

The Limits of D2D

Modelling the extent of D2D connectivity

February 2026





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Direct-to-device (D2D) satellite connectivity

Mobile covers

96%

of the global population



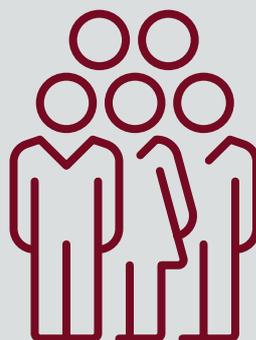
D2D

can extend outdoor services to low-density rural and uninhabited locations for people that have a mobile phone



D2D can never replace terrestrial mobile networks and will not close the usage gap

38% OF THE GLOBAL POPULATION



D2D can help close the coverage gap that affects

300 MILLION PEOPLE

Today, D2D using IMT spectrum typically uses 2×5 MHz to offer SOS / SMS



15,000 satellites could offer **2 Mbps** (3G speeds) to:

5.9% of the global population with **1100 MHz** of mobile spectrum

0.5% of the global population with **80 MHz** of mobile spectrum

0.3% of the global population with **60 MHz** of satellite spectrum

0.8% of the global population with **140 MHz** of satellite spectrum



With **42,000** satellites



and **1100 MHz** of mobile spectrum, **D2D** can offer

2 Mbps (3G speeds) to



45%

of the world's rural population

Summary

Direct-to-device (D2D) satellite connectivity has emerged as a notable development in the mobile ecosystem, promising to extend basic mobile services beyond the reach of terrestrial networks. It has the potential to enhance coverage in remote and underserved areas and to provide an additional layer of resilience for emergency communications. However, while the technology has clear benefits, is advancing rapidly, and attracting significant attention, its practical role remains constrained by fundamental limitations in capacity and spectral efficiency.

Understanding D2D's strengths with realistic expectations and not expecting it to substitute terrestrial networks but to supplement mobile's coverage, will help define its use cases. To do this GSMA has studied the impact of different constellation and spectrum scenarios on D2D's capabilities. Our analysis considers extremely positive scenarios where D2D has, for example, every MHz of mobile spectrum available to it and the maximum planned number of satellites in orbit. While this is an optimistic scenario, it paints the greatest extent of connectivity that can be offered through D2D.

The 'optimistic scenario' finds that:

D2D can extend outdoor services to low-density rural and uninhabited locations

A constellation of 15,000 satellites could support the use of a 2 Mbps service by around 65 million people at any given time. With 42,000 satellites, this increases to approximately 180 million people. D2D can therefore provide mobile connectivity (for those that have devices) in remote and uninhabited locations where there is no terrestrial coverage (for example remote tourist locations and maritime areas, including the 71% of Earth covered by water).

D2D can never replace terrestrial mobile networks

The laws of physics mean that even with a satellite constellation size of 42,000 and with access to all IMT bands, D2D could only provide a basic 2 Mbps (3G-like) service to 12% of the global population and a 20 Mbps (4G-like) service to less than 2% of the global population.

Two technical factors affect the ability of D2D to offer higher bandwidth services. The signal loss that occurs when transmitting from space, and the limits on spectrum reuse. While mobile networks can have cell diameters of some hundreds of metres, D2D spotbeams may be around 25 to 50km.

Mobile covers 96% of the global population

For most of the time, mobile users will not actively need D2D, as they will be served by terrestrial networks that already cover 96% of the global population. In indoor situations, where the majority of mobile usage occurs, D2D signals are unlikely to be received. While addressing this 4% coverage gap is an important issue, the usage gap - those that live within mobile networks but do not use them - stands at 38%. The usage gap will not be impacted by D2D and policy makers seeking to connect the unconnected will need to address this in order to have the most impact on connecting the unconnected.

D2D can help close the coverage gap that affects 300 million people

D2D has the potential to extend network coverage to the 4% of the global population that live outside mobile broadband coverage, provided they can afford a device and subscription. In a scenario where a constellation of 15,000 satellites uses all mobile satellite (MSS) bands, there is sufficient capacity to support an adoption rate of more than 10% for a 2 Mbps service in areas with a population density below 40 people per square kilometre. This increases to more than 20% at population densities below 20 people per square kilometre. These remote locations are where most countries, particularly in low-income countries, lack coverage.

What will D2D achieve?



