MULTIPLE ACCESS INTERFERENCE CHALLENGES IN GNSS: THE ROLE OF EMERGING LEO-PNT CONSTELLATIONS

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Session: LEO-PNT Performance and Interference Challenges
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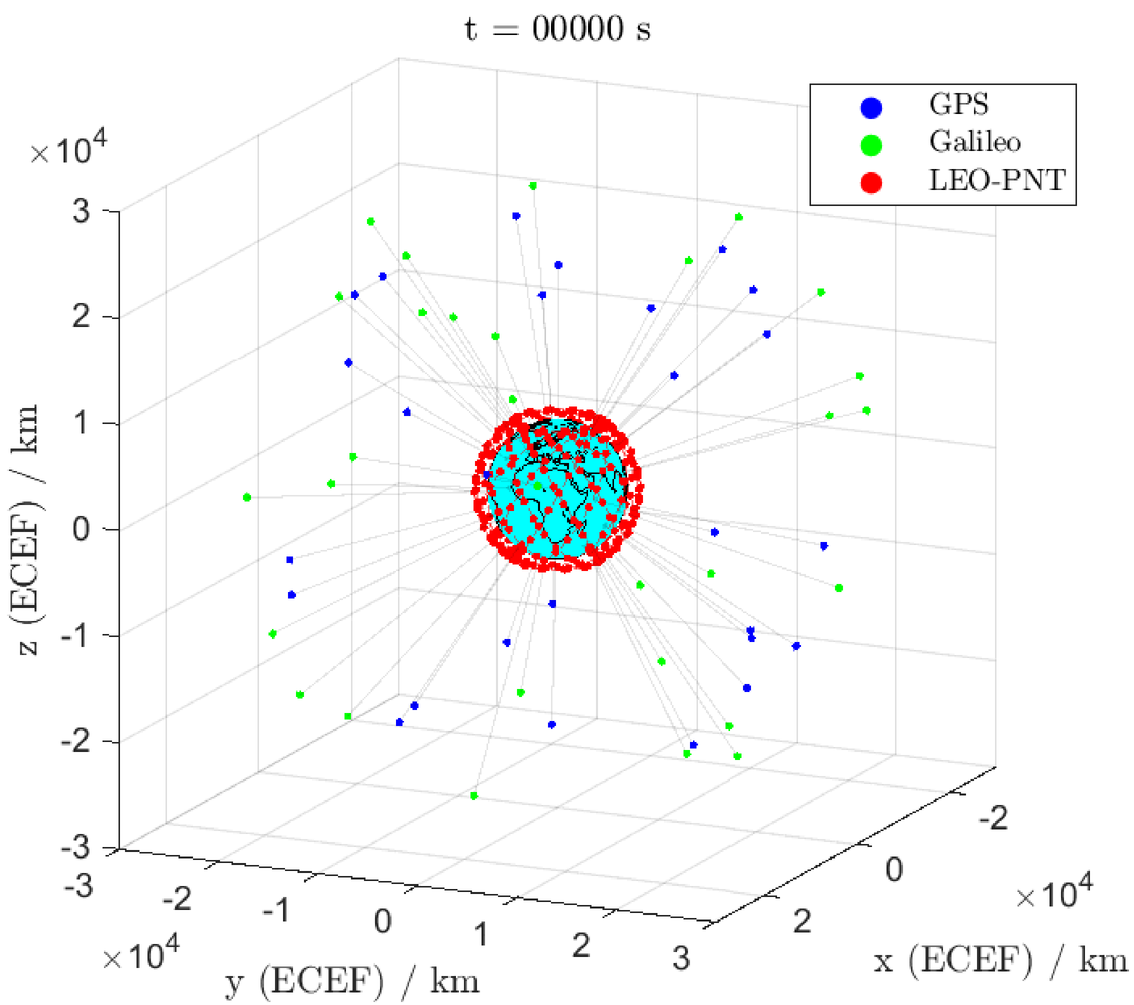
[2] RWTH Aachen University,
Aachen, Germany

DLR

Introduction

- LEO-PNT systems in the focus of current research

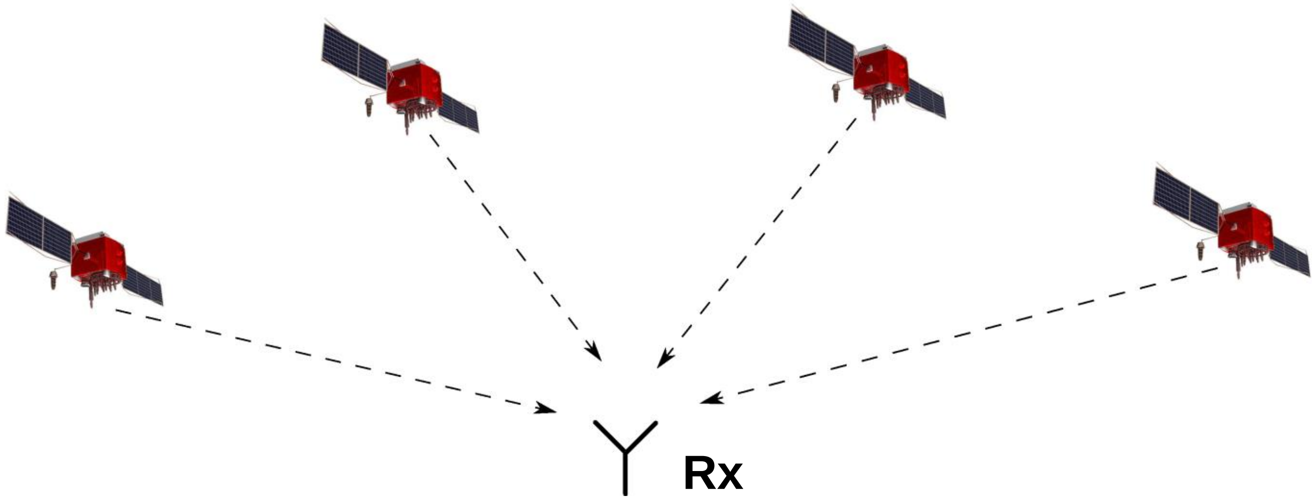
- Identified challenges:
  - Larger path loss variation than MEO between horizon and zenith
  - Increased intra- and inter-system interference due to additional LEO satellites (300+)



What is intra- and inter-system interference?

- Each correlator sees all signals from all satellites, but only one is the desired signal

- All other signals are multiple access interference (MAI):
  - **Intra-system MAI (same system)**

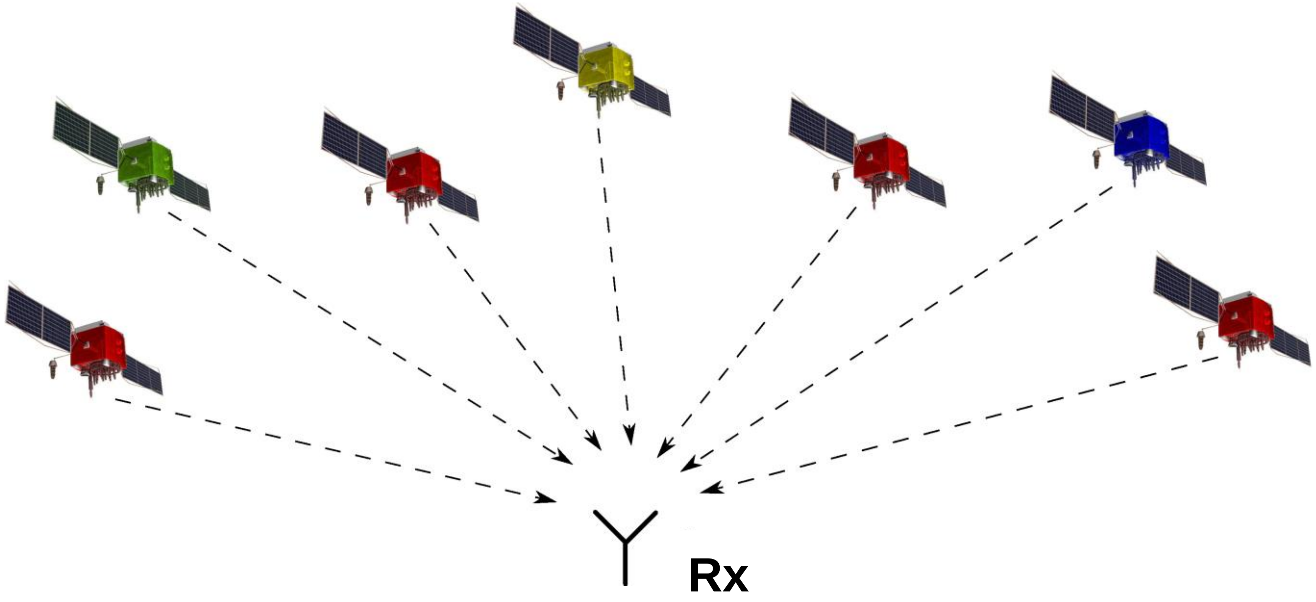


What is intra- and inter-system interference?

