Annex 10

Determination of the basic transmission loss in the Fixed Service

PREDICTION PROCEDURE FOR THE EVALUATION OF BASIC TRANSMISSION LOSS

1 Introduction

The prediction procedure provided in this chapter is based on the Recommendation ITU-R P.452-13. The procedure is appropriate to radio relay links operating in the frequency range of about 0.7 GHz to 50 GHz. The method includes a complementary set of propagation models, which ensure that the predictions embrace all the significant propagation mechanisms relevant to long-term interference. 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.
The prediction is achieved in four steps described in the sections 3, 4, 5 and 6.

2 Bases for the models used in the prediction

It is assumed that interference, which is significant during a small percentage of time (short-term) can not deteriorate the performance and the ability of the transmission. As a result of that assumption, only long-term interference is taken into account, and therefore the time percentage, for which the calculated basic transmission loss is not exceeded, is taken as 20%. Accordingly, the procedure uses four propagation models listed below:

- line-of-sight (including signal enhancements due to multipath and focusing effects);
- diffraction (embracing smooth-Earth, irregular terrain and sub-path cases);
- tropospheric scatter;
- surface ducting and layer reflection.

Depending on the type of path, as determined by a path profile analysis, one or more of these models are exercised in order to provide the required prediction of basic transmission loss.
The propagation prediction models predict the average annual distribution of basic transmission loss.
As the radio-meteorological and topographical features for the terrain of all signatory's countries appeared to be almost the same, the common values were adopted. The values for such parameters are as follows:

ΔN :	the average radio-refractive index lapse-rate through the lowest 1 km of the atmosphere, (N-units/km) = 45
N_0:	the sea-level surface refractivity, (N-units)= 325
p :	Pressure = 1013 hPa
t :	temperature = 15 °C

3 Step 1 of the prediction procedure: Preparation of the input data

The basic input data required for the procedure is given in Table1. 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	0.00001	Frequency (GHz)
φ_t, φ_r	1	Latitude of station (seconds)
p	1	Required time percentage(s) for which the calculated basic transmission loss is not exceeded
ψ_t, ψ_r	1	Longitude of station (seconds)
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)

NOTE 1 For the interfering and interfered-with stations:
t: interferer
r: interfered-with station

4 Step 2 of the prediction procedure: Radiometeorological data

The values of radio-meteorological parameters, which could be determined as common to all countries of West, South and Central Europe are given in § 2. In the prediction procedure 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, β_0 (%) must be evaluated. This parameter 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. Point incidence of anomalous propagation, β_0 (%), for the path centre location is determined using:

$$\text{(i)}\quad \beta_0 = \begin{cases} 10^{-0.015|\varphi| + 1.67}\mu_1\mu_4 & \% \quad \text{for } |\varphi| \le 70^\circ \\ 4.17\mu_1\mu_4 & \% \quad \text{for } |\varphi| > 70^\circ \end{cases} \qquad (1.)$$

where

φ : path centre latitude (degrees) which is not greater than 70° and not less than -70°

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:

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

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

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

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.

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

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 is 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)

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 km^2, 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 km^2, 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 requested to register with the TWG HCM 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.

<u>Effective Earth's radius</u>
The median effective Earth radius factor k_{50} for the path is determined using:

$$k_{50} = \frac{157}{157 \pm \Delta N} \tag{5.}$$

Assuming a true Earth radius of 6 371 km and the average radio-refractive index ΔN (N-units/km) for West, South and Central Europe of 45, the median value of effective Earth radius a_e [km] can be determined from:

$$a_e = 6371 \cdot k_{50} \tag{6.}$$

The effective Earth radius [km] exceeded for $\beta_{0\%}$ time, a_β, is given by:

$$a_\beta = 6\,371 \cdot k_\beta \tag{7.}$$

where k_β = 3.0 is an estimate of the effective Earth radius factor exceeded for β_0% time.

5 Step 3 of the prediction procedure: Path profile analysis

Values for a number of path-related parameters necessary for the calculations, as indicated in Tables 3 and 4, must be derived via an initial analysis of the path profile based on the value of a_e given by equation (6.). For path profile analysis, a path profile of terrain heights above mean sea level is required. Having thus analysed the profile, the path will also have been classified into transhorizontal or line of sight.

TABLE 3

Parameter values to be derived from the path profile analysis

Parameter	Description
d	Great-circle path distance (km)
d_{lt}, d_{lr}	For a transhorizon path, distance from the transmit and receive antennas to their respective horizons (km).). For a line-of-sight path, each is set to the distance from the terminal to the profile point identified as the principal edge in the diffraction method for 50% time.
θ_t, θ_r	For a transhorizon path, transmit and receive horizon elevation angles respectively (mrad). For a line-of-sight path, each is set to the elevation angle of the other terminal.
θ	Path angular distance (mrad)
h_{ts}, h_{rs}	Antenna centre height above mean sea level (m)
d_b	Aggregate length of the path sections over water (km)
ω	Fraction of the total path over water: $\omega = d_b / d$ (8.) where d is the great-circle distance (km) For totally overland paths $\omega = 0$
d_{ct}' d_{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.

