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ESA's DSA New Norcia 3: Geographical considerations for the site selection of a new deep space ground station antenna

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Abstract

Due to the increasing congestion of the radio spectrum, the frequency bands between different terrestrial and Earth-to-space services are often shared. When selecting a location for a deep space ground station, care must be taken to meet defined criteria while guaranteeing compliance with the regulatory procedures in place. In this paper, the site selection process for a new deep space ground station antenna in ESA's New Norcia (NNO) site is explored, focusing on the radio-frequency interference (RFI) problematic, analysing key aspects which were used to ensure the required coexistence with the local terrestrial services, both to meet the defined radio regulations and to guarantee no service disruptions. The ITU-R P-452 propagation model is used to predict the radio-frequency interference (RFI) to and from the new deep space ground station and existing terrestrial services, examining how the terrain impacts the predicted propagation loss. An overview of the main propagation mechanisms contained in the model is also given.

Keywords: radio-frequency interference; radio propagation; radio regulations; satellite communications

Acronyms/Abbreviations

EIRP	Effective Isotropic Radiated Power
ESA	European Space Agency
DEM	Digital Elevation Model
DSA	Deep Space Antenna
ITU	International Telecommunication Union
NNO	New Norcia
RFI	Radio Frequency Interference
RR	Radio Regulations
SRTM	Shuttle Radar Topography Mission
TOB	Television Outside Broadcast

1. Introduction

The European Space Agency (ESA) ground station (ESTRACK) network supports numerous missions across different orbital planes, including several deep space missions, served by deep space antennas spread across various longitudes around the globe to maximise the satellite visibility and thus extend the contact time to 24 hours per day. To expand the agency's capacity to serve present and future science missions, and in cooperation with the Australian Space Agency, ESA has decided to construct a second 35-metre deep-space antenna in its NNO site in Western Australia. It will be the fourth deep space antenna of the ESTRACK network, the other two being located in Spain and Argentina, in order to provide continuous coverage, and it is expected to be completed in 2024, entering operation in early 2025 [2].

The site selection process for a new ground station can be influenced by criteria, often conflicting, spread across different fields, and choosing the exact location for the antenna implies conducting detailed analysis to cover the technical aspects which impact the decision, both from a civil engineering perspective and a Radio Frequency Interference (RFI) one. The International Telecommunication Union (ITU) plays a central role in defining guidelines for an effective and efficient shared use of radio frequencies, which are usually developed with inputs from multiple stakeholders across industry and academia. To study if coexistence with the existing microwave terrestrial links is achievable, the ITU P-452 propagation model "*Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz*" [3] is used. This model enables the estimation of the potential risk for RFI and evaluates if the proposed locations identified by the project team meet the applicable protection criteria while also identifying the most suitable location from an RFI standpoint. While atmospheric phenomena can have notable impacts on the propagation of signals, especially short-term effects, it is expected that nearby areas will have similar atmospheric behaviours. Nevertheless, different locations in the same area can have substantially different horizon masks and path profiles to a given radio station, leading to some having additional shielding to and from a potential co-frequency link.

It is thus essential to conduct a survey of the terrain around the identified sites, to select a location with sufficient shielding from interference sources while still complying with the performance criteria for the deep space links and respecting at the same time the minimum horizon angles defined by the local communications' regulatory agency.

The ITU RR defines interference as *"the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation or loss of information which could be extracted in the absence of such unwanted energy"* [1], which can be categorised under three levels:

- **Permissible interference** (*RR, No. 1.167*) [1]: "Observed or predicted interference which complies with quantitative interference and sharing criteria contained in these Regulations or in ITU-R Recommendations or in special agreements as provided for in these Regulations";
- **Accepted interference** (*RR, No. 1.168*) [1]: "Interference at a higher level than defined as permissible interference and which has been agreed upon between two or more administrations without prejudice to other administrations."
- **Harmful interference** (*RR, No. 1.169*) [1]: "Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radio communication service operating in accordance with Radio Regulations"

Interference to radio systems can be both intentional and unintentional, as without considerable attention in the selection of all the parameters of a radio link, including its geographical location, the operation of that same radio link can cause interference which disrupts a different service sharing the same frequency band. Thus, in this paper, we analyse the considerations which should be contemplated when defining the location of a deep-space ground station to guarantee the coexistence with different terrestrial radio services.

