Path Loss as a Function of Environment Type

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May 9, 2025

Introduction

Signal propagation in urban and suburban environments represents a significant challenge for wireless communication network design, especially in scenarios where line-of-sight between transmitter and receiver is not guaranteed. To predict signal losses in these environments, various empirical models have been developed, among which the ITU-R P.1411 model and the Weissberger model stand out. These models allow estimating additional attenuation due to obstacles such as buildings, vegetation, and other characteristic elements of the environment.

The ITU-R P.1411 model provides propagation loss estimates based on empirical parameters adjusted for different types of urban environments, differentiating between below-rooftop and above-rooftop transmission situations. On the other hand, the Weissberger model focuses on estimating losses due to vegetation, using frequency and forest canopy thickness as variables.

This report presents the results of simulations performed with both models for different propagation environments, considering both additional losses and total losses. These simulations were carried out by implementing the models in a Python system, which allows selecting the environment, propagation distance, and transmission frequency.

The results obtained for the four frequency bands used in Nicaragua (B2, B4, B5 and B28) are analyzed, considering different propagation distances. The main objective is to compare the total and additional losses estimated by each model, highlighting the differences, advantages, and limitations of each approach depending on the environment type.

1 Propagation Loss Models

1.1 ITU-R P.1411 Model

The ITU-R P.1411 model is an empirical model recommended by the International Telecommunication Union for calculating propagation losses in urban and suburban environments. Its general formula is:

$$L_b(d,f) = 10\alpha \log_{10}(d) + \beta + 10\gamma \log_{10}(f) \tag{1}$$

where:

- $L_b(d,f)$: mean losses in decibels (dB)
- d: distance between transmitter and receiver, in meters
- f: operating frequency, in GHz
- α, β, γ: empirical coefficients determined according to the environment type

Additionally, the model includes a standard deviation σ that represents the statistical dispersion of losses.

The coefficients for different environments are:

Environment	α	β	γ	σ (dB)
Below rooftop				
Dense Residential	3.01	18.8	2.07	3.07
Urban	4.00	10.2	2.36	7.60
Dense Urban	5.06	-4.68	2.02	9.33
Industrial	2.12	29.2	2.11	5.06
Above rooftop				
Building blocks	2.29	28.6	1.96	3.48
High buildings	4.39	-6.27	2.30	6.89

Table 1: Coefficients of the ITU-R P.1411 model for different environments

1.2 Weissberger Model

This model estimates propagation losses in environments with vegetation, such as forests or rural areas, considering the thickness of the vegetation traversed. The total loss is expressed as:

$$L_{\text{ewb}}(dB) = P_{\text{fsl}}(dB) + P_{\text{wb}}(dB) \tag{2}$$

where:

- $P_{\text{fsl}}(dB)$: free space losses
- $P_{\text{wb}}(dB)$: additional losses due to vegetation according to Weissberger

Free space losses are calculated by:

$$P_{\text{fsl}}(dB) = 32.5 + 20\log_{10}(f) + 20\log_{10}(d) \tag{3}$$

with:

- f: frequency in GHz
- d: distance in km

The vegetation loss term is:

$$P_{\text{wb}}(dB) = \begin{cases} 0.45 \cdot f^{0.284} \cdot d_f & \text{if } 14 < d_f \leq 400 \\ 0.45 \cdot f^{0.284} \cdot 14 & \text{if } d_f \leq 14 \end{cases} \tag{4}$$

where:

- f: frequency in GHz
- d_f: foliage thickness (thickness of vegetation traversed, in meters)

This model is typically applicable at frequencies from 230 MHz to 95 GHz.

For environments with different vegetation types, the following d_f values are assumed:

- Dense forest: $d_f = 400$ m
- Sparse forest: $d_f = 200$ m
- Low vegetation: $d_f = 100$ m
- Arid terrain: $d_f = 40$ m

2 Results

Environment	**Additional (dB)**	**Total (dB)**
Dense Residential	76.85	114.87
Urban	98.75	136.78
Dense Urban	114.73	152.75
Building blocks	64.74	102.76
High buildings	93.82	131.84
Industrial	60.66	98.68
Dense forest	92.69	130.71
Sparse forest	61.66	99.69
Low vegetation	41.02	79.05
Arid terrain	23.93	61.96
Inland water	10.00	48.03
Open sea	10.00	48.03
Urban open space	0.00	38.03
Residential with trees	69.25	107.28
Residential with few trees	58.93	96.96
Town	80.21	118.23
Wetland	35.83	73.86
Airport	NA	NA

Table 2: Losses by environment at 1.90 GHz (B2) for a distance of 1.00 km.
Free space losses: 38.03 dB.

Environment	Additional (dB)	Total (dB)
Dense Residential	76.81	113.87
Urban	98.58	135.64
Dense Urban	114.72	151.78
Building blocks	64.76	101.82
High buildings	93.67	130.73
Industrial	60.60	97.66
Dense forest	89.80	126.86
Sparse forest	59.74	96.80
Low vegetation	39.75	76.80
Arid terrain	23.19	60.25
Inland water	10.00	47.06
Open sea	10.00	47.06
Urban open space	0.00	37.06
Residential with trees	68.28	105.34
Residential with few trees	58.28	95.34
Town	79.16	116.22
Wetland	34.87	71.93
Airport	NA	NA

Table 3: Losses by environment at 1.70 GHz (B4) for a distance of 1.00 km. Free space losses: 37.06 dB.

Environment	Additional (dB)	Total (dB)
Dense Residential	76.88	115.77
Urban	98.91	137.80
Dense Urban	114.73	153.63
Building blocks	64.72	103.62
High buildings	93.95	132.84
Industrial	60.70	99.60
Dense forest	95.36	134.25
Sparse forest	63.44	102.33
Low vegetation	42.20	81.10
Arid terrain	24.62	63.52
Inland water	10.00	48.89
Open sea	10.00	48.89
Urban open space	0.00	38.89
Residential with trees	70.16	109.05
Residential with few trees	59.54	98.43
Town	81.17	120.07
Wetland	36.72	75.61
Airport	NA	NA

Table 4: Losses by environment at 2.10 GHz (B4) for a distance of 1.00 km. Free space losses: 38.89 dB.

Environment	**Additional (dB)**	**Total (dB)**
Dense Residential	76.60	107.64
Urban	97.50	128.53
Dense Urban	114.66	145.69
Building blocks	64.88	95.92
High buildings	92.77	123.81
Industrial	60.27	91.31
Dense forest	73.76	104.80
Sparse forest	49.07	80.11
Low vegetation	32.64	63.68
Arid terrain	19.05	50.08
Inland water	10.00	41.04
Open sea	10.00	41.04
Urban open space	0.00	31.04
Residential with trees	62.83	93.87
Residential with few trees	54.62	85.66
Town	73.28	104.32
Wetland	29.53	60.57
Airport	NA	NA

Table 5: Losses by environment at 0.85 GHz (B5) for a distance of 1.00 km. Free space losses: 31.04 dB.

Environment	**Additional (dB)**	**Total (dB)**
Dense Residential	76.54	105.89
Urban	97.19	126.54
Dense Urban	114.64	143.99
Building blocks	64.91	94.26
High buildings	92.52	121.87
Industrial	60.18	89.53
Dense forest	69.80	99.15
Sparse forest	46.44	75.79
Low vegetation	30.89	60.24
Arid terrain	18.02	47.38
Inland water	10.00	39.35
Open sea	10.00	39.35
Urban open space	0.00	29.35
Residential with trees	61.49	90.84
Residential with few trees	53.72	83.07
Town	71.81	101.17
Wetland	28.22	57.57
Airport	NA	NA

Table 6: Losses by environment at 0.70 GHz (B28) for a distance of 1.00 km. Free space losses: 29.35 dB.

3 Discussion

The main objective of this research was to estimate theoretical losses per kilometer traveled for 18 different types of *clutter*. For this purpose, two propagation models were used: the ITU-R P.1411 Recommendation and the Weissberger model, in addition to the free space loss model. The ITU-R P.1411 model is mainly oriented towards urban environments, while the Weissberger model focuses on vegetation.

The ITU-R P.1411 model is based on empirical coefficients (Table 1) that vary according to the relative position of the transmitting antenna relative to the average roof height. In this study, it was considered that the receiver is always below this height. Therefore, the environments *Dense Residential*, *Urban*, *Dense Urban* and *Industrial* were classified as below rooftop, while the environments *Building blocks* and *High buildings* were treated as above rooftop.

The results obtained show that the additional losses for these environments are not less than 60 dB. In particular, the environments *Urban*, *Dense Urban* and *High buildings* present losses greater than 90 dB per kilometer, with the *Dense Urban* environment being the most critical, with more than 114 dB. It is important to mention that the additional losses show little variation with frequency, since they are obtained as the difference between the total loss of the model and the free space loss (see Equation 1). Therefore, to analyze the effects of frequency, it is more pertinent to examine the total losses.

On the other hand, the Weissberger model already includes free space losses, so the differences between environments and frequencies are reflected in both additional and total losses. This model was applied to the environments of *Dense forest*, *Sparse forest*, *Low vegetation* and *Arid terrain*. Weissberger introduces a correction based on the foliage penetration depth, which depends on whether it is less than 14 m or between 14 m and 400 m. In this study, the second case was assumed for all environments, using a distance of 1000 m. To differentiate between vegetation types, different penetration coefficients (d_f) were used: 1, 0.5, 0.25 and 0.1, respectively, under the assumption that the model is primarily designed for dense forests.

Additionally, four mixed environments modeled as averages between two base environments were considered, assuming they can be represented as a combination of these. The composite environments were: *Residential with trees* (Dense Residential + Sparse forest), *Residential with few trees* (Dense Residential + Low vegetation), *Town* (Urban + Sparse forest) and *Wetland* (Inland water + Sparse forest). Since the first three include urban models, it is recommended to consult the total losses to better observe the differences with respect to frequency.

Finally, for the environments of *Inland water* and *Open sea*, a constant additional loss of 10 dB over the free space loss was assumed. In the case of *Urban open space*, only free space losses were considered. Lastly, no results were obtained for the *Airport* environment, as this requires a more detailed analysis due to possible interference and particularities of the environment.

4 Conclusions

- The ITU-R P.1411 model allows a detailed estimation of total propagation losses, differentiating between environment types and the relative position of antennas (below or above rooftop). However, since it does not explicitly incorporate free space losses in its formulation, the differences in additional losses with respect to frequency are not significant.
- The combination of models to analyze mixed environments introduces a certain degree of uncertainty, especially when assuming arbitrary percentages of contribution from each environment. Additionally, the empirical coefficients used in the ITU-R P.1411 model may not accurately reflect specific local characteristics, which limits their direct applicability without contextual validation.
- For low frequencies (such as 700 MHz), both models predict lower losses, although the differences between environments remain relevant. As frequency increases, losses also increase, especially in dense urban environments or with thick vegetation.

References

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