5.1 Construction of path profile

Based on the geographical co-ordinates of the interfering (φ_t, ψ_t) and interfered-with (φ_r, ψ_r) stations, terrain heights (above mean sea level) along the great-circle path should be derived from a topographical database or from appropriate large-scale contour maps. The preferred distance resolution of the profile is that giving an integer number of steps of 0.1 km. The profile should include the ground heights at the interfering and interfered-with station locations as the start and end points. To the heights along the path should be added the necessary Earth's curvature, based on the value of a_e found in equation (6.).

For the purposes of this Annex the point of the path profile at the interferer is considered as point 0, and the point at the interfered-with station is considered as point n. The path profile therefore consists of n + 1 points. Figure 1 gives an example of a path profile of terrain heights above mean sea level, showing the various parameters related to the actual terrain.

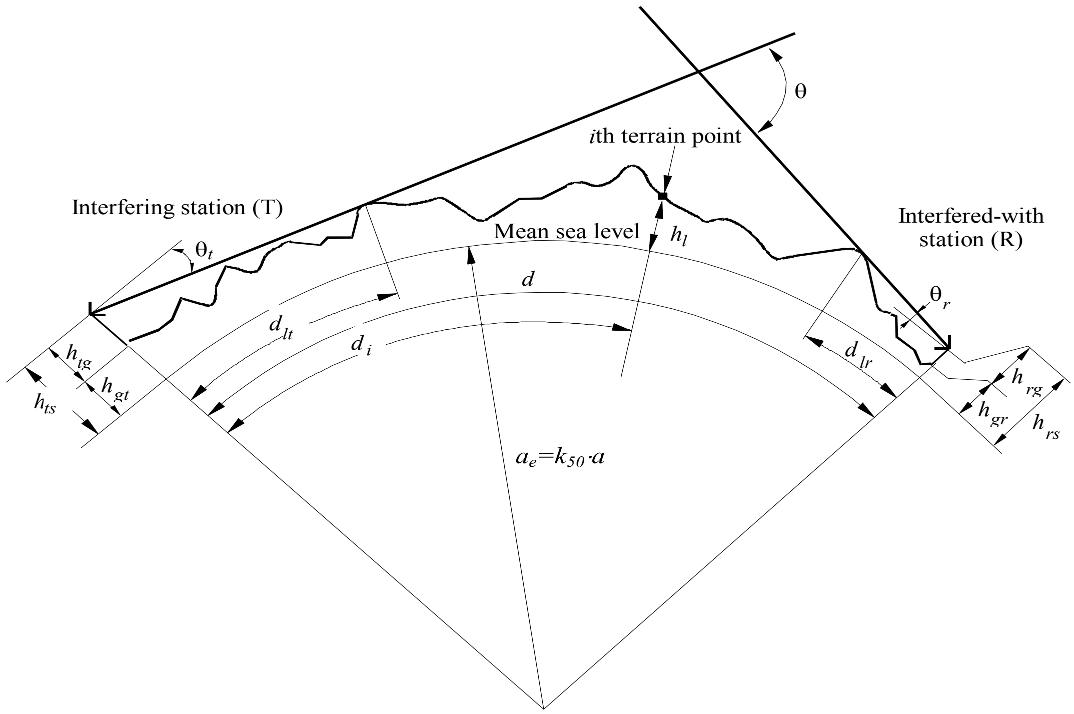
Table 4 defines parameters used or derived during the path profile analysis.

The path length, d (km), should be calculated according to the formula related to the great circle distance:

$$d = 6371 \cdot \arccos(\sin(\varphi_t)\sin(\varphi_r) + \cos(\varphi_t)\cos(\varphi_r)\cos(\psi_t - \psi_r)) \qquad (9.)$$

FIGURE 1

Example of a (trans-horizon) path profile



Note 1– The value of θ_t as drawn will be negative.

TABLE 4

Path profile parameter definitions

Parameter	Description
a_e	Effective Earth's radius (km)
d	Great-circle path distance (km)
d_i	Great-circle distance of the *i*-th terrain point from the interferer (km)
d_{ii}	Incremental distance for regular path profile data (km)
f	Frequency (GHz)
λ	Wavelength (m)
h_{ts}	Interferer antenna height (m) above mean sea level (amsl)
h_{rs}	Interfered-with antenna height (m) (amsl)
θ_t	For a transhorizon path, horizon elevation angle above local horizontal (mrad), measured from the interfering antenna. For a line-of-sight path this should be the elevation angle of the interfered-with antenna
θ_r	For a transhorizon path, horizon elevation angle above local horizontal (mrad), measured from the interfered-with antenna. For a line-of-sight path this should be the elevation angle of the interfering antenna

5.2 Path classification

The path must be classified into line-of-sight or transhorizon. The path profile must be used to determine whether the path is line-of-sight or transhorizon based on the median effective Earth's radius of a_e.

