Research Center Space
Universität der Bundeswehr München

Session B3: GNSS Integrity and Robustness in Safety-Critical Applications

A case study for potential implications on the reception of Galileo E6 by amateur radio interference on German highways considering various transmitter-receiver-signal combinations

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Outline

The Galileo E6 Band and Amateur Radio Signals

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- Signals
- Transmitters
- Receivers

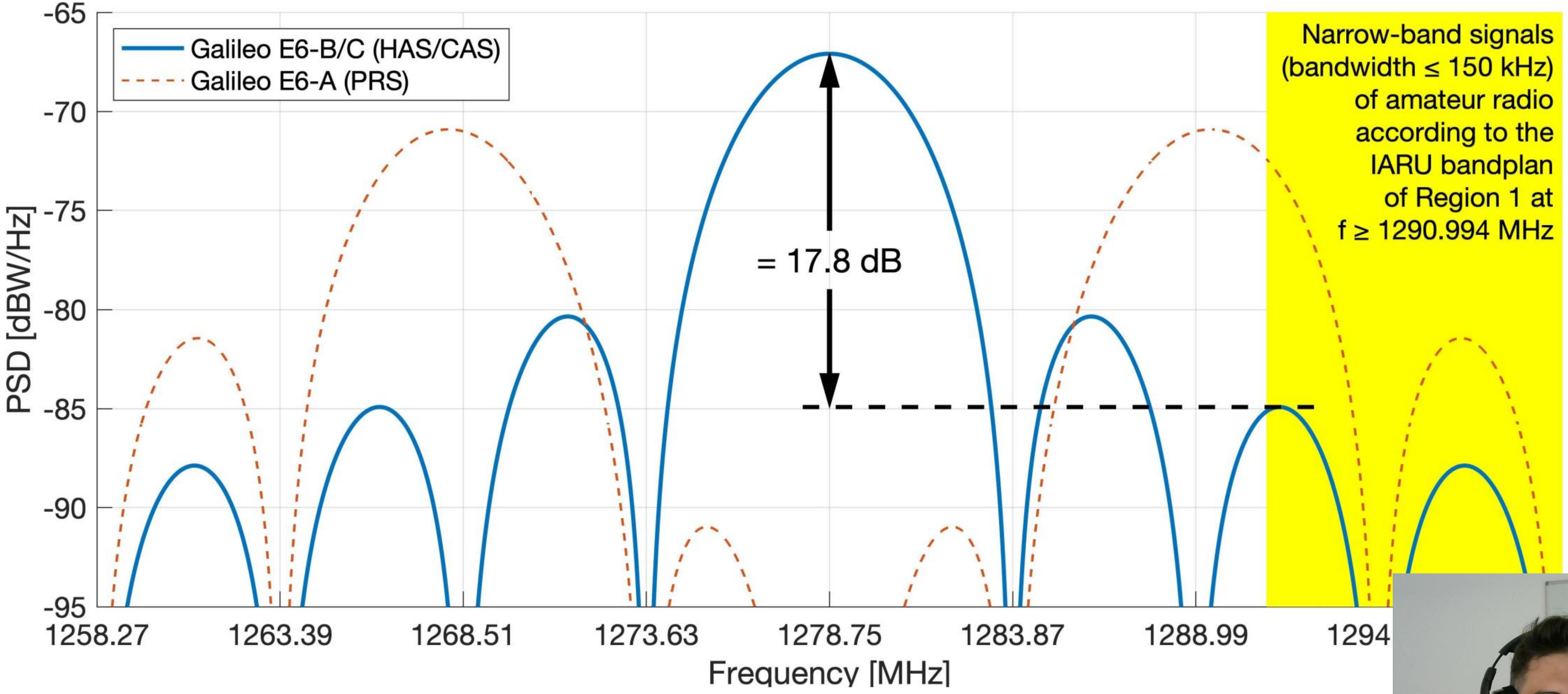
Identify Areas of Conflict and Coexistence

Setup and Heatmaps

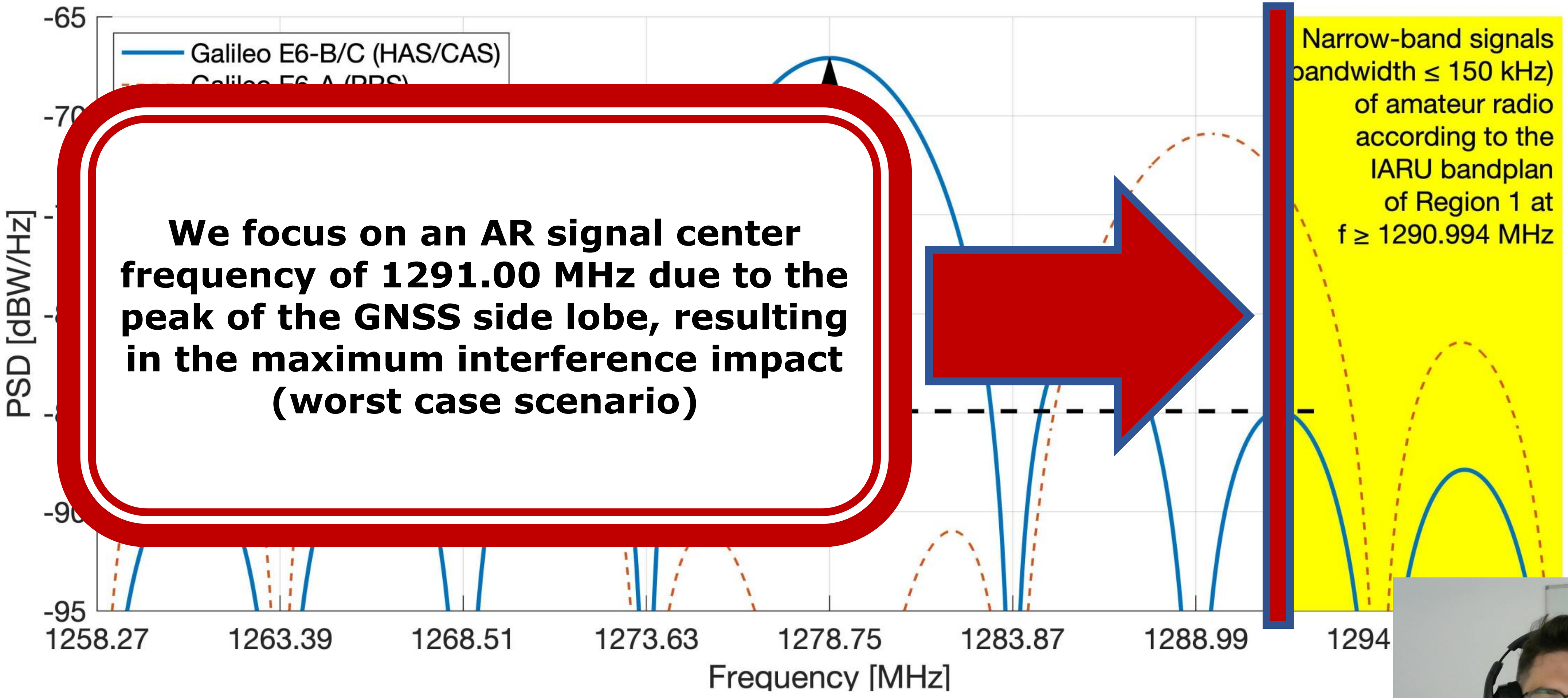
The Galileo E6 Band and Amateur Radio Signals

