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SPECTRUM MANAGEMENT CONSIDERATIONS FOR D2D SERVICES

(Item on the Agenda: 3.4)

(Informative document submitted by the Mobile Satellite Services Association, MSSA)

Impact on the sector:

Direct-to-Device (D2D) satellite services are transforming the mobile communications sector by extending coverage into underserved and unserved areas where terrestrial networks cannot reach. For regulators, this technology offers a practical path to advance universal service objectives while avoiding unsustainable infrastructure costs for Mobile Network Operators (MNOs). The Mobile Satellite Services Association (MSSA) White Paper *"Spectrum Management Considerations for D2D Services"* provides an in-depth analysis of the regulatory and technical frameworks required to enable these deployments. By leveraging Mobile Satellite Service (MSS) spectrum, regulators can deliver reliable, interference-free connectivity that strengthens national policy goals and drives socio-economic development.

Executive Summary:

Direct-to-Device (D2D) satellite services are transforming the mobile communications sector by extending coverage into underserved and unserved areas where terrestrial networks cannot reach. The Mobile Satellite Services Association (MSSA) White Paper *"Spectrum Management Considerations for Direct-to-Device (D2D) Services"* provides a comprehensive analysis of the regulatory and technical frameworks required to support these deployments, particularly where terrestrial infrastructure is economically or technically unfeasible.

The paper compares two spectrum approaches to the provision of D2D services: (1) shared use of terrestrial mobile service spectrum used by Mobile Network Operators (MNOs) for D2D, and (2) leveraging dedicated Mobile Satellite Service (MSS) spectrum for D2D use. While the shared use of MNO spectrum by Satellite Network Operators (SNOs) raises significant challenges, including interference risks, separation zones, and complex cross-border coordination, the use of MSS spectrum for D2D avoids these issues due to the long-standing and globally harmonized regulatory framework for MSS band that exists under the ITU Radio Regulations. For MNOs, D2D offers a cost-effective solution to expand coverage, enhance service quality, and meet regulatory obligations without prohibitive infrastructure costs. On the other hand, for SNOs, D2D

creates new commercial opportunities through partnerships with MNOs, positioning satellites as an integral complement to terrestrial networks.

The White Paper also highlights the benefits of MSS spectrum: reliable, extensive outdoor coverage with minimal interference, compatibility with global 3GPP standards (Releases 17 and 18), and readiness for immediate deployment. It also emphasizes the importance of clear regulatory frameworks to ensure coexistence between satellite and terrestrial services while promoting investment and innovation.

MSSA urges administrations within CITEL to consider the benefits of MSS-based D2D services as part of regional preparations for WRC-27 Agenda Item 1.13. Supporting the use of MSS spectrum for D2D will accelerate digital inclusion, strengthen emergency and public safety communications, and generate new economic opportunities across the Americas and beyond.

For the convenience of all readers, a copy of the text of the MSSA White Paper *"Spectrum Management Considerations for D2D Services"* is provided below. The original document may also be accessed via the following link: [MSSA White Paper.](#)

Spectrum Management Considerations for D2D Services

MSSA

Mobile Satellite Service Association

Advancing the Future of Global Mobile Connectivity

SUMMARY

Direct-to-Device (D2D) satellite services offer Mobile Network Operators (MNOs) a cost-effective option for extending network coverage into underserved and unserved areas. These include regions with coverage gaps or dead zones, as well as areas outside the reach of traditional cellular coverage. Deploying terrestrial infrastructure in low subscriber density or remote areas is often economically unviable for MNOs. In this situation, D2D via satellite can offer an attractive solution for providing ubiquitous coverage.

The largest business opportunity lies in addressing underserved areas located at the edge of terrestrial cellular coverage, often in areas situated between semi-urban and rural regions. These areas offer significant opportunities to increase traffic volume and increase Average Revenue Per User (ARPU) since many subscribers often experience coverage gaps from terrestrial networks. Deploying D2D services enables both MNOs and Satellite Network Operators (SNOs) to capitalize on this demand, unlocking substantial revenue growth as well as bridging the digital divide.

