COMPARATIVE ANALYSIS OF TRI-BAND PAYLOAD UTILIZATION IN SATELLITE ACCESS NODE FOR FUTURE 5G NTN

DOI: 10.36724/2072-8735-2025-19-5-62-74

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Manuscript received 10 April 2025;
Accepted 12 May 2025

Keywords: *5G NTN, Satellite Access Node, Tri-Band Payload, Non-Terrestrial Networks, Doppler effect, Propagation Characteristics*

One of the most important socio-technical promises of these advancements is the elimination of the digital divide, ensuring that even the most remote and underserved regions have access to modern digital infrastructure. However, deploying traditional terrestrial cellular networks in such areas is often economically infeasible and logistically challenging due to factors such as low population density, difficult terrain, and lack of supporting infrastructure. This paper explores the use of 5G frequency bands (n254, n255, n256) for a tri-band payload in Satellite Access Node (SAN) designed for next-generation IoT and D2D non-terrestrial networks (NTN). A comparative analysis is conducted to examine key challenges, including spectrum coexistence with incumbent systems, Doppler effects, and signal propagation characteristics for each band. Additionally, the study evaluates regulatory hurdles associated with obtaining access to these frequencies. An expert as-sessment is provided for each factor, measuring its impact on IoT service delivery in NTN. Finally, an overall classification is assigned to each band based on a three-tier ranking system: high, mid, or low.

Для цитирования:
Пастух А.С., Тихвинский В.О., Дымкова С.С. Сравнительный анализ использования трехдиапазонной полезной нагрузки в узле спутникового доступа для будущей сети 5G NTN // T-Comm: Телекоммуникации и транспорт. 2025. Том 19. №5. С. 62-74.

For citation:
A.S. Pastukh, V.O. Tikhvinskiy, S.S. Dymkova, “Comparative Analysis of Tri-Band Payload Utilization in Satellite Access Node for Future 5G NTN,” *T-Comm*, 2025, vol. 19, no. 5, pp. 62-74.

1 Introduction

The evolution of mobile communication technologies from 5G to future 6G networks is centered around the goal of delivering ubiquitous, high-speed, and reliable connectivity. One of the most important socio-technical promises of these advancements is the elimination of the digital divide, ensuring that even the most remote and underserved regions have access to modern digital infrastructure. However, deploying traditional terrestrial cellular networks in such areas is often economically infeasible and logistically challenging due to factors such as low population density, difficult terrain, and lack of supporting infrastructure.

To address these limitations, the 3rd Generation Partnership Project (3GPP) has introduced the concept of Non-Terrestrial Networks (NTNs) – networks that leverage satellite systems and high-altitude platforms (HAPs) to complement terrestrial networks. These NTNs are especially well-suited for extending coverage in rural, maritime, mountainous, and airborne environments where conventional infrastructure cannot be easily deployed. NTNs are now considered an integral component of the 5G and 6G ecosystem.

With the release of 3GPP Release 17, NTNs were formally incorporated into the 3GPP framework, marking a significant milestone in satellite-based mobile communication. This release defined two NTN frequency bands within Frequency Range 1 (FR1):

- Band n255: Uplink (UL) 1626,5-1660,5 MHz / Downlink (DL) 1525-1559 MHz
- Band n256: UL 1980-2010 MHz / DL 2170-2200 MHz

Later, with the arrival of Release 18, a third FR1 band was added:

- Band n254: UL 1610-1626.5 MHz / DL 2483,5-2500 MHz

These bands, operating within the L- and S-band ranges, were specifically selected to facilitate NTN operations due to their favorable propagation characteristics, existing satellite service use, and global regulatory considerations.

Despite their inclusion in the 3GPP standard, the practical feasibility and suitability of each NTN band remain active areas of investigation. Implementing NTNs using these bands presents various technical and regulatory challenges, such as:

- Propagation conditions and atmospheric loss
- Doppler shift induced by satellite motion
- Compatibility with incumbent satellite and terrestrial services
- Spectrum regulation and licensing
- Support in commercial chipsets and user equipment (UE)

Given these complexities, it becomes crucial to evaluate and compare the performance and implementation readiness of bands n254, n255, and n256. This article aims to address that gap by systematically analyzing the trade-offs and practical considerations associated with each band and proposing a ranking of the bands based on their overall viability for NTN deployment.

2 State of the Art

The integration of Non-Terrestrial Networks (NTNs) into 3GPP standards has sparked significant academic and industrial interest, with a growing body of literature exploring the key technological challenges and opportunities. However, while various aspects of NTN implementation – uch as frequency planning, propagation modeling, Doppler compensation, and interference management – have been studied, these investigations are often fragmented. A comprehensive comparison of the FR1 NTN bands (n254, n255, n256) remains largely unexplored in the literature.

The technical feasibility of using bands n254, n255, and n256 for NTN deployments is discussed in several recent works. For example, [1-4] analyze the general deployment considerations of NTN frequency bands in the context of 5G and beyond. These studies examine link budget design, satellite-to-device communication strategies, and multi-connectivity frameworks, emphasizing the importance of seamless integration between terrestrial and non-terrestrial segments.

The Doppler effect, caused by the high relative velocities of low Earth orbit (LEO) satellites, is one of the most critical physical-layer challenges in NTN systems. The works in [5-8] present various methods for Doppler shift estimation and compensation in OFDMA systems, which are the basis of 5G New Radio (NR). These studies explore both open-loop and closed-loop compensation schemes, as well as synchronization algorithms designed to mitigate signal distortion and maintain robust links between satellites and user terminals.

Propagation losses, which differ significantly depending on frequency, elevation angle, and environmental factors, have been addressed in [9] and [10]. These works provide empirical and modeled comparisons of signal attenuation in the L- and S-band spectrum, demonstrating that while lower frequencies generally offer better penetration and lower free-space loss, they are also subject to higher levels of interference due to coexisting services.

Spectrum compatibility and interference analysis are particularly relevant for NTN implementation, given that bands like n255 and n256 are shared with existing Mobile Satellite Services (MSS) and other legacy systems. The compatibility of these bands with incumbent services has been explored in [11], highlighting challenges such as adjacent-channel interference and the need for coordinated coexistence. Similarly, [12] provides an in-depth assessment of potential interference scenarios related to the terrestrial n25 band, which, while not an NTN band itself, shares spectral proximity with NTN allocations and may introduce or experience harmful interference under certain deployment models. Several other works study compatibility issues of NTN systems mostly compatibility with terrestrial segment of IMT [13-15].

Notably, band n254, introduced in Release 18, has not yet been the focus of dedicated compatibility or coexistence studies, despite its potential advantages such as increased downlink spectrum and partial overlap with existing MSS allocations. This lack of research presents a gap in the NTN landscape that this article seeks to address.

