# Feasibility Analysis of Isolation-Based Spectrum Sharing Between Terrestrial and Non-Terrestrial Networks

Rahul Chintalapati[1], Nishith.D.Tripathi[2], Manoj Kumar[3] Jeffrey.H.Reed[4]
The Bradley Department of Electrical and Computer Engineering, Virginia Tech, Blacksburg, USA
[1]crahulvarma@vt.edu, [2]nishith@vt.edu, [3]manoj.kumar@vt.edu [4]reedjh@exchange.vt.edu

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***Abstract*— The rise of data-intensive applications necessitates development of techniques that maximize the use of scarce spectrum. This paper carries out the feasibility analysis of spectrum sharing between 5G-based terrestrial and non-terrestrial networks. Three spectrum sharing strategies- spatiotemporal spectrum sharing, spectrum reuse, and dynamic spectrum sharing are identified. The paper illustrates these methodologies and summarizes their benefits and challenges. Spectrum reuse between an outdoor NTN and an indoor TN network is analyzed in detail using suitable radio propagation models and multiple analysis scenarios. Sensitivity analysis with critical system parameters such as the co-channel interference distance and the number of interfering transmitters is also carried out. The paper concludes that it is feasible to implement a spectrum sharing strategy that enables spectrum reuse between terrestrial and non-terrestrial networks.**

***Keywords*— NTN, Spectrum Sharing, 5G, 6G, Wireless networks, dynamic spectrum sharing, spectrum reuse**

## I. INTRODUCTION

Non-Terrestrial Networks (NTNs) aim to complement Terrestrial Networks (TNs) to provide scalable, continuous, and ubiquitous services across the globe[1]. Currently, NTNs and TNs operate in their dedicated frequency bands. Thus, to efficiently utilize the spectrum, a technique called spectrum sharing is used.

### A. Related Work

Two types of spectrum sharing methods, the normal pairing mode and the reverse pairing mode, are studied in [1]. The NTN and TN systems perform Uplink (UL) and Downlink (DL) transmissions in the same UL and DL bandwidths, in the normal pairing mode. The NTN performs UL transmissions in the same bandwidth as the TN, which performs DL transmissions, in the reverse pairing mode. Using the reverse pairing spectrum sharing method, the authors obtained a higher SINR for NTN UL than the normal pairing method. Additionally, the authors provided services comparable to cellular networks using the reverse pairing methods for NTN UL [1].
The authors in [2] propose a novel dynamic spectrum sharing method between TN and NTN systems using a Spectrum Management Server (SMS), where Resource Blocks (RB) are shared between TN and NTN. The SMS prioritizes the utilization of resources by TN and assigns these resources to an NTN when the TN is not utilizing these resources. In a rural scenario, the TN users are not negatively affected when this spectrum sharing method is used to share resources. In a high traffic scenario, edge TN and NTN users' performance improves while causing minimal performance degradation to the primary TN users in the cell [2].
The rest of the paper is organized as follows. Section II discusses the 5G TN-NTN architecture in an urban environment. Section III proposes three novel spectrum sharing strategies for TN-NTN systems. Section IV describes the TN-NTN spectrum reuse strategy for four scenarios. Section V evaluates the feasibility of this strategy for these four scenarios for the spectrum reuse strategy. Section VI provides the concluding remarks, and Section VII discusses the future work.

[1]This work focuses on 3GPP defined 5G based NTNs, and there are other non-3GPP NTNs such as Iridium, Globalstar, Skybridge, Orbcomm among others and play an important role in providing crucial wireless global NTN services.

## II. 5G NETWORK ARCHITECTURES FOR TERRESTRIAL AND NON-TERRESTRIAL NETWORKS

A 5G-based NTN with a transparent NTN payload supports an NTN capable User Equipment (UE) and consists of a transparent NTN payload residing on an NTN platform (e.g., a Low Earth Orbit or LEO satellite), an NTN-Gateway (NTN-GW), Terrestrial gNB infrastructure, the 5G Core (5GC) and the Data Network (DN), as shown in Fig. 1. The interface between the UE and the NTN Payload is the service link, and the interface between the NTN Payload and the NTN-GW is the feeder link.