Dedicated Mobile Satellite Service (MSS) spectrum offers several advantages for D2D satellite services. One of the primary benefits is that using MSS spectrum avoids the potential for interference with terrestrial mobile networks. MSS spectrum is allocated and assigned specifically for mobile satellite services under relevant regulatory frameworks and generally is not used for terrestrial services. Consequently, there is no risk that D2D operations in MSS spectrum will disrupt, or be disrupted by, co-frequency terrestrial cellular operations.

Another significant benefit of using MSS spectrum is its ability to support service in nearly 100% of the outdoor area within the coverage of the relevant satellite's beams (except in the most densely packed urban areas). This extensive coverage is particularly valuable for reaching underserved and unserved areas, where deploying terrestrial infrastructure is often economically unviable. MSS spectrum allows MNOs to extend their network coverage efficiently and cost-effectively, addressing coverage gaps and enhancing service quality for subscribers.

Sharing MNO terrestrial spectrum for D2D services poses challenges related to interference and potential disruptions to MNO operations. However, reusing MNO terrestrial spectrum in remote areas where there is no terrestrial usage of the same frequencies is feasible. Addressing interference between satellite and terrestrial reuse of MNO terrestrial spectrum near each other may also be achievable, but this will depend on updated regulations and technological advancements. Overall, MSS spectrum offers a reliable, efficient and current solution for deploying D2D services, providing comprehensive coverage and avoiding interference with existing terrestrial networks.

CONTEXT

D2D satellite services offer MNOs a cost-effective alternative to extend network coverage into under-served and unserved areas. These include regions with coverage gaps or dead zones, as well as areas outside the reach of traditional cellular coverage. This paper explores the opportunities and challenges MNOs face when integrating D2D services alongside existing terrestrial services.

Building terrestrial infrastructure in remote or sparsely populated areas is often not cost-effective for MNOs. In these cases, D2D via satellite can provide a practical solution for broad coverage addressing underserved areas located at the edge of coverage, often situated between semi-urban and rural regions These areas offer significant opportunities to increase traffic volume and increase Average Revenue Per User (ARPU)[1] since many subscribers often experience terrestrial coverage gaps and degraded signals. Deploying D2D services enables both MNOs and Satellite Network Operators (SNOs) to capitalize on this demand, unlocking substantial revenue growth.

This paper examines the benefits of leveraging MSS spectrum for D2D services. MSS spectrum offers the advantage of avoiding interference to MNO operations – facilitating coexistence of SNO with MNO operations. It also addresses the trade-offs MNOs should consider when planning utilization of their terrestrial spectrum for D2D services, balancing coverage expansion with spectrum efficiency and service quality.

This paper also provides insights into the regulatory, legal, and market challenges that must be addressed to enable the widespread adoption of D2D services.

[1] Example: ABI Research Report; The Role of Satellite in 5G: NTN Mobile

UNSERVED AREAS

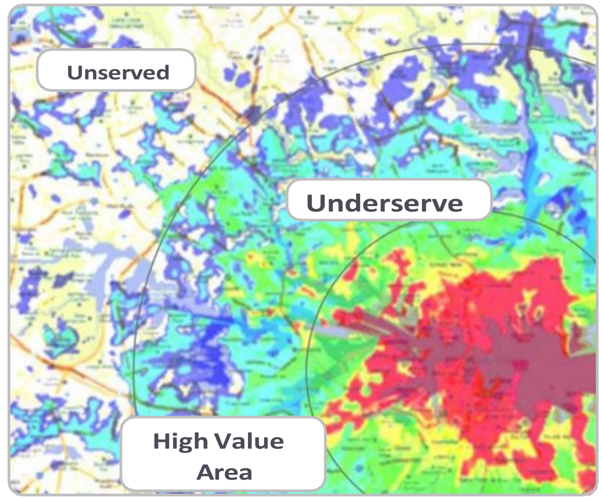


Figure 1: Unserved and underserved areas.

Unserved areas (see Figure 1) persist even in mature mobile markets, particularly in countries with large land masses or challenging terrains, or low population densities. These gaps may also result from zoning restrictions or infrastructure limitations While MNOs may not anticipate significant traffic in such regions, or the cost and time required to provide coverage may be prohibitive, they may still face obligations to extend emergency and basic services to less dense or harder-to-cover areas. Building new terrestrial infrastructure in these areas necessitates the cross-subsidization of services in unserved areas by revenue generated from more profitable regions.

