RECOMMENDATION ITU-R F.1333

ESTIMATION OF THE ACTUAL ELEVATION ANGLE FROM A STATION IN THE FIXED SERVICE TOWARDS A SPACE STATION TAKING INTO ACCOUNT ATMOSPHERIC REFRACTION

(Question ITU-R 163/9)

(1997)

The ITU Radiocommunication Assembly,

considering

a) that in some frequency sharing studies between the fixed service and space radiocommunication services, including fixed-satellite, broadcasting-satellite and space science services, it is necessary to estimate various factors related to propagation such as slant path attenuation by atmospheric gases and attenuation due to Fresnel zone blockage;

b) that the above attenuation is a function of the actual elevation angle as seen from a station in the fixed service towards a space station (geostationary or non-geostationary);

c) that it is necessary to establish a simplified calculation method to estimate the actual elevation angle towards a space station taking into account atmospheric refraction where the elevation angle of a space station is known only in free-space propagation conditions in vacuum;

d) that it is generally appropriate to estimate the actual elevation angle of a space station under the condition of the reference atmosphere for refraction given in Recommendation ITU-R P.369-6 (Geneva, 1994),

recommends

1 that the method for estimating the actual elevation angle as seen from a station in the fixed service towards a space station (geostationary or non-geostationary) under the condition of the reference atmosphere for refraction in Recommendation ITU-R P.369-6 (Geneva, 1994) as described in Annex 1 should be used where the elevation angle towards a space station is known only in free-space propagation conditions in vacuum (see Notes 1 and 2);

2 that for an atmospheric refractivity model other than the reference atmosphere for refraction as given in Recommendation ITU-R P.369-6 (Geneva, 1994), a different numerical formula should be derived corresponding to the specific atmospheric refractivity model (see Note 3).

NOTE 1 – This Recommendation can be used, for example, for estimation of slant path attenuation by atmospheric gases and Fresnel zone blockage attenuation required in Recommendation ITU-R F.1249.

NOTE 2 – Annex 1 to Recommendation ITU-R F.1108 gives an example method for calculating the elevation angle towards a non-geostationary space station in free-space propagation conditions, and Annex 2 to Recommendation ITU-R F.1249 gives a method for calculating the elevation angle towards a geostationary space station in free-space propagation conditions.

NOTE 3 – Annex 2 to Recommendation ITU-R SF.765 (and also Annex 2 to Recommendation ITU-R F.1249) gives an example of the numerical formulae for refraction corrections corresponding to the model of $N_0 = 400$ and $\Delta N = -68$ (for maximum refraction correction) and the model of $N_0 = 250$ and $\Delta N = -30$ (for minimum refraction correction), where N_0 is the sea-level radio refractivity and ΔN is the gradient (difference between sea level and 1 km altitude), which are used for determination of the separation angle between the fixed service antenna main beam direction and the direction towards the geostationary-satellite orbit (GSO) (or a specific orbital location in the GSO).

ANNEX 1

Actual elevation angle where the elevation angle of a space station is known only in free-space propagation conditions

1 Introduction

In some cases of sharing studies, the elevation angle of a space station (geostationary or non-geostationary), as seen from a fixed service station, is known only in free-space propagation conditions in vacuum. In such cases, it is necessary to estimate the actual elevation angle taking account of atmospheric refraction. This annex gives a calculation method for such a need.

2 Visibility of space station

Under an exponential model of atmosphere for refraction, such as in Recommendation ITU-R P.369-6 (Geneva, 1994), the radio beam emitted from a fixed service station (h (km) altitude above sea level and θ (degrees) elevation angle) is bent towards the Earth due to the effect of atmospheric refraction. This refraction correction, τ (degrees), can be evaluated by the following integral:

$$\tau = -\int_h^\infty \frac{n'(x)}{n(x) \cdot \tan\varphi} \, dx \qquad (1)$$

where φ is determined as follows on the basis of Snell's law in polar coordinates:

$$\cos\varphi = \frac{c}{(r+x) \cdot n(x)} \qquad (2)$$

$$c = (r + h) \cdot n(h) \cdot \cos\theta \qquad (3)$$

where:

r: Earth's radius (6 370 km)

$$n(x) = 1 + a \times \exp(-bx) \qquad (4)$$

with:

$a = 0.000315$

$b = 0.1361$.

The function $n(x)$ is the atmospheric refractive index at altitude x (km), and the values of a and b are for the reference atmosphere defined in Recommendation ITU-R P.369-6 (Geneva, 1994). In addition, $n'(x)$ is the derivative of $n(x)$, i.e., $n'(x) = -ab \times \exp(-bx)$.

The values of τ (h, θ) (degree) have been evaluated under the condition of the reference atmosphere and it was found that the following numerical formula gives a good approximation:

$$\tau(h, \theta) = 1 / [1.314 + 0.6437\,\theta + 0.02869\,\theta^2 + h\,(0.2305 + 0.09428\,\theta + 0.01096\,\theta^2) + 0.008583\,h^2] \qquad (5)$$

The above formula has been derived as an approximation for $0 \le h \le 3$ km and $\theta_m \le \theta \le 10°$, where θ_m is the angle at which the radio beam is just intercepted by the surface of the Earth and is given by:

$$\theta_m = -\arc\cos\left(\frac{r}{r+h}\;\frac{n(0)}{n(h)}\right) \qquad (6)$$

or, approximately, $\theta_m = -0.875\sqrt{h}$ degrees.

Equation (5) gives a reasonable approximation for $10° < \theta \le 90°$, too.

Now, assume that the elevation angle of a space station is θ_0 (degrees) under free-space propagation conditions. The minimum elevation angle from a fixed service station for which the radio beam is not intercepted by the surface of the Earth is θ_m. The refraction correction corresponding to θ_m is $\tau\,(h,\,\theta_m)$. Therefore, the space station is visible only when the following inequality holds:

$$\theta_m - \tau(h, \theta_m) \leq \theta_0 \tag{7}$$

3 Estimation of the actual elevation angle

When the inequality in equation (7) holds, the actual elevation angle, θ (degrees), taking account of atmospheric refraction can be calculated by solving the following equation:

$$\theta - \tau(h, \theta) = \theta_0 \tag{8}$$

We define that the solution of equation (8) is given as follows:

$$\theta = \theta_0 + \tau_s(h, \theta_0) \tag{9}$$

where the values of $\tau_s\,(h,\,\theta_0)$ are identical with those of $\tau\,(h,\,\theta)$, but are expressed as a function of θ_0.

The function $\tau_s\,(h,\,\theta_0)$ (degrees) can be closely approximated by the following numerical formula:

$$\begin{aligned}\tau_s\,(h, \theta_0) = 1 / [&1.728 + 0.5411\,\theta_0 + 0.03723\,\theta_0^2 + \\ &+ h\,(0.1815 + 0.06272\,\theta_0 + 0.01380\,\theta_0^2) + h^2\,(0.01727 + 0.008288\,\theta_0)]\end{aligned} \tag{10}$$

Now, the value of θ calculated by equation (9) is the actual elevation angle to be used in the estimation of various factors such as slant path attenuation and attenuation due to Fresnel zone blockage.

4 Summary of calculations

Step 1: The elevation angle of a space station in free-space propagation conditions in vacuum is designated as θ_0.

Step 2: By using equations (5) and (6), examine whether the inequality in equation (7) holds or not. If the answer is no, the satellite is not visible and, therefore, no further calculations are required.

Step 3: If the answer in Step 2 is yes, calculate θ by using equations (9) and (10). This is the actual elevation angle to be used for estimation of various factors such as slant path attenuation and attenuation due to Fresnel zone blockage.