Satellite and Amateur Radio Signal Plan

The Galileo E6 Band and & AR Signals



The Galileo E6 Band and & AR Signals



We focus on an AR signal center frequency of 1291.00 MHz due to the peak of the GNSS side lobe, resulting in the maximum interference impact (worst case scenario)

The Galileo E6 Band and & AR Signals

- The presence of interference causes the satellite $CN0$ to become:

$$CN0_{effective} = \frac{C}{N_0 + \frac{I_{in}}{QR_c}}$$

- R_c … Chip-rate
- Q … $Quality$ -factor
- I_{in} … Received Power from Interference
- C … Received Power from Satellite
- N_0 … Noise Power Spectral Density

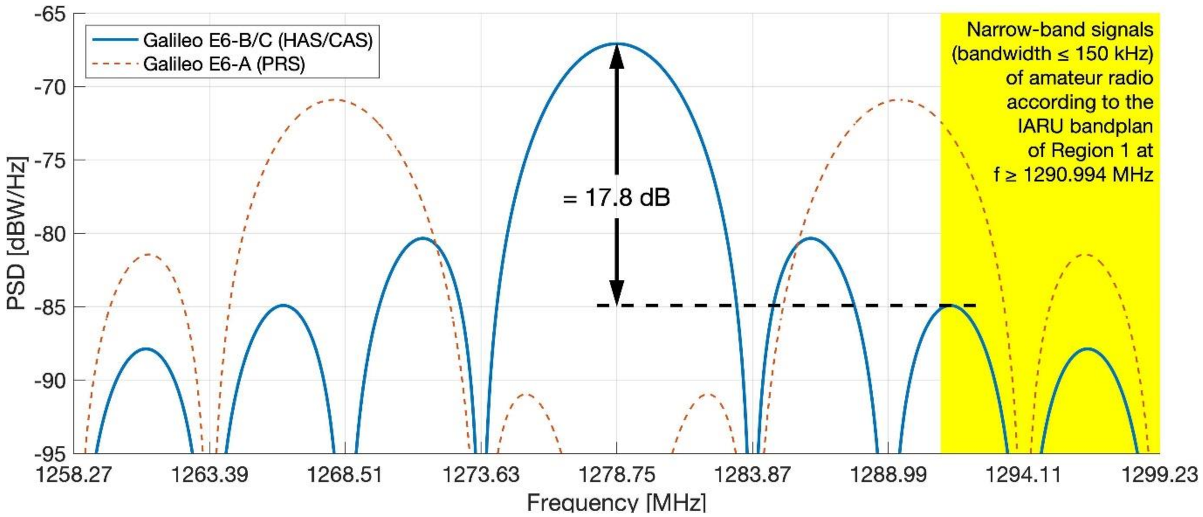
The Galileo E6 Band and & AR Signals

- We use the Q-factor to describe the robustness of the receiver with respect to the interference signal

- A Q-factor of $0dB$ would indicate a single spectrum line interference at center frequency, assuming an infinite bandwidth receiver with no filter

- Approximate Q-factor for interference on side lobe:

$$Q = 84.9\,dB - 67.1\,dB = 17.8\,dB$$



General Assumptions

Setting up the perimeter for the investigation

General Assumptions

- We aim to assume representative transmitter/receiver characteristics without loss of generality:
  - AR transmitter is an isotropic antenna
  - “Worst case”, no influence of topography and foliage considered
  - 5° elevation for interfering signals
  - Signal degradation is in first approximation independent of abs. satellite $CN0$
  - Reception of only one single amateur transmitter at a time

General Assumptions

- We define 2 signals to investigate, again without loss of generality:
  - CW-signal like FM Voice (up to $20\ \mathrm{kHz}$ Bandwidth) at $1291.00\ MHz$

    Low power signal
  - FSK-Signal ($150\ \mathrm{kHz}$ Bandwidth) with a fixed sequence of typical data traffic at $1291.00\ MHz$

    High power signal

General Assumptions

- We define 3 receivers to investigate, again without loss of generality:
  - Infinite Bandwidth, no filter according to Galileo ICD, $Q = 15\ dB$
    Galileo ICD Receiver
  - $30\ \mathrm{MHz}$ Bandwidth with frequency offset, $Q = 50\ dB$
    Geodetic Receiver
  - $15 - 20\ \mathrm{MHz}$ MHz Bandwidth, input filter, $Q = 50\ dB$
    Mass-Market Automotive Receiver

Identify Areas of Conflict and Coexistence

Generating easy access to location associated Interference information

Identify Areas of Conflict and Coexistence

Scenario:

Positioning and Navigating an autonomous car on a German Highway with lane accuracy in open sky conditions.

Primary service to receive GNSS corrections is the Galileo High-Accuracy Service, Verification through Galileo Open Service Navigation Message Authentication.

What is the impact of potential AR interference on the user?

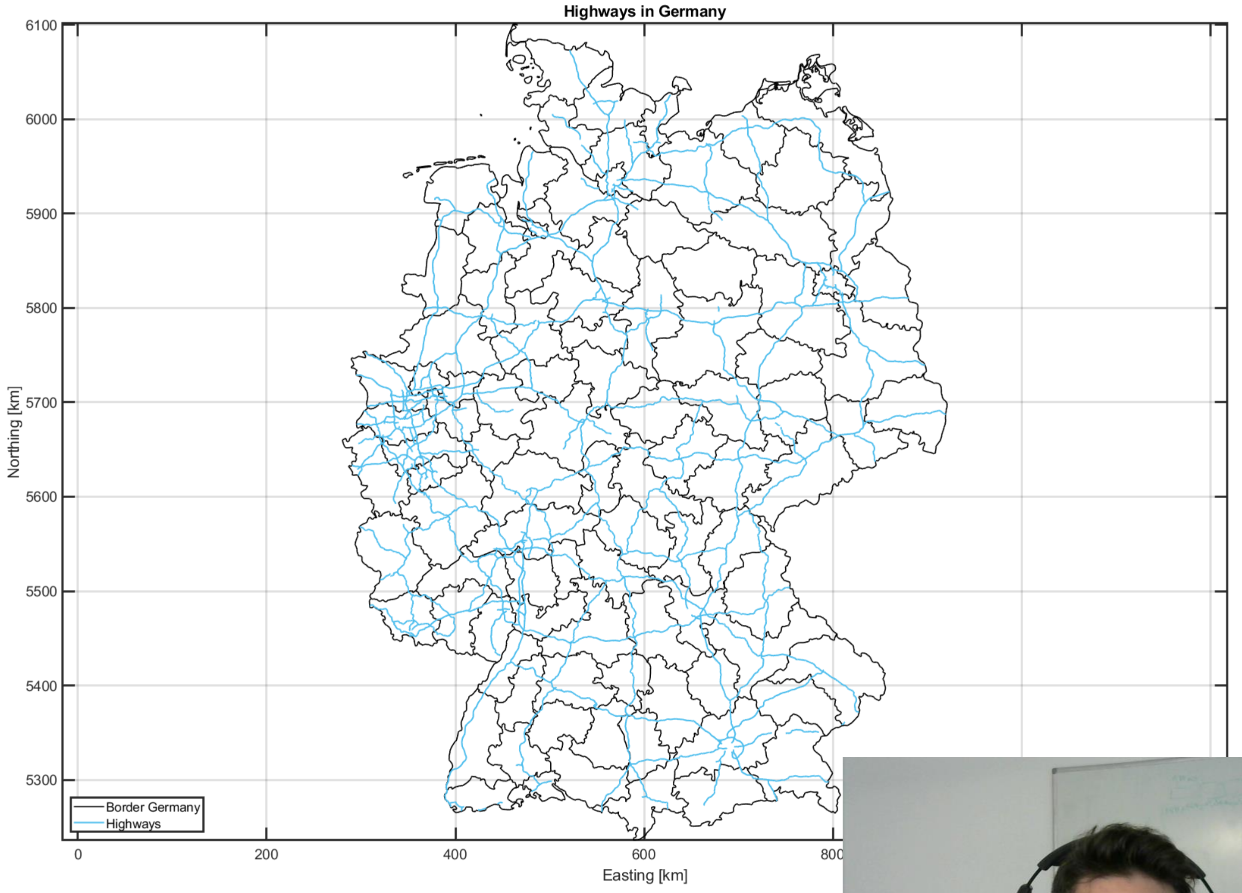
Identify Areas of Conflict & Coexistence