UNDERSERVED AREAS

Underserved areas are regions located at the edges of cellular networks that experience inconsistent or poor coverage, often due to existing gaps that are challenging to address because of business or technical limitations or due to statistical variation of multi-path propagation. These areas, frequently situated in semi-urban, and relatively affluent environments, hold strategic importance for MNOs as subscribers often travel through or spend time in these regions, representing a significant untapped revenue opportunity.

While the percentage of time mobile subscribers spend outside coverage or in coverage “holes” is generally low[2], it varies significantly based on proximity to higher-density centers. Figure 1 illustrates the increase in the incidence of coverage holes with proximity to the edge of radio coverage. On average, traffic lost due to coverage gaps increases as subscribers move from urban centers to the edges of cellular networks where coverage holes are more prevalent.

MSSA analysis reveals, for example, that 30% of the population that lives within 20km of the edge of the network service area experience service loss 3% or more of the time. This trend highlights that the closer subscribers are to the footprint edge, the more frequently they encounter coverage issues. Such challenges result in significant traffic loss and increased subscribers’ dissatisfaction, which ultimately leads to higher churn rates.

THE D2D BUSINESS CASE

MNOs continually invest in network improvements to enhance coverage in both unserved and underserved regions. In some cases, service must be extended to economically low-activity areas to fulfill spectrum license obligations typically defined as percentage of population or territory covered with terrestrial cellular services.

More and more governments and local regulators are mandating MNOs to achieve 100% coverage. This growing trend is driven by the increasing reliance on mobile connectivity for essential services, economic activities, and social interactions. As a result, MNOs are under pressure to expand their networks to reach

[2] Open Signal Report

even the most remote and underserved areas. This mandate not only aims to bridge the digital divide but also to ensure that all citizens have access to reliable communication services, which are crucial for emergency response, education, healthcare, and overall quality of life.

While unserved areas present a notable opportunity, the areas between the suburban areas and the footprint limits of terrestrial cellular networks offer the greatest untapped potential. These areas hold significant opportunities for MNOs to boost ARPU and enhance subscriber satisfaction. Addressing both unserved and underserved regions through conventional cellular networks would, however, require substantial capital investment in terrestrial infrastructure, often yielding economically unsustainable returns.

MNOs often acquire the right to access mobile service spectrum at significant cost through auctions. Addressing all coverage deficiencies within the current cost structure of terrestrial sites and mobile service spectrum is often economically unfeasible for MNOs. D2D satellite services offer a cost-effective and practical alternative, enabling MNOs to extend and enhance mobile coverage in both underserved and unserved areas.

SUMMARIZING THE D2D BUSINESS CASE

- D2D services provide a cost-effective solution for extending coverage to both unserved and underserved areas.
- For unserved areas, the business case is particularly compelling as D2D services enable MNOs to achieve expanded coverage with lower capital (CAPEX) and operational expenses (OPEX) in ways that would not be cost-justified if addressed through traditional means.
- In underserved areas and regions with coverage gaps, the D2D business case is straightforward and robust for both MNOs and SNOs. D2D services offer substantial benefits over the deployment of terrestrial infrastructure, providing an efficient alternative to bridge coverage gaps or supplement the MNOs, limited network capacity.
- D2D services can be deployed using either existing MNO spectrum or SNO MSS spectrum.

SHARED MNO SPECTRUM UTILIZATION

This section examines the potential of sharing MNO spectrum with SNOs to support D2D services.

Interference and Separation Zones

A typical D2D satellite, even in low Earth orbit (LEO), provides extensive ground coverage through multiple beams. While this broad coverage is advantageous for reaching unserved and underserved areas, it complicates network planning and increases the risk of interference with terrestrial mobile cellular sites operating on the same frequencies.

Interference primarily arises from the satellite's beam pattern and the elongation of cells as the satellite moves to lower elevation angles in the sky. This interference degrades the signal-to-noise ratio (SNR) of terrestrial cells, leading to decreased spectral efficiency and service quality.

