RECOMMENDATION ITU-R S.1256

METHODOLOGY FOR DETERMINING THE MAXIMUM AGGREGATE POWER FLUX-DENSITY AT THE GEOSTATIONARY-SATELLITE ORBIT IN THE BAND 6 700-7 075 MHz FROM FEEDER LINKS OF NON-GEOSTATIONARY-SATELLITE SYSTEMS IN THE MOBILE-SATELLITE SERVICE IN THE SPACE-TO-EARTH DIRECTION

(Question ITU-R 206/4)

(1997)

The ITU Radiocommunication Assembly,

considering

a) that the band 6 700-7 075 MHz is allocated to the fixed-satellite service (FSS), in the space-to-Earth direction, on a primary basis, for the use by feeder links of non-geostationary satellite networks in the mobile-satellite service (MSS);

b) that the band 6 700-7 075 MHz is also allocated to the FSS in the Earth-to-space direction, on a primary basis, and the band 6 725-7 025 MHz is subject to the Allotment Plan of Appendix 30B of the Radio Regulations (RR) for geostationary satellite networks;

c) that, under No. S22.5A of the RR, the maximum aggregate power flux-density (pfd) produced within ± 5° of the geostationary-satellite orbit (GSO) by a non-geostationary satellite system in the FSS shall not exceed −168 dB(W/m^2) in any 4 kHz band;

d) that Resolution 115 of the World Radiocommunication Conference (Geneva, 1995) (WRC-95) invites ITU-R to establish a methodology to determine the maximum aggregate power flux-density at the GSO from a non-geostationary satellite network;

e) that non-geostationary satellite networks of the mobile-satellite service have orbital and transmission parameters available as specified in § A.3 vii) of Annex 1 to Resolution 46 (Rev.WRC-95),

recommends

1 that the methodology given in Annex 1 shall be followed to determine the maximum level of aggregate power flux-density (dB(W/m^2) in any 4 kHz band), at any location within ± 5° inclination of the GSO, from the feeder links of a non-geostationary satellite network operating in the band 6 700-7 075 MHz, in the space-to-Earth direction.