- The significance of the interference is chosen to be represented by the **difference in signal strength** $\Delta CN0 = CN0 - CN0_{effective}$
- $\Delta CN0$ is the difference between **undisturbed** satellite signal strength at the receiver $CN0$ and the satellite signal power received **in presence of interference** $CN0_{effective}$
- $CN0_{effective}$ however depends on multiple parameters

Identify Areas of Conflict & Coexistence

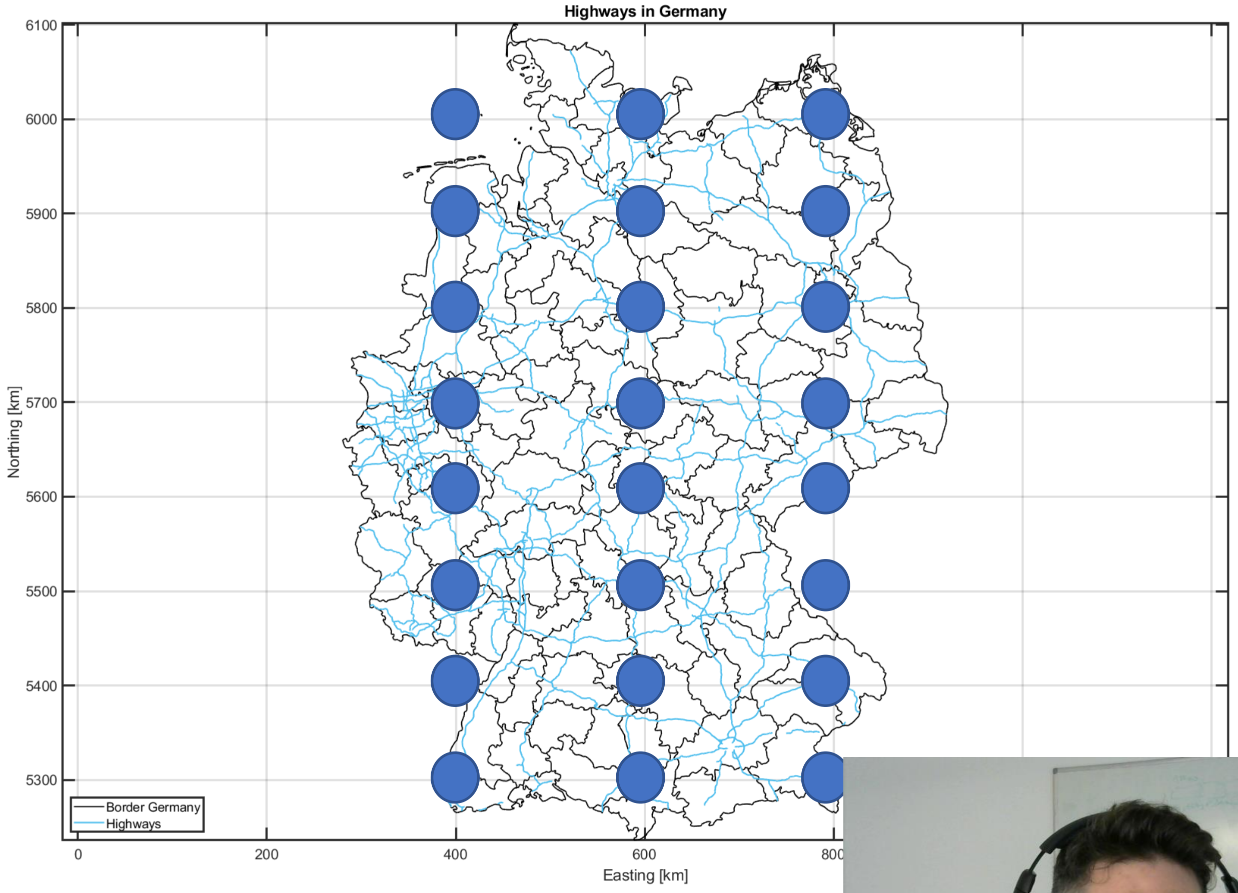
Target:

Compute $CN0_{effective}$ for a specific AR transmitter – GNSS receiver combination at the nearest highway point of effect, given a specific transmitter location.



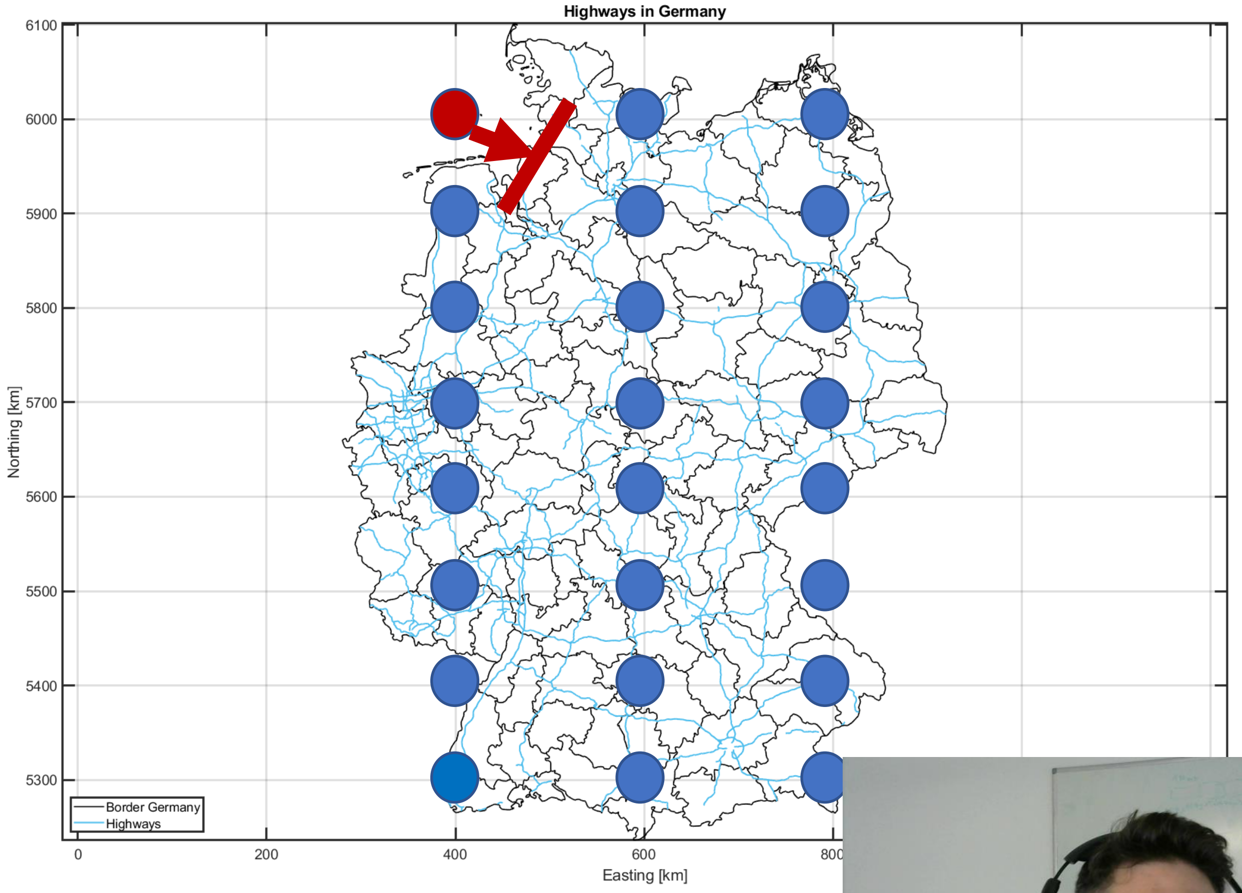
Identify Areas of Conflict & Coexistence

