In: 2025 Integrated Communications, Navigation and Surveillance Conference (ICNS), 8-10 April 2025, Brussels, Belgium
DOI:10.1109/icns65417.2025.10976797

Robust Aeronautical Communications Enabled by UAV Operations and LEO Satellites

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***Abstract*—In the realm of modern aerospace communications, the integration of Unmanned Aerial Vehicles (UAVs) with Low Earth Orbit (LEO) satellite constellations can offer a transformative solution for enabling Beyond Visual Line of Sight (BVLOS) operations. Due to initial safety operation demand of UAV BVLOS communication new metrics, this paper proposes a new quality of service (QoS) framework for uplink communication between IRIDIUM satellite constellation and UAV. The objective is to benchmark key QoS metrics for UAV-LEO communications using a Non-Terrestrial Network (NTN) narrowband (NB) channel. However, this study performs metrics such as latency and throughput across various elevation angles and environments. Different sample rates are evaluated to assess their impact on communication performance. Simulation analysis indicate that lower sample rates provide reduced latency and stable throughput suitable for telemetry, while higher sample rates increase throughput at the cost of higher latency. This study can be a road map for QoS metrics for optimizing satellite communication systems in UAV operations and demonstrates optimal communication for BVLOS missions in rural, suburban and underserved areas where ground infrastructure is limited. The findings are compared against current standards and regulatory benchmarks for validation.**

***Index Terms*—Future Communication, NTN, UAV, QoS, LEO satellites, SatCom.**

I. Introduction

Unmanned Aerial Vehicles (UAVs) are rapidly emerging as transformative solution for on-demand air transport, utilized for a wide range of applications, including wildfire and smoke detection [1], in both urban and rural areas, supported by advanced infrastructure and real-time communication systems [2], [3]. However, achieving widespread adoption depends on overcoming significant challenges, especially the integration of reliable communication technologies such as data transfer in the realm of future communication missions.

Third Generation Partnership Project (3GPP) future communication is promised to ensure high data rates, low latency, and ability to connect a vast number of devices [4] meaning it can support UAV operations. However, challenges arise in regions with limited or no ground-based infrastructure, such as rural or remote areas. To address these gaps, this study proposed to benchmark the integration of Low Earth Orbit (LEO) satellite constellations with future communication capabilities that can offer a promising solution to support beyond visual line of sight (BVLOS) missions. One of the main advantages of LEO satellites is the reduced altitude compared to Medium Earth Orbit (MEO) or Geostationary Earth Orbit (GEO) satellites. Lower altitude can sustain faster data transmission and lower latency, that could influence the communication in dynamic and real-time mission operations. Although LEO satellites could bring significant improvements in telecommunication, challenges like handovers arise due to high velocity of satellites, terrain elevation, and line of sight (LOS) obstacles. Once the link has been established between the UAV and the LEO satellite, further study must be done to assess the reliability of the link. An inconsistent communication link can hinder the success of the mission, cause damages to UAV and surroundings, or even fatalities.

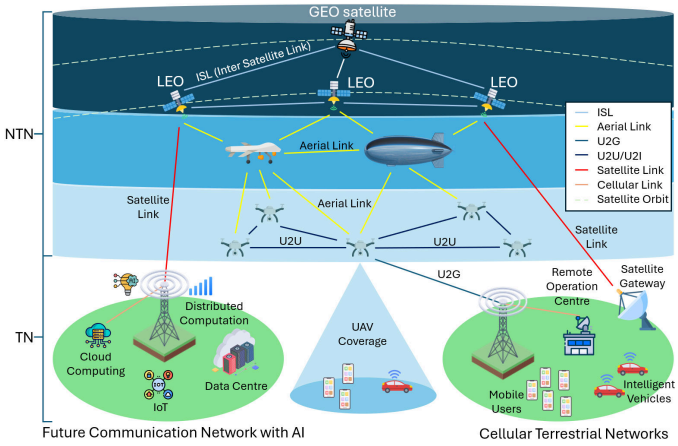

Fig. 1. Future Communication Capability and Structure

To overcome the above mentioned problems, this study proposes new framework including Quality of Service (QoS) metrics like throughput and latency that are utilized to assess communication link performance. In 5G-enabled UAV communications, 3GPP introduced 5G QoS identifiers (5QI) to define specific behaviors for different data flows, [5] aligning with the standard 5G system communication requirements. Several studies have analyzed QoS metrics to optimize UAV operations. The air to ground communication between UAV and base station has been addressed before in [6] where link budget analysis for different altitudes was presented. Moreover, a QoS-Prior algorithm [7] was developed to deploy UAV-mounted mobile base stations (UAV-MBS) for ground users (GUs) with diverse QoS needs. Others have explored

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the infrastructure necessity in UAV usage [8], performance and challenge analysis on ground wireless communication [9], [10], and explored different 5G use cases applications such as QoS in Internet of Things (IoT) systems [11], dense network management frameworks [12] and securing communication links in 5G and above [13]. Other studies [14], [15] have explored the realm of LTE UAV communication with focusing on uplink video and air to ground (A2G) links to assess multiple solutions to this evolving mobility trend. In addition, the rapid expansion and the race to conquer 6G technology steers the focus from 5G, which is not fully implemented in all areas of communication. Future communication capabilities could include the incorporation of IoT and intelligent vehicles control through dense heterogeneous terrestrial/non-terrestrial networks as represented in Figure 1. Using a more forward thinking approach, autonomous self-optimization scheme for pilot power in femtocell networks aimed at optimizing coverage and reducing power consumption in future mobile communication systems with showing direct impact in network capacity and energy efficiency [16]. Dense and automated airspace is one of the core next steps in UAV missions and studies such as [17] help shape the future inter communication through leveraging vehicle-to-vehicle (V2V) capabilities. Alongside those, [18]–[20] have proposed and explored possible 6G communication concepts and frameworks that can represent a baseline of future communications through seamless connectivity in a multi-layered network consisting of terrestrial, aerial, and satellite components. UAVs transition between terrestrial base stations and LEO satellites using handover algorithms for decision-making process by evaluating key parameters such as RSS, SNR, and elevation angle.