The Transparent Payload performs the functions of an RF repeater, amplifier, and a frequency converter. The NTN-GW is the terrestrial entity that acts as a gateway for communication between the NTN Payload and the terrestrial gNB infrastructure. In an example network traffic flow for the uplink data transfer, the UE transmits information to the NTN Payload through the service link, the RF signal is processed by the transparent payload, and forwarded to the terrestrial gNB through the NTN-GW. The traffic then flows from the gNB to the 5GC and finally to the Data Network.

This paper focuses on the spectrum sharing aspects over the service link between an outdoor NTN capable UE and the NTN Payload, and the indoor gNB serving indoor UEs of a TN.

## III. SPECTRUM SHARING STRATEGIES

Spectrum sharing is a technique of using underutilized spectrum bands by transceivers. From an NTN- TN perspective, this section discusses three spectrum sharing strategies, the Spatiotemporal spectrum sharing strategy, the spectrum reuse strategy between the outdoor Non-Terrestrial Networks

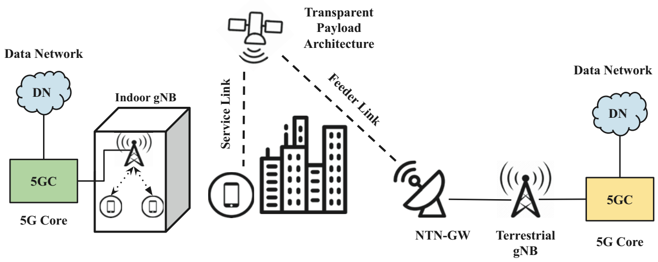


Fig. 1. Overall TN-NTN Network Architecture

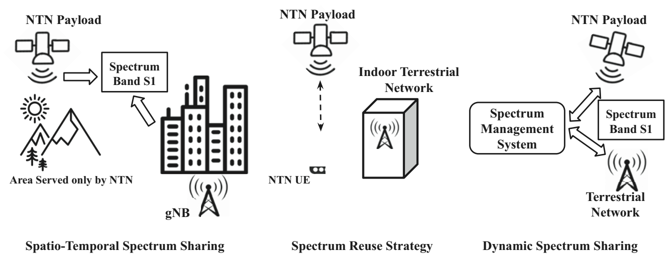


Fig. 2. NTN-TN Spectrum Sharing Candidate Strategies

(NTNs) and indoor terrestrial networks, and the dynamic spectrum sharing strategy through an active spectrum management system. Suitable coordination between TN operators and NTN operators is needed to implement spectrum sharing strategies effectively.

### A. *Spatiotemporal Spectrum Sharing*

**Methodology.** NTNs could use a dedicated spectrum band for operation.However, the amount of spectrum allocated to the satellite communication systems is limited. More spectrum can be accessible to both a TN and an NTN if spectrum is shared between the two systems.

The spatiotemporal spectrum sharing strategy involves the usage of a specific spectrum by an NTN and a TN in different geographical locations, as shown in Fig.2.

**Benefits and Challenges.** Spectrum, owned by the incumbent terrestrial network, can be leased to an NTN system on a geographical area basis for long periods of time without affecting the functioning of the existing terrestrial network infrastructure or vice versa.

Non-Geostationary Satellites provide coverage to different areas at different times. It is challenging for these satellites to operate at different spectrum bands constantly, as the geographical area they serve changes with time. Additionally, it is difficult for these satellites to know what spectrum bands to operate in without the assistance of either a pre-defined set of spectrum bands of operation in different geographical areas, or a dedicated entity to constantly update the satellites on the appropriate spectrum band of operation.

### B. *TN-NTN Spectrum Reuse Strategy: A Closer Look*

**Methodology.** The spectrum reuse strategy refers to the use of a specific spectrum band by both NTN and indoor TN systems as co-primary users. This strategy leverages the underlying fact that low powered indoor gNBs or the UEs they serve are low powered devices and may cause little or no interference to the outdoor NTN systems, in most cases. The outdoor NTN system (NTN Payload and NTN UEs) functions independently from the indoor TN system (indoor gNB and indoor UEs) without affecting each other, as shown in Fig.2.

**Benefits and Challenges.** Both the outdoor NTN and the indoor TN can exist independently and harmoniously. Low-power sidelink communications in a TN may be able to reuse the spectrum if spectrum-sensing mechanisms are implemented to account for the NTN spectrum. Indeed, 5G NR does support listen-before-talk mechanism that is used in NR-Unlicensed.