In addition to these technical articles, broader analyses of NTN standards, spectrum policies, and deployment strategies are covered in [16-20], which are comprehensive references that discusses the end-to-end design considerations for 5G NTN systems.

Taken together, these studies form a fragmented but growing foundation for evaluating the viability of FR1 NTN bands. However, to date, no unified study has compared the three FR1 NTN bands from a holistic implementation perspective, incorporating propagation, Doppler, interference, chipset support, and regulatory readiness.

This article aims to fill that gap by synthesizing available data and offering a comparative analysis that informs future NTN deployment strategies.

3 Types of the NTN networks

NTN systems for IoT and D2D applications will consist of two main elements:

– Space component: could be either GSO satellite or NGSO system. NGSO system involves a constellation of hundreds or even thousands of satellites. The number of satellites required will depend upon the required latency, link budget parameters and constellation sizing, with more satellites required for lower altitudes.

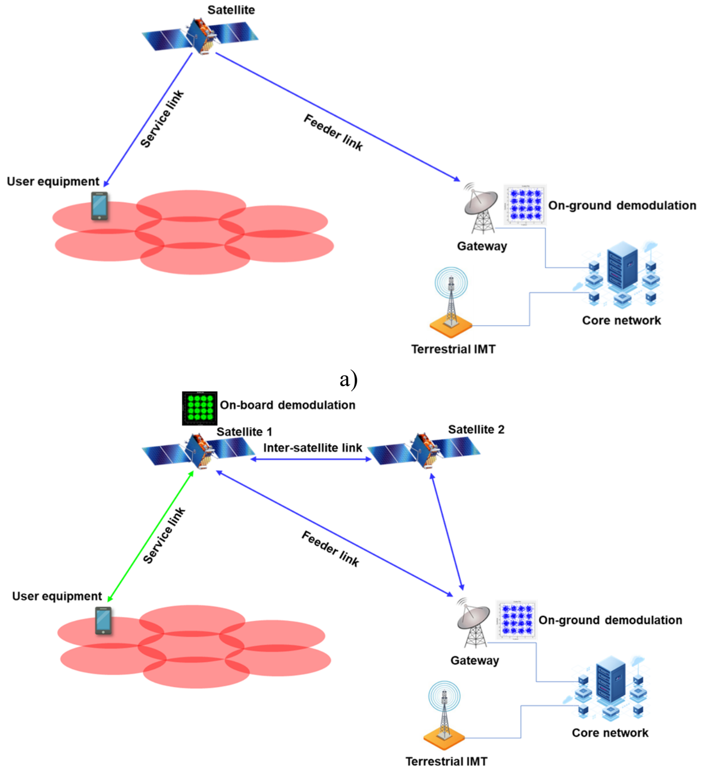
– Ground component, including the user equipment (UEs) and gateways.

The deployment of NTN systems for IoT and D2D is possible in two architectures: transparent mode and regenerative mode.

– In transparent mode the satellite payload forwards the Satellite Radio Interface (SRI) protocol between the service link and the feeder link. For example, such payload may implement radio frequency filtering, frequency conversion, signal processing and amplification. Protocol-related base station functions are handled at the gateway earth stations. The use of inter-satellite links is not foreseen in this case.

– In regenerative mode the payload processes the SRI protocol between the service link and the feeder link, with potential use of inter-satellite links depending on the chosen architecture. For example, such payload may implement radio frequency filtering, frequency conversion, signal processing, routing/switching, protocol handling and RF amplification. This is effectively equivalent to having protocol-related base station functions on board the satellite.

In the case of implementing a payload with direct retransmission (transparent), it would be necessary to take into account additional feeder links in a "star" topology, which would increase the signal transmission and corresponding latency by 2 times. Figure 1 provides two types of NTN payloads.



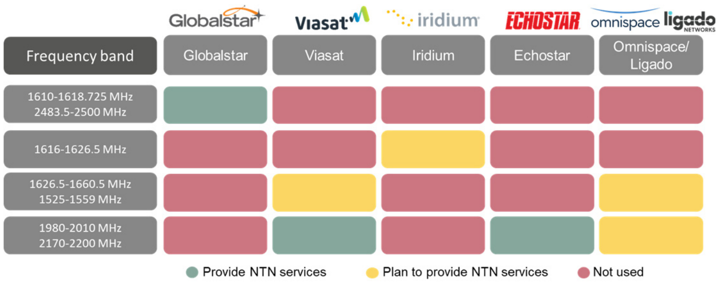
a)

b)

Fig. 1. Types of the NTN payloads (a) transparent (b) regenerative

Several companies have already begun using, or plan to use, FR1-NTN frequency bands. For instance, parts of the n254 band are currently utilized by Globalstar to provide SOS messaging services on iPhones. Meanwhile, Bullitt and Skylo offer IoT and D2D services via GEO satellites from ViaSat and EchoStar. Other companies are also developing services in these bands—Iridium, for example, has announced Project Stardust, which aims to deliver standards-based NB-IoT NTN communication using its operational LEO constellation.

Figure 2 illustrates the basic NTN architecture with a regenerative SAN payload and highlights current usage across the n254, n255, and n256 bands.



Frequency band	Globalstar	Viasat	Iridium	Echostar	Omnispace/ Ligado
1610-1618.725 MHz 2483.5-2500 MHz	🟩	🟥	🟥	🟥	🟥
1616-1626.5 MHz	🟥	🟥	🟨	🟥	🟥
1626.5-1660.5 MHz 1525-1559 MHz	🟥	🟨	🟥	🟥	🟨
1980-2010 MHz 2170-2200 MHz	🟥	🟩	🟥	🟩	🟨

🟩 Provide NTN services 🟨 Plan to provide NTN services 🟥 Not used

Fig. 2. Current utilization of n254, n255 and n256 for NTN services

Despite these developments, widespread use of the n254, n255, and n256 bands by NTN networks remains limited. The n254 band is currently used only for emergency SOS messaging on the latest iPhone models. The n255 and n256 bands, to date, support just six released devices from manufacturers such as Caterpillar, Motorola, and uleFone.

Additionally, current usage is largely confined to companies that had previously operated in these bands with systems not originally designed for NTN. Unlocking the full potential of NTN services in these bands will require new satellite constellations specifically tailored to NTN capabilities.

However, even though 3GPP has standardized these FR1-NTN bands for NTN use, companies that do not already own incumbent systems in these bands are likely to encounter significant regulatory hurdles. For instance:

– The n256 band is extensively used by ViaSat and Omnispace.

– The n255 band is occupied by ViaSat and Ligado.

– The n254 band is utilized by Globalstar and Iridium.

Any new entrant intending to operate in these bands must coordinate with the incumbent users as part of the ITU-R filing process.

