

Recommendation ITU-R P.452-18

(08/2023)

P Series: Radiowave propagation

**Prediction procedure for the evaluation
of interference between stations on the
surface of the Earth at frequencies
above about 100 MHz**

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P	Radiowave propagation
RA	Radio astronomy
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SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
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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.452-18

**Prediction procedure for the evaluation of interference between stations
on the surface of the Earth at frequencies above about 100 MHz**

(Question ITU-R 208/3)

(1970-1974-1978-1982-1986-1992-1994-1995-1997-1999-2001-2003-2005-2007-2009-2013-2015-
2021-2023)**Scope**

This Recommendation contains a prediction method for the evaluation of interference between stations on the surface of the Earth at frequencies from about 100 MHz to 50 GHz, accounting for both clear-air and hydrometeor scattering interference mechanisms.

Keywords

Interference, Ducting, Tropospheric scatter, Diffraction, Hydrometeor Scattering, Digital Data Products

Abbreviations/Glossary

Amsl Above mean sea level

IDWM ITU Digitized World Map

LoS Line-of-sight

Related ITU Recommendations, Reports

Recommendation ITU-R S.465

Recommendation ITU-R S.580

Recommendation ITU-R P.676

Recommendation ITU-R F.699

Recommendation ITU-R P.837

Recommendation ITU-R P.838

Recommendation ITU-R P.839

Recommendation ITU-R P.1058

Recommendation ITU-R P.1144

Recommendation ITU-R F.1245

Recommendation ITU-R F.1336

NOTE – The latest revision/edition of the Recommendation/Report should be used.

The ITU Radiocommunication Assembly,

considering

a) that due to congestion of the radio spectrum, frequency bands must be shared between different terrestrial services, between systems in the same service and between systems in the terrestrial and Earth-space services;

- b) that for the satisfactory coexistence of systems sharing the same frequency bands, interference prediction procedures are needed that are accurate and reliable in operation and acceptable to all parties concerned;
- c) that propagation predictions are applied in interference prediction procedures which are often required to meet “worst-month” performance and availability objectives;
- d) that prediction methods are required for application to all types of paths in all areas of the world,

recommends

that the interference prediction procedure given in Annex 1 should be used for the evaluation of the available propagation loss over unwanted signal paths between stations on the surface of the Earth for frequencies above about 100 MHz.

Annex 1

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1 Introduction

Congestion of the radio-frequency spectrum has made necessary the sharing of many frequency bands between different radio services, and between the different operators of similar radio services. In order to ensure the satisfactory coexistence of the terrestrial and Earth-space systems involved, it is important to be able to predict with reasonable accuracy the interference potential between them, using propagation predictions and models which are acceptable to all parties concerned, and which have demonstrated accuracy and reliability.

Many types and combinations of interference path may exist between stations on the surface of the Earth, and between these stations and stations in space, and prediction methods are required for each situation. This Annex addresses one of the more important sets of interference problems, i.e. those situations where there is a potential for interference between radio stations located on the surface of the Earth.

The models contained within this Recommendation work from the assumption that the interfering transmitter and the interfered-with receiver both operate within the surface layer of atmosphere. Use of exceptionally large antenna heights to model operations such as aeronautical systems is not appropriate for these models. The prediction procedure has been tested for radio stations operating in the frequency range of about 0.1 GHz to 50 GHz.

The models within this Recommendation are designed to calculate propagation losses not exceeded for time percentages over the range $0.001 \leq p \leq 50\%$. This assumption does not imply the maximum loss will be at $p = 50\%$.

The method includes a complementary set of propagation models which ensure that the predictions embrace all the significant interference propagation mechanisms that can arise. Methods for analysing the radio-meteorological and topographical features of the path are provided so that predictions can be prepared for any practical interference path falling within the scope of the procedure up to a distance limit of 10 000 km.