Even before the addition of NTNs to the existing TN network, various TN entities may already be sharing the spectrum, such as Cognitive Radio (CR) users sensing idle spectrum bands and transmitting information over that band or sharing spectrum during Device-to-Device (D2D) Communications [3]. The addition of an NTN to this scenario would increase interference between TN and NTNs. This strategy might also increase the minimum separation distance between NTN UEs and TN UEs due to interference. Additionally, the indoor-outdoor propagation path loss may vary depending on the materials used for construction of the building, thereby making the interference predictions challenging.

### C. *Dynamic Spectrum Sharing*

**Methodology.** Dynamic Spectrum Sharing strategy enables efficient utilization of the spectrum between NTNs and TNs. This strategy, as shown in Fig.2, introduces a new network entity called the Spectrum Management System (SMS), which co-ordinates the use of spectrum resources between the NTNs and TNs. This coordination occurs in three steps. First, the SMS checks for available spectrum not being used by the incumbent users. Then it informs the secondary user about the available spectrum for operations. Finally, if the primary owner of the spectrum resource requires the shared spectrum, the SMS indicates to the secondary user to release the shared spectrum resource.

The spectrum owned by one incumbent user can be utilized by a secondary user and vice versa. Specifically, if the spectrum owned by user X is occupied, the SMS will be able to allocate spectrum resources owned by user Y which are not currently being used. Similarly, if the spectrum owned by user Y is occupied, the management system will be able to allocate spectrum resources owned by user X which are not being used.

**Benefits and Challenges.** The SMS manages spectrum resources such that the entities utilizing the same spectrum band do not cause significant interference to each other. As a result, SMS decreases the minimum separation distance between the NTN UEs and TN UEs, thereby making this strategy more viable for deployment. This strategy will significantly mitigate the challenge of co-channel interference, as a specific portion of spectrum will not be allocated to multiple entities at the same time.

## IV. Co-channel Interference Analysis

One of the spectrum sharing strategies discussed above aims to reuse the same he same spectrum for both indoor TNs and outdoor NTNs. One of the primary challenges in reusing the same spectrum band is the co-channel interference between the entities reusing the portion of the spectrum. This section studies the feasibility of the spectrum reuse strategy between Terrestrial Networks and Non-Terrestrial Networks by evaluating the effect of co-channel interference in four scenarios, discussed in Section IV.A. Section IV.B comprehensively describes the steps undertaken while performing the analysis for each scenario.

### A. Path Loss Model Considerations

The analysis considers different pathloss models to calculate interference caused by various network elements, as shown in Fig. 3. The dotted red lines in Fig. 4 indicate interference caused by various network elements. The analysis also assumes values of parameters like the operating frequency, LEO satellite operating altitudes, Physical Resource Blocks (PRBs), and channel bandwidth among others, which are mentioned in Table 1.

The pathloss model used in the above scenarios, between the LEO satellite transmitter and the NTN-UE receiver or the indoor gNB and the LEO satellite, is the free space pathloss model, which is calculated as:

$$FSPL(dB) = -10 * log_{10}[(\lambda/(4\pi R))^2] \quad (1)$$

Where $\lambda$ is the wavelength at an operating frequency fc , and R is the distance between the LEO satellite and the NTN-UE, measured in km.

The received power at the receive antenna is calculated as the difference between the transmitter Effective Isotropic Radiated Power (EIRP) and the free space path loss, and is calculated as:

$$R_X(dBm) = EIRP_{T_X}(dBm) - FSPL(dB) \quad (2)$$

The interference caused by the indoor gNB to the NTN-UE is calculated using the COST 231-HATA path loss model ($PL_{COST231-HATA}$) , and is calculated as:

$$PL_{COST231-HATA}(dB) = 46.3 + 33.9 * Log_{10}(fc) - 13.82 * Log_{10}(h_b) - a(h_m) + (44.9 - 6.55 * Log(h_b)) * Log(R) + C_m + BPL \quad (3)$$

Where $h_b$ is the effective indoor gNB antenna height, $a(h_m)$ is the correction factor for the NTN-UE antenna height $h_m$, and $C_m$ is an additional pathloss correction component which is 3 dB for a dense urban environment and 0 otherwise [4]. Our analysis assumes 25 dB $Building\ Penetration\ Loss$ (BPL), but note that BPL is a function of multiple factors like the type of building materials.

