RECOMMENDATION ITU-R S.1647

Methodology to determine the worst-case interference among certain types of non-GSO FSS systems in situations where no in-line interference exists

(Question ITU-R 231/4)

(2003)

The ITU Radiocommunication Assembly,

considering

a) that, by adopting equivalent power flux-density (epfd) limits in certain frequency bands in Article 22 of the Radio Regulations, the introduction of FSS systems employing non-GSO satellites has been facilitated;

b) that the use of the certain types of non-GSO orbit (see Note 1) typically results in the active arc being limited to distinct "windows" in the sky, and that these windows are often distinctly separate from the windows of other certain types of non-GSO orbit (see Note 1) systems thereby ensuring that no in-line interference exists;

c) that in-line interference may also be avoided when the "windows" overlap, if it is possible to adjust the relative phasing of the two systems such that satellites from different systems do not simultaneously appear in the overlapping window;

d) that it could be useful to determine whether in-line events occur or not in order to study the sharing between non-GSO FSS systems;

e) that, in addition, it could be useful to identify the worst-case interference levels that occur when there are no in-line events;

f) that, if worst-case interference is unacceptable, a full statistical characterization of the interference is required,

recommends

1 that the methodology in Annex 1 to be used by administrations for the calculation of worst-case co-directional interference between certain types of non-GSO (see Note 1) systems considered here in situations where no in-line interference exists;

2 that the methodology in Annex 3 to be used by administrations to confirm that in-line events do not occur between certain types of non-GSO (see Note 1) systems concerned.

NOTE 1 – The certain types of non-GSO systems covered in this Recommendation are those whose orbits fall into the following categories:

– an orbit with an eccentricity of at least 0.05, an inclination between 35° and 145°, an apogee of at least 18 000 km, and a period that is the geosynchronous period (23 h 56 min) multiplied by m/n where m and n are integers (the ratio m/n may be less than, equal to, or greater than one); or

– a circular orbit (with an eccentricity of at most 0.005), with the geosynchronous period (23 h 56 min) and an inclination between 35° and 145°.

Annex 1

Methodology to calculate the worst-case co-directional interference between certain types of non-GSO FSS systems in situations where no in-line interference exists

The following methodology should be used to calculate the interference between non-GSO FSS systems operating co-frequency, where no in-line interference situations exist. This methodology is limited to co-directional transmission case.

The calculations shown in this Annex are to be performed for values of time, *t*, which generate all possible combinations of orbital locations of operating satellites as per Annex 2. The calculations are to be performed in accordance with the following sequence;

– to determine whether in-line events occur (see Annex 3);

– to identify the worst-case interference levels that occur when there are no in-line events.

Because certain types of non-GSO systems have repeating ground tracks and the limited portions of them are the active arcs, the number of these combinations is significantly smaller than that of interference between LEO/MEO type non-GSO systems.

In this Annex, the methodology to calculate the interference between one type of non-GSO-satellite system α and the other type of non-GSO-satellite system β is described.

1 Data concerning non-GSO system α

The following information is required for the calculation of interference between the non-GSO systems.

Earth-to-space transmissions of non-GSO system α

$\theta_{U\text{-}min\,(NGSO\alpha)}$: minimum angular separation at the active earth station of non-GSO system α between the line-of-sight (LoS) to its associated satellite and the LoS of the satellite of non-GSO system β (degrees) (see Fig. 2a)).

$\varphi_{U\text{-}min\,(NGSO\alpha)}$: minimum angular separation at an active satellite of non-GSO system α between the LoS to the earth station of non-GSO system β and the LoS to the associated earth station of non-GSO system α (degrees) (see Fig. 2b)). For the transmitting earth station antenna, Recommendation ITU-R S.465 or ITU-R S.580 provides reference in this respect.

$PFD_{U\text{-}NGSO\alpha\text{-}max}$: maximum pfd at the satellite of non-GSO system α caused by transmissions from the earth station of non-GSO system α (dB(W/(m^2 · Hz))).

$PFD_{U\text{-}NGSO\alpha\text{-}\beta}$: maximum pfd at the satellite of non-GSO system β caused by transmissions from the earth station of non-GSO system α (dB(W/(m^2 · Hz))).

$N_{U\text{-}NGSO\alpha\text{-}ES}$: maximum number of co-frequency earth stations of non-GSO system α transmitting towards the same satellites. (An indication of the number of such earth stations as a function of the percentage of time is needed.)

These values mentioned above can be obtained from the methodology described in Annex 2.

Receiving satellite sensitivity of non-GSO FSS system α. (The information required for the calculation of interference from non-GSO system β to non-GSO system α.)

$G_{NGSO\alpha\text{-}S\text{-}max}$: the assumed maximum gain of the receiving satellite of non-GSO system α in a direction of the earth station of non-GSO system α (dBi).

$G_{NGSO\alpha\text{-}S\text{-}\beta}$: the assumed maximum off-axis gain of the receiving satellite of non-GSO system α in the direction corresponding to the minimum angular separation ($\varphi_{U\text{-}min\text{-}(NGSO\alpha)}$) of the earth station of non-GSO system β (dBi). For the receiving satellite of non-GSO FSS system, Recommendation ITU-R S.672 provides a reference in this respect.

$T_{U\text{-}NGSO\alpha}$: assumed clear-sky receive system noise temperature (including receive antenna noise) of the receiving satellite of non-GSO system α (K).

Space-to-Earth transmissions of non-GSO system α

$\theta_{D\text{-}min(NGSO\alpha)}$: minimum angular separation at the earth station of non-GSO system α between the LoS to its associated satellite and the LoS to the transmitting satellite of non-GSO system β (degrees) (see Fig. 1b)).

$\varphi_{D\text{-}min(NGSO\alpha)}$: minimum angular separation at an active satellite of non-GSO system α between the LoS to an earth station of non-GSO system β and the LoS to the associated earth station of non-GSO system α (degrees) (see Fig. 1a)). For the transmitting space station antenna, Recommendation ITU-R S.672 provides a reference in this respect.

$PFD_{D\text{-}NGSO\alpha\text{-}max}$: maximum pfd at the location on the Earth's surface of the earth station of non-GSO system α caused by transmissions from the satellite of non-GSO system α in the constellation (dB(W/(m^2 · Hz))).

$PFD_{D\text{-}NGSO\alpha\text{-}\beta}$: maximum pfd at the location on the Earth's surface of the earth station of non-GSO system β caused by transmissions from the satellite of non-GSO system α in the constellation (dB(W/(m^2 · Hz))).

$N_{D\text{-}NGSO\alpha\text{-}S}$: maximum number of co-frequency satellites of non-GSO system α transmitting towards the same geographic region of the Earth. (An indication of the number of such satellites as a function of the percentage of time is needed.)

These values mentioned above can be obtained from the methodology described in Annex 2.

Receiving earth station (ES) sensitivity of non-GSO FSS system α. (The information required for the calculation of interference from non-GSO system β to non-GSO system α.)

$G_{NGSO\alpha\text{-}ES\text{-}max}$: the assumed maximum gain of the receiving earth station of non-GSO system α in a direction corresponding to the satellite of non-GSO system α (dBi).