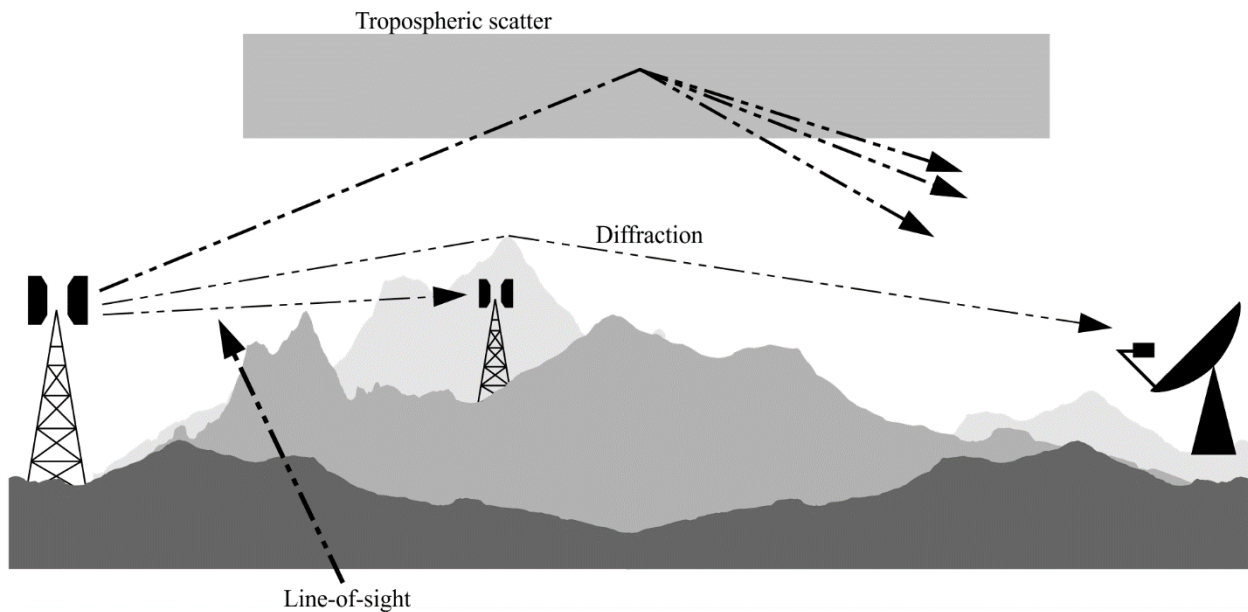
2 Interference propagation mechanisms

Interference may arise through a range of propagation mechanisms whose individual dominance depends on climate, radio frequency, time percentage of interest, distance and path topography. At any one time a single mechanism or more than one may be present. The principal interference propagation mechanisms are as follows:

- *Line-of-sight* (Fig. 1): The most straightforward interference propagation situation is when a line-of-sight transmission path exists under normal (i.e. well-mixed) atmospheric conditions. However, an additional complexity can come into play when subpath diffraction causes a slight increase in signal level above that normally expected. Also, on all but the shortest paths (i.e. paths longer than about 5 km) signal levels can often be significantly enhanced for short periods of time by multipath and focusing effects resulting from atmospheric stratification (see Fig. 2).
- *Diffraction* (Fig. 1): Beyond line-of-sight (LoS) and under normal conditions, diffraction effects generally dominate wherever significant signal levels are to be found. For services where anomalous short-term problems are not important, the accuracy to which diffraction can be modelled generally determines the density of systems that can be achieved. The diffraction prediction capability must have sufficient utility to cover smooth-earth, discrete obstacle and irregular (unstructured) terrain and clutter situations.
- *Tropospheric scatter* (Fig. 1): This mechanism defines the “background” interference level for longer paths (e.g. more than 100-150 km) where the diffraction field becomes very weak. However, except for a few special cases involving sensitive receivers or very high power

interferers (e.g. radar systems), interference via troposcatter will be at too low a level to be significant.