The Effective interference observed at the NTN-UE is calculated as :

$$RX(dBm) = EIRP(dBm) - PL_{COST\ 231-HATA}(dB) \quad (4)$$

The pathloss model used to measure the received power between the indoor TN network, i.e., the indoor gNB and the indoor UE, is the ITU-R M.1225 Indoor Path Loss Model ($PL_{Indoor}$). It is caluculated as:

$$PL_{Indoor}(dB) = 37 + 30 * Log_{10}(R) + 18.3 * n * ((n + 2/n + 1) - 0.46) \quad (5)$$

Where 'n' is 3 or 4 for an average indoor environment [4]. An alternate propagation model is available in [5].

An additional antenna gain is used by the LEO satellite when the LEO satellite is receiving information from the NTN-UE. It is calculated as:

$$R_{x+Gain}(dBm) = R_X(dBm) + R_{x(LEO)} Antenna\ Gain \quad (6)$$

Finally, the effective SINR is calculated as the difference between the received power at the network element and the interference power of the interfering signal.

$$SINR(dB) = R_x(dBm) - (Interference(dBm) + TNF(dBm)) \quad (7)$$

The Thermal Noise Floor (TNF) in (7) is calculated as:

$$TNF(dBm) = -174dBm/Hz + NF + 10 * Log_{10}(PRBs * SC_{PRB} * SCS) \quad (8)$$

where NF is the noise figure at the UE (=8 dB), PRBs are the number of PRBs in a given channel bandwidth, $SC_{PRB}$ is the number of sub carriers per PRB (=12), and SCS is the Subcarrier Spacing (=15,000 Hz).

Finally, to analyze the impact of multiple interference elements, the interference[2] is calculated in mW, summed up, and added to the noise floor to get the total interference observed at the receiver (9).

$$Total\ interference = \sum_{n=1}^{n} Interference\ in\ mW + TNF(in\ mW) \quad (9)$$

### B. Scenarios for Spectrum Reuse Strategy

#### 1) Downlink Interference from an indoor gNB to an outdoor NTN-UE

When the LEO satellite is transmitting information to the NTN-UE, there exists co-channel interference between the indoor gNB and the NTN-UE, due to the use of the same frequency band in the spectrum reuse strategy. First, the received signal power at the NTN- UE is computed as the difference between the LEO satellite transmit power and the free space path loss between the LEO satellite and the NTN-UE (2). When the indoor gNB also transmits in the

[2]This work assumes maximum overlap between the signal and the interference. The actual amount of interference depends upon the overlap between the signal and the interference.

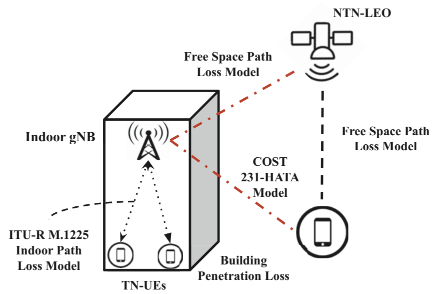


Fig. 3. Pathloss Models Used for Analysis

same frequency band, it causes interference at the NTN-UE. Effective interference of the indoor gNB is calculated as the difference between the transmit power of the indoor gNB and the pathloss of the interference signal by the time it reaches the NTN-UE (4). The path loss of the interfering signal is calculated using the COST 231 HATA indoor outdoor path loss model (3). In addition to the interference, the thermal noise is also calculated. The effective SINR at the NTN-UE is thus the difference between the received power (LEO satellite –NTN UE) and the sum of interference and noise (indoor-gNB – NTN UE) (7).

A sensitivity analysis is performed in this scenario, where the SINR is evaluated as a function of distance between the indoor gNB and the outdoor NTN-UE. Additionally, sensitivity analysis is performed where the SINR is evaluated as a function of number of base stations for a given circumference.

