Novel Radio Environment Map for the ns-3 Simulator

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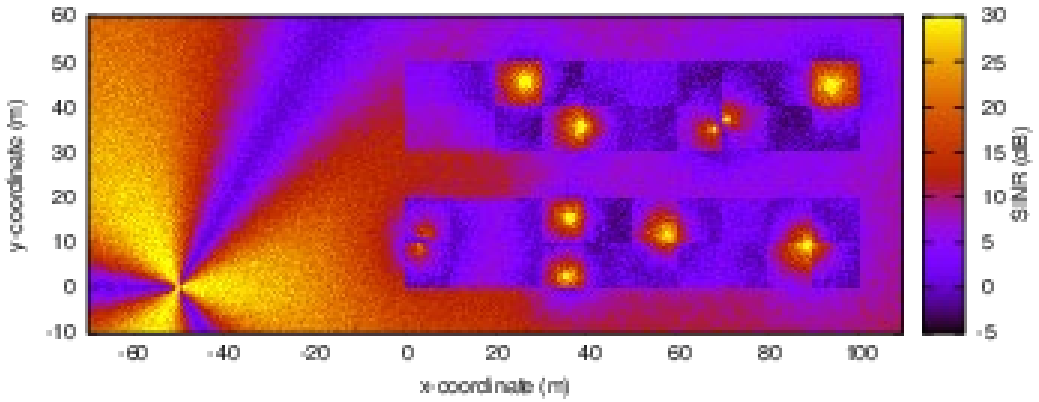
REM Definition

- Tool that combines various network environment information:
  - Received signal strength, interference measurements, propagation conditions, etc., for specific locations and frequencies
- The target is to construct a map that provides a general view of the network coverage
- Allows the visualization of the network interference, as well as the signal quality and its propagation

Useful for network design and analysis phases

LENA REM Definition

- A uniform 2D grid of values that represent the Signal to Noise Ratio (SNR) in DL with respect to the eNB that has the strongest signal at each point



- Implemented through the `RadioEnvironmentMapHelper` class
- Considers omnidirectional transmissions/receptions (LTE/sub 6 GHz bands)
- Supports only FDD in DL direction

Motivation

- NR employs multi-antenna transmissions/receptions and higher frequencies (above 24 GHz bands)
  - Directional transmissions/receptions, beamforming techniques

- 5G-LENA module uses new propagation and spectrum models not considered in LENA module
  - Examples include, among others, directional antenna elements, beamforming, multi-antenna array gain, channel condition model

ns-3 includes visualization tools only for omnidirectional transmissions/receptions (LENA module) and single directional transmissions (WiGig module)

5G-LENA REM Proposal

- In this work, we present a novel REM implementation through the `NrRadioEnvironmentMapHelper` that takes under consideration:
  - Antenna array configuration
  - A pair of devices and their corresponding antenna array
- Designed to support both TDD and FDD and both DL and UL directions
- Independent of the type of transmitting device, i.e., gNB/UE

5G-LENA REM Proposal

- As such we have defined two general cases of REM maps:

Beam Shape REM	The REM is generated for a user-defined configuration of beamforming vectors for each transmitting device, i.e., the REM shows the actual/effective coverage map in user's scenario (like how REM feature is used in LENA)
Coverage Area REM	The beams are reconfigured for each REM Point in order to visualize the coverage area in terms of SNR and SINR (5G-LENA specific REMs)

5G-LENA REM

- 5G-LENA REM has been envisioned to provide the network status visualization through various types of maps, depending on the specific user's requirements.
- To provide this flexibility, we introduce the following terminology:

RTD

REM Transmitting Device

RRD

REM Receiving Device

REM Point

The positions for which calculations will take place, considering as receiving device at that point the RRD defined by the user

REM Value

The metric that is represented on the map (SNR, SINR, IPSD)

NR-REM Maps

We focus on the following cases, although additional types of maps can be easily supported:

DL Beam Shape Map	• *Considers a specific beamforming vectors configuration for each device* • *Multi-Device Single-Beam REM type map* • *The user can visualize in terms of SNR/SINR the shape of the beams*
DL Coverage Area Map	• *Multi-device multi-beam REM type* • *The beams are reconfigured during the map generation for each REM Point* • *Best SNR targets the visualization of the best available beam (as if interference is not present)* • *Worst case SINR considers a worst-case scenario, where all the other RTDs (gNBs) are steering its antenna towards the RRD at each REM Point*

NR-REM Maps

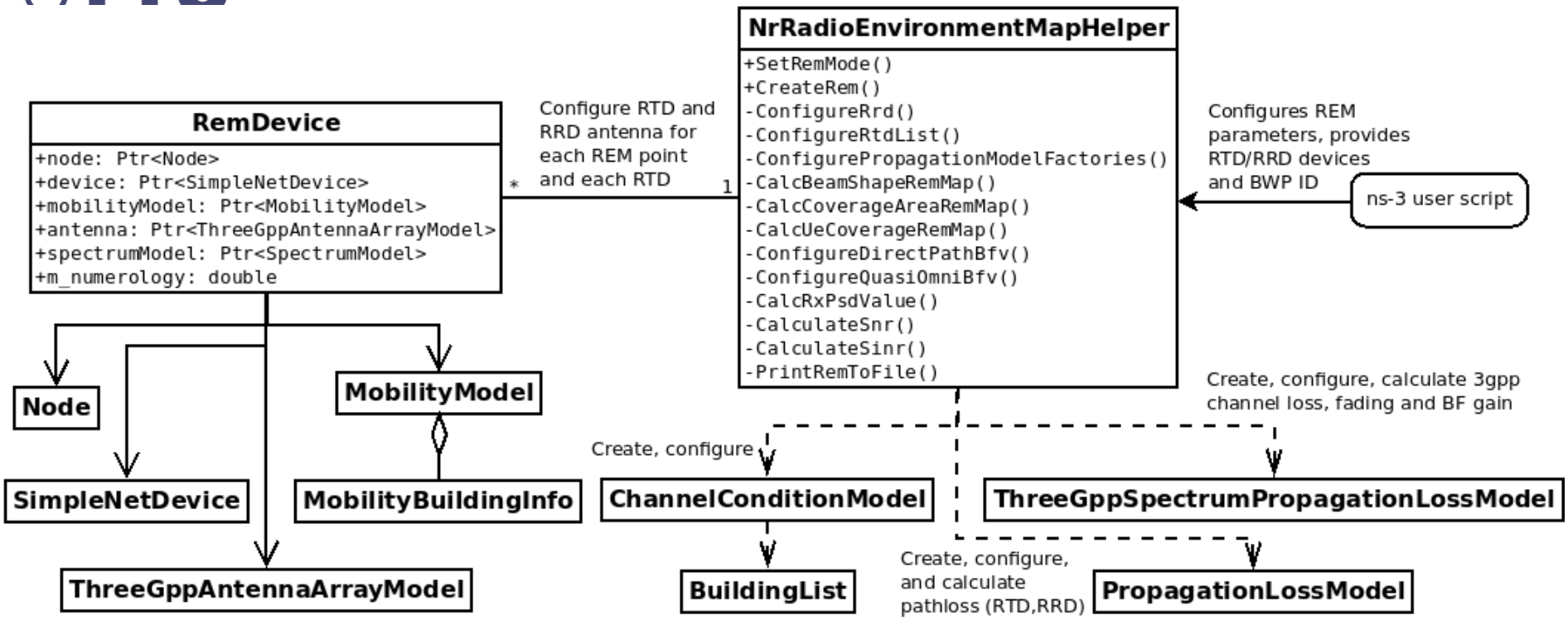
UL Maps	• *RTDs are the UEs of interest and RRD the gNB of interest* • *This map allows the visualization of the UL network interference* • *Particularly useful for Spectrum Sharing cases (IPSD map)*
UL UE Coverage Map	• *RTD is the UE of interest and RRD is the gNB of interest* • *The rest of gNBs (if present) are pointing their beams towards each REM Point* • *The coverage area of the UE can be visualized* • *Possibility to consider a worst case mixed FDD-TDD scenario (DL interference from neighbor gNBs)* • *Shows the SNR/SINR/IPSD for the UL signals of the selected UE as received in the selected gNB for a given area*