$G_{NGSO\alpha\text{-}ES\text{-}\beta}$: the assumed maximum off-axis gain of the receiving earth station of non-GSO system α in the direction corresponding to the minimum angular separation ($\theta_{D\text{-}min(NGSO\beta)}$) of the satellite of non-GSO system β when it is actively transmitting (dBi). For the receiving earth station of non-GSO FSS system, Recommendation ITU-R S.465 or ITU-R S.580 provides a reference in this respect.

$T_{D\text{-}NGSO\alpha}$: assumed clear-sky receive system noise temperature (including receive antenna noise) of the receiving earth station of non-GSO system α. To err on the conservative side this need not include degradations caused to the overall link resulting from the uplink or from other internal or external sources of interference (K).

2 Data concerning non-GSO system β

The following information is required for the calculation of interference between the non-GSO systems.

Receive satellite sensitivity of non-GSO system β. (The information required for the calculation of interference from non-GSO FSS system α to non-GSO system β.)

$G_{NGSO\beta\text{-}S\text{-}max}$: the assumed maximum gain of the satellite of non-GSO system β in a direction of the earth station of non-GSO system β (dBi).

$G_{NGSO\beta\text{-}S\text{-}\alpha}$: the assumed maximum off-axis gain of the satellite of non-GSO system β in the direction corresponding to the minimum angular separation ($\varphi_{U\text{-}min(NGSO\beta)}$) of the earth station of non-GSO system α (dBi). For the receiving satellite of a non-GSO FSS system, Recommendation ITU-R S.672 provides a reference in this respect.

$T_{U\text{-}NGSO\beta}$: assumed clear-sky receive system noise temperature (including receive antenna noise) of the receiving satellite of non-GSO system β (K).

Earth-to-space transmissions of non-GSO system β

$\theta_{U\text{-}min(NGSO\beta)}$: minimum angular separation at the earth stations of non-GSO system β between the LoS to its associated satellite and the LoS to the receiving satellite of non-GSO system α (degrees) (see Fig. 2b)).

$\varphi_{U\text{-}min(NGSO\beta)}$: minimum angular separation at the satellite of non-GSO system β between the LoS to the earth station of non-GSO system α and the LoS to the associated earth station of non-GSO system β (degrees) (see Fig. 2a)). For the transmitting earth station antenna, Recommendation ITU-R S.465 or ITU-R S.580 provides a reference in this respect.

$PFD_{U\text{-}NGSO\beta\text{-}max}$: maximum pfd at the satellite of non-GSO system β caused by transmissions from the earth station of non-GSO system β (dB(W/(m$^2 \cdot$ Hz))).

$PFD_{U\text{-}NGSO\beta\text{-}\alpha}$: maximum pfd at the satellite of non-GSO system α caused by transmissions from the earth station of non-GSO system β (dB(W/(m$^2 \cdot$ Hz))).

$N_{U\text{-}NGSO\beta\text{-}ES}$: maximum number of co-frequency earth stations of non-GSO system β transmitting towards the same satellites. (An indication of the number of such earth stations as a function of the percentage of time is needed.)

Receive earth station sensitivity of non-GSO system β. (The information required for the calculation of interference from the non-GSO system α to non-GSO FSS system β.)

$G_{NGSO\beta\text{-}ES\text{-}max}$: the assumed maximum gain of the earth station of non-GSO system β in the direction corresponding to the satellite of non-GSO system β (dBi).

$G_{NGSO\beta\text{-}ES\text{-}\alpha}$: the assumed maximum off-axis gain of the earth station of non-GSO system β in the direction corresponding to the minimum angular separation ($\theta_{D\text{-}min(NGSO\alpha)}$) of the satellite of non-GSO system α when it is actively transmitting (dBi). For the receiving earth station of non-GSO FSS system, Recommendation ITU-R S.465 provides a reference in this respect.

$T_{D\text{-}NGSO\beta}$: assumed clear-sky receive system noise temperature (including receive antenna noise) of the non-GSO system β downlink. To err on the conservative side this need not include degradations caused to the overall link resulting from the uplink or from other internal or external sources of interference (K).

Space-to-Earth transmissions of non-GSO system β

$\theta_{D\text{-}min(NGSO\beta)}$: minimum angular separation at the earth station of non-GSO system β between the LoS to its associated satellite and the LoS in the direction to the transmitting satellite of non-GSO system α and its associated satellite (degrees) (see Fig. 1a)).

$\varphi_{D\text{-}min(NGSO\beta)}$: minimum angular separation at an active satellite of non-GSO system β between the LoS to the earth station of non-GSO system α and the LoS to the associated earth station of non-GSO system β (degrees) (see Fig. 1b)). For the transmitting space station antenna, Recommendation ITU-R S.672 provides a reference in this respect.

$PFD_{D\text{-}NGSO\beta\text{-}max}$: maximum pfd at the location on the Earth's surface of the earth station of non-GSO system β caused by transmissions from the satellite in the constellation of non-GSO system β (dB(W/(m^2 · Hz))).

$PFD_{D\text{-}NGSO\beta\text{-}\alpha}$: maximum pfd at the location on the Earth's surface of non-GSO system α caused by transmissions from the satellite in the constellation of non-GSO system β (dB(W/(m^2 · Hz))).

$N_{D\text{-}NGSO\beta\text{-}S}$: maximum number of co-frequency satellites of non-GSO system β transmitting towards the same geographic region of the Earth, as well as an indication of the number of such satellites as a function of the percentage of time.

These values mentioned above can be obtained from the methodology described in Annex 2.

3 Interference geometry

Figure 1 shows the downlink interference geometry described in Section 2. Fig. 1a) shows the interference geometry for the calculation of the interference from the satellite of non-GSO system α to the receive earth station of non-GSO system β. Fig. 1b) shows the interference geometry for the calculation of the interference from the satellite of non-GSO system β to the receiving earth station of non-GSO system α.

FIGURE 1

The interference geometry for calculation of interference between non-GSO system α and non-GSO system β (downlink)