D2D technology¹ describes the connectivity between satellites and mobile handsets, without the need for a terrestrial base station or large receiving equipment.² There are multiple satellite operators planning D2D, including Starlink, ViaSat, AST SpaceMobile, Lynk Global and Globalstar.³

The expectation for D2D is that it will provide a valuable supplement to mobile operators' existing coverage by allowing them to extend mobile services into remote and sparsely populated locations, along with added resilience and connectivity in emergency situations. However, two important questions follow on from this:

- i) What types of mobile data service will be provided by D2D in the future? While today, D2D is limited to low bandwidth services, will it ever provide services comparable to 3G, 4G or 5G?
- ii) For a given D2D service, what is the number of users that can be supported?

Answering both these questions means understanding what spectrum is utilised. D2D can use frequency bands allocated to the mobile service and identified for IMT, or they can use bands that are allocated to mobile satellite spectrum (MSS). Both approaches are used by D2D today.⁴

1 This is sometimes referred to as 'Direct-to-Cell' or DTC connectivity.

2 This paper is focused on D2D and does not consider satellite fixed broadband, which refers to the provision of broadband to homes or businesses via a satellite dish.

3 A more detailed review of the services provided by satellite operators, including D2D, and their partnerships with operators can be found in the GSMA Intelligence Satellite and NTN tracker series.

4 For further discussion on the two spectrum approaches, see GSMA (2025), Spectrum for D2D: The Use of Satellite to Supplement Mobile Coverage

How many users can D2D support?

The number of D2D users that a satellite constellation can support depends on several parameters, including:

1. design of the satellite constellation (for example, the altitude of satellites, inclination, orbital plans and the number of satellites)
2. satellite specifications (e.g. antenna design, aperture size, transmit power, beamforming capability and modulation scheme)
3. frequencies used and the bandwidth available
3. 1,100 MHz of IMT spectrum – i.e. using all existing IMT bands for D2D up to 3.8 GHz. While this is not a realistic scenario, it is useful to understand the absolute maximum addressable market for D2D
4. 60 MHz of MSS spectrum – spectrum available in S-band
5. 140 MHz of MSS spectrum – all the MSS spectrum available in L- and S-bands

All of these parameters will vary significantly across different satellite operators. For the purposes of this paper, we model the addressable market based on Starlink satellites, as they are the current market leader and there exists sufficient information to model D2D capacity. While Starlink had approximately 650 D2D satellites in orbit at the end of 2025⁵, this is expected to increase going forward. We therefore took as an example, a constellation size of 15,000 satellites⁶ and 42,000 satellites⁷, which are based on SpaceX announcements and regulatory filings.

Based on these constellations, we consider five spectrum scenarios for D2D utilisation:

1. 10 MHz of IMT spectrum (consisting of 2×5 MHz channels) – the typical amount used by D2D today with IMT spectrum⁸
2. 80 MHz of IMT spectrum (consisting of 16×5 MHz channels) – this models the impact of D2D using a greater IMT allocation than what is used today⁹

Figure 1 shows the proportion of the global population that could be served by D2D assuming a 2 Mbps data service (similar to a 3G-like connection) under each of the five scenarios. The analysis shows that even when considering the highest capacity scenario, with 42,000 D2D satellites using all IMT spectrum, it would support usage by no more than 12% of the global population. With a constellation of 15,000 D2D satellites, the service would support usage by 6% of the global population.

Considering more realistic IMT spectrum scenarios of between 10–80 MHz, the D2D service would support a global adoption rate between 0.1% and 0.5% for a constellation size of 15,000 and between 0.2% and 1.3% for a constellation of 42,000 satellites.

When considering MSS bands, 60 MHz of spectrum would support an adoption rate for 2 Mbps of between 0.3% to 0.9% (depending on the constellation size) and using all MSS bands would support global adoption between 0.8% and 2.2%.