*2) Downlink Interference from an NTN-LEO satellite to an indoor TN-UE*

When the indoor gNB is transmitting information to the indoor TN-UE, there is co-channel interference caused by the NTN-LEO satellite, which is also transmitting information in the same frequency band. The received power at the TN-UE is calculated as the difference between the transmit power of the indoor gNB and the indoor path loss experienced by the signal. The indoor path loss is calculated using the ITU R M.1225 indoor path loss model (5). The interference caused by the NTN LEO satellite is calculated as the difference between the transmit power of the satellite and the free space path loss between the LEO satellite and the indoor TN- UE (2). The interference signal is further deteriorated due to the signal experiencing additional path loss in the form of building penetration path loss (25 dB). Thus, the effective SINR at the indoor TN-UE is calculated as the difference between the received power (indoor gNB – indoor TN-UE) and the interference signal (NTN-LEO satellite – indoor TN-gNB) (7).

A sensitivity analysis is performed, where the SINR at the indoor TN-UE is evaluated as the altitude of the LEO-satellite increases from its minimum altitude from the earth's surface to its maximum altitude.

*3) Uplink Interference from indoor TN-UE to LEO-Satellite*

When an NTN-UE transmits information to the NTN-LEO satellite, there exists co-channel interference caused by the indoor UE, which is also transmitting in the same frequency band. The received power at the NTN-LEO satellite is calculated as the difference between the transmit power of the NTN-UE and the free space path loss between LEO satellite and the NTN-UE (2). An additional receive antenna gain is added to this received power, as the transmit power of the NTN-UE is low, and by the time the signal reaches the LEO satellite, it will be very weak. To overcome this challenge, a receive antenna gain is used at the NTN-LEO satellite to obtain a minimum Received Signal Received Power (RSRP) of -105 dBm. The interference caused from the indoor UE is calculated as the difference between the indoor UE transmit power and the free space path loss between the indoor UE and the NTN-LEO satellite (2). The interference signal further deteriorates due to an additional building penetration loss. On the other hand, the interference from the indoor UE to the LEO satellite increases due to the receive antenna gain of a signal at the LEO satellite. Thus, the effective SINR is calculated as the difference between the received power (NTN-UE – NTN LEO satellite) and the interference signal (indoor UE – NTN-LEO satellite).

A distance-based sensitivity analysis is performed, where the SINR at the NTN-LEO satellite is evaluated as a function of the distance between the LEO satellite and the indoor UE. Additionally, SINR at the LEO Satellite is evaluated as a function of number of indoor TN-UEs utilizing the same spectrum band.

*4) Uplink Interference outdoor NTN UE to indoor TN gNB*

When an indoor TN-UE transmits information to the indoor gNB, there exists co-channel interference caused by the outdoor NTN-UE, which is also transmitting in the same frequency band. The received power at the indoor gNB is calculated as the difference between the transmit power of the TN-UE and the indoor path loss between TN-UE and the indoor gNB. The interference caused by the NTN-UE is calculated as the difference between the NTN-UE transmit power and the indoor-outdoor path loss between the NTN-UE and the indoor gNB. The interference signal further deteriorates due to an additional building penetration loss. Thus, the effective SINR is calculated as the difference between the received power (TN-UE – indoor gNB) and the interference signal (NTN-UE – indoor gNB).

A distance-based sensitivity analysis is performed, where the SINR at the indoor gNB is evaluated as a function of the distance between the NTN-UE and the indoor gNB.

## V. Discussion and Results

*A. Analysis of the interference from an indoor gNB to an outdoor NTN-UE*

This scenario discusses the trends in SINR at the NTN-UE, as a function of distance between the indoor gNB causing

Table 1. Analysis Parameters

| Analysis Parameters | Assumed Values |
|---|---|
| Operating Frequency (fc) | 2.2 GHz |
| LEO Altitude Range | 500-2000 km |
| Indoor gNB EIRP Range | -20 dBm – 30 dBm |
| Physical Resource Blocks | 106 PRBs |
| NTN-LEO EIRP Range | 79-91 dBm |
| TN-UE EIRP | 23 dBm |
| Building Penetration Loss | 25 dBm |
| Channel Bandwidth | 20 MHz |
| LEO Receive Antenna Gain | 56–69 dB |
| Minimum RSRP of $R_X$ Signal | -105 dBm |

