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| U.S. Radiocommunication Sector  Fact Sheet | |
| **Working Party:** ITU-R WP 7D | **Document No:** USWP7D\_25Sept-doc6-RA.[IMT-6GHZ] |
| **Ref.**Doc [7D/186](https://www.itu.int/md/R23-WP7D-C-0186/en), Annex 20  Doc [7D/206](https://www.itu.int/md/R23-WP7D-C-0206/en) | **Date:** 7/31/2025 |
| **Document Title:** Input for Working Document towards a Preliminary Draft New Recommendation/Report ITU-R RA.[IMT-6GHZ] / (IMT compatibility at 6 GHz) | |
| **Author(s)/Contributors(s):**  Chris De Pree  Frank Schinzel | *cdepree@nrao.edu*  *fschinze@nrao.edu* |
| **Purpose/Objective:** To propose appropriate edits to this work | |
| **Abstract:** This issue has received several inputs in past meetings; this document is a placeholder for any inputs the U.S. may consider necessary toward direction of the ongoing work. In the attached draft, we propose to emphasize this document as report rather than recommendation, which should be developed in a separate contribution. Some edits are suggested to be incorporated after reviewing the document and following suggestions noted in 7D/206.  NOTE: Additional input may be forthcoming regarding some of this text, based upon verification of developments in WP5D. | |

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| INPUT FOR WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW RECOMMENDATION/REPORT ITU-R RA.[IMT-6GHZ] | |
| **Methods to address the determination of the coordination area around existing RAS stations from IMT stations in the frequency band 6 650-6 675.2 MHz** | |

**Introduction**

The attached document provides edits proposed to be incorporated into the draft report ITU-R RA.[IMT-6GHZ]. The proposed modifications are primarily editorial in nature, and also include changes following suggestions provided by Working Party 5D in Document 7D/206 in Sections 2 and 3, as well as Annexes 2 and 4. Modifications are indicated through track changes.

Specifically, “separation distance” was replaced with “coordination distance” throughout the document. Edits to section 1 and 2 addressed suggestions by WP 5D 7D/206. Annex 2 and 4 are proposed to be removed given that these study examples do not use typical deployment parameters or methodologies for simulating IMT and can produce exaggerated coordination zone distances and thus should not be included for clarity.

**Attachment**

ATTACHMENT

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| **Radiocommunication Study Groups** |  |
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| Source: Document [7D/186](https://www.itu.int/md/R23-WP7D-C-0186/en), Annex 20 | Document |
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| WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW REPORT ITU-R RA.[IMT-6GHZ] | |
| Methods to address the determination of the coordination area around existing RAS stations from IMT stations in the frequency band 6 650-6 675.2 MHz | |

{Editor’s note: reference to Document [5D/716 (Annex 4.4)](https://www.itu.int/dms_ties/itu-r/md/19/wp5d/c/R19-WP5D-C-0716!H4-N4.04!MSW-E.docx) throughout the document needs to be resolved.}

# 1 Introduction

WRC-23 agenda item 1.2 resulted in a Conference decision to identify the frequency band 6 425‑7 125 MHz for IMT. Resolution **220 (WRC-23)** invites ITU-R “to develop an ITU‑R Recommendation to address methods for the determination of the protection area around existing RAS stations from IMT stations in the frequency band 6 650‑6 675.2 MHz”. Furthermore, the resolution invites administrations “to take all practical steps to protect the radio astronomy service (RAS) from harmful interference in the frequency band 6 650-6 675.2 MHz, […]”.

This report provides the methods for determining the coordination area around existing RAS stations from IMT stations in the frequency band 6 650‑6 675.2 MHz.

{*Editor’s note:* A paragraph or two about how the report is structured and what it contains will be drafted in future meetings.}

# 2 RAS systems

Radio astronomy uses parts of the upper 6-GHz spectrum for observations of the methanol spectral line in the band 6 650.0-6 675.2 MHz, which is addressed in the ITU-R Radio Regulations footnote No. **5.149**. The 6.6685192 GHz methanol (CH3OH) maser line is essential to study the formation of massive stars. Radio telescopes have been deployed on a global basis, which are equipped with state-of-the-art receivers to perform measurements of this spectral line and a fair share of the total observing time is invested, both with single dishes but also with telescope networks, including VLBI.

RR No. **5.149** states that “in making assignments to stations of other services to which the bands: […] 6 650-6 675.2 MHz […] are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. […]”.

## 2.1 RAS parameters

The parameters to be used in the study include the antenna pattern and antenna height above the ground of RAS receiver.

Example values of parameters for a generic RAS station are listed in Table X. However, for coordination of an actual site, the site-specific values for these parameters should be, e.g. the height above ground of the focal point. The antenna pattern for the RAS can be obtained from Recommendation ITU‑R SA.509/RA.1631, but in many cases involving terrestrial sources of interference a flat level of 0 dBi is used for reasons outlined in Recommendation ITU-R RA.769.

Table X

Example RAS parameters

|  |  |
| --- | --- |
| *Parameter* | *Value* |
| Frequency range | 6650-6675.2 MHz |
| Channel bandwidth | 50 kHz |
| Antenna height | 50 m |
| Antenna pattern | an isotropic antenna with a gain of 0 dBi |
| Noise temperature | 10 K |
| Antenna temperature1 | 12 K |
| 1 Contributions from ground and atmosphere, cosmic microwave background, and galactic background. | |

The location of RAS station should also be provided in order to take into account the surrounding terrain for calculation of the propagation loss.

## 2.2 RAS protection criteria

The RAS band 6 650-6 675.2 MHz is used for spectroscopic observations of the methanol molecule, VLBI and Pulsar observations, but primarily used for spectral line measurements of the methanol molecule.

RR Nos. **5.149** refers to RAS usage in the frequency band of 6 650-6 675.2 MHz; However, this frequency band is not allocated to RAS.

The Recommendation ITU‑R RA.769‑2 “Protection criteria used for radio astronomical measurements” recommends “*2 that administrations should afford all practicable protection to the frequencies and sites used by radio astronomers in their own and neighbouring countries and when planning global systems, taking due account of the levels of interference given in Annex 1*”.

Although there is no interference threshold level entry for this band in the tables of Recommendation ITU-R RA.769, the threshold levels can be computed in the same fashion for a centre frequency of 6662.6 MHz. The resulting values are comparable to the RAS allocated bands centered at 4 830 or 4 995 MHz, provided in Recommendation ITU-R RA.769, and should be considered in studies, which are summarized as in Table X.

Table X

Threshold levels that could be considered in this study

|  |  |
| --- | --- |
| Observation type | Threshold interference level  (dB(W/m2 ⋅ Hz))) |
| Spectral-line observation | –230 |
| VLBI observation | –200 |

Recommendation ITU-R RA.1513, which defines levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis, provides with 2% data loss to the RAS due to interference by all stations of one service. This percentage of data loss is not directly translated to a percentage of instances (e.g. time) considered in a Monte Carlo simulation. Since 6 650-6 675.2 MHz is not allocated to radio astronomy, Recommendation ITU-R RA.1513 does not apply. However, in order to calculate coordination areas, Recommendation ITU-R RA.1513 could still be considered in studies with appropriate consideration of how the data loss percentage is translated to a Monte Carlo simulation.

Alternatively, less strict protection criteria and data loss metrics could be considered by the relevant administrations, which would accordingly lead to smaller coordination areas.