ANNEX 1

Methodology

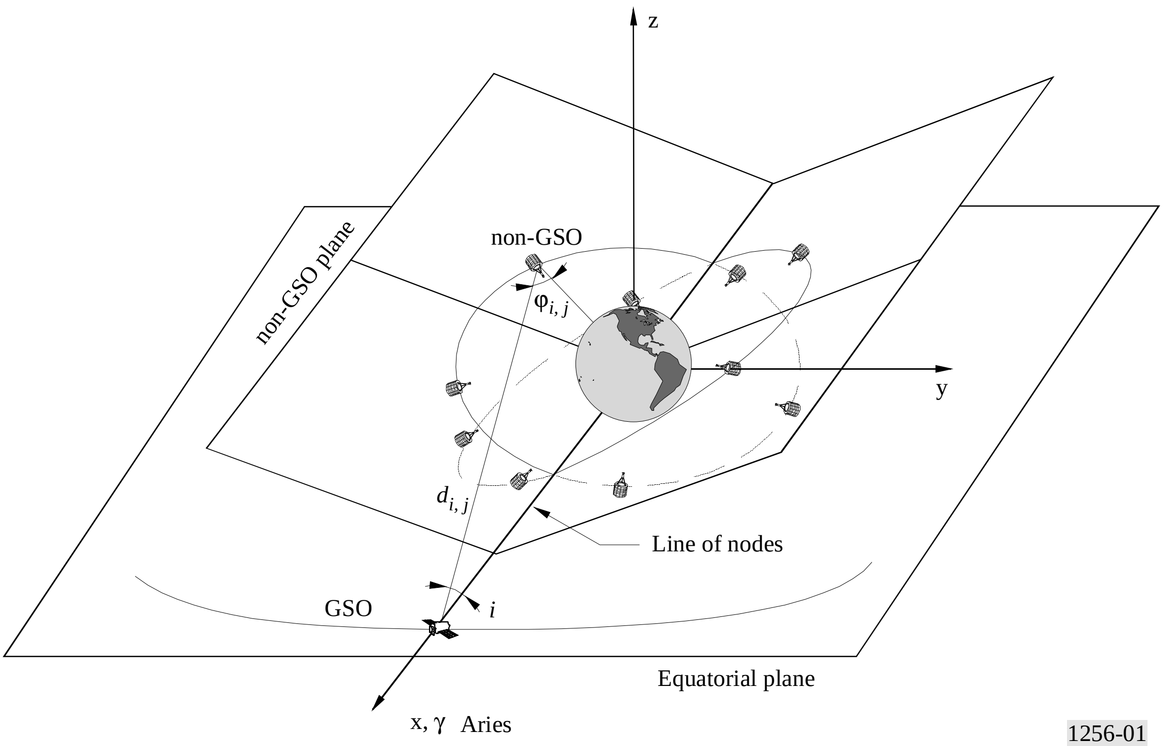
1 Description of methodology

To calculate the aggregate pfd from a non-geostationary orbiting satellite (non-GSO) network to a single test location at the GSO, computer modelling of the full non-GSO constellation and a test location at the GSO is needed.

Basically, noting that in an ordinary situation a GSO satellite will orbit the geostationary orbit with a period of about T_{GSO} = 24 h and that the orbital period of a non-GSO satellite ($T_{non\text{-}GSO}$) is not necessarily a submultiple of T_{GSO}, extensive time-consuming statistical simulations may be needed to assess the worst-case scenario that would lead to the maximum pfd level at the GSO location.

A simple and very much less time-consuming simulation can be performed to assess the maximum pfd at any GSO location. Instead of a real orbiting GSO satellite, a fixed test location at the GSO is considered whose orbital position is fixed with respect to a 0xyz Cartesian reference system (see Fig. 1) but not with respect to the rotating Earth reference system. With this in mind, since the non-GSO satellites have an orbital period $T_{non\text{-}GSO}$, it implies that the position of the non-GSO satellites, as seen from the fixed GSO test location (see Fig. 1), will be repeated at least once every orbital period $T_{non\text{-}GSO}$. Moreover, in the case where the non-GSO satellites are uniformly distributed on each orbital plane, the same geometrical disposition of the non-GSO satellites will be repeated with a period equal to $T_{non\text{-}GSO}/N_s$ (where N_s is the number of non-GSO satellites uniformly distributed on one plane). With these basic considerations, the aggregate pfd level (aggregated over the visible non-GSO satellites) at the GSO test location will have values that will be repeated within this period.

FIGURE 1
GSO/non-GSO constellation geometry to calculate pfd: $\Delta\Omega$ = 0°



The aggregate pfd can be calculated for each time step and a maximum aggregate pfd, for the chosen GSO test location, can be derived during the simulation period from T_0 to $T_0 + T_{non\text{-}GSO}/N_s$.

The value found for the particular GSO test location in Fig. 1 is not necessarily the maximum pfd level. In order to find the highest possible maximum aggregate pfd level, the same procedure must be repeated to the other GSO test locations by incrementing the angle $\Delta\Omega$ (see Fig. 2) between the GSO test location and the non-GSO line of nodes. This second iteration will be done for angles of $\Delta\Omega$ between 0° and $\Delta\Omega_{max} = 360°/N_p$, where N_p is the number of non-GSO satellite orbital planes. In cases where N_p is even (as per LEO-F and LEO-D) then $\Delta\Omega_{max} = 180°/N_p$.

The method can also apply to any non-GSO constellation which does not meet the orbital requirements as stated above (e.g. non-uniform satellite distribution, elliptical orbits). In such cases the time simulation will be performed for a period of time equal to the minimum repeatability period of the constellation configuration, which in many cases is equal to the constellation period $T_{non\text{-}GSO}$.

The § 2 reports all the basic equations needed to arrive at the aggregate pfd level from a given non-GSO network to a given test location at the GSO and Fig. 3 shows the flow chart for the software implementation of the methodology here described.