NR-REM Maps

Coverage Hole Visualization

- `NrRadioEnvironmentMapHelper` *allows the visualization of the coverage when obstacles, such as buildings, are added in the scenario*
- *Provides a tool to study the impact of the buildings in the signal transmission*

5G LENA REM design



- `NrRadioEnvironmentMapHelper` gets as inputs:
  - The parameters defined in the user script
  - The `ChannelConditionModel`, `PropagationLossModel` and `ThreeGppSpecrtumPropagationLossModel` and creates deep copies of them to use them for various calculations.
- RTD(s) and RRD include a copy of the `ThreeGppAntennaArrayModel` and `SpectrumModel`

Implementation Considerations

- The values of SNR/SINR/IPSD for each REM Point are written in a csv file that can be plotted using *gnuplot*
- REM Helper generates a custom *gnuplot* file that is used for generating figures from the csv files.

Implementation Considerations

- Initial study has been carried out in order to study the randomness of the channel
  - High frequency bands supported in the 3GPP channel model present significant variations in the channel realizations in different instants
  - Spatial-temporal correlation considered in 3GPP channel model

- As such, we have included in our model the following features:
  - *Averaging of REM values*:
    - Due to the randomness of the channel, SNR/SINR/IPSD calculations are the average of N iterations for each point
  - *3GPP channel spatial/temporal correlations*:
    - To avoid spatial and temporal dependencies among independent REM Point calculations, we re-create 3GPP channel matrix for each REM Point

- Multi-cell configurations:
  - Support different numerologies configurations at gNBs, perform spectrum model conversions in order to calculate REM values

Examples and usages

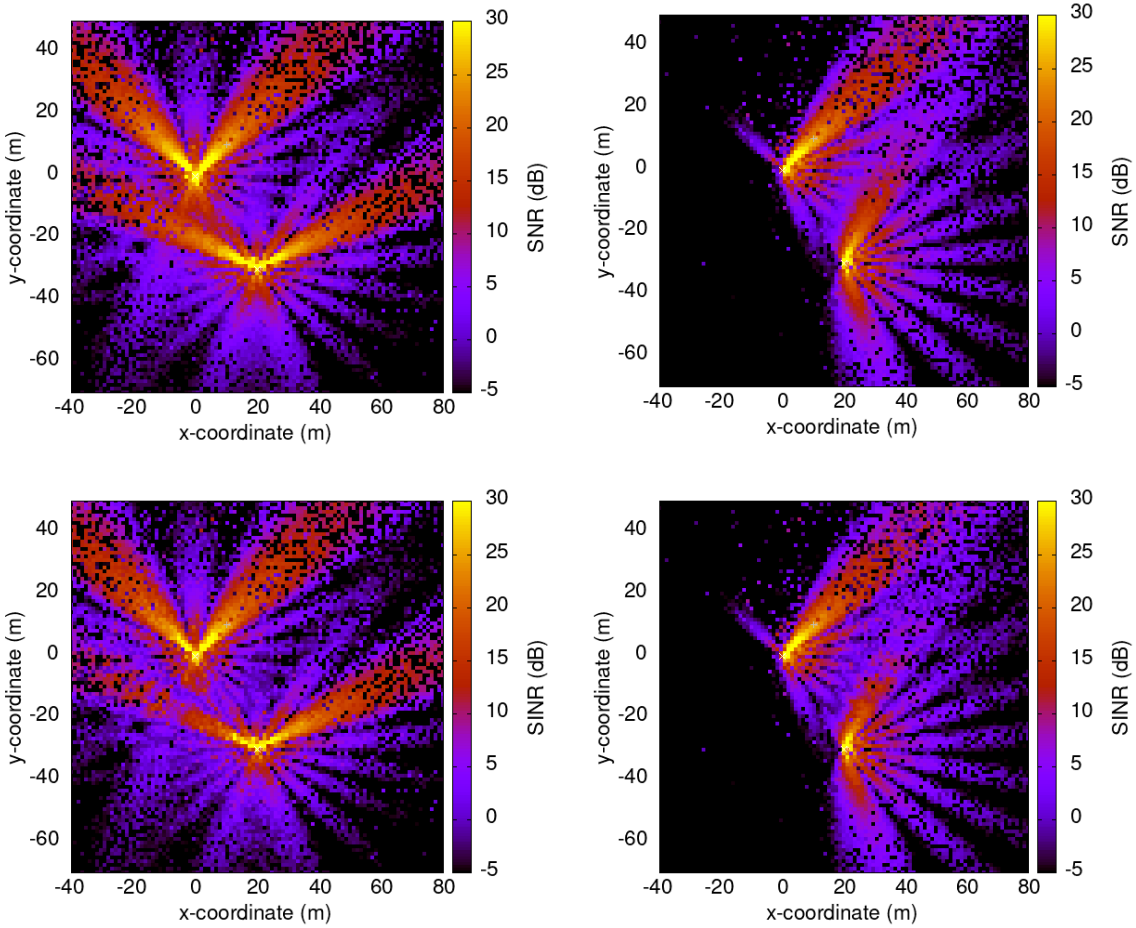
- 5G-LENA REM can be generated for any scenario script by adding the corresponding part of code