# 3 IMT systems

{*Editor’s note:* Inclusion of those parameters defined in Document 5D/716 (Annex 4.4) in this section. Additional parameters that we could agree on after reviewing the studies in Annexes could be added to this section in later stage.}

*{Editor’s note: The IMT parameters in section 3 of the working document of WP 7D should be in line with those in Annex 4.4 to Document [5D/716](https://www.itu.int/md/R19-WP5D-C-0716/en) (study period 2019-2023), e.g., there should be no superscript number in the row “Spectral mask (relative to total conducted power of carrier).*

*In addition, for IMT AAS systems operating within the 6 425‑7 125 MHz frequency band in adjacent channels to the RAS band (6 650‑6 675.2 MHz), the operating band unwanted emissions (OBUE) are contained in the draft new Recommendation ITU-R M.[IMT-2020.UNWANT.BS] “Unwanted emission characteristics of base stations using the terrestrial radio interface of IMT-2020” (see [Annex 5.9](https://www.itu.int/dms_ties/itu-r/md/23/wp5d/c/R23-WP5D-C-0792!H5-N5.09!MSW-E.docx) to Document [5D/792](https://www.itu.int/md/R23-WP5D-C-0792/en) (WP 5D Chair’s Report). It should be noted that IMT beamforming is fully correlated within the entire 6 425‑7 125 MHz frequency band}*

IMT technical parameters will vary depending on the local circumstances. However, in the following example parameters as in Table X are provided, which may be useful for the purpose of generic calculations. These parameters are based on those provided by ITU-R WP 5D for studies of 6 425-7 125 MHz under WRC-23 agenda item 1.2 as in Document [[5D/716 (Annex 4.4)](https://www.itu.int/dms_ties/itu-r/md/19/wp5d/c/R19-WP5D-C-0716!H4-N4.04!MSW-E.docx)](https://www.itu.int/dms_ties/itu-r/md/19/wp5d/c/R19-WP5D-C-0716!H4-N4.04!MSW-E.docx). The typical deployment densities are defined as a function of the deployment environment of the IMT BS and UE. The base stations are usually not operating at 100% of their maximum capacity. In the calculations a network loading factor of 20% could be assumed. The time division duplex (TDD) activity factors could be assumed as 75% for base stations and 25% for user equipment. Antenna pattern parameters were originally introduced in Document [5D/716 (Annex 4.4)](https://www.itu.int/dms_ties/itu-r/md/19/wp5d/c/R19-WP5D-C-0716!H4-N4.04!MSW-E.docx) and refer to Recommendation ITU-R M.2101-0. Specific information about a potential total integrated gain correction was not provided during the study cycle 2019-2023. Uniform distribution for radial distance (UE-BS) sampling was used in studies of 6425-7125 MHz under WRC-23 agenda item 1.2 and the minimum BS-UE distance is calculated based on the Down-Tilt for each scenario. The “below rooftop” parameter is provided for IMT BS deployments to describe the environment surrounding the BS. The above/below rooftop ratio in this table should not be interpreted as indicating whether or not additional clutter loss should be applied. Depending on the sharing scenarios [and associated guidance from SG3], relevant propagation models related to clutter loss should be used accordingly.

Table X

Example IMT parameters for base stations and user equipment in the band 6 425-7 025 MHz

| Parameters | IMT Base station | IMT User equipment |
| --- | --- | --- |
| ***Band parameters*** | | |
| Frequency | 6.65 GHz | 6.65 GHz |
| Carrier bandwidth | 100 MHz | 100 MHz |
| ***Antenna parameters (Rec. ITU-R M.2101-0)*** | | |
| Antenna pattern | *Suburban*  8 × 16 × 2 Array elements (H+V) Beamwidth H/V = 90°/65°  *Gelem*= 6.4 dBi 30 dB f/b ratio  Spacing H/V = 0.5/0.7  *Urban*  8 × 16 × 2 Array elements (H+V) Beamwidth H/V = 90°/90°  *Gelem*= 5.5 dBi 30 dB f/b ratio  Spacing H/V = 0.5/0.5 | −4 dBi (avg. isotropic)  Single-element |
| Antenna polarization | Linear/±45 degrees | n/a |
| Down-Tilt | 6° *(Suburban)*  10° *(urban)* | n/a |
| Antenna height | 20 m *(Suburban)* 18 m *(Urban)* | 1.5 m |
| Below rooftop base station antenna deployment | 15% *(Suburban)* 65% *(Urban)* | n/a |
| ***Emitted powers*** | | |
| Ptx | 22 dBm per element | 23 dBm |
| Spectral mask (relative to total conducted power of carrier) | −50.1 dBc/MHz (adjacent)  −76.1 dBc/MHz (spurious) | −30 dBc/MHz (adjacent)  −53 dBc/MHz (spurious) |
| Ohmic losses (included in Gelem) | 2 dB | 2 dB |
| Other losses | n/a | 4 dB (body loss) |
| Conducted spectral power density (Total array, without gain) | 26 dBm/MHz (in‑band)  −4 dBm/MHz (adjacent) | 3 dBm/MHz (in‑band)  −7 dBm/MHz (adjacent) |
| Power into RAS frequency band (Spectroscopy channel width: 50 kHz) | 13 dBm (in‑band)  −17 dBm (adjacent) | −10 dBm (in‑band)  −20 dBm (adjacent) |
| UE power control parameters | n/a | PCMAX = 23 dBm  P0 PUSCH = −95.5 dBm  α = 0.8 |
| Network loading factor | 20% | n/a |
| TDD activity factor | 75% | 25% |
| ***Deployment*** | | |
| Rb (housing ratio) | 2% | |
| Ra (ratio of hotspot area to housing area) | 5% *(Suburban)*  10% *(Urban)* | |
| Deployment density in hotspot area (number of sectors; 3 sectors per BS position) | 2.4 km‑2 *(Suburban)* 10 km‑2 *(Urban)* | 3 UEs per BS sector |
| Fraction of indoor devices | n/a | 70% *(Suburban)* 70% *(Urban)* |
| ***Distribution of user equipment (relative to base station)*** | | |
| BS cell radii (ISD) | 0.6 km *(Suburban)*  0.3 km *(Urban)* | |
| Distance distribution | Uniform (104.9, 600) *(Suburban)*  Uniform (35, 300) *(Urban)* | |
| Angular distribution | Normal (0, 30) (clipped at ± 60°) | |

# 4 Propagation model and clutter loss model [and polarization loss]

The signal propagating from the IMT base stations to RAS station is subject to the following propagation losses/attenuations:

• Free space loss

• Atmospheric loss

• Diffraction loss due to the surrounding terrain

• Clutter loss

• [Polarization loss].

## 4.1 Basic propagation loss for terrestrial paths

The recommended method to determine the path propagation loss between the IMT equipment and the RAS station is provided in Recommendation ITU-R P.452 or Recommendation ITU-R P.2001. Topographic information, i.e., terrain height data, should be incorporated, as it has a significant effect on the diffraction loss. The calculation of propagation loss according to the models in these Recommendations requires a specific terrain profile to be used for Monte Carlo simulations by running the model repeatedly on real (but random) paths of a fixed length. Such paths should be chosen by using a terrain database for a region representative of the environment of interest (for example, by choosing a specific city to represent an urban area or choosing a specific mountain range to represent a mountainous area). Within this region, for each path a random starting point is generated, and the end point is calculated at a random azimuth, using the path length of interest. The propagation analysis is then performed on each path, and the Monte Carlo approach is used to derive the statistics of the loss for this path length. This can then be repeated for other path lengths. For generic studies or in absence of real terrain data, the models could be used with flat terrain, but it is emphasized that this will lead to an overestimation of coordination distances. It is noted that Recommendation ITU-R P.452 or ITU-R P.2001 refers to Recommendation ITU-R P.676 for calculation of atmospheric losses. If available, atmospheric/weather data may be taken into account for more precise estimates of the atmospheric attenuation.

