Enhancing Signal Prediction Across Brazil: A Clutter Mapping Module for the ITU-R P.1812

Douglas R. C. Aguiar, Higo T. P. Silva, Hugerles S. Silva and Ugo S. Dias

Abstract— **In this study, we developed a clutter mapping module to enhance radio frequency signal prediction, refining the ITU-R P.1812 recommendation of the International Telecommunication Union. Utilizing data from the National Telecommunications Agency (ANATEL) and National Aeronautics and Space Administration's (NASA) Digital Elevation Model (DEM), we evaluated and demonstrated the module's precision and effectiveness. Supported by the Ministry of Communications of Brazil (MCom), this solution is crucial for advanced telecommunications planning and accountability in infrastructure development. The proposed tool provides reliable signal propagation assessments, supporting efficient and responsible telecommunications management.**

Keywords— **ITU-R P.1812, Clutter Mapping, Signal Propagation, Telecommunications Planning.**

I. Introduction

Near the end of the first quarter of the 21st century, the crucial role of technologies that offer precise and mobile information is clear, supporting national development through the efficient utilization of radio waves. In Brazil, where 96.7% of households depend on radio waves for televisions [1], optimizing radio wave propagation models's prediction is essential for both technological progress and strategic telecommunications planning. Ongoing advancements in broadcasting technology highlight the importance of accurate prediction models like ITU-R P.1812 [2] for diverse environments, such as urban areas, rural regions, and coastal zones.

The main features of the ITU-R P.1812 include a wide frequency range of application, from $30\,\mathrm{MHz}$ to $6000\,\mathrm{MHz}$, and the extensive distance range covered, from $0.25\,\mathrm{km}$ to $3000\,\mathrm{km}$. Additionally, the mentioned recommendation incorporates a variety of clutter classes and adjusts to different radio-climatic zones, including coastal and inland terrains as well as maritime environments. Accurate classification of clutter types is crucial, as misclassifications can lead to significant errors in the calculation of path loss and field intensity, thereby affecting the accuracy of predictions. This flexibility facilitates a detailed and comprehensive signal propagation analysis in diverse contexts. The recommendation's adaptability is particularly beneficial for Brazil, as its territory encompasses diverse propagation scenarios, ranging from vast rural and forested areas to densely populated urban regions. To enhance the applicability of this model, the approach is refined to include complex environments and improve terrain and clutter mapping—key factors in characterizing path loss and influencing signal coverage predictions. This includes integrating advanced remote sensing data and updated land cover databases. To address these issues, one critical dataset, the MCD12Q1, derived from Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on NASA's satellites [3], plays a central role in the advanced system for terrain and clutter mapping proposed in this study.

The system module proposed significantly optimize the ITU-R P.1812 model for Brazil's diverse environment, improving propagation predictions across complex terrains. This work, part of an initiative by the Ministry of Communications of Brazil (MCom) [4], addresses the critical need for accurate radio wave propagation models. By utilizing advanced terrain remote sensing, an innovative module is developed to enhances the ITU-R P.1812 model's applicability to Brazil's conditions, leading to more precise predictions and optimized digital transmission infrastructure. To the best of our knowledge, no research refines ITU-R P.1812 model predictions through precise clutter mapping in environments as diverse as Brazil. Additionally, there is no open system available to the Brazilian population offering such precise signal predictions. This advancement supports the MCom's objectives and benefits society by improving telecommunication strategies and accessibility.

Importantly, this study aims to optimize the application of ITU-R P.1812 by carefully selecting clutter categories, rather than modifying the model itself. "Blind methodologies" can lead to inaccurate link condition estimates. The proposed approach ensures reliable propagation predictions through refined clutter classification.

The remainder of this paper is organized as follows. Section II presents the related works. Section III provides a detailed description, testing, and validation of the proposed system model. The simulation results and their applicability are discussed in Section IV. Finally, Section V exposes the conclusions.