- `rem-example.cc` has been additionally implemented
  - Various parameters related to the radiation pattern can be configured (e.g. antenna configuration, scenario type, frequency, etc.)

- `cttc-channel-randomness.cc`:
  - Allows to test if the same channel realization is reproduced within the same run
  - Used to study channel randomness

Beam Shape REM SNR/SINR 28GHz

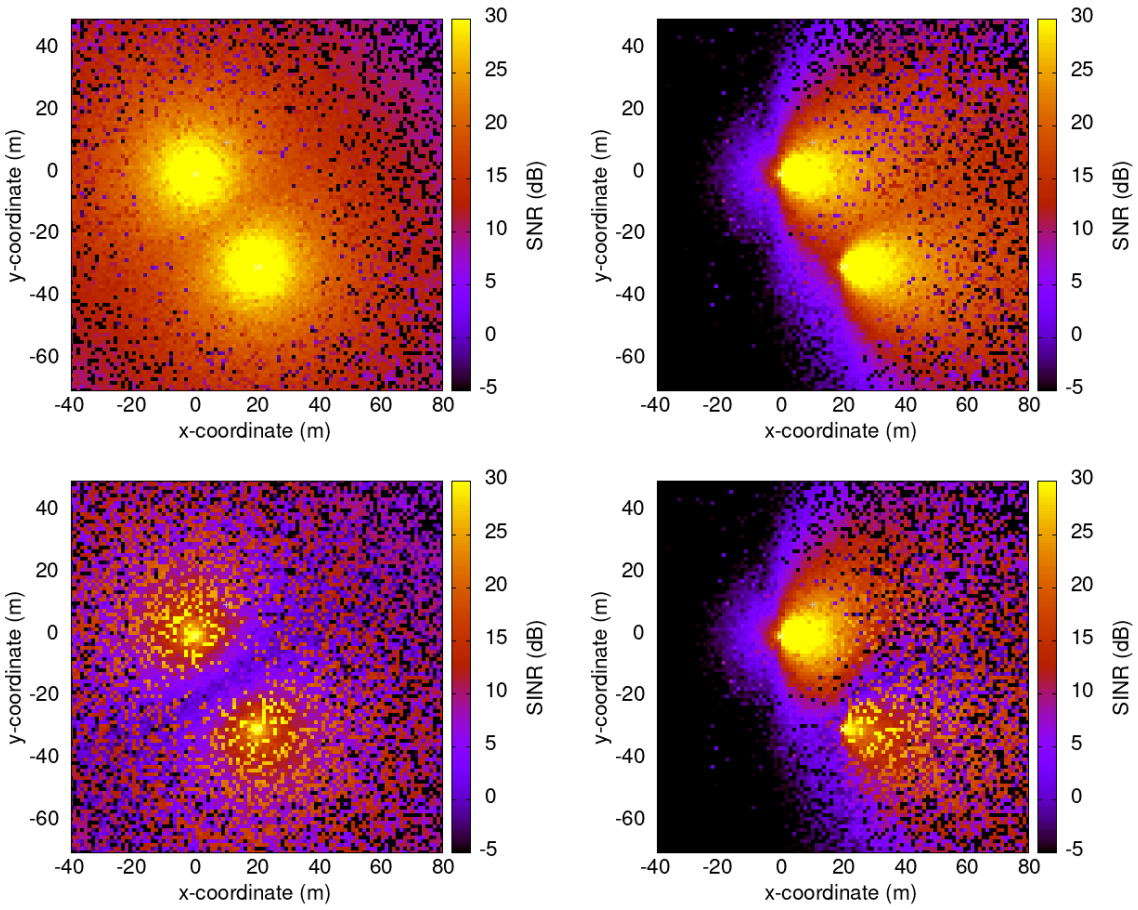
- **Scenario configuration:** UMa
- **Example:** rem-example.cc
- **Devices:** 2 gNBs and 1 UE each
  (SNR up, SINR down)
- **RTDs:**
  - gNB1 (0, 0, 1.5)
  - gNB2 (20, -30, 1.5)
  - gNBs antenna: 8x8
  - **ISO (left) / 3GPP (right)**
  - Frequency = **28 GHz**
  - Bandwidth = **100 MHz**
  - gNB txPower: 1 dBm
  - Numerology: 4
- **RRD:**
  - Ue1 with position (10, 10, 1.5)
  - UE antenna: 1x1
  - Iso
  - Noise figure: 5 dBi
- **Rest UE(s)**
  - Ue2 with position (**50**, -15 , 1.5)
  - Ue2 with position (**25**, -15 , 1.5)