Most of the existing studies primarily focus on terrestrial networks whereas only a few focus on Non-Terrestrial Networks (NTN) UAV communication over 5G and beyond [21], [22]. There is a lack of research exploring QoS benchmarks for satellite-based communication, particularly in relation to different elevation angles between UAVs and LEO satellites with future communication technologies. This gap becomes particularly critical when considering NTN narrowband (NB) channels, where satellite elevation can significantly impact signal quality, latency, and throughput.

The main contribution fo this paper it to present novel framework of QoS metrics of uplink communication link between a UAV and LEO satellite specifically IRIDIUM constellation. IRIDIUM is a satellite constellation that ensures world coverage using 66 satellites across 11 orbits at altitudes approximately 780 km from Earth's surface. Due to the low altitude in comparison with other satellite constellation, IRIDIUM is expected to ensure beyond 5G communication requirements. With low altitude comes high satellite velocity according to Kepler's second law which can influence the amount of horizontal handovers to maintain continuous communication, but handover consideration is beyond the scope of this research. By exploring a NTN narrowband channel model, this research evaluates latency and throughput, part of QoS metrics list across different elevation angles. The primary aim is to assess the impact of these parameters on communication performance under varying conditions and establish a benchmark for future satellite communication (SatCom) enabled UAV flights. This study includes Doppler effect and environmental factors that impact the communication. By determining latency and throughput evolution across different elevation angles, novel standards and regulations can be produced to support future telecommunication systems for UAV-enabled missions across the world.

To ensure a comprehensive understanding, this research is organized as follows: Section II outlines the system design and communication architecture for UAV-LEO integration using an NTN channel and briefly present the mathematical model used. Section III presents the proposed logic and analyzes the results, benchmarking them against current standards. Finally, Section IV concludes with key findings and discusses directions for future work.

II. System Design and Methods

This section will highlight the proposed system and key techniques and parameters used in the simulation.

The overall data communication pathway between UAV and remote operator via LEO satellite system is over viewed as an end-to-end communications. The system's diagram is illustrated in Figure 2. The data transmission process begins with the UAV establishing an uplink connection to the LEO satellite. The elevation angle between the UAV and the satellite can influence the quality of the communication link. Once the data is transmitted to the satellite, it is relayed back to Earth via downlink to satellite gateway which can be located anywhere on the surface of the planet, in field of view (FOV) of the satellite. In other systems, inter-satellite communication links are used to relay information between satellites when the gateway is outside the FOV. However, for the purposes of this research, only single satellite is considered, as the UAV relies on one satellite for telemetry transmission. This is in contrast to Global Navigation Satellite Systems (GNSS), which require connections to three or more satellites simultaneously to transmit corrections for position, navigation, and timing (PNT). At the gateway, the signal is forwarded through a 5G narrowband (NB) connection to the ground control station (GCS) where the remote operator manages the UAV's operations. This end-to-end communication, illustrated in enables real-time data exchange supporting the UAV to be controlled remotely. For the purposes of this study, the focus was exclusively on the uplink, also known as service link, between the UAV and one LEO satellite.

Onboard the UAV, data (e.g. telemetry data) is processed and prepared for transmission by the communication system, as presented in Figure 3. The data is modulated and sent through signal processing components before being sent via the UAV's transmitter (T_x^{UAV}) antenna. The T_x^{UAV} sends the signal through a service link to space. On the satellite side, the signal is received by the R_x^{sat} then processed, amplified, and forwarded through the satellite's internal systems to a frequency transponder. Sometimes the satellite is equiped with

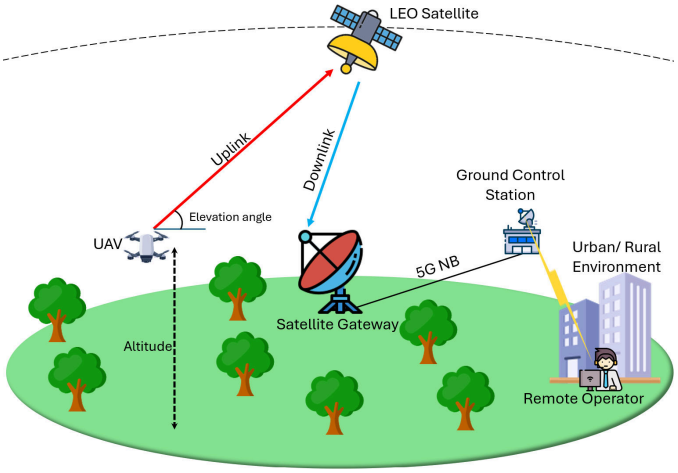

Fig. 2. End-to-End Communication in UAV mission via SatCom

a transponder, but the onboard components remain the same. The satellite transponder T_x^{sat} then relays the processed signal to an NTN Gateway on the ground through downlink, also known as feeder link.

In UAV-satellite communication, various protocols and technologies can be utilized to optimize data transmission. For instance, the 5G network delivers real-time telemetry and high-definition data streaming while protocols such as MAVLink and UranusLink are commonly employed for encrypted communication between UAVs and base stations using exclusively terrestrial networks. However, for UAV-to-satellite communication, Transmission Control Protoco (TCP) is considered the optimal choice due to its connection-oriented nature, which ensures data delivery over long distances and provides greater security compared to User Datagram Protocol (UDP).