4 Doppler shift

In contrast to terrestrial networks, where the term "base station" implies a stationary infrastructure, satellites in non-terrestrial networks move at significant velocities, resulting in carrier frequency deviation due to the Doppler effect. Additionally, the propagation of radio waves through the ionosphere leads to polarization rotation of the waveform, a phenomenon known as Faraday rotation.

The development of 5G New Radio (NR) to support Non-Terrestrial Networks (NTN), particularly satellite communication systems, is currently under investigation within 3GPP. The mobility of spaceborne platforms in NTN introduces significant variation in Doppler shift over time, which differs across user equipment (UE) based on their geographic location. When employing Orthogonal Frequency-Division Multiple Access (OFDMA) in the uplink, each UE must apply an individualized frequency adjustment to compensate for the Doppler shift.

To address this, 3GPP Release 17 for NTN assumes that the UE is equipped with a D (GNSS) chipset. This enables the device to determine its own position and compute the necessary frequency adjustment based on its location and satellite ephemeris data. Such an approach offers the potential to reduce the dependency of NTN operations on continuous GNSS usage, achieving a reasonable trade-off between implementation complexity and system performance.

The classical formula for Doppler shift is:

$$f_D = \frac{v}{c} f_c \cos(\theta), \quad (1)$$

where:

- f_D: Doppler shift (Hz)
- v: Relative velocity between transmitter and receiver (m/s)
- c: Speed of light (approximately 3×1083 \times 10^83×108 m/s)
- f_c: Carrier frequency (Hz)
- θ: Angle between direction of motion and wave propagation

In 5G, OFDMA is used for both uplink and downlink in the New Radio (NR) interface. Each user gets allocated a set of subcarriers, and the overall bandwidth is divided into numerous orthogonal subcarriers.

However, Doppler shift can break the orthogonality between subcarriers, causing Inter-Carrier Interference (ICI), which degrades system performance. Each subcarrier in OFDM is a sinc function in the frequency domain. In ideal conditions:

$$\int_0^T e^{j\pi f_n t} \cdot e^{-j\pi f_m t} dt = 0 \text{ for } n \neq m \quad (2)$$

But if there's a frequency shift (e.g., due to Doppler), the integral is no longer zero, meaning interference occurs between subcarriers nnn and mmm. In presence of Doppler, a subcarrier at frequency f_k becomes:

$$s_k(t) = e^{j\pi(f_k + f_D)t} \quad (3)$$

When demodulating, the receiver uses:

$$r_k(t) = s_k(t) \cdot e^{-j\pi f_k t} = e^{j\pi f_D t} \quad (4)$$

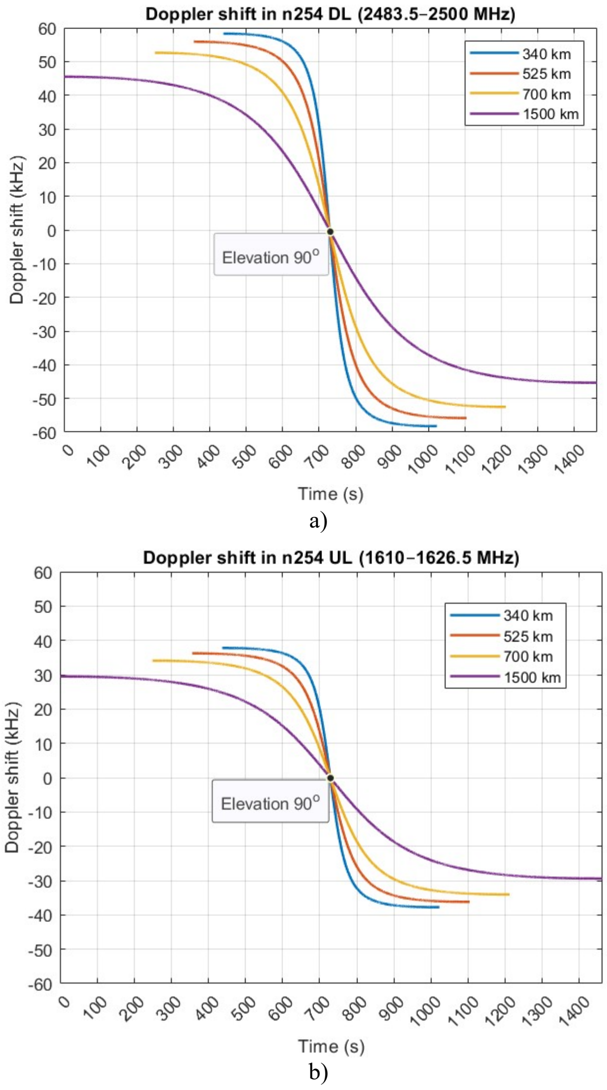
This extra exponential term leads to a time-varying phase rotation and loss of orthogonality, which causes ICI when taking the FFT during demodulation.

In 3GPP TS 38.101-5 V19.0.0 (2025-03) [21], the focus is primarily on the uplink (UL) aspects of 5G NR satellite communications, particularly regarding how User Equipment (UE) should pre-compensate for Doppler shifts when transmitting signals to satellites. The document provides detailed specifications for UL frequency accuracy and compensation techniques.

However, for the downlink (DL) – where signals are transmitted from satellites to the UE – the document does not specify particular Doppler compensation methods or requirements. This omission suggests that the UE is expected to handle Doppler effects in the DL through its inherent receiver design and synchronization processes. Typically, UE receivers are designed to track and correct frequency shifts caused by Doppler effects to maintain accurate signal reception.

To evaluate the Doppler characteristics of 5G NR NTN bands, simulations were performed for frequency ranges corresponding to n254, n255, and n256, as defined for non-terrestrial S-band and L-band operation. The Doppler shift was computed assuming a spot beam scenario, with the user terminal located directly beneath the satellite's ground track (i.e., elevation 90° at closest approach).

Figures 3-5 provide Doppler shift for n254, n256 and n255 bands. Overall, the results confirm that orbit selection, frequency band choice, and waveform design must be jointly considered to ensure robust NTN performance across diverse deployment scenarios.

