

RECOMMENDATION ITU-R P.530-6

**PROPAGATION DATA AND PREDICTION METHODS REQUIRED FOR
THE DESIGN OF TERRESTRIAL LINE-OF-SIGHT SYSTEMS**

(Question ITU-R 204/3)

(1978-1982-1986-1990-1992-1994-1995)

The ITU Radiocommunication Assembly,

considering

- a) that for the proper planning of terrestrial line-of-sight systems it is necessary to have appropriate propagation prediction methods and data;
- b) that methods have been developed that allow the prediction of some of the most important propagation parameters affecting the planning of terrestrial line-of-sight systems;
- c) that as far as possible these methods have been tested against available measured data and have been shown to yield an accuracy that is both compatible with the natural variability of propagation phenomena and adequate for most present applications in system planning,

recommends

- 1 that the prediction methods and other techniques set out in Annex 1 be adopted for planning terrestrial line-of-sight systems in the respective ranges of parameters indicated.

ANNEX 1

1 Introduction

Several propagation effects must be considered in the design of line-of-sight radio-relay systems. These include:

- diffraction fading due to obstruction of the path by terrain obstacles under adverse propagation conditions;
- attenuation due to atmospheric gases;
- fading due to atmospheric multipath or beam spreading (commonly referred to as defocusing in the English technical literature) associated with abnormal refractive layers;
- fading due to multipath arising from surface reflection;
- attenuation due to precipitation or solid particles in the atmosphere;
- variation of the angle-of-arrival at the receiver terminal and angle-of-launch at the transmitter terminal due to refraction;
- reduction in cross-polarization discrimination in multipath or precipitation conditions;
- signal distortion due to frequency selective fading and delay during multipath propagation.

One purpose of this Annex is to present in concise step-by-step form simple prediction methods for the propagation effects that must be taken into account in the majority of fixed line-of-sight links, together with information on their ranges of validity. Another purpose of this Annex is to present other information and techniques that can be recommended in the planning of terrestrial line-of-sight systems.

Prediction methods based on specific climate and topographical conditions within an administration's territory may be found to have advantages over those contained in this Annex.

With the exception of the interference resulting from reduction in cross-polarization discrimination, the Annex deals only with effects on the wanted signal. Other interference aspects are treated in separate Recommendations, namely:

- interference involving other terrestrial links and earth stations in Recommendation ITU-R P.452,
- interference involving space stations in Recommendation ITU-R P.619.

To optimize the usability of this Annex in system planning and design, the information is arranged according to the propagation effects that must be considered, rather than to the physical mechanisms causing the different effects.

It should be noted that the term “worst month” used in this Recommendation is equivalent to the term “any month” (see Recommendation ITU-R P.581).

2 Propagation loss

The propagation loss on a terrestrial line-of-sight path relative to the free-space loss (see Recommendation ITU-R P.525) is the sum of different contributions as follows:

- attenuation due to atmospheric gases,
- diffraction fading due to obstruction or partial obstruction of the path,
- fading due to multipath, beam spreading and scintillation,
- attenuation due to variation of the angle-of-arrival/launch,
- attenuation due to precipitation,
- attenuation due to sand and dust storms.

Each of these contributions has its own characteristics as a function of frequency, path length and geographic location. These are described in the subsections that follow.

Sometimes propagation enhancement is of interest. In such cases it is considered following the associated propagation loss.

2.1 Attenuation due to atmospheric gases

Some attenuation due to absorption by oxygen and water vapour is always present, and should be included in the calculation of total propagation loss at frequencies above about 10 GHz. The attenuation on a path of length d km is given by:

$$A_a = \gamma_a d \quad \text{dB} \quad (1)$$

The specific attenuation γ_a (dB/km) should be obtained using Recommendation ITU-R P.676.

NOTE 1 – On long paths at frequencies above about 20 GHz, it may be desirable to take into account known statistics of water vapour density and temperature in the vicinity of the path. Some information on water vapour density is given in Recommendation ITU-R P.836.