The communication system between UAV and LEO satellite is established using a Land Mobile-Satellite (LMS) NTN NB channel. This channel is modeled to simulate the real-world conditions of a satellite communication link in rural environments. The LMS channel characterized by parameters in Table I represent a frequency-flat fading environment where signal fluctuations occur due to movement and distance that affect the transmitted signal. The frequency used is 2.6 GHz part fo the S-band spectrum range for communications.

TABLE I
LMS CHANNEL CHARACTERISTICS

Parameter	Value	Unit
Carrier Frequency	2.6×10^9	Hz
Satellite Altitude	781×10^3	m
Mobile Altitude	110	m
Mobile Speed	11.11	m/s
Random Stream Generator	Mersenne Twister (with seed)	N/A
Sinusoids in fading	48	N/A
Elevation Angles	0:90	degrees

The propagation environments considered are defined by [23] and for this research, only *RuralWooded* and *Suburban*

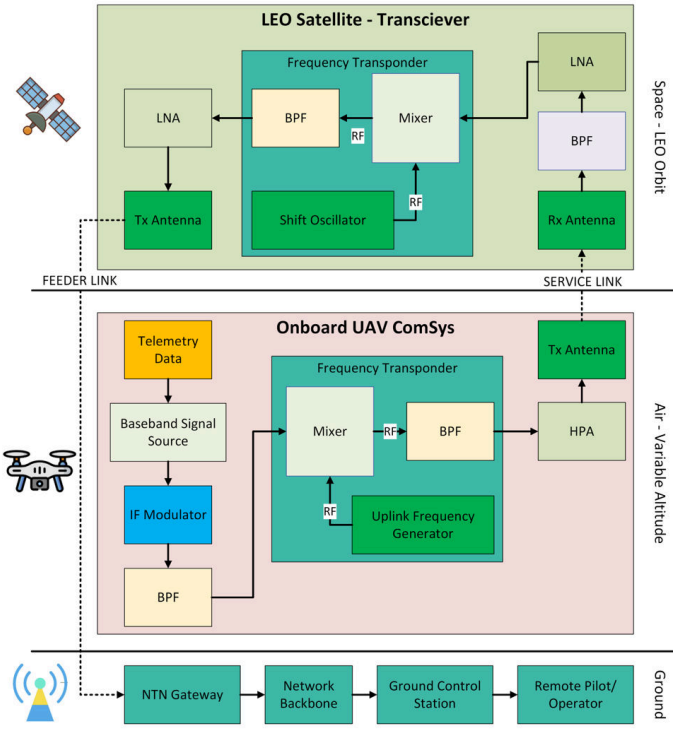

Fig. 3. UAV to LEO Satellite Communication Architecture

scenarios are used to assess the communication performance. These scenarios are specific for S-band and Ka-band only according to [23]. Describing this scenario, includes the LOS probability depending on environment and elevation angle between the UAV and satellite as presented in Table II.

TABLE II
LOS PROBABILITY [23]

Elevation	Dense Urban Scenario	Urban Scenario	Suburban and Rural Scenarios
10°	28.20%	24.60%	78.20%
20°	33.10%	38.60%	86.90%
30°	39.80%	49.30%	91.90%
40°	46.80%	61.30%	92.90%
50°	53.70%	72.60%	93.50%
60°	61.20%	80.50%	94.00%
70°	73.80%	91.90%	94.90%
80°	82.00%	96.80%	95.20%
90°	98.10%	99.20%	99.80%

A. UAV-Satellite Distance

The communication link assessment is strongly influenced by elevation angle. A relationship between elevation angle θ and distance, denoted D, comes from basic geometry. Although the information travels at the speed of light c, other factors such as atmospheric attenuation, atmospheric absorption, terrain elevation, and obstacles which can hinder the communication performance over time. Distance between

the UAV and satellite is also knowns as slant range is shown in Figure 4.

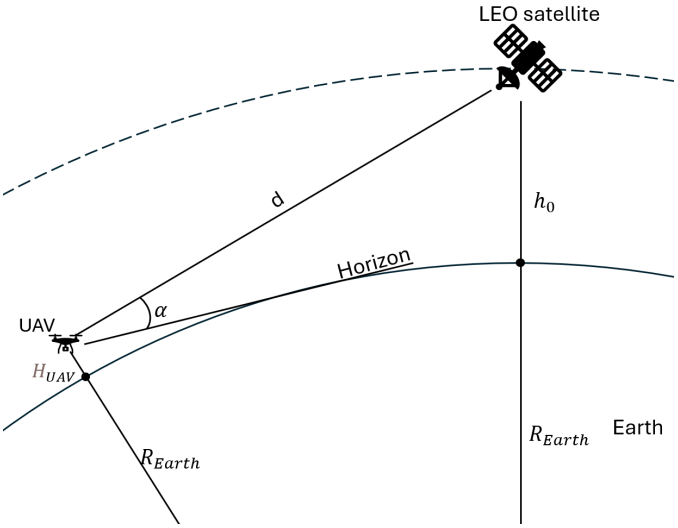

Fig. 4. UAV-Satellite Distance

To calculate UAV-Satellite distance, first construct the distance (radius) of the satellite and the UAV relative to Earth center as follows:

$$\begin{aligned} R_{sat} &= R_{Earth} + h_0 \\ R_{UAV} &= R_{Earth} + H_{UAV} \end{aligned} \tag{1}$$

where R_{Earth} is 6371 km and H_{sat} and H_{UAV} are from Table I. Therefore, the distance between the satellite and the UAV is calculated using the law of cosine as follows:

$$d = \sqrt{R_{UAV}^2 \sin^2 \alpha + h_0^2 + 2h_0 R_{UAV}} - R_{UAV} \sin \alpha \tag{2}$$

B. Doppler Effect

Due to high relative velocity between UAV and satellites, Doppler shift f_d occurs [24]. For the satellite in circular orbit, this effect is calculated using the following formula:

$$f_d = \frac{V_{rel} \cdot f_c}{c} \tag{3}$$

The relative velocity between the UAV and the satellite, V_{rel} is given by:

$$V_{rel} = \sqrt{\frac{G \cdot M}{R_{sat}}} - V_{UAV} \cdot \cos(\theta) \tag{4}$$

where θ is the elevation angle and V_{UAV} is the UAV speed. This angle ranges from $[0, 90]^\circ$ and is inversely proportional to distance. The satellites sit at its furthest possible distance at θ minimum, and the closest at 90° also known as zenith.