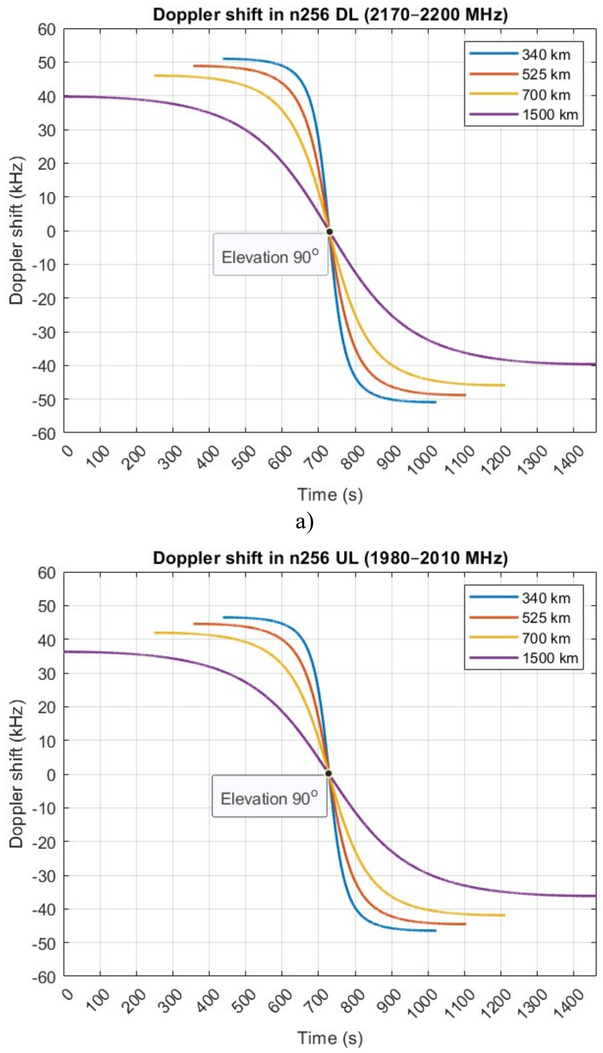


a)

b)

Fig. 3. Doppler shift for different types of orbits in the n254 band (a) downlink band (b) uplink band

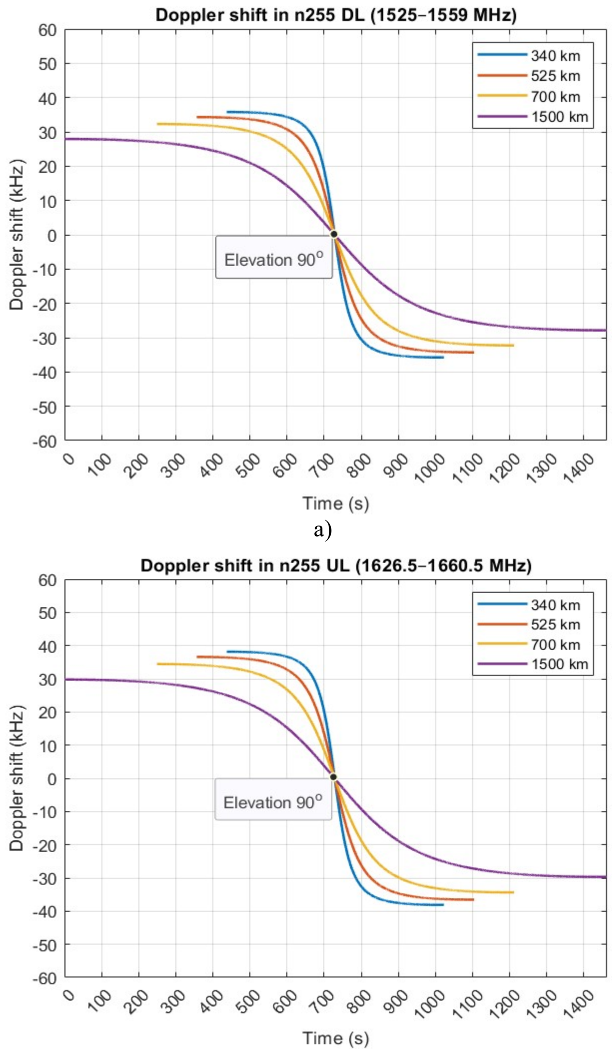
Simulated Doppler shift vs. time for a spot beam downlink in the n254 band at four different LEO satellite altitudes: 340 km, 525 km, 700 km, and 1500 km. The peak Doppler shift exceeds ±55 kHz for the lowest orbits, highlighting the impact of S-band operation in LEO. Doppler shift simulation for the uplink portion of band n254. Due to the lower frequency compared to the downlink, the maximum Doppler shift is proportionally reduced, peaking near ±33 kHz at 340 km altitude.



a)

b)

Fig. 4. Doppler shift for different types of orbits in the n256 band (a) downlink band (b) uplink band



a)

b)

Fig. 5. Doppler shift for different types of orbits in the n255 band (a) downlink band (b) uplink band

Downlink Doppler shift simulation for band n256, showing time-varying frequency shift across four LEO satellite altitudes. The Doppler shift reaches up to ±50 kHz at 340 km, illustrating the challenges in maintaining frequency synchronization in S-band downlink transmissions. Uplink Doppler simulation for band n256, showing a symmetric Doppler shift curve with values approaching ±45 kHz for low-altitude LEO orbits.

Uplink Doppler behavior for band n255, operating in the upper L-band. Doppler magnitude remains within ±35 kHz, providing slightly more tolerance than the S-band cases. Downlink Doppler shift shows similar levels for band n255, reaffirming moderate Doppler behavior across altitudes.

The figures illustrate the instantaneous Doppler shift as a function of time for several LEO satellite altitudes: 340 km, 525 km, 700 km, and 1500 km. As expected, the maximum Doppler shift increases with carrier frequency and decreases with orbital altitude. For the S-band downlink of band n254 (2483,5-2500 MHz), the maximum Doppler exceeds ±55 kHz at 340 km altitude. In contrast, the L-band frequencies used in n255 (1525-1559 MHz DL) exhibit lower peak Doppler values, typically within ±35 kHz under similar conditions.

These results emphasize the need for effective Doppler compensation techniques in both uplink and downlink paths. In the downlink case, where the satellite is the transmitter, pre-compensation of the carrier frequency may be applied to mitigate the observed shift at the UE receiver. Such compensation is crucial in maintaining subcarrier orthogonality in OFDM systems and avoiding inter-carrier interference (ICI), particularly when the subcarrier spacing is narrow.

5 Propagation losses

The considerable distance between user equipment (UE) and a satellite introduces significant path loss, which is a critical factor in the link budget of satellite communication systems. Total path loss consists of several components, each contributing to signal attenuation:

– Free-Space Path Loss (FSPL): FSPL is the dominant component of path loss in satellite links and is primarily determined by the distance between the transmitter and receiver, as well as the operating frequency.

– Atmospheric Losses: Gaseous absorption caused mainly by oxygen and water vapor, particularly in higher frequency bands such as the Ka-band.

– Atmospheric fading (scintillation): Arises due to variations in atmospheric conditions, including turbulence, rain, and cloud cover, leading to signal fluctuations and degradation.

– Building Penetration Loss: Signal attenuation can also occur when UE is located indoors. The extent of this loss depends on building materials and structural design, and can significantly reduce received signal strength.