- Each correlator sees all signals from all satellites, but only one is the desired signal

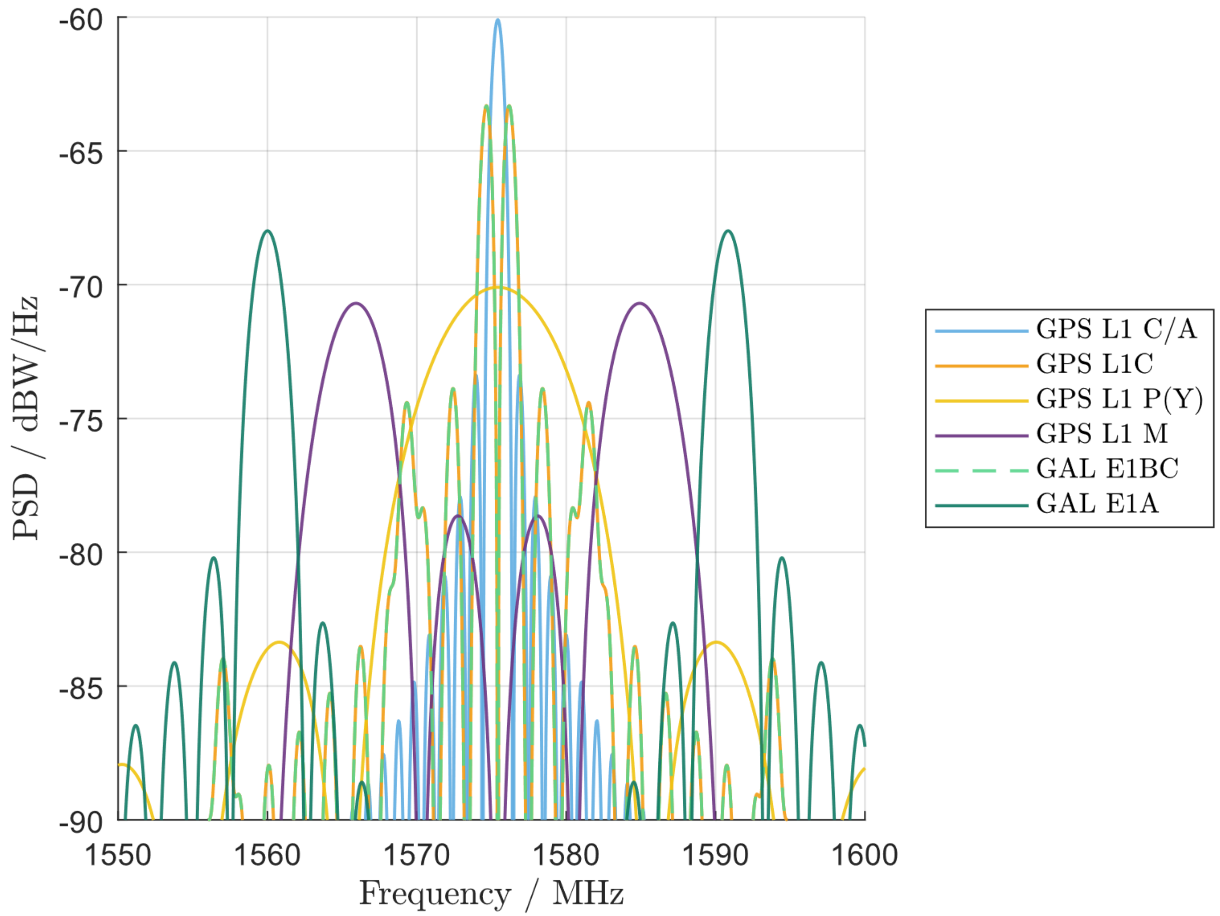
- All other signals are multiple access interference (MAI):
  - Intra-system MAI (same system)
  - **Inter-system MAI (other systems)**

- Mitigation of MAI:
  - Quasi-orthogonal PRN codes
  - Spectral Separation
  - Negotiations



Status quo in upper L-band

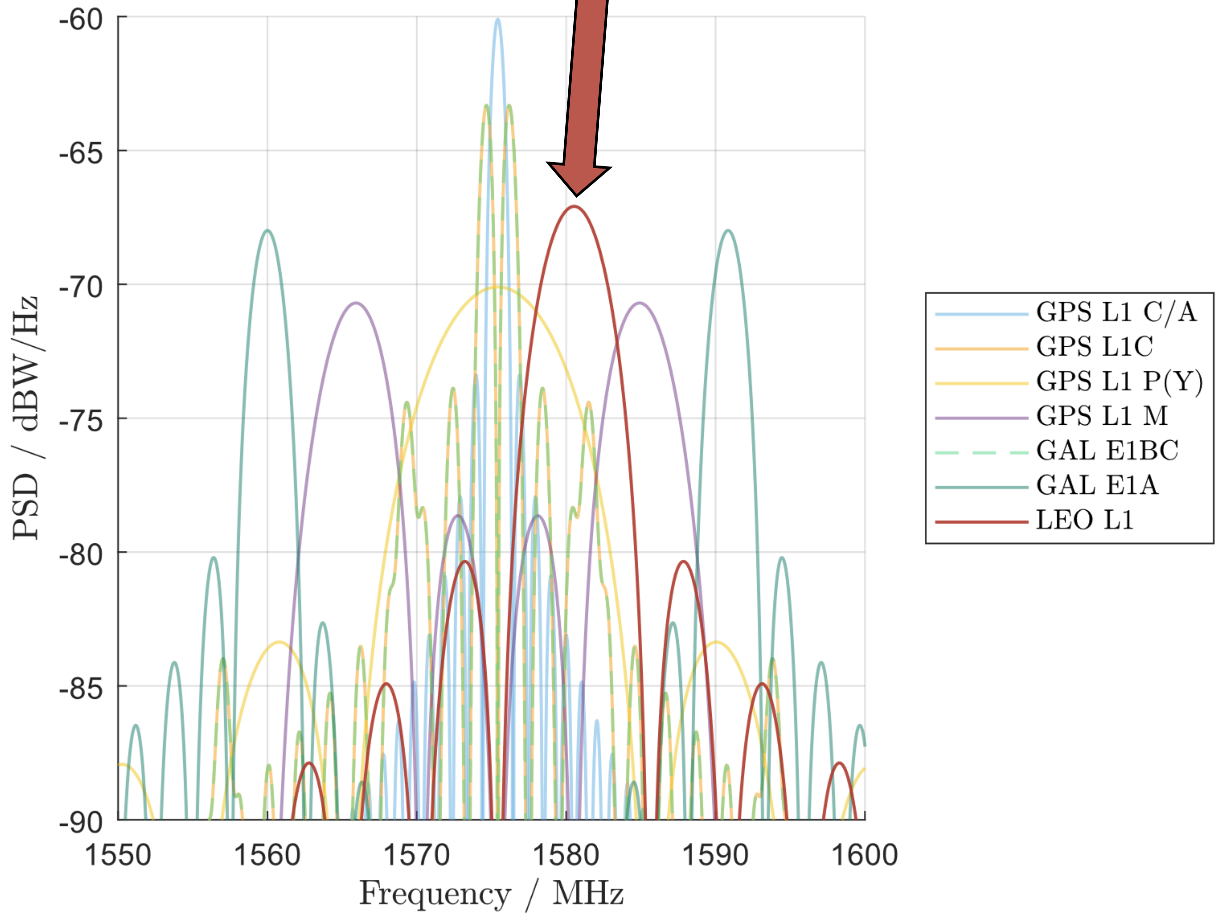
- Upper L-band is already spectrally congested
- Trade-off between
  - Ranging performance
  - Interoperability
  - Spectral separation



Multiple access interference challenges

- Upper L-band is already spectrally congested
- Trade-off between
  - Ranging performance
  - Interoperability
  - Spectral separation
- LEO signal candidates have been identified based on spectral separation considerations [1]

LEO signal candidate in L1:
OBPSK(5,5)



[1] Sharma, H., Dötterböck, D., and Pany, T., "Assessment of Potential System Interference through Radio Frequency Compatibility Analysis on Existing GNSS Frequencies by Emerging LEO Constellations," Proceedings of the 2024 International Technical Meeting of The Institute of Navigation, Long Beach, California, January 2024, pp. 490-504. https://doi.org/10.33012/2024.19555

Multiple access interference challenges

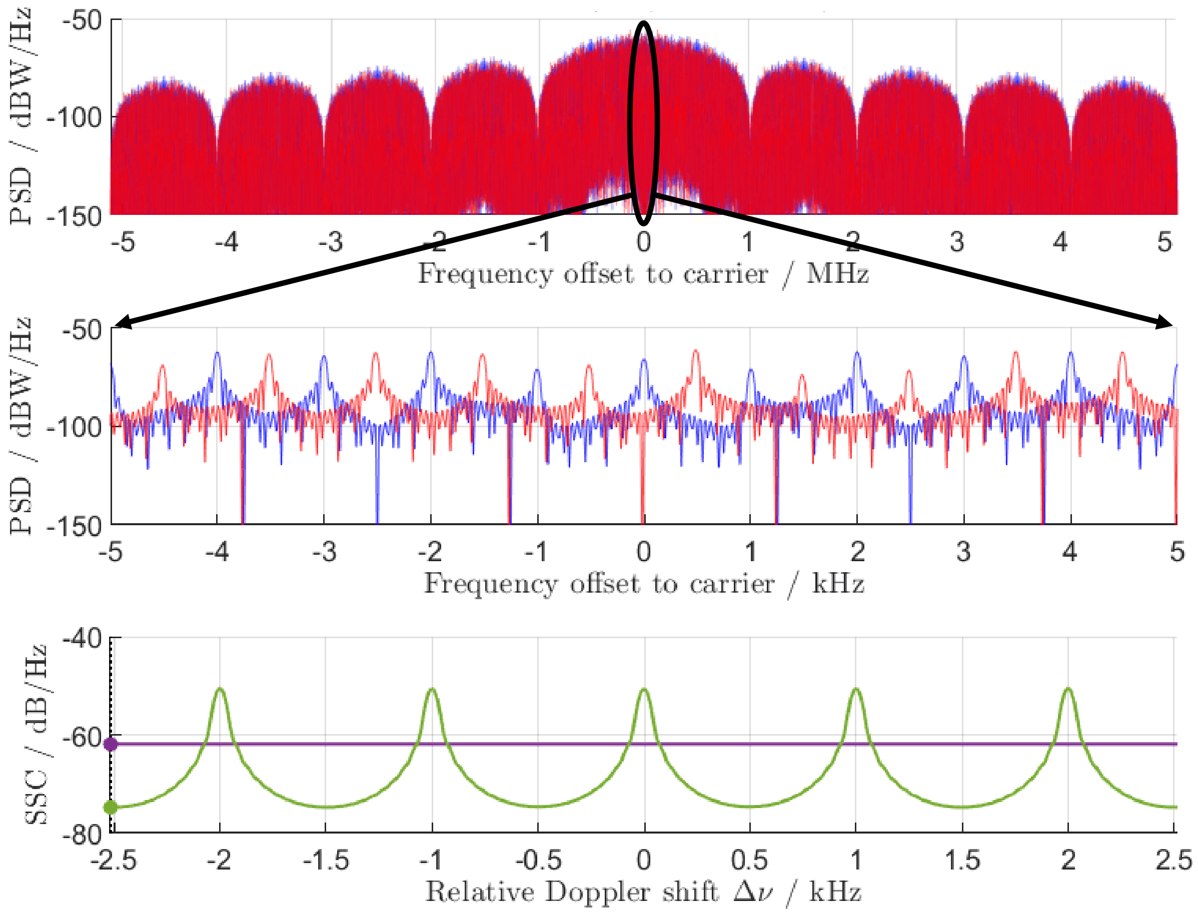
- Introduction of new signal/service would have to adhere to ITU-R M.1831
  - Standard is based on spectral separation coefficients (SSCs)
  - Standard lacks methodology for **short PRN codes** (L1 C/A-like)