Once V_{rel} is known, the frequency shift, $f_{received}$ can be calculated by subtracting the Doppler shift if the UAV is moving away from the satellite or adding when UAV is approaching.

C. Sample Rate

The sample rate (SR) determines how finely the signal is captured and processed during transmission between the UAV and the satellite. The SR must be chosen such that the total Doppler shift (which includes both the UAV's maximum Doppler shift and the satellite's absolute Doppler shift) remains below one-tenth of the SR. This requirement ensures aliasing does not distort the signal components within the frequency-flat fading channel. If the Doppler shift approaches or exceeds this limit relative to the SR, aliasing can introduce distortions that compromise the accuracy of the simulation results.

In this performance analysis, MATLAB sets the minimum allowable SR to 577.8 kHz. This choice corresponds to an upper limit for the combined Doppler shift of 57.78 kHz calculated using Equation 3. As the minimum allowable SR is known, this study covers 3 different SR to help benchmark and formulate a conclusion. The second SR is set to $1.5 \times SR$ and the third is set to $3 \times SR$. Usually in communication, higher SR means that the signal is sampled more frequently within a given time period. This results in a more accurate representation of the original analog signal because more data points are captured.

The scenarios are structured in Table III along with different SR.

TABLE III
SCENARIOS AND CORRESPONDING PROPAGATION ENVIRONMENTS WITH SAMPLE RATES

Scenario ID	Propagation Environment	Sample Rate (Hz)
SC1	RuralWooded	57.78×10^4
SC2	RuralWooded	86.67×10^4
SC3	RuralWooded	173.34×10^4
SC4	Suburban	57.78×10^4
SC5	Suburban	86.67×10^4
SC6	Suburban	173.34×10^4

D. Pseudorandom Number Generator

Pseudorandom Number Generator (PRNG) is used to simulate the random variations in the transmitted signal. It allows for generating different random conditions across multiple iterations, that can assess the system's performance in unpredictable real-world scenarios. By using a PRNG with a seed, the randomness is controlled and reproducible, enabling consistent results for validation, debugging, and comparison.

The research implemented a Mersenne Twister algorithm with a period length of $2^{19937} - 1$. This algorithm generates a sequence of pseudorandom numbers x_n that are uniformly distributed over the output space, which mimic real-world random processes like channel fading and noise. For each simulation, a random seed S is chosen and the recurrence relation for number calculation is:

$$x_{k+n} = x_{k+m} \oplus \left(\left(x_k^u \mid x_{k+1}^l \right) A \right) \tag{5}$$

where x_k^u and x_{k+1}^l are the upper and lower portion of x_k, and A is the transformation matrix. The numbers generated by this algorithm construct the signal's random variations to realistically simulate data transmission.

E. Quality of Service Parameters

Latency (τ_p) refers to the time delay experienced in the transmission of data from source (UAV) to destination (satellite), also called the propagation delay. This delay is expressed as the distance (d) over speed of light (c). The results are enhanced by adding the processing delay (p_d), which is defined as the time it takes to process the signal at both the UAV transmitter and the satellite receiver. Then the total latency is expressed as:

$$\tau = \tau_p + p_d \tag{6}$$

The calculation of p_d is performed by keeping track of the time when the signal is received and the time when it is processed. Specifically, p_d is the difference between the received time and the end of the processing time.

Throughput (T) refers to the rate at which data is successfully transmitted. The data transfer rate was measured and displayed in megabits per second (Mbps). Modulation is done using quadrature phase shift keying (QPSK) for signal transmission where each symbol encodes two bits. In the proposed system, the prioritization is on spectral efficiency since bandwidth is limited in SatCom. QPSK modulation scheme can be mathematically described as:

$$s(t) = A\cos(2\pi f_c t + \phi) \tag{7}$$

where A is the amplitude of the signal and ϕ is the phase shift. Therefore, T is described by:

$$T = \frac{2N_{\text{samples}}}{\frac{N_{\text{samples}}}{SR} + \tau} \tag{8}$$

III. Performance Analysis

This section provides an in-depth analysis of the UAV-to-satellite communication system's performance, focusing QoS metrics. The analysis evaluates the impact of varying elevation angles, sample rates, and environmental conditions on the communication link. A simulation framework is developed to model the interaction between UAV and LEO satellite, incorporating effects such as Doppler shift, pseudorandom signal variations, and narrowband channel configurations. The simulation iteratively assesses the system performance under different scenarios, ensuring statistical reliability through multiple iterations at each elevation angle.