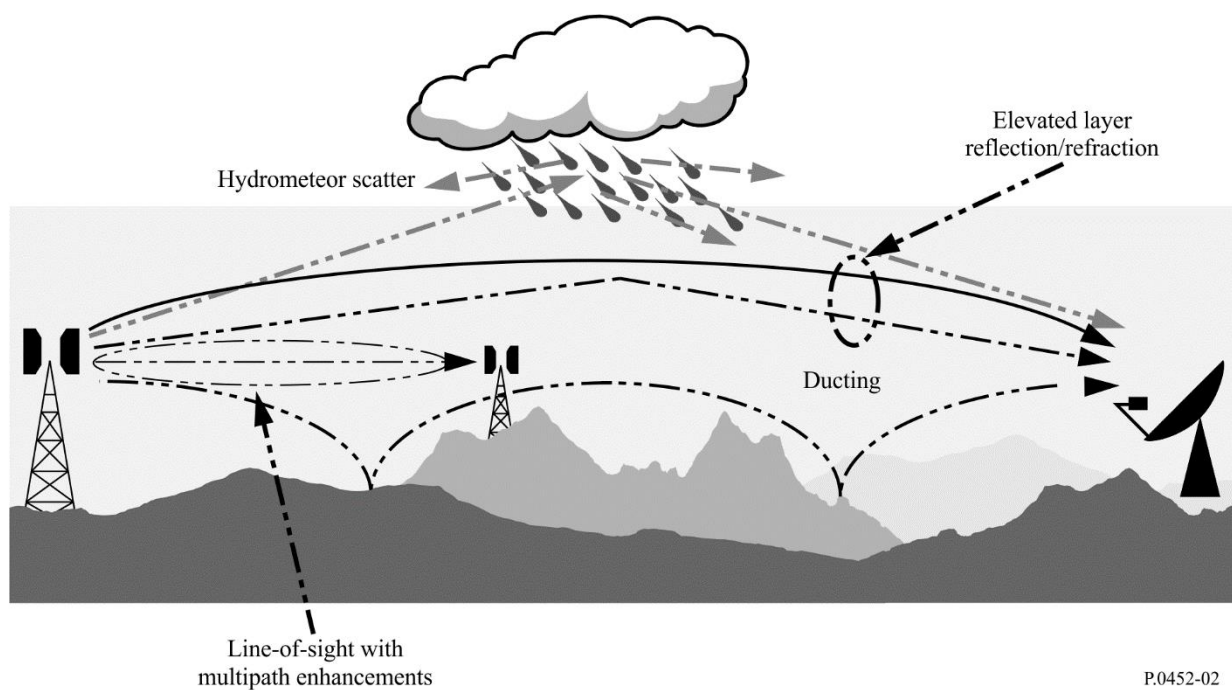
FIGURE 1

Long-term interference propagation mechanisms

P.0452-01

- *Surface ducting* (Fig. 2): This is the most important short-term propagation mechanism that can cause interference over water and in flat coastal land areas, and can give rise to high signal levels over long distances (more than 500 km over the sea). Such signals can exceed the equivalent “free-space” level under certain conditions.

FIGURE 2

Anomalous (short-term) interference propagation mechanisms

P.0452-02

- *Elevated layer reflection and refraction* (Fig. 2): The treatment of reflection and/or refraction from layers at heights up to a few hundred metres is of major importance as these mechanisms enable signals to overcome the diffraction loss of the terrain very effectively under favourable path geometry situations. Again the impact can be significant over quite long distances (up to 250-300 km).
- *Hydrometeor scatter* (Fig. 2): Hydrometeor scatter can be a potential source of interference between terrestrial link transmitters and earth stations because it may act virtually omnidirectionally, and can therefore have an impact off the great-circle interference path. However, the interfering signal levels are quite low and do not usually represent a significant problem.

A basic problem in interference prediction (which is indeed common to all tropospheric prediction procedures) is the difficulty of providing a unified consistent set of practical methods covering a wide range of distances and time percentages; i.e. for the real atmosphere in which the statistics of dominance by one mechanism merge gradually into another as meteorological and/or path conditions change. Especially in these transitional regions, a given level of signal may occur for a total time percentage which is the sum of those in different mechanisms. The approach in this procedure has been to define completely separate methods for clear-air and hydrometeor-scatter interference prediction, as described in §§ 4 and 5 respectively.