5 See https://starlink.com/public-files/starlinkProgressReport_2025.pdf

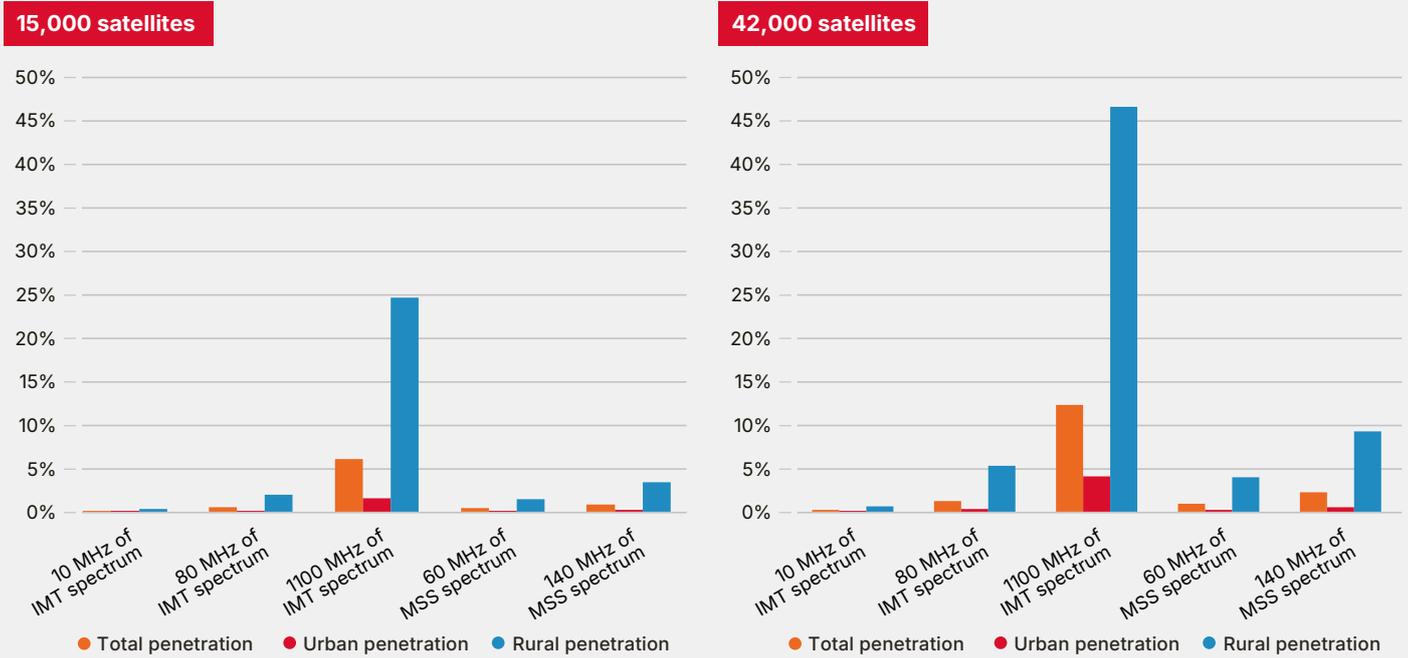
6 We use this given Starlink's request to the FCC to deploy 15,000 very-low-Earth-orbit (VLEO) satellites for D2D using the MSS spectrum it acquired from EchoStar Corporation

7 This is the total number of satellites Starlink could eventually have in its constellation. We assume all of them have D2D capabilities to provide an upper bound on capacity, though this may not happen in practice.

8 For example, T-Mobile US allows its D2D service with Starlink to utilise 2×5 MHz channels in the PCS band.

9 Some operators are expected to increase the amount of IMT spectrum used for D2D. For example, One New Zealand increased its spectrum resources allocated to D2D from 2×5 to 2×15 MHz.

Figure 1
D2D adoption for a 2 Mbps service (% of population)