II. Related Works

Pérez García et al. [5] discusses the optimization of the ITU-R P.1812 model, taking into account Digital Terrestrial Television (DTT) within a specific region (Caracas, Venezuela). For the mapping of clutter and the refinement of predictions, field measurements are conducted by the authors. This implies high

Douglas R. C. Aguiar is with the Electrical Engineering Department, University of Brasília (UnB) and the Higher School of the Public Prosecution Office (ESMPU), Brasília, Brazil (e-mail: douglasaguiar@escola.mpu.mp.br). Higo T. P. Silva is with the Electrical Engineering Department, Federal Institute of Paraíba (IFPB), Paraíba, Brazil (e-mail: higo.silva@ee.ufcg.edu.br). Hugerles S. Silva and Ugo S. Dias are with the Electrical Engineering Department, University of Brasília (UnB), Brasília, Brazil (e-mail: hugerles.silva@unb.br; udias@unb.br).

accuracy. However, for broader analyses, such as developing a solution applicable across the entire Brazilian territory, this approach proves impractical. A similar strategy is adopted by Medbo et al. [6], who developed a clutter loss model for urban environments based on extensive measurements in cities across Denmark, Sweden, and Japan. The proposed model does not consider vegetation-induced clutter loss.

Urban clutter is also the focus of Fujii et al. [7], under the ITU-R P.452 recommendation. They proposes a method to estimate clutter height, which is validated using three-dimensional (3D) maps. However, this mapping process may face limitations in Brazil's diverse geography beyond urban areas. In the studies by Anedda et al. [8] and Paunovska et al. [9], the authors evaluate signal propagation models, including ITU-R P.1812. Anedda et al. focus on optimizing DVB-T2 Single Frequency Networks (SFNs) using ITU-R P.1546 and ITU-R P.1812, incorporating clutter loss modeling and terrain data to enhance coverage predictions. Paunovska et al. compare the ITU-R P.1546 and ITU-R P.1812 models through empirical terrain measurements, emphasizing the models' accuracy in different environments. However, neither study delves into the specifics of how clutter mapping is performed. Conversely, Lanza [10] provides information that clutter mapping is conducted using a topographic database at a scale of 1:25000.

Overall, while these studies offer valuable insights into signal propagation and clutter modeling, a approach tailored to Brazil's diverse geography remains necessary.

III. System Model

Modeling radio signal propagation in complex environments is essential and sophisticated for broadcasting systems. To address this issue, the present work adopts the ITU-R P.1812-7 recommendation [2], due to its high generalization capacity. This advanced model is capable of calculating path loss and field intensity, expressed in dB and $\mathrm{dB}\mu$V/m, respectively. It is highly applicable to precise point-to-area predictions, relevant for MCom systems and initiatives.

The ITU-R P.1812 distinctly acknowledges the necessity of incorporating Digital Elevation Model (DEM) data, a recognition that underlines the model's ability to enhance prediction accuracy through detailed topographical information. This level of specificity allows the model to tailor its predictions to the exact contours of the land cover. The model utilize in it's specification the standard deviation of location variability, σ_{L}. An empirical formula defines it, which accounts for the required frequency and prediction resolution, enhancing the accuracy of location variability across different environments. The formula describing this relationship is given by

$$\sigma_{\mathrm{L}} = 0.024f + 0.52w_a^{0.28}, \tag{1}$$

in which f is the required frequency in GHz, and w_a is the prediction resolution in meters. At this moment, the clutter height will act, in outdoor environments, as an adjustment factor of σ_{L} through the function $u(h)$, that represents the location variability height variation and will multiplies σ_{L}. The function $u(h)$ is defined as

$$u(h) = \begin{cases} 1 & \text{for } 0 \leq h < R, \\ 1 - \frac{(h-R)}{10} & \text{for } R \leq h < R+10, \\ 0 & \text{for } h \geq R+10, \end{cases} \tag{2}$$

in which h represents the height of the receiver or mobile above the ground and R is the height of the representative clutter at the location. Finally, the result of this adjustment for the standard deviation, called σ_{Loc}, is used to calculate the basic transmission loss and, consequently, the field strength.

The proposed system employs high-resolution land cover data sourced from the MODIS instruments. The specific product employed, MCD12Q1, facilitates a further refined calibration of the ITU-R P.1812 model by integrating sophisticated clutter classifications and terrain features, thus providing a more granular understanding of how local environmental characteristics influence radio wave propagation.

