Verification of Communication Parameters for NTN Communication

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***Abstract*—Non-terrestrial networks (NTNs) are envisioned to extend 5G coverage globally, with Narrowband IoT (NB-IoT) identified as a key technology for massive machine-type communication in remote or underserved areas. Accurate modeling of the satellite channel is crucial to assess reliability and system performance. This paper presents a comparative study of two widely used NTN propagation models: the ETSI Rician fading model and the ITU-R P.681 land mobile-satellite model. Using MATLAB simulations of the NB-IoT NPDSCH link in a LEO 1200 km scenario, we evaluate block error rate (BLER) performance across elevation angles from 0° to 90° with varying numbers of repetitions. Results demonstrate that the ETSI Rician model, while simple and analytically tractable, produces overly optimistic BLER predictions at low elevations. In contrast, the ITU-R P.681 model proved to be more versatile and capable of capturing diverse propagation environments. These findings highlight the importance of model selection for NTN design, particularly in low-elevation and urban scenarios.**

***Index Terms*—NB-IoT, Non-terrestrial networks, Propagation models, Elevation angle, BLER**

I. INTRODUCTION

As the number of devices connected to 5G-enabled IoT (5G-IoT) systems continues to grow, the demand for diverse types of connectivity and ubiquitous coverage also increases. The 5G vision of supporting up to one million connected devices per square kilometer has accelerated research into new deployment paradigms. While terrestrial networks (TN) currently provide sufficient coverage for most use cases, their inherent geographical and infrastructural limitations make them unsuitable for ensuring truly global service availability. This has motivated the integration of non-terrestrial networks (NTN) into the 5G ecosystem.

The first formal discussions on NTN communication appeared in 3GPP Release 14 and were further developed in Release 15, targeting both massive Machine-Type Communications (mMTC) and enhanced Mobile Broadband (eMBB). More detailed specifications for NTN integration emerged in Release 17, which introduced initial standardization efforts for IoT technologies in NTN scenarios. Although the standards are still under evolution, the direction is clear: enabling IoT technologies, in particular Narrowband IoT (NB-IoT) and enhanced Machine-Type Communication (eMTC), to operate reliably over satellite-based NTN [1], [2].

NB-IoT is particularly well-suited for early adoption in NTN, as it is optimized for low-throughput, delay-tolerant applications requiring robust coverage and energy efficiency. However, extending NB-IoT from TN to NTN poses several technical challenges. Key difficulties arise from satellite altitude and propagation conditions, which can necessitate higher transmit power or antenna gains, as well as from Doppler shifts induced by the high relative velocity of low-Earth orbit (LEO) and very-low-Earth orbit (VLEO) satellites. Moreover, unlike fixed terrestrial infrastructure, LEO satellites continuously move relative to the user equipment (UE), leading to varying link conditions and intermittent visibility [3].

Among these challenges, the elevation angle between the satellite and UE plays a critical role in determining link reliability. At low elevation angles, signal attenuation, shadowing, and fading effects are more severe, directly impacting the block error rate (BLER) and overall communication quality. Therefore, accurate modeling of channel conditions is essential for assessing NB-IoT performance in NTN deployments [4], [5].

This paper investigates the impact of elevation angle on NB-IoT performance over NTN by comparing two widely used channel models: the ETSI Rician model and the ITU-R P.681 recommendation. Simulations are carried out in the MATLAB 5G Toolbox under a LEO 1200 km orbital scenario. The contributions of this paper are:

- Analytics of the influence of elevation angle on BLER performance in NTN NB-IoT systems.
- Comparison the applicability of ETSI Rician and ITU-R P.681 models under identical conditions.
- We highlight the strengths and limitations of each model for NTN system design and evaluation.

The remainder of this paper is organized as follows. Section II introduces NB-IoT over NTN and highlights the key differences from TN deployments. Section III describes the simulation setup and scenarios. Section IV presents the results and discussion. Finally, Section V concludes the paper and outlines directions for future work.

II. TERRESTRIAL VS. NON-TERRESTRIAL NB-IOT

The conventional terrestrial network (TN) model is based on fixed base stations (gNodeBs) arranged in a cellular framework, where each cell provides coverage over a predefined geographical area determined by the operator. This architecture enables relatively uniform coverage, scalable deployment in densely populated regions, and the ability to serve hundreds or thousands of devices per cell. In such systems, user equipment (UE) remains connected to a largely static access node, and handover procedures are well established [3].