2.2 Diffraction fading

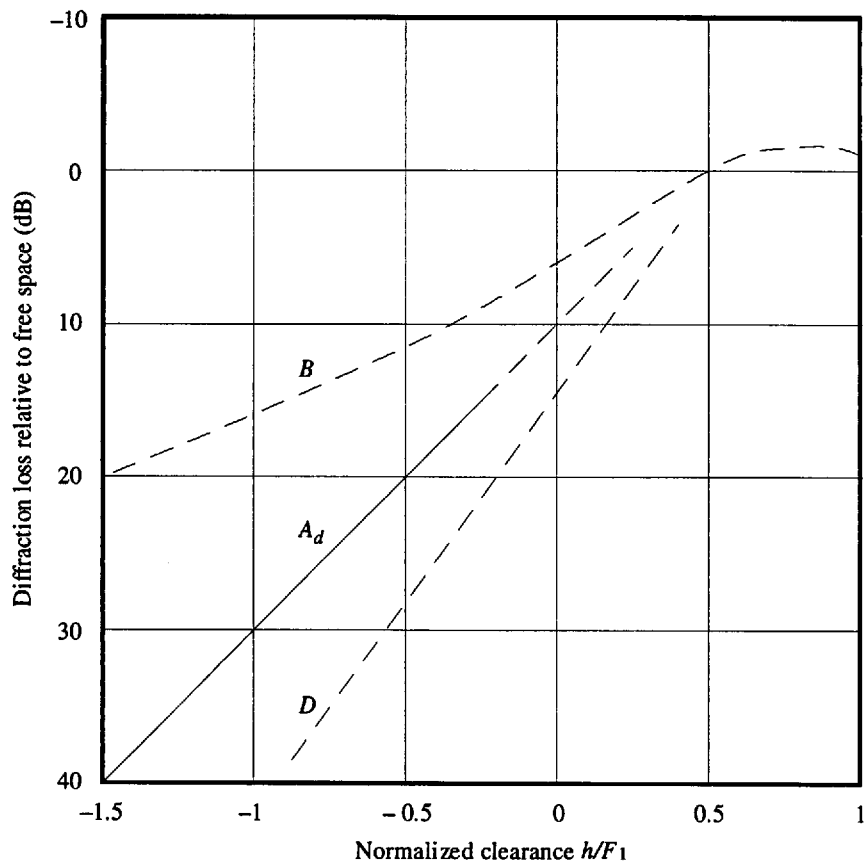
Variations in atmospheric refractive conditions cause changes in the effective Earth's radius or k -factor from its median value of approximately 4/3 for a standard atmosphere (see Recommendation ITU-R P.310). When the atmosphere is sufficiently sub-refractive (large positive values of the gradient of refractive index, low k -factor values), the ray paths will be bent in such a way that the Earth appears to obstruct the direct path between transmitter and receiver, giving rise to the kind of fading called diffraction fading. This fading is the factor that determines the antenna heights.

k -factor statistics for a single point can be determined from measurements or predictions of the refractive index gradient in the first 100 m of the atmosphere (see Recommendation ITU-R P.453 on effects of refraction). These gradients need to be averaged in order to obtain the effective value of k for the path length in question, k_e . Values of k_e exceeded for 99.9% of the time are discussed in terms of path clearance criteria in the following section.

2.2.1 Diffraction loss dependence on path clearance

Diffraction loss will depend on the type of terrain and the vegetation. For a given path ray clearance, the diffraction loss will vary from a minimum value for a single knife-edge obstruction to a maximum for smooth spherical Earth. Methods for calculating diffraction loss for these two cases and also for paths with irregular terrain are discussed in Recommendation ITU-R P.526. These upper and lower limits for the diffraction loss are shown in Fig. 1.

FIGURE 1
Diffraction loss for obstructed line-of-sight
microwave radio paths



- B: theoretical knife-edge loss curve
- D: theoretical smooth spherical Earth loss curve, at 6.5 GHz and $k_e = 4/3$
- A_d : empirical diffraction loss based on equation (2) for intermediate terrain
- h : amount by which the radio path clears the Earth's surface
- F_1 : radius of the first Fresnel zone

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The diffraction loss over average terrain can be approximated for losses greater than about 15 dB by the formula:

$$A_d = -20 h / F_1 + 10 \qquad \text{dB} \qquad (2)$$

where h is the height difference (m) between most significant path blockage and the path trajectory (h is negative if the top of the obstruction of interest is above the virtual line-of-sight) and F_1 is the radius of the first Fresnel ellipsoid given by:

$$F_1 = 17.3 \sqrt{\frac{d_1 d_2}{f d}} \quad \text{m} \tag{3}$$

with:

- f :

frequency (GHz)
- d :

path length (km)
- d_1 and d_2 :

distances (km) from the terminals to the path obstruction.

A curve, referred to as A_d , based on equation (2) is also shown in Fig. 1. This curve, strictly valid for losses larger than 15 dB, has been extrapolated up to 6 dB loss to fulfil the need of link designers.

2.2.2 Planning criteria for path clearance

At frequencies above about 2 GHz, diffraction fading of this type has in the past been alleviated by installing antennas that are sufficiently high, so that the most severe ray bending would not place the receiver in the diffraction region when the effective Earth radius is reduced below its normal value. Diffraction theory indicates that the direct path between the transmitter and the receiver needs a clearance above ground of at least 60% of the radius of the first Fresnel zone to achieve free-space propagation conditions. Recently, with more information on this mechanism and the statistics of k_e that are required to make statistical predictions, some administrations are installing antennas at heights that will produce some small known outage.