2. RFI assessment: modelling and assumptions

After the general area for the ground station is selected, an RFI study needs to be conducted. First, and as radio propagation does not stop at national borders, it must be identified which countries might be affected by the radio emissions so that the administrations of those countries can be put in touch in order to be determined potentially impacted services and start the coordination process if necessary. For this, a coordination contour is generated based on worst-case and conservative assumptions. This regulatory concept will provide an overview of the countries which might be affected by the RFI from the Earth station, after which a more detailed analysis is necessary. For the case of the NNO station and due to its location in the southwest part of Australia, the process did not require to involve any foreign administrations, since the resulting coordination areas were found to be within the Australian territory.

Then, a survey of the existing microwave stations in the area is performed. Concretely, there is an interest in stations which share the same frequency range as that of the ground station. However, even high-power stations that fall on a different band, such as broadcast FM radio, can negatively impact the performance of the ground station with respect to unwanted emissions in adjacent bands, which might fall under the operational frequency ranges of the receiver chain. Without adequate shielding, a high-power microwave station can lead to interference and even overload the receiver.

After identifying the stations in the area that share the same frequency bands, an analysis of the antenna pointing angles when in operation should be conducted, determining the angular offsets between transmitting and receiving beams radiation beams. As even a highly directional antenna can transmit (and receive) a considerable amount of energy through its sidelobes, the analysis should include an accurate description of the antenna radiation pattern, which can be approximated with the ITU reference Earth station patterns [4]-[5], properly modelled taking into account the horizon profile information.

For the NNO site, a microwave Television Outside Broadcast (TOB) station located in Perth, at about 140 km from NNO, was identified as the most critical link, particularly because of its location at the top of Perth's highest skyscraper, at more than 200 m of altitude. The TOB station operates in the 7100-7235 MHz receive band and in the 8275-8401 MHz transmit band. The TOB terminal was modelled as a directional radio link with a given gain, pointing directly towards the NNO earth station and ignoring the relative TOB horizon angle to account for the worst-case scenario.

Figure 1 – NNO1 and NNO2 at ESA's NNO site [2].

It is essential to define the radiation pattern of the antenna accurately. A highly directional parabolic antenna, as used in the NNO site, can still leak a considerable amount of energy through its sidelobes. As such, it is not sufficient to know the maximum gain of the antenna. The NNO terminal complies with a gain pattern $G(\varphi)$ [dBi] modelled following a modified version of the ITU-RR APP7 Annex III [5] and described as follows:

$$G(\varphi) = \begin{cases} G_{max} - 2.5 \cdot 10^{-3} \cdot (\varphi \cdot D/\lambda)^2 & \text{for } 0 < \varphi < \varphi_m \\ G_1 & \text{for } \varphi_m < \varphi < \varphi_r \\ 29 - 25 \cdot \log(\varphi) & \text{for } \varphi_r < \varphi < 48 \text{ deg} \\ -13 & \text{for } 48 \text{ deg} < \varphi < 180 \text{ deg} \end{cases} \quad (1)$$

with:

$$G_1 = 15 \cdot \log(D/\lambda) - 1$$
$$\varphi_m = 20 \cdot (\lambda/D) \cdot (G_{max} - G_1)^{0.5}$$
$$\varphi_r = 15.85 \cdot (D/\lambda)^{-0.6}$$

where G_{max} is the maximum gain [dBi], φ is the off-axis angle [deg], D is the antenna diameter [m], and λ is the wavelength [m]. Terrestrial systems use linear polarisation, whereas the NNO station uses circular polarisation in most cases. Polarisation losses are ignored in first approximation.

The potential for RFI was studied for several scenarios in both directions, considering the NNO antenna as interfering transmitter and victim receiver. In particular, the RFI impact of NNO transmissions in the 7-GHz Space Research Services (SRS) bands for deep space and near-Earth missions was evaluated at two availability levels, 3% and 1%. Concerning the RFI potential from Perth's TOB transmissions into the 8 GHz deep space band, the applicable protection criteria are -220.0 dBW/Hz not to be exceeded for more than 0.001%.

3. The ITU-R P-452 propagation model

While the behaviour of electromagnetic waves can be defined through Maxwell's equations, approximated models are usually used due to the computation complexity that using them entails. Moreover, a complete and accurate description of the propagation scenario would be needed in order to use this theoretical model. Thus, there are instead several models that have been proposed throughout the years which approximate the propagation losses, usually for a given frequency range and considering different propagation mechanisms (usually the ones that have more impact for the frequency range being considered).