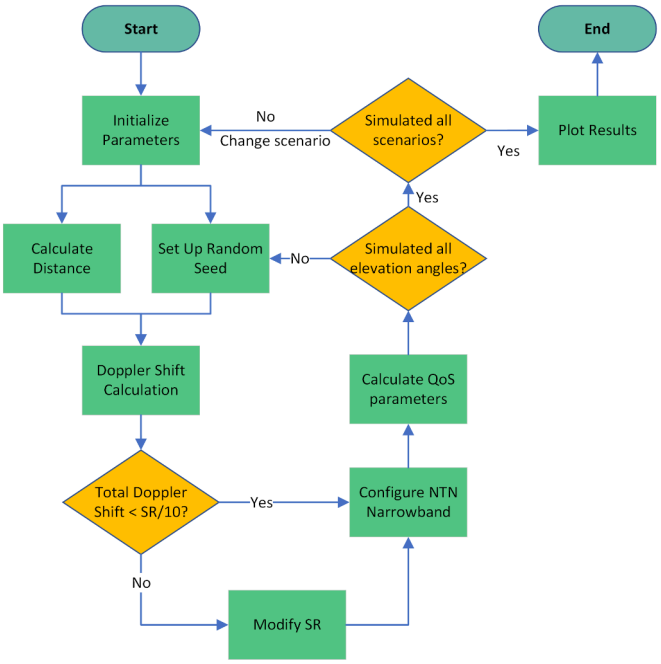

Fig. 5. UAV to LEO Satellite communication architecture for QoS metrics

The simulation process, shown in Figure 5, first initializes all relevant system parameters for the UAV-to-satellite communication link. This includes defining satellite parameters such as orbit altitude, velocity, and carrier frequency, as well as UAV parameters such as flight altitude and intended range of elevation angles. Communication parameters are likewise specified: these include the baseline sampling rate, the channel bandwidth, the number of iterations for each scenario, and the policy for the pseudo-random number generator (PRNG) used in the randomization process. By setting these parameters up front, the simulation ensures consistency when comparing different elevation angles and sample rates. Once the initialization is complete, the algorithm transitions into its main loop, where the elevation angle is varied from 0° to 90° in increments of 1°. For a given elevation angle, the distance between the UAV and the LEO satellite is computed based on geometric considerations, and the corresponding Doppler shift is calculated by taking into account the relative velocity between the UAV and the satellite. If the total Doppler shift remains below one-tenth of the current sampling rate, the algorithm proceeds to configure the narrowband NTN channel and then performs 100 simulation runs with different random seeds. The simulation workflow can be seen in pseudo code form in Algorithm 1, outlining the structured process for evaluating QoS metrics. Random seeds feed into the PRNG, introducing variability in the simulated signals and channel conditions. For each of these runs, latency τ and throughput T are computed, and the results are stored for averaging. If the Doppler shift constraint is not satisfied, the sampling rate is adjusted accordingly, and the simulation attempts the scenario again until the threshold is met. Upon completing

Algorithm 1 QoS Metric Performance

Require: Scenarios, θ, Satellite Parameters, UAV Parameters, SR

Ensure: Mean τ and Mean T

```
Initialize Parameters;
while all scenarios are not simulated do
    while all elevation angles are not simulated do
        Calculate d;
        Set S;
        Compute f_d;
        if f_d < SR/10 then
            Configure NTN NB channel;
            Generate random input signal using PRNG;
            Process signal;
            Calculate τ;
            Calculate T;
        else
            Change SR;
        end if
    end while
    Change scenario;
end while
Plot QoS Results;
```

all 100 runs for each elevation angle and sample rate combination, the algorithm advances to the next elevation angle, continuing until every angle in the specified range has been processed. Afterward, the next scenario commences, which may involve using the updated sample rate or other parameter changes. Once all scenarios have been exhausted, latency and throughput values are visualized and analyzed to understand how different elevation angles, sample rates, and Doppler conditions affect the UAV-to-LEO satellite communication performance. This end-to-end workflow ensures a thorough exploration of both the system parameters and the stochastic nature of the communication channel.

IV. Simulation and Results

This section presents the simulation results and analysis of latency and throughput performance across rural and suburban scenarios under varying sampling rates (SRs). QoS metrics are evaluated to understand their behavior under different communication conditions and environments. Comparisons are made against established benchmarks and standards to validate the findings. The analysis highlights the trade-offs between latency and throughput, emphasizing the importance of balancing these metrics for optimal UAV communication performance in NTNs.

Figure 6 presents latency comparisons for rural and suburban scenarios across different SRs: 577.8 kHz, 866.7 kHz, and 1733.4 kHz, plotted against elevation angles. The mean latency values for rural and suburban scenarios are displayed as horizontal lines for each subplot. Figure 6 a. compares SC1 and SC4 at an SR of 577.8 kHz, the rural mean latency is approximately 0.070 s, while the suburban mean latency is slightly lower at around 0.065 s. The plot shows notable spikes in latency, likely due to the influence of the PRNG used in the simulation. The rural scenario consistently exhibits higher latency than the suburban scenario at this SR, although both demonstrate fluctuations that align with changing elevation angles. The descending trend is also present in Figures 6 b., c. where comparison between SC2 (rural) with SC5 (suburban) at an SR of 866.7 kHz output that the mean value for the latency in rural is 0.13 seconds. The findings show that suburban scenarios generally yield lower mean latencies and fewer spikes, suggesting more stable and favorable communication conditions compared to rural scenarios.