In contrast, non-terrestrial networks (NTN) that rely on Low Earth Orbit (LEO) or Very Low Earth Orbit (VLEO) satellites cannot be organized in this fixed-cell structure. Satellites must move at high velocity to maintain orbital stability, which results in a constantly changing network topology. Consequently, NTN architectures face the challenge of providing reliable, on-demand connectivity to multiple devices while maintaining seamless integration into the broader 5G ecosystem. From the perspective of radio access network (RAN) design, two primary approaches are recognized for satellite payloads:

- Transparent systems - the received information from the UE is conveyed to the other parts of the network i.e. another node in the orbit on ground-based gateway
- Regenerative systems - the node acts as a simplified gNodeB with on-board data processing implemented to handle local radio protocols before forwading it to other nodes that are part of the system.

Transparent architectures benefit from reduced satellite complexity and cost, while regenerative systems provide greater flexibility and potentially reduced latency by offloading some processing from the ground segment.

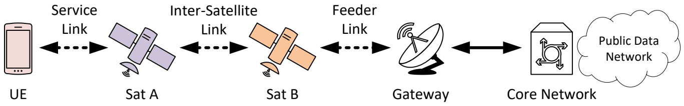

Fig. 1: NTN Communication Chain.

As of 3GPP Release 17, NTN standardization efforts have defined reference scenarios for deployment at different orbital altitudes, including LEO at 600 km, LEO at 1200 km, and Geostationary Orbit (GEO), with an emphasis on the S-band around 2 GHz for initial evaluations. In the baseline architecture, the satellite nodes terminate user-plane connections at ground-based gateways, which then forward traffic to the corresponding data networks. This approach simplifies interoperability with existing terrestrial infrastructure and ensures backward compatibility with conventional TN deployments [6], [7].

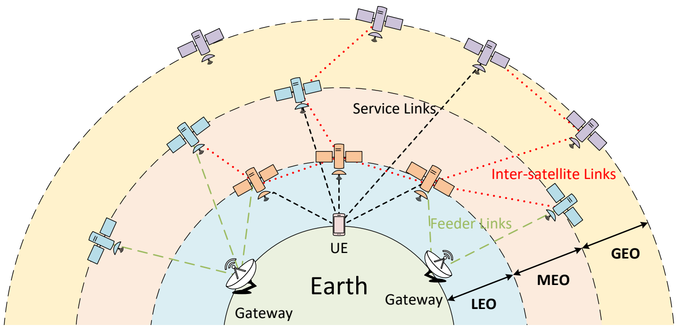

Fig. 2: NTN environment layout.

A. NTN Challenges

As described above, while NTN architectures provide global coverage and complement terrestrial networks, they also introduce several unique challenges that must be addressed to ensure the reliable operation of technologies such as NB-IoT. The most critical issues arise from the fundamental characteristics of satellite communication. High orbital altitudes lead to increased free-space path loss, while the high relative velocity of LEO and VLEO satellites induces significant Doppler shifts that narrowband waveforms must tolerate. Propagation delays are considerably longer than in terrestrial systems, complicating timing and synchronization. In addition, the time-varying elevation angle between the user equipment and the satellite strongly impacts link quality due to fading, shadowing, and changing propagation geometry. Together with the dynamic nature of satellite visibility and mobility management, these aspects highlight the need for careful adaptation of terrestrial technologies to NTN environments [5], [7].

One of the primary challenges in NTN is the Doppler effect caused by the high orbital velocity of LEO and VLEO satellites, which can exceed 7 km/s. This motion induces frequency shifts of several kHz in the received signal, a magnitude significant compared to the narrow subcarrier spacing of NB-IoT. Such shifts can severely degrade demodulation and synchronization if not properly compensated, making Doppler correction and robust frequency tracking essential for reliable communication [4], [7].