FIGURE 2

GSO/non-GSO constellation geometry to calculate pfd: $\Delta\Omega \neq 0°$

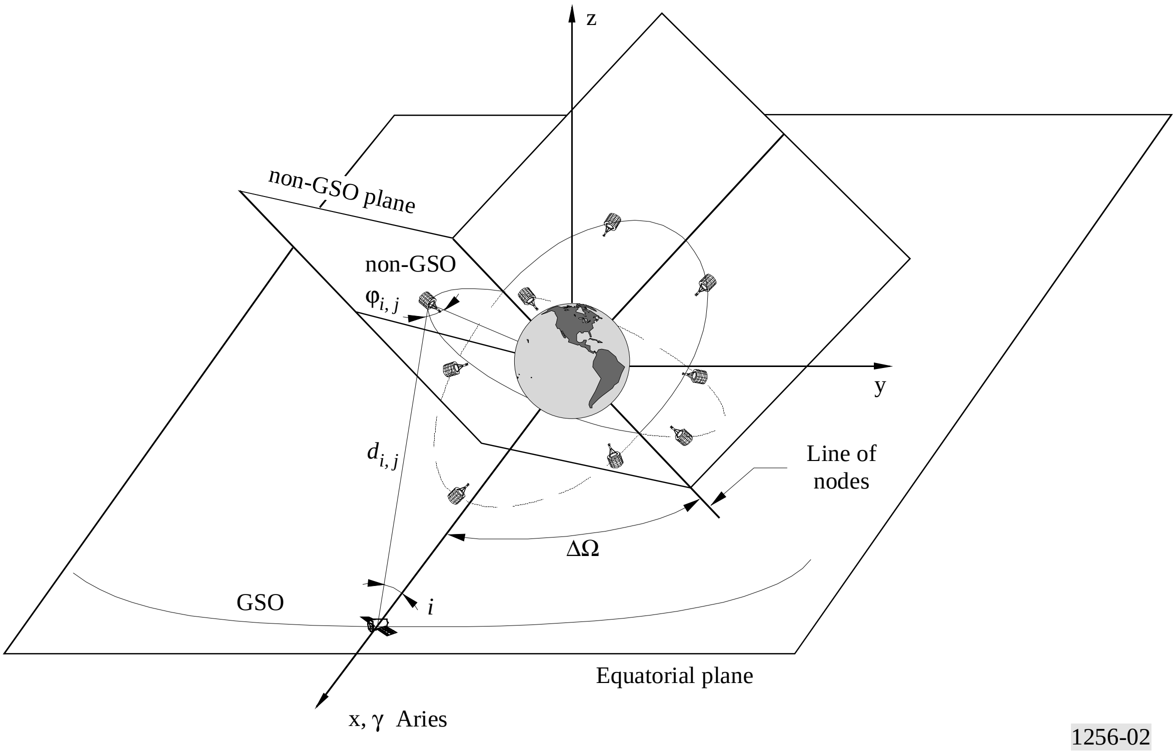
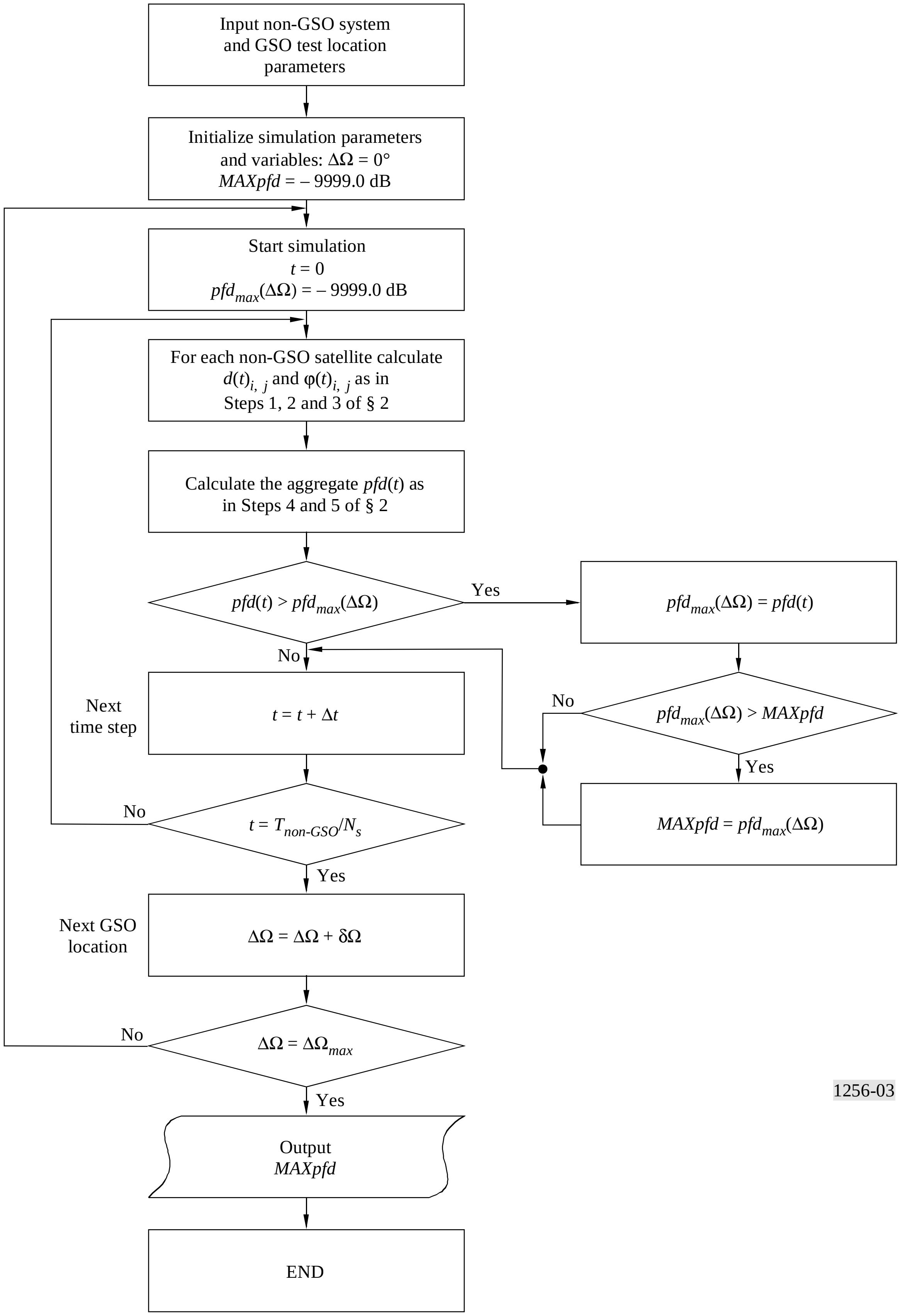