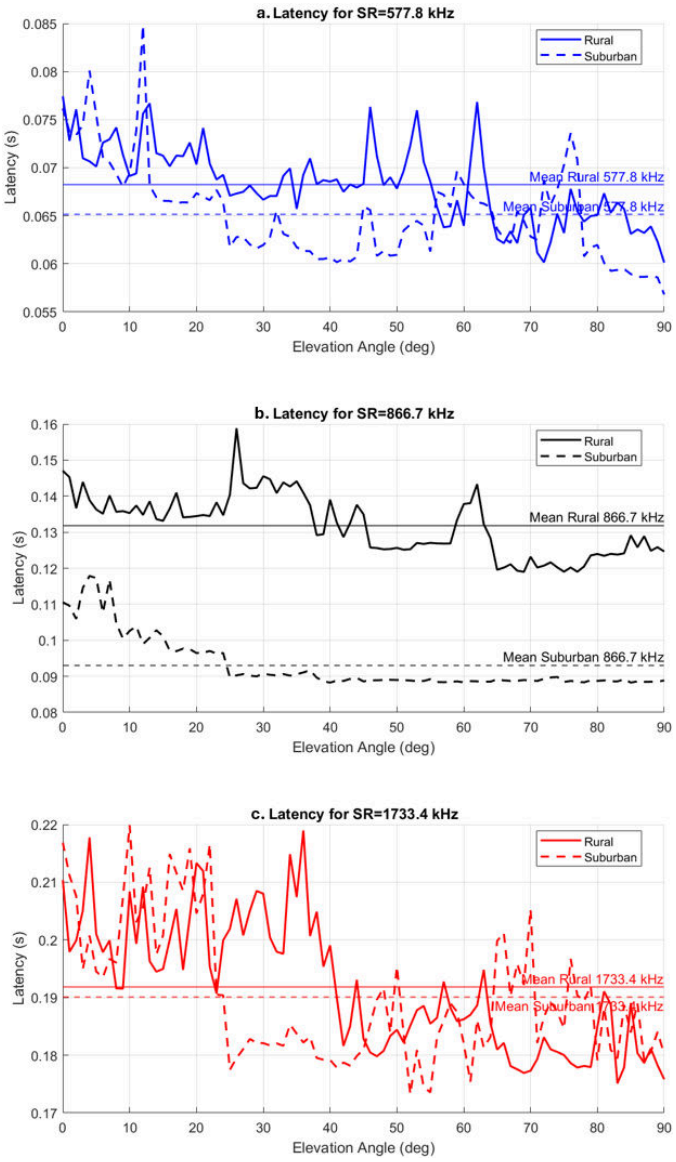

Fig. 6. Latency Comparison across all three SR

In throughput analysis the results in Figure 7 indicate that higher rates are favorable for high data transfer needs but can be less stable, posing challenges for consistent communication. In contrast, lower sampling rates like 577.8 kHz offer more

stable and predictable performance with reduced throughput, which may be beneficial when maintaining a steady link is prioritized over data speed. The same principle stands for the fluctuations in these scenarios, as before. Explicitly, in Figure 7 a. results show that both scenarios are stable but suburban conditions yield slightly higher and more consistent throughput than rural. At 866.7 kHz in Figure 7 b., suburban throughput remains higher and steadier, while rural values show more variability. In Figure 7 c., at 1733.4 kHz, both scenarios achieve significantly greater throughput, but suburban results again appear more stable, showing fewer dips. In general, increasing the sample rate improves throughput for both scenarios.

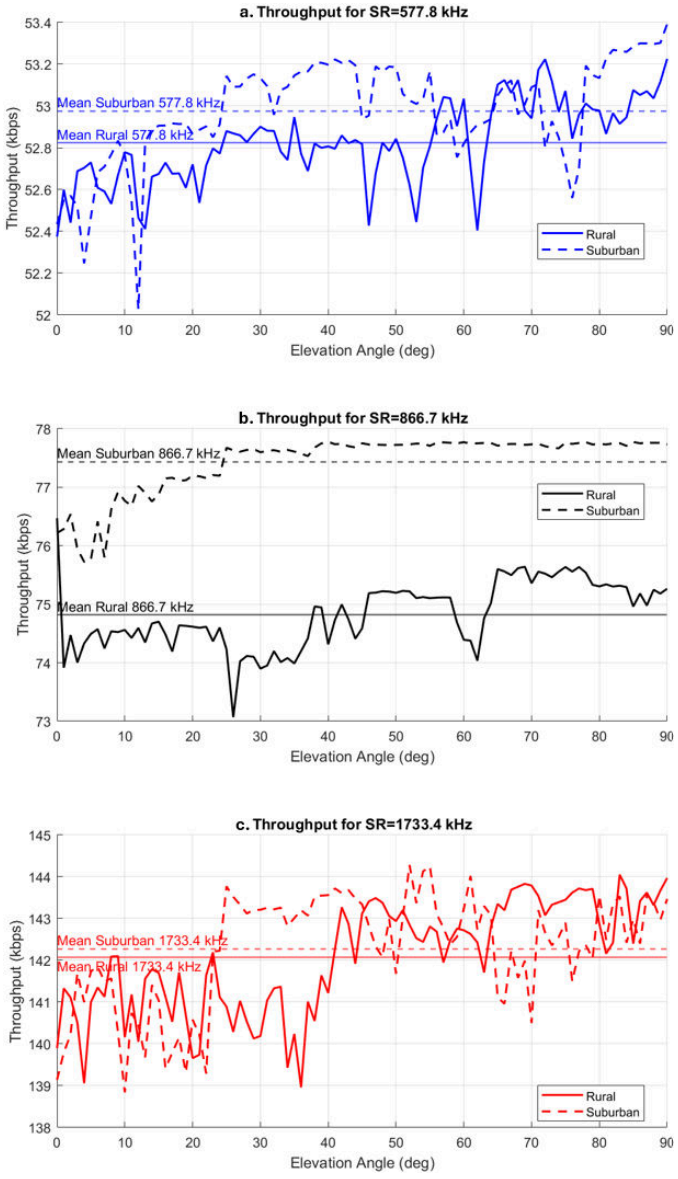

Fig. 7. Throughput Comparison across all three SR

Moreover, results show that improved latency comes at the cost of throughput at illustrated in Figure 8. While higher SRs (such as 1733.4 kHz) can provide better data resolution and potentially higher throughput, they also introduce greater processing loads, which result in increased latency and variability. In real case scenario, this could be translated in additional weight on board of UAV or more expensive components. For optimal communication, balance between throughput and latency must be achieved. Low latency is beneficial for time-sensitive UAV operations, but throughput is needed for handling larger data volumes. Therefore, selecting an SR that offers a compromise—sufficient throughput without causing excessive latency—is favorable for consistent communication performance.