Mitigating this interference, particularly when spectrum is shared, requires careful management between satellite and terrestrial cells. In scenarios where D2D services are deployed near existing terrestrial cells, precise frequency channel coordination is required to maintain spectral efficiency. While higher mid- band frequencies offer greater separation and typically include larger MNO spectrum assignments, the situation becomes more challenging at lower and low mid-band frequencies. These bands are often the last resort for maintaining connectivity at the edges of coverage, making them particularly sensitive to interference.

Typical Satellite Cell Sizes and Configuration

Typical MNO cell sizes range from 1km in urban areas to up to 20km in rural areas, whereas D2D satellite cells are significantly larger, typically ranging from 30km to 50km. The table below illustrates typical D2D satellite configurations, highlighting key differences between medium-sized and large satellites.

Table 1: Typical Satellite Configuration and Earth-Fixed Cells

	Medium-sized Satellite	Large-sized Satellite
Altitude	600km	600km
Antenna Aperture	2-5m	5-8m
Earth Cell Size	20 to 50km	15 to 20km
Satellite Cost	Medium	High

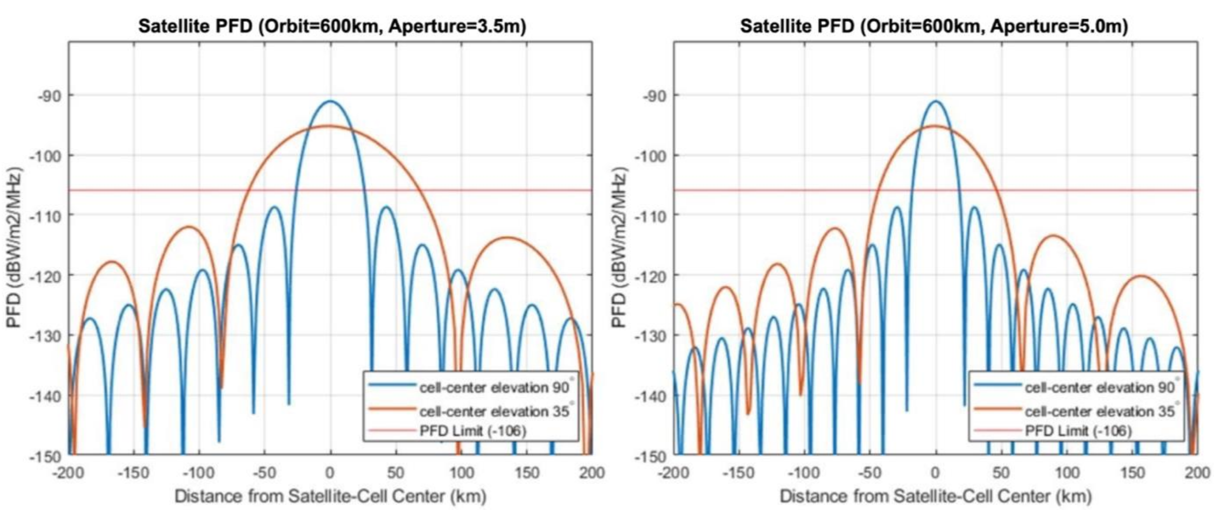
Satellite costs are directly related to factors such as antenna size and the number of generated or active cells. These factors significantly impact the D2D business case due to the higher capital expenditure requirements associated with advanced satellite configurations. Some SNOs have chosen to deploy larger satellites capable of generating smaller cells. While this strategy reduces interference and enhances network capacity, it comes at the cost of a higher upfront capital investment.

Effect of Interference

Figure 2 below illustrates the typical Power Flux Density (PFD) of D2D satellite beams and the requirements for coexistence in adjacent service areas, specifically in the 1900 MHz terrestrial bands (source: ISED SRSP-510/RSS-133). While sidelobe interference can be minimized with reduction of Effective Isotropic Radiated Power (EIRP), the elongation of the main beam at low elevations poses a significant challenge in Earth-fixed cell deployment scenarios.

The figure below shows a typical deployment of medium and large Earth-fixed satellite cell configurations using a circular aperture antenna, as specified in 3GPP TR38.811. It compares performance at nadir and low elevation 35°. In both scenarios, the EIRP is fixed to achieve a 10 dB SNR at the cell center when the satellite is at 90° elevation.