FIGURE 3

Methodology flow chart



2 Basic simulation steps

Step 1: Orbital position of the non-GSO satellites

FIGURE 4

Non-GSO orbit and reference systems

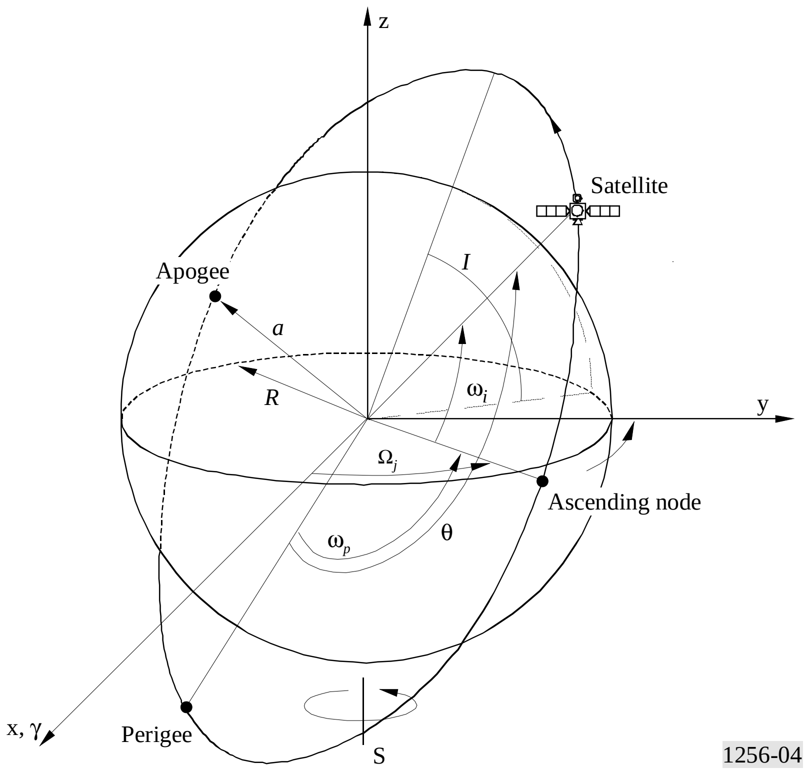


Figure 4 indicates the various parameters that are needed to fully assess at any instant the position of any non-GSO satellite on its orbit. These parameters are referenced in § A.3 vii) of Annex 1 to Resolution 46 (Rev.WRC-95):

a : semi-major axis, in case of a circular orbit the semi-major axis is constant and equal to the orbit radius;