Introducing free-space attenuation between isotropic antennas, also known as the free-space basic transmission loss (symbols: Lbf or Abf), it can be calculated as follows [22]:

$$L_{bf} = -10\log_{10}\left(\frac{\lambda}{4\pi d^2}\times\frac{\lambda^2}{4\pi}\right) = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right), \qquad (5)$$

where:

- L_{bf} : free-space basic transmission loss (dB)
- d : distance
- λ : wavelength, and
- d and λ are expressed in the same unit.

The Figure 6 illustrates the Free-Space Path Loss (FSPL) as a function of distance for both downlink (DL) and uplink (UL) transmissions across 3GPP-specified NTN frequency bands: n254, n255, and n256.

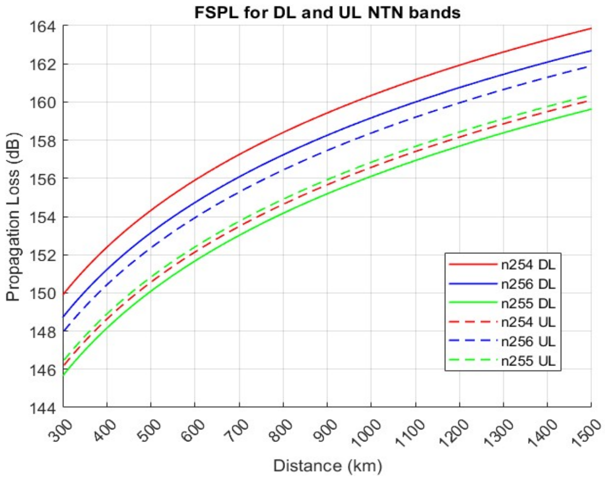


Fig. 6. Free space loss for n254, n256 and n255 bands

The x-axis represents the distance between the transmitter and receiver in kilometers, ranging from 300 km to 1500 km – typical for LEO satellite altitudes. As may noted from the above results, for downlink case n255 has the best propagation conditions, the n256 band has 2.5 dB worse link budget whereas n254 has almost 4 dB worse link budget. For the uplink case n254 and n255 show nearly identical results whereas n256 show almost 2 dB more attenuation.

The atmospheric losses are typically a challenge for Ku and Ka bands, rather than L and S band therefore in this case will be negligible. Building entry loss (BEL) will vary depending on building type, location within the building and movement in the building. In Recommendation ITU-R P.2109 [23] the building entry loss distribution is given by a combination of two lognormal distributions. The BEL not exceeded for the probability, P, is given by:

$$L_{BEL}^{omni}(P) = 10\log(10^{0.1A(P)} + 10^{0.1B(P)} + 10^{0.1C}), \qquad (6)$$

where:

$$A(P) = F^{-1}(P)\sigma_1 + \mu_1, \qquad (7)$$

$$B(P) = F^{-1}(P)\sigma_2 + \mu_2, \qquad (8)$$

$$C = -3.0, \qquad (9)$$

$$\mu_1 = L_h + L_e, \qquad (10)$$

$$\mu_2 = w + x\log(f), \qquad (11)$$

$$\sigma_1 = u + v\log(f), \qquad (12)$$

$$\sigma_2 = y + z\log(f), \qquad (13)$$

where: L_h: median loss for horizontal paths, given by:

$$L_h = r + s\log(f) + t\,(\log(f))^2, \qquad (14)$$

L_e: correction for elevation angle of the path at the building façade:

$$L_e = 0.212\,|\theta|, \qquad (15)$$

and:

f: frequency (GHz)

θ: elevation angle of the path at the building façade (degrees)

P: probability that loss is not exceeded ($0.0 \le P \le 1.0$)

$F^{-1}(P)$:inverse cumulative normal distribution as a function of probability.

The coefficients are as given in Table 1.

Table 1

Model coefficients

Building type	***r***	***s***	***t***	***u***	***v***	***w***	***x***	***y***	***z***
Related to:	μ1			σ1		μ2		σ2	
Traditional	12.64	3.72	0.96	9.6	2.0	9.1	−3.0	4.5	−2.0

Figure 7 presents the cumulative distribution functions (CDFs) of BEL for three frequency bands (n254, n255, and n256), comparing traditional and thermally-efficient buildings.

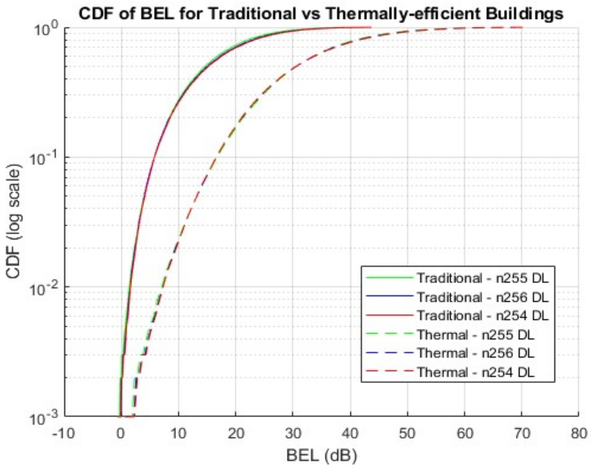


Fig. 7. Building entry losses for n254, n256 and n255 bands

The curves for all three bands are nearly identical within each building type, indicating that frequency-dependent variation in BEL is minimal for indoor users.

However, a clear distinction is observed between the two building categories. For thermally-efficient buildings, approximately 98% of cases experience a BEL exceeding 10 dB, compared to 72% for traditional buildings. This substantial difference highlights the impact of modern construction materials on signal penetration and suggests that, in most scenarios, reliable satellite connectivity may not be achievable indoors, particularly in thermally-efficient environments.

6 Spectrum sharing challenges

As was indicated in the study [11] for the bands n255 and n256 bands there is a significant challenge in terms of compatibility with existing satellite systems in this band, particularly with Inmarsat, Omnispace and other systems. Studies indicated that there is a considerable amount of interference that would be caused by potential D2D system to the existing systems.