A path is trans-horizon if the physical horizon elevation angle as seen by the interfering antenna (relative to the local horizontal) is greater than the angle (again relative to the interferer's local horizontal) subtended by the interfered-with antenna.
The test for the trans-horizon path condition is thus:

$$\theta_{max} > \theta_{td} \quad \text{(mrad)} \tag{10.}$$

where:

$$\theta_{max} = \max_{i=1}^{n-1}(\theta_i) \quad \text{(mrad)} \tag{11.}$$

θ_i : elevation angle to the i th terrain point

$$\theta_i = \frac{h_i - h_{ts}}{d_i} - \frac{10^3 d_i}{2a_e} \quad \text{(mrad)} \tag{12.}$$

where:

h_i : height of the i th terrain point (m) amsl

h_{ts} : interferer antenna height (m) amsl

d_i : distance from interferer to the i th terrain element (km)

$$\theta_{td} = \frac{h_{rs} - h_{ts}}{d} - \frac{10^3 d}{2a_e} \quad \text{(mrad)} \tag{13.}$$

where:

h_{rs} : interfered-with antenna height (m) amsl

d : total great-circle path distance (km)

a_e : median effective Earth's radius appropriate to the path (equation (6.)).

Derivation of parameters from the path profile for trans-horizon paths

The parameters to be derived from the path profile are those contained in Table 4.

Interfering antenna horizon elevation angle, θ_t

The interfering antenna's horizon elevation angle is the maximum antenna horizon elevation angle when equation (11.) is applied to the n – 1 terrain profile heights.

$$\theta_t = \theta_{max} \qquad \text{(mrad)} \qquad (14.)$$

with θ_{max} as determined in equation (11.).

Interfering antenna horizon distance, d_{lt}

The horizon distance is the minimum distance from the transmitter at which the maximum antenna horizon elevation angle is calculated from equation (11.).

$$d_{lt} = d_i \qquad \text{(km)} \ \textit{for} \ \max(\theta_i) \qquad (15.)$$

Interfered-with antenna horizon elevation angle, θ_r

The receive antenna horizon elevation angle is the maximum antenna horizon elevation angle when equation (11.) is applied to the n – 1 terrain profile heights.

$$\theta_r = \max_{j=1}^{n-1} (\theta_j) \qquad \text{(mrad)} \qquad (16.)$$

$$\theta_j = \frac{h_{ji} - h_{rs}}{d - d_j} - \frac{10^3 (d - d_j)}{2a_e} \qquad \text{(mrad)} \qquad (17.)$$

Angular distance θ (mrad)

The angular distance θ is calculated using formula :

$$\theta = \frac{10^3 d}{a_e} + \theta_t + \theta_r \qquad \textit{(mrad)} \qquad (18.)$$

Interfered-with antenna horizon distance, d_{lr}

The horizon distance is the minimum distance from the receiver at which the maximum antenna horizon elevation angle is calculated from equation (11.).

$$d_{lr} = d - d_j \qquad \text{(km)} \quad \text{for} \quad \max(\Theta_j) \qquad (19.)$$

6 Step 4 of the prediction procedure: Calculation of propagation predictions

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

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

The following should be evaluated for both line-of-sight and transhorizon paths.
Basic transmission loss due to free-space propagation and attenuation by atmospheric gases:

$$L_{bfsg} = 92.5 + 20 \log f + 20 \log d + A_g \quad \text{dB} \qquad (20.)$$

where:

A_g : total gaseous absorption (dB):

$$A_g = [\gamma_o + \gamma_w(\rho)]d \quad \text{(dB)} \qquad (21.)$$

where:

γ_o, $\gamma_w(\rho)$: specific attenuation due to dry air and water vapour, respectively, and are found from the equations (23.), (24.)

ρ : water vapour density:

$$\rho = 7.5 + 2.5\,\omega \quad (\text{g/m}^3) \qquad (22.)$$

ω : fraction of the total path over water.

For dry air, the attenuation γ_o (dB/km) is given by Recommendation ITU-R P.676-7 as follows:

$$\gamma_o = \left[\frac{7.2\, r_t^{2.8}}{f^2 + 0.34\, r_p^2\, r_t^{1.6}} + \frac{0.62\,\xi_3}{(54-f)^{1.16\xi_1} + 0.83\,\xi_2} \right] f^2 r_p^2 \times 10^{-3} \qquad (23.)$$

where:

f : frequency (GHz)

r_p = p / 1013

r_t = 288/(273 + t)

p : pressure (hPa) - see § 2

t : temperature (°C) see § 2.

$$\xi_1 = \varphi(r_p, r_t, 0.0717, -1.8132, 0.0156, -1.6515)$$

$$\xi_2 = \varphi(r_p, r_t, 0.5146, -4.6368, -0.1921, -5.7416)$$

$$\xi_3 = \varphi(r_p, r_t, 0.3414, -6.5851, 0.2130, -8.5854)$$

$$\varphi(r_p, r_t, a, b, c, d) = r_p^a r_t^b \exp[c(1-r_p) + d(1-r_t)]$$

For water vapour, the attenuation γ_w (dB/km) is given by:

$$\gamma_w = \left\{ \frac{3.98\eta_1 \exp[2.23(1-r_t)]}{(f-22.235)^2 + 9.42\eta_1^2} g(f,22) + \frac{11.96\eta_1 \exp[0.7(1-r_t)]}{(f-183.31)^2 + 11.14\eta_1^2} \right.$$
$$+ \frac{0.081\eta_1 \exp[6.44(1-r_t)]}{(f-321.226)^2 + 6.29\eta_1^2} + \frac{3.66\eta_1 \exp[1.6(1-r_t)]}{(f-325.153)^2 + 9.22\eta_1^2}$$
$$+ \frac{25.37\eta_1 \exp[1.09(1-r_t)]}{(f-380)^2} + \frac{17.4\eta_1 \exp[1.46(1-r_t)]}{(f-448)^2} \qquad (24.)$$
$$+ \frac{844.6\eta_1 \exp[0.17(1-r_t)]}{(f-557)^2} g(f,557) + \frac{290\eta_1 \exp[0.41(1-r_t)]}{(f-752)^2} g(f,752)$$
$$\left. + \frac{8.3328 \times 10^4 \eta_2 \exp[0.99(1-r_t)]}{(f-1\,780)^2} g(f,1\,780) \right\} f^2 r_t^{2.5} \rho \times 10^{-4}$$

where:

$$\eta_1 = 0.955 r_p r_t^{0.68} + 0.006\rho$$
$$\eta_2 = 0.735\, r_p r_t^{0.5} + 0.0353\, r_t^4 \rho$$
$$g(f, f_i) = 1 + \left(\frac{f - f_i}{f + f_i} \right)^2$$

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

$$E_{sp} = 2.6\ [1 - \exp(-0.1\ \{d_{lt} + d_{lr}\})] \log (p/50) \quad \text{dB} \qquad (25.)$$

$$E_{s\beta} = 2.6\ [1 - \exp(-0.1\ \{d_{lt} + d_{lr}\})] \log (\beta_0/50) \quad \text{dB} \qquad (26.)$$

Basic transmission loss not exceeded for time percentage, p%, due to line-of-sight propagation:

$$L_{b0p} = L_{bfsg} + E_{sp} \quad \text{dB} \qquad (27.)$$

Basic transmission loss not exceeded for time percentage, β_0%, due to line-of-sight propagation:

$$L_{b0\beta} = L_{bfsg} + E_{s\beta} \quad \text{dB} \qquad (28.)$$

6.2 Diffraction

The diffraction model calculates the following quantities required in § 6.5:

- 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 for all paths using a hybrid method based on the Deygout construction and an empirical correction. This method provides an estimate of diffraction loss for all types of paths, including over-sea or over-inland or coastal land, and irrespective of whether the land is smooth or rough.

This method should be used, even if the edges identified by the Deygout construction are adjacent profile points.

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

$$J(\nu) = 6.9 + 20\log\left(\sqrt{(\nu - 0.1)^2 + 1} + \nu - 0.1\right) \qquad (29.)$$

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

6.2.1 Median diffraction loss

The median diffraction loss, L_{d50} (dB), is calculated using the median value of the effective Earth radius, a_e, given by equation (6.).

Median diffraction loss for the principal edge

Calculate a correction, ζ_m, for overall path slope given by:

$$\zeta_m = \cos\left(\tan^{-1}\left(10^{-3}\frac{h_{rs}-h_{ts}}{d}\right)\right) \tag{30.}$$

Find the main (i.e. principal) edge, and calculate its diffraction parameter, ν_{m50}, given by:

$$\nu_{m50} = \max_{i=1}^{n-1}\left(\zeta_m H_i \sqrt{\frac{2\times10^{-3}d}{\lambda d_i(d-d_i)}}\right), \tag{31.}$$

where the vertical clearance, H_i, is:

$$H_i = h_i + 10^3\frac{d_i(d-d_i)}{2a_e} - \frac{h_{ts}(d-d_i)+h_{rs}d_i}{d} \tag{32.}$$

and

- $h_{ts,rs}$: transmitter and receiver heights above sea level (m) (see Table3.)
- λ : wavelength (m) = 0.3/*f*
- *f* : frequency (GHz)
- *d* : path length (km)
- d_i : distance of the *i*-th profile point from transmitter (km) (see § 5.2)
- h_i : height of the *i*-th profile point above sea level (m) (see § 5.2).

Set i_{m50} to the index of the profile point with the maximum value, ν_{m50}.
Calculate the median knife-edge diffraction loss for the main edge, L_{m50}, given by:

$$\begin{aligned} L_{m50} &= J(\nu_{m50}) && \text{if } \nu_{m50} \geq -0.78 \\ &= 0 && \text{otherwise} \end{aligned} \tag{33.}$$

If L_{m50} = 0, the median diffraction loss, L_{d50}, and the diffraction loss not exceeded for β_0% time, $L_{d\beta}$, are both zero and no further diffraction calculations are necessary.

Otherwise possible additional losses due to secondary edges on the transmitter and receiver sides of the principal edge should be investigated, as follows.