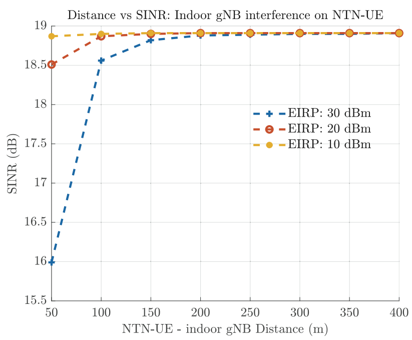


Fig. 4. Distance vs SINR: indoor gNB interference on NTN-UE

interference, and the NTN-UE. As the distance between the indoor gNB and the NTN-UE increases, the SINR at the NTN-UE improves. Fig. 4 shows that after the 200 m mark, the SINR at the NTN-UE reaches the maximum value. Thus, the NTN networks and indoor terrestrial networks can safely use the same spectrum band without causing interference to each other.
Additionally, as the EIRP of the indoor gNB decreases, the trends in Fig.4 show an improvement in SINR at the NTN-UE. This shows that spectrum sharing is more feasible at lower indoor gNB EIRP.
The scenario also discusses the trends in SINR at the NTN-UE as a function of number of indoor gNBs in a specific vicinity of the NTN-UE. As the number of base stations increases, the SINR at the NTN-UE deteriorates, as shown in Fig.5. This analysis assumes the EIRP of all the indoor gNBs causing interference to be 30 dBm. Thus, spectrum sharing would be feasible with low number of indoor gNBs in close vicinity to the NTN-UE. Multiple indoor gNBs at larger distances have little or no impact on the SINR at the NTN-UE. It can also be inferred from the these figures that lower the indoor gNB EIRP, the lower the impact of multiple indoor gNBs in a given vicinity of the NTN-UE.

### *B. Analysis of the interference of an NTN-LEO satellite on an indoor TN-UE*

This scenario analyzes the effect of interference from a LEO satellite to an indoor TN-UE. The scenario studies the trends in SINR at the indoor TN-UE as a function of NTN-

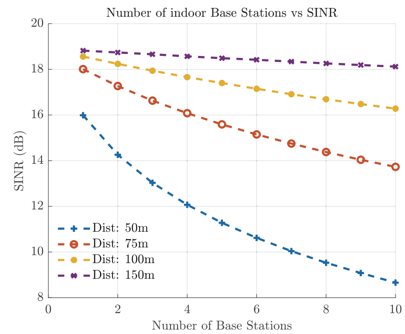


Fig. 5. Impact of multiple indoor base stations on the SINR of NTN-UE

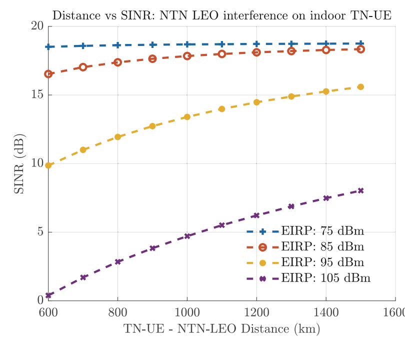


Fig. 6. Distance vs SINR: NTN-LEO satellite interference on TN-UE

LEO satellite EIRP.
As the distance between the TN-UE and the LEO satellite increases, the SINR at the TN UE improves as shown in Fig.6. However, as the altitude of the LEO satellite increases from the earth's surface, the overall service deteriorates and additional factors must be taken into consideration to provide seamless services to users.
The NTN-LEO satellite EIRP also plays a significant role in making spectrum reuse strategy achievable. As the NTN-LEO satellite EIRP increases, the SINR at the TN-UE decreases significantly, as shown in Fig.6.
Thus, an optimal NTN-LEO satellite altitude and an optimal NTN-LEO satellite EIRP would make this spectrum sharing strategy feasible.