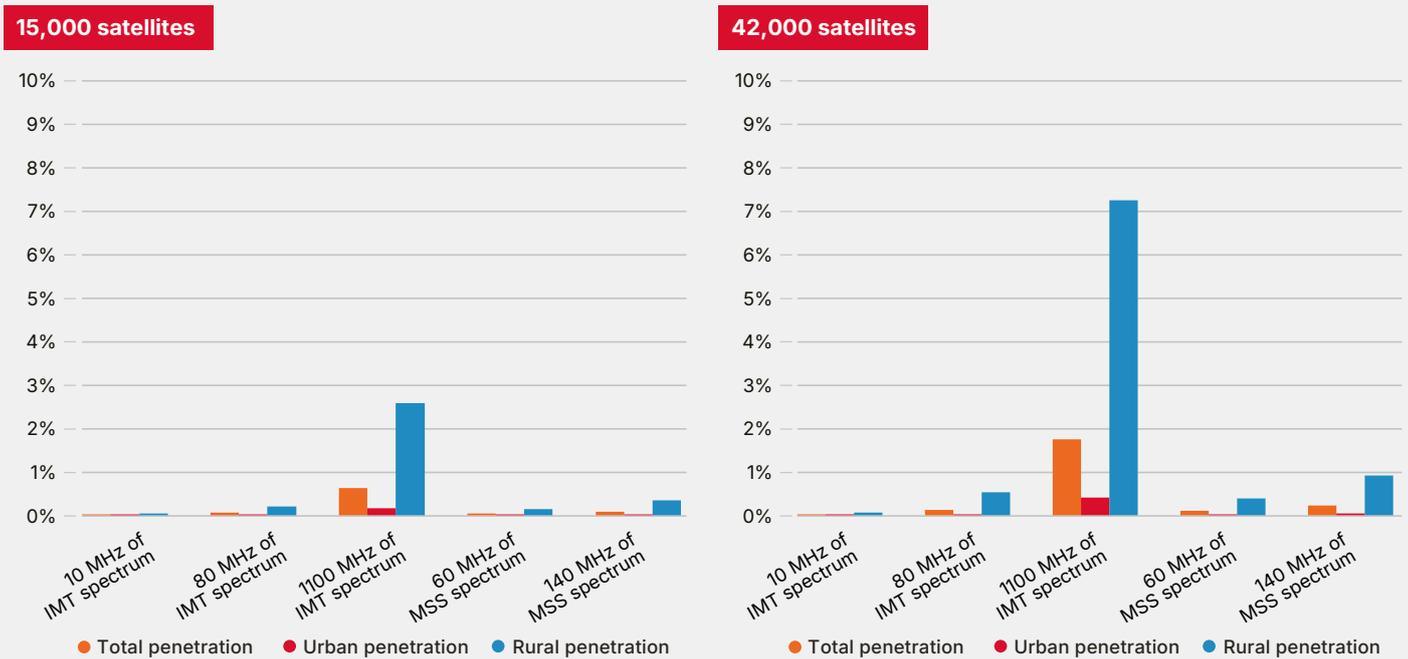


Source: GSMA Intelligence

Figure 2 provides the same analysis for a 20 Mbps service (similar to a 4G-like connection). Here, under a maximum capacity scenario of 42,000 satellites using all IMT spectrum bands, the maximum global adoption rate is just less than

2%. In all the other spectrum scenarios, D2D would not support more than 1% of the global population using a 20 Mbps service. This clearly demonstrates that D2D satellite is not a replacement for terrestrial networks.

Figure 2
D2D adoption for a 20 Mbps service (% of population)



Source: GSMA Intelligence

Where does D2D fit with mobile networks?



While the overall global adoption rates are low for D2D and it cannot replace terrestrial networks, it is important to emphasise the role the technology can play in enhancing global connectivity. In absolute terms, a constellation of 15,000 satellites could support the concurrent use of a 2 Mbps service for between 5 and 35 million people using 10 to 80 MHz of IMT spectrum. If all MSS bands were used, around 65 million people could be served at any given time. With 42,000 satellites, this increases to approximately 180 million people.

In practice, the majority of mobile users will not actively need D2D on a regular basis, as they will be served by terrestrial networks that already cover 96% of the global population. Furthermore, in indoor situations, where the majority of mobile usage occurs, D2D signals will be compromised due to building losses. Instead, D2D can provide connectivity in remote and uninhabited locations where there is no terrestrial coverage (for example remote tourist locations, maritime areas).

D2D can also extend some network coverage to the 300 million people that currently do not live in an area covered by a mobile broadband network. Figure 3 shows how the adoption of D2D changes with population density when using all MSS bands. Due to capacity constraints, the proportion of users that can be supported is very low in urban and even most rural locations. However, there is sufficient capacity to support an adoption rate of more than 10% for a 2 Mbps service in areas with a population density below 40 people per square kilometre. This increases to more than 20% at population densities below 20 people per square kilometre.

These very low density places are where many countries, particularly in low-income countries, lack coverage as it is too expensive to deploy terrestrial networks. The cost of infrastructure increases exponentially for the final 1-3% of population coverage, and it is generally not financially viable for either an operator or government to subsidise it.¹⁰ This is precisely where D2D can supplement existing coverage, as it can provide sufficient capacity for a small number of users at very low incremental costs.

¹⁰ For further analysis, see World Bank and GSMA (2022), Using Geospatial Analysis to Overhaul Connectivity Policies: How to Expand Mobile Internet Coverage and Adoption in Sub-Saharan Africa