Another critical challenge is timing and synchronization, which are directly affected by the long propagation distances in NTN. Round-trip delays can reach several hundred milliseconds, far exceeding those in terrestrial networks. This impacts not only the initial access procedures but also the maintenance of uplink timing advance and downlink synchronization. The extended delay budget further complicates the operation of mechanisms such as Hybrid Automatic Repeat reQuest (HARQ), where retransmission cycles become inefficient or even impractical at satellite latencies. When combined with Doppler-induced frequency offsets, these effects demand enhanced synchronization and error-recovery strategies to ensure stable and reliable NTN operation [4], [7].

Finally, the elevation angle between the user equipment and the satellite is one of the most decisive factors for NTN performance, as it directly influences propagation conditions and, consequently, the block error rate (BLER). At low elevation angles, the signal experiences higher attenuation, stronger shadowing, and more severe fading, particularly in urban environments, all of which increase the likelihood of decoding errors. Since NB-IoT relies on achieving very low BLER to ensure reliability, these conditions can significantly reduce system performance. Moreover, low elevation angles exacerbate the inefficiency of HARQ processes, as retransmissions suffer from both long round-trip delays and increased error probability. Accurate modeling of the elevation angle impact is therefore essential for evaluating NB-IoT over NTN and forms the central focus of this work [4].

B. *NB-IoT over NTN*

In terrestrial systems, NB-IoT benefits from relatively stable channels with modest delay spreads and minimal Doppler effects. HARQ feedback is effective thanks to short round-trip times, and synchronization procedures are straightforward because of low propagation delays. In NTN, however, these assumptions no longer hold. To maintain reliable operation, several modifications and enhancements are considered [4], [8].

The impact of Doppler shifts is mitigated by extending frequency tracking capabilities and employing more robust synchronization signals. NB-IoT's narrowband structure simplifies Doppler estimation, while making the waveform more sensitive to frequency offsets. Long propagation delays necessitate modifications in the HARQ process. In Release 17, alternative schemes such as increased HARQ timing, relaxed retransmission procedures, or the use of repetition-based mechanisms are introduced to compensate for the inefficiency of conventional feedback loops [**?**], [6].

The power control and link budget adaptations are needed to cope with the high path loss of satellite channels. NB-IoT already supports coverage enhancement modes in terrestrial deployments, such as repeated transmissions and low-order modulation, which naturally extend to NTN and help to counter the severe attenuation at large distances [4].

Finally, the strong dependence on elevation angle introduces variability not present in TN. To handle this, system-level techniques such as adaptive repetition, link adaptation, and elevation-aware resource allocation are being introduced to ensure reliable data transmission even under unfavorable conditions [6].

III. NON-TERRESTRIAL PROPAGATION MODELS

Accurate propagation modeling is fundamental to the design and evaluation of any wireless communication system. Propagation models characterize the statistical and deterministic behavior of radio channels, enabling realistic simulation of link performance under varying conditions. In terrestrial networks, widely used models such as Okumura-Hata or COST-231 describe large-scale path loss and fading effects in urban, suburban, and rural environments, where the geometry of the link and propagation conditions are primarily determined by fixed base stations and cluttered ground environments [9].

In non-terrestrial networks, however, the situation is hugely different. The satellite–Earth link is characterized by long free-space paths, satellite movement, and strong dependence on elevation angle. Traditional terrestrial propagation models are therefore not directly applicable. Instead, channel models for NTN must account for line-of-sight conditions, statistical fading distributions, and additional atmospheric effects such as gaseous absorption or rain attenuation. For NB-IoT over NTN, accurate modeling of these aspects is essential to capture the impact on link reliability and block error rate (BLER), especially at low elevation angles where signal degradation is most severe.

This study focuses on two widely recognized propagation models for NTN scenarios: the ETSI Rician channel model and the ITU-R P.681 recommendation. The former represents a simplified, statistically driven approach well suited for system-level simulations, while the latter incorporates detailed empirical factors such as atmospheric losses and elevation-angle dependence. By comparing these two models under identical conditions, this paper highlights their relative strengths and limitations in evaluating NB-IoT performance in NTN deployments.

A. *ETSI Rician Model*

The ETSI Rician channel model is a widely used statistical fading model originally developed for satellite and mobile satellite links. In ETSI TS 101 376-5-5 (part of the GMR / mobile satellite radio interface standards), it is accepted as a valid representation of fast fading in satellite channels, excluding large-scale shadowing. The model describes the case where a dominant line-of-sight (LoS) component coexists with multiple weaker multipath components [10], [11].