The MCD12Q1 product offers a diverse range of land cover classification schemes, among which the International Geosphere-Biosphere Programme (IGBP) [11] has been selected for this system. The IGBP classification is prevalent in DEM researches and aligns with other land cover models like GLOBCOVER [12], providing a coherent framework for comparative analysis. This DEM outlines 17 land cover categories that represent a variety of natural and urban features.

Strategic factors helped the selection of MCD12Q1 to optimize the ITU-R P.1812 model, with annual data update and review being paramount. This cyclical refresh ensures that the land cover classifications remain pertinent, mirroring the dynamic nature of environmental changes. Such up-to-date accuracy is vital for the precision of the signal propagation model, particularly in locales experiencing swift land-use changes, whether due to urbanization surges or agricultural modifications. As delineated in Fig. 1, the workflow of the proposed system module integrates the IGBP land cover classifications with annually revised MCD12Q1 data to refine the signal loss estimates within the ITU-R P.1812 framework.

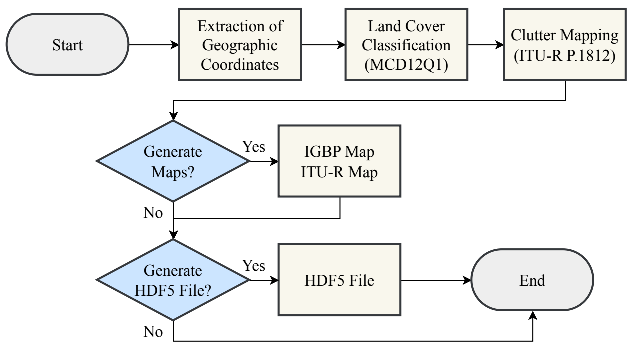

Fig. 1. System module flowchart.

The clutter classification mapping in the system is aligned according to Table I, which maps IGBP land cover classes, provided by MCD12Q1, to the corresponding classes and codes used by the ITU-R P.1812 model along with the associated clutter heights. This mapping is carefully defined to ensure the most accurate fit within the ITU-R P.1812 recommendation. It should be highlighted that, for areas that

"Unclassified" in the IGBP classification, a deliberate decision is made to assign them to the "Open/Rural" category in the ITU-R P.1812 model. This strategy ensures unclassified areas do not affect the prediction process.

TABLE I
MAPPING OF IGBP LAND COVER CLASSES TO ITU-R P.1812 CLASSES WITH ASSOCIATED CLUTTER HEIGHTS.

IGBP	ITU-R P. 1812 Clutters		
	Description	Code	Height (m)
Urban and Built-up Lands	Dense Urban	5	20
Evergreen Needleleaf Forests	Urban/Trees/Forest	4	15
Evergreen Broadleaf Forests	Urban/Trees/Forest	4	15
Deciduous Needleleaf Forests	Urban/Trees/Forest	4	15
Deciduous Broadleaf Forests	Urban/Trees/Forest	4	15
Mixed Forests	Urban/Trees/Forest	4	15
Closed Shrublands	Suburban	3	10
Open Shrublands	Suburban	3	10
Woody Savannas	Open/Rural	2	0
Savannas	Open/Rural	2	0
Grasslands	Open/Rural	2	0
Croplands	Open/Rural	2	0
Unclassified	Open/Rural	2	0
Permanent Wetlands	Water/Sea	1	0
Permanent Snow and Ice	Water/Sea	1	0
Barren	Water/Sea	1	0
Water Bodies	Water/Sea	1	0

A. *Evalution and Validation*

To assess and validate our proposal, the MOSAICO platform provided by National Telecommunications Agency (ANATEL) [13], which compiles information about the use of the radio frequency spectrum in Brazil, is utilized. The focus is on the spectrum designated by ANATEL as the basic plan for television (TV) and frequency modulation (FM) broadcasting. As of the time of this work, this basic plan comprises 37,150 sites distributed across the national territory.

Due to the potential for some sites to share identical geographic locations, duplicate positions are not included in this particular analysis, although they may be considered in the broader system implementation. After removing these repetitions, the number of unique location sites in the basic TV and FM plan is reduced to 23,366.