## 4.2 Clutter loss

For the IMT base stations deployed in urban and suburban scenarios, Recommendation ITU-R P.2108 section 3.2 (terrestrial paths) provides a statistical clutter loss model. In an aggregation calculation (Monte Carlo simulation) for each IMT device, a randomly chosen value (uniformly distributed between 0 and 100%) should be used. As RAS antenna heights are usually very large, the Recommendation ITU-R P.2108 model should be used with a single-end point clutter model, i.e., for the IMT equipment only. In case IMT base station deployed in rural scenario, Recommendation ITU-R P.2108 section 3.2 (terrestrial paths) does not apply. If BS antenna heights are well above the clutter heights along the propagation path towards RAS station, the model will not necessarily be applicable. A thorough analysis is beyond the scope of this report. Administrations may need to investigate the situation around RAS stations in their countries in more detail.

## [4.3 Polarization loss

The polarization loss will be specific to the loss caused by the polarization mismatch. IMT base station is using linear ±45 degrees dual polarization. RAS station is usually using dual polarization.]

# 5 Possible Scenarios

## 5.1 Single entry scenarios

Single entry scenarios, in which the compatibility between a single IMT transmitter (base station or user terminal) and the RAS station is studied, can be useful for quick assessments of a situation. While in practice, the total (aggregated) effect of a whole cell-phone network is usually of higher interest, experience shows that single-entry results can provide a reasonable first estimate for the required coordination distances. However, even if worst-case conditions are assumed (e.g., flat terrain conditions without clutter and maximum antenna gains), the aggregate scenario may still yield somewhat larger coordination distances, depending on the deployment numbers and other factors.

Single-entry calculations are usually laid out as worst-case scenarios. For example, even if a site-specific case is under study, where terrain and clutter information is available, one may still need to assess the path attenuation also for the no-clutter case. In practice, there may always be a particular transmitter location that is not fully affected by clutter. Likewise, the maximum transmitter antenna gain should be adopted.

### 5.1.1 Generic (flat-terrain) calculation

In absence of any further information on the terrain properties or clutter types along the propagation path between the transmitter and receiver, a flat terrain (zero profile heights) could be assumed. It is noted that in some propagation models flat-terrain conditions do not necessarily lead to the lowest possible path attenuation. Such calculations should usually only be employed if no specific RAS site is studied or if the terrain does not matter for any other reason.

### 5.1.2 Considering terrain, clutter and other constraints

For site-specific studies, terrain height profiles, clutter information and other relevant environmental or physical conditions should be obtained from an appropriate database. Such analyses are often conducted for a specific link (when a certain transmitter is to be constructed) or for an area surrounding an RAS station (e.g. to define coordination zones). In the first case, the exact clutter and maximum expected antenna gain towards an RAS station may be known and should hence be considered. In the second case, clutter data bases will only provide a statistical result, which is why it is necessary to conduct an analysis, at least for reference, assuming zero clutter losses. This is important because in some locations, the expected type of clutter may deviate from the actual one.

## 5.2 Aggregation scenarios

Aggregation scenarios, where the total received power from all IMT transmitters entering an RAS station receiver is calculated, should be performed by default. Here it is important, that a realistic estimate of the number of deployed IMT transmitters is fed into the simulations, as this number has immediate influence on the results. Likewise, all potentially mitigating factors need to be considered properly. For example, terrain and clutter can effectively shield many transmitter locations and will significantly reduce the overall received power. In addition, if beamforming antennas are used, the fact that the beams typically point towards the ground (in the sector in front of the antenna) will usually reduce the interference probability. However, as antenna side-lobes play a role for active array antenna systems, the dynamic beam pointing must be carefully considered, which usually requires information about the deployment distribution of user equipment as base station beams are formed into the direction of the user terminals.

### 5.2.1 Generic studies (in absence of terrain profiles and other information)

As for the single-entry case, generic studies can be useful for information. They allow to draw some conclusions if no particular site is investigated. Unlike for the single-entry case, clutter should be taken into account owing to the statistical nature of aggregation calculations. As such studies usually assume a mixture of urban, suburban, and sometimes rural deployment, typical clutter properties for such areas may be considered. One example would be to use the Recommendation ITU-R P.2108 clutter model for urban and suburban areas (more details are provided in Section A.4).

### 5.2.2 Simulation of actual deployments

The most realistic estimate of the expected received power at the RAS station will be gained, if the exact location of the transmitters, the according terrain heights, clutter information etc. are fed into the calculations. However, as compatibility calculations are usually made well before such specifics are known, this study case is probably very rare.

## 5.3 Mixed scenarios

Instead of assuming flat-terrain and no clutter losses in the generic scenarios, it would in principle also be possible to derive prototypical terrain height profiles and clutter zones from a variety of real-world cases. This would allow to overcome some of the issues that propagation models have with flat-terrain. However, this approach is beyond the scope of this recommendation.

# 6 Calculation of received power level at RAS receiver

The generic methodology for calculating a coordination area using a Monte-Carlo simulation consists of the following steps. The aim is to calculate the aggregate interference from IMT network at a RAS station receiver and compare it with the RAS protection criteria. If the threshold levels are exceeded, a minimal coordination distance can be derived.

**Step 1**: Determine the parameters as shown in § 2 and § 3

**Step 2a** (if RAS station surrounded by IMT network): place RAS station, IMT base stations and user equipment within the simulation area, following typical deployment numbers and distributions, except in an area of (initial) radius r around the RAS station. The simulation area must be large enough such that the resulting distribution functions (of received power) converge.

**Step 2b** (if RAS at some distance of an IMT network): place the IMT base stations and user equipment at an initial distance of the RAS receiver.

**Step 3**: Run a Monte Carlo simulation to calculate the aggregated power from IMT base stations in the simulation area received at the RAS earth station, as shown in formulas below.

**Step 4**: Compare the aggregated interference with the protection criterion of the RAS station, as shown in § 2. If the criterion is exceeded, continue with Step 5, otherwise the coordination distance is found.

**Step 5a** (if RAS station surrounded by IMT network): Increase the radius r around the RAS station, i.e., remove contributions from devices within the area defined by r. Continue with Step 3.

**Step 5b** (if RAS at some distance of an IMT network): Increase the distance between the RAS station and the IMT network. Continue with Step 3.

The above procedure should be repeated a number of times to determine (statistically stable) coordination distances and possibly typical scatter of the results.

Single-entry scenarios are in principle treated in the same manner, with the only difference that only a single IMT base station is considered.

If possible site-specific information should be used in single-entry and aggregation scenarios.

As IMT network is deployed on a large scale, it is often necessary to assess the impact of large portions of a network. In such cases, not only the technical parameters of individual terminals and base stations play a role, but also the deployment properties of the networks itself. Owing to the beamforming capabilities of modern IMT equipment, the link budget of each connection, between base station and user terminals, can be optimized in real-time, which also means that power control algorithms are viable that help to reduce the overall energy consumption. More information on this is provided in Recommendation ITU-R M.2101-0.

The transmitted power towards an RAS station (or to the local horizon in direction of an RAS station for trans-horizon paths) is subject to path propagation and clutter losses. These are discussed in Section A.4.

The interference from each IMT transmitter in the simulation experienced at RAS station is to be calculated in dB domain as follow:

where:

[dBm/MHz] Single entry interference power from the *n*th BS/UE

[dBm/MHz] Power spectral density of the *n*th BS/UE

[dB] Antenna gain of the *n*th BS/UE in the direction of RAS station

[dB] Clutter loss affecting from the *n*th BS/UE

[dB] Propagation loss between the *n*th BS/UE and the RAS station

[ [dB] Polarisation loss]

[dB] RAS station receiver antenna gain in the direction of the *n*th BS/UE

The values in the formula above are dependent on various angles between IMT transmitters and RAS receiver.