When selecting a propagation model for an interference study, it should be taken into account that the model can have a tremendous impact on the results, often transforming a scenario where harmful interference is not expected into one that is, or the opposite. In interference analysis, another crucial parameter that needs to be defined is the percentage of time where we could expect a propagation loss smaller than a given value, leading to a higher interference margin. Defining the link availability is then crucial, since the constantly changing nature of the atmosphere can have a substantial impact in the propagation loss. Rain, for instance, is especially relevant at higher frequencies, and coastal areas can be particularly affected by the formation of ducts – reflection layers which can extend the range of a given signal.

The P-452 propagation model includes a set of propagation mechanisms, ensuring that the propagation analysis includes all the major interference propagation mechanisms, which might be present simultaneously. The principal interference mechanisms, as defined in the recommendation are as follows:

- Line-of-sight
- Multipath enhancement
- Diffraction
- Tropospheric scatter
- Surface ducting
- Elevated layer reflection and refraction
- Hydrometeor scatter

Additionally, the model can also predict the clutter loss. As it is intended to be used to predict interference, the clutter loss model used is conservative. Nonetheless, if possible, it should be used to obtain a more accurate modelling of the signal strength for the studied links. For the current scenario, clutter losses were not considered, given that an analysis of the neighbouring terrain around the station shows that the trees lie below the antenna height.

The ITU-R P-452 propagation model is a terrain-specific model that requires as input the terrain height profile between the interfering source and the victim receiver. Several digital elevation models (DEMs) exist, with varying precision and Earth coverage. For our analysis, the openly available SRTM (Shuttle Radar Topography Mission) DEM was used, which offers a near-global coverage (between 54°S and 60°N) and up to 1 arc-second resolution, which corresponds to a spatial resolution of approximately 30 metres at the equator. For locations outside the SRTM latitude range of coverage, models such as the ASTER (83°S to 83°N at 1 arc-second) and the GTOPO30 (covers the whole globe at 30 arc-seconds), which have been made freely available can also be considered, although the SRTM dataset remains the most ubiquitous.

The determination of the coordination area is based on the concept of the permissible interference power at the antenna terminals of a receiving terrestrial station or earth station. Hence, the attenuation required to limit the level of interference between a transmitting terrestrial station and a receiving earth station to the permissible interference power for p% of the time is represented by the "minimum required loss", which is the loss that needs to be equalled or exceeded by the predicted path loss for all but p% of the time.

The propagation mode required distance, at the azimuth under consideration, is taken as the largest distance developed from a set of calculations, each of which is based on the following equation:

$$L_{req}(p) = P_t + G_t + G_r - I(p) \qquad \text{dB} \qquad (2)$$

where:

- p is the maximum percentage of time for which the permissible interference power may be exceeded
- P_t is maximum available transmitting power level (dBW) in the reference bandwidth at the terminals of the antenna of a transmitting terrestrial station or earth station
- $I(p)$ is the permissible interference level (dBW) in the reference bandwidth to be exceeded for no more than p% of the time at the terminals of the antenna of a receiving terrestrial station or earth station that may be subject to interference

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- G_t is gain towards the physical horizon on a given azimuth (dBi) of the transmitting antenna. The maximum main beam axis antenna gain is to be used.
- G_r is gain towards the physical horizon on a given azimuth (dBi) of the victim earth station antenna. The maximum main beam axis antenna gain is to be used.
- $L_{req}(p)$ is the propagation mode minimum required loss (dB) for p% of the time; this loss must be exceeded by the propagation mode predicted path loss for all but p% of the time

Additional details and procedures can be found in Appendix 7 of the ITU Radio Regulations [6].

3. Analysing the terrain around the New Norcia ESA site

A topographic map of the area between one of the identified potential NNO locations and the antenna in central Perth, is shown in Figure 2. It was generated using SRTM data with an internally developed MATLAB tool for terrain analysis.