In baseband, the received signal can be expressed as

$$r(t) = \sqrt{\frac{K}{K+1}} \cdot s_{\mathrm{LoS}}(t) + \sqrt{\frac{1}{K+1}} \cdot s_{\mathrm{mp}}(t), \tag{1}$$

where K is the Rician K-factor denoting the power ratio between LoS and multipath components, $s_{\mathrm{LoS}}(t)$ is the complex LoS component, and $s_{\mathrm{mp}}(t)$ denotes the multipath (Rayleigh) component. The corresponding envelope amplitude follows the Rician probability density function

$$f_R(r) = \frac{2r(1+K)}{\Omega} \exp\left(-K - \frac{(1+K)r^2}{\Omega}\right) \cdot I_0\left(2r\sqrt{\frac{K(1+K)}{\Omega}}\right), \tag{2}$$

where r is the signal envelope amplitude, Ω is the average signal power, K is the Rician K-factor, and $I_0(\cdot)$ is the modified Bessel function of the first kind and zero order [11].

The strength of the ETSI Rician model lies in its simplicity and analytical tractability. It effectively captures the dominance of the LoS component, which is a reasonable assumption in satellite links, while still including residual multipath effects. The model is also easy to parametrize through the K-factor and can be efficiently implemented in system-level simulation tools, making it well suited for baseline evaluations and initial performance studies [10].

However, when applied to NTN scenarios and NB-IoT specifically, the model shows several limitations. It does not inherently capture elevation-angle dependent attenuation, atmospheric absorption, or rain fading, all of which strongly influence satellite communication. The assumption of a stationary K-factor and a fixed scattering environment may not hold in practice, as satellite geometry, elevation angle, and ground clutter vary dynamically. Furthermore, the model does not explicitly represent shadowing or blockage effects, which are important large-scale fading phenomena, and it may oversimplify propagation at very low elevation angles where non-LoS conditions and diffraction dominate. For these reasons, the ETSI Rician model is often complemented with additional path-loss or shadowing terms when used in realistic NTN simulations.

B. ITU-R P.681

Compared to the single-state ETSI Rician fading model, ITU-R P.681 is a state-based land mobile-satellite (LMS) propagation framework that explicitly accounts for shadowing, blockage, and elevation-angle dependence in addition to multipath fading. It is based on extensive measurement campaigns covering frequencies from 0.8 to 20 GHz and consolidates effects such as tropospheric attenuation, ionospheric variation, and environmental clutter. For narrowband, time-varying LMS channels, the Recommendation specifies semi-Markov state models: earlier editions (e.g., P.681-7) describe a three-state model (good/intermediate/bad), while P.681-11 §6.2 standardizes a two-state (GOOD/BAD) model widely used in receiver performance simulations [9], [12].

Within each channel state, the received envelope is Ricean conditioned on a lognormally distributed LoS component, leading to the so-called Loo distribution. This is expressed as

$$f_{R|A}(r \mid A, \sigma_s^2) = \frac{r}{\sigma_s^2} \exp\left(-\frac{r^2 + A^2}{2\sigma_s^2}\right) I_0\left(\frac{rA}{\sigma_s^2}\right), \qquad (3)$$

where r is the received envelope amplitude, A is the shadowed LoS amplitude in state s, σ_s^2 is the diffuse multipath power, and $I_0(\cdot)$ is the modified Bessel function of the first kind. The overall channel statistics are then obtained by mixing across states with lognormal weighting of the LoS term:

$$f_R(r) = \sum_{s\in \mathrm{G,B}} \pi_s \int_0^\infty f_{R|A}(r \mid A, \sigma_s^2) \cdot \\ \cdot f_A(A; \mu_s^{(\mathrm{LN})}, \sigma_s^{(\mathrm{LN})}) \mathrm{d}A, \qquad (4)$$

where π_s is the probability of being in state s (GOOD or BAD), and $f_A(\cdot)$ is the lognormal pdf of the LoS amplitude with mean $\mu_s^{(\mathrm{LN})}$ and standard deviation $\sigma_s^{(\mathrm{LN})}$.