The clear-air method consists of separate models for diffraction, ducting/layer-reflection, and troposcatter. All three are applied for every case, irrespective of whether a path is LoS or transhorizon. The results are then combined into an overall prediction using a blending technique that ensures for any given path distance and time percentage that the signal enhancement in the equivalent notional line-of-sight model is the highest attainable.

3 Clear-air interference prediction

3.1 General comments

Although the clear-air method is implemented by three separate models, the results of which are then blended, the procedure takes account of four basic types of propagation mechanism:

- line-of-sight (including signal enhancements due to multipath and focusing effects);
- diffraction (embracing smooth-earth, irregular terrain, clutter and sub-path cases);
- tropospheric scatter;
- anomalous propagation (ducting and layer reflection/refraction).

3.2 Deriving a prediction

3.2.1 Outline of the procedure

The steps required to achieve a prediction are as follows:

Step 1: Input data

The basic input data required for the procedure is given in Table 1. All other information required is derived from these basic data during the execution of the procedure.

TABLE 1
Basic input data

Parameter	Preferred resolution	Description
f	0.01	Frequency (GHz)
p	0.001	Required time percentage(s) for which the calculated basic transmission loss is not exceeded
φ_t, φ_r	0.001	Latitude of station (degrees)
ψ_t, ψ_r	0.001	Longitude of station (degrees)
h_{tg}, h_{rg}	1	Antenna centre height above ground level (m)
h_{ts}, h_{rs}	1	Antenna centre height above mean sea level (m)
G_t, G_r	0.1	Antenna gain in the direction of the horizon along the great-circle interference path (dBi)
Pol	N/A	Signal, e.g. vertical or horizontal

NOTE 1 – For the interfering and interfered-with stations:

t : interferer

r : interfered-with station.

Polarization in Table 1 is not a parameter with a numerical value. The information is used in § 4.2.2.1 in connection with equations (30a), (30b) and (31).

Step 2: Selecting average year or worst-month prediction

The choice of annual or “worst-month” predictions is generally dictated by the quality (i.e. performance and availability) objectives of the interfered-with radio system at the receiving end of the interference path. As interference is often a bidirectional problem, two such sets of quality objectives may need to be evaluated in order to determine the worst-case direction upon which the minimum permissible basic transmission loss needs to be based. In the majority of cases the quality objectives will be couched in terms of a percentage “of any month”, and hence worst-month data will be needed.

The propagation prediction models predict the annual distribution of basic transmission loss. For average year predictions the percentages of time p , for which particular values of basic transmission loss are not exceeded, are used directly in the prediction procedure. If average worst-month predictions are required, the annual equivalent time percentage, p , of the worst-month time percentage, p_w , must be calculated for the path centre latitude φ using:

$$p = 10^{\left(\frac{\log_{10}(p_w) + \log_{10}(G_L) - 0.186\omega - 0.444}{0.816 + 0.078\omega} \right)} \quad (1)$$

where:

ω : fraction of the path over water (see Table 4).

$$G_L = \begin{cases} \sqrt{1.1 + |\cos 2 \varphi|^{0.7}} & \text{for } |\varphi| \leq 45^\circ \\ \sqrt{1.1 - |\cos 2 \varphi|^{0.7}} & \text{for } |\varphi| > 45^\circ \end{cases} \quad (1a)$$

If necessary, the value of p must be limited such that $12p \geq p_w$.

Note that the latitude φ (degrees) is deemed to be positive in the Northern Hemisphere.

The calculated result will then represent the basic transmission loss for the required worst-month time percentage, $p_w\%$.

Step 3: Radiometeorological data

The prediction procedure employs three radio-meteorological parameters to describe the variability of background and anomalous propagation conditions at the different locations around the world.

- ΔN (N-units/km), the average radio-refractivity 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.
- β_0 (%), the time percentage for which refractivity lapse-rates exceeding 100 N-units/km can be expected in the first 100 m of the lower atmosphere, is used to estimate the relative incidence of fully developed anomalous propagation at the latitude under consideration. The value of β_0 to be used is that appropriate to the path centre latitude.
- N_0 (N-units), the sea-level surface refractivity, is used only by the troposcatter model as a measure of location variability of the troposcatter scatter mechanism. As the scatter path calculation is based on a path geometry determined by annual or worst-month values of ΔN , there is no additional need for worst-month values of N_0 . The correct values of ΔN and N_0 are given by the path-centre values as derived from the appropriate maps.