The next step involves performing a stratified sampling by Brazilian state, taking into account the territorial area of each state proportional to the total area of Brazil. These data are obtained from the Brazilian Institute of Geography and Statistics (IBGE) [14], and the sample size for each state is calculated using Cochran's formula [15], adjusted for the finite population, which is the total area of Brazil. The resulting sample consists of 1,401 sites spread throughout the Brazilian territory. To ensure the most extensive spatial representation across all states, the allocation of sample sites is guided by Halton's sequence. This random sequence distributes the sample points evenly across the states, minimizing clustering and enhancing the sample's representativeness of Brazil's varied terrain and land cover.

For each of the 1,401 selected sites, a high-resolution GeoTIFF image with dimensions of 2×2 degrees and a 7200×7200 pixel grid is produced, ensuring each map is centered on the site in question. Prior to the clutter classification analysis within the proposed system, these GeoTIFF images undergo a resampling process to match the approximately 463-meter pixel size characteristic of the MCD12Q1 data. Around 66,000 coordinates, each site's refined maps offer a dense and comprehensive dataset for analysis.

IV. RESULTS AND DISCUSSION

Among the 1401 samples analyzed, not a single coordinate is categorized as "Unclassified". This absence of undefined classifications across all analyzed data points underscores the robustness of the MCD12Q1 dataset. The dataset's comprehensive coverage and precise classification capabilities are evidenced by its ability to consistently provide clear and actionable insights across a broad spectrum of geographical and environmental conditions. This level of detail and accuracy not only enhances the reliability of the proposed system but also validates the effectiveness of using MCD12Q1 to refine ITU-R P.1812 model predictions in the diverse Brazilian landscape.

The distribution depicted in the Table. II shows a clear predominance of certain land cover types across Brazilian regions, as classified by the MCD12Q1 data set and aligned with ITU-R P.1812 clutter categories, according to the mapping of Table I. Notably, the Urban/Trees/Forest category is significantly more represented in the North region, which aligns with the expected land use of this area, known for its vast rainforest and lower population density. Furthermore, this region also displays the largest percentage of the Water/Sea category, which can be explained by the extensive rivers, that are characteristic of this area's geography. In contrast, the Northeast region, characterized by diverse ecosystems including caatinga and coastal zones, shows a very high representation in the Open/Rural classification. This may reflect the region's extensive rural areas and the nature of land use. The Central-West region not only shows a large percentage of Open/Rural areas, indicative of its sprawling farms and pastures, but it also presents the smallest representation of Water/Sea categories. This is attributable to the fact that it is the only Brazilian region without coastal access.

TABLE II
DISTRIBUTION OF LAND COVER ACROSS BRAZILIAN REGIONS, MAPPED ACCORDING TO ITU-R P.1812 CLASSES'S CODES, FOR 1401 SAMPLES.

Region	Clutter Code				
	1	2	3	4	5
North	8.035%	34.172%	0.006%	57.615%	0.172%
Northeast	5.069%	88.096%	0.922%	5.687%	0.225%
Central-West	0.688%	84.329%	0.044%	14.616%	0.323%
Southeast	5.071%	83.335%	0.115%	9.492%	1.987%
South	4.666%	79.153%	0.001%	15.100%	1.079%

The Southeast and South regions, which include some of the most urbanized and industrially developed areas in Brazil, show a mix of Dense Urban and Open/Rural areas, representing the urban-rural gradient present in these regions. The significant percentage of Dense Urban in the South region could be reflective of the population centers and the relatively smaller area of this region.

The distribution showcases the diverse nature of Brazil's geography and underscores the importance of region-specific approaches to clutter classification and radio wave propagation modeling. This nuanced understanding is essential for accurate telecommunications planning, ensuring that services are effectively tailored to each region's unique characteristics.

Continuing the assessment of the proposed approach's efficacy, ANATEL data is further utilized for a comprehensive evaluation. 27 samples, one from each Brazilian capital city, are randomly selected. To concentrate on a higher density of data, the maps are reduced to 1×1 degrees. A Python-developed simulation tool is employed to implement the ITU-R P.1812 recommendation [16]. This reduction in map size facilitates a more detailed examination of local signal variations, which is crucial for verifying the accuracy of the clutter mapping model. Additionally, the maps are resampled to the MCD12Q1 pixel size, enabling analysis with over 260,000 coordinates per map.