In the absence of a general procedure that would allow a predictable amount of diffraction loss for various small percentages of time and therefore a statistical path clearance criterion, the following procedure is advised for temperate and tropical climates:

2.2.2.1 Non-diversity antenna configurations

- a) determine the antenna heights required for the appropriate median value of the point k -factor (see § 2.2; in the absence of any data, use $k = 4/3$) and $1.0 F_1$ clearance over the highest obstacle (temperate and tropical climates);
- b) obtain the value of k_e (99.9%) from Fig. 2 for the path length in question;
- c) calculate the antenna heights required for the value of k_e obtained from step b) and the following Fresnel zone clearance radii:

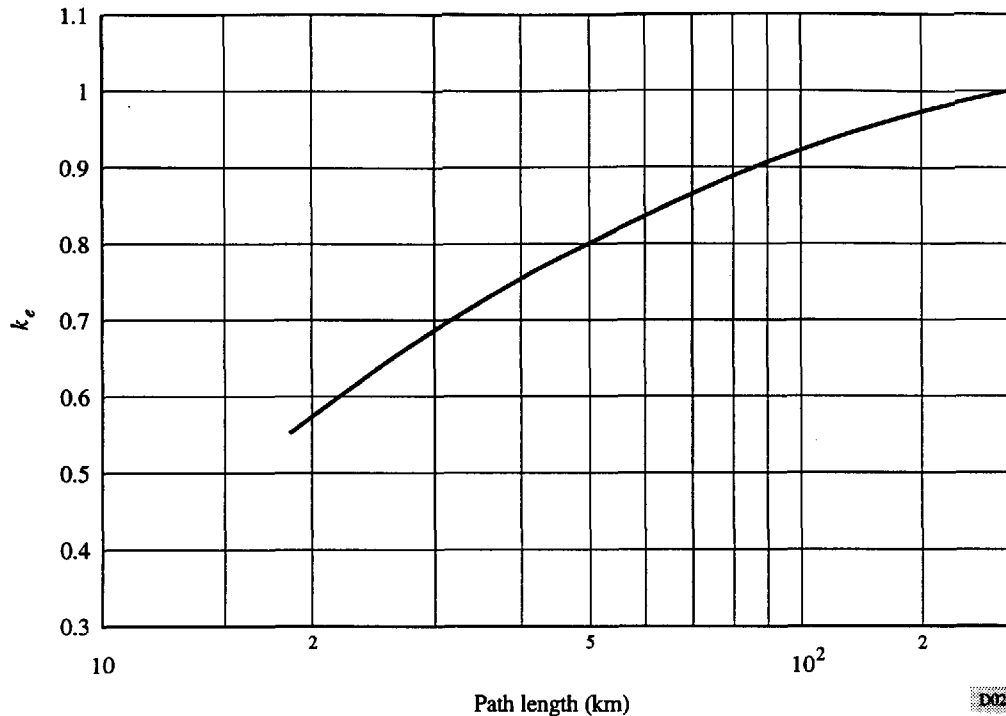
Temperate climate	Tropical climate
0.0 F_1 (i.e. grazing) if there is a single isolated path obstruction	0.6 F_1 for path lengths greater than about 30 km
0.3 F_1 if the path obstruction is extended along a portion of the path	

- d) use the larger of the antenna heights obtained by steps a) and c).

In cases of uncertainty as to the type of climate, the more conservative clearance rule for tropical climates may be followed or at least a rule based on an average of the clearances for temperate and tropical climates. Smaller fractions of F_1 may be necessary in steps a) and c) above for frequencies less than about 2 GHz in order to avoid unacceptably large antenna heights.

Higher fractions of F_1 may be necessary in step c) for frequencies greater than about 10 GHz in order to reduce the risk of diffraction in sub-refractive conditions.

FIGURE 2
Value of k_e exceeded for approximately 99.9% of the worst month
(Continental temperate climate)



2.2.2.2 Two antenna space-diversity configurations

a) Calculate the height of the lower antenna for the appropriate median value of the point k -factor (in the absence of any data use $k = 4/3$) and the following Fresnel zone clearances:

0.6 F_1 to 0.3 F_1 if the path obstruction is extended along a portion of the path,

0.3 F_1 to 0.0 F_1 if there are one or two isolated obstacles on the path profile.

One of the lower values in the two ranges noted above may be chosen if necessary to avoid increasing heights of existing towers or if the frequency is less than 2 GHz.

Alternatively, the clearance of the lower antenna may be chosen to give about 6 dB of diffraction loss during normal refractivity conditions (i.e. during the middle of the day), or some other loss appropriate to the fade margin of the system, as determined by test measurements. Measurements should be carried out on several different days to avoid anomalous refractivity conditions.