The aggregate interference I from IMT BSs and UEs experienced at the RAS station is to be calculated in linear domain as follows:

where:

*NBS* / *NUE* Total number of IMT BSs and UEs in the simulation area with consideration of network loading factor

*FBS\_TDD* / *FUE\_TDD* IMT BS and UE TDD activity factor.

# 7 Summary

Annex 1

An example of calculation of protection areas (Doc. 96)

{Editor notes: the parameters and studies have not been reviewed by WP 7D}

It presents an example for calculating the protection areas around the RAS station using the method defined in this report. The topographic information, i.e., terrain height data, is not considered at this stage and will be added in next meeting.

**Step 1** – Generate RAS station, IMT base stations and user equipment.

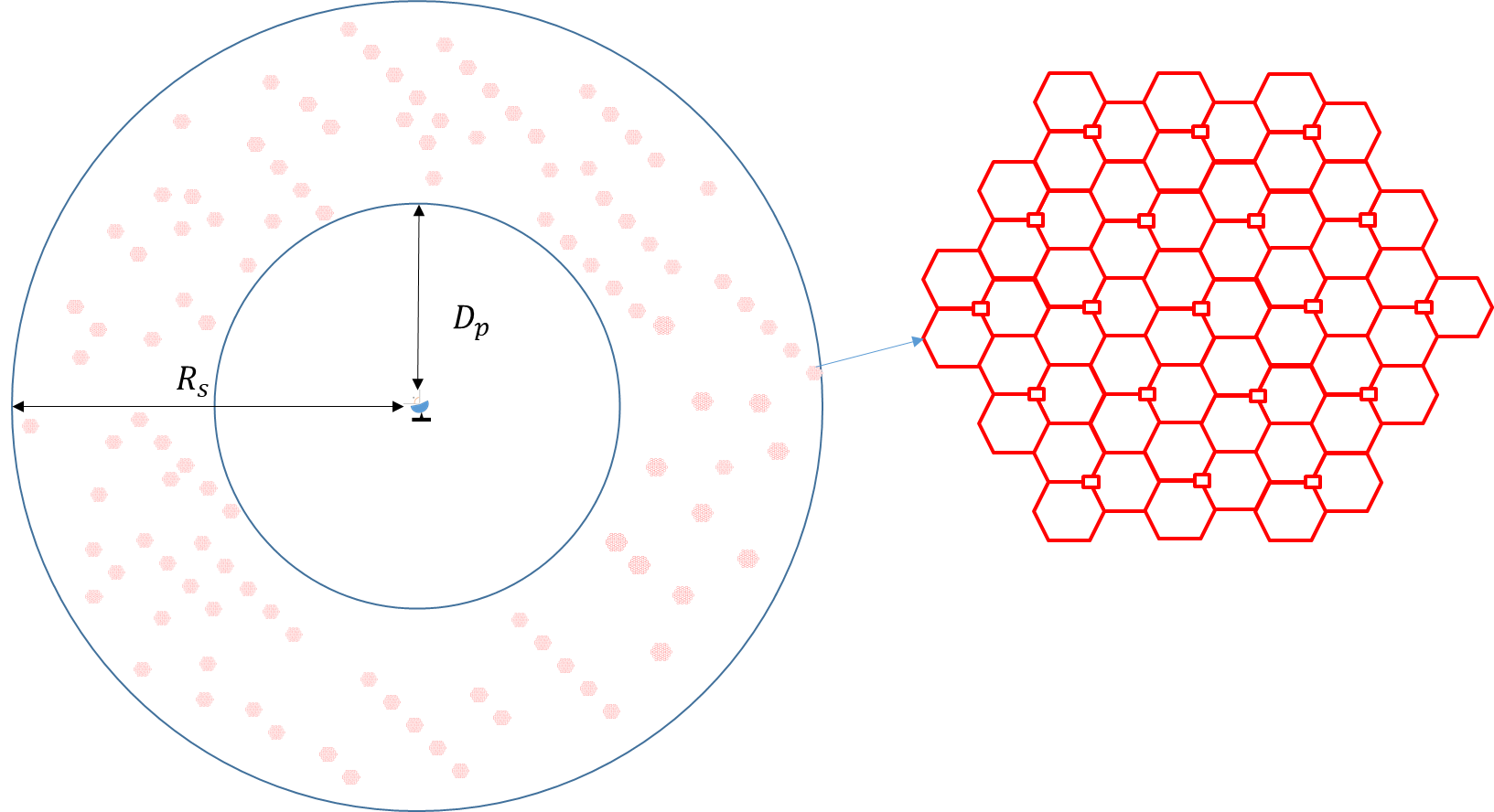
The IMT network will be generated as a cluster consisting of 19 sites \* 3 sector IMT base stations (see Figure 1 (right)).

Clusters of IMT networks are generated within the ring area uniformly.

The range of the distance D between RAS to the IMT network would be ≤ D ≤, where is the coordination distance, and is the radius of the simulated area.

Figure 1

Illustration of the scenario (left). Single IMT network is depicted on the right figure



**Step 2 –** Calculate cluster number in the simulation area

Where the subscript “u” refers to urban and suburban values, and

= density of simultaneously transmitting BS cells in km–2

= simulation area in km2

= BS cell deployment density in km–2

= ratio (<1) of built-up areas to total area of region under study

= ratio (<1) coverage areas to areas of cities/built-up areas/districts.

**Step 3** – Model IMT BSs, as well as user equipment in each sector of each BS for the purpose of modelling BS beamforming.

– According to the ITU-R terminology, an IMT BS means 1 sector in a 3-sector cell (see Figure 2).

– Each IMT BS in a cluster is given a random horizontal orientation based   
on a uniform distribution (0 to 360°). This is because the orientation of BSs  
is a function of local coverage planning, and is independent of the orientation  
of the RAS station.

– Each IMT BS in a cluster forms beams towards UEs which are modelled randomly located within the BS’s coverage area with a uniform distribution.

Figure 2

IMT BS illustration according to the ITU-R terminology

|  |  |
| --- | --- |
|  |  |

**Step 4 –** Calculate the interference from each IMT BS in the simulation area (see illustration of different angles on Figure 2 (right)):

where:

Single entry interference power from the *n*th BS in mW/MHz

Total radiated power (TRP) spectral density of the BS in mW/MHz

Elevation and azimuth angles between RAS station and BS

Elevation and azimuth angles of UE when viewed from the BS

Antenna gain of the BS in the direction of the RAS station

Clutter loss from the BS to RAS station

Propagation loss from the BS to the RAS station

Polarization loss

Angle of the BS with respect to the RAS station receiver’s boresight

RAS station receiver antenna gain in the direction of the BS.

**Step 5 –** Calculate the statistical distribution of the aggregate interference *I* from IMT Base Stations   
experienced at the RAS station:

where:

*NBS* Total number of IMT base stations in the simulation area

*FTDD* IMT BS TDD activity factor of 75% (see Table 7-1 in section a.1).

This aggregate interference is compared with target threshold level of interference for the protection of the RAS receiver and then derive the coordination distance.

Number of IMT Urban BS at 6 GHz considered in the study

***Note:*** According to ITU-R terminology “1 BS” = 1 sector in 3-sector cell.

According to the methodology agreed by WP5D, the number of IMT BSs per 100 MHz channel in the 6 GHz band can be written as

where:

Density of simultaneously transmitting BS cells in km–2

Area of interest in km2 (i.e., larger than 200 000 km2)

Base station deployment density in km–2

Ratio of built areas to total area of region in study

Ratio of coverage areas to areas of cities/built areas/districts

and “u” refer to urban values.