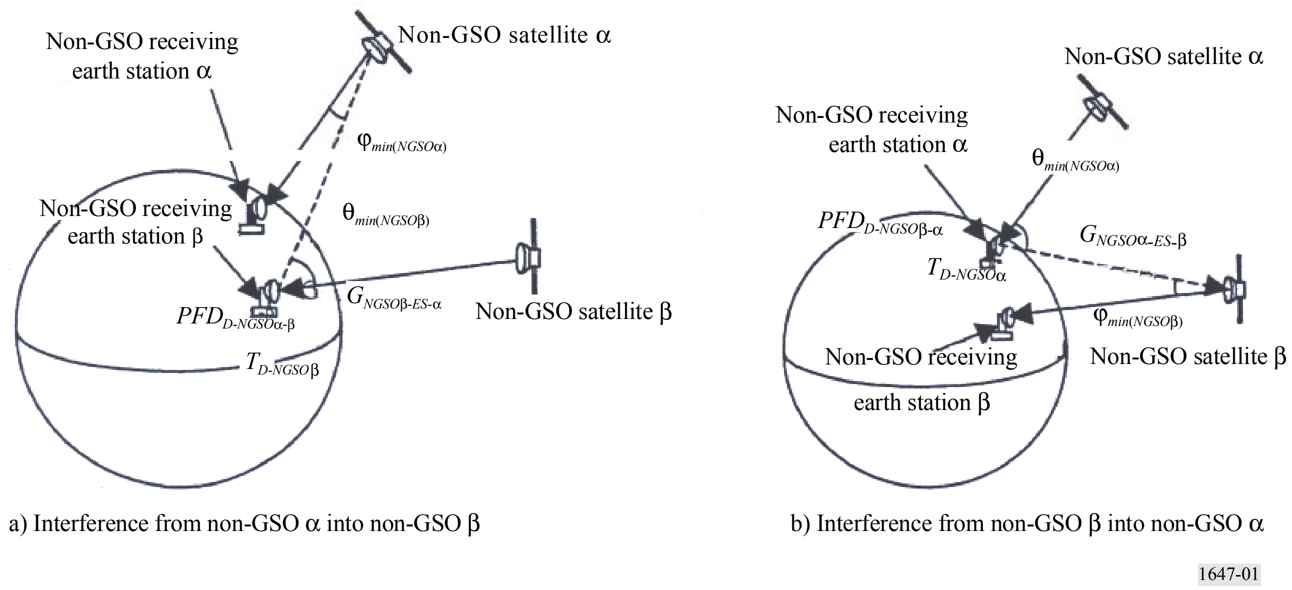
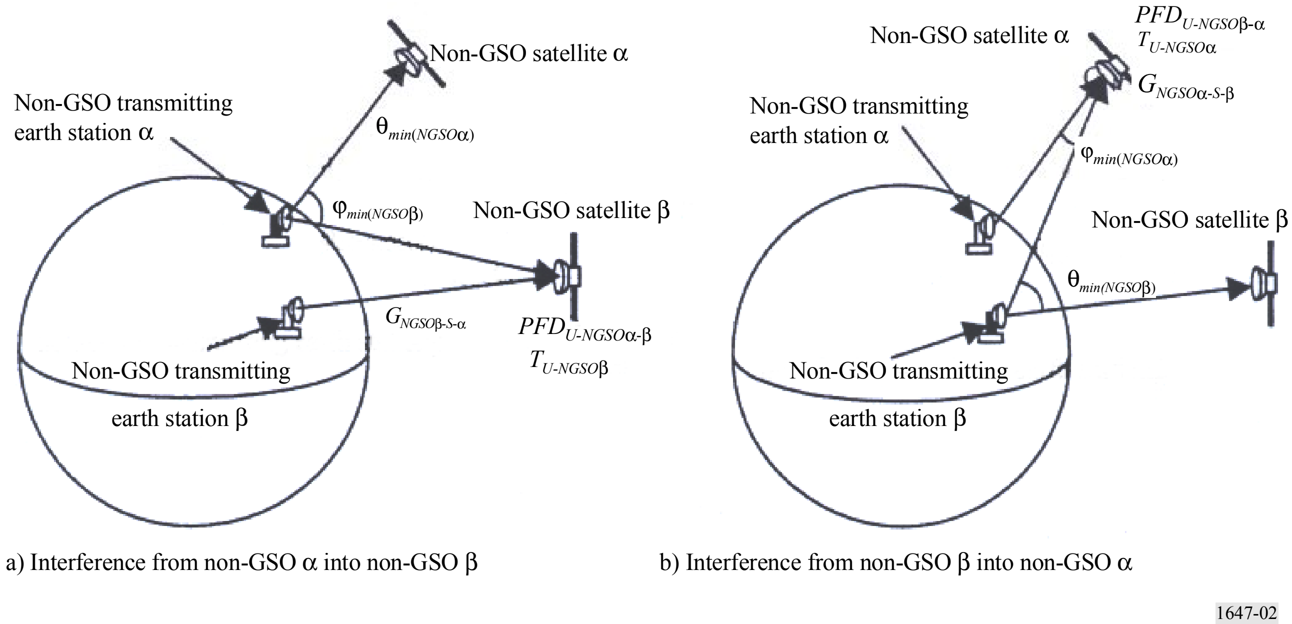


Figure 2 shows the uplink interference geometry described in Section 2. Fig. 2a) shows the interference geometry for the calculation of the interference from the earth station of non-GSO system α to the receive satellite of non-GSO system β. Fig. 2b) shows the interference geometry for the calculation of the interference from the earth station of non-GSO system β to the receiving satellite of non-GSO system α.

FIGURE 2

The interference geometry for calculation of interference between non-GSO system α and non-GSO system β (uplink)



4 Calculation of downlink interference from the non-GSO system α into the non-GSO system β

Step A1_β1(d): Calculate the maximum interfering signal power spectral density ($I_{1\text{-}NGSO\alpha\text{-}ES}$) (dB(W/Hz)) from a satellite of non-GSO system α at the earth station antenna input of non-GSO system β:

$$I_{1\text{-}NGSO\alpha\text{-}ES} = PFD_{D\text{-}NGSO\alpha\text{-}\beta} + G_{NGSO\beta\text{-}ES\text{-}\alpha} + 10\log\left(\frac{\lambda^2}{4\pi}\right) \tag{1}$$

where λ is the wavelength (m).

Step A1_β2(d): Calculate the wanted carrier power density ($C_{NGSO\beta\text{-}ES}$) (dB(W/Hz)) at the earth station antenna input of non-GSO system β:

$$C_{NGSO\beta\text{-}ES} = PFD_{D\text{-}NGSO\beta\text{-}max} + G_{NGSO\beta\text{-}ES\text{-}max} + 10\log\left(\frac{\lambda^2}{4\pi}\right) \tag{2}$$

Step A1_β3(d): Calculate the carrier-to-interference ratio ($C_{NGSO\beta\text{-}ES}/I_{1\text{-}NGSO\alpha\text{-}ES}$) from each of the satellites of non-GSO system α, i.e. $10^{0.1(C\text{-}I)}$ where C and I (dB(W/Hz)) derived from equations (1) and (2).

Step A1_β4(d): Calculate the aggregate carrier-to-interference ratio ($C_{NGSO\beta\text{-}ES}/I_{NGSO\alpha\text{-}ES}$) from the constellation of satellites of non-GSO system α:

$$\begin{aligned}(C_{NGSO\beta\text{-}ES}/I_{NGSO\alpha\text{-}ES})^{-1} &= (C_{NGSO\beta\text{-}ES}/I_{1\text{-}NGSO\alpha\text{-}ES})^{-1} \\ &+ \cdots + (C_{NGSO\beta\text{-}ES}/I_{N_{D\text{-}NGSO\alpha\text{-}S}\text{-}NGSO\alpha\text{-}ES})^{-1}\end{aligned} \tag{3}$$

$N_{D\text{-}(NGSO\alpha)\text{-}S}$ is the number of satellites in the non-GSO FSS system α.

5 Calculation of downlink interference from the non-GSO system β into the non-GSO FSS system α

Step A1_α1(d): Calculate the maximum interfering signal power spectral density ($I_{1\text{-}NGSO\beta\text{-}ES}$) (dB(W/Hz)) from a non-GSO satellite β at the receiving earth station of non-GSO system α antenna input:

$$I_{1\text{-}NGSO\beta\text{-}ES} = PFD_{D\text{-}NGSO\beta\text{-}\alpha} + G_{NGSO\alpha\text{-}ES\text{-}\beta} + 10\log\left(\frac{\lambda^2}{4\pi}\right) \tag{4}$$

where λ is the wavelength (m).