Median diffraction loss for transmitter-side secondary edge

If i_{m50} = 1, there is no transmitter-side secondary edge, and the associated diffraction loss, L_{t50}, should be set to zero. Otherwise, the calculation proceeds as follows. Calculate a correction, ζ_t, for the slope of the path from the transmitter to the principal edge:

$$\zeta_t = \cos\left(\tan^{-1}\left(10^{-3}\frac{h_{im50}-h_{ts}}{d_{im50}}\right)\right) \tag{34.}$$

Find the transmitter-side secondary edge and calculate its diffraction parameter, ν_{t50}, given by:

$$\nu_{t50} = \max_{i=1}^{i_{m50}-1}\left(\zeta_t H_i \sqrt{\frac{2\times10^{-3} d_{i_{m50}}}{\lambda d_i \left(d_{i_{m50}} - d_i\right)}}\right) \quad (35.)$$

where:

$$H_i = h_i + 10^3 \frac{d_i\left(d_{i_{m50}} - d_i\right)}{2a_e} - \frac{h_{ts}\left(d_{i_{m50}} - d_i\right) + h_{i_{m50}} d_i}{d_{i_{m50}}} \quad (36.)$$

Set i_{t50} to the index of the profile point for the transmitter-side secondary edge (i.e. the index of the terrain height array element corresponding to the value ν_{t50}).
Calculate the median knife-edge diffraction loss for the transmitter-side secondary edge, L_{t50}, given by:

$$\begin{aligned} L_{t50} &= J\left(\nu_{t50}\right) && \text{for } \nu_{t50} \geq -0.78 \text{ and } i_{m50} > 2 \\ &= 0 && \text{otherwise} \end{aligned} \quad (37.)$$

Median diffraction loss for the receiver-side secondary edge

If $i_{m50} = n$-1, there is no receiver-side secondary edge, and the associated diffraction loss, L_{r50}, should be set to zero. Otherwise the calculation proceeds as follows. Calculate a correction, ζ_r, for the slope of the path from the principal edge to the receiver:

$$\zeta_r = \cos\left(\tan^{-1}\left(10^{-3} \frac{h_{rs} - h_{i_{m50}}}{d - d_{i_{m50}}}\right)\right) \quad (38.)$$

Find the receiver-side secondary edge and calculate its diffraction parameter, ν_{r50}, given by:

$$\nu_{r50} = \max_{i=i_{m50}+1}^{n-1}\left(\zeta_r H_i \sqrt{\frac{2\times10^{-3}\left(d - d_{i_{m50}}\right)}{\lambda\left(d_i - d_{i_{m50}}\right)\left(d - d_i\right)}}\right) \quad (39.)$$

where:

$$H_i = h_i + 10^3 \frac{\left(d_i - d_{i_{m50}}\right)\left(d - d_i\right)}{2a_e} - \frac{h_{i_{m50}}\left(d - d_i\right) + h_{rs}\left(d_i - d_{i_{m50}}\right)}{d - d_{i_{m50}}} \quad (40.)$$

Set i_{r50} to the index of the profile point for the receiver-side secondary edge (i.e. the index of the terrain height array element corresponding to the value ν_{r50}).
Calculate the median knife-edge diffraction loss for the receiver-side secondary edge, L_{r50}, given by:

$$\begin{aligned} L_{r50} &= J\left(\nu_{r50}\right) && \text{for } \nu_{r50} \geq -0.78 \text{ and } i_{m50} < n-1 \\ &= 0 && \text{otherwise} \end{aligned} \quad (41.)$$

Combination of the edge losses for median Earth curvature

Calculate the median diffraction loss, L_{d50}, given by:

$$\begin{aligned} L_{d50} &= L_{m50} + \left(1 - \mathrm{e}^{-\frac{L_{m50}}{6}}\right)\left(L_{t50} + L_{r50} + 10 + 0.04d\right) && \text{for } \nu_{m50} > -0.78 \\ &= 0 && \text{otherwise} \end{aligned} \quad (42.)$$

In equation (42.) L_{t50} will be zero if the transmitter-side secondary edge does not exist and, similarly, L_{r50} will be zero if the receiver-side secondary edge does not exist.
If $L_{d50} = 0$, then the diffraction loss not exceeded for β_0% time will also be zero.
If the prediction is required only for p = 50%, no further diffraction calculations will be necessary (see § 6.2.3). Otherwise, the diffraction loss not exceeded for β_0% time must be calculated, as

follows.

6.2.2 The diffraction loss not exceeded for β_0% of the time

The diffraction loss not exceeded for β_0% time is calculated using the effective Earth radius exceeded for β_0% time, a_β, given by equation (7.). For this second diffraction calculation, the same edges as those found for the median case should be used for the Deygout construction.

The calculation of this diffraction loss then proceeds as follows.