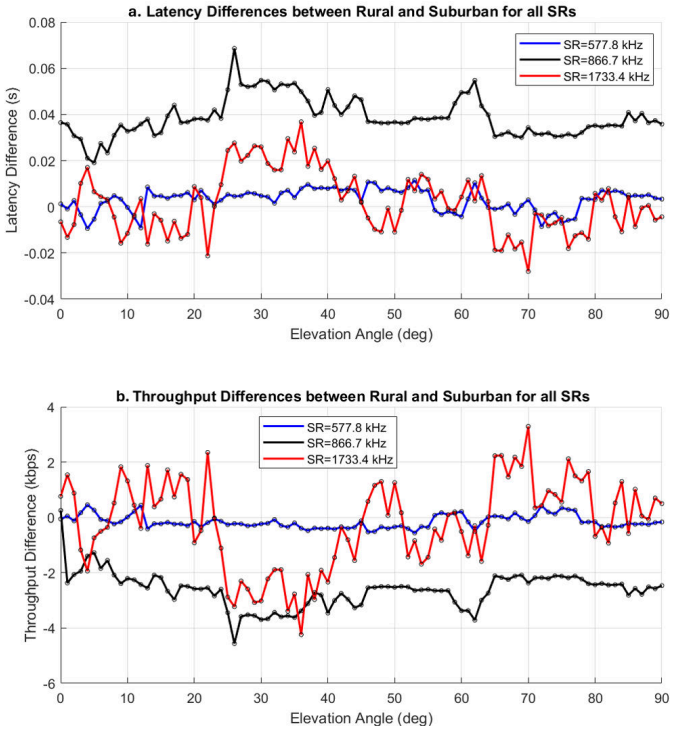

Fig. 8. Communication comparison between scenarios

Table IV summarizes the mean latency and throughput values for each scenario, consolidating the observed trends in both rural and suburban contexts. Suburban scenarios generally provide lower latency and slightly higher throughput at comparable SR settings, indicating more favorable communication conditions.

TABLE IV
QoS Parameters Obtained Values

	Scenarios	Average Latency (s)	Average Throughput (Mbps)
Rural	SC1	0.0682	52.8241
	SC2	0.1319	74.8180
	SC3	0.1918	142.0744
Suburban	SC4	0.0652	52.9770
	SC5	0.0931	77.4371
	SC6	0.1901	142.2755

To validate the results obtained a comparison against 5G

Quality of Service Indicators (5QI) catering Mission Critical Key Performance Indicators (KPIs) requirements in [5] that imply latency is expected to be below the 70 ms threshold for Mission Critical Data, which was achieved in this research only with a low SR. On the other hand, [25] indicates that the average uplink throughput for the S band is approximately 5.4 Mbps, while for the Ka band, it reaches up to 201 Mbps. Moreover, [26] reports that the average latency for LEO uplinks is around 65.2 ms, with an uplink throughput averaging 19.1 Mbps. These values are in the same range as our findings; however, it is important to note that the LEO constellation's altitude in [26] was set at 540 km, compared to the 781 km altitude used in this research. This difference in altitude is the factor that impacted latency and throughput. Furthermore, the results in this study were obtained using 3GPP-defined scenarios in [23] like propagation model for data transmission over the NTN LMS channel. This confirms the system validation not only theoretically sound, but also applicable in different real-world scenarios.

V. Conclusion

In conclusion, this study presents a comprehensive analysis of UAV-to-LEO satellite communication performance by evaluating key QoS metrics such as latency and throughput using NTN narrowband channels. The findings highlight that lower sample rates, such as 577.8 kHz, achieve latency below the 70 ms threshold suitable for mission-critical applications, with an average of 0.0682 s observed in rural SC1 scenarios. However, these lower rates come at the cost of reduced throughput, which averaged 52.82 Mbps. Conversely, higher sample rates, such as 1733.4 kHz, provide higher throughput (up to 142.27 Mbps in suburban SC6 scenarios) but result in increased latency (0.1918 s in rural SC3). The results score better than 5G QoS requirements and can be considered for future benchmarks in SatCom communication, supporting the development of beyond 5G communication systems for UAV-enabled missions.

References

[1] A. Kumar, A. Perrusquía, S. Al-Rubaye, and W. Guo, "Wildfire and smoke early detection for drone applications: A light-weight deep learning approach," *Engineering Applications of Artificial Intelligence*, vol. 136, p. 108977, 10 2024.

[2] M. S. Adam Cohen and S. Shaheen, "Advanced air mobility: Opportunities, challenges, and research needs for the state of california (2023-2030)," Feb. 2024. Technical Report.

[3] K. Wang, A. Li, and X. Qu, "Urban aerial mobility: Network structure, transportation benefits, and sino-us comparison," *The Innovation*, vol. 4, p. 100393, 3 2023.

[4] M. Pons, E. Valenzuela, B. Rodríguez, J. A. Nolazco-Flores, and C. Del-Valle-Soto, "Utilization of 5g technologies in iot applications: Current limitations by interference and network optimization difficulties—a review," *Sensors*, vol. 23, p. 3876, 4 2023.

[5] 3GPP, "3gpp tr 23.700-01: 3rd generation partnership project; technical specification group services and system aspects; study on application enablement for satellite access enabled 5g services; (release 19)," 2024.

[6] S. Subasu, S. Al-Rubaye, A. Warrier, and H. Whitworth, "Unmanned air vehicle operational framework for public safety communications," in *2024 AIAA DATC/IEEE 43rd Digital Avionics Systems Conference (DASC)*, pp. 1–9, IEEE, 9 2024.