1. Lay a $250\,m$ spaced grid over Germany



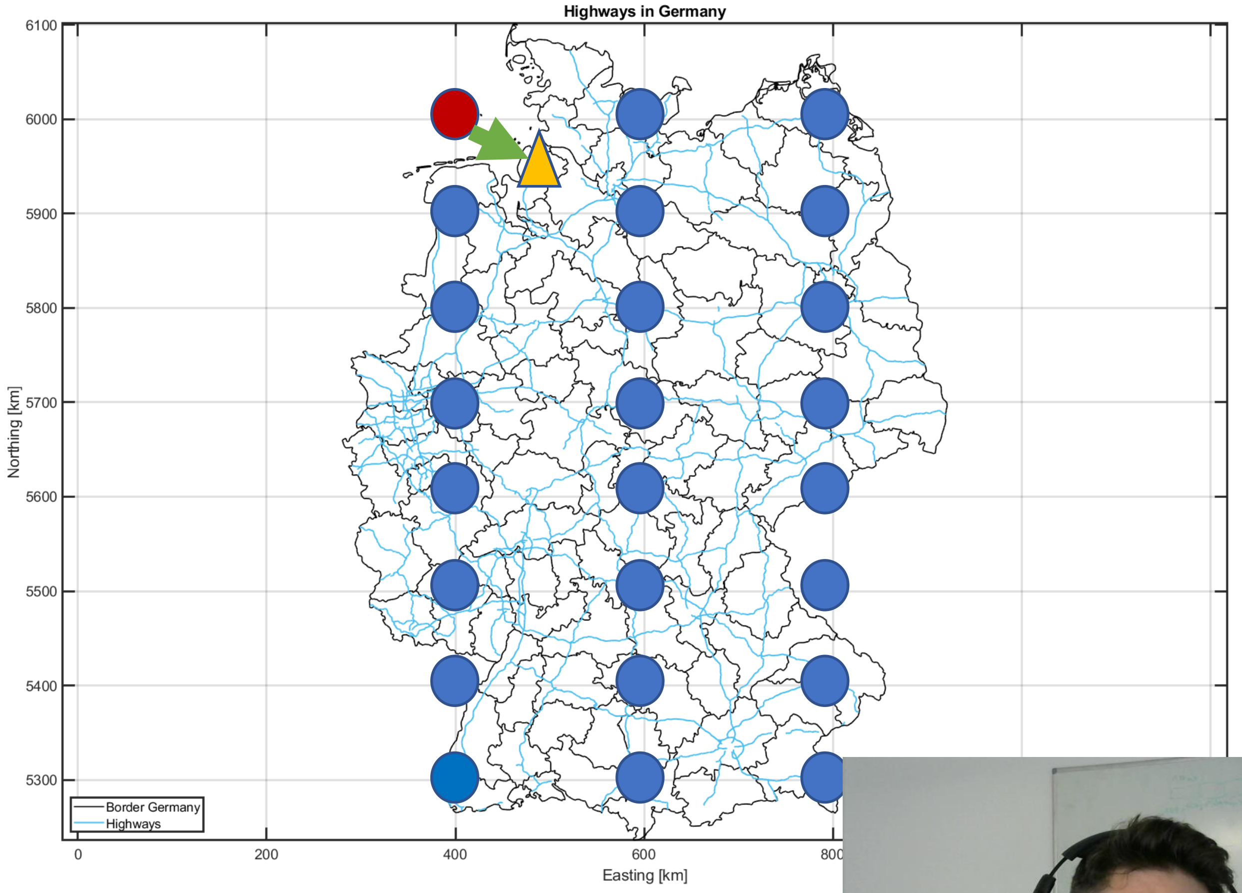
Identify Areas of Conflict & Coexistence

1. Lay a $250\,m$ spaced grid over Germany
2. Start at point 1 and compute the distance to the nearest highway



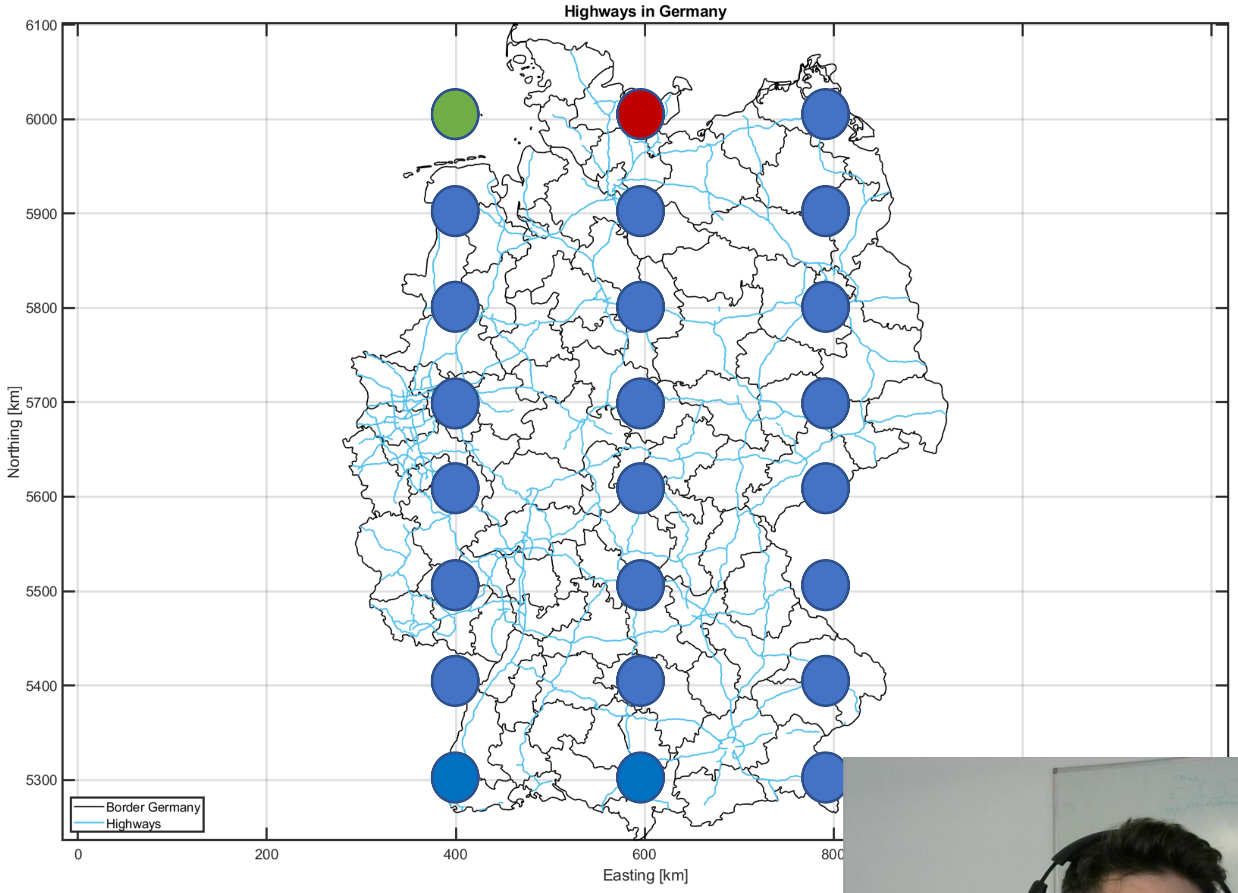
Identify Areas of Conflict & Coexistence