Figure 2: Impact of satellite beam on PFD limits for small and medium satellites



The figure also shows that the main beam elongation at low elevation angles will require extra isolation distance to comply with PFD limits as outlined in ISED SRSP-510/RSS-133.

Based on this assumption, D2D satellite services require minimum separation zones to ensure coexistence with the nearest terrestrial cells using the same frequency channel. These separation (or service exclusion) zones grow proportionally with satellite cell sizes, for instance, from at least 25km for 20km satellite cells, to more than 45km for 30km satellite cells.

Effect of Separation Zone on Cell Planning

To maintain spectrum efficiency, MNOs and SNOs must integrate separation zones into their frequency planning when deploying D2D services. These separation zones should include an additional margin to account for the statistical variability inherent in wireless communication. The size of these zones tends to increase for LEO constellations operating at low elevation angles.

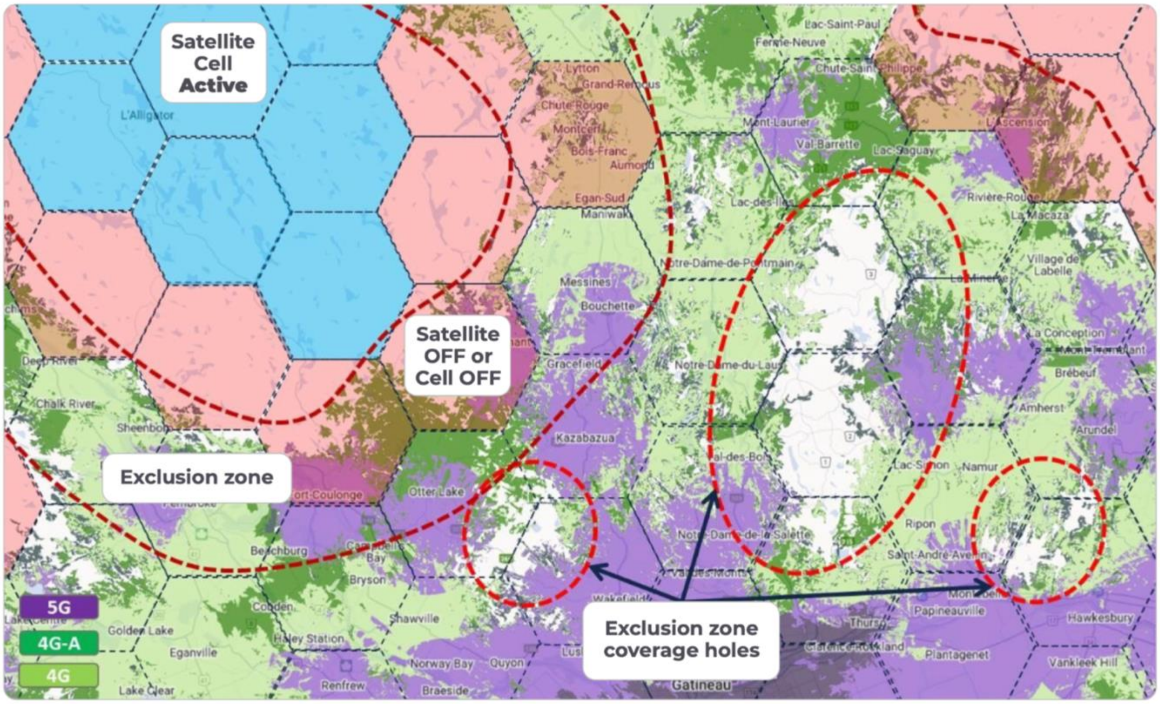
A proper separation zone at the edge of a cellular network's footprint can typically be achieved by ensuring that the outermost terrestrial sites or cells do not utilize the same frequency channels as those designated for D2D satellite services, or by deactivating satellite cells in overlapping regions. Due to the risk of spectrum efficiency degradation, however, separation zones must also encompass or overlap coverage holes within a cellular service area. Coverage holes smaller than the separation zone cannot be effectively served without deactivating multiple adjacent terrestrial cell sites.