In this alternative case the diffraction loss can also be estimated using Fig. 1 or equation (2).

- b) Calculate the height of the upper antenna using the procedure for single antenna configurations noted above.
- c) Verify that the spacing of the two antennas satisfies the requirements for diversity under multipath fading conditions. If not, increase the height of the upper antenna accordingly.

This fading, which results when the path is obstructed or partially obstructed by the terrain during sub-refractive conditions, is the factor that governs antenna heights.

2.3 Fading and enhancement due to multipath and related mechanisms

Three clear-air fading mechanisms caused by extremely refractive layers in the atmosphere must be taken into account in the planning of links of more than a few kilometres in length; beam spreading (commonly referred to as defocusing in the English technical literature), antenna decoupling, surface multipath, and atmospheric multipath. Most of these

mechanisms can occur by themselves or in combination with each other (see Note 1). A particularly severe form of frequency selective fading occurs when beam spreading of the direct signal combines with a surface reflected signal to produce multipath fading. Scintillation fading due to smaller scale turbulent irregularities in the atmosphere is always present with these mechanisms but at frequencies below about 40 GHz its effect on the overall fading distribution is not significant.

NOTE 1 – Antenna decoupling governs the minimum beamwidth of the antennas that should be chosen.

Two methods for predicting the single-frequency (or narrow-band) fading distribution at large fade depths in any part of the world are given below. Method 1 in § 2.3.1 does not make use of the path profile and can be used for initial planning, licensing, or even design purposes. Method 2 in § 2.3.2, which does employ the path profile, should be used for critical link designs, particularly if geoclimatic factors K are available from measured data. Appropriate equations are given in these methods for overland and overwater paths. A third method in § 2.3.3 that is suitable for all fade depths employs Methods 1 or 2 for large fade depths as appropriate and an interpolation procedure for small fade depths. All methods take into account an average mixture of the clear-air fading mechanisms noted above.

A method for predicting enhancement is given in § 2.3.4. The method uses the fade depth predicted by the method in § 2.3.1 or § 2.3.2 as the only input parameter.

2.3.1 Method for initial planning purposes at small percentages of time (Method 1)

a) For the path location in question, estimate the geoclimatic factor K for the average worst month from fading data for the area if these are available (see Annex 2). If such data are not available, K can be estimated from the contour maps of Figs. 7-10 of Recommendation ITU-R P.453 for the percentage of time p_L that the average refractivity gradient in the lowest 100 m of the atmosphere is less than -100 N units/km, and the following empirical relations:

$$K = 10^{-(6.5 - C_{Lat} - C_{Lon})} p_L^{1.5} \quad \text{overland links for which the lower of the transmitting and receiving antennas is less than 700 m above mean sea level (see Note 2)} \quad (4)$$

$$K = 10^{-(7.1 - C_{Lat} - C_{Lon})} p_L^{1.5} \quad \text{overland links for which the lower of the transmitting and receiving antennas is higher than 700 m above mean sea level (see Notes 1 and 2)} \quad (5)$$

$$K = 10^{-(5.9 - C_{Lat} - C_{Lon})} p_L^{1.5} \quad \text{links over medium-sized bodies of water (see Note 3), coastal areas beside such bodies of water (see Note 4), or regions of many lakes (see Note 5)} \quad (6)$$

$$K = 10^{-(5.5 - C_{Lat} - C_{Lon})} p_L^{1.5} \quad \text{links over large bodies of water (see Note 3), or coastal areas beside such bodies of water (see Note 4)} \quad (7)$$

where the coefficient C_{Lat} of latitude ξ is given by:

$$C_{Lat} = 0 \quad \text{for} \quad 53^\circ \text{ S} \geq \xi \leq 53^\circ \text{ N} \quad (8)$$

$$C_{Lat} = -5.3 + \xi/10 \quad \text{for} \quad 53^\circ \text{ N or S} < \xi < 60^\circ \text{ N or S} \quad (9)$$

$$C_{Lat} = 0.7 \quad \text{for} \quad \xi \geq 60^\circ \text{ N or S} \quad (10)$$

and the longitude coefficient C_{Lon} , by:

$$C_{Lon} = 0.3 \quad \text{for longitudes of Europe and Africa} \quad (11)$$

$$C_{Lon} = -0.3 \quad \text{for longitudes of North and South America} \quad (12)$$

$$C_{Lon} = 0 \quad \text{for all other longitudes} \quad (13)$$

The month that has the highest value of p_L should be chosen from the four seasonally representative months of February, May, August and November for which maps are given in Figs. 7-10 of Recommendation ITU-R P.453. An exception to this is that only the maps for May and August should be used for latitudes greater than 60° N or 60° S.