Step A1_α2(d): Calculate the wanted carrier power density ($C_{NGSO\alpha\text{-}ES}$) (dB(W/Hz)) at the receiving earth station antenna input of non-GSO system α:

$$C_{NGSO\alpha\text{-}ES} = PFD_{D\text{-}NGSO\alpha\text{-}max} + G_{NGSO\alpha\text{-}ES\text{-}max} + 10\log\left(\frac{\lambda^2}{4\pi}\right) \tag{5}$$

Step A1_α3(d): Calculate the carrier-to-interference ratio ($C_{NGSO\alpha\text{-}ES}/I_{1\text{-}NGSO\beta\text{-}ES}$) from each of the satellite of non-GSO system β, i.e. $10^{0.1(C\text{-}I)}$ where C and I are derived from Tables 4 and 5.

Step A1_α4(d): Calculate the aggregate carrier-to-interference ratio ($C_{NGSO\alpha\text{-}ES}/I_{NGSO\beta\text{-}ES}$) from the constellation of satellites of non-GSO system β:

$$(C_{NGSO\alpha\text{-}ES}/I_{NGSO\beta\text{-}ES})^{-1} = (C_{NGSO\alpha\text{-}ES}/I_{1\text{-}NGSO\beta\text{-}ES})^{-1} + \cdots + (C_{NGSO\alpha\text{-}ES}/I_{N_{D\text{-}NGSO\beta\text{-}S}\text{-}NGSO\beta\text{-}ES})^{-1} \quad (6)$$

$N_{D\text{-}(NGSO\beta)\text{-}S}$ is the number of satellites in the non-GSO FSS system β.

6 Calculation of uplink interference from the non-GSO system α into the non-GSO system-β

Step A1_β1(u): Calculate the maximum interfering signal power spectral density ($I_{1\text{-}NGSO\alpha\text{-}S}$) from the earth station of non-GSO system α at the satellite antenna input of non-GSO system β:

$$I_{1\text{-}NGSO\alpha\text{-}S} = PFD_{U\text{-}NGSO\alpha\text{-}\beta} + G_{NGSO\beta\text{-}S\text{-}\alpha} + 10\log\left(\frac{\lambda^2}{4\pi}\right) \quad (7)$$

where λ is the wavelength (m).

Step A1_β2(u): Calculate the wanted carrier power density ($C_{NGSO\beta\text{-}S}$) (dB(W/Hz)) at the satellite antenna input of non-GSO system β:

$$C_{NGSO\beta\text{-}S} = PFD_{U\text{-}NGSO\beta\text{-}max} + G_{NGSO\beta\text{-}S\text{-}max} + 10\log\left(\frac{\lambda^2}{4\pi}\right) \quad (8)$$

Step A1_β3(u): Calculate the carrier-to-interference ratio ($C_{NGSO\beta\text{-}S}/I_{1\text{-}NGSO\alpha\text{-}S}$) from the earth stations of non-GSO system α, i.e. $10^{0.1(C\text{-}I)}$ where C and I are derived from equations (7) and (8).

Step A1_β4(u): Calculate the total entry carrier-to-interference ratio ($C_{NGSO\beta\text{-}S}/I_{NGSO\alpha\text{-}S}$) from the earth station of non-GSO system α:

$$(C_{NGSO\beta\text{-}S}/I_{NGSO\alpha\text{-}S})^{-1} = (C_{NGSO\beta\text{-}S}/I_{1\text{-}NGSO\alpha\text{-}S})^{-1} + \cdots + (C_{NGSO\beta\text{-}S}/I_{N_{U\text{-}NGSO\alpha\text{-}ES}\text{-}NGSO\alpha\text{-}S})^{-1} \quad (9)$$

$N_{U\text{-}(NGSO\alpha)\text{-}ES}$ is the number of interfering earth stations in the non-GSO FSS system α.

7 Calculation of uplink interference from the non-GSO system β into the non-GSO system α

Step A1_α1(u): Calculate the maximum interfering signal power spectral density ($I_{1\text{-}NGSO\beta\text{-}S}$) (dB(W/Hz)) from an earth station of non-GSO system β at the satellite antenna input of non-GSO FSS system α:

$$I_{1\text{-}NGSO\beta\text{-}S} = PFD_{U\text{-}NGSO\beta\text{-}\alpha} + G_{NGSO\alpha\text{-}S\text{-}\beta} + 10\log\left(\frac{\lambda^2}{4\pi}\right) \quad (10)$$

where λ is the wavelength (m).

Step A1_α2(u): Calculate the wanted carrier power density ($C_{NGSO\alpha\text{-}S}$) (dB(W/Hz)) at the satellite antenna input of non-GSO system α:

$$C_{NGSO\alpha\text{-}S} = PFD_{U\text{-}NGSO\alpha\text{-}max} + G_{NGSO\alpha\text{-}S\text{-}max} + 10 \log \left(\frac{\lambda^2}{4\pi} \right) \qquad (11)$$

Step A1_α3(u): Calculate the carrier-to-interference ratio ($C_{NGSO\alpha\text{-}S}/I_{1\text{-}NGSO\beta\text{-}S}$) from the earth station of non-GSO system β, i.e. $10^{0.1(C-I)}$ where C and I are derived from equations (10) and (11).

Step A1_α4(u): Calculate the aggregate carrier-to-interference ratio ($C_{NGSO\alpha\text{-}S}/I_{NGSO\beta\text{-}S}$) from all interfering earth stations of non-GSO system β:

$$\begin{aligned}(C_{NGSO\alpha\text{-}S}/I_{NGSO\beta\text{-}S})^{-1} &= (C_{NGSO\alpha\text{-}S}/I_{1\text{-}NGSO\beta\text{-}S})^{-1} \\ &+ \cdots + (C_{NGSO\alpha\text{-}S}/I_{N_{U\text{-}NGSO\beta\text{-}ES}\text{-}NGSO\beta\text{-}S})^{-1}\end{aligned} \qquad (12)$$

$N_{U\text{-}(NGSO\beta)\text{-}ES}$ is the number of interfering earth stations in the non-GSO FSS system β.

8 Example of the calculation of the interference from the non-GSO FSS system α into the non-GSO FSS system β

The orbit parameters non-GSO FSS system α employs are assumed in Table 1.

TABLE 1

The example orbit parameters assumed for non-GSO system α

Inclination angle	42.5°
Right ascension	25°
Semi-major axis	42 164 km
Eccentricity	0.21
Argument of perigee	270°
Initial phase angle	270°
Active arc	Between 3.5 h before the apogee and 4.5 h after the apogee
Number of satellites	3
Ground track	Three satellites follow a single repeating ground track

The orbit parameters non-GSO FSS system β employs are assumed in Table 2.