### *C. Analysis of the interference from indoor TN-UE to LEO-Satellite gNB*

This scenario analyzes the interference from an indoor TN-UE to a LEO satellite. The analysis studies the trends in SINR at the LEO satellite as a function of distance between the LEO satellite and the TN-UE. As the distance increases, the SINR observed at the LEO satellite, as shown in Fig.7. LEO satellites at higher altitudes will experience less interference from the indoor TN-UEs when compared to the LEO satellites at lower altitudes, deployed with the same configurations.
The paper also studies the impact of multiple TN-UEs on the SINR observed at the LEO satellite. For a given distance between the LEO satellite and the TN-UEs, as the number of

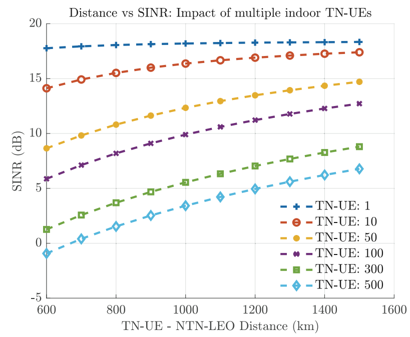


Fig. 7. Distance vs SINR: Impact of multiple TN-UEs on SINR of NTN-LEO satellite

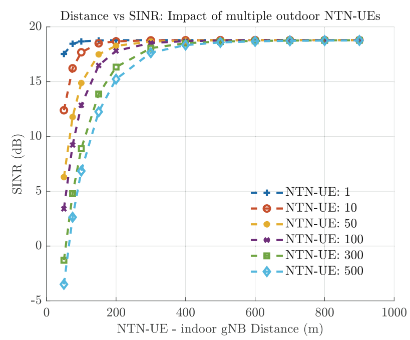


Fig. 8. Distance vs SINR: Impact of multiple NTN-UEs on SINR of TN gNB

indoor TN-UEs utilizing the same spectrum band increases, the SINR observed at the LEO satellite decreases, as shown in Fig.7.

Thus, an optimal LEO satellite altitude and an optimal number of indoor UEs that can utilize the same spectrum band as the NTN network, for a given LEO satellite coverage area would make this spectrum reuse strategy feasible.

### *D. Analysis of the interference from outdoor NTN UE to indoor TN gNB*

This scenario studies the trends in SINR at the indoor gNB as a function of distance between the indoor gNB and the NTN-UE. As the distance increase, the SINR observed at the indoor gNB increases and becomes constant after 400m. It can be inferred from Fig.8 that after a minimum threshold distance between the indoor gNB and the NTN-UE, the interference caused by the NTN-UE no longer significantly affects the indoor gNB.

The scenario also studies the impact of multiple NTN-UEs on the SINR observed at an indoor gNB. As the number of NTN-UEs increase, the SINR at the indoor gNBs decreases. Thus, the number of NTN-UEs utilizing the same spectrum band as the indoor gNB until a certain threshold distance has a significant impact on the SINR at the indoor gNB.

Thus, assigning the spectrum band to an optimal number of outdoor-NTN UEs operating in proximity to the indoor gNB will make this strategy feasible.

## VI. Conclusion and Future Work

Spectrum sharing is a prime technique to efficiently utilize spectrum between NTNs and TNs. This paper discusses the various spectrum sharing strategies that can be used between NTNs and TNs, their benefits and their shortcomings. An in-depth study is done on the spectrum reuse strategy between indoor terrestrial networks and outdoor non-terrestrial networks using suitable radio propagation models and multiple scenarios.

The trends in SINR are observed at the receiver based on critical system parameters like the distance between co-channel interference elements and number of interfering transceivers. Based on the analysis, it can be concluded that to minimize the co-channel interference from the indoor gNB, transmit power of the indoor gNB can be configured to a suitable operational value to enable spectrum reuse between the NTN system and the indoor TN network.

Additionally, the number of indoor TN-UEs utilizing the same spectrum band as the NTN system affect the SINR observed at the LEO satellite, and the number of NTN-UEs utilizing the same spectrum band as the indoor terrestrial network affect the SINR observed at the indoor gNB.

In conclusion, the analysis proves that spectrum sharing is feasible between terrestrial and non-terrestrial networks, especially between indoor terrestrial networks and outdoor non-terrestrial networks.

This study performs a theoretical analysis on the spectrum reuse strategy. In the future, this work can be extended to a simulation based analysis, where the simulations reflect scenarios close to the real world to understand the feasibility of this strategy. To understand the true effectiveness of this strategy, a scenario must be studied where multiple TN and NTN entities are introduced. Finally, other spectrum sharing methods need to be evaluated to understand their feasibility.


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