For n254 band, there are two systems that operate in this band or parts of that band, specifically Globalstar that operates in the frequency bands 2483.5-2500 MHz (space-to-Earth)/1610-1618.725 MHz (Earth-to-space) and Iridium that operates in TDD mode in the 1616-1626.5 MHz band. The following interference scenarios of mutual interference have been analyzed in this contribution (Table 1):

Table 1

Interference scenarios analyzed in this study

Interference Band (MHz)	Interferer	Victim	Type of interference
2483.5-2500	Globalstar Satellite	NTN UE	Downlink interference
	NTN Satellite	Globalstar UE	Downlink interference
1610-1618.725	NTN UE	Globalstar Satellite	Uplink interference
	Globalstar UE	NTN Satellite	Uplink interference
1616-1626.5	Iridium Satellite	NTN Satellite	Satellite-to-satellite interference
	Iridium Satellite	NTN UE	Downlink interference
	NTN UE	Iridium Satellite	Uplink interference
	NTN UE	Iridium UE	Handset-to-handset interference
	Iridium Satellite	NTN Satellite	Satellite-to-satellite interference

Handset-to-handset interference was not analyzed due to the inherently low probability of occurrence and limited impact such scenarios pose in practical deployments. Mobile user terminals, particularly those operating in MSS bands, typically have low transmission power and are subject to significant path loss due to ground-level operation, environmental obstructions, and user body losses. Furthermore, the likelihood of two mobile terminals operating in close physical proximity, within line-of-sight, and on overlapping frequencies is minimal, especially considering that NTN and Iridium services often rely on geographically dispersed and independently operated networks. As a result, the focus of the

$$P_{int} = P_t \cdot G_t(\theta, \phi) \cdot G_r(\theta, \phi) \cdot \left(\frac{\lambda}{4\pi d}\right)^2 \cdot L_{misc}, \qquad (16)$$

where:

– P_{int}: Interference power at the receiver (W)

– P_t: Transmit power of the interfering satellite (W)

– $G_t(\theta, \phi)$: Transmit antenna gain in the direction of the victim receiver

– $G_r(\theta, \phi)$: Receive antenna gain of the victim receiver toward the interferer

– λ: Wavelength of the signal (m)

– d: Distance between the two satellites (m)

– L_{misc}: Miscellaneous losses, including polarization mismatch, filter rejection, and any pointing loss if any exist

In this study, link degradation for satellite communication systems – Globalstar, Iridium, and Non-Terrestrial Networks (NTN) – is evaluated under various interference scenarios. The key metric used to quantify degradation is the carrier-to-noise degradation $\Delta C/N$, which represents the reduction in effective $\Delta C/N$ due to interference.

To compute this, we begin by estimating the interference-to-noise ratio (I/N) at the victim receiver, where the thermal noise power N is defined as:

$$N = kTB,$$

where:

– k: 1.38×10^{-23} J/K is Boltzmanns' constant

– T: is the system noise temperatire (K)

– B: is the receiver bandwidth (Hz)

Given this, the degradation in carrier-to-noise ratio due to interference, in linear scale, is:

$$\frac{\Delta C}{N} = \frac{N + I}{N} = 1 + \frac{I}{kTB},$$

Which can be rewritten in decibels as:

$$\frac{\Delta C}{N} = 10\log\left(1 + 10^{\frac{(I/N)_{dB}}{10}}\right), \qquad (17)$$

Accoridng to ITU-R Recommendations protection threshold of the that the maximum level of interference power in any such digital channel caused by the transmitters of another mobile-satellite network or fixed-satellite network, should not exceed for more than (100 – X)% of any month, 6% of the total noise power at the input to the demodulator which would give rise to the desired performance objectives. This corresponds to I/N = -12.2 dB [26].

For NTN systems given that they use IMT radio interference, protection threshold would correspond to the terrestrial IMT levels. According to ITU-R Reommendations and Reports, permissible interference is I/N = -6 dB, which corresponds to the link degradation by 1 dB [27].

Parameters for NTN were obtained from numerous sources which include 3GPP TR 38.821 and Report ITU-R M.2514 and provided in Table 2 below [28-30]. It should be noted that in practice, NTN systems in n254 may have varieties in these parameters, however they will not affect too much at the spectrum sharing conditions.

Table 2

Parameters of NTN used in the study

Parameter	Value
Orbit height	340/525 km
Number of satellites	3360 with 340 km orbit 5280 with 525 km orbit
Operational frequency	1610-1626.5 MHz (Earth-to-space) 2483.5-2500 MHz (space-to-Earth)
Bandwidth	180 kHz-5 MHz
Satellite EIRP	4 dBW/MHz
Satellite antenna gain	30 dBi
Satellite antenna pattern	Rec. ITU-R S.1528
Satellite receiver noise temperature	500 K
User equipment power	23 dBm
User equipment antenna pattern	Circular
User equipmentantenna gain	-4 dBi
User equipment receiver noise temperature	2700 K

6.1. Interference simulation between NTN and Iridium

Parameters of Iridium were obtained from HIBLEO-2 of ITU-R filing [31] and presented in Table 3.

Table 3

Parameters of HIBLEO-2 (Iridium) satellite system

Parameter	Value
Orbital height	780 km
Inclination	86.5 degrees
Number of planes	6
Number of satellites per plane	11
Operational frequency	1616-1626.5 MHz (TDD)
Bandwidth	31.5 kHz
Satellite max power	3.4 dBW
Satellite min power	-12.2 dBW
Satellite antenna pattern	Rec. ITU-R S.1528
Satellite antenna gain	24.3 dBi
Satellite receiver noise temperature	500 K
Subscriber unit max power	2.2 dBW
Subscriber unit min power	-9.8 dBW
Subscriber unit antenna pattern	Circular
Subscriber unit antenna gain	1 dBi
Subscriber unit receiver noise temperature	250 K
Target C/N	9.1 dB

Figure 8 below illustrates the simulation results of mutual interference between the Non-Terrestrial Network (NTN) and the Iridium system where white dots are the satellites of the NTN system.

The interference analysis covers the 1616-1626.5 MHz frequency bands and is visualized in the following figures (Fig. 9).

In case of Iridium interference to NTN the downlink interference reaches I/N levels as high as +13 dB, while uplink interference also exceeds the –6 dB threshold for a significant percentage of time, indicating unacceptable interference to NTN from both satellites and user equipment of Iridium. This result shows that for NTN it would be problematic to operate within the 1616-1626.5 MHz portion of n254 band.