The model embeds explicit dependence on elevation angle and environment class (urban, suburban, rural) through state probabilities, degree of fading, and parameter tables. It also includes empirical roadside tree-shadowing procedures that yield fade distributions as a function of elevation angle and frequency, highlighting the significant degradation at low angles [12], [13].

The strength of ITU-R P.681 lies in its realism and adaptability: by combining state-based fading with lognormal shadowing and elevation dependence, it captures blockage, partial shadowing, and low-elevation degradation more accurately than single-state models such as ETSI Rician. At the same time, it is considerably more complex to implement, requiring semi-Markov state processes, lognormal fading distributions, and careful parameterization for specific environments. This complexity can limit its use in large-scale NB-IoT simulations, where simplicity and tractability are often necessary. For this reason, P.681 is frequently adopted as a conservative reference model, complementing simpler baselines like ETSI Rician [12], [13].

IV. SIMULATION

This section is structured into two main subsections. The first subsection details the simulation setup, including the channel models and parameterization. The second subsection presents and interprets the simulation results, with selected figures illustrating the most representative outcomes.

A. Simulation Setup

To evaluate the NB-IoT over NTN's we utilized MATLAB 5G/Satellite Communication toolbox heavily modifying the NPDSCH throughput example to suit the requirements for evaluating the performance of the technology. The communication link chain is SISO (Single Input, Single Output) with NPDSCH, NRS and synchronization modeled according to 3GPP NB-IoT specifications.

The goal of the simulation scenario is to provide a detailed overview of the model's behaviour with respect to the changing elevation angle and shed a light into the expected performance in terms of reliability when using both models. The simulation relies on adjusting the respective elevation angle between UE and orbital gNodeB and evaluating the BLER over a 500 transport blocks. The elevation angle is swept from 0° with granular steps of 1° for angles 0°-20° and a step of 10° for angles 20-90°. The simulation is performed for two propagation models:

- ETSI Rician, parameterized by a fixed K-factor of 10 dB to represent a dominant LoS with residual multipath.
- ITU-R P.681 - exercised across all provided environment modes (Urban, Suburban, Rural-Wooded, Residential) with azimuth orientation equal to 0°.

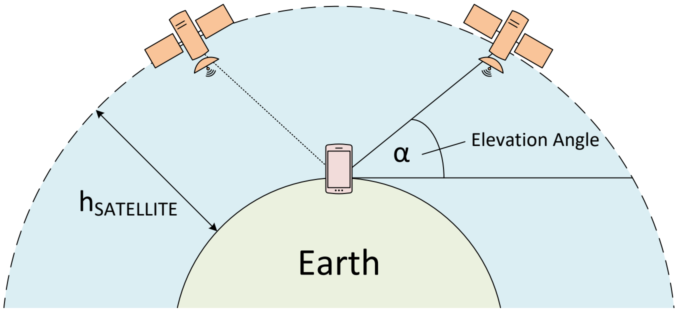

Fig. 3: Visualization of simulation scenario.

For the simulation, TBS size was selected 408 bits as well as the standalone mode of operation is considered.

Full simulation parameters are depicted in Table I.

B. Simulation

As described earlier, the elevation angle was swept from 0° to 90°, with a fine granularity of 1° between 0° and 20° and coarser steps of 10° for higher angles. This procedure

TABLE I: Simulation parameters for NB-IoT over NTN

Parameter	**Value**
Carrier frequency	2 GHz (S-band)
Satellite altitude	1200 km (LEO)
UE speed	0 km/h
Operation mode	Standalone
Link configuration	SISO
Transmit power	44 dBm
Noise figure	6 dB
Antenna temperature	290 K
Transport blocks	500 per run
TBS	408 bits
Free-space path loss	Included (slant range)
Doppler compensation	TX on (pre-comp.), RX off
Channel model (1)	ETSI Rician, K = 10 dB
Channel model (2)	ITU-R P.681 (Urban, Suburban, Rural-Wooded, Residential)
Elevation angle sweep	10°–90° (step 10°)
Repetitions = 1, 2, 4, 8, 16, 32, 64, 128	
Mobile altitude	0 m above sea level

was applied to both channel models while varying the number of repetitions from 1 to 128. Although using 128 repetitions is not practical in real deployments due to increased energy consumption and reduced spectral efficiency, this configuration was nevertheless included to explore the theoretical limits of NB-IoT operation in extreme scenarios such as emergency messaging, where reliability outweighs efficiency.