I : inclination of the orbit relative to the equatorial plane

Ω_j : right ascension of the ascending node for the j-th orbital plane, measured counter-clockwise in the equatorial plane from the direction of the vernal equinox to the point where the satellite makes its south-to-north crossing of the equatorial plane ($0° \leq \Omega_j < 360°$)

ω_p : argument of perigee, for a circular orbit, the perigee is equal to the apogee and thus ω_p can be put to 0°

ω_i : initial phase angle of the i-th satellite in its orbital plane at reference time $t = 0$, measured from the point of ascending node ($0° \leq \omega_i < 360°$)

θ : true anomaly of the satellite.

For a constellation of non- GSO satellites using circular orbits, a and I will be constant and ω_p will be equal to zero, then the variation of the position of each satellite will be defined by Ω and θ.

For a circular orbit, the angular velocity of a satellite is constant, the angular position of a satellite is then equal to its true anomaly and is given by:

$$\theta(t)_{i,\,j} = \frac{360°}{T}\ t + \omega_{i,\,j} \tag{1}$$

for $i = 1$ to N_s and $j = 1$ to N_p where N_s is the number of satellites in each orbital plane, N_p is the number of orbital planes and T is the orbital period in seconds given by:

$$T = 2\,\pi\ \sqrt{a^3/\mu} \tag{2}$$

where μ is the geocentric gravitational constant and is equal to 3.986 E14($m^3 s^{-2}$).

The various values of Ω_j will depend on the geometry of the constellation and will be given in the set of elements found in § A.3 vii) of Annex 1 to Resolution 46 (Rev.WRC-95). The same principal applies to the values of $\omega_{i,\,j}$.

Knowing for each satellite its true anomaly $\theta_{i,\,j}(t)$ and the right ascension of its ascending node Ω_j, its geocentric coordinates are given by:

$$x(t)_{i,\,j} = a\left[\cos\Omega_j\ \cos\theta(t)_{i,\,j} - \cos I\ \sin\Omega_j\ \sin\theta(t)_{i,\,j}\right] \tag{3}$$

$$y(t)_{i,\,j} = a\left[\sin\Omega_j\ \cos\theta(t)_{i,\,j} + \cos I\ \cos\Omega_j\ \sin\theta(t)_{i,\,j}\right] \tag{4}$$

$$z(t)_{i,\,j} = a\left[\sin I\ \sin\theta(t)_{i,\,j}\right] \tag{5}$$

The position of the GSO test location with respect to the line of nodes of the non-GSO constellation is determined by ΔΩ (see § 1). Hence, in equations (3), (4) and (5) $\Omega_j = \Omega_{j,\,0} + \Delta\Omega$, where ΔΩ ranges from 0 to $\Delta\Omega_{max}$ (see § 1) and $\Omega_{j,\,0} = \Omega_j$ for $\Delta\Omega = 0$.

Step 2: Distance between the non-GSO satellite and the test location at the GSO

x_{GSO}, y_{GSO} and z_{GSO} are the geocentric coordinates of the GSO test location given by:

$$x_{GSO} = a_{GSO} \cdot \cos I_{GSO} \tag{6}$$

$$y_{GSO} = 0 \tag{7}$$

$$z_{GSO} = a_{GSO} \cdot \sin I_{GSO} \tag{8}$$

where:

a_{GSO}: semi-major axis of the geostationary orbit (42 164 km)

I_{GSO}: inclination of the geostationary orbit ($-5° \le I_{GSO} \le 5°$).

These equations remain constant during the simulation since it is simpler to vary Ω_j in equations (3), (4) and (5) by incrementing the offset ΔΩ.