Point incidence of anomalous propagation, β_0 (%), for the path centre location is determined using:

$$\beta_0 = \begin{cases} 10^{-0.015|\varphi| + 1.67} \mu_1 \mu_4 & \% \quad \text{for } |\varphi| \leq 70^\circ \\ 4.17 \mu_1 \mu_4 & \% \quad \text{for } |\varphi| > 70^\circ \end{cases} \quad (2)$$

where:

φ : path centre latitude (degrees).

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

$$\mu_1 = \left[10^{\frac{-d_{tm}}{16 - 6.6\tau}} + \left[10^{-(0.496 + 0.354\tau)} \right]^5 \right]^{0.2} \quad (3)$$

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

with:

$$\tau = \left[1 - e^{-(4.12 \times 10^{-4} \times d_{lm}^{2.41})} \right] \quad (3a)$$

where:

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 radioclimatic zones to be used for the derivation of d_{tm} and d_{lm} are defined in Table 2.

$$\mu_4 = \begin{cases} 10^{(-0.935 + 0.0176|\varphi|) \log_{10} \mu_1} & \text{for } |\varphi| \leq 70^\circ \\ 10^{0.3 \log_{10} \mu_1} & \text{for } |\varphi| > 70^\circ \end{cases} \quad (4)$$

TABLE 2
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, i.e. 300 ft, 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)

Large bodies of inland water

A “large” body of inland water, to be considered as lying in Zone B, is defined as one having an area of at least 7 800 km², but excluding the area of rivers. Islands within such bodies of water are to be included as water within the calculation of this area if they have elevations lower than 100 m above the mean water level for more than 90% of their area. Islands that do not meet these criteria should be classified as land for the purposes of the water area calculation.

Large inland lake or wet-land areas

Large inland areas of greater than 7 800 km² which contain many small lakes or a river network should be declared as “coastal” Zone A1 by administrations if the area comprises more than 50% water, and more than 90% of the land is less than 100 m above the mean water level.

Climatic regions pertaining to Zone A1, large inland bodies of water and large inland lake and wetland regions, are difficult to determine unambiguously. Therefore, administrations are invited to register with the ITU Radiocommunication Bureau (BR) those regions within their territorial boundaries that they wish identified as belonging to one of these categories. In the absence of registered information to the contrary, all land areas will be considered to pertain to climate Zone A2.

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.

Effective Earth radius

The median effective Earth radius factor k_{50} for the path is determined using:

$$k_{50} = \frac{157}{157 - \Delta N} \quad (5)$$

Assuming the average physical Earth radius of $a = 6371$ km, the median value of effective Earth radius a_e can be determined from:

$$a_e = k_{50}a \quad \text{km} \quad (6a)$$

The effective Earth radius exceeded for $\beta_0\%$ time, a_β , is given by:

$$a_\beta = k_\beta a \quad \text{km} \quad (6b)$$

where $k_\beta = 3.0$ is an estimate of the effective Earth radius factor exceeded for $\beta_0\%$ time.

A general effective earth radius, a_p , will be set to a_e for 50% time and to a_β for $\beta_0\%$ time in §§ 4.2.1 and 4.2.2.

Step 4: Radio path profile

The path profiles used in the method described below require path-specific data for terrain (bare-earth) and path-specific clutter (ground cover) categories along the path. The method includes:

- the construction of a terrain profile using actual terrain heights;
- based on the clutter categories, the addition of representative clutter heights to the terrain profile.

If this method is used to calculate diffraction loss using the terrain profile without clutter, the diffraction loss will be under-estimated in cluttered environments, as opposed to combined representation of terrain and clutter. This method has been developed and validated against digital terrain data, by combining digital terrain data with statistical representative clutter categories as opposed to direct use of 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 over-estimated if terrain profiles include surface-height data. If accurate surface-height data are available, other techniques such as 3-D ray tracing, which would include the effect of diffraction around buildings, could be explored to arrive at a more accurate estimation of the propagation losses.