1. Lay a $250\,m$ spaced grid over Germany
2. Start at point 1 and compute the distance to the nearest highway
3. Compute & store Link Budget respective $CN0_{effective}$



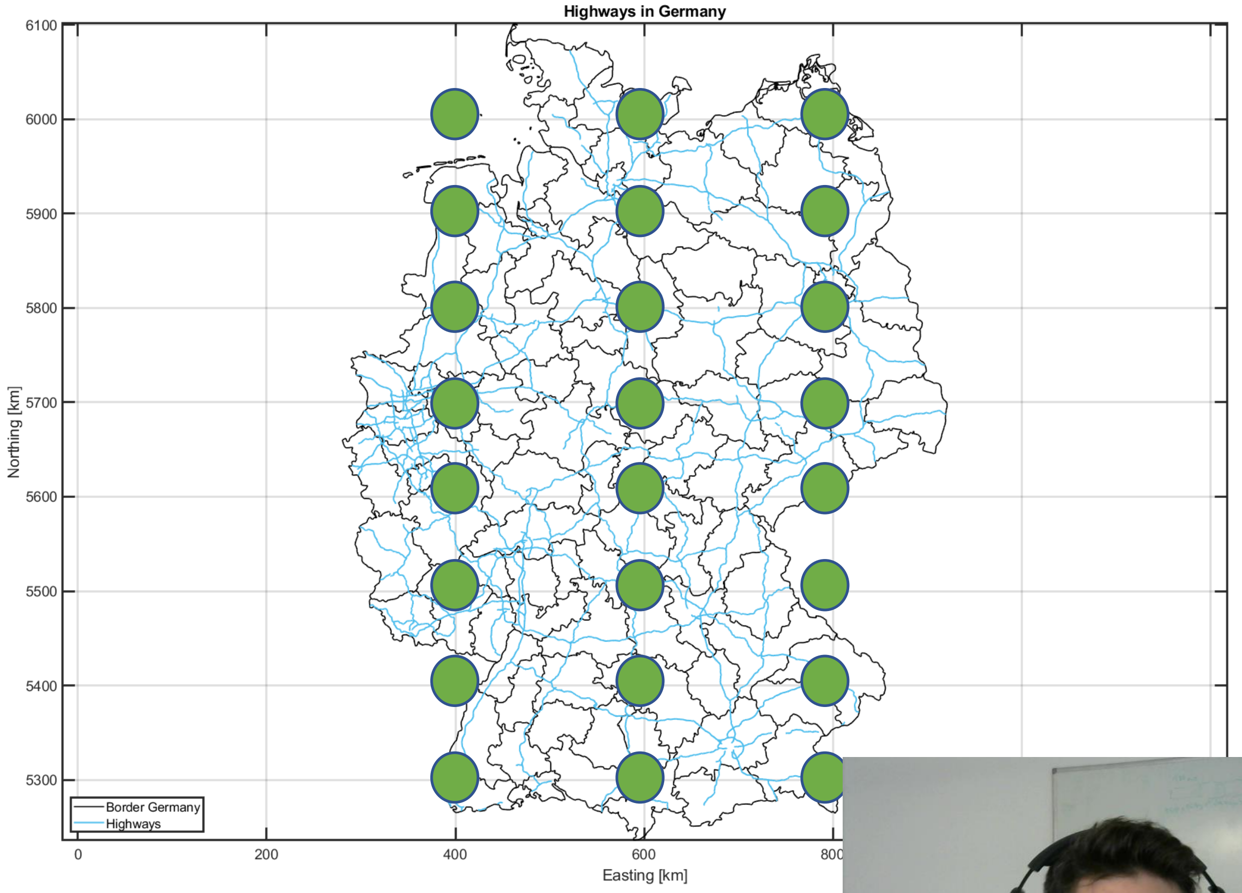
Identify Areas of Conflict & Coexistence

1. Lay a $250\,m$ spaced grid over Germany
2. Start at point 1 and compute the distance to the nearest highway
3. Compute & store Link Budget respective $CN0_{effective}$
4. Move to next grid point and repeat



Identify Areas of Conflict & Coexistence

When iterated through the whole grid, we receive a 2D **map of AR transmitters with the $CN0_{effective}$** each respective transmitter causes individually with respect to the nearest highway, **displayed at the AR transmitter's location**.