The ring area size of 360 000 km2 is simulated.

Table 1

The values of and used in this document

|  |  |
| --- | --- |
|  | Macro |
|  | 10% Urban (area > 200 000 km2) |
|  | 2% (200 000 - 1 000 000 km2) |

IMT PARAMETERS

Table 2 below summarizes IMT system parameters for urban IMT BS.

Section A.1 shows the full list of parameter values proposed in the WP 5D Chair’s Report [5D/716, Annex 4.4](https://www.itu.int/md/R19-WP5D-C-0716/en) (June 2021). IMT BS cell antenna array parameters as specified in Recommendation ITU-R M.2101 are also presented in Annex 1.

Table 2

IMT parameters used in this coexistence study

|  |  |
| --- | --- |
| Parameter | Parameter value |
| Network topology | Aggregate case: clusters of IMT networks (57 BSs) are generated within the ring area uniformly. |
| Coordination distances | Considered from center IMT network |
| Network loading factor | 20% (Note 1) |
| Polarization loss | 3 dB (Note 2) |
| IMT BS antenna pattern | WP5D/716 Chapter 4 Annex 4.4 (see Table X in section 3 for details) |
| IMT Tx power | 26 dBm/MHz |
| IMT BS height | 18 m (urban) |
| Number of UE per BS | 3 UEs per BS (uniform distribution) |
| Note 1: Network loading factor was assumed as 20% in the ring area larger than 50 km2.  Note 2: The IMT base station antenna is the ±45° cross-polar, but polarization of a signal received by RAS station antenna can be different, and it would not fully match with that of IMT antenna with high probability, so a polarization loss of = 3 dB was implied. | |

RAS PARAMETERS AND protection criteria

The Recommendation ITU R RA.769 2 “Protection criteria used for radio astronomical measurements” recommends “2 that administrations should afford all practicable protection to the frequencies and sites used by radio astronomers in their own and neighbouring countries and when planning global systems, taking due account of the levels of interference given in Annex 1”. However, the frequency band 6 650-6 675.2 MHz is not listed in Annex and no threshold level of interference is specified for this band.

Document 7D/13 in its study assumes the threshold level as −218.1 dB(W/50 kHz) not exceeded by 2% of time and provides calculated protection areas. For comparison of the study, this study uses the same criterion. Other assumptions of the RAS station is also aligned with those in Document 7D/13 for comparison purpose.

Table 3

RAS parameters used in this study

|  |  |
| --- | --- |
|  | Parameter considered in the study |
| Antenna Pattern | an isotropic antenna with a gain of 0 dBi |
| Antenna height | 50 m |
| Location | 51°N,16° E |
| RAS protection criteria | −218.1 dB(W/50 kHz) not exceeded by 2% of time |

PROPAGATION MODELLING

According to ITU-R SG3 WP 3K/3M[[1]](#footnote-1), liaison statement to the Working Groups carrying out sharing studies (Document 5D/722) Recommendation ITU-R P.2001 and ITU-R P.452 are recommended for sharing between stations on the surface of the Earth.

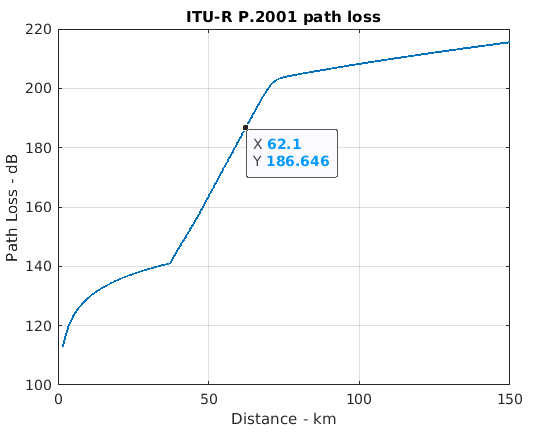
When considering larger coordination distances, it is to be noted that ITU-R P.2001 includes meteorological data maps and interpolates parameters such as sea-level refractivity and refraction index gradient based on latitude and longitudes whereas Recommendation ITU-R P.452 includes consideration of latitude only and requires user defined information which might not be exact especially for long paths.

Therefore the coexistence analysis in this document is based on Recommendation ITU-R P.2001, and 50% time percentage is assumed. According to Recommendation ITU-R P.2001, Tpc (time percentage) for the following sub-models are statistically-independent and randomly-generated in the range 0-100%. The path loss with 50% time percentage matches the path loss median value if we use a random time percentage uniformly distributed within 0 – 100% and randomized at each simulated event. So, 50% time percentage for the Recommendation ITU-R P.2001 is an accurate assumption for statistical simulations considering long-term interference.

|  |  |
| --- | --- |
| Propagation model | P. 2001 (longitude 16 degrees; latitude 51 degrees); time percentage: 50% |

Figure 3

Propagation model



This study uses the updated P.2108 clutter loss model included in SG3 guidance (Doc. 5D/722).

In order to define propagation conditions, line-of-sight (LOS) or non-line-of-sight (NLOS) concept is used in this paper in order to decide whether clutter loss to be applied or not in Urban scenario. There is a number of LoS/NLoS models in ITU, 3GPP, e.g. Report ITU-R M.2412, 3GPP TR38.901 and WINNER2, demonstrating that for transmitter and receiver heights up to 20 m, there is a very high probability of NLoS condition at distances beyond 1.5 km.

With considerations above clutter loss model is applied to all IMT BSs in this study.

Table 4

Propagation modelling summary

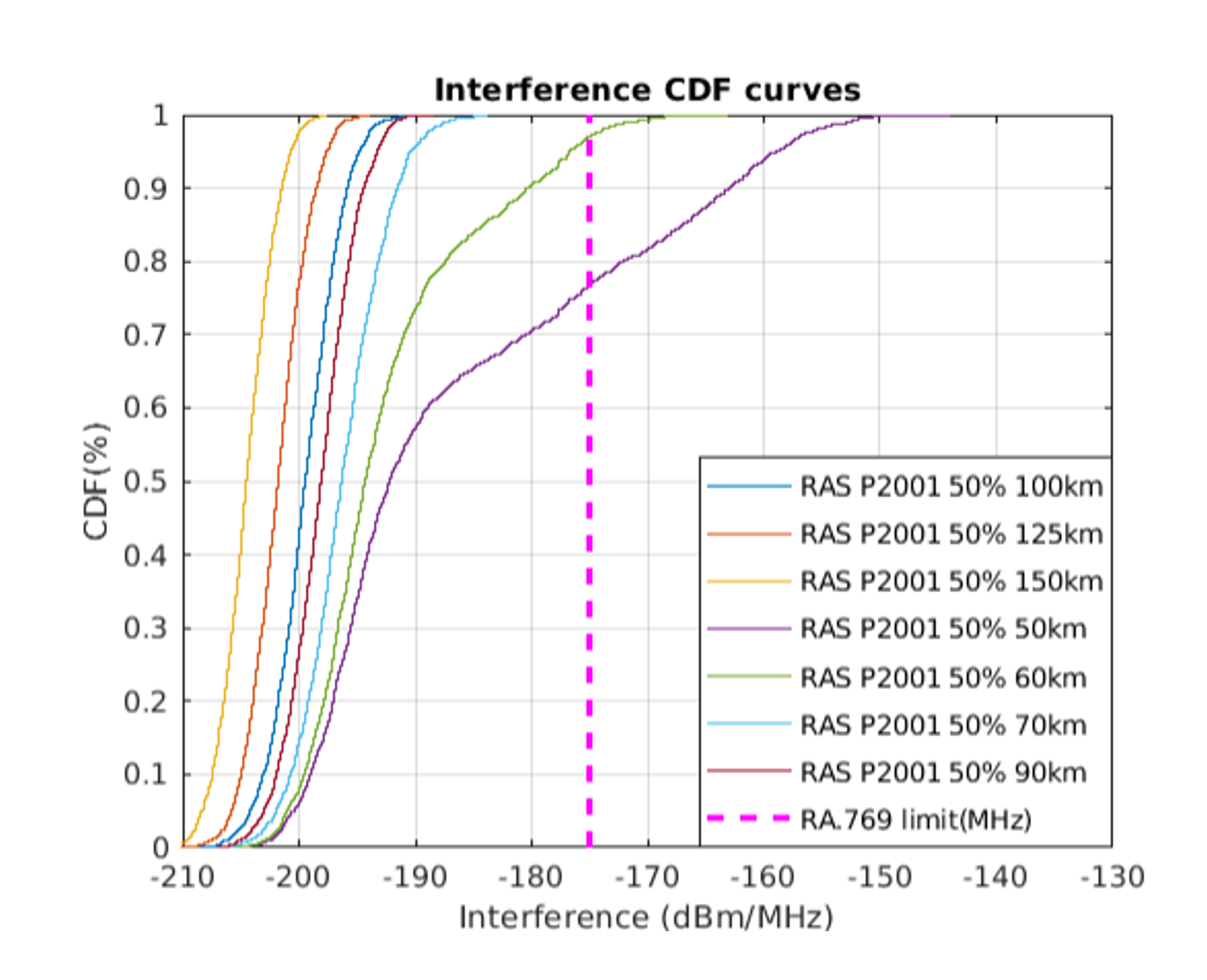
|  |  |
| --- | --- |
| Clutter loss model | Parameters |
| 0~100% uniform random value for percentage of locations in Recommendation ITU-R P. 2108 |
| Apply clutter loss model of the entire location distribution for all IMT urban BSs |
| No clutter loss applied for RAS |
| Section 3.2 of P.2108-1 based on guidance from SG3 |