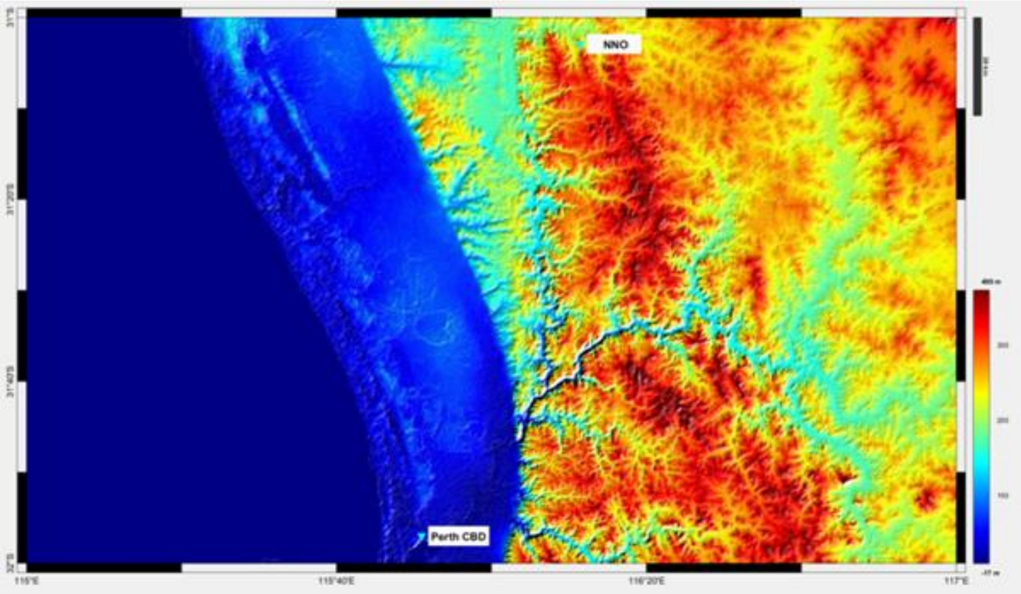

Figure 2 - Topography between Perth and NNO

This tool was used to generate the path profiles and horizon masks used to feed the ITU P-452 propagation model and enabled the study of the topography of the area around the locations of interest. In Figure 2, it is seen that New Norcia is located at higher elevation than Perth. This is also clear by looking at the path profile in Figure 3, from one of the pre-selected NNO locations to Perth's central area, where the TOB antenna is located. It becomes evident that the area is located behind a hill in the direction of Perth, offering shielding.

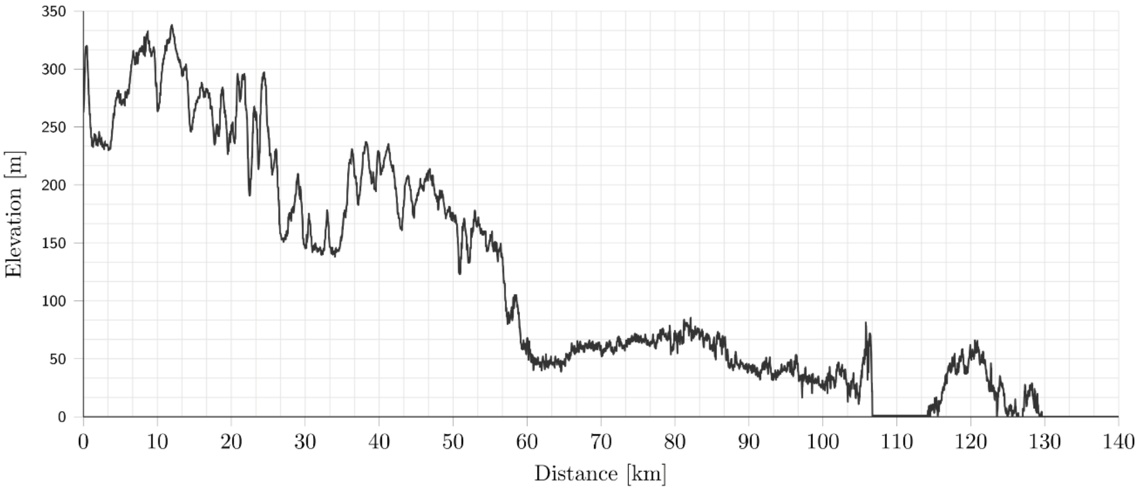

Figure 3 – Path profile between NNO and Perth

This is also visible when looking at the horizon profile around that same location, shown in Figure 4. The horizon profile of NNO is not ideal with respect to mutual visibility with the Perth city, due to its relative offset position with respect to the hill that exists between NNO and Perth. As already pointed out, this hill acts as a barrier and provides additional shielding to and from the station as the TOB antenna is located at about 200º from the identified NNO site, where the horizon mask assumes its highest value. The location was selected so that this hill shields NNO in the direction of Perth, where the exclusion cone was set up, as the city is the most critical area from an RFI point-of-view.