TABLE 2

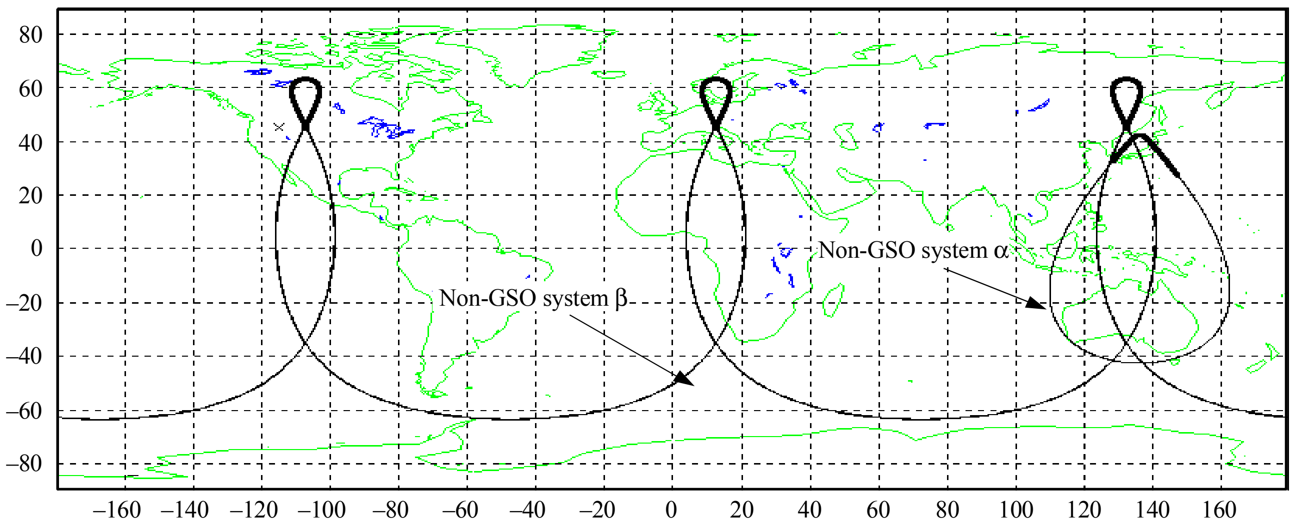
The example orbit parameters assumed for non-GSO system β

Inclination angle	63.4°
Right ascension	15°
Semi-major axis	32 170 km
Eccentricity	0.53
Argument of perigee	270°
Initial phase angle	238.9°
Active arc	Above latitude 45° (Loopus hand-over is adopted)
Number of satellites	6

The ground tracks of non-GSO FSS system α and non-GSO FSS system β are shown in Fig. 3.

FIGURE 3

Ground tracks of non-GSO system α and non-GSO system β



Note – Active service arcs are shown in bold.

In this calculation example, orbital locations of the satellites in the two non-GSO systems are compared with 30 min time-spacing in their active arcs. As the active arcs of each non-GSO system have an 8 h duration, 289 (= 17 × 17) calculations are enough to find the worst case. This is a considerably smaller number than that of interference calculations between LEO/MEO type non-GSO systems, where, in most cases, more than 1 000 000 calculations are required because the calculations are needed to make for smaller time step and couple of years length.

8.1 Calculation of downlink interference into non-GSO FSS system β

With respect to these examples, the earth station of non-GSO system β is assumed to be located at 140.8° E, 38.7° N.

In this calculation example, orbital locations of the satellites in the two non-GSO systems were compared with 30 min time-spacing in their active arcs.

Table 3 shows the basic parameters for calculating the downlink interference from non-GSO system α into non-GSO system β.

TABLE 3

The basic parameters for calculating the downlink interference from non-GSO system α into non-GSO system β

Parameter	Value	Note
Position of earth station of non-GSO system β	140.8° E, 38.7° N	
$\theta_{D\text{-}min(NGSO\beta)}$	4.9°	Minimum topocentric angular separation between satellite of non-GSO system α and satellite of non-GSO system β from the associated earth station of non-GSO system β
Boresight of the antenna beam of the satellite of non-GSO system α	140.8° E, 38.7° N	
$\varphi_{D\text{-}min(NGSO\alpha)}$	0.0°	Off-axis angle from the boresight of the satellite antenna of non-GSO system α to the earth station of non-GSO system β
$N_{D\text{-}NGSO\alpha\text{-}S}$	1	Only one satellite is operated in the active arc

The maximum envelope of the space station antenna radiation patterns is assumed by the following formulas, as defined in Recommendation ITU-R S.672:

$$G(\psi) = G_m - 3\left(\frac{\psi}{\psi_b}\right)^{\alpha} \quad \text{dBi} \quad \text{for} \quad \psi_b \le \psi \le a\psi_b$$

$$G(\psi) = G_m + L_N \quad \text{dBi} \quad \text{for} \quad a\psi_b < \psi \le b\psi_b$$

$$G(\psi) = X - 25\log(\psi) \quad \text{dBi} \quad \text{for} \quad b\psi_b < \psi \le Y$$

$$G(\psi) = L_F \quad \text{dBi} \quad \text{for} \quad Y < \psi \le 180^\circ$$

where:

$$X = G_m + L_N + 20\log(b\psi_b) \quad \text{and} \quad Y = b\psi_b 10^{0.04(G_m + L_N - L_F)}$$

$G(\psi)$: gain at the angle ψ from the main beam direction in any other direction (dBi)

G_m: maximum antenna gain (dBi)

ψ_b: one-half the 3 dB beamwidth in the plane of interest (3 dB below G_m) (degrees)

L_N: near-side-lobe level (dB) relative to G_m

L_F: far-side-lobe level (dBi)

and:

$\alpha =$ 2.0

$a =$ 2.58

$b =$ 14.0

$\psi_b =$ 1.0°

$L_N =$ –20 dB

$L_F =$ $(G_m - 20)$ dBi.

The analysis of worst-case downlink interference from non-GSO system α into the receiving earth station of non-GSO system β is shown in Table 4.

TABLE 4

Analysis of worst-case downlink interference from non-GSO system α into non-GSO system β

Parameter	Value	Units
Maximum pfd on Earth's surface produced by the satellite of non-GSO system β in 4 kHz	–132.6	dB(W/(m^2 · 4 kHz))
Off-axis angle from the boresight of the antenna radiation pattern of the satellite of non-GSO system α to earth station of non-GSO system β	0.0	degrees
Tx antenna relative gain of the satellite of non-GSO system α towards the earth station of non-GSO system β (assuming the radiation pattern described above)	40.5	dBi
Maximum pfd of the satellite of non-GSO system α in 4 kHz towards the earth station of non-GSO system β	–135.0	dB(W/(m^2 · 4 kHz))
Minimum topocentric separation angle (θ) from the earth station of non-GSO system β between the satellite of non-GSO system α and the satellite of non-GSO system β	4.9	degrees
Rx earth station gain of non-GSO system β towards the satellite of non-GSO system α (assuming 29 – 25 log(θ))	11.7	dBi
Frequency	12.5	GHz
Maximum Rx earth station gain of non-GSO system β	55.4	dBi
***C/I* at Rx earth station input of non-GSO system β**	**46.1**	**dB**

This analysis shows the interference from non-GSO system α into non-GSO system β. The worst-case *C/I* results 46.1 dB. This value is great enough to establish RF link of non-GSO system β. In this analysis, the same satellite e.i.r.p. (53.5 dBW) and the same carrier bandwidth (2.3 MHz) are used for both non-GSO system α and non-GSO system β.

Actually, *C*/*I* values continuously vary between approximately 46.1 dB and 63.9 dB during a single active service arc period of non-GSO system α.

