

# Interference Analysis of 5G NR on Radio Astronomy in the Upper 6 GHz Frequency Range: Mitigation Techniques and Strategies

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**Abstract** — This article addresses interference mitigation strategies for radio astronomy service (RAS) within the 6650–6675.2 MHz frequency band, focusing on the 5G NR network deployment and its potential impact on RAS operations. Guided by ITU-R recommendations and methodologies, the study explores both generic and site-specific interference cases. Using Monte-Carlo simulations and propagation models, including Recommendations ITU-R P.2001 and ITU-R P.2108, it estimates interference levels from 5G NR base stations, highlighting necessary separation distances across various deployment scenarios. The results indicate that urban IMT deployment requires a minimum separation of 55–60 km, while rural and suburban setups may necessitate 30–70 km based on terrain shielding and adjacent channel conditions. This study is useful for regulators and network planners that plan to implement 5G NR networks in the countries where the frequency band 6650–6675.2 MHz is in use by RAS, providing adaptable separation guidelines according to local environments and 5G NR deployment specifics.

**Keywords** — 5G, 6 GHz, Radioastronomy, co-existence, Monte-Carlo simulations.

## I. INTRODUCTION

The upper 6 GHz band (6425–7125 MHz) was identified for International Mobile Telecommunications (IMT) in certain countries within ITU-R Regions 1 and 3 following the WRC-23 conference in Dubai [1]. This spectrum is particularly appealing for the expansion of 5G NR and the anticipated development of 6G networks due to its advantageous balance between propagation characteristics and the availability of contiguous bandwidth. Such properties enable the provision of high-data-rate services while ensuring efficient coverage in both urban and suburban environments. Prior to the allocation decision, the ITU-R study group conducted compatibility assessments, though these studies primarily focused on cross-border interference scenarios between IMT systems and satellite services. However, domestic interference scenarios, which are critical for national regulatory bodies aiming to implement IMT within their territories, were not extensively explored.

A significant portion of the 6650.0–6675.2 MHz frequency range is allocated for radio astronomy service (RAS),

specifically for methanol spectral line observations. These radio astronomy facilities are typically located in remote areas where interference from other spectrum users is minimized. Although RAS does not hold a primary allocation within the upper 6 GHz band, its role in methanol line studies remains vital. The 6.6685192 GHz methanol (CH<sub>3</sub>OH) maser line serves as a crucial tool for investigating the formation of high-mass stars, which, despite constituting a small fraction of the stellar population, significantly influence the structural and evolutionary dynamics of galaxies. High angular resolution observations of these masers are essential for pinpointing star-forming regions, making them indispensable in radio astronomy [2], [3], [4].

The importance of methanol masers is underscored by their extensive use in both single-dish and interferometric surveys to detect massive star-forming regions within the Milky Way [5], [6], [7], [8]. Their compact emission profile makes them highly suitable for very long baseline interferometry (VLBI) using networks such as the Very Long Baseline Array (VLBA) in the US and the European VLBI Network (EVN). These global collaborations span multiple continents within ITU-R Regions 1 and 3, providing astronomers with milliarcsecond-level resolution necessary to study stellar evolution. The loss of access to the 6.7 GHz band would pose a significant setback to current research efforts aimed at unraveling the mechanisms governing high-mass star formation.

Given the increasing deployment of 5G NR networks in the upper 6 GHz band, understanding potential interference to RAS is imperative. This study examines interference mitigation strategies for RAS in the 6650–6675.2 MHz range, employing Monte-Carlo simulations and ITU-R propagation models (ITU-R P.2001 and ITU-R P.2108) to estimate interference levels from 5G NR base stations. By analyzing different deployment scenarios, this research provides essential insights for regulators and network planners, offering adaptable separation distance recommendations to facilitate the coexistence of IMT and RAS while safeguarding astronomical observations.

## II. SIMULATION PARAMETERS

### A. IMT Characteristics in 6425-7125 MHz

To simulate the 5G NR link, characteristics of the base station for urban deployment and typical user equipment characteristics were configured. The characteristics of 5G NR for the 6425-7125 MHz frequency band are presented in Table 1 these are the characteristics based on the 3GPP report. These parameters are also used for the studies with incumbent services in ITU-R. The channel bandwidth of 5G NR in the 6425-7125 MHz can vary from 20 MHz to 100 MHz, for this particular study the channel bandwidth was 100 MHz [9].