Setup and Heatmaps

Results for specific cases

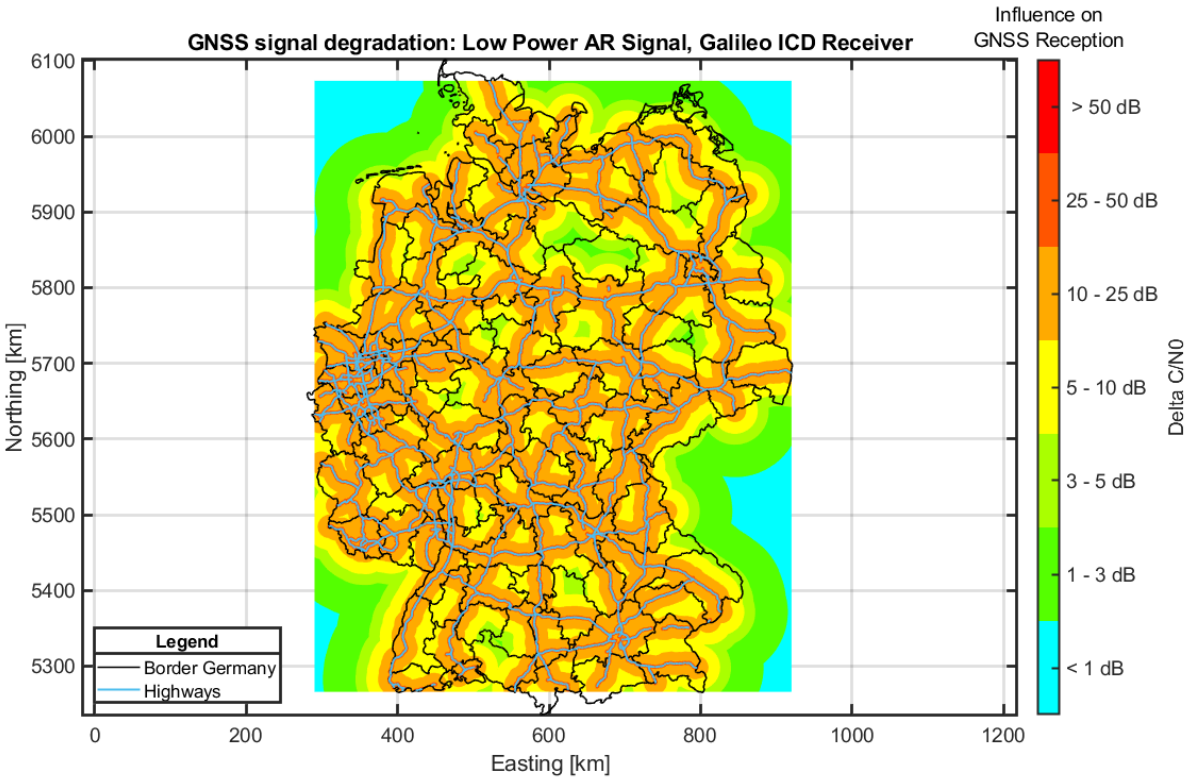
Setup – Signals and Receivers

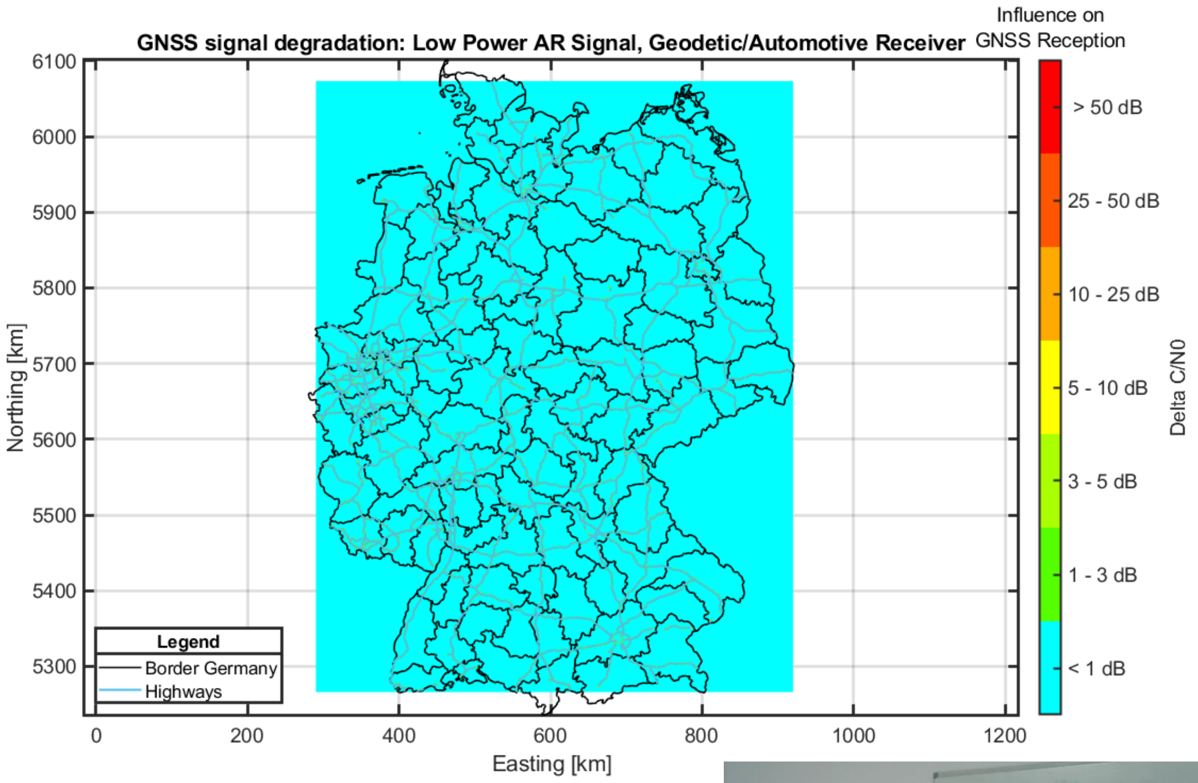
Signal	Generic Name	EIRP	Center Frequency	Bandwidth
FM (Voice)	Low Power Signal	13.50 dBW	1291.00 MHz	up to 20.00 kHz
FSK (Data)	High Power Signal	18.26 dBW	1291.00 MHz	150.00 kHz

Receiver Type	Q-factor
Galileo ICD	15.0 dB
Geodetic	50.0 dB
Automotive	50.0 dB

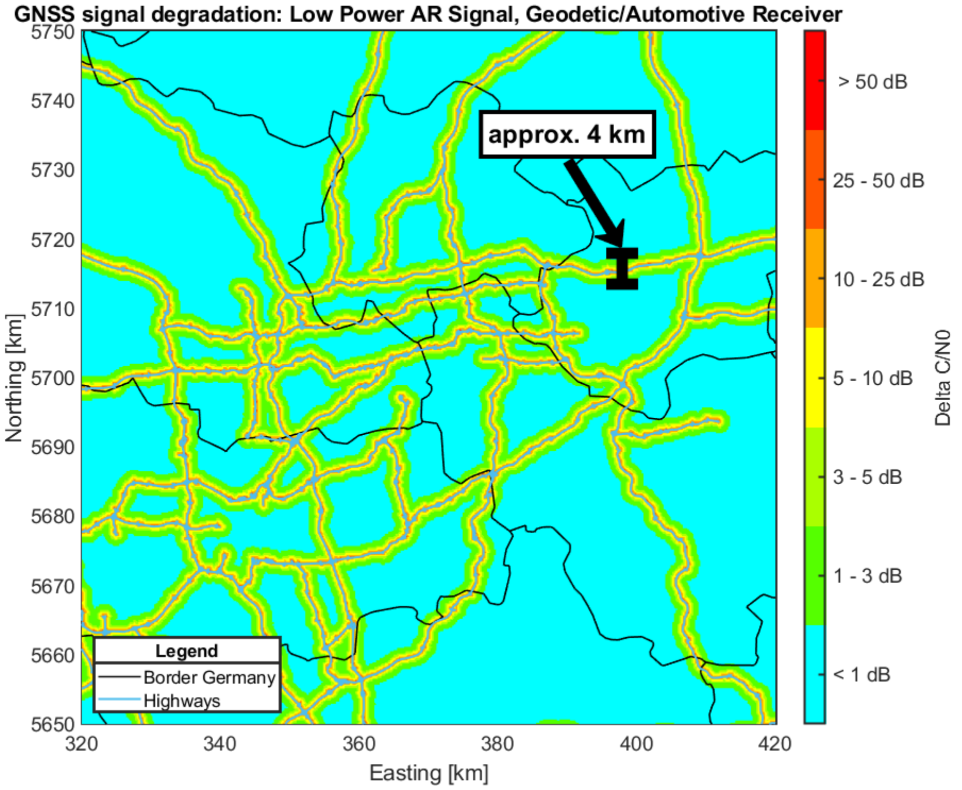
Geodetic and Automotive Receiver may achieve the same $\mathbf{Q}$*-factor incorporating different techniques (sophisticated filtering vs. simple Bandwidth limitation) for the proposed AR signals.*