In the uplink direction, satellite base stations face significant aggregate interference from thousands of terrestrial and satellite users operating on the same frequency. This interference reduces the link spectral efficiency and overall satellite network capacity compared to terrestrial networks.

Figure 3 below illustrates a typical D2D satellite network using shared MNO spectrum, highlighting separation or exclusion zones around terrestrial coverage3 areas. The depicted scenario encompasses both underserved and unserved areas.

Figure 3: Typical D2D spectrum sharing deployment scenarios with service exclusion zones[3]

[3] Background coverage map: Telus website



Mandatory Spectrum Coordination Areas *Spectrum Reuse Areas*

The satellite cells (Earth-fixed cells) depicted in this example have a diameter of approximately 30km. In this example, only a limited number of D2D satellite cells can be activated in unserved areas, while underserved areas would require disabling co-channel frequencies across a significant number of terrestrial cell sites.

An additional technical study conducted by Qualcomm[4] observed that spectrum sharing with MNOs can negatively impact SNO services, especially in the uplink. Even with the presence of separation or buffer zones, as illustrated in Figure 3, the aggregate interference due to the uplink transmission of the user equipment (mobile devices) managed by the MNOs could create significant loss in uplink signal to interference plus noise ratio (SINR) at the satellite. Since, for D2D, uplink is the weakest link, additional interference in the shared spectrum can make D2D potentially infeasible. However, it is to be noted that the amount of interference may depend on the SNO deployment density, cell size, and load conditions. Mitigation of this uplink interference, if present, is non-trivial.

This example demonstrates the trade-offs MNOs must consider when planning utilization of their terrestrial spectrum for D2D services, balancing coverage expansion with spectrum efficiency and service quality.

Managing Cross-Border Interference

Another consideration when terrestrial spectrum is shared with D2D satellite services is managing cross-border interference. Interference may occur if frequencies used along borders are not compatible, harmonized, or subject to bilateral or multilateral coordination agreements.

[4] Spectrum Sharing Evaluation

Separation zones along borders may be sizeable, leading to substantial unusable global areas. This raises critical questions currently under discussion with domestic and national administrations and regulators, including:

- Will separation zones along borders need to be defined for satellite operators using MNO spectrum?
- If these separation zones encompass remote areas without terrestrial coverage, how would those coverage gaps be handled?
- Who will be responsible for coordinating and enforcing compliance within these separation zones?

Addressing these challenges will require close collaboration among regulators, national administrations, and industry stakeholders to ensure effective and equitable spectrum management.

Conclusions to MNO Spectrum Sharing

In unserved rural areas where subscriber density is low, interference due to spectrum sharing can possibly be managed by properly defining a separation zone, thereby ensuring that the edge cell sites do not use the same channels terrestrially as the ones used by satellite networks for D2D.

In underserved areas such as semi-urban, where separation zones are also required to protect existing MNO services, turning off channels or aggregated channels on a large number of cells surrounding coverage holes raises efficiency questions. The issue of MNOs sharing their spectrum with SNOs is currently under study at the ITU, in preparation for the World Radiocommunication Conference 2027 under Agenda Item 1.13.[5]

[5] ITU WRC-27 Agenda Item 1.13, "to consider studies on possible new allocations to the mobile-satellite service for direct connectivity between space stations and International Mobile Telecommunications (IMT) user equipment to complement terrestrial IMT network coverage, in accordance with Resolution 253 (WRC-23)"

MSS SPECTRUM UTILIZATION

MSS spectrum offers an alternative for MNOs deploying D2D services, by leveraging spectrum already allocated for MSS services under applicable regulatory frameworks, including the ITU's longstanding MSS framework (defined in the ITU Radio Regulations and Recommendations) which effectively manages potential interference risks and enables the effective use of these bands for D2D. MSS spectrum is already coordinated with other services and has been put in use for many years, which ensures and provides solid established ground for D2D use.

Using MSS spectrum minimizes interference risk in the first instance by avoiding any need to repurpose spectrum for satellite communications or operate on a co-frequency basis with terrestrial networks.

