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Implementation of a Channel Model for Non-Terrestrial Networks in ns-3

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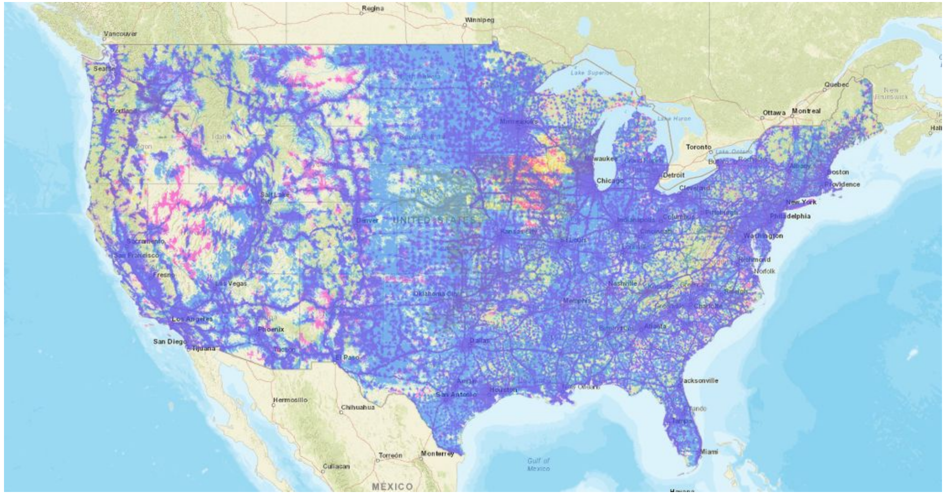
Outline

- Non-Terrestrial Networks
- ns-3 implementation
- Results and performance evaluation
- Conclusions and future work

Non-Terrestrial Networks (NTNs)

- In 2018, 55% of the global population lived in urban areas.
- 67% of the world's population had a mobile subscription, but…
- …only 3.9 billion people used the Internet → **3.7 billion people unconnected [1]!**



U.S. LTE coverage (~areas where users can expect 5 Mbps DL, 1 Mbps UL) of AT&T, T-Mobile, UScellular, and Verizon, Source: FCC

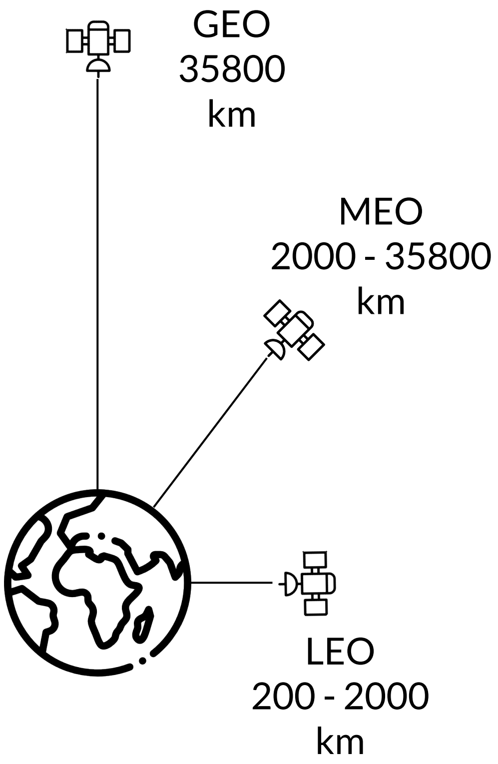
Non-Terrestrial Networks (NTNs)

- **NTNs ~ use of aerial vehicles and satellites to provide cellular coverage.**
- Comprises:
  - Satellites (**focus of this work)…**
  - **…and also** High Altitude Platform Stations (HAPS) and
  - Unmanned Aerial Vehicles (UAV).
- Satellites have been used in the past to offer services such as phone, television broadcasting.
- In the early 2010s the cost of satellite deployments has decreased, enabling a new set of satellite-offered services and giving rise to a renewed research interest.

Non-Terrestrial Networks (NTNs)

Satellite orbits:

- **Geostationary Equatorial Orbit (GEO)**
  - Rotates synchronously with the Earth.
  - Vast coverage area on the ground.
  - Long propagation distances.
- **Medium Earth Orbit (MEO)**
- **Low Earth Orbit (LEO)**
  - Shorter propagation distances.
  - Orbits around the Earth multiple times per day.
  - Relatively small coverage area on the ground.