A profile for the radio path is required for the application of the propagation prediction method. The profile should include information on terrain (bare earth) heights and clutter (ground cover) heights along the path.

It is convenient to store information in three arrays each having the same number of values, $n + 1$, as follows:

$$d_i: \text{distance from transmitter of } i\text{-th profile point (km)} \quad (6c)$$

$$h_i: \text{terrain height of the } i\text{-th profile point above sea level (m)} \quad (6d)$$

$$g_i = \begin{cases} h_i + \text{representative clutter height of } i\text{-th profile point (m)} & \text{for } i = 1, \dots, n - 1 \\ h_0 & \text{for } i = 0 \\ h_n & \text{for } i = n \end{cases} \quad (6e)$$

where:

i : 0, 1, 2, ..., n = index of the profile point

$n + 1$: number of profile points.

There must be at least one intermediate profile point between the transmitter and the receiver. Thus, n must satisfy $n \geq 2$. 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_0 is zero and h_0 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 is 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 digital terrain elevation and ground cover (clutter) datasets, a suitable spacing will typically be similar to the point spacing of the source datasets of similar resolution to each other. 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 and no less than of the order of 30 m.

The arrays used for the calculations comprise distances, d_i , terrain heights, h_i , as given by equation (6d) and terrain heights with representative clutter heights added, g_i , as given by equation (6e). The representative clutter height should not be added to the terrain heights at the transmitter and the

receiver and if the distance from the transmitter or the receiver is less than 50 m. Thus, g_0 is the terrain height at the transmitter in metres above sea level and g_n is the terrain height at the receiver in metres above sea level and g_i is the terrain height in metres above sea level for all the points at a distance from transmitter or receiver less than 50 m.

The “representative clutter height” referred to in equation (6e) 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. Smaller values of representative heights rather than the physical clutter heights may be appropriate in such cases.

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 representative heights, rather than zero, might be appropriate in many cases.

Thus, representative clutter height 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 3 suggests default values for representative clutter heights which may be used in the absence of region/country specific information.

TABLE 3

Default representative clutter height values

Clutter category	Representative clutter height (m)
	Add to profile of equation (6e) for $i = 1$ to $n - 1$
Water/sea	0
Open/rural	0
Suburban	10
Urban/trees/forest	15
Dense urban	20

Values for a number of path-related parameters necessary for the calculations, as indicated in Table 4, must be derived via an initial analysis of the path profile based on the value of a_e given by

equation (6a). Information on the derivation, construction and analysis of the path profile is given in Attachment 2 to Annex 1.

TABLE 4
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	For a transhorizon path, transmit and receive horizon elevation angles respectively (mrad). For a LoS path, each is set to the elevation angle to the other terminal
θ	Path angular distance (mrad)
h_{ts}, h_{rs}	Antenna centre height above mean sea level (m)
h_{te}, h_{re}	Effective heights of antennas above the terrain (m) for the ducting/layer-reflection model (see Attachment 2 to Annex 1 for definitions). Note that the same parameter names are used for effective heights in the diffraction model, but h_{te} and h_{re} have different definitions in the diffraction model. See equations (39a) and (39b)
d_b	Aggregate length of the path sections over water (km)
ω	Fraction of the total path over water: $\omega = d_b/d \quad (7)$ where d is the great-circle distance (km) calculated using equation (134). For totally overland paths: $\omega = 0$
$d_{ct,cr}$	Distance over land from the transmit and receive antennas to the coast along the great-circle interference path (km). Set to zero for a terminal on a ship or sea platform

4 Clear-air propagation models

Basic transmission loss, L_b (dB), not exceeded for the required annual percentage time, p , is evaluated as described in the following sub-sections.

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

The following should be evaluated for both LoS and transhorizon paths.