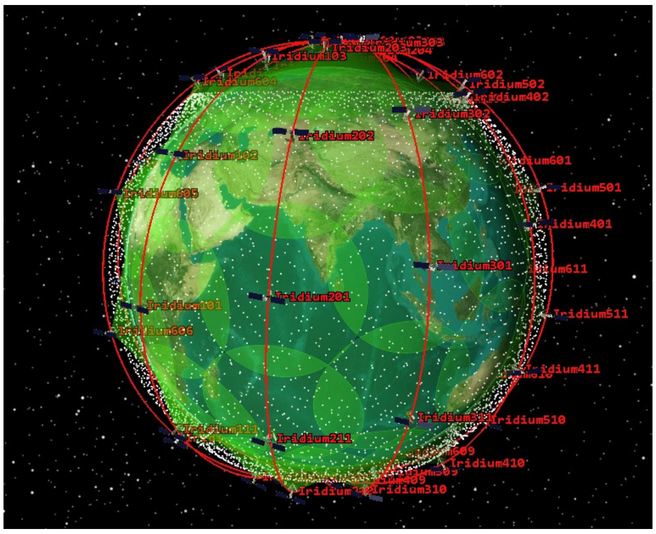
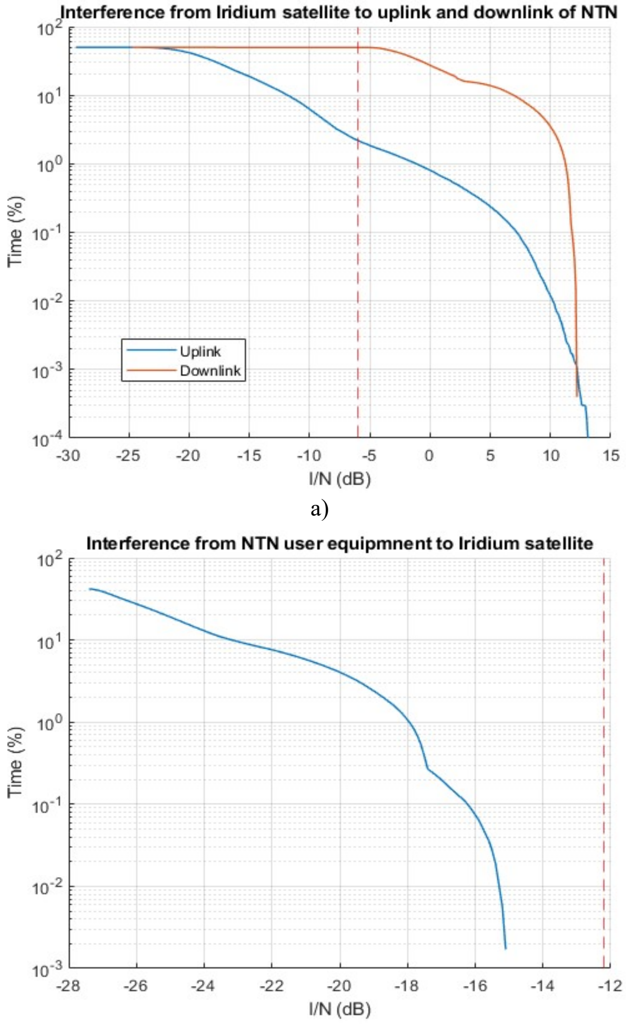


Fig. 8. Free space loss for n254, n256 and n255 bands



a)

b)

Fig. 9. Mutual interference between Iridium and NTN (a) from Iridium to NTN (b) from NTN to Iridium

In the case of interference from NTN user equipment to Iridium satellites, I/N levels peaking around –15 dB and remaining well below the –12.2 dB threshold. This suggests that NTN user equipment would cause limited interference to Iridium's uplink operations, staying within acceptable limits for most of the time.

6.2. Interference simulation between NTN and Globalstar

Parameters of Globalstar were obtained from HIBLEO-4 and HIBLEO-X [31] of ITU-R filing and presented in Table 4:

Table 4

Parameters of HIBLEO-2 (Iridium) satellite system

Parameter	Value
Orbital height	1414 km
Inclination	53 degrees
Number of planes	6
Number of satellites per plane	8
Operational frequency	1610-1618.725 MHz (Earth-to-space) 2483.5-2500 MHz (space-to-Earth)
Bandwidth	1 MHz
Satellite max power	5.3 dBW
Satellite min power	-12.9 dBW
Satellite antenna pattern	Rec. ITU-R S.1528
Satellite antenna gain	24.3 dBi
Satellite receiver noise temperature	400 K
User terminal max power	5.5 dBW
User terminal min power	-16 dBW
User terminal antenna pattern	Circular
User terminal antenna gain	2.4 dBi
User terminal receiver noise temperature	295 K
Target C/N	-24 dB

Figure 10 below illustrates the simulation results of mutual interference between the Non-Terrestrial Network (NTN) and the Globalstar system where white dots are the satellites of the NTN system.

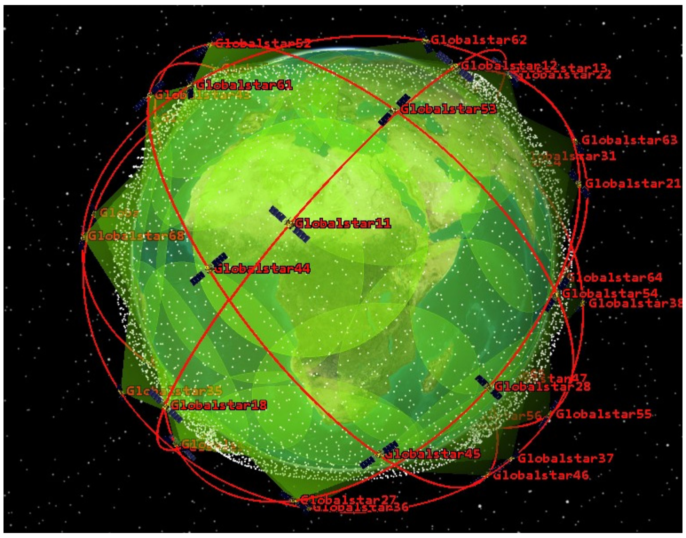
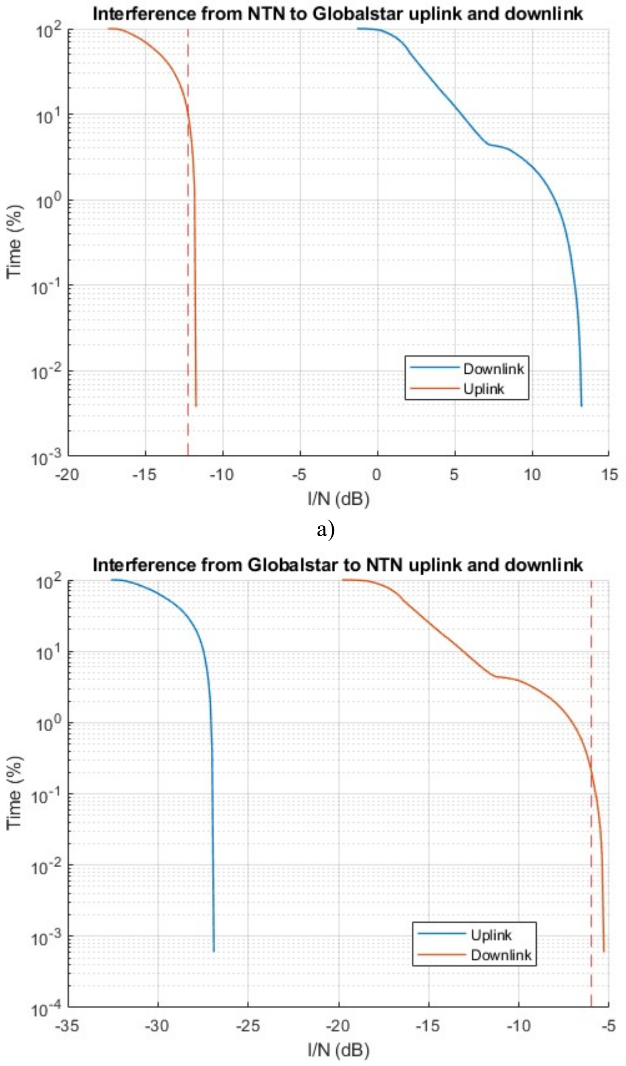


