



Recommendation ITU-R P.1812-4
(07/2015)

**A path-specific propagation prediction
method for point-to-area terrestrial services
in the VHF and UHF bands**

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Note: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.

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RECOMMENDATION ITU-R P.1812-4

A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands

(Question ITU-R 203/3)

(2007-2009-2012-2013-2015)

Scope

This Recommendation describes a propagation prediction method suitable for terrestrial point-to-area services in the frequency range 30 MHz to 3 GHz. It predicts signal levels at the median of the multipath distribution exceeded for a given percentage of time, $p\%$, in the range $1\% \leq p \leq 50\%$ and a given percentage of locations, p_L , in the range $1\% \leq p_L \leq 99\%$. The method provides detailed analysis based on the terrain profile.

The method is suitable for predictions for radiocommunication systems utilizing terrestrial circuits having path lengths from 0.25 km up to about 3 000 km distance, with both terminals within approximately 3 km height above ground. It is not suitable for propagation predictions on either air-ground or space-Earth radio circuits.

This Recommendation complements Recommendation ITU-R P.1546.

The ITU Radiocommunication Assembly,

considering

- a) that there is a need to give guidance to engineers in the planning of terrestrial radiocommunication services in the VHF and UHF bands;
- b) that, for stations working in the same or adjacent frequency channels, the determination of the minimum geographical distance of separation required to avoid unacceptable interference due to long-distance terrestrial propagation is a matter of great importance,

noting

- a) that Recommendation ITU-R P.528 provides guidance on the prediction of point-to-area path loss for the aeronautical mobile service for the frequency range 125 MHz to 30 GHz and the distance range up to 1 800 km;
- b) that Recommendation ITU-R P.452 provides guidance on the detailed evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz;
- c) that Recommendation ITU-R P.617 provides guidance on the prediction of point-to-point (P-P) path loss for trans-horizon radio-relay systems for the frequency range above 30 MHz and for the distance range 100 to 1 000 km;
- d) that Recommendation ITU-R P.1411 provides guidance on prediction for short-range (up to 1 km) outdoor services;
- e) that Recommendation ITU-R P.530 provides guidance on the prediction of P-P path loss for terrestrial LoS systems;
- f) that Recommendation ITU-R P.1546 provides guidance on the prediction of point-to-area field strengths in the VHF and UHF bands based principally on statistical analyses of experimental data;
- g) that Recommendation ITU-R P.2001 provides a wide-range terrestrial propagation model for the frequency range 30 MHz to 50 GHz including both fading and enhancement statistics which is well suited for use in Monte-Carlo simulations;

h) that Recommendation ITU-R P.2040 provides guidance on the effects of building material properties and structures on radiowave propagation,

recommends

that the procedure given in Annex 1 should be used for the detailed evaluation of point-to-area signal levels in connection with these services.

NOTE – Long range propagation paths may also occur at VHF via the ionosphere. These modes are summarized in Recommendation ITU-R P.844.

Annex 1

1 Introduction

The propagation prediction method described in this Annex is recommended for the detailed evaluation of signal levels suitable for use in connection with terrestrial point-to-area services in the VHF and UHF bands. It predicts the signal level (i.e. electric field strength) exceeded for a given percentage, $p\%$, of an average year in the range $1\% \leq p \leq 50\%$ and $p_L\%$ locations in the range $1\% \leq p_L \leq 99\%$. Therefore, this method may be used to predict both the service area and availability for a desired signal level (coverage), and the reductions in this service area and availability due to undesired, co- and/or adjacent-channel signals (interference).

The propagation model of this method is symmetric in the sense that it treats both radio terminals in the same manner. From the model's perspective, it does not matter which terminal is the transmitter and which is the receiver. However, for convenience in the model's description, the terms "transmitter" and "receiver" are used to denote the terminals at the start and end of the radio path, respectively.

The method is first described in terms of calculating basic transmission loss (dB) not exceeded for $p\%$ time for the median value of locations. The location variability element is then characterized statistically with respect to receiver locations, in addition to the building entry loss element from Recommendation ITU-R P.2040. A procedure is then given for converting to electric field strength (dB(μ V/m)) for an effective radiated power of 1 kW.