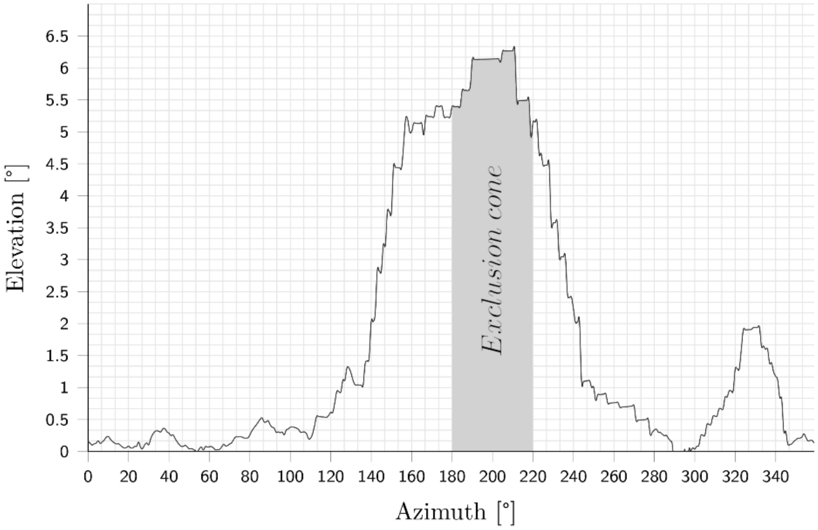

Figure 4 - Horizon profile around the NNO site, from the antenna radiation centre

4. Propagation loss simulation and sensitivity analysis

After a careful analysis of the terrain, the deep-space antenna site was selected to have some natural shielding in the Perth direction, the major metropolitan area in the vicinity. This natural shielding ensures that the margins obtained guarantee compliance with the applicable protection criteria, with care being taken to obtain enough margin to allow upgrades to the station, namely an increase in the transmitted power, which might be necessary to support upcoming deep-space missions.

The path loss obtained when feeding the terrain and climate information to the P-452 model, was always above 190 dB from the selected NNO locations to Perth's TOB antenna, obtained at an availability of 0.001% in the 7 GHz band. For 10% of the time, that path loss was more than 10 dB above, at around 200 dB. When defining the TOB as the interferer in the 8 GHz band, the path loss obtained was some dBs higher. Generally speaking, if the protection criteria are not met, or in order to obtain more confident margins or immunity from RFI, several mitigation strategies can be deployed, such as trying to find a new place with better natural shielding, adapting transmission levels, controlling the antenna pointing, or even installing artificial shielding if need be.

In this study case, the propagation loss estimate appears to be very sensitive to the antenna terrain height, probably because the terrain around such site is not as flat as for the other sites. In particular, the minimum and maximum altitude values, over a DEM grid of 3x3 pixels centred on the nominal NNO coordinates, range over more than 30-35 metres. The analysis is based on the raw SRTM data at 1 arc-sec resolution, which corresponds to about 30-m ground resolution in between pixels' centres. A small delta in the longitude and latitude results in a significant change in the antenna pedestal position and in the resulting horizon profile. To make sure that this was indeed the case, a sensitivity analysis was considered for the NNO antenna, showing how the propagation path loss varies depending on the considered antenna height (assuming the same path profile in between antennas.)

Figure 5 and Figure 6 show the propagation loss behaviour within the altitude range described above for both transmission and reception cases at the percentages of interest. In addition, Figure 6 also shows how the deltas in propagation losses at different terrain heights are further accentuated by the 0.001% time percentage considered.