8.2 Calculation of uplink interference into non-GSO satellite system β

With respect to these examples, the earth station of non-GSO system β was assumed to be located at 140.8° E, 38.7° N.

In this calculation example, orbital locations of the satellites in the two non-GSO systems were compared with 30 min time-spacing in their active arcs.

Table 5 shows the basic parameters for calculating the uplink interference from non-GSO system α into non-GSO system β.

TABLE 5

The basic parameters for calculating the uplink interference from non-GSO system α into non-GSO system β

Parameter	Value	Note
Position of earth station of non-GSO system α	140.8° E, 38.7° N	
$\theta_{U\text{-}min(NGSO\alpha)}$	4.9°	Minimum topocentric angular separation between satellite of non-GSO system α and satellite of non-GSO system β from the associated earth station of non-GSO system α
Boresight of the antenna beam of the satellite of non-GSO system β	140.8° E, 38.7° N	
$\varphi_{U\text{-}min(NGSO\beta)}$	0.0°	Off-axis angle from the boresight of the satellite antenna of non-GSO system β to the earth station of non-GSO system α
$N_{U\text{-}NGSO\beta\text{-}S}$	1	Only one satellite is operated in the active arc

The maximum envelope of the earth station antenna radiation patterns is assumed by the following formulas, as defined in Recommendation ITU-R S.580:

$$G(\varphi) = 29 - 25 \log \varphi \quad \text{dBi} \quad \text{for} \quad 1° \leq \varphi \leq 20°$$

$$G(\varphi) = -3.5 \quad \text{dBi} \quad \text{for} \quad 20° < \varphi \leq 26.3°$$

$$G(\varphi) = 32 - 25 \log \varphi \quad \text{dBi} \quad \text{for} \quad 26.3° < \varphi \leq 48°$$

$$G(\varphi) = -10 \quad \text{dBi} \quad \text{for} \quad 48° < \varphi \leq 180°$$

where:

$G(\varphi)$: gain relative to an isotropic antenna

φ: off-axis angle.

The analysis of worst-case uplink interference from non-GSO system α into the receiving satellite of non-GSO system β is shown in Table 6.

TABLE 6

Analysis of worst-case uplink interference from non-GSO system α into non-GSO system β

Parameter	Value	Units
Maximum pfd produced by the earth station of non-GSO system β in 4 kHz at the satellite of non-GSO system β	–131.5	dB(W/(m^2 · 4 kHz))
Minimum topocentric separation angle (θ) from the earth station of non-GSO system α between the satellite of non-GSO system α and the satellite of non-GSO system β	4.9	degrees
Tx antenna relative gain of the earth station of non-GSO system α towards the satellite of non-GSO system β (assuming the radiation pattern described above)	11.7	dB
Maximum pfd by the earth station of non-GSO system α in 4 kHz towards the satellite of non-GSO system β	–176.3	dB(W/(m^2 · 4 kHz))
Off-axis angle from the boresight of the antenna radiation pattern of the satellite of non-GSO system β to earth station of non-GSO system α	0.0	degrees
Rx satellite gain of non-GSO system β towards the earth station of non-GSO system α (antenna pattern: Recommendation ITU-R S.672)	40.5	dBi
Frequency	14.25	GHz
Maximum Rx satellite gain of non-GSO system β	40.5	dBi
***C/I* at Rx satellite input of non-GSO system β**	**44.8**	**dB**

This analysis shows the interference from non-GSO system α into non-GSO system β. The worst-case *C/I* results in 44.8 dB. This value is greater enough to establish RF link of non-GSO system β. In this analysis, the same earth station e.i.r.p. (66.5 dBW) and the same carrier bandwidth (17.8 MHz) are used for both non-GSO system α and non-GSO system β.

Actually, *C/I* value continuously varies between approximately 44.8 dB and 60.6 dB during a single active service arc period of non-GSO system α.

Annex 2

Calculation methodology of topocentric angular separation among non-GSO satellite systems, and pfd from one non-GSO satellite system over the service area of the other non-GSO satellite system

1 Introduction

The method to calculate the physical data to evaluate the interference from non-GSO satellite systems is described in this Annex.

The calculation of the topocentric angular separation and pfd is needed for the interference analysis.

2 Calculation of topocentric angular separation and pfd from geographical orbital location

The topocentric angular separation and pfd can be derived from the following method.

To determine the worst-case interference levels, values of t must be chosen which generate all possible combinations of orbital locations of operating satellites.

Step A.2.1: Orbital position of non-GSO satellite system α

Based on the latitude (geocentric) $\varphi'(t)_{NGSO\alpha}$, longitude $\lambda(t)_{NGSO\alpha}$ and altitude $h(t)_{NGSO\alpha}$ of a non-GSO satellite system α, its geocentric coordinates are given by:

$$X(t)_{NGSO\alpha} = (R_E + h(t)_{NGSO\alpha})\cos\varphi'(t)_{NGSO\alpha}\cos\lambda(t)_{NGSO\alpha}$$

$$Y(t)_{NGSO\alpha} = (R_E + h(t)_{NGSO\alpha})\cos\varphi'(t)_{NGSO\alpha}\sin\lambda(t)_{NGSO\alpha} \qquad (13)$$

$$Z(t)_{NGSO\alpha} = (R_E + h(t)_{NGSO\alpha})\sin\varphi'(t)_{NGSO\alpha}$$

where R_E is the radius of the Earth.

Step A.2.2: Orbital position of non-GSO satellite system β

Based on the latitude $\varphi'(t)_{NGSO\beta}$, longitude $\lambda(t)_{NGSO\beta}$ and altitude $h(t)_{NGSO\beta}$ of a non-GSO satellite system β, its geocentric coordinates are given by:

$$X(t)_{NGSO\beta} = (R_E + h(t)_{NGSO\beta})\cos\varphi'(t)_{NGSO\beta}\sin\lambda(t)_{NGSO\beta}$$

$$Y(t)_{NGSO\beta} = (R_E + h(t)_{NGSO\beta})\cos\varphi'(t)_{NGSO\beta}\sin\lambda(t)_{NGSO\beta} \qquad (14)$$

$$Z(t)_{NGSO\beta} = (R_E + h(t)_{NGSO\beta})\sin\varphi'(t)_{NGSO\beta}$$

Step A.2.3: Geographical position of the test point on the Earth's surface

Based on the latitude φ'_{tp} and longitude λ_{tp} of the test point, its geocentric coordinates are given by:

$$X_{tp} = R_E \cos\varphi'_{tp} \cos\lambda_{tp}$$
$$Y_{tp} = R_E \cos\varphi'_{tp} \sin\lambda_{tp} \qquad (15)$$
$$Z_{tp} = R_E \sin\varphi'_{tp}$$

Step A.2.4: Distance between the satellite of non-GSO satellite system α and the test point

This distance $D(t)_{NGSO\alpha\_tp}$ can be calculated using Pythagoras' theorem:

$$D(t)_{NGSO\alpha\_tp} = \sqrt{(X(t)_{NGSO\alpha} - X_{tp})^2 + (Y(t)_{NGSO\alpha} - Y_{tp})^2 + (Z(t)_{NGSO\alpha} - Z_{tp})^2} \qquad (16)$$

Step A.2.5: Distance between the satellite of non-GSO satellite system α and the satellite of non-GSO satellite system β