This method is intended primarily for use with systems using low-gain antennas. However, the change in accuracy when high-gain antennas are used only affects the troposcatter element of the overall method, and the change in the predictions is small. For example, even with 40 dBi antennas at both ends of the link the over-estimation of troposcatter signals will amount to only about 1 dB.

The method is suitable for predictions for radiocommunication systems utilizing terrestrial circuits having path lengths from 0.25 km up to about 3 000 km distance, with both terminals within approximately 3 km height above ground. It is not suitable for propagation predictions on either air-ground or space-Earth radio circuits.

The propagation prediction method in this Annex is path-specific. Point-to-area predictions using this method consist of series of many P-P (i.e. transmitter-point-to-receiver-multipoint) predictions, uniformly distributed over notional service areas. The number of points should be large enough to ensure that the predicted values of basic transmission losses or field strengths thus obtained are reasonable estimates of the median values, with respect to locations, of the corresponding quantities for the elemental areas that they represent.

In consequence, it is assumed that users of this Recommendation are able to specify detailed terrain profiles (i.e. elevations above mean sea level) as functions of distance along the great circle paths (i.e. geodesic curves) between the terminals, for many different terminal locations (receiver-points). For most practical applications of this method to point-to-area coverage and interference predictions, this assumption implies the availability of a digital terrain elevation database, referenced to latitude and longitude with respect to a consistent geodetic datum, from which the terrain profiles may be extracted by automated means. If these detailed terrain profiles are not available, then Recommendation ITU-R P.1546 should instead be used for predictions.

In view of the foregoing, the location variability element of this Recommendation and the building entry loss model element of Recommendation ITU-R P.2040 are characterized via the statistics of lognormal distributions with respect to receiver locations. Although this statistical characterization of the point-to-area propagation problem would appear to make the overall model unsymmetrical (i.e. non-reciprocal), users of this Recommendation should note that the location variability could, in principle, be applied at either end of the path (i.e. either terminal), or even both (i.e. the transmitter and the receiver). However, the location variability correction is only meaningful in situations when exact location of a given terminal is unknown and a statistical representation over that terminal's potential locations is required. There are unlikely to be many situations where this could meaningfully be applied to the transmitter location. If the locations of both terminals are known exactly and this procedure is being used in P-P mode, then this Recommendation is only applicable with $p_L = 50\%$.

A similar point is true regarding building entry losses. The argument is slightly more complicated than for location variability owing to the fact that the median entry loss correction is non-zero. At the transmitter end, users should also add the building entry loss to the basic transmission loss if the transmitter is inside a building, but users must also be aware that the use of median loss values may be misleading if the transmitter is not in a "median" location.

2 Model elements of the propagation prediction method

This propagation prediction method takes account of the following model elements:

- *line-of-sight* (LoS)
- *diffraction* (embracing smooth-Earth, irregular terrain and sub-path cases)
- *tropospheric scatter*
- *anomalous propagation* (ducting and layer reflection/refraction)
- *height-gain variation in clutter*
- *location variability*
- *building entry losses* (from Recommendation ITU-R P.2040).

3 Input parameters

3.1 Basic input data

Table 1 describes the basic input data, which defines the radio terminals, the frequency, and the percentage time and locations for which a prediction is required.

The latitude and longitude of the two stations are stated as basic inputs on the basis that they are needed to obtain the path profile. Radiometeorological parameters must be obtained for a single location associated with the radio path, and for a long path the path-centre should be selected. It is appropriate to obtain the radiometeorological parameters for the transmitter location when predicting its coverage area.

TABLE 1
Basic input data

Parameter	Units	Minimum	Maximum	Description
f	GHz	0.03	3.0	Frequency (GHz)
p	%	1.0	50.0	Percentage of average year for which the calculated signal level is exceeded
p_L	%	1	99	Percentage of locations for which the calculated signal level is exceeded
φ_t, φ_r	degrees	−80	+80	Latitude of transmitter, receiver
ψ_t, ψ_r	degrees	−180.0	180.0	Longitude of transmitter, receiver (positive = East of Greenwich)
h_{tg}, h_{rg}	m	1	3 000	Antenna centre height above ground level
Polarization				Signal polarisation, e.g. vertical or horizontal
w_s	m	1	100	Width of street. The value of 27 should be used unless specific local values are available.