Given the large volume of results, only selected plots are presented here, chosen to illustrate the most representative differences between the models and environmental conditions. Additional results are referenced but omitted for brevity.

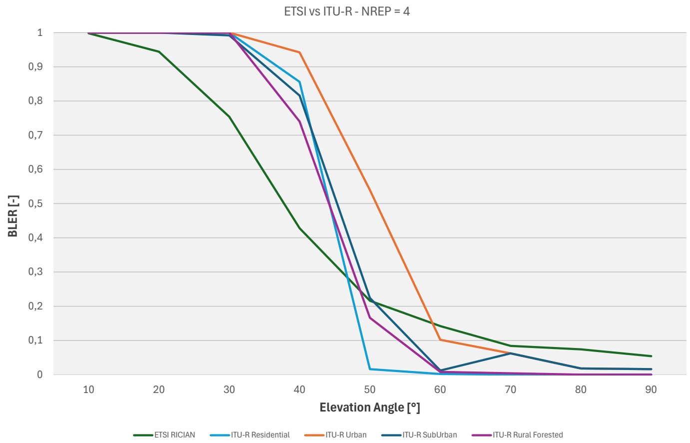

Fig. 4: ETSI Rician vs ITU-R submodels for 4 repetitions.

Fig 4 shows the case of four repetitions. A clear difference is observed between the ETSI Rician and ITU-R models in terms of BLER as a function of elevation angle. The ETSI Rician curve begins to exhibit reduced reliability at lower elevation angles, while ITU-R models remain at full outage (BLER = 1) until approximately 20°. For example, at 20° elevation the ETSI Rician model predicts a BLER of 0.944, whereas all ITU-R variants indicate complete data loss. This discrepancy arises from the simplified nature of the ETSI model, which does not capture fading and shadowing effects that dominate in realistic NTN conditions. Consequently, ETSI produces a smoother, more gradual error-rate curve, whereas ITU-R models incorporate shadowing and blockage, resulting in sharper transitions—particularly between 40° and 50° elevation, where the probability of LoS rapidly increases and link quality improves

A similar trend is observed in Fig. 5, which depicts results for 16 repetitions. The higher repetition count improves overall reliability, narrowing the gap between the two models in rural conditions. Nonetheless, the ETSI Rician model remains more optimistic, while ITU-R Urban and Suburban scenarios still maintain high BLER values up to approximately 20° elevation. This reflects the inclusion of environmental obstructions, such as buildings, that delay the onset of LoS dominance in the ITU-R framework.

The same statement mentioned above holds true for 16 repetitions, depicted on the plot 5, where due to the increased repetitions - therefore increased probability of success - both models are close to each other in their predictions for rural areas while the ETSI model is more optimistic as in the previous case. However, the ITU-R Urban and SubUrban models maintain high BLER to approximately 20° as the environmental model considers a LoS infringments caused by buildings and other environmental objects.

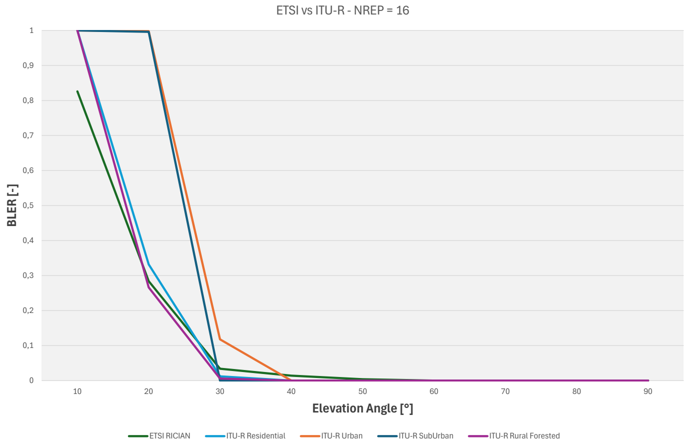

Fig. 5: ETSI Rician vs ITU-R submodels for 16 repetitions.