This distance $D(t)_{NGSO\alpha\_\beta}$ can also be calculated using Pythagoras' theorem:

$$D(t)_{NGSO\alpha\_\beta} = \sqrt{(X(t)_{NGSO\alpha} - X(t)_{NGSO\beta})^2 + (Y(t)_{NGSO\alpha} - Y(t)_{NGSO\beta})^2 + (Z(t)_{NGSO\alpha} - Z(t)_{NGSO\beta})^2} \qquad (17)$$

Step A.2.6: Distance between the satellite of non-GSO satellite system β and the test point

This distance $D_{NGSO\beta\_tp}$ can be calculated using Pythagoras' theorem:

$$D(t)_{NGSO\beta\_tp} = \sqrt{(X(t)_{NGSO\beta} - X_{tp})^2 + (Y(t)_{NGSO\beta} - Y_{tp})^2 + (Z(t)_{NGSO\beta} - Z_{tp})^2} \qquad (18)$$

Step A.2.7: Separation angle between the satellite of non-GSO satellite system α and the satellite of non-GSO satellite system β at the test point

This topocentric angular separation $\nu(t)$ can be calculated using cosine theorem:

$$\theta(t) = \arccos\left(\frac{D(t)_{NGSO\alpha\_tp}{}^2 + D(t)_{NGSO\beta\_tp}{}^2 - D(t)_{NGSO\alpha\_\beta}{}^2}{2D(t)_{NGSO\alpha\_tp} D(t)_{NGSO\beta\_tp}}\right) \qquad (19)$$

Step A.2.8: pfd from the satellite of non-GSO satellite system α at the test point of non-GSO satellite system β

The pfd (dB(W/(m^2 · 4 kHz))) can be expressed as:

$$PFD_{D\text{-}NGSO\alpha\text{-}\beta}(t) =$$
$$G_{NGSO\alpha\text{-}S\text{-}max} + PD_{NGSO\alpha\text{-}S\text{-}max} + \Delta G_{\alpha\text{-}\beta\text{-}S\text{-}ant} - 10\log(4\pi D(t)_{NGSO\alpha\_tp}{}^2) + 10\log(4\,000) \qquad (20a)$$

where:

$G_{NGSO\alpha\text{-}S\text{-}max}$: maximum satellite antenna gain (dBi)

$PD_{NGSO\alpha\text{-}S\text{-}max}$: maximum power density of the satellite of non-GSO satellite system α(dB(W/Hz))

$\Delta G_{\alpha\text{-}\beta\text{-}S\text{-}ant}$: relative satellite antenna gain toward the test point of the earth station of non-GSO satellite system β.

pfd (dB(W/(m² · 4 kHz))) from the earth station of non-GSO satellite system α at the satellite of non-GSO satellite system β can also be expressed as:

$$PFD_{U\text{-}NGSO\alpha\text{-}\beta}(t) = G_{NGSO\alpha\text{-}ES\text{-}max} + PD_{NGSO\alpha\text{-}ES\text{-}max} + \Delta G_{\alpha\text{-}\beta\text{-}ES\text{-}ant} - 10\log(4\pi D(t)_{NGSO\beta\_tp}{}^2) + 10\log(4\,000) \tag{20b}$$

where:

$G_{NGSO\alpha\text{-}ES\text{-}max}$: maximum earth station antenna gain (dBi)

$PD_{NGSO\alpha\text{-}ES\text{-}max}$: maximum power density of the earth station of non-GSO satellite system α (dB(W/Hz))

$\Delta G_{\alpha\text{-}\beta\text{-}S\text{-}ant}$: relative earth station antenna gain toward the satellite of non-GSO satellite system β.

When the off-axis angle of the satellite antenna toward the test point φ(*t*) is needed to calculate $\Delta G_{\alpha\text{-}\beta\text{-}S\text{-}ant}$, φ(*t*) can also be calculated using the cosine theorem:

$$\varphi(t) = \arccos\left(\frac{D(t)_{NGSO\alpha\_tp}{}^2 + D(t)_{NGSO\alpha\_bs}{}^2 - D_{tp\_bs}{}^2}{2D(t)_{NGSO\alpha\_tp} D(t)_{NGSO\alpha\_bs}}\right) \tag{21}$$

$D(t)_{NGSO\alpha\_bs}$ and D_{tp_bs} are the distance between the satellite of non-GSO satellite system α and its antenna boresight, and the distance between the test point and the satellite antenna boresight of non-GSO satellite system α, respectively. These values can be calculated by the similar equations such as (15) and (16).

Annex 3

Calculation methodology to check the existence of in-line path from one non-GSO satellite system into the other non-GSO satellite system

1 Introduction

The method to check the existence of the interference from non-GSO satellite systems is described in this Annex.

The calculation of the angular separation of the satellites of one non-GSO system from the LoS between its associated non-GSO earth station and the satellites of the other non-GSO system is needed for this interference analysis.

2 Calculation of geographical orbital location from orbital elements in Ap4 filing

The calculation of the orbital location of non-GSO satellite is needed in order to calculate the angular separation.

The geographical orbital location is to be obtained prior to the checking of the existence of in-line events. The calculation methodology of the graphical orbital location described in Annex 2 can also be adopted for this purpose.

To determine whether in-line events occur, the following methodology must be performed for values of *t* which generate all possible combinations of orbital locations of operating satellites.

Step 0: To calculate the positions in space of the non-GSO satellites in their active service arcs.

Step 1: To check whether the following conditions occur or not for every combination of the positions of the non-GSO satellites in their active service arc:

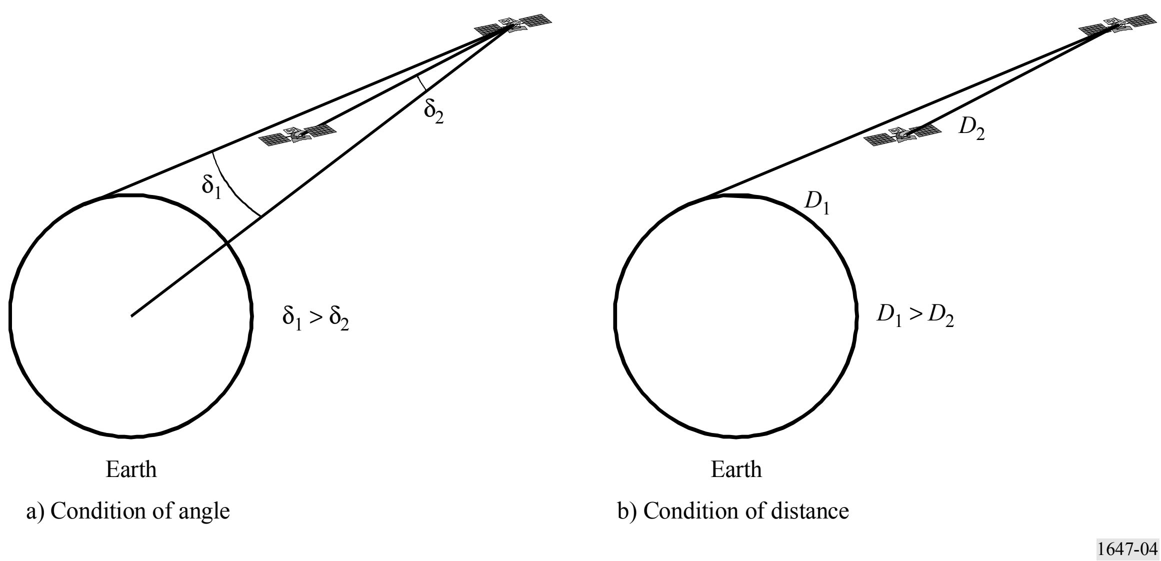
– The angle subtended at the non-GSO satellite with the highest altitude by the Earth's centre and the Earth's edge is greater than the angle subtended at the same non-GSO satellite by the Earth's centre and the other non-GSO satellite (see Fig. 4a)).