The distance between a non-GSO satellite and the GSO test location can then be calculated using Pythagora's theorem:

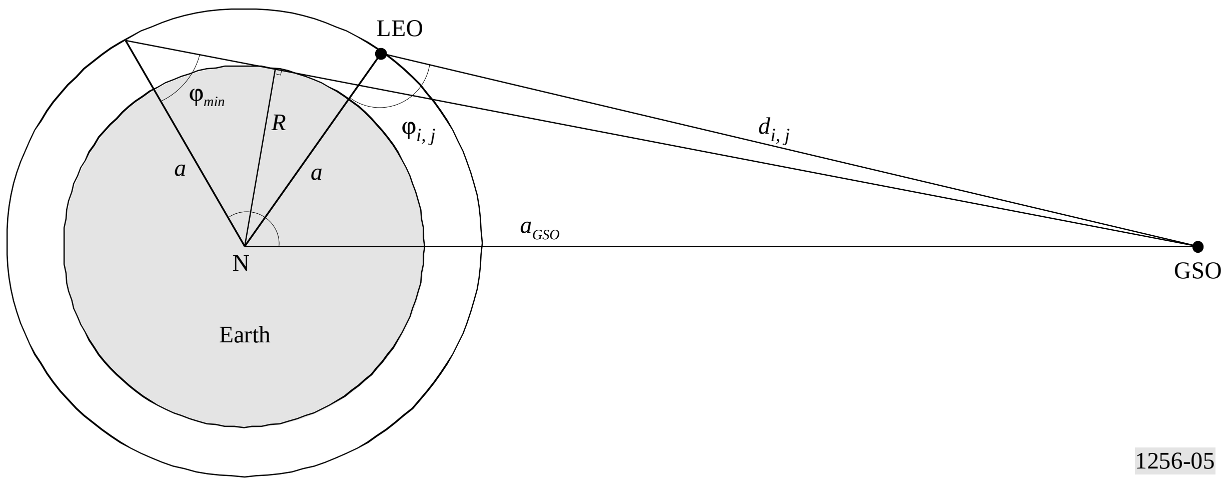
$$d(t)_{i,\,j} = \sqrt{\left(x_{GSO} - x(t)_{i,\,j}\right)^2 + y(t)_{i,\,j}^2 + \left(z_{GSO} - z(t)_{i,\,j}\right)^2} \tag{9}$$

Step 3: Calculation of the non-GSO antenna off-axis angle to the test location at the GSO

Fig. 5 shows the geometry, represented in a two-dimensional diagram, of the non-GSO satellite off-axis angle relative to the test location at the GSO.

FIGURE 5

Calculation of $\varphi_{i,j}$



The non-GSO antenna off-axis angle can be determined using Carnot's theorem (known also as the "cosine" theorem):

$$\varphi(t)_{i,j} = \arccos\left(\frac{a^2 + d(t)^2_{i,j} - a^2_{GSO}}{2\,a\,d(t)_{i,j}}\right) \tag{10}$$

Step 4: Calculation of the non-GSO off-axis antenna gain toward the test location at the GSO

Taken the off-axis angle calculated in equation (10), for each visible satellite it is possible to calculate the off-axis antenna gain $G(\varphi(t)_{i,j})$. However, as seen in Fig. 5, this is only necessary if $\varphi(t)_{i,j}$ is higher than a minimum value of φ_{min} given by:

$$\varphi_{min} = \arcsin\left(R/a\right) \tag{11}$$

Step 5: Calculation of the aggregate pfd level towards the GSO test location

The aggregate pfd level can be expressed as:

$$pfd(t) = \frac{P_{peak,\,4\,kHz}}{4\pi} \sum_{i \cdot j = 1 \text{ to } N(t)_v} \frac{G\left(\varphi(t)_{i,j}\right)}{d(t)^2_{i,j}} \qquad \text{for} \quad \varphi(t)_{i,j} \ \geq \ \varphi_{min} \tag{12}$$

where:

$P_{peak,\,4\,kHz}$: peak power in the worst 4 kHz band at the input of the non-GSO satellite antenna, assumed constant and equal for all the non-GSO satellites

$N(t)_v$: number of visible non-GSO satellites from the GSO test location at the time *t*.

3 Total number of simulation steps and simulation step increments

Two simulation steps are needed to perform the calculation of the maximum aggregate pfd toward the GSO from a non-GSO network, the time step Δt and the right ascension step $\delta\Omega$.

Since there is no direct in-line interference from the non-GSO satellites (either they use isoflux low gain antenna or interference comes from the side lobes of the transmitting antenna), various simulations (for LEO-D and LEO-F) have shown that an angular step of no more than 0.5° is sufficient to get valid results. The calculation steps will then be:

$$\Delta t = \frac{T\ (\mathrm{s}) \times 0.5°}{360°}$$

$$\delta\Omega = 0.5°$$

The total simulation time for each GSO test location and the total number of GSO test locations are given in § 1.