Notably, D2D services use of MSS spectrum is already possible in most jurisdictions without requiring administrations to adopt new regulations using the following L-band and S-band ITU allocations:

- 1518-1525 MHz (space-to-Earth) paired with 1668-1675 MHz (Earth-to-space)
- 1525-1559 MHz (space-to-Earth) paired with 1626.5-1660.5 MHz (Earth-to-space)
- 1610-1626.5 MHz (Earth-to-space and space-to-Earth) paired with 2483.5-2500 MHz (space-to-Earth)
- 1980-2010 MHz (Earth-to-space) paired with 2170-2200 MHz (space-to-Earth)

The mobile satellite industry has developed technology for interoperable D2D solutions. In 2022, 3GPP Release 17 enabled direct communication between satellites, smartphones, and other devices, advancing satellite networking.

3GPP Release 17 improves the 5G architecture to support Non-Terrestrial Networks (NTNs) for coverage extension, IoT, disaster communications, global roaming, and broadcasting. Release 18 identifies three MSS frequency bands under 6 GHz for 5G New Radio (NR) and narrowband IoT (NB-IoT) to enable satellite connectivity, as defined by the ITU table of frequency allocations. Release 19 is considering additional MSS frequency bands. Table 2 summarizes the MSS bands in FR1-NTN.

Table 2: NTN satellite bands in FR1-NTN

NTN satellite operating band	Uplink (UL) operating band Satellite Access Node receive / UE transmit FUL,low – FUL,high	Downlink (DL) operating band Satellite Access Node transmit / UE receive FDL,low – FDL,high	Duplex mode
n256	1980 MHz – 2010 MHz	2170 MHz – 2200 MHz	FDD
n255	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
n254	1610 MHz – 1626.5 MHz	2483.5 MHz – 2500 MHz	FDD
n252	2000 MHz – 2020 MHz	2180 MHz – 2200 MHz	FDD
NOTE: NTN satellite bands are numbered in descending order from n256.			

D2D services using MSS spectrum can provide nearly 100% outdoor coverage, except in the most densely packed urban areas. This can help provide critical connectivity for underserved populations, delivering important social and economic development gains. It can also expand connectivity across multiple large and diverse segments, including industrial, government, agriculture, automotive, public safety, and others

SUMMARY OF SPECTRUM OPTIONS

The table below compares delivering D2D services using MNO spectrum versus using MSS spectrum.

Deployment Spectrum	Terrestrial (Shared)	MSS
Risk of interference with terrestrial spectrum	High	Low
Availability of handsets	Existing cellular handsets if utilizing non-NTN technology	New NTN capable handsets
Addressable market	Unserved areas	All underserved and unserved areas
Spectrum availability	MNO/Regulatory constrained	Technology/Regulatory constrained[6]
Route to market	MNOs	MNOs
Support for Open standards	Yes - 3GPP standards - 2G/4G Terrestrial waveform	Yes - 3GPP standards - NTN Satellite waveform
Global regulatory framework	Developing	In existence

CONCLUSIONS

D2D satellite operators offer a compelling solution for MNOs to cost-effectively expand coverage in unserved and underserved areas while enhancing service quality for their subscribers and avoiding complexities of separation zones near cell edges or along borders to protect the performance of existing terrestrial services.

MSS spectrum offers the advantage of providing 100% outdoor coverage enhancement for MNOs without interfering with existing services. One reason for this is because MSS frequency bands have long-standing regulations defined in the ITU Radio Regulations and Recommendations to manage potential interference issues and enable the use of these bands for D2D.

A recently published report, Spectrum for Emerging Direct-to-Device Satellite Services[7], concludes that MSS frequency bands offer significant advantages for nationwide and potentially global deployment of D2D services. These advantages stem from established global regulations and market access grants already

[6] Efforts underway in preparation for the WRC27 to make additional spectrum available for MSS
[7] Spectrum for Emerging Direct-to-Device Satellite Service. SATNow.com, January 28, 2025

secured by several existing operators. Additionally, millions of MSS users rely on these services, many for critical safety-of-life applications that must be protected. The most effective way to ensure this protection is through commercial agreements between D2D providers and existing MSS operators; a worldwide model that has already proven viable through multiple real-world examples.

While the business case for D2D services, particularly in underserved areas, demonstrates strong revenue potential, addressing this market requires a thorough analysis to identify the most appropriate spectrum that aligns with evolving business needs.