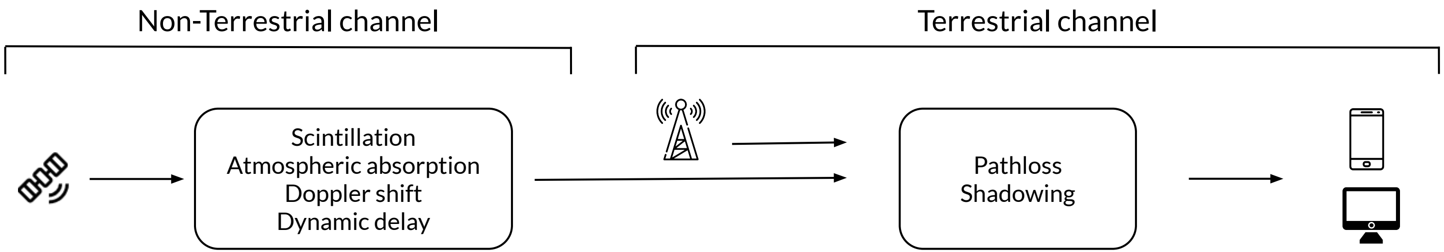


State of the art and contributions

- NTNs are considered one of the key technology enablers for 6G…
- …however, most NTN simulators, e.g., *5G K-Simulator*, *5GVienna*, and *Simu5G*, are proprietary, and/or require some type of commercial license to be used.
- Open-source options exist, but they tend to sacrifice higher layers accuracy for the sake of reducing computational complexity, e.g., *5G-air-simulator.*
- → this work aims at filling these gaps, **implementing in ns-3 the 3GPP TR 38.811 channel model** → **paving the way towards a 5G NR/6G NTN simulator.**

Channel model implementation

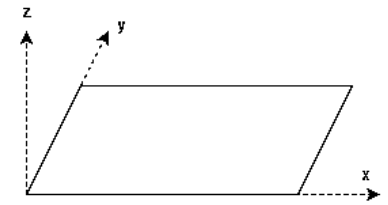
- The **baseline model is the 3GPP TR 38.901**, implemented in [1] and which the 3GPP TR 38.811 [6] extends to model non-terrestrial wireless links.
- Notably, TR 38.811 considers also:
  - The impact of longer propagation distances (modified doppler shift, non-negligible propagation delay).
  - Atmospheric absorption, ionospheric and tropospheric scintillation.
- Our implementation extends [1] by both modifying the existing code and creating new classes.



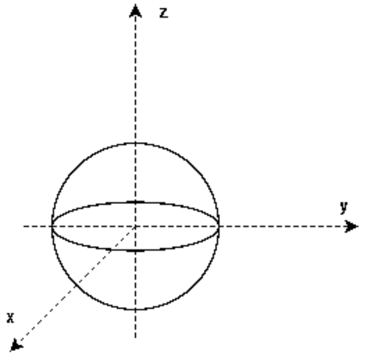
NTN Channel Model Implementation

- **A new mobility model, i.e., `GeocentriConstantPositionMobilityModel`:**
  - Accounts for the Earth spherical shape and the satellite orbits.
  - Estimate and accounts for the elevation angle.
  - **Supports Earth Centered Earth Fixed (ECEF) and geographic coordinates**, and provide conversion methods between them.
  - Compatible with the ns-3 planar Cartesian coordinates, i.e., conversion to/from the former to achieve compatibility with the rest of the existing code.