– The distance between the edge of the Earth and the non-GSO satellite with the highest altitude is greater than the distance between the same non-GSO satellite and the other non-GSO satellite (see Fig. 4b)).

Step 2: To determine that no in-line events occur if one of the above two conditions is not satisfied. (In-line events can occur only when both of the above conditions are satisfied.)

FIGURE 4

Condition to check the in-line events



3 Checking of the existence of in-line paths

The following method can be applied to check the existence of in-line paths.

Step A.3.1: Orbital position of non-GSO satellite system α

Based on the latitude (geocentric) $\varphi'(t)_{NGSO\alpha}$, longitude $\lambda(t)_{NGSO\alpha}$ and altitude $h(t)_{NGSO\alpha}$ of a non-GSO satellite system α, its geocentric coordinates are given by:

$$X(t)_{NGSO\alpha} = (R_E + h(t)_{NGSO\alpha})\cos\varphi'(t)_{NGSO\alpha}\cos\lambda(t)_{NGSO\alpha}$$

$$Y(t)_{NGSO\alpha} = (R_E + h(t)_{NGSO\alpha})\cos\varphi'(t)_{NGSO\alpha}\sin\lambda(t)_{NGSO\alpha} \tag{22}$$

$$Z(t)_{NGSO\alpha} = (R_E + h(t)_{NGSO\alpha})\sin\varphi'(t)_{NGSO\alpha}$$

where R_E is the radius of the Earth.

Step A.3.2: Orbital position of non-GSO satellite system β

Based on the latitude $\varphi'(t)_{NGSO\beta}$, longitude $\lambda(t)_{NGSO\beta}$ and altitude $h(t)_{NGSO\beta}$ of non-GSO satellite system β, its geocentric coordinates are given by:

$$X(t)_{NGSO\beta} = (R_E + h(t)_{NGSO\beta})\cos\varphi'(t)_{NGSO\beta}\sin\lambda(t)_{NGSO\beta}$$

$$Y(t)_{NGSO\beta} = (R_E + h(t)_{NGSO\beta})\cos\varphi'(t)_{NGSO\beta}\sin\lambda(t)_{NGSO\beta} \tag{23}$$

$$Z(t)_{NGSO\beta} = (R_E + h(t)_{NGSO\beta})\sin\varphi'(t)_{NGSO\beta}$$

Step A.3.3: Distance between the satellite of a non-GSO satellite system α and the satellite of a non-GSO satellite system β

This distance $D(t)_{NGSO\alpha\_\beta}$ can be calculated using Pythagoras' theorem:

$$D(t)_{NGSO\alpha\_\beta} = \sqrt{(X(t)_{NGSO\alpha} - X(t)_{NGSO\beta})^2 + (Y(t)_{NGSO\alpha} - Y(t)_{NGSO\beta})^2 + (Z(t)_{NGSO\alpha} - Z(t)_{NGSO\beta})^2} \tag{24}$$

Step A.3.4: Checking of the existence of in-line paths using angular separation

Angular separation of the satellites of non-GSO system α from the LoS between its sub-satellite point and the satellites of non-GSO satellite system β $\psi_{\alpha\_\beta}(t)$ can be calculated using the cosine theorem:

$$\psi_{\alpha\_\beta}(t) = \arccos\left(\frac{D(t)_{NGSO\alpha\_\beta}{}^2 + (X(t)_{NGSO\alpha}{}^2 + Y(t)_{NGSO\alpha}{}^2 + Z(t)_{NGSO\alpha}{}^2) - (X(t)_{NGSO\beta}{}^2 + Y(t)_{NGSO\beta}{}^2 + Z(t)_{NGSO\beta}{}^2)}{2D(t)_{NGSO\alpha\_\beta}\sqrt{X(t)_{NGSO\alpha}{}^2 + Y(t)_{NGSO\alpha}{}^2 + Z(t)_{NGSO\alpha}{}^2}}\right) \tag{25}$$

In order to check whether in-line paths exist or not, the following inequalities should be checked.

If:

$$\sqrt{X(t)_{NGSO\alpha}{}^2 + Y(t)_{NGSO\alpha}{}^2 + Z(t)_{NGSO\alpha}{}^2} \geq \sqrt{X(t)_{NGSO\beta}{}^2 + Y(t)_{NGSO\beta}{}^2 + Z(t)_{NGSO\beta}{}^2},$$

$$D(t)_{NGSO\alpha\_\beta} < \sqrt{X(t)_{NGSO\alpha}{}^2 + Y(t)_{NGSO\alpha}{}^2 + Z(t)_{NGSO\alpha}{}^2 - R_E{}^2} \tag{26}$$

$$\psi_{\alpha\_\beta}(t) < \arccos\left(\frac{\sqrt{X(t)_{NGSO\alpha}{}^2 + Y(t)_{NGSO\alpha}{}^2 + Z(t)_{NGSO\alpha}{}^2 - R_E{}^2}}{\sqrt{X(t)_{NGSO\alpha}{}^2 + Y(t)_{NGSO\alpha}{}^2 + Z(t)_{NGSO\alpha}{}^2}}\right) \tag{27}$$

If:

$$\sqrt{X(t)_{NGSO\alpha}{}^2 + Y(t)_{NGSO\alpha}{}^2 + Z(t)_{NGSO\alpha}{}^2} < \sqrt{X(t)_{NGSO\beta}{}^2 + Y(t)_{NGSO\beta}{}^2 + Z(t)_{NGSO\beta}{}^2},$$

$$D(t)_{NGSO\beta\_\alpha} < \sqrt{X(t)_{NGSO\beta}{}^2 + Y(t)_{NGSO\beta}{}^2 + Z(t)_{NGSO\beta}{}^2 - R_E{}^2} \tag{28}$$

$$\psi_{\beta\_\alpha}(t) < \arccos\left(\sqrt{\frac{X(t)_{NGSO\beta}{}^2 + Y(t)_{NGSO\beta}{}^2 + Z(t)_{NGSO\beta}{}^2 - R_E{}^2}{X(t)_{NGSO\beta}{}^2 + Y(t)_{NGSO\beta}{}^2 + Z(t)_{NGSO\beta}{}^2}}\right) \tag{29}$$

When the both inequalities are satisfied, there exist in-line paths somewhere on the Earth's surface. That is to say, the possibility of the in-line situation can be equal to zero if either of these inequalities is not satisfied.

Even if this checking indicates the existence of in-line interference events somewhere on the Earth's surface, there is a possibility that there are no in-line interference events when the detailed data of the service area of both systems is taken into account.