Principal edge diffraction loss not exceeded for β_0% time

Find the main (i.e. principal) edge diffraction parameter, $\nu_{m\beta}$, given by:

$$\nu_{m\beta} = \zeta_m H_{i_{m\beta}} \sqrt{\frac{2\times10^{-3} d}{\lambda d_{i_{m50}} \left(d - d_{i_{m50}}\right)}} \tag{43.}$$

where:

$$H_{i_{m\beta}} = h_{i_{m50}} + 10^3 \frac{d_{i_{m50}}\left(d - d_{i_{m50}}\right)}{2a_\beta} - \frac{h_{ts}\left(d - d_{i_{m50}}\right) + h_{rs} d_{i_{m50}}}{d} \tag{44.}$$

Calculate the knife-edge diffraction loss for the main edge, $L_{m\beta}$, given by:

$$\begin{aligned} L_{m\beta} &= J\left(\nu_{m\beta}\right) && \text{for } \nu_{m\beta} \geq -0.78 \\ &= 0 && \text{otherwise} \end{aligned} \tag{45.}$$

Transmitter-side secondary edge diffraction loss not exceeded for β_0% time

If $L_{t50} = 0$, then $L_{t\beta}$ will be zero. Otherwise calculate the transmitter-side secondary edge diffraction parameter, $\nu_{t\beta}$, given by:

$$\nu_{t\beta} = \zeta_t H_{i_{t\beta}} \sqrt{\frac{2\times10^{-3} d_{i_{m50}}}{\lambda d_{i_{t50}} \left(d_{i_{m50}} - d_{i_{t50}}\right)}} \tag{46.}$$

where:

$$H_{i_{t\beta}} = h_{i_{t50}} + 10^3 \frac{d_{i_{t50}}\left(d_{i_{m50}} - d_{i_{t50}}\right)}{2a_\beta} - \frac{h_{ts}\left(d_{i_{m50}} - d_{i_{t50}}\right) + h_{i_{m50}} d_{i_{t50}}}{d_{i_{m50}}} \tag{47.}$$

Calculate the knife-edge diffraction loss for the transmitter-side secondary edge, $L_{t\beta}$, given by:

$$\begin{aligned} L_{t\beta} &= J\left(\nu_{t\beta}\right) && \text{for } \nu_{t\beta} \geq -0.78 \\ &= 0 && \text{otherwise} \end{aligned} \tag{48.}$$

Receiver-side secondary edge diffraction loss not exceeded for β_0% time

If $L_{r50} = 0$, then $L_{r\beta}$ will be zero. Otherwise, calculate the receiver-side secondary edge diffraction parameter, $\nu_{r\beta}$, given by:

$$\nu_{r\beta} = \zeta_r H_{i_{r\beta}} \sqrt{\frac{2\times10^{-3}\left(d - d_{i_{m50}}\right)}{\lambda \left(d_{i_{r50}} - d_{i_{m50}}\right)\left(d - d_{i_{r50}}\right)}} \tag{49.}$$

where:

$$H_{ir\beta} = h_{ir50} + 10^3 \frac{(d_{ir50} - d_{im50})(d - d_{ir50})}{2a_\beta} - \frac{h_{im50}(d - d_{ir50}) + h_{rs}(d - d_{im50})}{d - d_{im50}} \qquad (50.)$$

Calculate the knife-edge diffraction loss for the receiver-side secondary edge, $L_{r\beta}$, given by:

$$\begin{aligned} L_{r\beta} &= J(\nu_{r\beta}) && \text{for } \nu_{r\beta} \geq -0.78 \\ &= 0 && \text{otherwise} \end{aligned} \qquad (51.)$$

Combination of the edge losses not exceeded for β_0% time

Calculate the diffraction loss not exceeded for β_0% of the time, $L_{d\beta}$, given by:

$$\begin{aligned} L_{d\beta} &= L_{m\beta} + \left(1 - e^{\frac{L_{m\beta}}{6}}\right)(L_{t\beta} + L_{r\beta} + 10 + 0.04d) && \text{for } \nu_{m\beta} > -0.78 \\ &= 0 && \text{otherwise} \end{aligned} \qquad (52.)$$

6.2.3 The diffraction loss not exceeded for *p*% of the time

The application of the two possible values of effective Earth radius factor is controlled by an interpolation factor, F_i, based on a log-normal distribution of diffraction loss over the range $\beta_0\% < p < 50\%$. given by:

$$F_i = 0 \quad p = 50\% \qquad (53.)$$

$$= \frac{I\left(\frac{p}{100}\right)}{I\left(\frac{\beta_0}{100}\right)} \quad \text{for } 50\% > p > \beta_0\% \qquad (54.)$$

$$= 1 \quad \text{for } \beta_0\% \geq p \qquad (55.)$$

where $I(x)$ is the inverse cumulative normal function. An approximation for $I(x)$ which may be used with confidence for $x < 0.5$ is given in (59.).

The diffraction loss, L_{dp}, not exceeded for p% time, is now given by:

$$L_{dp} = L_{d50} + F_i\,(L_{d\beta} - L_{d50}) \quad \text{dB} \qquad (56.)$$

where L_{d50} and $L_{d\beta}$ are defined by equations (42.) and (52.), respectively, and F_i is defined by equations (53. to 55.), depending on the values of p and β_0.
The median basic transmission loss associated with diffraction, L_{bd50}, is given by:

$$L_{bd50} = L_{bfsg} + L_{d50} \quad \text{dB} \qquad (57.)$$

where L_{bfsg} is given by equation (20.).
The basic transmission loss associated with diffraction not exceeded for p% time is given by:

$$L_{bd} = L_{b0p} + L_{dp} \quad \text{dB} \qquad (58.)$$

where L_{b0p} is given by equation (27.).