Polarisation in Table 1 is not a parameter with a numerical value. The information is used in § 4.3.3 in connection with equations (29a), (29b) and (30).

3.2 Terrain profile

A terrain profile for the radio path is required for the application of the propagation prediction method. In principle, this consists of three arrays each having the same number of values, n , as follows:

d_i : distance from transmitter of i -th profile point (km) (1a)

h_i : height of i -th profile point above sea level (m) (1b)

$g_i = h_i +$ representative clutter height of i -th profilepoint (m) (1c)

where:

i : 1, 2, 3 ... n = index of the profile point

n : number of profile points.

There must be at least one intermediate profile point between the transmitter and the receiver. Thus n must satisfy $n \geq 3$. Such a small number of points is appropriate only for short paths, less than of the order of 1 km.

Note that the first profile point is at the transmitter. Thus d_1 is zero and h_1 is the terrain height at the transmitter in metres above sea level. Similarly, the n -th profile point is at the receiver. Thus d_n is the path length in km, and h_n the terrain height at the receiver in metres above sea level.

No specific distance between profile points is given. Assuming that profiles are extracted from a digital terrain elevation model, a suitable spacing will typically be similar to the point spacing of the source data. The profile points are not required to be equally-spaced, but it is desirable that they are at a similar spacing for the whole profile.

It is desirable to have information on ground cover (clutter) along the path. It is convenient to store clutter categories in an additional array of n points to match the profile height data.

The “representative clutter height R ” referred to in equation (1c) concerns statistical height information associated with ground cover classification, such as vegetation and buildings, i.e., a single height value assigned to each ground cover /clutter class. Adding representative clutter heights

to a profile is based on the assumption that the heights h_i represent the bare surface of the Earth. If the radio path passes over woodland or urbanization where diffraction or sub-path obstruction occurs, in general the effective profile height will be higher because the radio signal will travel over the clutter. Thus a more suitable representation of the profile can be obtained by adding representative heights to account for the clutter.

The appropriate addition is not necessarily physical, such as rooftop heights in the case of buildings. Where gaps exist between clutter objects, as seen by the radio wave, some energy may travel between rather than over them. In this situation the presence of clutter is expected to increase diffraction loss, but not by as much as raising the profile to the physical clutter height.

This applies particularly to high-rise urban areas. Categories such as “dense urban” or “high-rise urban” tend to be associated with building heights of 30 metres or more. But some high-rise areas have large spaces between the tall buildings, and it is possible for low-loss paths to exist passing around them, rather than over the roofs.

At the other extreme, even in areas classified as “open” or “rural” it is unusual for the ground to be completely bare, that is, free of any objects which might add to propagation losses. Thus small values of R , rather than zero, might be appropriate in many cases.

Thus representative clutter height R depends not only on the typical physical height of clutter objects but also on the horizontal spacing of objects and the gaps between them. There is no accepted standard as to what a clutter category, such as “urban”, represents in physical terms in different countries. Where available, representative clutter height information based on local clutter height statistics or other sources should be used, Table 2 suggests default values for R which may be used in the absence of region/country specific information.

There is a separate use of clutter information to estimate terminal clutter losses, as described in § 4.7. The concept of representative clutter height, R , is retained, but may be interpreted differently. This is to acknowledge the wider availability of high resolution three dimensional clutter height information, such as accurate building heights and vegetation. Where available, representative clutter heights based on accurate clutter height information should be used in § 4.7.

TABLE 2
Default information for clutter-loss modelling

Clutter type	Representative clutter height (m)		Terminal clutter loss model
	Add to profile equation (1c) for $i = 2$ to $n - 1$	Terminal clutter losses § 4.7 and add to profile equation (1c) for $i = 1$ and n	
Water/sea	0	10	Equation (64b)
Open/rural	0	10	Equation (64b)
Suburban	10	10	Equation (64a)
Urban/trees/forest	15	15	Equation (64a)
Dense urban	20	20	Equation (64a)

The method described above, in which representative clutter heights are added to a bare-earth or terrain profile, requires separate data on terrain heights and the presence of clutter. It is not suitable for the direct use of remotely-sensed surface-height data, where heights include clutter with no explicit distinction between terrain and clutter. It is important to note that diffraction loss may be

seriously over-estimated if terrain profiles are extracted directly from surface, as opposed to bare-earth, height data.