*"The analytical model described above approximates the spectrum of the received signals as an aggregate spectrum, where the fine structures of individual signal spectra are averaged together into an essentially continuous spectrum. This "**continuous spectrum" modelling is valid for RNSS signals with long PRN codes**. (...)*

*However, this model is **not appropriate for analysis of short PRN codes** (…). In those cases, dynamic modelling is necessary to account for the detailed modulation properties of the signals, such as data rate and PRN code characteristics, as well as relative Doppler frequency shift (...)"* [2]

↔ C/A-like signal for LEO-PNT is desirable

Desired: GPS L1 C/A (PRN 1)
Interferer: GPS L1 C/A (PRN 2) [*intra*]



Standard model:	SSC = -61.86 dB/Hz
Refined model:	-74.72 dB/Hz ≤ SSC ≤ -50.43 dB/Hz

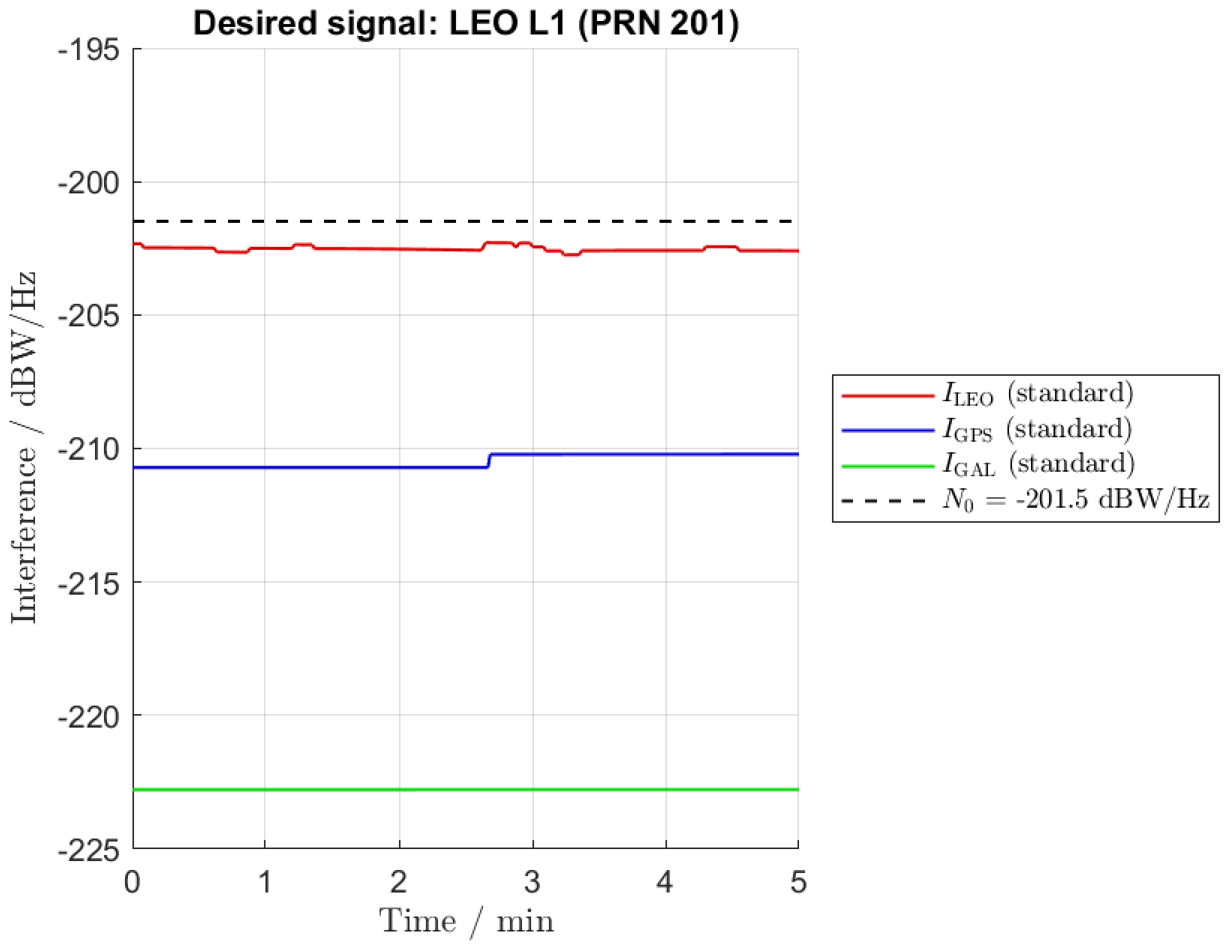
[2] ITU-R M.1831-1, Section 6

MAI assessment – Desired signal: LEO L1

- Desired signal LEO L1:
  - OBPSK(5,5)
  - 50 Hz data stream
  - 1023 chips PRN code

- Interferer
  - Intra-system: LEO
  - Inter-system: GPS
  - Inter-system: Galileo

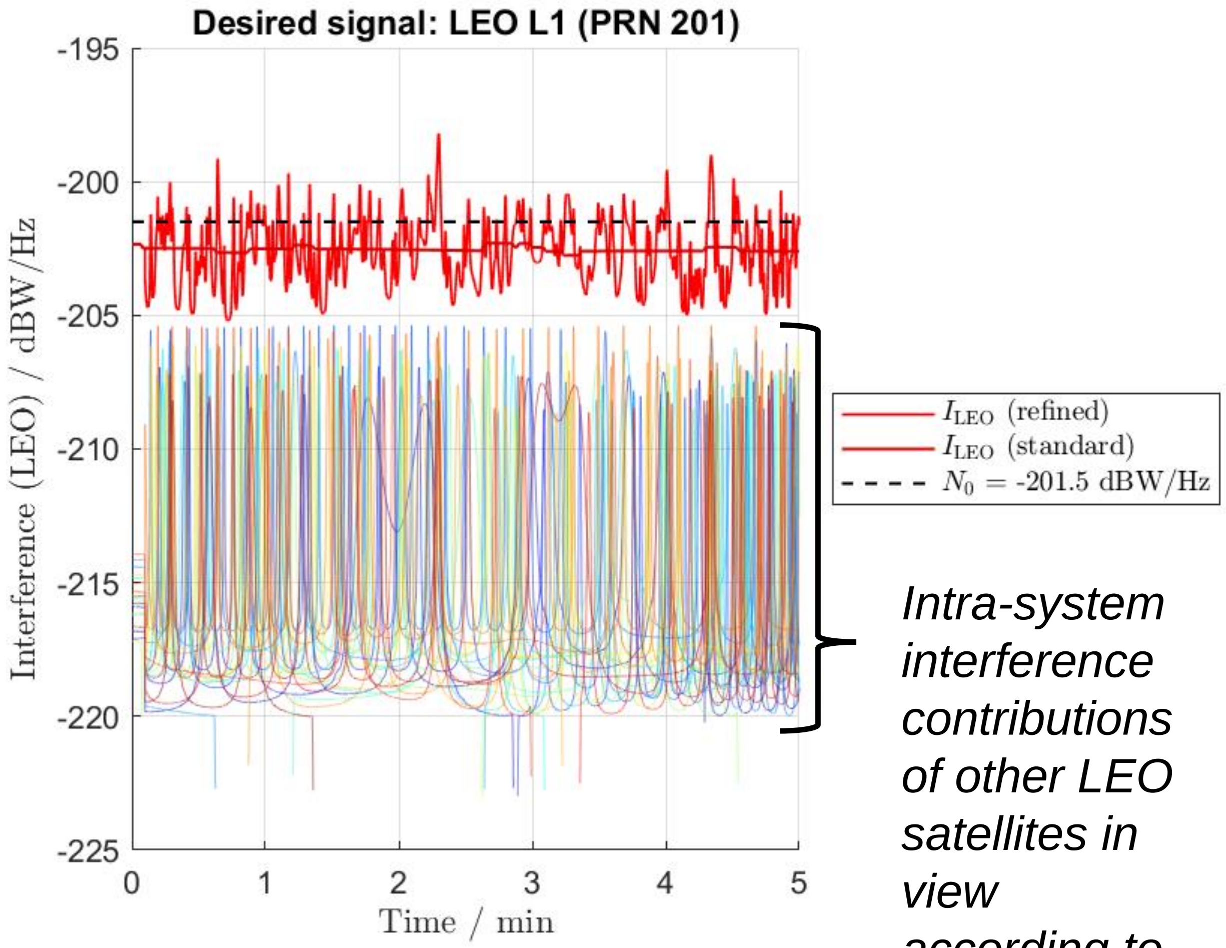
- Standard model:
  - Variations due to satellite visibility and antenna patterns