The following approximation to the inverse cumulative normal distribution function is valid for $0.000001 \leq x \leq 0.5$ and is in error by a maximum of 0.00054. It may be used with confidence for the interpolation function in equation (54.). If $x < 0.000001$, which implies $\beta_0 < 0.0001\%$, x should be set to 0.000001. The function I(x) is then given by:

$$I(x) = \xi(x) - T(x) \qquad (59.)$$

where:

$$T(x) = \sqrt{-2\ln(x)} \qquad (60.)$$

$$\xi(x) = \frac{(C_2 \cdot T(x) + C_1) \cdot T(x) + C_0}{[(D_3 \cdot T(x) + D_2)T(x) + D_1]T(x) + 1} \qquad (61.)$$

$$C_0 = 2.515516698 \qquad (62.)$$

$$C_1 = 0.802853 \qquad (63.)$$

$$C_2 = 0.010328 \qquad (64.)$$

$$D_1 = 1.432788 \qquad (65.)$$

$$D_2 = 0.189269 \qquad (66.)$$

$$D_3 = 0.001308 \qquad (67.)$$

6.3 Tropospheric scatter

The basic transmission loss due to troposcatter, L_{bs} (p) (dB) not exceeded for any time percentage, p, is given by:

$$L_{bs} = 190 + L_f + 20\log d + 0.573\theta - 0.15 N_0 + L_c + A_g - 10.1[-\log(p/50)]^{0.7} \qquad (68.)$$

where:

L_f : frequency dependent loss:

$$L_f = 25\log f - 2.5[\log(f/2)]^2 \quad \text{(dB)} \qquad (69.)$$

L_c : aperture to medium coupling loss (dB):

$$L_c = 0.051 \cdot e^{0.055(G_t + G_r)} \quad \text{(dB)} \qquad (70.)$$

A_g: gaseous absorption derived from equation (21.) using ρ = 3 g/m^3 for the whole path length

6.4 Ducting/layer reflection

The prediction of the basic transmission loss, L_{ba} (dB) occurring during periods of anomalous propagation (ducting and layer reflection) is based on the following function:

$$L_{ba} = A_f + A_d(p) + A_g \quad \text{dB} \qquad (71.)$$

where:

A_f : total of fixed coupling losses (except for local clutter losses) between the antennas and the anomalous propagation structure within the atmosphere:

$A_f = 102.45 + 20 \log f + 20 \log (d_{lt} + d_{lr}) + A_{st} + A_{sr} + A_{ct} + A_{cr}$ dB (72.)

A_{st}, A_{sr} : site-shielding diffraction losses for the interfering and interfered-with stations respectively:

$$A_{st,sr} = \begin{cases} 20\log\left[1 + 0.361\,\theta''_{t,r}\left(f \cdot d_{lt,lr}\right)^{1/2}\right] + 0.264\,\theta''_{t,r}\, f^{1/3} & \text{dB} \quad \text{for } \theta''_{t,r} > 0 \quad \text{mrad} \\ 0 & \text{dB} \quad \text{for } \theta''_{t,r} \le 0 \quad \text{mrad} \end{cases} \qquad (73.)$$

where:

$$\theta''_{t,r} = \theta_{t,r} - 0.1\, d_{lt,lr} \quad \text{mrad} \qquad (74.)$$

A_{ct}, A_{cr}: over-sea surface duct coupling corrections for the interfering and interfered-with stations respectively:

$$A_{ct,cr} = -3\,\mathrm{e}^{-0.25 d_{ct,cr}^2}\left[1 + \tanh\ (0.07(50 - h_{ts,rs}))\right] \quad \text{dB} \quad \text{for} \quad \omega \ge 0.75$$

$$d_{ct,cr} \le d_{lt,lr} \qquad (75.)$$

$$d_{ct,cr} \le 5 \text{ km}$$

$$A_{ct,cr} = 0 \quad \text{dB} \quad \text{for all other conditions} \qquad (76.)$$

It is useful to note the limited set of conditions under which equation (75.) is needed.

$A_d(p)$: time percentage and angular-distance dependent losses within the anomalous propagation mechanism:

$$A_d(p) = \gamma_d\ \theta' + A(p) \quad \text{dB} \qquad (77.)$$

where:

γ_d : specific attenuation:

$$\gamma_d = 5 \times 10^{-5}\, a_e\ f^{1/3} \quad \text{dB/mrad} \qquad (78.)$$

θ': angular distance (corrected where appropriate (via equation (79.)) to allow for the application of the site shielding model in equation (73.)):

$$\theta' = \frac{10^3 d}{a_e} + \theta'_t + \theta'_r \quad \text{mrad} \qquad (79.)$$

$$\theta'_{t,r} = \begin{cases} \theta_{t,r} & \text{for } \theta_{t,r} \le 0.1\, d_{lt,lr} \quad \text{mrad} \\ 0.1\, d_{lt,lr} & \text{for } \theta_{t,r} > 0.1\, d_{lt,lr} \quad \text{mrad} \end{cases} \qquad (80.)$$