Fig. 2 presents a heatmap illustrating the predicted basic transmission loss across various parts of Brasília, considering the site with the channel ID[1] 57dbab805f780. The color scale indicates the level of signal attenuation due to geographical features and built structures. Key areas are marked to show their relative positions within the propagation model. The transmitter location is centrally positioned near Sobradinho, providing a focal point for signal distribution analysis. The map effectively demonstrates how the complex terrain and urban structures in the region influence radio wave propagation, with denser urban areas generally showing higher loss levels. These visualizations are critical for designing and optimizing communication systems, particularly in varying urban and suburban settings.

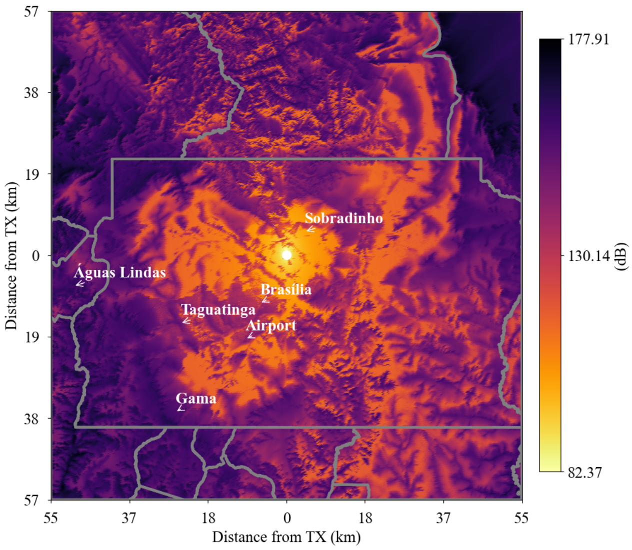

Fig. 2. Basic transmission loss at site with channel ID 57dbab805f780, located in Brasília.

The map in Fig. 3 highlights the city of Belém, which is crucial for understanding urban impact on radio wave propagation. The transmitter is strategically located in the center of Belém, illustrating how the dense urban setting contributes to significant signal loss even over relatively short distances. This visualization underscores the challenges faced in maintaining signal integrity in urban environments where built structures and human-made obstacles substantially alter the path loss characteristics. The geographical features of the area, including the proximity to large water bodies like the Bay of Marajó, further influence the signal dynamics, adding another layer of complexity to the propagation model.

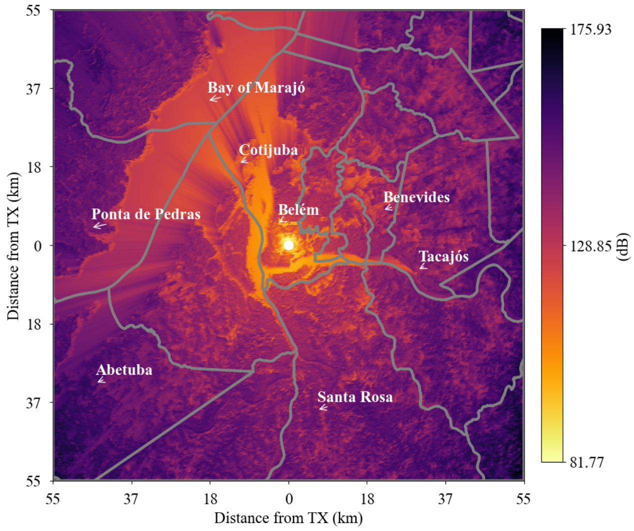

Fig. 3. Basic transmission loss at site with channel ID 65255123b3904, located in Belém.

Fig. 4 shows a site located in Porto Velho, a region characterized by dense forestation. The map illustrates significant signal loss across forested areas, highlighting the substantial impact of natural landscapes on signal degradation. This effect is particularly notable along the extensive waterways and in densely wooded regions surrounding the city, where signal propagation faces high levels of attenuation. These environmental factors are key to understanding the challenges in maintaining communication links in densely vegetated areas.

Finally, the clutter mapping module is compared with two approaches. The first approach adopts the Open/Rural pattern for all classifications, representing the absence of obstruction; whereas the second approach considers the dominant (most frequent) type of clutter in the analyzed map, reflecting the operator's empirical intuition through clutter inspection. The aim of this analysis is to evaluate the errors between these approaches and the clutter mapping module. The results are shown in Fig. 5.

The present analysis seeks to eliminate null errors, focusing only on instances in which the clutter classification module has some influence. The frequency of the measured errors is depicted through histograms, which display a lognormal distribution, supporting the suitability of the lognormal distribution for modeling prediction errors. A noteworthy observation is that, considering a holistic view of the terrain, the dominant clutter strategy outperforms the Open/Rural pattern,

[1]Channel identifier used in ANATEL's MOSAICO system.

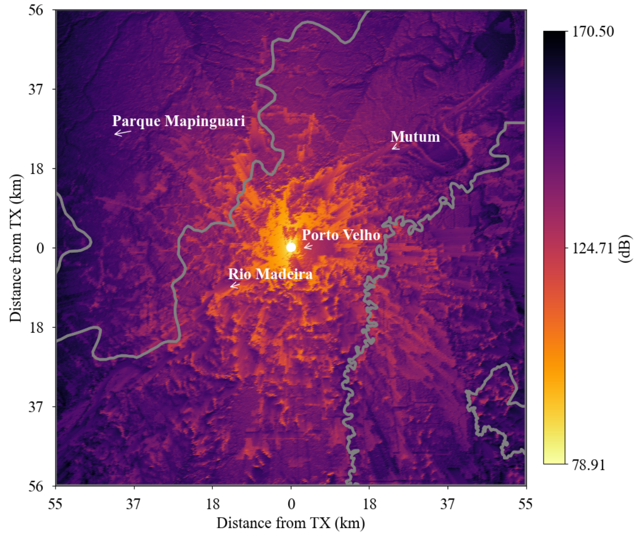

Fig. 4. Basic transmission loss at site with channel ID 65c0d1d7ae9d5, located in Porto Velho.

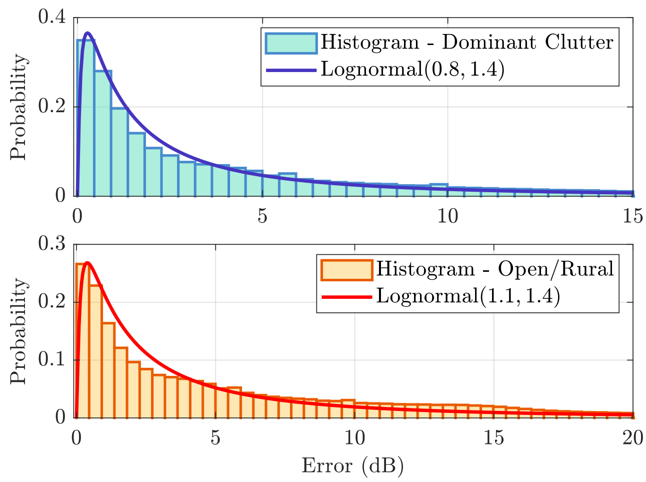

Fig. 5. Probability distribution of error between the two classification approaches and the proposed clutter mapping module.

which lacks detailed clutter information, as evidenced by the lognormal right tail. The proposed clutter mapping module demonstrates a high potential for optimizing ITU-R P.1812 predictions, regardless of the comparison strategy. Although rare, there are instances of high errors, indicating that the proposed methodology significantly improves link prediction accuracy and mitigates underestimation or overestimation of broadcasting link conditions. Inaccurate clutter mapping can result in significant discrepancies in the predictions.

V. Conclusion

In this study, a clutter mapping module was developed to enhance radio frequency signal prediction capabilities. This module integrated with and refined predictions made by the ITU-R P.1812 recommendation, specifically tailored to address the complex geographic and topographic landscape of Brazil. Using data from ANATEL and employing DEM data sourced from NASA satellites, the precision of the solution was evaluated, and its effectiveness in diverse environments was demonstrated. This corroborated the critical need for such advanced solutions in telecommunications planning and optimization. As this work was intended to be open to the Brazilian society, it hold significant potential for enhancing telecommunications planning and, importantly, for promoting accountability in infrastructure development. This makes the solution indispensable for reliable and precise signal propagation assessments, supporting efficient and responsible telecommunications management.