To further investigate low-elevation performance, the ITU-R Urban model with 128 repetitions was selected as a worst-case scenario for NTN reliability. While impractical for continuous operation, this setting provides valuable insight into emergency communications, where message delivery must be guaranteed despite adverse conditions and limited satellite visibility. The dataset is depicted in Fig. 6 compared with performance of lower repetitions settings of 32 and 64. The results highlight both the resilience and the inherent limitations of NB-IoT in NTN environments under highly challenging link conditions.

As shown in Fig. 6, the ITU-R Urban model indicates that with 128 repetitions, the system remains usable for NB-IoT transmission down to elevation angles of approximately 9°, where the BLER reaches about 10%, which aligns with the 3GPP's target for acceptable performance. For for ex-

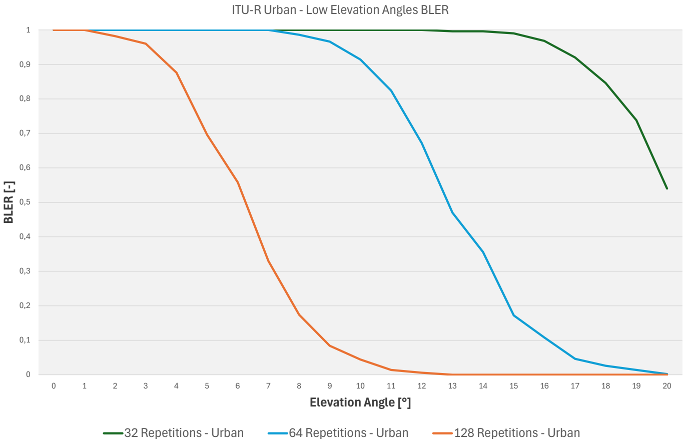

Fig. 6: Low elevation angles BLER for ITU-R Urban.

ample emergency-oriented scenarios, communication can be sustained even at elevation angles as low as 7°, although with a higher BLER of around 0.33 when using 128 repetitions. While such performance is not suitable for general-purpose operation, it still enables the transmission of critical messages under severely degraded link conditions.

It should be emphasized, however, that achieving these reliability levels at low elevation angles comes at a significant cost. The use of 128 repetitions considerably increases the transmission latency and system load, impacting both the UE and the gNodeB. For battery-powered NB-IoT devices, this results in substantially higher energy consumption, potentially reducing device lifetime in practical deployments. Likewise, on the network side, frequent reliance on high-repetition modes would reduce spectral efficiency and overall system capacity. Consequently, while these results demonstrate the theoretical feasibility of low-elevation NB-IoT over NTN links for emergency communications, such operation would remain highly constrained in real deployments and should be regarded as a fall-back rather than a primary mode of operation.

V. CONCLUSION

This work has presented a comparative study of NB-IoT performance over NTN channels using two standardized propagation models: ETSI Rician and ITU-R P.681. By sweeping elevation angles from 0° to 90° and testing multiple repetitions, the simulations highlighted the crucial role of elevation angle and channel modeling assumptions on BLER performance.

It should be noted that these results are based on simulations only and were not validated against a real-world deployment and measurements. The following statements are based on each models approach for modeling the environment and general observation and the results should be validated against a real-world scenario.

The simulation results demonstrate that the ETSI Rician model, while analytically simple, in theory, tends to underestimate the impact of fading and shadowing, thereby yielding overly optimistic reliability predictions at low elevation angles in the simulation environment. In contrast, the ITU-R P.681 framework, through its state-based modeling and explicit integration of environmental effects, seems to provide a more conservative but apparently realistic estimate of performance, particularly in challenging conditions such as urban environments, due to the environmental effects, such as shadowing and fading, consideration.

For practical NB-IoT over NTN deployments, this study showcases that repetition mechanisms are critical in mitigating reliability losses at low elevation angles, with ITU-R models capturing the sharp improvement in link quality once line-of-sight conditions dominate. While high repetition values are not sustainable for everyday communication due to energy and capacity constraints, they remain, according to the simulation results, a viable strategy for emergency transmissions in adverse conditions.

Overall, the comparison highlights the importance of selecting appropriate propagation models for NTN system design and evaluation, with ITU-R P.681 apparently offering a more robust basis for reliability assessment, while ETSI Rician yielding useful results to estimate for the baseline and analytical benchmarking. Based on the results the recommendation is to utilize the ITU.R P.681 model for simulating and evaluating performance of NTN applications.

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