3.3 Radio-climatic zones

Information is also needed on what lengths of the path are in the radio-climatic zones described in Table 3.

For maximum consistency of results between administrations the calculations of this procedure should be based on the ITU Digitized World Map (IDWM) which is available from the BR. If all points on the path are at least 50 km from the sea or other large bodies of water, then only the inland category applies.

If the zone information is stored in successive points along the radio path, it should be assumed that changes occur midway between points having different zone codes.

TABLE 3
Radio-climatic zones

Zone type	Code	Definition
Coastal land	A1	Coastal land and shore areas, i.e. land adjacent to the sea up to an altitude of 100 m relative to mean sea or water level, but limited to a distance of 50 km from the nearest sea area. Where precise 100 m data are not available an approximate value may be used
Inland	A2	All land, other than coastal and shore areas defined as “coastal land” above
Sea	B	Seas, oceans and other large bodies of water (i.e. covering a circle of at least 100 km in diameter).

3.4 Terminal distances from the coast

If the path is over zone B two further parameters are required, d_{ct} , d_{cr} , giving the distance of the transmitter and the receiver from the coast (km), respectively, in the direction of the other terminal. For a terminal on a ship or sea platform the distance is zero.

3.5 Basic radio-meteorological parameters

The prediction procedure requires two radio-meteorological parameters to describe the variability of atmospheric refractivity.

- ΔN (N-units/km), the average radio-refractive index lapse-rate through the lowest 1 km of the atmosphere, provides the data upon which the appropriate effective Earth radius can be calculated for path profile and diffraction obstacle analysis. Note that ΔN is a positive quantity in this procedure.
- N_0 (N-units), the sea-level surface refractivity, is used only by the troposcatter model as a measure of variability of the troposcatter mechanism.

If local measurements are not available, these quantities can be obtained from the maps in the integral digital products supplied with this Recommendation. The maps are contained in the files DN50.txt and N050.txt, respectively. The data are from 0° to 360° in longitude and from +90° to –90° in latitude, with a resolution of 1.5° in both latitude and longitude. The data are used in conjunction with the companion data files LAT.txt and LON.txt containing respectively the latitudes

and longitudes of the corresponding entries (grid points) in the files DN50.txt and N050.txt. For a location different from the grid points, the parameter at the desired location can be derived by performing a bi-linear interpolation on the values at the four closest grid points, as described in Recommendation ITU-R P.1144.

TABLE 4
Integral digital products

Filename	Origin	Latitude			Longitude		
		From (deg)	To (deg)	Spacing (deg)	From (deg)	To (deg)	Spacing (deg)
DN50.txt	P.453	90	−90	1.5	0	360	1.5
N050.txt	P.453	90	−90	1.5	0	360	1.5
LAT.txt	P.453	90	−90	1.5	0	360	1.5
LON.txt	P.453	90	−90	1.5	0	360	1.5

These digital maps were derived from analysis of a ten-year (1983–1992) global dataset of radiosonde ascents.

The digital maps are contained in the zip file [R-REC-P.1812-3-201309-I!!ZIP-E](#).

3.6 Incidence of ducting

The degree to which signal levels will be enhanced due to anomalous propagation, particularly ducting, is quantified by a parameter β_0 (%), the time percentage for which refractive index lapse-rates exceeding 100 N-units/km can be expected in the first 100 m of the lower atmosphere. The value of β_0 is calculated as follows.

Calculate the parameter μ_1 , which depends on the degree to which the path is over land (inland and/or coastal) and water:

$$\mu_1 = \left(10^{\frac{-d_{tm}}{16-6.6\tau}} + 10^{-5(0.496 + 0.354\tau)} \right)^{0.2} \quad (2)$$

where the value of μ_1 shall be limited to $\mu_1 \leq 1$,

and

$$\tau = 1 - \exp\left(-0.000412d_{lm}^{2.41}\right) \quad (3)$$

d_{tm} : longest continuous land (inland + coastal) section of the great-circle path (km)

d_{lm} : longest continuous inland section of the great-circle path (km).