References

[1] Organisation for Economic Co-operation and Development (OECD), “Avaliação da OCDE sobre Telecomunicações e Radiodifusão no Brasil,” https://www.oecd.org/pt/publications/avaliacao-da-ocde-sobre-telecomunicacoes-e-radiodifusao-no-brasil-2020_0a4936dd-pt.html, 2020, Accessed on April 22, 2024.

[2] International Telecommunication Union, “P.1812: A Path-Specific Propagation Prediction Method for Point-to-Area Terrestrial Services in the Frequency Range 30 MHz to 6 GHz,” Radiocommunication Sector of International Telecommunication Union, International Telecommunication Union, 2023, ITU Recommendation.

[3] M. Friedl and D. Sulla-Menashe, “MODIS/Terra+Aqua Land Cover Type Yearly L3 Global 500m SIN Grid V061,” NASA EOSDIS Land Processes Distributed Active Archive Center, 2022.

[4] Ministry of Communications of Brazil, “Termo de Execução Descentralizada (TED) Nº01/SERAD/2022,” https://www.gov.br/mcom/pt-br/arquivos/ted/221207_ted_plano-de-trabalho_sei10396820, 2023, Accessed on May 9, 2024.

[5] N. A. Pérez García, A. D. Pinto, J. M. Torres, J. E. Rengel, L. M. Rujano, N. Robles Camargo, and Y. Donoso, “Improved ITU-R model for digital terrestrial television propagation path loss prediction,” *Electron. Lett.*, vol. 53, no. 13, pp. 832–834, 2017.

[6] J. Medbo, C. Larsson, B.-E. Olsson, F. S. Chaves, H. C. Nguyen, I. Rodriguez, T. B. Sorensen, I. Z. Kovács, P. Mogensen, K.-T. Lee, J. Woo, M. Sasaki, and W. Yamada, “The development of the ITU-R terrestrial clutter loss model,” in *12th European Conference on Antennas and Propagation (EuCAP 2018)*, 2018, pp. 1–6.

[7] H. Fujii and A. Sato, “Method for Estimating Representative Values of Clutter Heights for Recommendation ITU-R P.452,” in *2009 IEEE 70th Vehicular Technology Conference Fall*, 2009, pp. 1–5.

[8] M. Anedda, A. Anedda, and M. Murroni, “Coverage optimization for DVB-T2 SFNs using ITU-R P.1546 and ITU-R P.1812,” in *2015 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting*, 2015, pp. 1–5.

[9] L. Paunovska and L. Gavrilovska, “Comparison of propagation models ITU.R-P.1546 and ITU.R-P.1812,” in *2014 4th International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronic Systems (VITAE)*, 2014, pp. 1–5.

[10] M. Lanza, L. Gutierrez, J. R. Perez, J. Morgade, M. Domingo, L. Valle, P. Angueira, and J. Basterrechea, “Coverage Optimization and Power Reduction in SFN Using Simulated Annealing,” *IEEE Transactions on Broadcasting*, vol. 60, no. 3, pp. 474–485, 2014.

[11] International Geosphere-Biosphere Programme, “International Geosphere-Biosphere Programme (IGBP),” https://www.igbp.net/, 2015, Accessed on April 10, 2024.

[12] O. Arino, J. J. R. Perez, V. Kalogirou, S. Bontemps, P. Defourny, and E. V. Bogaert, “Global Land Cover Map for 2009 (GlobCover 2009),” PANGAEA, © European Space Agency (ESA) & Université Catholique de Louvain (UCL), 2012.

[13] National Telecommunications Agency (ANATEL), “Mosaico,” https://sistemas.anatel.gov.br/se/public/view/b/srd.php, 2024, Accessed on: April 20, 2024.

[14] Brazilian Institute of Geography and Statistics (IBGE), “Brasil | Cidades e Estados | IBGE,” https://www.ibge.gov.br/cidades-e-estados, 2024, Accessed on: April 22, 2024.

[15] W. G. Cochran, *Sampling Techniques*, 3rd ed. John Wiley & Sons, 1977.

[16] I. Stevanovic, “Python Implementation of Recommendation ITU-R P.1812,” Accessed on: July 16, 2024. [Online]. Available: https://github.com/eeveetza/Py1812