Cartesian coordinate system

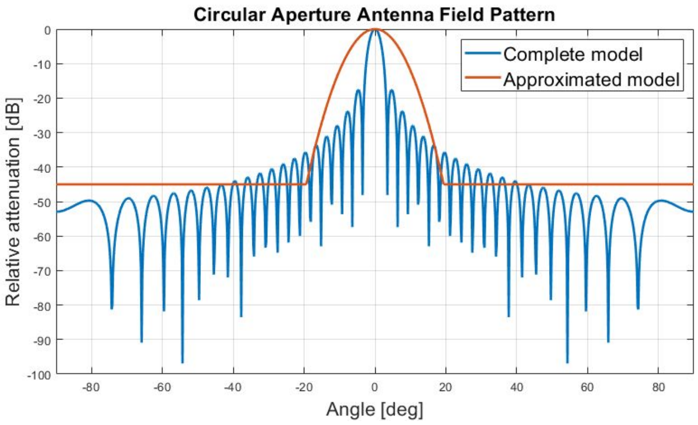


Earth Centered Earth Fixed coordinate system



NTN Channel Model Implementation

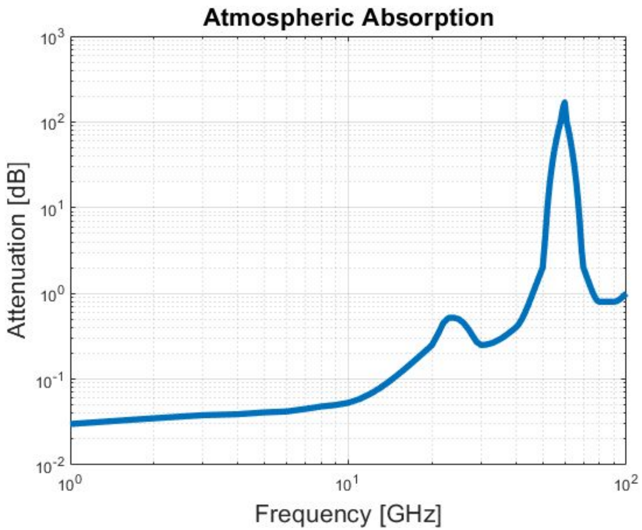
- **A new antenna model, i.e., `CircularApertureAntennaModel`**
  - Antenna field pattern based on the Bessel function of the first kind.
  - Conversely from the currently implemented models (CosineAntennaModel, ParabolicAntennaModel), CircularApertureAntennaModel implements the exact pattern with no approximations.
  - Leverages the efficient Bessel functions implementation introduced with C++17.



NTN Channel model implementation

Additions:

- **Atmospheric absorption**
  - Based on the International Telecommunication Union (ITU) model P.676 [2].
  - Relevant for frequencies above 10 GHz, or when dealing with small elevation angles (< 10°).
- **Scintillation**
  - Ionospheric scintillation: based on the Gigahertz scintillation model from ITU model P.531 [3]. Relevant only for frequencies < 6 GHZ.
  - Tropospheric scintillation: non-negligible only for frequencies > 6 GHz, and based on data given in ITU model P.618 [4].



NTN Channel Model Implementation

Class: `ThreeGppPropagationLossModel`

- Support for all NTN propagation scenarios: Dense Urban, Urban, Suburban and Rural.
- Path loss modeling for NTN scenarios.
- Shadow fading and clutter loss parameters for NTN scenarios.

Class: `ThreeGppChannelModel`

- Support for all NTN propagation scenarios.
- Support for NTN-small scale fading, via the corresponding 3GPP parameters tables [6].
    - Each parameter depends on: frequency band, scenario, line of sight conditions, and *elevation angle.*

Simulation setup

- First, we perform **link-level simulations to validate our implementation.**
- We deploy two nodes:
  - "UE" on the ground.
  - "gNB" in orbit.
- We inspect the SNR, by computing the PSD of the received signal after the channel between the nodes.
- We average over 100 channel realizations to account for the statistical nature of the channel.

	Ground	**Orbit**
Antennas	Uniform Planar Array (UPA) - Circular Aperture	Circular Aperture
TX power, gain, noise figure	Set according to Table 6.1.1.1-1 [5]	
Frequency	S band (2 GHz) - Ka band (20 - 30 GHz)	
Bandwidth	400 KHz	
Altitude	1 m	600 km (LEO) 1200 km (LEO) 35'786 km (GEO)
Simulation duration	1 s	

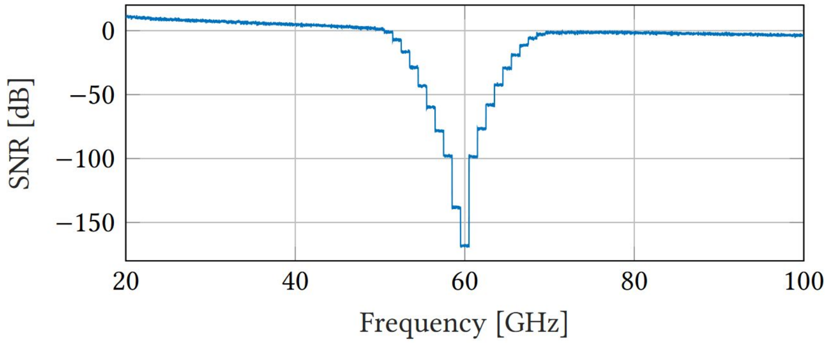
Channel model calibration

- We first calibrate our implementation, by comparing link-level results with the reference ones provided by 3GPP in Tab. 6.1.3.3-1, TR 38.811 [5].
- We consider eight of the scenarios outlined by 3GPP in [5], which comprise all types of orbits and frequency bands combinations.
- **The obtained average SNR values deviate at most of 0.4 dB from the reference ones, thus validating our implementation.**