[7] X. Luo, J. Xie, L. Xiong, Z. Wang, and C. Tian, "3-d deployment of multiple uav-mounted mobile base stations for full coverage of IoT ground users with different QoS requirements," *IEEE Communications Letters*, vol. 26, pp. 3009–3013, 12 2022.

[8] S. Al-Rubaye, A. Tsourdos, and K. Namuduri, "Advanced air mobility operation and infrastructure for sustainable connected evtol vehicle," *Drones*, vol. 7, p. 319, 5 2023.

[9] S. A. Busari, S. Mumtaz, S. Al-Rubaye, and J. Rodriguez, "5G millimeter-wave mobile broadband: Performance and challenges," *IEEE Communications Magazine*, vol. 56, pp. 137–143, 6 2018.

[10] A. Al-Dulaimi, S. Al-Rubaye, Q. Ni, and E. Sousa, "5g communications race: Pursuit of more capacity triggers lte in unlicensed band," *IEEE Vehicular Technology Magazine*, vol. 10, pp. 43–51, 3 2015.

[11] S. Li, Q. Ni, Y. Sun, G. Min, and S. Al-Rubaye, "Energy-efficient resource allocation for industrial cyber-physical IoT systems in 5G era," *IEEE Transactions on Industrial Informatics*, vol. 14, pp. 2618–2628, 6 2018.

[12] A. Al-Dulaimi, S. Mumtaz, S. Al-Rubaye, S. Zhang, and C.-L. I, "A framework of network connectivity management in multi-clouds infrastructure," *IEEE Wireless Communications*, vol. 26, no. 3, pp. 104–110, 2019.

[13] C. Li, W. Guo, S. C. Sun, S. Al-Rubaye, and A. Tsourdos, "Trustworthy deep learning in 6G-enabled mass autonomy: From concept to quality-of-trust key performance indicators," *IEEE Vehicular Technology Magazine*, vol. 15, pp. 112–121, 12 2020.

[14] M. Ozpolat, S. Al-Rubaye, A. Williamson, and A. Tsourdos, "Integration of unmanned aerial vehicles and LTE: A scenario-dependent analysis," in *2022 International Conference on Connected Vehicle and Expo (ICCVE)*, pp. 1–6, 2022.

[15] V. Towhidlou, S. Al-Rubaye, and A. Tsourdos, "LTE handover design for cellular-connected aircraft," in *2022 IEEE/AIAA 41st Digital Avionics Systems Conference (DASC)*, pp. 1–5, 2022.

[16] S. Al-Rubaye, A. Al-Dulaimi, and J. Cosmas, "Pilot power optimization for autonomous femtocell networks," in *2011 Wireless Advanced*, pp. 170–175, 2011.

[17] K. Bandelier, S. Al-Rubaye, S. Savazzi, and K. Namuduri, "Use cases for vehicle-to-vehicle (V2V) communications for unmanned aircraft systems," *Use Cases for Vehicle-to-Vehicle (V2V) Communications for Unmanned Aircraft Systems*, pp. 1–24, 2023.

[18] A. Warrier, L. Aljaburi, H. Whitworth, S. Al-Rubaye, and A. Tsourdos, "Future 6G communications powering vertical handover in non-terrestrial networks," *IEEE Access*, vol. 12, pp. 33016–33034, 2024.

[19] K. Mohanta and S. Al-Rubaye, "Towards 6g satellite–terrestrial networks: Analysis of air mobility operations," *Electronics*, vol. 13, p. 2855, 7 2024.

[20] H. Whitworth, S. Al-Rubaye, A. Tsourdos, J. Jiggins, N. Silverthorn, and K. Thomas, "Aircraft to operations communication analysis and architecture for the future aviation environment," in *2021 IEEE/AIAA 40th Digital Avionics Systems Conference (DASC)*, pp. 1–8, IEEE, 10 2021.

[21] J. C. Borromeo, K. Kondepu, N. Andriolli, L. Valcarenghi, R. Bassoli, and F. H. P. Fitzek, "5G NR support for UAV-assisted cellular communication on non-terrestrial network," in *European Wireless 2022; 27th European Wireless Conference*, pp. 1–7, 2022.

[22] M. Bacco, F. Davoli, G. Giambene, A. Gotta, M. Luglio, M. Marchese, F. Patrone, and C. Roseti, "Networking challenges for non-terrestrial networks exploitation in 5G," in *2019 IEEE 2nd 5G World Forum (5GWF)*, pp. 623–628, IEEE, 9 2019.

[23] 3GPP, "3rd generation partnership project; technical specification group radio access network; study on new radio (NR) to support non-terrestrial networks (release 15)," 2019.

[24] F. Alhashmi, S. Al-Rubaye, and A. Tsourdos, "Advanced mobility flight dynamics restriction to support high availability communication systems," in *2024 AIAA DATC/IEEE 43rd Digital Avionics Systems Conference (DASC)*, pp. 1–10, 2024.

[25] J. Sedin, L. Feltrin, and X. Lin, "Throughput and capacity evaluation of 5G new radio non-terrestrial networks with leo satellites," in *GLOBECOM 2020 - 2020 IEEE Global Communications Conference*, pp. 1–6, IEEE, 12 2020.

[26] M. Lopez, S. B. Damsgaard, I. Rodriguez, and P. Mogensen, "An empirical analysis of multi-connectivity between 5G terrestrial and leo satellite networks," in *2022 IEEE Globecom Workshops (GC Wkshps)*, pp. 1115–1120, IEEE, 12 2022.

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2025-04-08
IEEE
https://doi.org/10.1109/icns65417.2025.10976797
Subasu S, Al-Rubaye S, Tsourdos A. (2025) Robust aeronautical communications enabled by UAV operations and LEO satellites. In: 2025 Integrated Communications, Navigation and Surveillance Conference (ICNS), 8-10 April 2025, Brussels, Belgium

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