The radio-climatic zones to be used for the derivation of d_{tm} and d_{lm} are defined in Table 3. If all points on the path are at least 50 km from the sea or other large bodies of water, then only the inland category applies and d_{tm} and d_{lm} are equal to the path length, d .

Calculate the parameter μ_4 , which depends on μ_1 and the latitude of the path centre in degrees:

$$\begin{aligned} \mu_4 &= \mu_1^{(-0.935 + 0.017\phi)} & \text{for } |\phi| \leq 70^\circ \\ \mu_4 &= \mu_1^{0.3} & \text{for } |\phi| > 70^\circ \end{aligned} \quad (4)$$

where:

φ : path centre latitude (degrees).

Calculate β_0 :

$$\beta_0 = \begin{cases} 10^{-0.015|\varphi| + 1.67} \mu_1 \mu_4 & \% & \text{for } |\varphi| \leq 70^\circ \\ 4.17 \mu_1 \mu_4 & \% & \text{for } |\varphi| > 70^\circ \end{cases} \quad (5)$$

3.7 Effective Earth radius

The median effective Earth radius factor k_{50} for the path is given by:

$$k_{50} = \frac{157}{157 - \Delta N} \quad (6)$$

The value of the average radio-refractivity lapse-rate, ΔN , may be obtained from the integral digital map DN50.txt, using the latitude and longitude of the path centre as representative for the entire path.

The median value of effective Earth radius a_e is given by:

$$a_e = 6371 k_{50} \quad \text{km} \quad (7a)$$

The effective Earth radius exceeded for β_0 time, a_β , is given by:

$$a_\beta = 6371 k_\beta \quad \text{km} \quad (7b)$$

where $k_\beta = 3.0$ is an estimate of the effective Earth-radius factor exceeded for β_0 time.

A general effective Earth radius is defined, where $a_p = a_e$ for 50% of time, and $a_p = a_\beta$ for $\beta_0\%$ of time.

3.8 Parameters derived from the path profile analysis

Values for a number of path-related parameters necessary for the calculations, as indicated in Table 5, must be derived via an initial analysis of the path profile based on the value of a_e given by equation (7a). Information on the derivation, construction and analysis of the path profile is given in Attachment 1 to this Annex.

4 The prediction procedure

4.1 General

The overall prediction procedure is described in this section. First, the basic transmission loss, L_b (dB), not exceeded for the required annual percentage time, $p\%$, and 50% locations is evaluated as described in § 4.2-4.6 (i.e. the basic transmission losses due to LoS propagation, propagation by diffraction, propagation by tropospheric scatter, propagation by ducting/layer reflection and the combination of these propagation mechanisms to predict the basic transmission loss, respectively). In § 4.7-4.10, methods to account for the inclusion of terminal clutter effects, the effects of location variability and building entry loss are described. Finally, § 4.11 gives expressions that relate the basic transmission loss to the field strength (dB $\mu\text{V/m}$) for 1 kW effective radiated power.

TABLE 5
Parameter values to be derived from the path profile analysis

Parameter	Description
d	Great-circle path distance (km)
d_{lt}, d_{lr}	Distance from the transmit and receive antennas to their respective horizons (km)
θ_t, θ_r	Transmit and receive horizon elevation angles respectively (mrad)
θ	Path angular distance (mrad)
h_{ts}, h_{rs}	Antenna centre height above mean sea level (m)
h_{tc}, h_{rc}	$\max(h_{ts}, g_1)$ and $\max(h_{rs}, g_n)$ respectively
h_{te}, h_{re}	Effective heights of antennas above the terrain (m)
d_b	Aggregate length of the path sections over water (km)
ω	Fraction of the total path over water: $\omega = d_b / d$ where d is the great-circle distance (km) calculated using equation (73). For totally overland paths: $\omega = 0$.

4.2 Line-of-sight propagation (including short-term effects)

The following should all be evaluated for both LoS and trans-horizon paths.