RESULTS FROM SHARING STUDIES

The aggregated interference level from the IMT urban Macro BSs is calculated using the parameters and models described in the previous sections of the document, the corresponding CDF curves are shown in Figure 4 below.

Figure 4

CDF curve for in-band scenario



The minimum coordination distance required to ensure coexistence between RAS spectral line measurements and urban IMT macro base stations (in-band scenario) is obtained by comparing the interference levels at the RAS station receiver for the different coordination distances with the RAS protection criteria (-218.1 dB(W/50kHz) which is equivalent to -175.1 dBm/MHz, at 98th percentile of CDF curve for the protection of the RAS receiver).

Therefore, based on this analysis the minimum coordination distance required to ensure protection for the RAS stations from the aggregated interference from the surrounding IMT urban macro cellular network is 62 km.











Annex 3

Proposals on Methods in Document/99

{Editor notes: the parameters and studies have not been reviewed by WP 7D}

# C Mathematical tools

## C.1 Calculating effective transmitted IMT power towards RAS stations

This Annex contains procedures and formulae which can be used to determine the (aggregate) received power from an IMT BS and/or UE, or from a full network. It is assumed that the BS locations are known, while the position of UE devices is quasi-random. For typical deployment densities in an IMT network and for information on how BS locations can be derived (if not yet known), see Annex C.3.

### C.1.1 Introduction

Every BS can serve up to a given number of UE devices per frequency channel, which will use TDD, i.e., the up- and downlink communication occurs in time slots, which cannot be shared by different user devices. This also means that for a network simulation one needs to average the transmitted power from all devices over a sufficiently large period. To increase the link budget, the BS will dynamically steer its AAS beam towards each of the UE devices within the associated time slot. This also must be considered in a simulation by averaging over the effective antenna gains in time. Likewise, the UE may use AAS beamforming to improve the link budget. As the UE antenna frames can be arbitrarily rotated, the UE beams are also highly dynamic. It is usually assumed, however, that the angular distance between the UE antenna boresight and the actual direction to the host BS is, at most, 60° (otherwise, the UE antenna gain would be too low and the UE device would try to establish a connection to a different BS).

In the following, will represent a Cartesian coordinate frame around the RAS station, with measured to the East, measured to the North, and being the height above mean sea level (amsl). Thus, and are the positions of each individual IMT antenna. It is noted that Earth’s curvature must be considered for radio wave propagation. This will be accounted for in a subsequent step. The frame can be thought of as a local flat projection of the simulation area, such as UTM or ETRS89. Each BS antenna sector will have a certain bearing (azimuthal direction), .

### C.1.2 Sampling UE positions in a BS sector

The UEs, which are linked to a certain BS, are not uniformly distributed. It is assumed that each BS serves a given sector covering 120° in azimuth. In this sector, the azimuthal distribution of the UEs is modelled with a normal distribution:

(A.1)

with and the azimuthal separation from the BS antenna frame boresight. However, positions shall be restricted to the interval , which means that when sampling from the distribution, values outside this interval must be discarded. This accounts for about 5% of the drawn samples.

For the radial distribution of the UEs, i.e., the distance, , on the ground between UE and BS, log-normal or Rayleigh distributions are usually employed. The former is recommended for open-space hotspots, while the latter shall be used for other types, i.e., for urban and suburban (outdoor) hotspots. The log-normal distribution is defined as:

(A.2)

with and . The Rayleigh distribution is given by:

(A.3)

with .

A general method for sampling random numbers adhering to a distribution function is to sample uniformly distributed numbers, , from the interval , and feed them into the inverse cumulative distribution function (CDF), which is also called the quantile function (QF). This technique is also known as “Inverse Sampling,” and is a versatile tool for all sorts of random number generators. For continuous probability distributions it is not always possible to derive the QF in analytic form, but for discrete distributions (or approximations of continuous distributions) the strategy explained in Annex A.4 can be employed.

The QF for the normal distribution is:

(A.4)

with the inverse error function, . The QF for the log-normal distribution is:

(A.5)

likewise, the QF for the Rayleigh distribution is given by:

(A.6)

However, numerical libraries for most programming languages or math algebra software provide functionality to sample random values from these distributions, and it is usually recommended to use this for performance reasons.

After sampling the UE positions relative to the BS sector, the position in the global frame is given by:

|  |  |
| --- | --- |
|  | (A.7) |

where is the height of the terrain (amsl).

## C.2 Beamforming, geometrical calculations, and effective antenna gain

It was already discussed that both BS and UE AAS will be used to actively steer the beam towards the (currently active) counterpart. As the antenna frames are, in general, rotated with respect to the global coordinate frame, it is necessary to compute the beam positions in the antenna frame for each time step and device in order to derive the effective antenna gain in the beam direction and – equally important – the side-lobe gain towards the RAS station receiver. It is noted that the AAS gain pattern is highly dependent on the beam pointing.

Before the equations for this geometrical problem are presented, a few tools are introduced. The calculations can be performed very conveniently and efficiently using 3D linear algebra; in particular, employing rotation matrices. On the other hand, antenna gain formulae are often expressed in terms of spherical angles (i.e., azimuth and elevation). Hence, conversion between the Cartesian description and the spherical coordinate systems is necessary. Furthermore, as the antenna gain calculations are most easily done in the antenna pattern frames, a change of the basis frames is required, which is also discussed below.

### C.2.1 Spherical coordinates

A cartesian vector can be converted to spherical coordinates via:

|  |  |
| --- | --- |
|  | (A.8) |

where is the distance of a point to the coordinate center, is the elevation (not zenith distance!) above the - plane, and is the angle between the projection of the vector in the - plane and the axis. It is noted that in most computer software, the function should be used to get the correct quadrant of the result. Below, the spherical coordinates , elevation and azimuth, will, for example, be required for determination of antenna gain values, as many ITU-R models work with spherical angles (and not with cartesian vectors). In this framework, the antenna normal points towards the (positive) -axis, while is the horizontal and the vertical axis.