MAI assessment – Desired signal: LEO L1

- Standard model:
  - Fluctuations due to satellite visibility and antenna patterns

- Refined model:
  - Fluctuations due to satellite visibility, antenna patterns and **relative Doppler**
  - Superposition of individual interferers leads to **intra-system interference** peaks exceed noise floor of $N_0 = $ -201.5 dBW/Hz (e.g. mass-market receiver)



Intra-system interference contributions of other LEO satellites in view according to refined model

MAI assessment – Desired signal: LEO L1

- Constellation simulation for one user position:
  - Systems: GPS, Galileo, & LEO
  - Sampling: 1s
  - Duration: 24h
  - Satellite parameters: gain pattern, transmit power

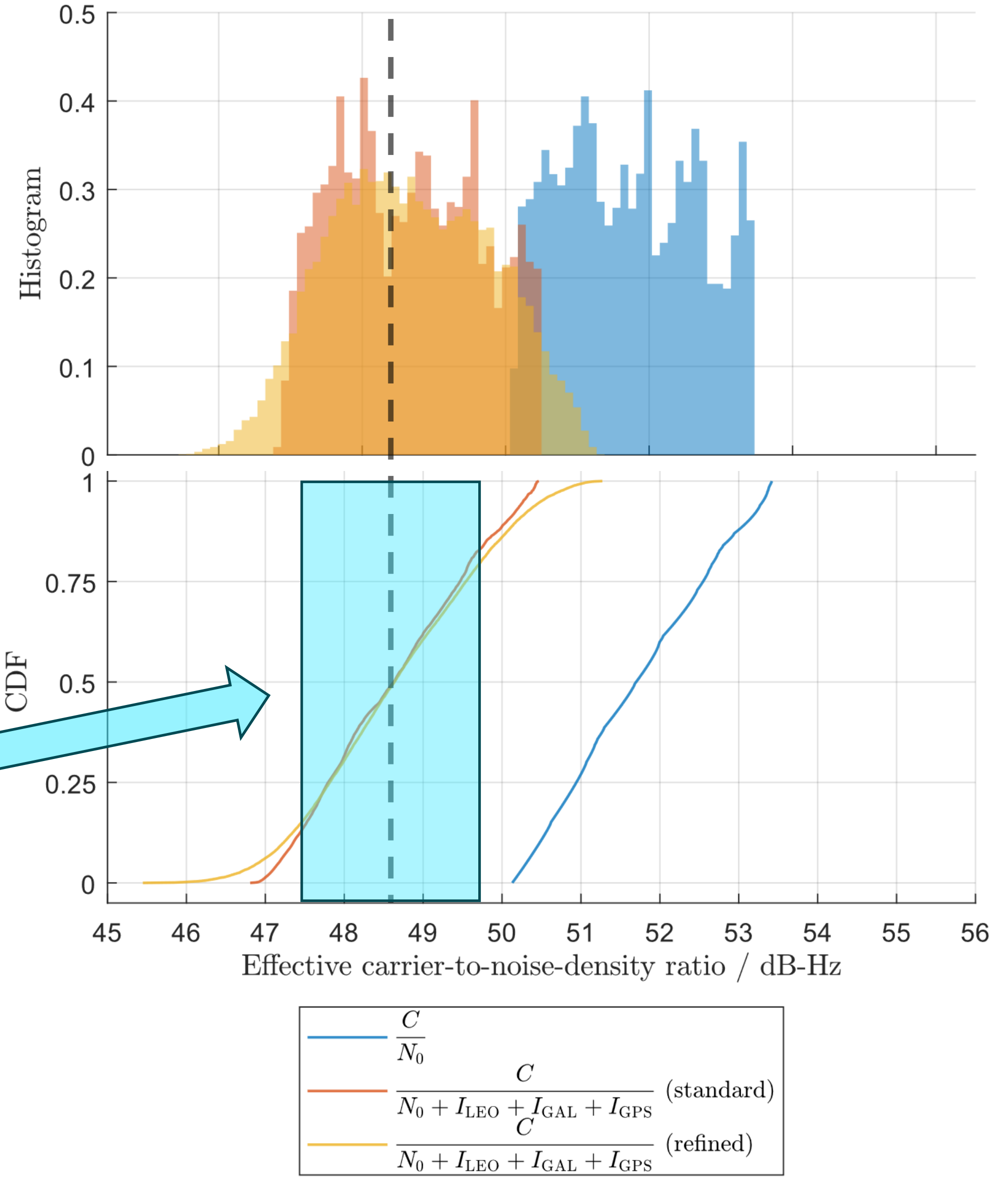
➔Retrieve values for C, I_{GPS}, I_{GAL}, & I_{LEO} for each time stamp

➔Evaluate histogram of effective C/N_0

➔Derive cumulative distribution functions (CDFs)

- Medians of standard and refined model align well
  ➔ Standard model sufficient for MAI analysis based on averages

Example: N45°E00°



Mean effective carrier-to-noise density ratio: LEO L1

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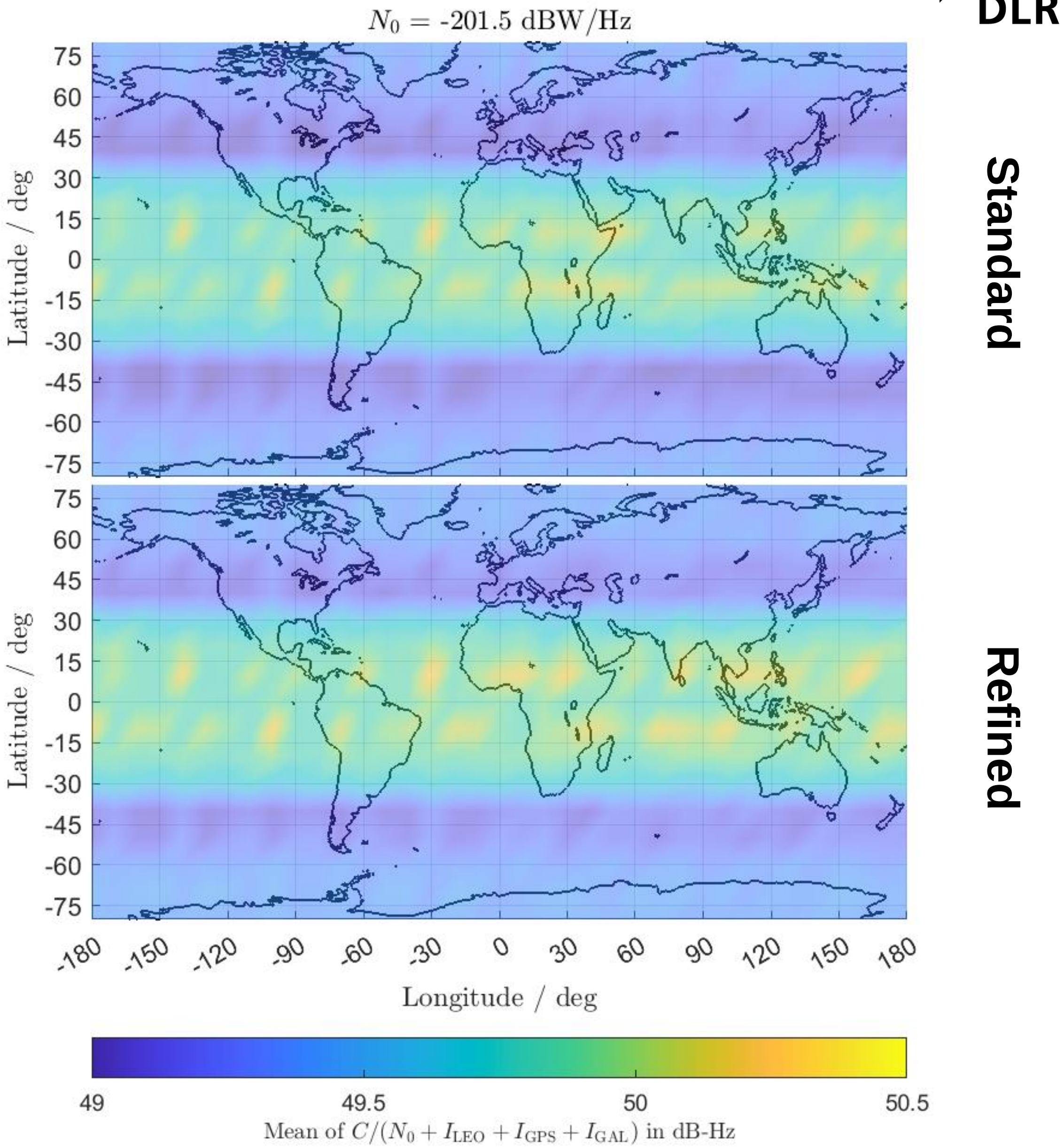

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- Extreme cases captured better with refined model
  ➔ Refined model suitable for interference over-bounding