3GPP scenario	Mode	Source	FSPL [dB]	Atmospheric Loss [dB]	Scintillation Loss [dB]	SNR [dB]
1	**DL**	3GPP	210.6	1.2	1.1	11.6
		Obtained	210.6	1.4	1.1	11.3
1	**UL**	3GPP	214.1	1.1	1.1	0.5
		Obtained	214.2	1.4	1.1	0.1
6	**DL**	3GPP	179.1	0.5	0.3	8.5
		Obtained	179.9	0.5	0.3	8.6
6	**UL**	3GPP	182.6	0.5	0.3	18.4
		Obtained	182.6	0.5	0.3	18.4
9	**DL**	3GPP	159.1	0.1	2.2	6.6
		Obtained	159.1	0.0	2.2	6.7
9	**UL**	3GPP	159.1	0.1	2.2	2.8
		Obtained	159.1	0.0	2.2	2.4
14	**DL**	3GPP	164.5	0.1	2.2	7.2
		Obtained	164.5	0.0	2.2	7.3
14	**UL**	3GPP	164.5	0.1	2.2	-2.6
		Obtained	164.5	0.0	2.2	-3

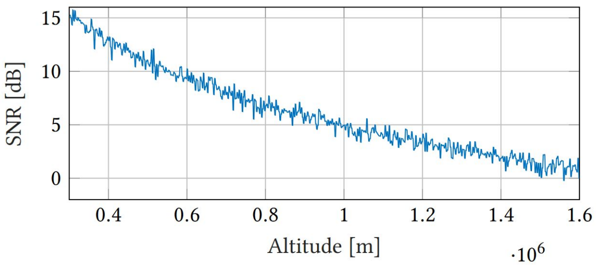
Link-level simulations

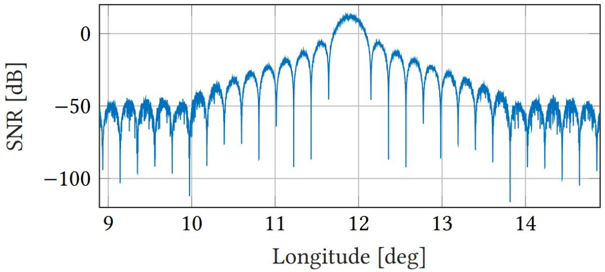
- **Then, we analyze the impact of the carrier frequency** (0.5 GHz - 100 GHz) **on the SNR.**
- We deploy a GEO satellite, transmitting a downlink signal towards a parabolic antenna on the ground.
    - The TX power is 37.5 dBm, with a 90° elevation angle.
- Attenuation peak ~60 GHz caused by oxygen absorption.



Link-level simulations

- **We complete our link-level analysis by performing a mobility test.**
- We deploy a satellite which transmits downlink signals towards a parabolic antenna on the ground.
    - The TX power is 37.5 dBm.
    - Satellite varies its altitude in [300, 1600] km (top) and its longitude in [8.8, 14.8]° (bottom).
    - In the longitude test, the receiver is perpendicular to the satellite at 11.8°, while the elevation angle is fixed to 90° for the altitude test.





End-to-end simulations

- Preliminary 5G NR end-to-end simulations using the mmWave module [7].
- Satellite gNB exchanges 10 Mbps constant bitrate UDP application data with a UE on the ground.

Scenario:	**1 GEO**	**6 LEO600**	**9 LEO600**	**14 LEO1200**
Tx Power:	37.52 dBm	21.52 dBm	48.77 dBm	54.77 dBm
Tput:	3.811 Mbit/s	3.286 Mbit/s	4.101 Mbit/s	5.161 Mbit/s
Drop ratio	0.61	0.67	0.45	0.36
Frequency band:	Ka-band	Ka-band	S-band	S-band
UE terminal:	VSAT	VSAT	Handheld	Handheld

Comparison between 4 of the scenarios (1, 6, 9, 14) outlined by 3GPP in Sec. 6, TR 38.821 [5].