The inverse conversion formulae are:

|  |  |
| --- | --- |
|  | (A.9) |

For some applications, it can also be useful to calculate the true angular distance, , between two positions on a sphere:

(A.10)

or the great circle bearing, , under which Position 2 would appear as seen from Position 1:

(A.11)

### C.2.2 Rotation matrices

All rotations in 3D cartesian space can be expressed as a 3×3 orthonormal matrix. It is , which means . These can be conveniently constructed from successive applications of up to three elementary rotations:

|  |  |
| --- | --- |
|  | (A.12) |

which rotate any vector around the , , or axis with a rotation angle (in a mathematically positive sense). There are many different possibilities as to how this can be done which are beyond the scope of this Report. To name just two possibilities, one could use each of the three elementary rotations, e.g., , or just two of them, e.g., . Some of the many possible combinations are known as (classic) Euler angle representations.

An alternative method is to express a rotation via its (normalized) rotation axis, , and angle, :

(A.13)

where:

(A.14)

### C.2.3 Basis systems and basis change

The elements (values) of vectors and matrices are tied to the choice of a basis frame. When a basis frame is changed, e.g., when one converts between a global frame (such as the simulation box) and a local frame (rotated antenna frame), the new elements need to be calculated. As an example, consider a vector in a given frame . This vector can be rotated with a given rotation matrix :

The resulting elements , however, will still be in frame . On the other hand, it is also possible to rotate the frame (with the same rotation matrix), resulting in frame , and calculate the elements of the same vector in the rotated frame:

(A.16)

Likewise, because it is also true that . It is also possible (and necessary) to change the elements of a matrix, , if a basis change is performed:

(A.17)

as can be seen when applying the matrix to a test vector (in frame ):

(A.18)

where in the first step, the vector is experiencing a basis change from to , then the matrix (expressed in basis ) is applied, and finally the result is expressed in basis by multiplication with . In the following, this technique will make it possible to easily convert (and concatenate) antenna frame rotations in a very simple manner.

### C.2.4 Beam pointing in rotated frames

Every BS antenna is usually subject to an azimuthal rotation (bearing), , and potentially a mechanical down-tilt, . This can be represented as a concatenation of two elementary rotations:

(A.19)

It is noted that this rotation must not be applied to the global coordinate of the BS, but to a device-local frame . Before any rotation is applied, this *non-rotated local* (*nrl*) frame is aligned with the global frame, but the origin is shifted to the antenna location. Likewise, we define the rotated local (*rl*) frame, , which stems from applying any rotation on the *nrl* frame about the origin of the *nrl* frame, i.e., the *nrl* and *rl* frames have an identical origin. The *rl* frame represents the actual antenna frames for quasi-randomly oriented antennas, while the *nr* frame is merely needed to convert device and antenna positions from *rl* to global coordinates. For brevity, we will use the notation and hereafter for the *nrl* and *rl* frames, respectively.

For the UE, an arbitrary (random) 3D rotation acts on the device-local *nrl* frame. However, there exists the constraint that the maximum separation between the UE antenna boresight and the pointing vector to the host BS is less than 60° (see above). There are three options to take this into account, with the first being the simplest, but the last being computationally more efficient and elegant.

Option 1: Create random rotation and discard samples

Sample three rotation angles from uniform distributions such that , and compute:

(A.20)

It is noted that other combinations of elementary rotations would also work and that the sphere is covered twice, i.e., for one angle it would suffice to use only angles from . This rotation could now be applied to any vector of length 1, such as , to create a random position on the unit sphere, which shall represent the normal vector of the UE antenna frame. Using Eq. (A.8) the corresponding azimuth and elevation angles can be calculated.

Now, determine the vector between the UE and host BS:

(A.21)

where the meaning of the subscript “” is: “the direction to the BS, as seen from the UE.” (The elements of the vector are thus again defined in the device-local *nrl* frame). After normalization:

(A.22)

this can again be converted to azimuth and elevation angles . Now the cases where the angular separation between the UE antenna normal and the direction to the BS (as seen from the UE) are larger than 60° can be discarded, i.e., keep only samples with:

(A.23)

This method is obviously somewhat inefficient, as more random samples need to be generated than are necessary. Furthermore, more complicated constraints may be more difficult to implement. It would also be possible to use a different procedure to create a unit vector on the sphere.

Option 2: Construct rotation matrix in world coordinates

Again, a rotation matrix will be constructed from three (non-elementary) rotations:

(A.24)

Start from the hypothetical situation where the UE antenna normal was pointing to the host BS already, i.e., take as defined in the method above. The first rotation matrix, , shall perform a rotation about the UE-BS axis with angle . It can be computed using the axis-angle approach, see Eq. (A.13). This rotation will leave the antenna normal vector untouched. Next, a rotation with a maximum angle of 60 around any axis perpendicular to the UE-BS axis is applied. Without loss of generality, the axis lying in the plane is used, as determined by:

(A.25)

Again, before equation (A.13) can be used, the (rotation) axis vector must be normalised, i.e., use and rotate with randomly sampled from . Finally, rotate again about with randomly sampled from . Unlike in the first step, this time the UE-BS vector is not invariant under the rotation because the second rotation has tilted the coordinate frame away from the UE-BS axis.

Option 3: Construct rotation matrix in local frame and apply basis change

The method described in the previous section can also be constructed from two concatenated rotations. First, one can define a rotation that converts from the *nrl* frame to an initial frame (*“init”*), in which the antenna normal vector points to the host BS. Afterwards, the random UE rotation can easily be constructed using elementary rotation matrices only:

(A.26)

with and . The initial rotation is given by:

(A.27)

where is the spherical coordinate of the vector in the *nrl* frame. To obtain the final UE rotation matrix (expressed in the *nrl* frame), a simple basis change is required:

(A.28)

### C.2.5 Determination of effective antenna gains

Several specific antenna gain values are necessary for aggregation simulations. For the UE power control algorithm, the link budget between UE and its host BS needs to be computed. For this, not only the path propagation according to 3GPP TR 38.901 (section 7.4.1) is considered, but also the antenna gains of the UE antenna (in direction of the host BS) and the gain of the BS antenna in the direction of the UE. In both cases, it is assumed that the beams are formed towards the communication partner, while the antenna normals are, in general, not pointing towards the other device. With the frame rotation matrices derived in the previous sections, we find for the UE position expressed in the BS frame (*rl*):

(A.29)

where the meaning of the subscript “” is: “the direction to the UE, as seen from the BS.” Likewise, the BS position expressed in the UE frame (*rl*) is:

(A.30)

in which the last equality is a trivial consequence of the choice of frames in Option 3 above.

The effective antenna gains can be calculated by converting the resulting cartesian vectors, which are expressed now in the *rl* antenna frames, to spherical angles and feeding these into the AAS pattern of Rec. ITU-R M.2101-0 Table 4 for both the actual angles[[2]](#footnote-2), and the beam position, .

The same must be done for the effective gain of the BS and UE antenna patterns in the direction of the RAS station. As both the terrain heights and the curvature of the Earth do play a role, in a first step, the bearing angles towards the RAS station as well as the local horizon elevation angles must be determined. These are usually calculated as a by-product in the path propagation (pp) calculations as proposed in Rec. ITU-R P.452-17, for example. We denote the direction to the RAS station as (in *nrl* frame)[[3]](#footnote-3).