Table 1. 5G NR characteristics in the 6425-7125 MHz band.

| Parameters   | 5G NR  |   |
|--|--|---|
|  | Base station (BS)  | User equipment (UE)   |
| Frequency band   | 6425-7125 MHz  |   |
| Channel bandwidth  | 100 MHz  |   |
| Type of deployment   | Urban  |   |
| Cell radius  | 300 m  |   |
| Mechanical downtilt  | 10°  | -   |
| Antenna height   | 18 m   | 1.5 m   |
| Antenna pattern  | 8x16 ITU-R M.2101  | Omnidirectional   |
| Antenna gain   | 5.5 dBi per element  | -4 dB   |
| Conducted power  | 22 dBm per element   | 23 dBm  |
| Noise figure   | 6-11 dB  | 9-13 dB   |
| ACS  | 42 dB  | 32 dB   |
| Body loss  | -  | 4 dB  |
| Power into RAS frequency band (Spectroscopy channel width: 50 kHz) | 13 dBm (in-band)<br>-17 dBm (adjacent)<br>-43 dBm (spurious) | -10 dBm (in-band)<br>-20 dBm (adjacent)<br>-43 dBm (spurious) |

radiation patterns and “pointing” (having maximum directivity) along the x-axis. A weighting function is used to direct the beam in various directions. Total antenna gain is the sum (logarithmic scale) of the array gain and the element gain [10]. The antenna pattern in the azimuth and elevation planes that is used in simulations for 5G NR base station that is electronically steered depending on the user’s position, an example of electronic antenna steering for scan angles 0, 30, 60 degrees and 0- and 10-degrees tilt based on Recommendation ITU-R P.2101 [10] is presented in Fig. 1.

### B. Radioastronomy Characteristics in 6650-6675.2 MHz

The parameters to be used in the study include the antenna pattern and antenna height above the ground of RAS receiver. The antenna pattern for the RAS can be obtained from Recommendation ITU R SA.509 [11], but in most cases of terrestrial sources of interference a flat level of 0 dBi should be used.

Example values of parameters for a generic RAS station are listed in Table 2. However, for coordination of actual site, the site-specific values for these parameters should be used in calculating the coordination distance, e.g. the height above ground of the focal point for a particular site.

Table 2. Radioastronomy characteristics in the 6650-6675.2 MHz band.

| Parameter           | Value                                     |
|---------------------|---|
| Frequency range     | 6650-6675.2 MHz                           |
| Channel             | 50 kHz                                    |
| Antenna height      | 50 m                                      |
| Antenna pattern     | an isotropic antenna with a gain of 0 dBi |
| Noise temperature   | 10 K                                      |
| Antenna temperature | 12 K                                      |

Example of radioastronomy telescope that conducts observations in the 6 GHz band is presented in Fig. 2 below.

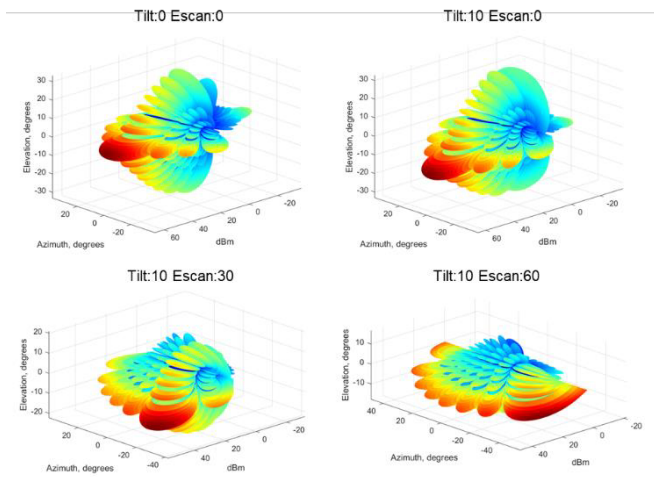


Fig. 1. 5G NR base station antenna pattern in the 6425-7125 MHz band.

The base station of 5G NR implements active antenna system with beamforming, the beamforming antenna is based on an antenna array and consists of a number of identical radiating elements located in the yz-plane with a fixed separation distance (e.g.  $\lambda/2$ ), all elements having identical



Fig. 2. Example of radiotelescope Badary that conducts observations in 6 GHz.

The study provides simulations for generic case where the location of the Radioastronomy station is indefinite, and for site-specific case of the radioastronomy station.