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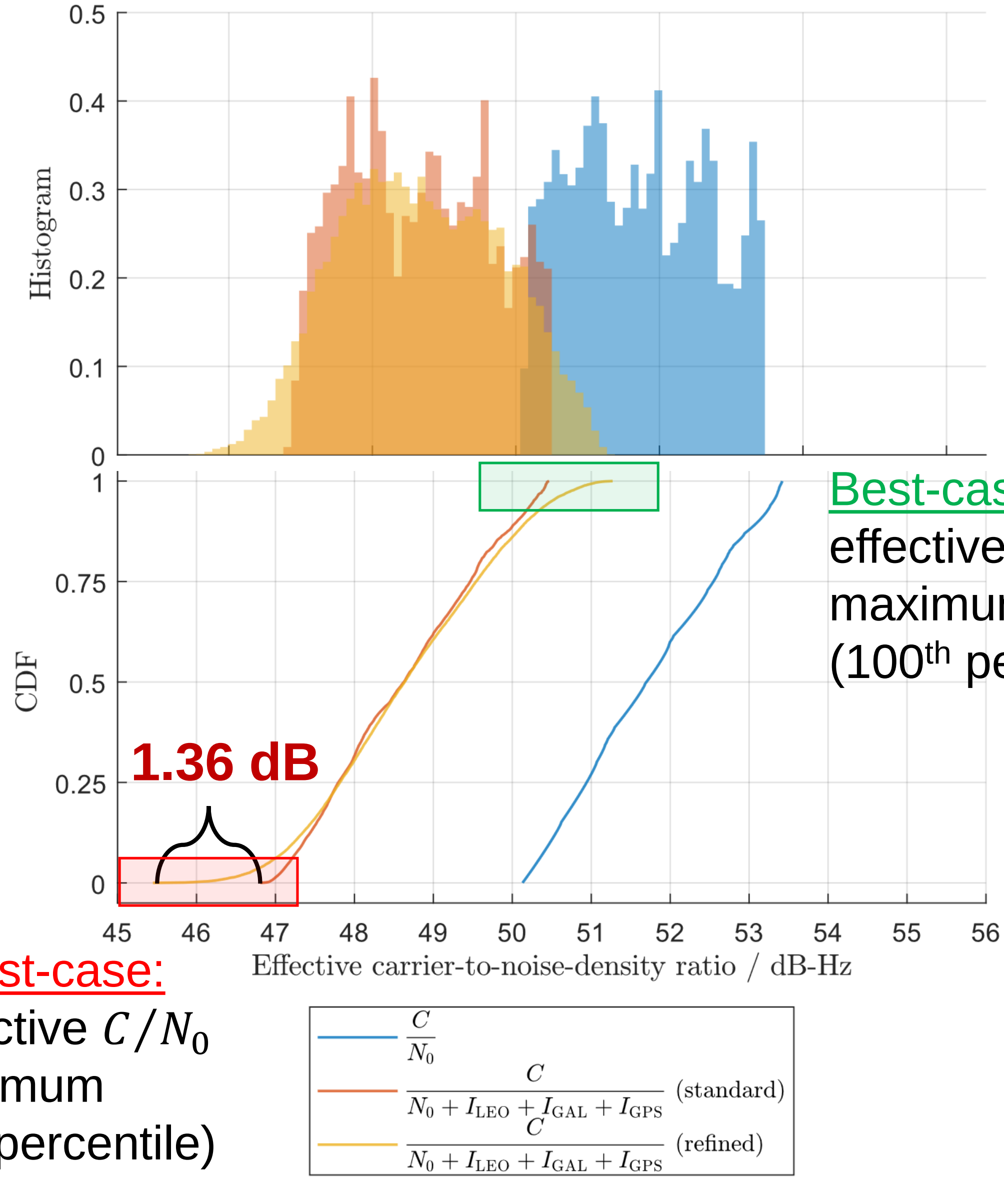

Best-case:
effective C/N_0 maximum (100th percentile)

Worst-case:
effective C/N_0 minimum (0th percentile)

Minimum effective carrier-to-noise density ratio: LEO L1

- Constellation simulation for one user position:
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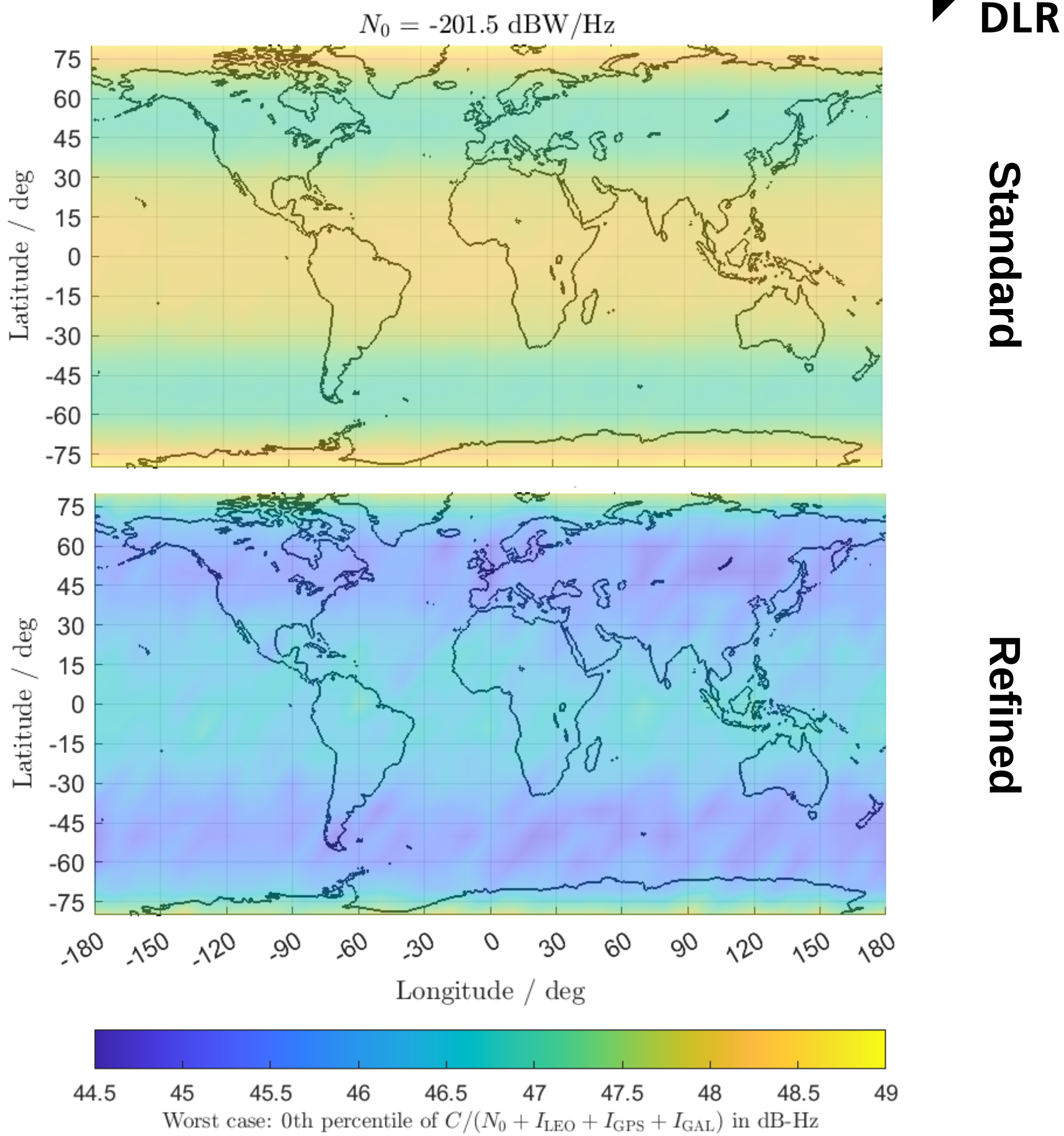
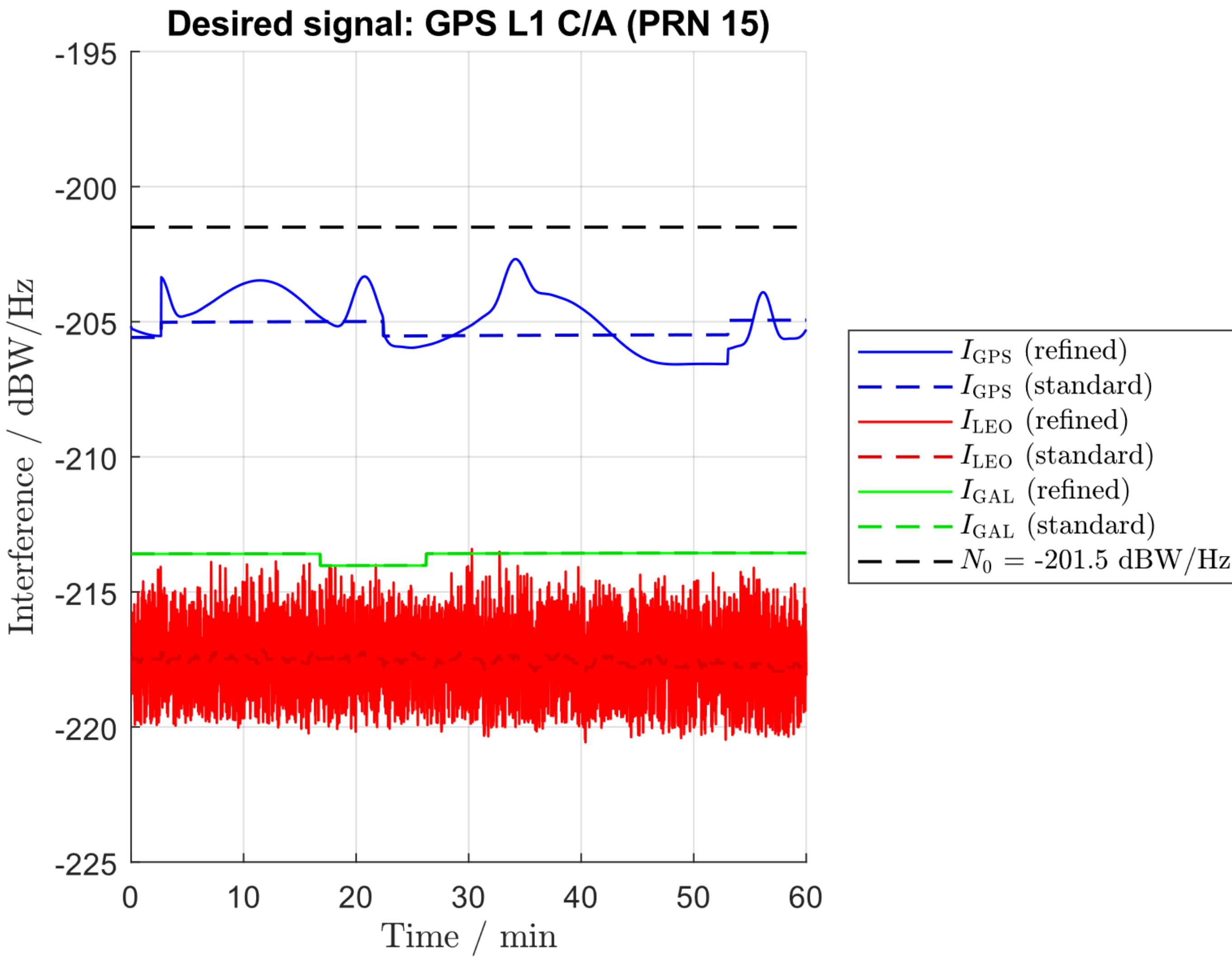