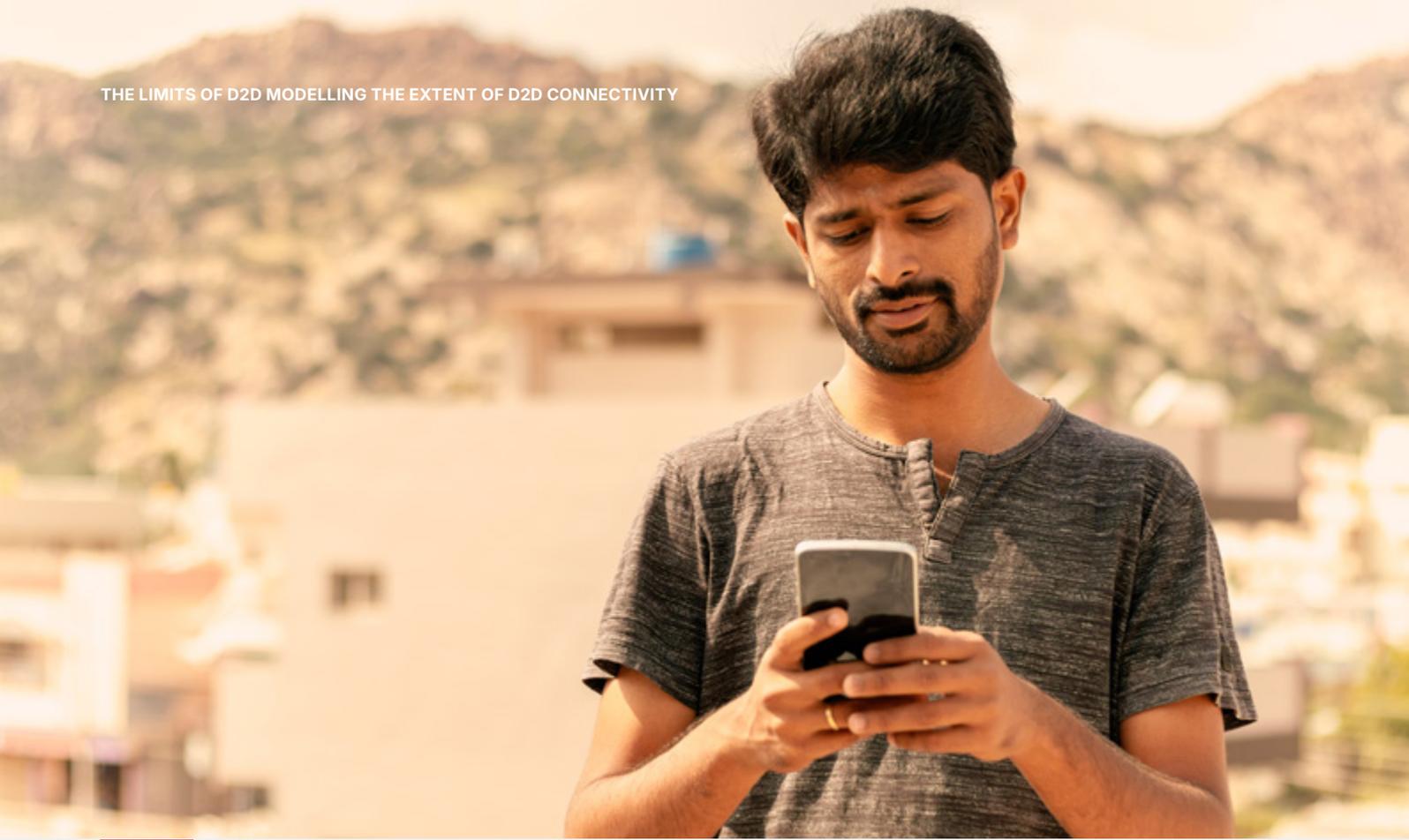
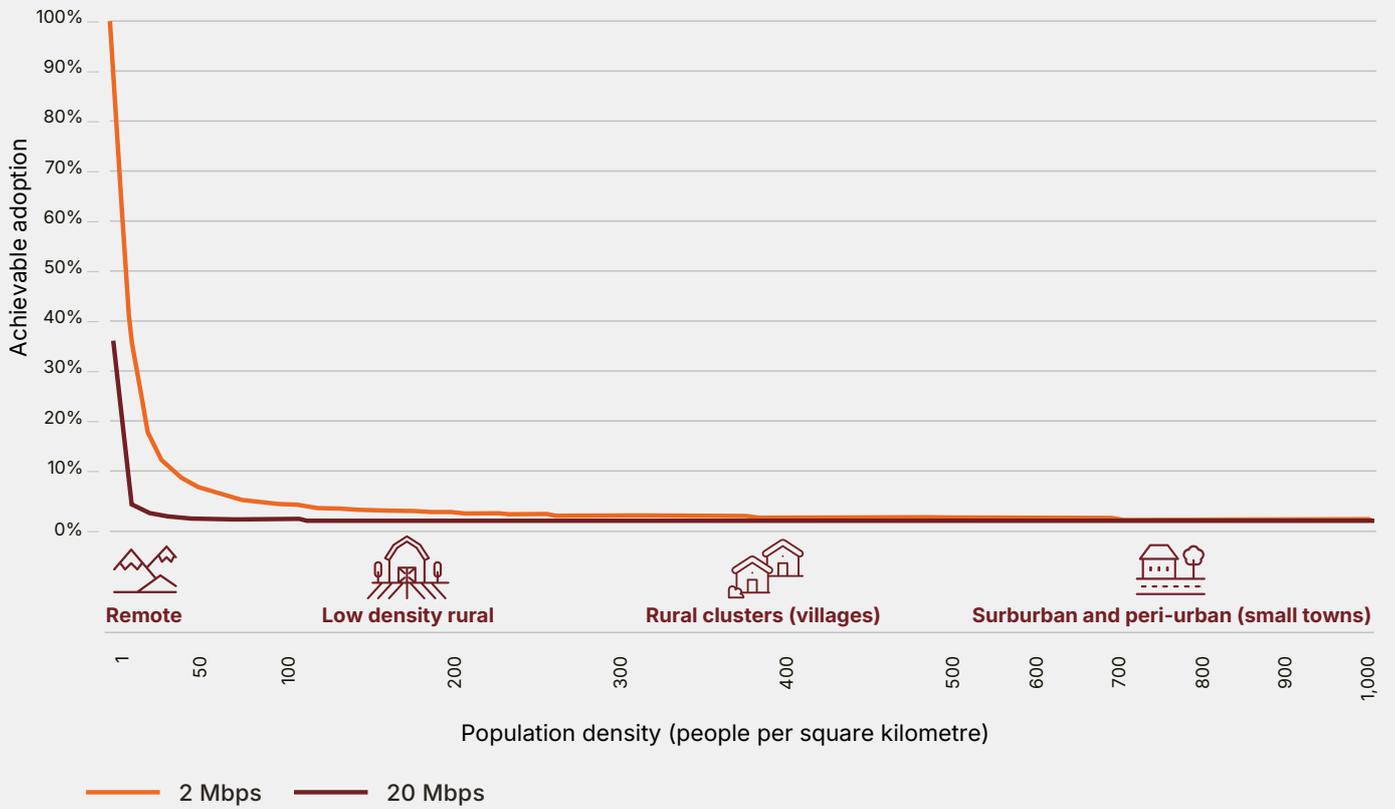