To calculate the gain, this position needs to be expressed in the antenna frames, i.e.:

|  |  |
| --- | --- |
|  | (A.31) |

where and are the cartesian vectors associated with at the BS and UE positions. As before, the gains can now be determined using Rec. ITU-R M.2101-0.

Figure B1

Coordinate frames of BS and UE antennas

A graph of a graph with lines and numbers

Description automatically generated with medium confidence

The various coordinate frames are visualized in Figure B1. The axes show the global coordinates, with the RAS station located at the origin of this frame. There is one BS at position with a bearing angle of and a down-tilt of . A UE device is placed at a distance of with an azimuthal angle of into the BS antenna footprint. Thus, the global position of the UE is . All terrain heights are assumed to be zero. For the UE rotation, the angles are used. In Fig. B1, the grey arrows show the *nrl* frames at the BS and UE positions, respectively. The green arrows indicate the antenna (*rl*) frames. For illustration, the *init* frame is also displayed, in which the UE antenna normal is pointing to the BS. Red arrows mark the path propagation vector towards the RAS receiving station.

In order to apply Recommendation ITU-R P.452-17, the BS and UE positions must be known in WGS84 longitudes and latitudes, . For the example in Figure B1, it is assumed that the RAS station is at . As previously mentioned, one can utilise a local flat projection such as UTM to convert between and WGS84 coordinates. Then, and . Recommendation ITU-R P.452 predicts and .

Figure B2

Phased-array antenna gain for BS and positions of the formed beam (black circle) and RAS station (red circle)

A picture containing colorfulness, graphics, art, screenshot

Description automatically generated

Based on this we find for the UE device position in the BS antenna frame (*rl*), , and for the RAS position (or rather the propagation path’s position) , respectively. The former is marked with a black circle in Figure B2, while the latter is indicated with a red circle.

Figure B3

Phased-array antenna gain for UE and positions of the formed beam (black circle) and RAS station (red circle)

A picture containing diagram

Description automatically generated

Likewise, the beam (to the BS) and RAS Rx positions in the UE frame (*rl*) are, and ; see Figure B3.

## C.3 Sampling BS locations according to land cover types

For generic aggregation studies, one of the first steps in the calculations is to simulate the deployment of BSs and UEs. In Recommendation ITU-R M.2101, several possible IMT network topologies are discussed, such as hexagonal or Manhattan-style (rectangular) grid layouts. However, typical deployment number densities and other technical parameters vary with the target IMT frequency band and technology generation. Such numbers are usually provided by the involved working parties.

For generic simulations, the provided IMT parameters usually include typical device densities for the relevant land-cover type zones, such as urban/suburban or rural areas. However, in most cases, no specifications are made with respect to the spatial distribution functions of devices. This usually has to do with the fact that for small-area simulations a single zone type can be assumed, and within these it makes sense to work with a relatively homogeneous deployment, as proposed in Recommendation ITU-R M.2101. For very large areas, the actual distribution usually has a less significant impact on the (statistical) results. For RAS, however, one can think of setups where the actual “clustering” of urban/suburban zones might play a role. Indeed, RAS stations are often in remote areas, but there could be some smaller towns nearby which would introduce a strong direction dependence with regards to minimum coordination distances.

Technically, some of the IMT studies make a difference between built-up area (i.e., having housings), in which (sub)urban zones are embedded, while in other studies —especially at lower frequencies— IMT BSs could also be deployed anywhere (i.e., also in rural areas) not necessarily associated with housings. In the following, as this Report is about 5G at mm waves, the former scenario will be used. For mm-wave 5G it is furthermore expected that BSs will only be installed in (sub)urban areas. The fraction of the total area that contains housings is usually denoted as . Within this, only a part of the area is thought to have urban or suburban land cover. This fraction is the so-called parameter.

The following recipe could be used to create quite realistic zone maps. It is based on the observation that densely populated areas, such as cities and towns, cover a certain (connected) area. In addition, suburban areas often surround urban cores in a city. Such spatial correlations can be introduced numerically in different ways, but one of the easiest methods is to smooth-down a map consisting of uncorrelated noise samples.

Figure B4

Creating pseudo-land-cover class zones by creating a spatially correlated noise map  
and applying thresholds

Chart

Description automatically generated

The method is visualized in Figure B4. The individual steps are:

1 Create a map of spatially uncorrelated noise, e.g., by drawing random samples from a normal distribution (independently for each pixel); see top left panel of Figure B4.

2 Apply a spatial filter, such as a Gaussian filter, , with various kernel sizes, . In the example in the figure, the kernel sizes and km have been used.

3 Sum the smoothed-down versions of the map. Applying weighting factors is an option and can be used to give certain distance scales more impact. The result of this is shown in the right panel of Figure B4.

4 Apply thresholds based on the percentile levels associated with the required housing () and/or area ratios (). In the example, , and and , respectively, i.e., the lowest threshold—which defines the housing area—is at 95% (), while the threshold for suburban areas is at 99.5% () and for urban it is at 99.65% (). Obviously, the area marked as “suburban” also includes the “urban” areas, such that the “highest” zone type should be used subsequently for each pixel in the simulation box.

The result can also be displayed in a different style, without contours, as in Figure B5. The next task to be addressed is how to sample BS locations into the simulation box, such that the given number densities and land cover types are respected. For this, again, the “inverse sampling” procedure can be used, which is discussed in Annex B.4. The method also works for n-dimensional data. The 2-D land cover map can be transformed into a number density map by assigning a (fixed) number density to each pixel according to the zone type. This density map can be understood as a discrete two-dimensional probability distribution, if it was normalized. Hence, the inverse sampling is realized by flattening the map (i.e., create a 1-D array consisting of the rows of the map), computing the cumulative sum, and dividing the result by the sum of all densities (or by the last element of the cumulative-sum array). To illustrate this, a toy map has been created with just one of each zone type; see Figure B6. If the pixel grid is relatively coarse, it is furthermore a viable strategy to add some sub-cell random shifts to each location. This helps to keep the computational costs small while not losing much accuracy.

Figure B5

Result of the procedure depicted in Figure B4 with the various zone types highlighted as coloured regions

Chart, scatter chart

Description automatically generated

Figure B6

Sampling BSs into different zones. The BS number densities are 10 / km2 for suburban   
and 30 / km2 for urban zones

Square

Description automatically generated with medium confidence

## C.4 Inverse sampling

If one needs to sample random numbers adhering to a given probability distribution, the “inverse sampling” technique can be used. Here the discrete version is explained, which works with any discrete probability distribution, and can also be used to approximate continuous cases. The basic idea is sketched in Figure A7. Mathematically, the inverse CDF, , is determined and random numbers from the uniform distribution are fed into it:

(3.32)

For discrete distributions or numerical approximations, the integral is replaced with the sum, in which case becomes the cumulative sum of . Taking the inverse is then a search operation in the CDF curve, i.e., finding the piece of the curve having the required -value, which gives the associated .

Figure B7

The inverse sampling technique can be used to generate random numbers adhering to a given target probability distribution by using the inverse CDF (or an approximation of it) and feeding in uniformly distributed random samples

Chart, histogram

Description automatically generated















\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Working Parties 3K and 3M meeting in July 2021. [↑](#footnote-ref-1)
2. It is noted that Rec. ITU-R M.2101-0 uses azimuth, , and zenith angle (wrongly referred to as elevation), , instead of elevation angle, . In contrast, the tilt angle, , is not used as a zenith angle, but as elevation with opposite sign. [↑](#footnote-ref-2)
3. In Rec. ITU-R P.452-17, the azimuthal direction to the receiver is given by (their equation 67), while the transmit elevation angle is denoted as (their equation 154). However, is defined with respect to North, while the system used in this Report is with respect to East, i.e., . [↑](#footnote-ref-3)