MAI assessment – Desired signal: GPS L1 C/A

- Desired signal GPS L1 C/A:
  - BPSK(1)
  - 50 Hz data stream
  - 1023 chips PRN code

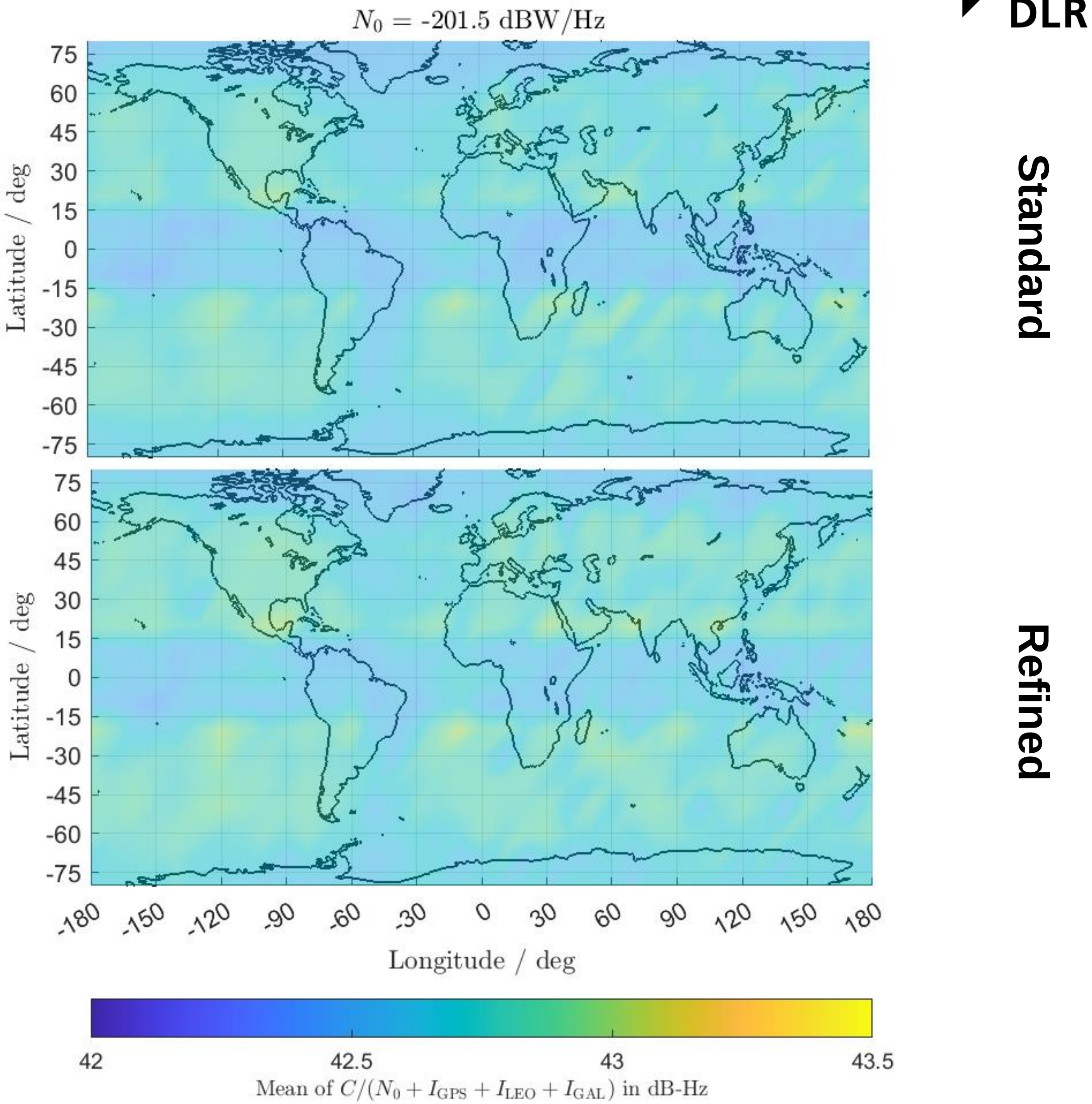
- Interferer
  - Intra-system: GPS
  - Inter-system: LEO
  - Inter-system: Galileo

- Refined model
  - MEO 🡐 MEO interference variations slower than MEO 🡐 LEO
  - Noise floor is above individual MAI terms



Mean effective carrier-to-noise density ratio: GPS L1 C/A

- Behavior of mean effective C/N_0 across globe
  - Standard: moderate variation (+/- 1 dB)
  - Refined: moderate variation (+/- 1 dB)



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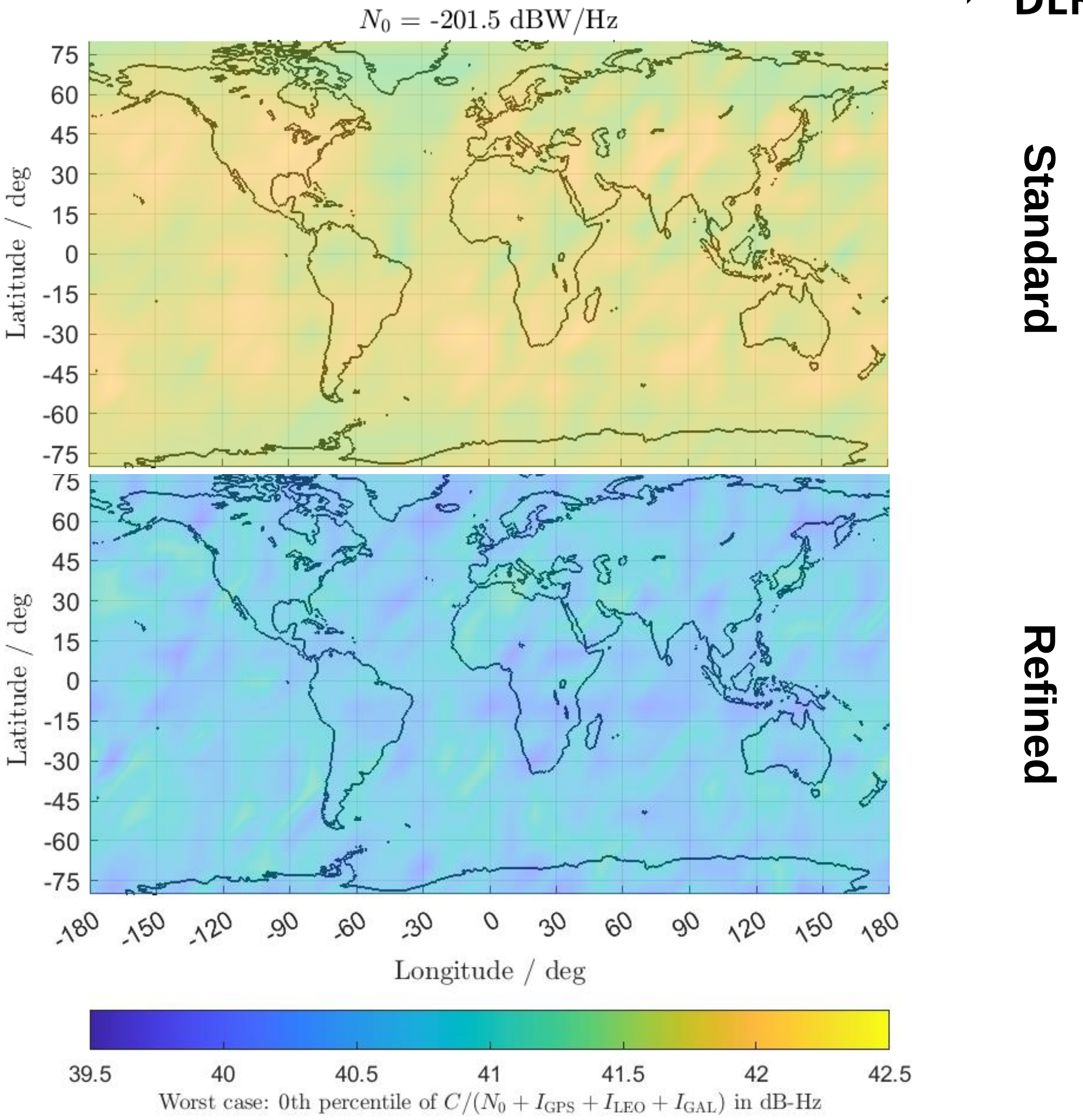
- Behavior of minimum effective C/N_0 across globe
  - Standard: moderate variation (+/- 1 dB)
  - Refined: moderate variation (+/- 1 dB) at lower base level than standard model