Figure 3
 Achievable adoption for a constellation of 15,000 satellites with all MSS bands, by population density (where one satellite operator holds all MSS spectrum)



Source: GSMA Intelligence

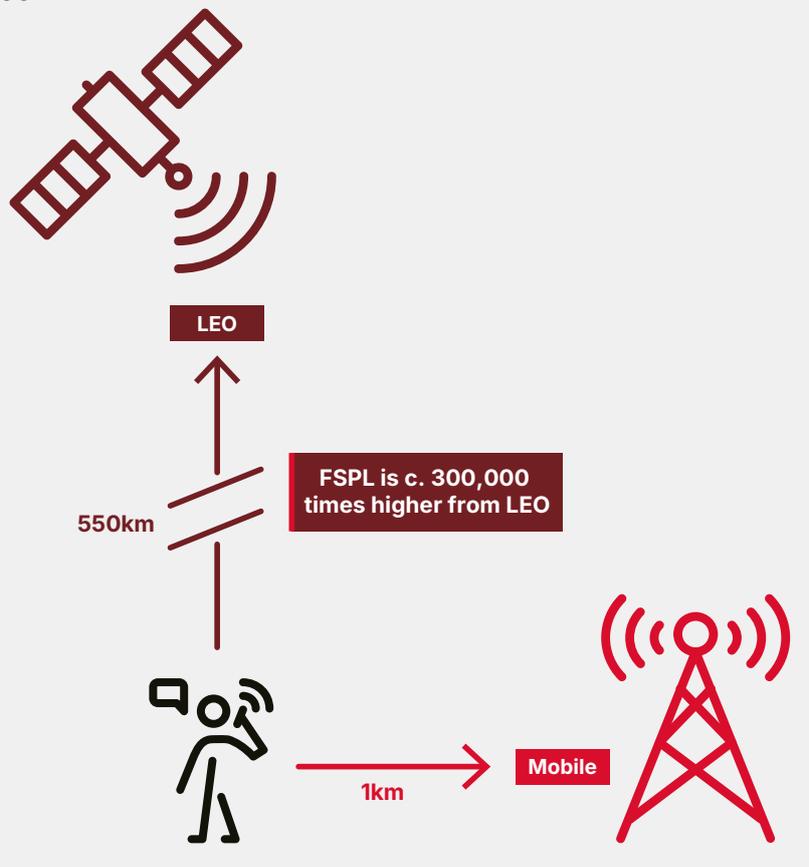
The laws of physics and D2D performance

The relatively low adoption rates that D2D can support is primarily driven by free space path loss (FSPL). This refers to the signal strength reduction that occurs when any electromagnetic wave (including radio waves, visible light, X-rays etc) propagates through free space. Specifically, the power of a signal falls in proportion to the square of the distance.