The basic transmission loss due to free-space propagation is given by:

$$L_{bfs} = 92.45 + 20 \log f + 20 \log d \quad \text{dB} \quad (8)$$

Corrections for multipath and focusing effects at p and β_0 percentage times, respectively, are given by:

$$E_{sp} = 2.6 \left[1 - \exp \left(- \frac{d_{lt} + d_{lr}}{10} \right) \right] \log \left(\frac{p}{50} \right) \quad \text{dB} \quad (9a)$$

$$E_{s\beta} = 2.6 \left[1 - \exp \left(- \frac{d_{lt} + d_{lr}}{10} \right) \right] \log \left(\frac{\beta_0}{50} \right) \quad \text{dB} \quad (9b)$$

Calculate the basic transmission loss not exceeded for time percentage, $p\%$, due to LoS propagation (regardless of whether or not the path is actually LoS), as given by:

$$L_{b0p} = L_{bfs} + E_{sp} \quad \text{dB} \quad (10)$$

Calculate the basic transmission loss not exceeded for time percentage, $\beta_0\%$, due to LoS propagation (regardless of whether or not the path is actually LoS), as given by:

$$L_{b0\beta} = L_{bfs} + E_{s\beta} \quad \text{dB} \quad (11)$$

4.3 Propagation by diffraction

Diffraction loss is calculated by the combination of a method based on the Bullington construction and spherical-Earth diffraction. The Bullington part of the method is an expansion of the basic Bullington construction to control the transition between free-space and obstructed conditions. This part of the method is used twice: for the actual path profile, and for a zero-height smooth profile with modified antenna heights referred to as effective antenna heights. The same effective antenna heights are also used to calculate spherical-earth diffraction loss. The final result is obtained as a combination of three losses calculated as above. For a perfectly smooth path the final diffraction loss will be the output of the spherical-Earth model.

This method provides an estimate of diffraction loss for all types of path, including over-sea or over-land or coastal land, and irrespective of whether the path is smooth or rough, and whether LoS or transhorizon.

This diffraction method is always used for median effective Earth radius. If an overall prediction is required for $p = 50\%$, no further diffraction calculation is necessary.

In the general case where $p < 50\%$, the diffraction calculation must be performed a second time for an effective Earth-radius factor equal to 3. This second calculation gives an estimate of diffraction loss not exceeded for $\beta_0\%$ time, where β_0 is given by equation (5).

The diffraction loss not exceeded for $p\%$ time, for $1\% \leq p \leq 50\%$, is then calculated using a limiting or interpolation procedure described in § 4.3.5.

The method uses an approximation to the single knife-edge diffraction loss as a function of the dimensionless parameter, v , given by:

$$J(v) = 6.9 + 20 \log \left(\sqrt{(v - 0.1)^2 + 1} + v - 0.1 \right) \quad (12)$$

Note that $J(-0.78) \approx 0$, and this defines the lower limit at which this approximation should be used. $J(v)$ is set to zero for $v \leq -0.78$.

The overall diffraction calculation is described in sub-sections as follows:

Section 4.3.1 describes the Bullington part of the diffraction method. For each diffraction calculation for a given effective Earth radius this is used twice. On the second occasion the antenna heights are modified and all profile heights are zero.

Section 4.3.2 describes the spherical-Earth part of the diffraction model. This is used with the same antenna heights as for the second use of the Bullington part in § 4.3.1.

Section 4.3.3 describes how the methods in § 4.3.1 and § 4.3.2 are used in combination to perform the complete diffraction calculation for a given effective Earth radius. Due to the manner in which the Bullington and spherical-earth parts are used, the complete calculation has come to be known as the “delta-Bullington” model.

Section 4.3.4 describes the complete calculation for diffraction loss not exceeded for a given percentage time $p\%$.

4.3.1 The Bullington part of the diffraction calculation

In the following equations slopes are calculated in m/km relative to the baseline joining sea level at the transmitter to sea level at the receiver. The distance and height of the i -th profile point are d_i kilometres and g_i metres above sea level respectively, i takes values from 1 to n where n is the number of profile points, and the complete path length is d kilometres. For convenience the terminals at the start and end of the profile are referred to as transmitter and receiver, with heights in metres