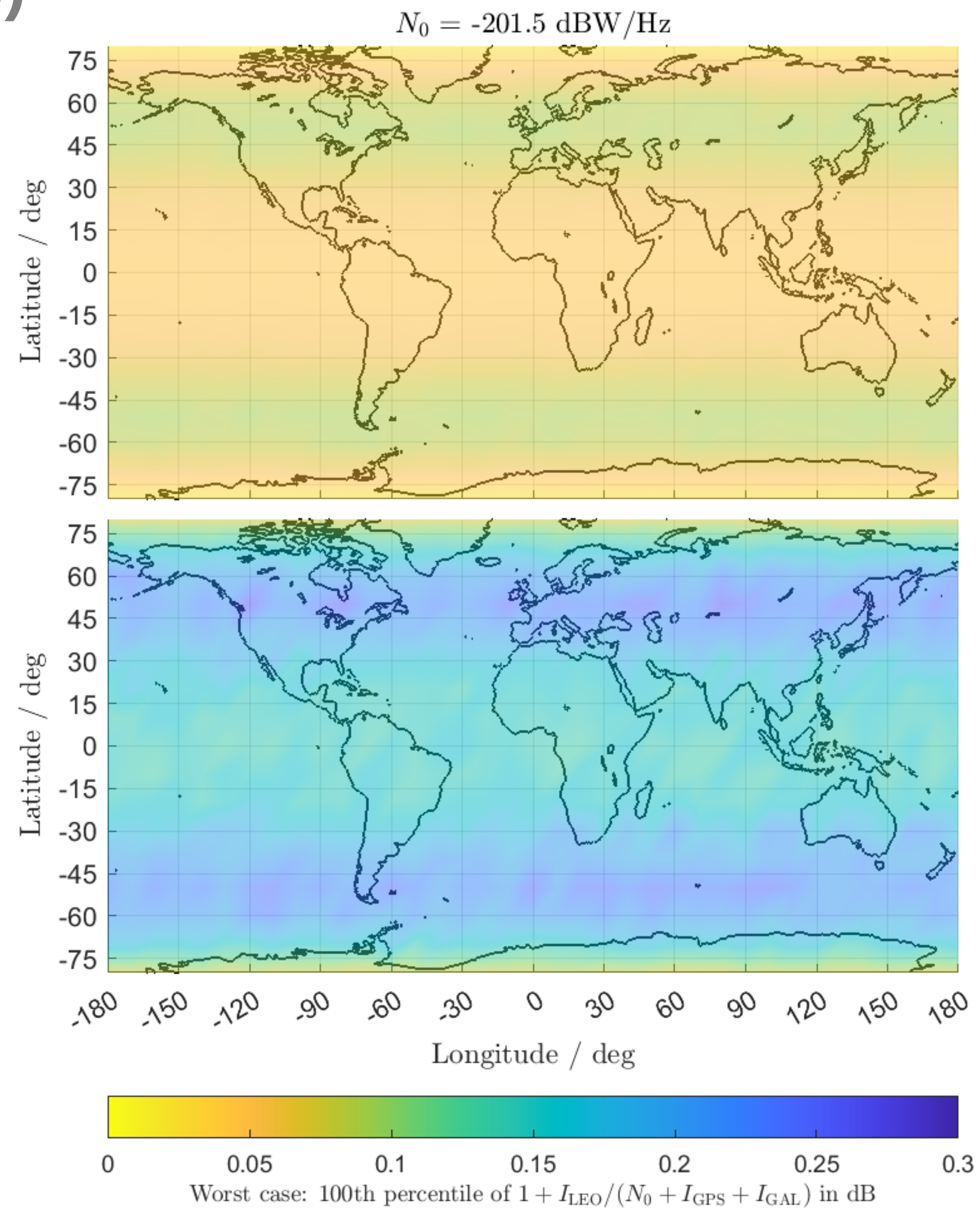
Maximum effective carrier-to-noise density ratio degradation: GPS L1 C/A 🡐 LEO L1 (OBPSK(5,5))

- Behavior of mean effective C/N_0 across globe
  - Standard: moderate variation (+/- 1 dB)
  - Refined: moderate variation (+/- 1 dB)

- Behavior of minimum effective C/N_0 across globe
  - Standard: moderate variation (+/- 1 dB)
  - Refined: moderate variation (+/- 1 dB) at lower base level than standard model

➔Refined model captures maximum effective C/N_0 degradation better than standard model

➔Mid-latitudes (~N50° / S50°) experience strongest degradation



Standard

Refined

Conclusion

If an emerging LEO-PNT broadcasts a C/A-like acquisition signal:

- Standard model can lead to too optimistic assumptions
- Refined model captures maximum effective C/N_0 degradation better than standard model ➔ more suitable for interference over-bounding

Future research

- Further scenarios
  - Variation of constellation parameters
    - Number of satellites
    - Orbit height
  - Signal parameters
    - Code rate
    - Code length
    - Data rate
    - Modulation
    - Center frequency

Thank you very much for your attention!

Imprint

Title:	Multiple Access Interference Challenges in GNSS: The Role of Emerging LEO-PNT Constellations
Date:	2024-12-12
Autor:	Florian C. Beck
DLR-Institute:	Kommunikation und Navigation
Picture credits:	German Aerospace Center (DLR)

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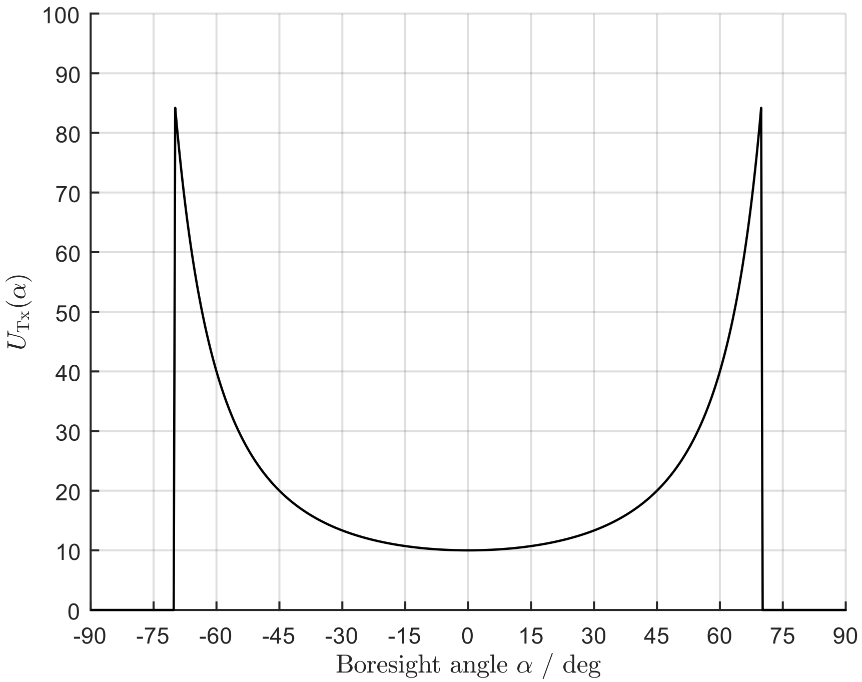
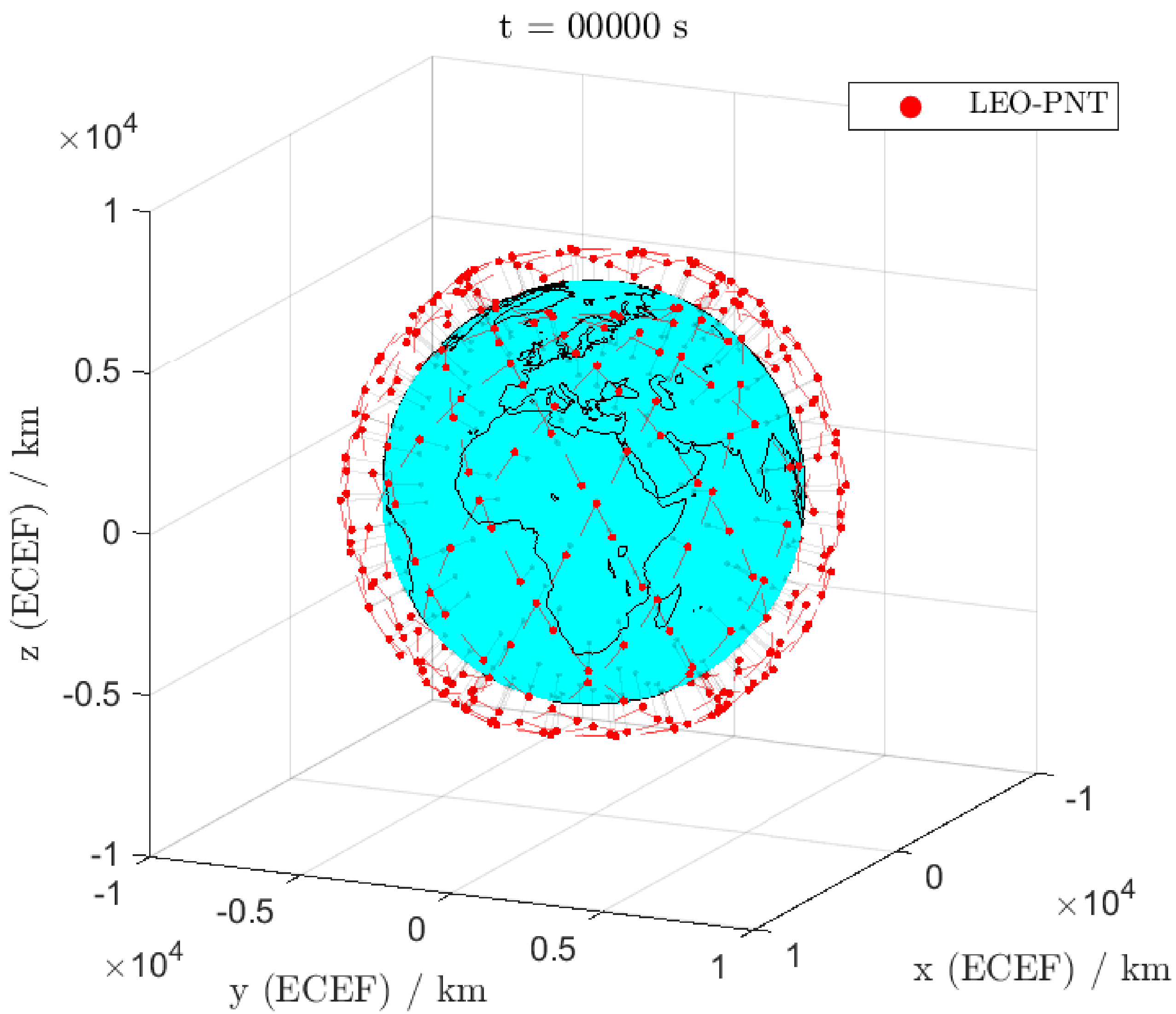
Back-up: LEO-PNT system parameters