For example, if one applies FSPL to mobile and satellite and assumes a person using a smartphone is 1km from the nearest mobile base station and

550km from a D2D satellite, the satellite needs to overcome a signal loss that is around 300,000 times larger than the terrestrial mobile base station.¹¹ Even for a VLEO constellation at around 330km, FSPL will be around 110,000 times worse than a terrestrial base station at 1km. In order to compensate for this loss entirely, the satellite would need to increase its transmit power or aperture to an extent that is not economically or technically feasible. It is also not possible to compensate for the signal loss on the device side, due to size, power and integration constraints.

Figure 4
Free space path loss



Source: GSMA Intelligence

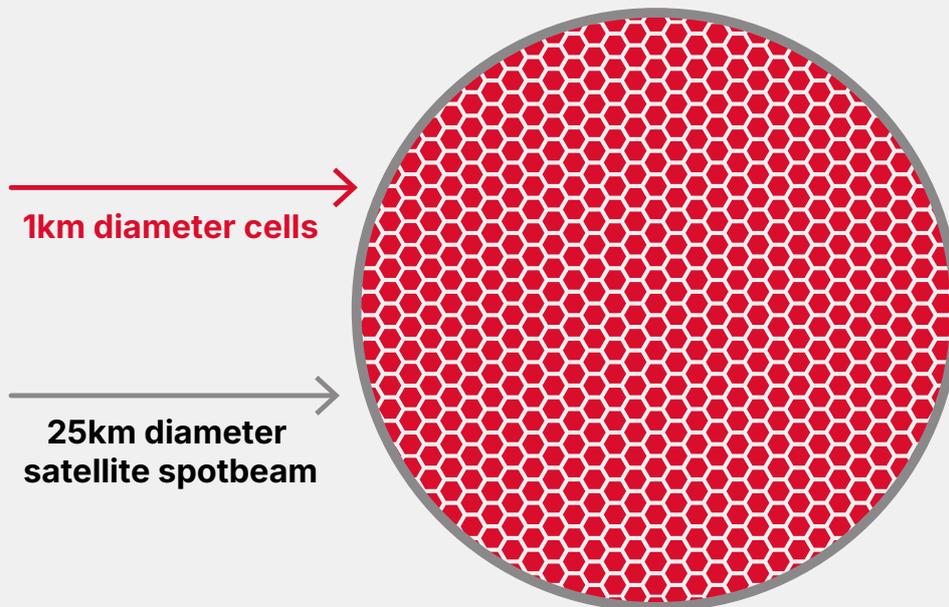
¹¹ The actual difference in FSPL will be impacted by clutter and other obstructions, but the general challenge remains.

Another important capacity constraint is the large size of the satellite beams (or cells), which is again driven by the large distance between the smartphone and satellite. This is important to bear in mind when considering the data rates reported for D2D, which often appear quite high, for example ~17 Mbps for Starlink¹² and ~120 Mbps for AST SpaceMobile.¹³ However, these are the speeds that can be delivered as aggregate capacity per beam rather than per user. If a D2D beam diameter is 25km, that means the total beam area is around 490 km² and all users in the area need to share the total capacity (e.g. of 17 or 120 Mbps). In dense

urban areas, this could mean sharing such capacity between more than 1 million people, while even in rural areas it could often be shared between more than 100,000 people.

It is important to note that D2D is completely different to a fixed satellite service, which can provide much higher capacity. This is because it utilises more spectrum in higher frequency bands (for example Ku and Ka bands) and the satellite communicates with a large dish rather than a small phone.¹⁴

Figure 5
Spectrum re-use of mobile vs satellite



12 See for example <https://www.ispreview.co.uk/index.php/2024/03/starlink-test-space-direct-to-cell-mobile-data-service-to-17mbps.html>

13 See for example <https://developingtelecoms.com/telecom-technology/satellite-communications-networks/17728-ast-spacemobile-signs-ten-year-commercial-deal-with-vodafone-group.html>