Fig. 10. Mutual interference simulation between NTN and Globalstar

The interference analysis covers the 2483.5-2500 MHz and 1610-1618.725 MHz frequency bands and is visualized in the following figures (Fig. 11).



a)

b)

Fig. 11. Mutual interference between Globalstar and NTN (a) from Globalstar to NTN (b) from NTN to Globalstar

In case of NTN interference to Globalstar, in the uplink scenario, the interference-to-noise (I/N) ratio curve approaches the threshold but remains just below –12.2 dB, indicating borderline acceptability. However, in the downlink scenario, the I/N levels reach significantly positive values – exceeding 20 dB – which implies substantial interference. These levels suggest that NTN transmissions in the 2483.5-2500 MHz band could cause unacceptable interference to Globalstar services.

In case of interference from Globalstar to NTN, for the uplink, I/N levels peak around –27 dB, which is well below the interference threshold and thus considered negligible. In the downlink, peak I/N levels reach approximately –6.5 dB, and only for a very brief duration. Therefore, Globalstar's impact on NTN operations remains within acceptable limits, showing no significant threshold exceedances.

7 Conclusions

This article explored the technical, regulatory, and practical considerations for deploying tri-band NTN payloads operating in 3GPP-defined FR1 bands: n254, n255, and n256. While prior sections detailed spectrum sharing and interference compatibility, it is essential to integrate these insights with other challenges – Doppler shift, propagation losses, device ecosystem, and regulatory constraints – to draw a holistic picture.

From the Doppler shift perspective, n254 and n256 exhibit higher sensitivity due to their S-band downlink frequencies, with peak shifts exceeding ±50 kHz in low LEO orbits, potentially compromising OFDM subcarrier orthogonality unless robust compensation techniques are applied. n255, being in L-band, shows more favorable Doppler behavior, making it more resilient for low-complexity user equipment, especially in D2D and IoT use cases.

In terms of propagation losses, n255 again demonstrates superior performance due to its lower frequencies, which result in lower free-space path loss. Although n256 has slightly better link budget in the downlink compared to n254, both bands suffer more loss than n255 – specially in challenging environments or at lower elevation angles. This favors n255 for both rural and mobile edge deployments.

The interference studies reveal asymmetric interference dynamics among NTN, Iridium, and Globalstar systems. NTN receives significant interference from Iridium and causes substantial interference to Globalstar. Whereas Iridium system appear less affected by NTN in the reverse direction and NTN appear to be negligible affected by Globalstar. In case implementing NTN in the n254 band, the use of shared spectrum between these systems must be carefully regulated, and coexistence strategies—such as beamforming, dynamic scheduling, guard bands, or regulatory coordination – should be considered to ensure mutual compatibility and operational integrity.

When it comes to regulatory challenges, all three bands face incumbent constraints, but the severity varies:

n254 is heavily occupied by Globalstar and Iridium, requiring precise coordination and possibly dynamic spectrum access methods.

n255 faces constraints from Viasat and Ligado, and n256 is similarly shared with Omnispace and others. These legacy uses often limit new players and require complex ITU coordination.

From a device ecosystem viewpoint, commercial support is still sparse, with only a handful of ruggedized or enterprise-class devices supporting n255 and n256. n254 is currently supported only in limited emergency features like Apple's SOS service, pointing to early-stage integration in mainstream consumer devices.

In conclusion, while n255 demonstrates the best overall performance for NTN in terms of Doppler tolerance, propagation, and current chipset support, it is not free of regulatory hurdles. n256 is more favorable than n254 in terms of compatibility but has higher attenuation and limited device support. n254, despite its spectrum size and dual-link potential, faces the greatest regulatory and interference-related challenges and will require novel mitigation strategies.

A strategic blend of these bands in a tri-band SAN payload can unlock performance synergies, provided spectrum coexistence, adaptive waveform design, and intelligent scheduling mechanisms are implemented to ensure resilient and scalable NTN service delivery. Table 5 provides comparison of n254, n255 and n256 bands based on several factors that are important to take into account.

Table 5

Interference scenarios analyzed in this study

Criteria	n254	n255	n256
Doppler Shift Challenge	High (±55 kHz DL @ 340km)	Moderate (±35 kHz)	High (±50 kHz)
Propagation Losses	Highest among the three (esp. DL)	Lowest propagation loss overall	Moderate, ~2.5 dB worse than n255
Spectrum Sharing / Compatibility	Complex	Moderate	Challenging
Regulatory Challenges	Very High – coordination with two global systems is required	Very High – spectrum coordination is required with companies that are part of MoU for L-band	High – requires coordination in several regions
Supported Devices	Very limited (e.g., iPhone SOS only)	Limited but growing (Caterpillar, etc.)	Also limited – only 6 known devices

Abbreviations

The following abbreviations are used in this manuscript:

BEL	Building Entry Loss
CDF	Cumulative distribution function
DL	Downlink
FSPL	Free Space Pathloss
GNSS	Global Navigation Satellite System
ISI	Inter-symbol interference
ITU	International Telecommunication Union
IMT	International Mobile Telecommunication
LEO	Low Earth Orbit
NR	New Radio
NTN	Non-terrestrial networks
MOU	Memorandum of Understanding
MSS	Mobile Satellite Service
OFDMA	Orthogonal Frequency Division Multiple Access
SAN	Satellite Access Node
UE	User equipment
UL	Uplink

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ИСПОЛЬЗОВАНИЯ ТРЕХДИАПАЗОННОЙ ПОЛЕЗНОЙ НАГРУЗКИ В УЗЛЕ СПУТНИКОВОГО ДОСТУПА ДЛЯ БУДУЩЕЙ СЕТИ 5G NTN

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Аннотация

В статье рассматривается использование диапазонов частот 5G (n254, n255, n256) для трехдиапазонной полезной нагрузки в узле спутникового доступа (SAN), разработанном для следующего поколения IoT и неземных сетей D2D (NTN). Проводится сравнительный анализ для изучения ключевых проблем, включая сосуществование спектра с действующими системами, эффекты Доплера и характеристики распространения сигнала для каждого диапазона. Кроме того, в исследовании оцениваются нормативные препятствия, связанные с получением доступа к этим частотам. Для каждого фактора предоставляется экспертная оценка, измеряющая его влияние на предоставление услуг IoT в NTN. Каждому диапазону присваивается общая классификация на основе трехуровневой системы ранжирования: высокий, средний или низкий.

Ключевые слова: *5G NTN, узел спутникового доступа*

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