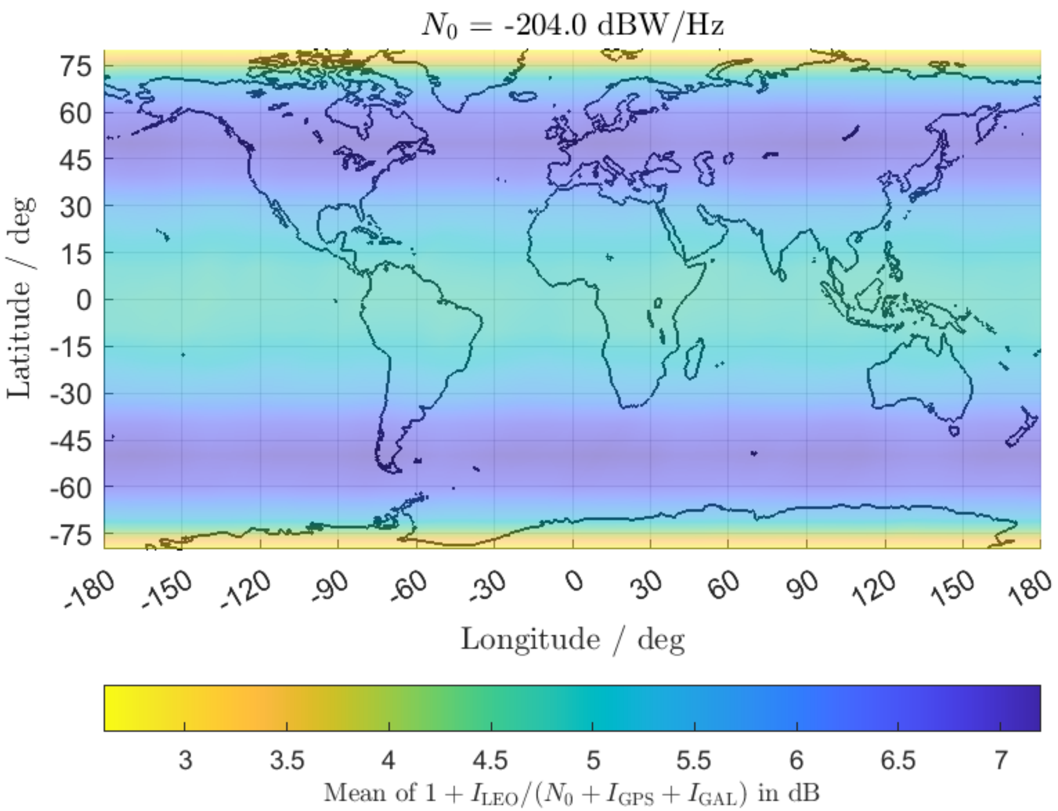
- 338 satellites in 13 planes
- 60° inclination
- 1200 km orbit height
- Minimum receive power: -155 dBW
- Maximum receive power: -145 dBW
- Transmit antenna gain:



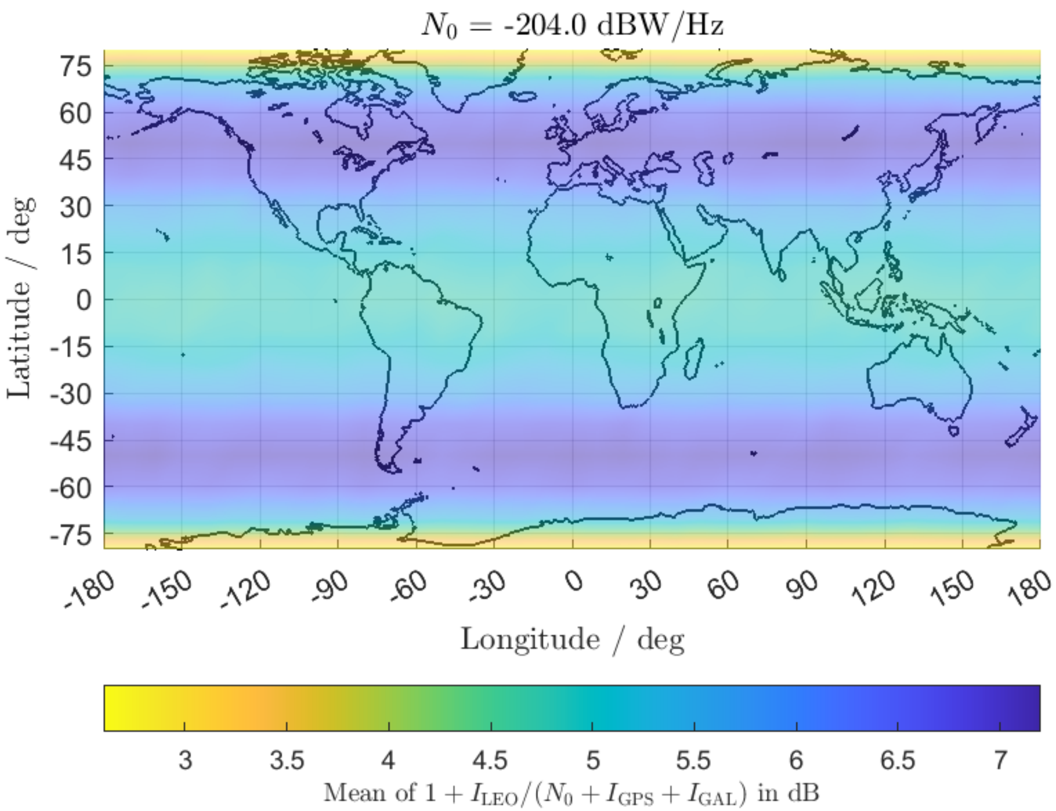


Back-up: LEO-PNT with BPSK(1) without offset

Standard



Refined



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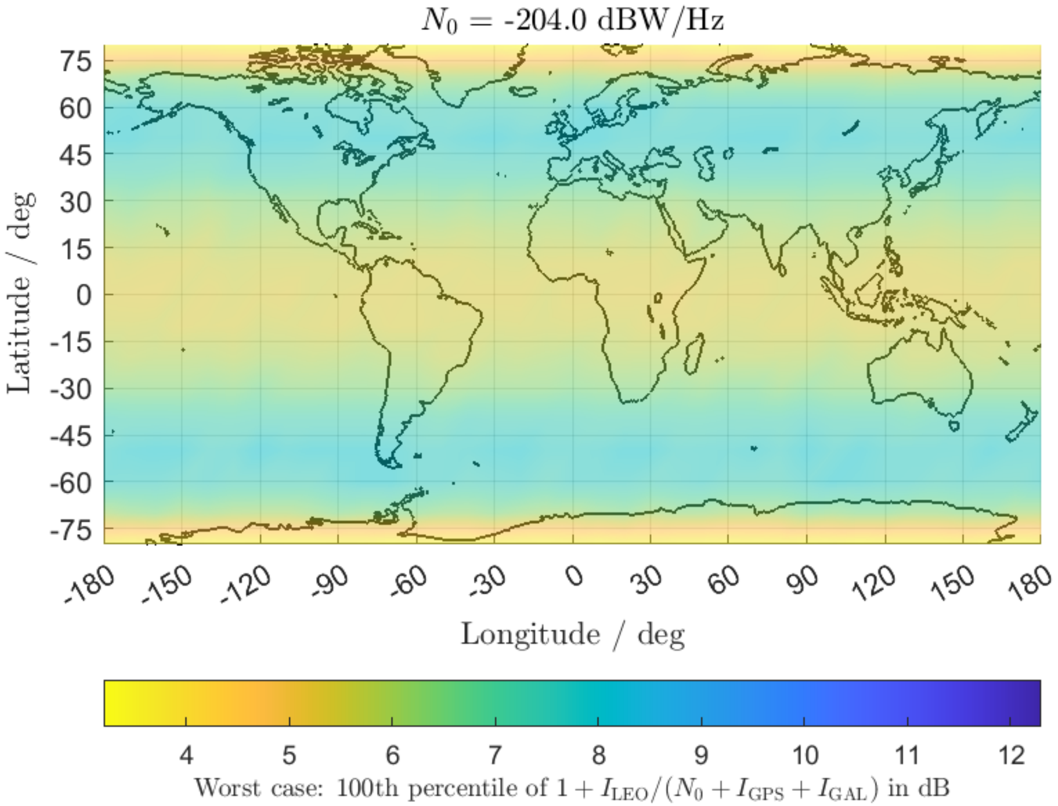

Refined