Basic transmission loss due to free-space propagation and attenuation by atmospheric gases:

$$L_{bfs_g} = 92.4 + 20 \log_{10} f + 20 \log_{10} d_{fs} + A_g(d_{fs}) \quad \text{dB} \quad (8)$$

where:

f : frequency (GHz)

d_{fs} : distance between the transmit and receive antennas (km):

$$d_{fs} = \sqrt{d^2 + \left(\frac{h_{ts} - h_{rs}}{1\,000}\right)^2} \quad (8a)$$

d : great-circle path distance (km)

h_{ts} : transmit antenna height above sea level (m)

h_{rs} : receive antenna height above sea level (m)

A_g : total gaseous absorption (dB):

$$A_g(d_{fs}) = [\gamma_0 + \gamma_w(\rho)] \cdot d_{fs} \quad \text{dB} \quad (9)$$

where:

$\gamma_0, \gamma_w(\rho)$: specific attenuation due to dry air and water vapour, respectively, and are found from the equations in Recommendation ITU-R P.676

ρ : water vapour density:

$$\rho = 7.5 + 2.5\omega \quad \text{g/m}^3 \quad (9a)$$

ω : fraction of the total path over water.

Corrections for multipath and focusing effects at p and β_0 percentage times:

$$E_{sp} = 2.6 [1 - \exp(-0.1 \{d_{lt} + d_{lr}\})] \log_{10} (p/50) \quad \text{dB} \quad (10a)$$

$$E_{s\beta} = 2.6 [1 - \exp(-0.1 \{d_{lt} + d_{lr}\})] \log_{10} (\beta_0/50) \quad \text{dB} \quad (10b)$$

Basic transmission loss not exceeded for time percentage, $p\%$, due to LoS propagation:

$$L_{b0p} = L_{bfs\beta} + E_{sp} \quad \text{dB} \quad (11)$$

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

$$L_{b0\beta} = L_{bfs\beta} + E_{s\beta} \quad \text{dB} \quad (12)$$

4.2 Diffraction

The time variability of the excess loss due to the diffraction mechanism is assumed to be the result of changes in bulk atmospheric radio refractivity lapse rate, i.e. as the time percentage p reduces, the effective Earth radius factor $k(p)$ is assumed to increase. This process is considered valid for $\beta_0 \leq p \leq 50\%$. For time percentages less than β_0 signal levels are dominated by anomalous propagation mechanisms rather than by the bulk refractivity characteristics of the atmosphere. Thus diffraction loss not exceeded for $p < \beta_0\%$ is assumed to be the same as for $p = \beta_0\%$ time.

Taking this into account, in the general case where $p < 50\%$, the diffraction calculation must be performed twice, first for the median effective Earth-radius factor k_{50} (equation (5)) and second for the limiting effective Earth-radius factor k_β 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 (2).

The diffraction loss L_{dp} not exceeded for $p\%$ time, for $0.001\% \leq p \leq 50\%$, is then calculated using a limiting or interpolation procedure described in § 4.2.4.

The diffraction model calculates the following quantities required in § 4.5:

L_{dp} : diffraction loss not exceeded for $p\%$ time

L_{bd50} : median basic transmission loss associated with diffraction

L_{bd} : basic transmission loss associated with diffraction not exceeded for $p\%$ time.

The 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 the 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 paths, including over-sea or over-land or coastal land, and irrespective of whether the land is smooth or rough, and whether LoS or transhorizon.

This method also makes extensive use of an approximation to the single knife-edge diffraction loss as a function of the dimensionless parameter, v , given by:

$$J(v) = 6.9 + 20 \log_{10} \left(\sqrt{(v - 0.1)^2 + 1} + v - 0.1 \right) \quad (13)$$

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 $v < -0.78$.

The overall diffraction calculation is described in the subsections as follows:

Section 4.2.1 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 4.2.2 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 § 4.2.1.

Section 4.2.3 describes how the methods in §§ 4.2.1 and 4.2.2 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 4.2.4 describes the complete calculation for diffraction loss not exceeded for a given percentage time $p\%$.