- Increasing satellite altitude 600 km → 1200 km requires an increase in the TX power 75 W → 300 W.
- Up to 67% packet loss in Scenario 6.
- **Communication is possible even with a GEO orbit, from an SNR standpoint… however, one-way propagation delay > 119.2 ms!**

Conclusions and future work

TLDR:

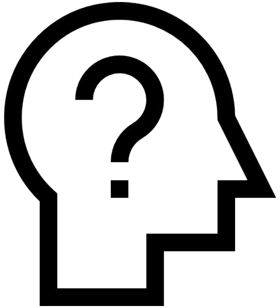
- **We implemented the TR 38.811 channel model in ns-3**, extending the mainline ns-3, and thus **enabling full stack end-to-end performance evaluation of NTN scenarios**.
- **We calibrated our implementation using 3GPP reference values.**

As part of our future work, we plan to:

- Account for the non-negligible propagation delay.
- Extend proposed mobility model with the support for realistic orbits.
- Support more complex simulations, such as:
  - Simulations with moving UEs and satellites.
  - HAP and UAV scenarios.

Thank you for your attention.

Questions, suggestions… ?



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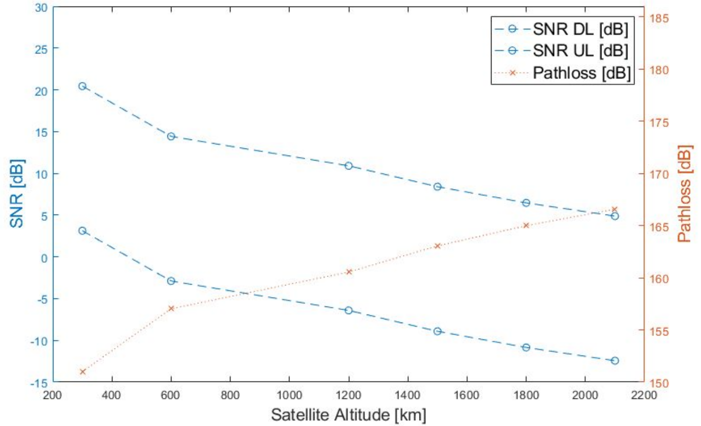
Backup slides

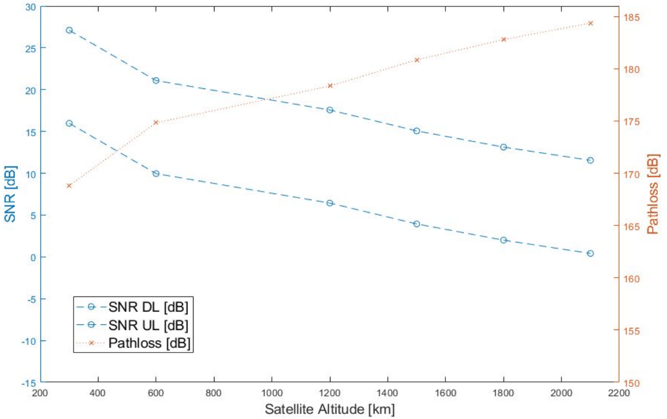
Link-level simulations

S-band 2 GHz   BW: 30MHz   UE antenna: UPA 2x2



- The use of handheld devices limits UL capabilities.
- High TX power (75W) required for DL.

Ka-band 20-30 GHz   BW: 40MHz   UE terminal: VSAT 39.7 dB



- More energy efficient thanks to the use of VSAT antennas.
- SNR > 0dB in UL.

References

[1] Chaoub, Abdelaali, et al. "6G for bridging the digital divide: Wireless connectivity to remote areas." IEEE Wireless Communications 29.1 (2021): 160-168.

[2] Tommaso Zugno, Michele Polese, Natale Patriciello, Biljana Bojović, Sandra Lagen, and Michele Zorzi. 2020. Implementation of a Spatial Channel Model for ns-3. In Proceedings of the 2020 Workshop on ns-3 (WNS3 '20), ACM

[3] ITU-R P.676: Attenuation by atmospheric gases in the frequency range 1-350 GHz

[4] ITU-R P.531: Ionospheric propagation data and prediction methods required for the design of satellite networks and systems

[5] ITU-R P.618: Propagation data and prediction methods required for the design of Earth-space telecommunications systems

[6] 3GPP TR 38.821: Solutions for NR to support Non-Terrestrial Networks (NTN)

[7] 3GPP TR 38.811: Study on New Radio (NR) to support non-terrestrial networks

[8] M. Mezzavilla et al., "End-to-End Simulation of 5G mmWave Networks"

NTN: Channel Model Implementation

- Bold: newly implemented code
- Dotted: modifications to the existing code