* Example with different UE 2 position to confirm the beam of gNB 2

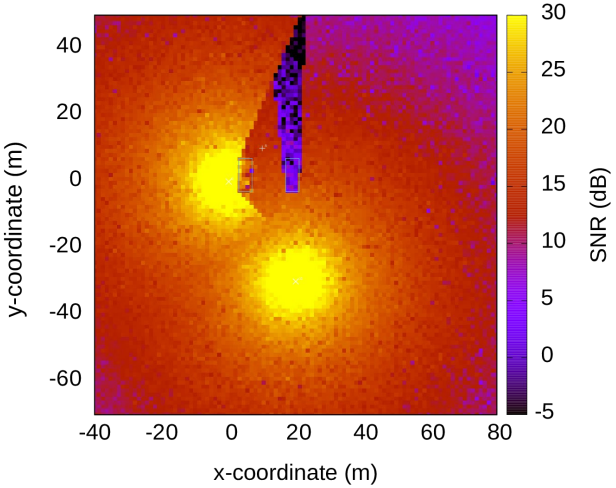
CoverageArea REM SNR/SINR 28GHz

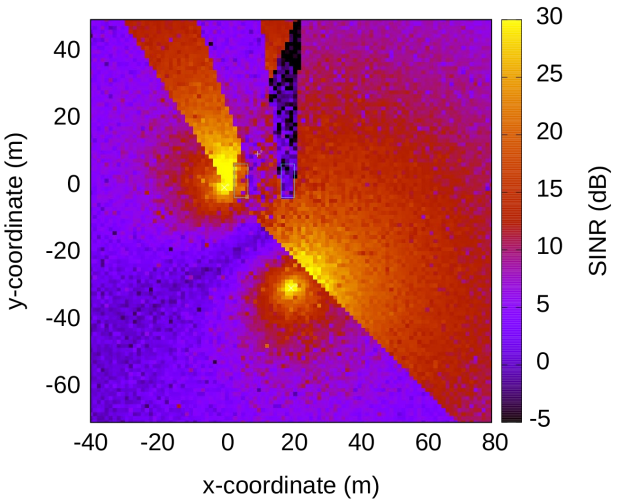
- **Scenario configuration:** UMa
- **Example:** rem-example.cc
- **Devices:** 2 gNBs and 1 UE each (SNR up, SINR down)
- **RTDs:**
  - gNB1 (0, 0, 1.5)
  - gNB2 (20, -30, 1.5)
  - gNBs antenna: 8x8
  - **ISO (left) / 3GPP (right)**
  - Frequency = **28 GHz**
  - Bandwidth = **100 MHz**
  - gNB txPower: 1 dBm
  - Numerology: 4
- **RRD:**
  - Ue1 with position (10, 10, 1.5)
  - UE antenna: 1x1
  - Iso
  - Noise figure: 5 dBi
- **Rest UE(s)**
  - Ue2 with position (50, -15, 1.5)



Coverage Area REM SNR/SINR 28GHz with Buildings

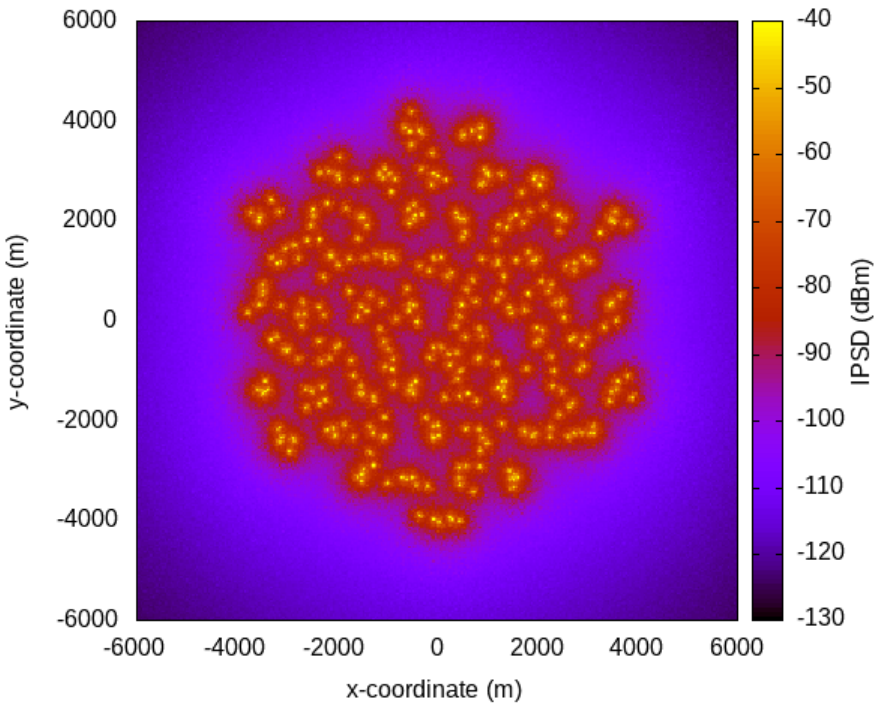
- **Scenario configuration:** UMa
- **Example:** rem-example.cc
- **Devices:** 2 gNBs and 1 UE each
- **RTDs:**
  - gNB1 (0, 0, 1.5)
  - gNB2 (20, -30, 1.5)
  - gNBs antenna: 8x8
  - **ISO**
  - Frequency = **28 GHz**
  - Bandwidth = **100 MHz**
  - gNB txPower: 1 dBm
  - Numerology: 4
- **RRD:**
  - Ue1 with position (10, 10, 1.5)
  - UE antenna: 1x1
  - Iso
  - Noise figure: 5 dBi
- **Rest UE(s)**
  - Ue2 with position (50, -15, 1.5)
- 2 buildings deployed in the scenario





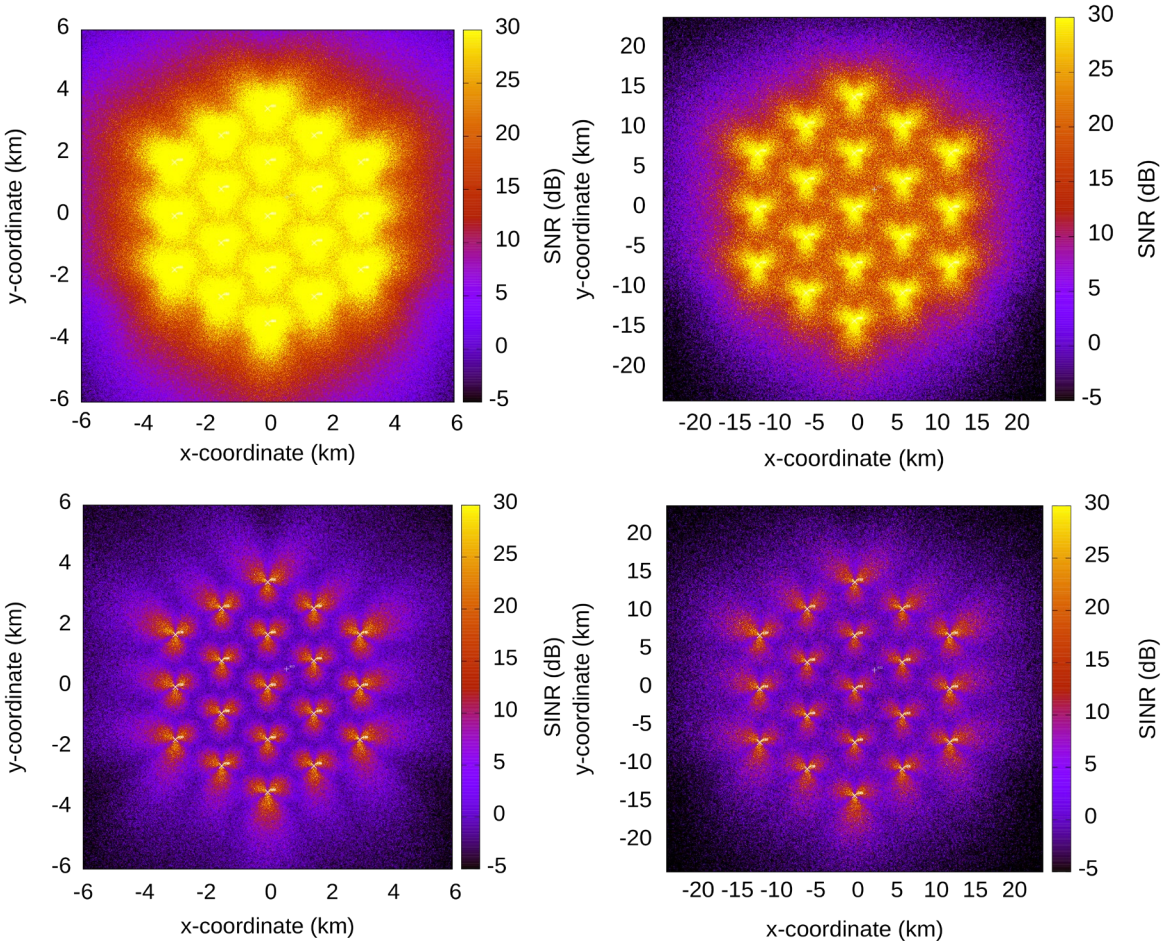
UL REM IPSD 2 GHz

- **Scenario configuration:** UMa
- **Example:** lena-lte-comparison-user.cc
- **Devices:** 19 sites x 3 sectors, 6 UEs per sector
  (SNR up, SINR down)
- **RTDs:**
  - gNBs antenna: 5x2
  - **3GPP**
  - Frequency = **1770 MHz**
  - Bandwidth = **10 MHz**
- **RRD:**
  - UEs position: random with uniform distribution
  - UE txPower: 23 dBm
  - UE antenna: 1x1
  - Iso
  - Noise figure: 5 dBi



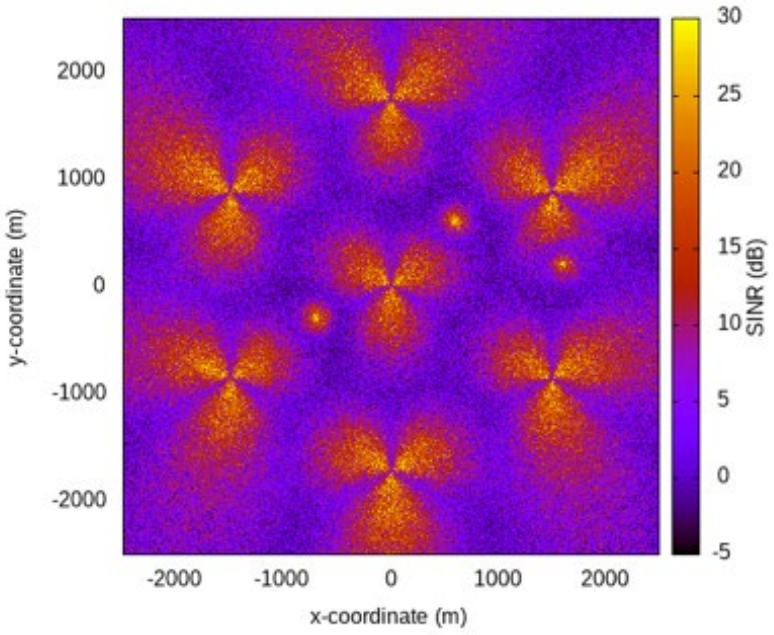
Hexagonal Deployment REM SNR/SINR 2 GHz

- **Scenario configuration:** UMa/RMa
- **Example:** lena-lte-comparison-user.cc
- **Devices:** 19 sites x 3 sectors,
  6 UEs per sector
  (SNR up, SINR down)
- **RTDs:**
  - gNBs antenna: 5x2
  - **3GPP**
  - Frequency = **2 GHz**
  - Bandwidth = **10 MHz**
  - gNB txPower: 43 dBm
- **RRD:**
  - UEs position: random with uniform distribution
  - UE txPower: 23 dBm
  - UE antenna: 1x1
  - Iso
  - Noise figure: 5 dBi



Heterogeneous Network REM SNR/SINR 2 GHz

- **Scenario configuration:** UMa
- **Example:** lena-lte-comparison-user.cc
- **Devices:** 19 sites x 3 sectors,
  6 UEs per sector
  3 small cells randomly deployed
  (SNR up, SINR down)
- **RTDs:**
  - gNBs antenna: 5x2
  - **3GPP**
  - Frequency = **2 GHz**
  - Bandwidth = **10 MHz**
  - gNB txPower: 43 dBm
  - SC txPower: 30 dBm
- **RRD:**
  - UEs position: random with uniform distribution
  - UE txPower: 23 dBm
  - UE antenna: 1x1
  - Iso
  - Noise figure: 5 dBi



Conclusions

- We have presented a novel design for REM implementation in 5G-LENA module as a visualization tool for multi-cell directional scenarios
- `NrRadioEnvironmentMapHelper` is publicly available in 5G-LENA
- It supports both FDD and TDD scenarios, DL and UL directions and operational areas on both FR1 and FR2 bands with directional beams
- Various types of maps can be generated, depending on the user needs, as well as various metrics can be represented
- REM usage examples have been illustrated, under different deployment scenarios and propagation conditions