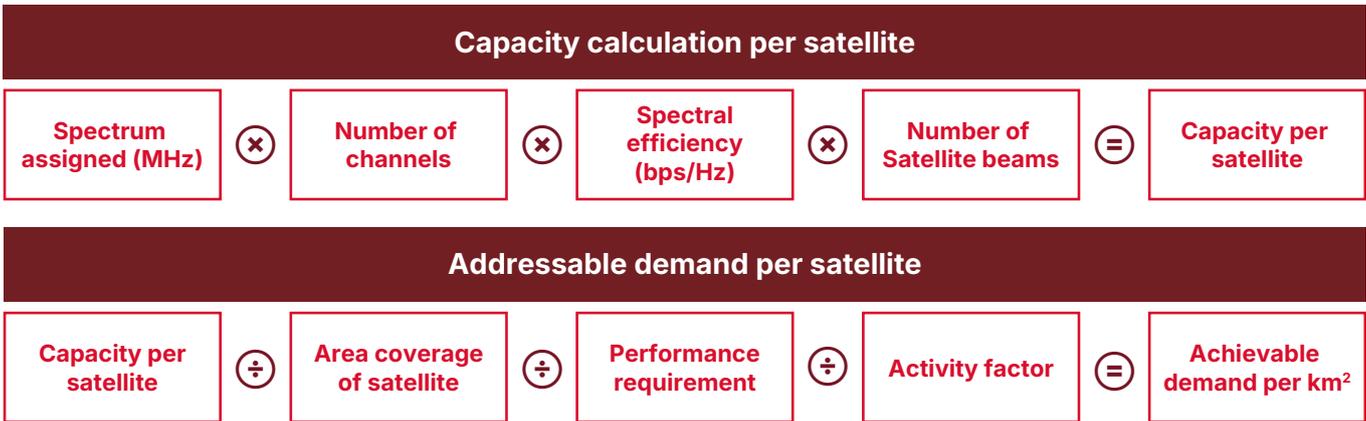
14 Fixed satellite dishes use directive antennas with high gains, which helps to compensate channel losses. This means they capture weaker signals and focus transmissions more effectively than smartphones, which have small omni-directional antennas.

Annex

How are the estimates of potential D2D users calculated?

In order to calculate the number of users that D2D can support, we estimate the capacity of each individual satellite as a function of spectrum assigned, number of channels, spectral efficiency and the number of satellite beams. We then estimate the area coverage of each satellite based on the number of satellites in the constellation,

which allows us to calculate the capacity per km². This is then divided by the performance requirement (2 or 20 Mbps) as well an activity factor that accounts for the fact that not all D2D users will be using the service at the same time. This gives the number of users that can be served per km².



Given the capacity is fixed in a given beam area, the adoption will depend on a country's geography and population distribution, with higher adoption rates in rural areas. We use the GHSL database¹⁵ to estimate demand in rural and urban areas for each country, before aggregating the results globally.

We expect our modelling is optimistic on potential D2D adoption and therefore provides an upper bound on the number of users it can support. The actual numbers are likely to be lower, for the following reasons:

- We assume individual satellite beams can aggregate multiple IMT frequency bands, which is not currently possible
- Using higher mid-band IMT frequencies in the 3.5 GHz range is currently challenging for D2D because the link budget is difficult to close for the uplink

- We assume the capacity of a constellation scales proportionately with the number of satellites, which means there is a proportionate reduction in beamwidth. However, there is likely to be a limit on how small a beamwidth can be achieved, given factors such as altitude and satellite design (e.g. physical aperture, antenna gain, steering angle, power limits and thermal and power constraints)
- We do not account for differences between indoor and outdoor usage. Depending on the country, 50 to 90% of mobile usage is indoors¹⁶ and here D2D signals will be compromised due to building losses.

For further details on the modelling, please contact GSMA Intelligence at info@gsmaintelligence.com

¹⁵ See [Global Human Settlement Layer](#)
¹⁶ See for example GSMA (2024), Mobile Evolution in 6 GHz

Table 1
Current IMT and MSS spectrum allocations (in MHz)

3GPP

Band	3GPP	Region 1	Region 2	Region 3
IMT Spectrum				
600 MHz	n71 , n105	N/A*	70	80
700 MHz	n12, n14, n28, n29	80	90	90
800 MHz	n20	60	N/A	N/A
850 MHz	n5	N/A	50	Up to 40**
900 MHz	n8	70	30	70
1.5 GHz	n50, n75	85	85	80
1.8 GHz	n3	150	N/A	150
2.1 GHz	n1	120	N/A	120
PCS	n2, n25	N/A	120	N/A
AWS	n66, n70	N/A	120	N/A
2.3 GHz	n40	100	100	100
2.6 GHz	n41, n90, n38, n7	190	190	190
3.5 GHz	n77	400	400	400
MSS spectrum				
2.0-2.2 GHz	n252	0	40	0
1.5-1.6 GHz	n253	14	14	14
1.6 / 2.4 GHz	n254	33	33	33
1.5-1.6 GHz	n255	68	68	68
1.9-2.2 GHz	n256	60	0	60

Source: GSMA Intelligence

* There is an IMT identification for 600 MHz in the Middle East.

** Several Region 3 markets are using this but not in full; if so they would not have the whole 900 MHz available