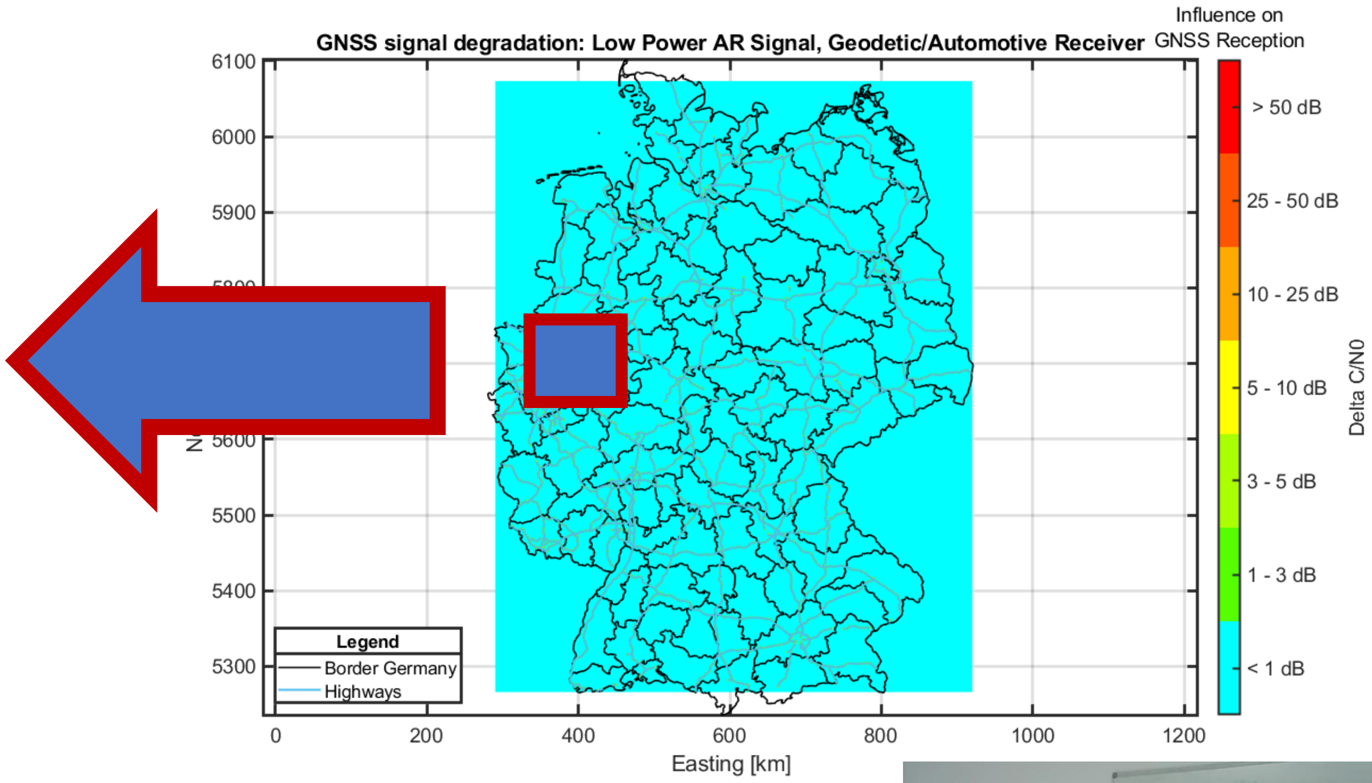
Heatmaps – Low Power Signal



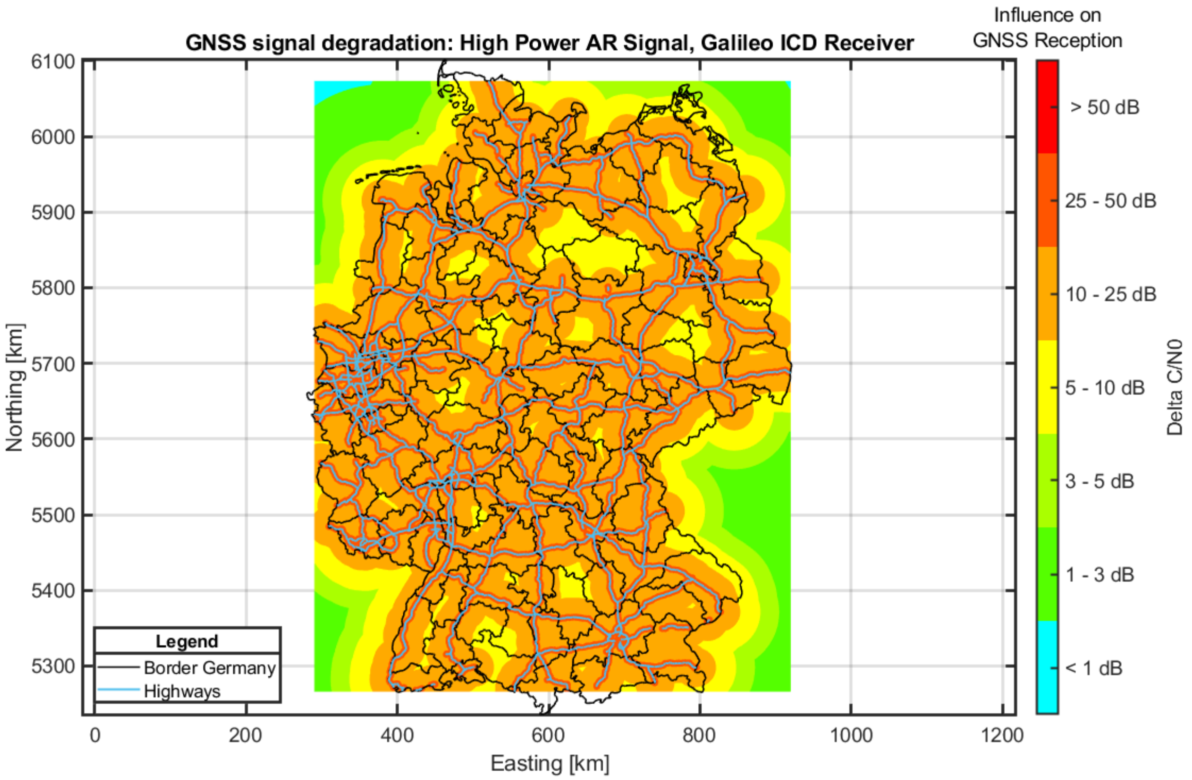


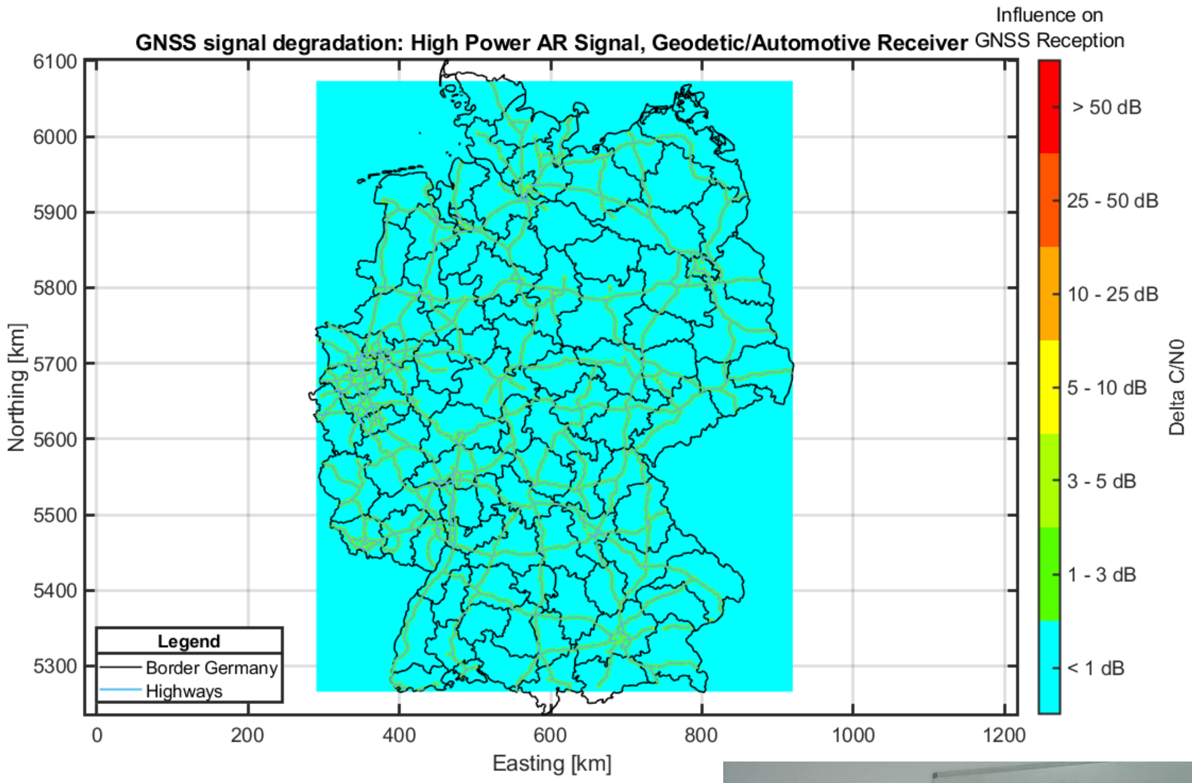
Heatmaps – Low Power Signal



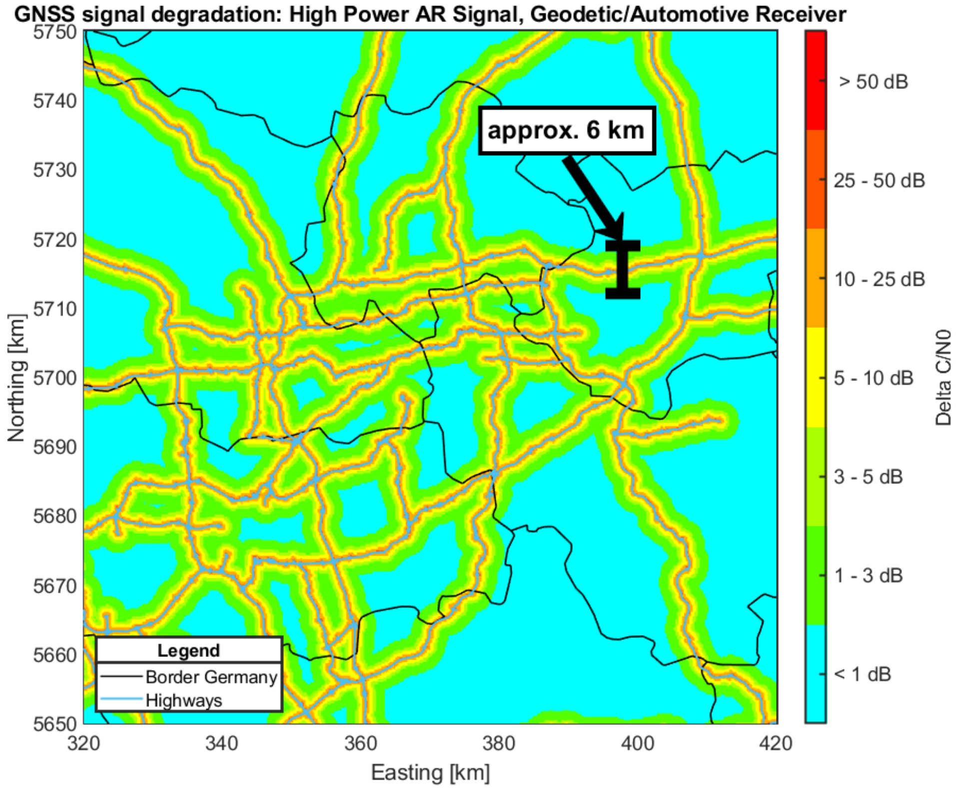


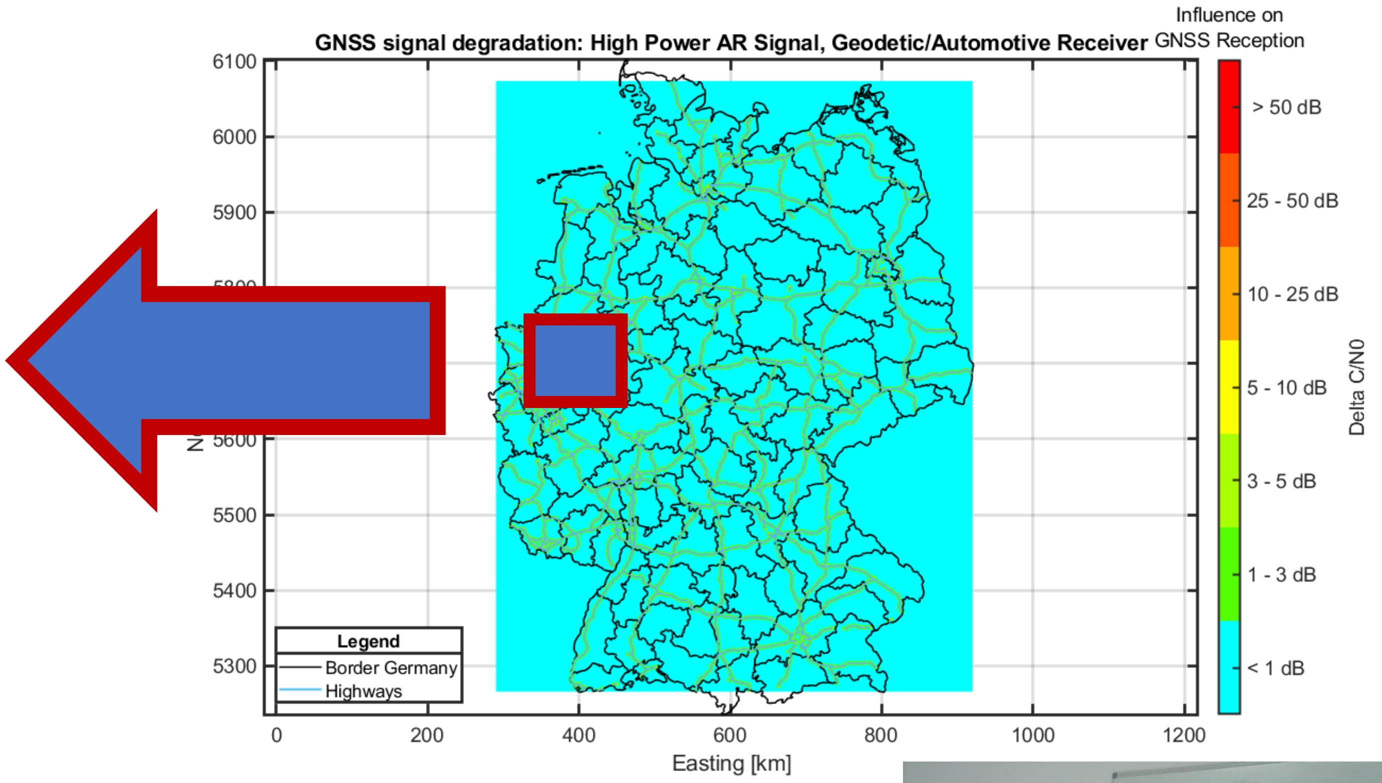
Heatmaps – High Power Signal





Heatmaps – High Power Signal





Some Final Remarks

- For the **Galileo ICD Receiver, there is no coexistence possible**, with neither of the 2 investigated AR signals w.r.t the $1dB\ IPC$ (Interference Protection Criterion)
- For the **Geodetic and Automotive Receiver** and for the introduced AR transmission modes, **coexistence is possible**, yet a small area (up to $\sim 6\ km$) around highways would need to be protected according to the $1dB\ IPC$
- The true worst-case interference is potentially lower for occluded transmitter/receiver locations (valleys etc.) or directional transmitter antennas, since **topography** and **antenna models were not considered**

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