$A(p)$: time percentage variability (cumulative distribution):

$$A(p) = -12 + (1.2 + 3.7 \times 10^{-3} d)\log\left(\frac{p}{\beta}\right) + 12\left(\frac{p}{\beta}\right)^{\Gamma} \quad \text{dB} \qquad (81.)$$

$$\Gamma = \frac{1.076}{(2.0058 - \log\beta)^{1.012}} \times \mathrm{e}^{-\left(9.51 - 4.8\log\beta + 0.198(\log\beta)^2\right) \times 10^{-6} \cdot d^{1.13}} \qquad (82.)$$

$$\beta = \beta_0 \cdot \mu_2 \cdot \mu_3 \qquad \% \tag{83.}$$

μ_2 : correction for path geometry:

$$\mu_2 = \left[\frac{500}{a_e} \frac{d^2}{\left(\sqrt{h_{te}} + \sqrt{h_{re}}\right)^2} \right]^{\alpha} \tag{84.}$$

The value of μ_2 shall not exceed 1.

$$\alpha = -0.6 - \varepsilon \cdot 10^{-9} \cdot d^{3.1} \cdot \tau \tag{85.}$$

where:

ε = 3.5

τ : is defined in equation (3.)
and the value of α shall not be allowed to reduce below –3.4

μ_3 : correction for terrain roughness:

$$\mu_3 = \begin{cases} 1 & \text{for } h_m \le 10 \text{ m} \\ \exp\left[-4.6 \times 10^{-5} \, (h_m - 10) \, (43 + 6 d_I)\right] & \text{for } h_m > 10 \text{ m} \end{cases} \tag{86.}$$

$$d_I = \min\,(d - d_{lt} - d_{lr}, 40) \qquad \text{km} \tag{87.}$$

A_g : total gaseous absorption determined from equation (21.).

6.5 The overall prediction

The following procedure should be applied to the results of the foregoing calculations for all paths.
Calculate an interpolation factor, F_j, to take account of the path angular distance:

$$F_j = 1.0 - 0.5\left(1.0 + \tanh\left(3.0\ \xi \frac{(\theta - \Theta)}{\Theta}\right)\right) \tag{88.}$$

where:

Θ = 0.3
ξ = 0.8
θ : path angular distance (mrad) (defined in Table 3).

Calculate an interpolation factor, F_k, to take account of the great circle path distance:

$$F_k = 1.0 - 0.5\left(1.0 + \tanh\left(3.0\,\kappa \frac{(d - d_{sw})}{d_{sw}}\right)\right) \tag{89.}$$

where:

d : great circle path length (km) (defined in Table 3)
d_{sw} : fixed parameter determining the distance range of the associated blending, set to 20
κ : fixed parameter determining the blending slope at the ends of the range, set to 0.5.

Calculate a notional minimum basic transmission loss, L_{minb0p} (dB) associated with line-of-sight propagation and over-sea sub-path diffraction.

$$L_{\min b0p} = \begin{cases} L_{b0p} + (1-\omega)L_{dp} & \text{for } p < \beta_0 \\ L_{bd50} + (L_{b0\beta} + (1-\omega)L_{dp} - L_{bd50}) \cdot F_i & \text{for } p \geq \beta_0 \end{cases} \quad \text{dB} \qquad (90.)$$

where:

L_{b0p} : notional line-of-sight basic transmission loss not exceeded for p% time, given by equation (27.)

$L_{b0\beta}$: notional line-of-sight basic transmission loss not exceeded for β% time, given by equation (28.)

L_{dp} : diffraction loss not exceeded for p% time, calculated using the method in § 6.2.

Calculate a notional minimum basic transmission loss, L_{minbap} (dB), associated with line-of-sight and transhorizon signal enhancements:

$$L_{minbap} = \eta \ln\left(\exp\left(\frac{L_{ba}}{\eta} \right) + \exp\left(\frac{L_{b0p}}{\eta} \right) \right) \quad \text{dB} \qquad (91.)$$

where:

L_{ba}: ducting/layer reflection basic transmission loss not exceeded for p% time, given by equation (71.)

L_{b0p}: notional line-of-sight basic transmission loss not exceeded for p% time, given by equation (27.)

η = 2.5

Calculate a notional basic transmission loss, L_{bda} (dB), associated with diffraction and line-of-sight or ducting/layer-reflection enhancements:

$$L_{bda} = \begin{cases} L_{bd} & \text{for } L_{minbap} > L_{bd} \\ L_{minbap} + (L_{bd} - L_{minbap})F_k & \text{for } L_{minbap} \leq L_{bd} \end{cases} \quad \text{dB} \qquad (92.)$$

where:

L_{bd} : basic transmission loss for diffraction not exceeded for p% time from equation (58.).

F_k : interpolation factor given by equation (89.) according to the values of p and β_0.

Calculate a modified basic transmission loss, L_{bam} (dB), which takes diffraction and line-of-sight or ducting/layer-reflection enhancements into account

$$L_{bam} = L_{bda} + (L_{minb0p} - L_{bda})\, F_j \quad \text{dB} \qquad (93.)$$

Calculate the final basic transmission loss not exceed for p% time, L_b (dB), as given by:

$$L_b = -5 \log\left(10^{-0.2L_s} + 10^{-0.2L_{bam}}\right) \quad \text{dB} \qquad (94.)$$