## III. SIMULATION METHODOLOGY

Generic study that estimates aggregate interference employs Monte-Carlo simulation analysis where at each step IMT base stations are generated around the victim receiver as

the 19 trisector BS clusters, so total number of sectors per each cluster is 57. In order to calculate the number of clusters,  $R_a R_b$  approach should be used.

Based on the methodology developed by WP5D, the number of IMT BSs per 100 MHz channel in the 6 GHz band can be calculated using the following equation:

$$N_{BS,total} = (\rho_u R_{a,u} R_b) S_{area}, \quad (1)$$

where  $\rho_u$  is the base station deployment density in  $\text{km}^2$ ;  $R_{a,u}$  is the ratio of coverage areas to areas of cities/built areas/districts;  $R_b$  is the ratio of built areas to total area of region in study;  $S_{area}$  is the studied area expressed in  $\text{km}^2$ .

In this study for  $R_a$  10% value was used and for  $R_b$  2% value was used. Total area size was  $360\,000\text{ km}^2$ . The area was divided into ring layers, the first layer was the required separation distance, whereas the second layer was the simulation area where 5G networks were deployed. The circle layer approach is presented in Fig. 3.

To estimate the number of simultaneously transmitting BS, time division duplex (TDD) activity factors and network loading factor should be taken into account. For the wide studying areas network loading factor is 20%, thus total number of simultaneously transmitting IMT clusters can be expressed below:

$$N_{clusters} = \frac{(\rho_u R_{a,u} R_b) S_{area} A_{TDD} A_{loading}}{57}, \quad (2)$$

where  $N_{clusters}$  represent the number of clusters that consist of 19 trisector sites clusters with 57 cells in total;  $A_{TDD}$  is a TDD activity factor of BS which equals 0.75 (BS is active in 75% of time and UEs in 25% of time);  $A_{loading}$  is a network activity factor which equals 0.5.

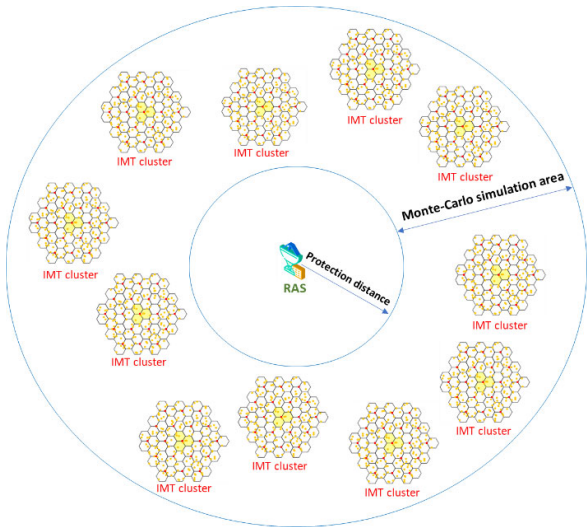


Fig. 3. Methodology of simulation the interference from IMT to RAS.

To calculate propagation losses the model based on Recommendation ITU-R P.2001 is used [12]. This Recommendation was among those that were allowed to be used for 6 GHz band by WP 3K/3L. This Recommendation describes a radio-wave propagation method for terrestrial paths. It has a wide range of applicability in frequency, distance, and percentage time. In particular, it predicts both

fading and enhancements of signal level. It is thus particularly suitable for Monte-Carlo simulations. For Monte-Carlo simulations random percentage of time for each interfering base station should be used, given that essentially it corresponds the average, 50% value has been used.

For IMT with urban deployment, clutter should be used. The clutter losses can be calculated using the propagation model based on Recommendation ITU-R P.2108 [13]. Random percentage of locations is used. Fig. 4 provides propagation losses of Recommendation ITU-R P.2001 for 50% of time without clutter (blue curve) and propagation losses taking into account clutter losses (red dots).

The clutter is applied for all transmitting BS given that their height is 18 meters and most of the urban building height is from 20 to 30 meters, therefore the probability that the path between the transmitting BS and RAS station will be covered by clutter is very high. Additionally, it should be noted that most of the WP 5D studies under 1.2 agenda item during the WRC-23 study cycles applied clutter for 100% base stations.

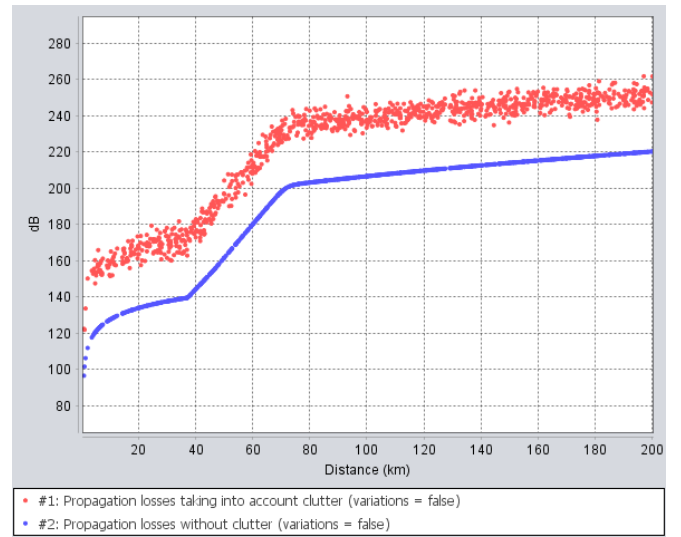


Fig. 4. Propagation losses of Recommendation ITU-R P.2001 with 50% percentage of time with and without clutter losses.

The study employed Monte-Carlo simulation, at each step the location of each use within the cell, was randomly distributed according to the uniform distribution. The interference at each step can be calculated using the following expression:

$$I = P_{tx} + G_{tx}(\theta, \varphi) + G_{rx}(\theta, \varphi) - L_{2001} - L_{clutter} - L_{pol}, \quad (3)$$

where  $P_{tx}$  is the output power of the BS in dBW;  $G_{tx}(\theta, \varphi)$  is the antenna gain of the BS towards the RAS station in dBi;  $G_{rx}(\theta, \varphi)$  is the antenna gain of the RAS towards the BS in dBi;  $L_{2001}$  is propagation losses based on Recommendation ITU-R P.2001 in dB;  $L_{clutter}$  is clutter losses based on Recommendation ITU-R P.2108 in dB;  $L_{pol}$  is polarization difference losses in dB.

Fig. 5 shows the simulation example of interference from IMT to RAS in the 6650-6675.2 MHz frequency band using Monte-Carlo approach.

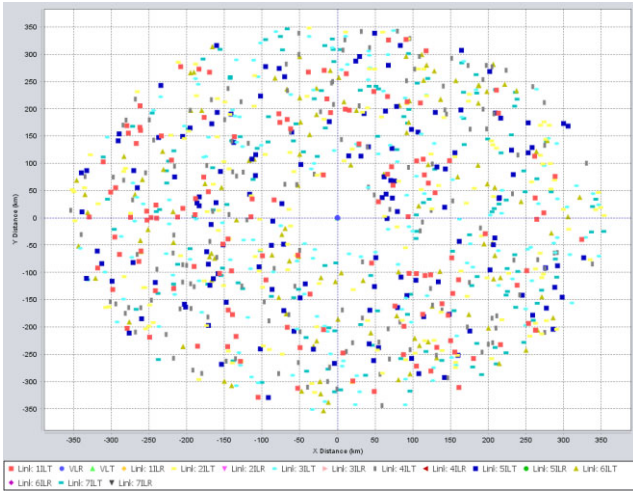


Fig. 5. Simulation of interference from BS 5G to RAS telescope.

For single-entry interference the BS with suburban/rural deployment has been considered, the clutter hasn't been applied in the scenario. Propagation mode based on the Recommendation ITU-R P.2001 was used. SRTM terrain was used to take into account the terrain losses. The single-entry interference was calculated using the following expression:

$$I = P_{tx} + G_{tx}(\theta, \varphi) + G_{rx}(\theta, \varphi) - L_{2001} - 10\log\left(\frac{1}{A_{TDD}}\right) - 10\log\left(\frac{1}{A_{loading}}\right) - L_{pol}, \quad (4)$$

where  $P_{tx}$  is the output power of the BS in dBW;  $G_{tx}(\theta, \varphi)$  is the antenna gain of the BS towards the RAS station in dBi;  $G_{rx}(\theta, \varphi)$  is the antenna gain of the RAS towards the BS in dBi;  $L_{2001}$  is propagation losses based on the Recommendation ITU-R P.2001 in dB;  $A_{TDD}$  is the TDD activity factor, equals 0.75;  $A_{loading}$  is the network loading factor, equals 0.5;  $L_{pol}$  is polarization difference losses in dB.

In this example site-specific study, Badary RAS station was considered. The Badary Radio Astronomical Observatory is situated in the Buryatia Republic (East Siberia) about 130 km east of Baikal Lake.

#### IV. SIMULATION RESULTS

The obtained during the simulation interference values were used to generate cumulative distribution functions (CDF) distributions, first the collected data after simulation comprised into the probability distribution function (PDF).

The PDF can be integrated into the CDF using:

$$CDF(X) = \int_{-\infty}^X PDF(x)dx. \quad (5)$$

The PDF and CDF data can be generated using the quantized data of the calculated values as histogram  $H(i)$  where  $I = \{0 \dots n\}$  and each value  $i$  can be mapped to a data value  $x$  using:

$$x(i) = xBinSize_{min}. \quad (6)$$

The bin relating to data value  $x$  is then:

$$i(x) = Round\left[\frac{x - x_{min}}{xBinSize}\right]. \quad (7)$$

The probability density histograms for each separation distance that was analyzed (50 km, 60 km, 70 km, and 100 km) are provided below in Fig. 6, 7, 8, 9.

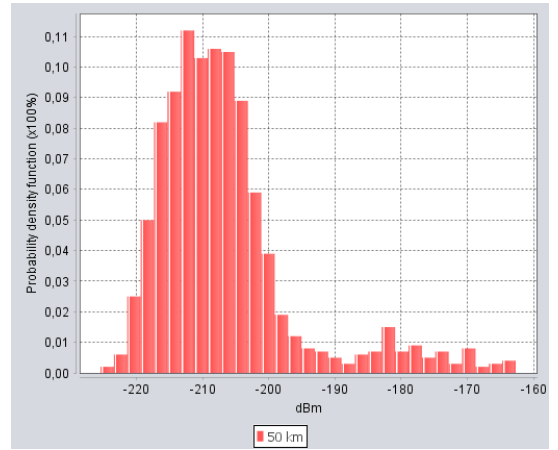


Fig. 6. Interference levels from IMT-2020 to RAS for 50 km separation distances.

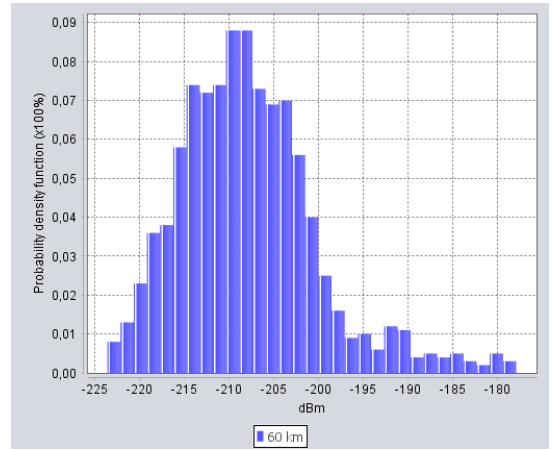


Fig. 7. Interference levels from IMT-2020 to RAS for 60 km separation distances.

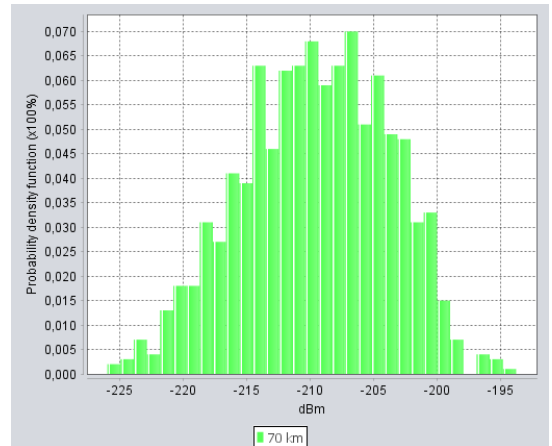


Fig. 8. Interference levels from IMT-2020 to RAS for 70 km separation distances.

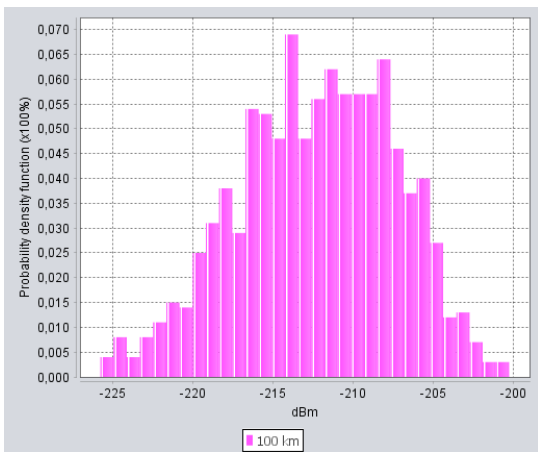


Fig. 9. Interference levels from IMT-2020 to RAS for 100 km separation distances.

Then the CDF can be generated from the histogram as a percentage using:

$$CDF(X) = 100 \frac{\sum_{i=0}^{i(X)} H(i)}{\sum_{i=0}^{i(n)} H(i)} \quad (8)$$

Fig. 10 shows the cumulative distribution function curves for each simulated separation distance. The red curve represents the CDF for a 50 km separation distance, the blue curve for a 60 km separation distance, the green curve for a 70 km separation distance, and the purple curve for a 100 km separation distance.

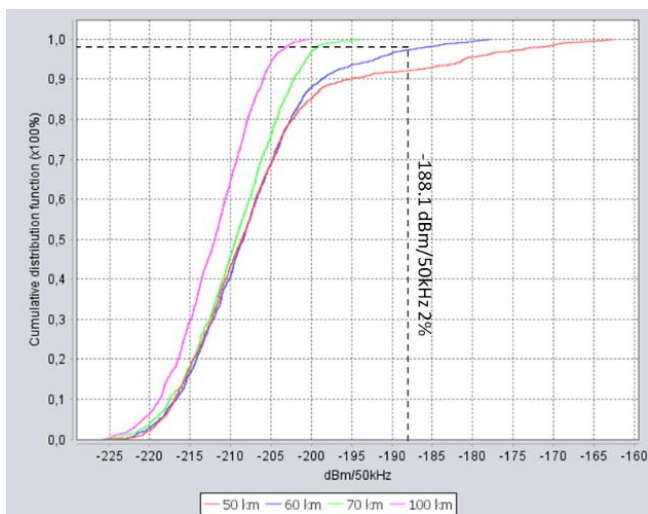


Fig. 10. Interference levels from IMT-2020 to RAS for different separation distances.

As may be seen from the curves the minimum separation distance that allows to protect RAS from aggregate interference of IMT with urban deployment is 60 km.

For site-specific case interference levels for inband scenario are presented in Fig. 11, 12, 13.

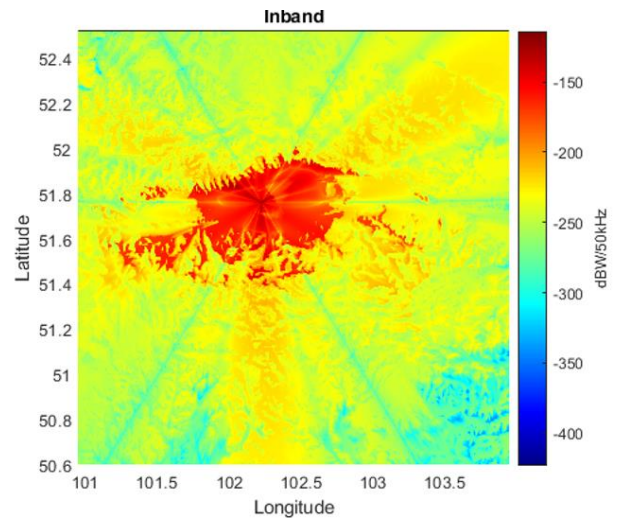


Fig. 11. Single-entry interference to Badary station for the inband scenario.

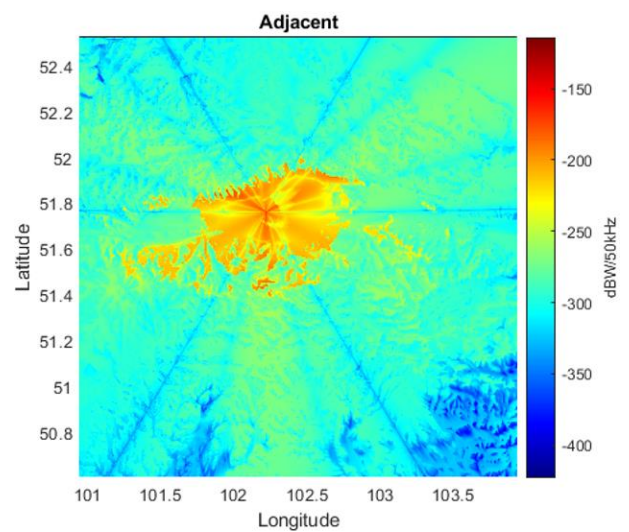


Fig. 12. Single-entry interference to Badary station for the adjacent band scenario.

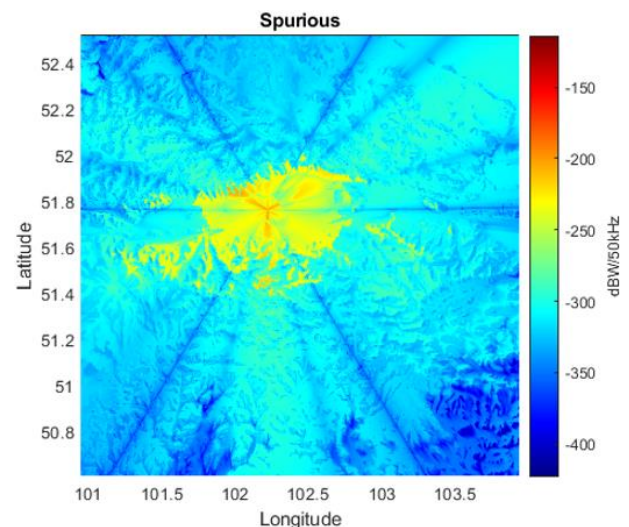


Fig. 13. Single-entry interference to Badary station for the spurious domain scenario.

Based on the interference levels, protection contours according to the  $-218.1$  dBW/50 kHz can be built. Fig. 14 shows protection contours on the SRTM map for the inband interference scenario (red lines), for adjacent channel interference (purple lines) and for the spurious domain interference (blue line).

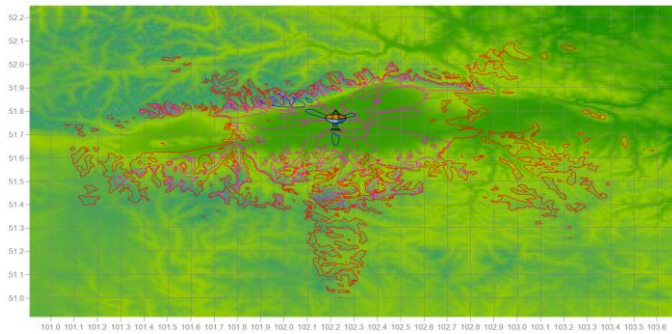


Fig. 14. Protection contours for Badary RAS station for the inband, adjacent band and spurious domain scenarios.

As may be noted, when taking into account terrain shielding, the interference to RAS can be mitigated quite significantly. It should be noted that in case the interfering BS would be shielded by the clutter, the contours would be even smaller, however to address the worst case, this example didn't take into account clutter losses. As may be seen from the obtained results, for the case of inband interference the separation distance would vary from 30 to 80 km, for the adjacent channel scenario it would vary from 10 to 50 km and for the spurious domain case the separation distance would be lower than 10 km.

## V. CONCLUSION

This study investigates the impact of 5G NR deployment within the 6425-7125 MHz frequency band on radio astronomy observations in the 6650-6675.2 MHz range. Through comprehensive Monte-Carlo simulations and ITU-R propagation models, we assess the interference levels generated by IMT base stations and propose necessary separation distances to mitigate potential disruptions. The findings suggest that urban deployments require a minimum separation of approximately 55-60 km, whereas suburban and rural environments necessitate distances ranging from 30-70 km, depending on terrain shielding and adjacent channel conditions.

The results highlight the necessity for careful spectrum management to balance the growing demand for 5G expansion with the preservation of critical scientific observations. Given the essential role of the 6.7 GHz methanol maser line in studying high-mass star formation, ensuring adequate protection for RAS facilities is paramount. Regulatory bodies and network planners should incorporate these findings into national spectrum policies to facilitate the coexistence of IMT and RAS. Future research should explore additional mitigation techniques, such as dynamic spectrum access and advanced filtering methods, to further enhance spectral efficiency while minimizing interference risks. By implementing these

strategies, both the telecommunications industry and the scientific community can continue to thrive without compromising their respective objectives.

## ACKNOWLEDGMENT

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