4.2.1 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 (including representative clutter height) of the i -th profile point are d_i kilometres and g_i metres above mean sea level respectively, i takes values from 0 to n where $n + 1$ 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 m above sea level, h_{ts} and h_{rs} , respectively. Effective Earth curvature $C_e \text{ km}^{-1}$ is given by $1/a_p$ where a_p is effective earth radius in kilometres. Wavelength in metres is represented by λ . Values to be used for a_p are given in § 4.2.4.

Care is needed close to the terminals to ensure that the addition of representative heights of local clutter does not cause an unrealistic increase in the horizon elevation angles as seen by each antenna.

Find the intermediate profile point with the highest slope of the line from the transmitter to the point.

$$S_{tim} = \max \left[\frac{g_i + 500 C_e d_i (d - d_i) - h_{ts}}{d_i} \right] \quad \text{m/km} \quad (14)$$

where the profile index i takes values from 1 to $n - 1$.

Calculate the slope of the line from transmitter to receiver assuming a LoS path:

$$S_{tr} = \frac{h_{rs} - h_{ts}}{d} \quad \text{m/km} \quad (15)$$

Two cases must now be considered.

Case 1. Path is LoS

If $S_{tim} < S_{tr}$ the path is LoS.

Find the intermediate profile point with the highest diffraction parameter v :

$$v_{\max} = \max \left\{ \left[g_i + 500 C_e d_i (d - d_i) - \frac{h_{ts}(d - d_i) + h_{rs} d_i}{d} \right] \sqrt{\frac{0.002d}{\lambda d_i (d - d_i)}} \right\} \quad (16)$$

where the profile index i takes values from 1 to $n - 1$.

In this case, the knife-edge loss for the Bullington point is given by:

$$L_{uc} = J(v_{\max}) \quad \text{dB} \quad (17)$$

where the function J is given by equation (13) for v_b greater than -0.78 , and is zero otherwise.

Case 2. Path is transhorizon

If $S_{tim} \geq S_{tr}$ the path is transhorizon.

Find the intermediate profile point with the highest slope of the line from the receiver to the point.

$$S_{rim} = \max \left[\frac{g_i + 500 C_e d_i (d - d_i) - h_{rs}}{d - d_i} \right] \quad \text{m/km} \quad (18)$$

where the profile index i takes values from 1 to $n - 1$.

Calculate the distance of the Bullington point from the transmitter:

$$d_{bp} = \frac{h_{rs} - h_{ts} + S_{rim} d}{S_{tim} + S_{rim}} \quad \text{km} \quad (19)$$

Calculate the diffraction parameter, v_b , for the Bullington point

$$v_b = \left[h_{ts} + S_{tim} d_{bp} - \frac{h_{ts}(d - d_{bp}) + h_{rs} d_{bp}}{d} \right] \sqrt{\frac{0.002d}{\lambda d_{bp} (d - d_{bp})}} \quad (20)$$

In this case, the knife-edge loss for the Bullington point is given by:

$$L_{uc} = J(v_b) \quad \text{dB} \quad (21)$$

For L_{uc} calculated using either equation (17) or (21), Bullington diffraction loss for the path is now given by:

$$L_{bull} = L_{uc} + [1 - \exp(-L_{uc}/6)](10 + 0.02 d) \quad \text{dB} \quad (22)$$

4.2.2 Spherical-Earth diffraction loss

The spherical-Earth diffraction loss for antenna heights h_{te} and h_{re} (m), L_{dsph} , is calculated as follows.

Calculate the marginal LoS distance for a smooth path:

$$d_{los} = \sqrt{2a_p} \cdot (\sqrt{0.001h_{te}} + \sqrt{0.001h_{re}}) \quad \text{km} \quad (23)$$

Values to be used for a_p are given in § 4.2.4. Effective antenna heights h_{te} and h_{re} are defined in equations (39a) and (39b).

If $d \geq d_{los}$ calculate diffraction loss using the method in § 4.2.2.1 below for $a_{dft} = a_p$ to give L_{dft} , and set L_{dsph} equal to L_{dft} . No further spherical-Earth diffraction calculation is necessary.

Otherwise continue as follows:

Calculate the smallest clearance height between the curved-Earth path and the ray between the antennas, h_{se} , given by: