercos further enhance network economics by enabling multi-tenant infrastructure sharing, reducing capital and operating costs through shared infrastructure models. In addition, tower sites can be incrementally upgraded as demand grows, allowing capacity to scale in line with usage. These characteristics are critical in rural environments, where deployment costs can be up to twice as high, operating costs up to three times higher, and revenues significantly lower than in urban areas. Collectively, these factors support commercially viable network expansion in low-density markets, where standalone deployments would otherwise be uneconomic.

Policymakers and regulators

Closing the remaining connectivity gap will require a technology-neutral policy approach that recognises the distinct and complementary roles of satellite and terrestrial networks. While Low Earth Orbit (LEO) satellite systems can accelerate coverage in hard-to-reach areas and improve network resilience, they do not replace ground-based infrastructure in delivering affordable, high-capacity connectivity at scale.

Policy frameworks should therefore prioritise interoperability between satellite and terrestrial networks, enable efficient and coordinated spectrum management, and reduce regulatory friction for hybrid deployment models. In parallel, universal service and digital inclusion policies should be aligned with realistic techno-economic outcomes, focusing not only on coverage targets but also on affordability, usage, and long-term sustainability.

Such an approach will help ensure that public policy supports scalable investment, encourages innovation across technologies, and delivers meaningful connectivity rather than coverage alone.

Stakeholders that prioritise collaboration, interoperability, and fit-for-purpose deployment across satellite and terrestrial technologies will be best placed to deliver resilient, inclusive, and future-ready connectivity.

Conclusion

Global data traffic is projected to increase almost 7x by 2040, driven by the rapid evolution of artificial intelligence and the growing reliance on data-intensive applications. In this period, mobile traffic is expected to be the largest contributor to data growth, rising by 13x.

As AI becomes embedded across sectors, connectivity will underpin productivity gains, innovation and economic growth at unprecedented scale.

This is even more pronounced in Africa and the Middle East, with data traffic in our nine markets expanding by 12x by 2040, almost double the pace of global growth, with mobile traffic carrying the highest share due to a lower prevalence of fixed line availability.

Independent forecasts show that the vast majority of global data volumes (approximately 97%) will continue to be carried by terrestrial mobile and fibre networks by 2040. Satellite traffic, while growing from a low base, is expected to remain a small share of total global volumes, reflecting its role in extending coverage rather than supporting high-capacity demand at scale.

Satellite coverage can help extend connectivity towards near-universal coverage, reaching the c.300 million people who still live outside mobile broadband networks.

However, the challenge of delivering inclusive economic growth through data connectivity is not solely one of coverage. The usage gap remains significantly larger, with approximately 3.1 billion people living within network coverage but not using mobile internet. Addressing this gap will require a focus on affordability, device access, digital skills and relevant services, rather than network expansion alone.

The evidence presented in this paper reinforces that ubiquitous digital connectivity depends on sustained investment in terrestrial infrastructure, complemented by satellite solutions where they are most effective.

Universal connectivity will not be achieved through substitution, but through integration, combining the strengths of satellite and terrestrial technologies to deliver inclusive, resilient and economically sustainable growth.

Appendix 1
Methodology and key assumptions

This analysis applies a system-level framework to compare satellite (GEO, MEO, LEO) and terrestrial (5G) network architectures using coverage area, spectral efficiency, capacity density, and user capacity. The methodology is intended to provide directional comparability across heterogeneous systems rather than precise performance modelling.

1. Coverage area

Coverage area is derived assuming circular beam or cell footprints:

$$\text{Coverage area} = \pi \times (\text{Coverage radius})^2$$

For satellite systems, coverage radius represents the effective ground footprint of a spotbeam, determined by orbital altitude and antenna characteristics. For terrestrial systems, it reflects representative site radius under typical deployment conditions.

2. Spectral efficiency

Spectral efficiency is defined as:

$$\text{Spectral Efficiency} = \frac{\text{Throughput}}{\text{Spectrum}}$$

Where spectrum is explicitly parameterised, spectral efficiency is calculated directly. For systems where it is not, spectral efficiency is embedded within system-level throughput assumptions and reflects effective operational performance. Throughput and spectral efficiency values are treated as effective system-level parameters and are used directly as inputs to the model. Protocol, control, and scheduling overheads are not modelled explicitly, but are assumed to be implicitly reflected in these values.

3. Capacity density

Capacity density is defined as:

$$\text{Capacity density} = \frac{\text{Throughput}}{\text{Coverage area}}$$

This metric provides a normalised measure of spatial capacity and is used as the primary basis for cross-technology comparison, consistent with the system-level approach outlined in the main analysis.

4. Spatial reuse

To reflect deployment characteristics, capacity density is adjusted for spatial reuse:

$$\text{Adjusted capacity density} = \text{Capacity density} \times \text{Spatial reuse factor}$$

Spatial reuse represents the reuse of spectrum across independent transmission domains. It is driven by multi-beam architectures in satellite systems and by cell densification and sectorisation in terrestrial networks.

5. Key assumptions

The analysis is based on the following system-level assumptions:

- Throughput is treated as aggregate downlink capacity per beam, satellite, or site, based on effective system-level performance.
- Coverage footprints are approximated as uniform and circular for spatial normalisation.
- Spectral efficiency reflects typical operational performance and is either explicitly calculated or embedded within throughput assumptions.
- Spatial reuse is represented as an aggregate factor and does not explicitly model interference or coordination constraints.
- Traffic distribution is assumed to be uniform across the coverage area.

For LEO systems, particularly fixed broadband configurations, assumptions include high beam multiplicity, advanced beamforming, and effective frequency reuse. These represent **optimised operating conditions** and should be interpreted as **upper-bound performance rather than network-wide averages**.

Appendix 1
Methodology and key assumptions

6. Limitations

The methodology does not explicitly model dynamic traffic behaviour, detailed link budgets, interference conditions, or temporal variability. Results are therefore indicative and intended to reflect structural differences in system architecture rather than precise operational outcomes.

7. Application to comparative scenarios

The methodology is applied consistently across GEO, MEO, and LEO satellite architectures, as well as terrestrial networks, using representative system characteristics for each.

Differences in capacity density across these systems are primarily driven by variations in coverage footprint, which are a function of orbital altitude and cell size, and by the degree of achievable spatial reuse.

The same framework is applied to illustrative deployment scenarios presented in the main analysis, including representative urban environments. In these cases, capacity density is evaluated by comparing a single satellite beam footprint with an equivalent geographic area served by a terrestrial network, incorporating typical site density and spectrum reuse characteristics.

These scenario-based comparisons are intended to demonstrate relative scaling behaviour under consistent assumptions, rather than to model specific network deployments.

8. User capacity and subscriber estimation

To translate capacity density into user-level metrics, a simplified demand model is applied.

Active user density is derived by normalising available capacity against per-user throughput requirements:

$$\text{Active users per km}^2 = \frac{\text{Capacity density}}{\text{Per-user throughput}}$$

To account for non-simultaneous usage, a concurrency factor is applied:

$$\text{Subscribers per km}^2 = \frac{\text{Active users per km}^2}{\text{Concurrency factor}}$$

Where:

- Per-user throughput represents average demand per active session
- The concurrency factor represents the proportion of users active at a given time

This approach enables translation from system-level capacity to indicative subscriber density under steady-state conditions. It assumes uniform traffic distribution and does not explicitly model peak demand, mobility, or scheduling effects.

Appendix 2
Glossary of terms

Active user
A subscriber who is actively transmitting or receiving data over the network at a given point in time. The number of active users is determined by applying the assumed concurrency rate to the total subscriber population.

Bandwidth
The amount of radio spectrum allocated to a communication channel or system, typically measured in hertz (Hz), kilohertz (kHz), megahertz (MHz) or gigahertz (GHz). Greater bandwidth allows more information to be transmitted and therefore supports higher potential network capacity.

Beam footprint
The geographic area on the Earth's surface covered by an individual satellite beam.

Capacity density
The amount of network capacity available within a given geographic area, typically expressed in Mbps/km^2. Capacity density is the primary metric used throughout this paper to compare terrestrial and satellite network performance.

Cellular backhaul
The process of transmitting data from remote cellular sites to the core network. Essential for mobile network functionality, especially in areas where traditional fibre or microwave links are not feasible.

Concurrency rate
The percentage of subscribers assumed to be simultaneously active on the network at any given time. It is used to estimate the relationship between network capacity, active users and the total subscriber population. This paper assumes a 10% concurrency rate for the illustrative capacity modelling.

Direct-to-device (D2D)
Technology that provides direct connectivity (voice and data services) from satellites to compatible end-user devices without the need for nearby cellular towers next to the users.

Geostationary earth orbit (GEO)
Satellites positioned at a stationary level approximately 35,786km above the Earth, offering wide coverage and high throughputs, but with high latency.

Geostationary orbit (GSO)
Satellites that remain fixed above one point on the Earth's surface, providing consistent coverage to the same area, but with higher latency compared to NGSO satellites.

High-altitude platform systems (HAPS)
Unmanned aircraft operating in the stratosphere at around 20km altitude. They offer telecommunications services like satellites but closer to the ground, making them suitable for voice and data services, but with some limitations.

Latency
The delay between a user's action and the response from the network. Lower latency is critical for applications requiring real-time communication.

Low earth orbit (LEO)
Satellites typically operating between approximately 300 and 2,000km above the Earth, providing relatively low latency and requiring large constellations to deliver continuous global coverage.

Medium earth orbit (MEO)
Satellites operating between Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO), typically at altitudes of around 20,000km. MEO provides a balance between coverage area, latency and capacity, and is widely used for global navigation satellite systems.

Appendix 2
Glossary of terms

Mobile network operator (MNO)
A telecommunications company licensed to own and operate mobile networks, providing voice, messaging and data services directly to subscribers using licensed radio spectrum.

Non-geostationary orbit (NGSO)
Satellites that move relative to the Earth's surface, including LEO and MEO satellites, providing global coverage and lower latency than GEO satellites.

Non-terrestrial networks
Networks that operate using space-based or high-altitude platforms, such as satellites and HAPS, rather than ground-based infrastructure.

Spatial spectrum reuse
The ability to reuse the same licensed radio spectrum across multiple geographically separated cells or beams, increasing overall network capacity.

Spectral efficiency
The amount of data that can be transmitted over a given amount of radio spectrum, measured in bits per second per Hertz (bit/s/Hz).

Spectrum
The range of electromagnetic radio frequencies allocated for wireless communications. Radio spectrum is a finite natural resource that is licensed and regulated by national authorities to support services such as mobile, satellite, broadcasting and public safety communications.

Terrestrial network
A telecommunications network that uses ground-based infrastructure, such as towers and cables, to provide connectivity.

Throughput
The amount of data transmitted over a network in a given amount of time. Higher throughput indicates faster and more efficient data transmission. Throughput is typically expressed in megabits per second (Mbps) or gigabits per second (Gbps).

Tower company (TowerCo)
A company that owns and operates shared telecommunications infrastructure used by multiple mobile network operators.



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