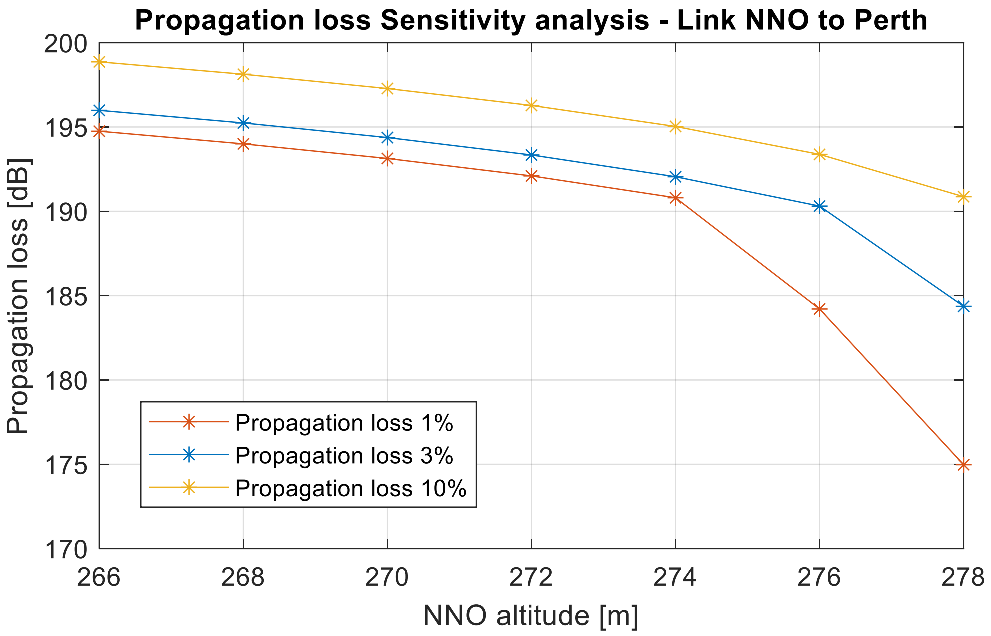

Figure 5 – Propagation loss sensitivity analysis to altitude uncertainty (Link New Norcia – Perth)

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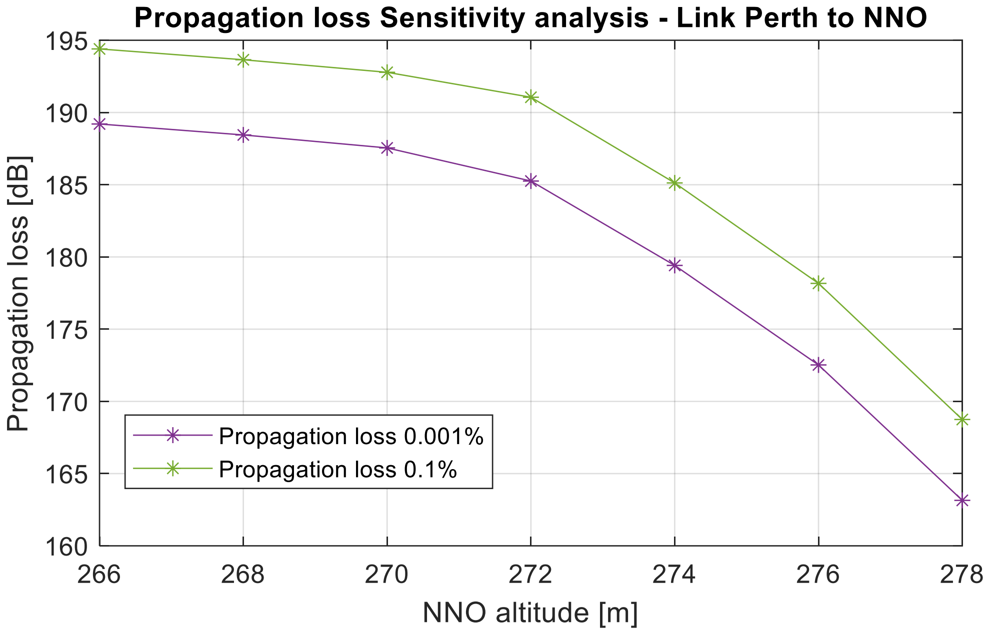

Figure 6 – Propagation loss sensitivity analysis to altitude uncertainty (Link Perth – New Norcia)

6. Conclusions

The analysis conducted here, performed to ensure the suitability of a location for the installation of a new deep-space ground station from an RFI point of view, showed that the surrounding terrain can have a meaningful impact on the path loss. Therefore, by carefully analysing the existent radio services and identifying the ones which present a higher risk of being interfered with or of causing harmful interference, one can select a location which uses the neighbouring terrain features as natural shielding. With this, the necessary margins to meet both the performance criteria defined for the operation of the station, as well as the ones defined in the ITU RR, can be met.

As initially pointed out, the site selection process for an upcoming deep-space station is a complex topic which involves considering several aspects that often are found to be conflicting. It becomes evident that the problem of RFI should be addressed. If care is not taken to properly understand if a given location is suitable, the team might be forced to define mitigation techniques which might increase the project costs or even reduce the usability of the station, if, for instance, an exclusion cone is necessary that reduces the satellite visibility, or if the transmitted power needs to be reduced to comply with the applicable regulations. Likewise, if there are co-frequency microwave links in the vicinity, the ability to correctly receive the signal from the spacecraft could be impaired.

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