

RECOMMENDATION ITU-R S.1325-3

Simulation methodologies for determining statistics of short-term interference between co-frequency, codirectional non-geostationary-satellite orbit fixed-satellite service systems in circular orbits and other non-geostationary fixed-satellite service systems in circular orbits or geostationary-satellite orbit fixed-satellite service networks

(Questions ITU-R 206/4 and ITU-R 231/4)

(1997-2000-2001-2003)

The ITU Radiocommunication Assembly,

considering

- a) that emissions from the earth stations as well as from the space station of a satellite network (GSO FSS; non-GSO FSS; non-GSO mobile-satellite service (MSS) feeder links) in the FSS may result in interference to another such network when both networks operate in the same bands;
- b) that it is desirable to have a common methodology of simulation for assessing interference between systems that have co-frequency, codirectional feeder links when one of the systems is non-GSO;
- c) that it is possible to make some simplifying assumptions for these systems;
- d) that the simplifications in *considering* c) should not adversely affect the output results;
- e) that it would be desirable to have a common set of input parameters for each of the two communication systems;
- f) that it is necessary for the methodology to consider the type of fade compensation to counteract signal fading such as adaptive power control;
- g) that the methodology should have the ability to accurately calculate the time dependence of a single interference event in order to more accurately assess the impact on the interfered system;
- h) that the vast majority of the non-GSO FSS systems are in circular orbits;
- j) that information on the numbers and precise locations of earth stations is usually unavailable from ITU sources,

recommends

- 1 that the methodology given in Annex 1 may be used to obtain cumulative probability statistics for assessing short-term interference between systems that have co-frequency, codirectional links with one system employing a non-GSO MSS feeder link or non-GSO FSS system;
- 2 that the output should be evaluated against an agreed set of common output statistics;

3 that the methodology given in Annex 2 may be used to compute the aggregate total interference produced by a non-GSO system into a GSO satellite network and may be used to calculate the cumulative density function of the equivalent power flux-density (epfd) for a given antenna diameter of the GSO earth station or the epfd of the non-GSO system in the uplink direction;

4 that the methodology given in Annex 2 may be used to compute the $\text{epfd}_{\downarrow}$ produced by a non-GSO system into an operational GSO earth station to assess compliance with additional operational limits contained in Article 22 of the Radio Regulations (RR);

5 that the following Notes should be regarded as part of this Recommendation.

NOTE 1 – Short-term interference refers to cumulative probability distribution of those bit error ratios (or C/N values) that are calculated for 1% of the time or less.

NOTE 2 – The methodology of Annex 1 also can be used to evaluate the time dependent nature of the interference during a single near in-line event.

NOTE 3 – Annex 2 provides a methodology for computing the $\text{epfd}_{\uparrow}$ and $\text{epfd}_{\downarrow}$ of a non-GSO system. Annex 3 provides approaches to relate the methodology of Annex 1 to compute $\text{epfd}_{\uparrow}$ and $\text{epfd}_{\downarrow}$ of a non-GSO system.

NOTE 4 – It should be assumed that the noise is thermal in nature and is referenced to the total system noise power including the antenna thermal noise at the input to the demodulator.

NOTE 5 – There is need to develop a methodology for characterizing and calculating the long-term interference between non-GSO FSS systems and GSO FSS networks.

NOTE 6 – Annex 3 is the description and example of computational methodology.

NOTE 7 – Annex 4 provides a list of subjects for continuing work on this Recommendation.

NOTE 8 – Software meeting Recommendation ITU-R S.1503 would be used by the Radiocommunication Bureau to validate compliance with epfd limits in Article 22 of the RR.

NOTE 9 – The Annexes to this Recommendation apply to non-GSO systems having circular orbit.

Annex 1

Methodology for determining statistics of short-term interference between co-frequency, codirectional non-GSO FSS systems in circular orbits and other non-GSO FSS systems in circular orbits or GSO FSS networks

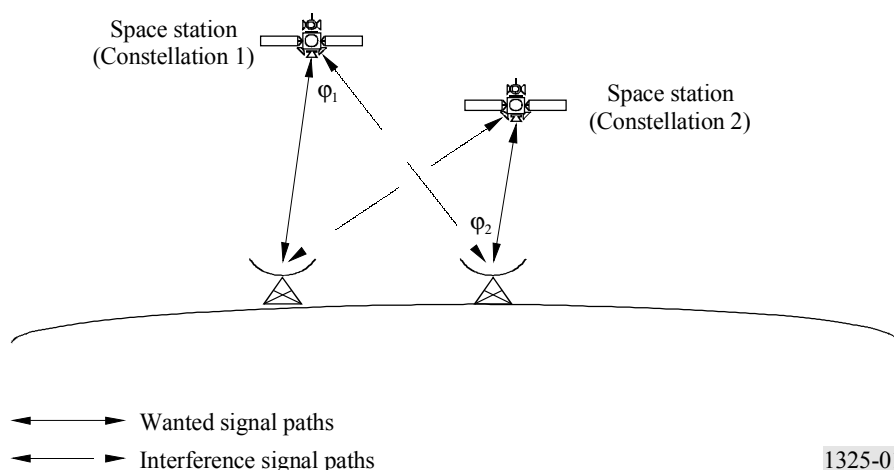
1 Method and simulation approach description

The framework for this methodology is to model the satellite systems in their orbits and allow each space station and earth station to track their respective aimpoints while taking into account the Earth's rotation. A simulation of this framework is sampled over a period of time at a relatively fine rate. At each sample the range gain product is computed. The raw data is a time history of the interference level versus time. It can be shown that if power control is not used on either system

then the range gain product (defined in equation (2)) can be directly related to the interference level. The raw data can be evaluated to compute the per cent of time that the range gain product for all interference paths is above a certain level. The interference geometry is shown in Fig. 1, and the interference paths considered are those below:

	Space station (Constellation 1)	Earth station (Constellation 1)
Space station (Constellation 2)	None	Uplink ₁ → Uplink ₂ Downlink ₂ → Downlink ₁
Earth station (Constellation 2)	Downlink ₁ → Downlink ₂ Uplink ₂ → Uplink ₁	None

FIGURE 1
Interference geometry



To compute the interference to noise ratio, I_0/N_0 , the following equation can be used:

$$\begin{aligned} \frac{I_0}{N_0} &= \frac{P_t}{BW_{tx}} G_t(\varphi_1) G_r(\varphi_2) \left(\frac{\lambda}{4\pi R_i} \right)^2 \frac{1}{kT} \frac{1}{L_p} \\ &= \frac{P_t}{BW_{tx}} \frac{\lambda^2}{4\pi} \frac{1}{kT} \frac{1}{L_p} \frac{G_t(\varphi_1) G_r(\varphi_2)}{4\pi R_i^2} \end{aligned} \quad (1)$$

where:

- P_t : available transmit power (W)
- BW_{tx} : transmit bandwidth (Hz)
- $G_t(\varphi_1)$: transmit gain (relative intensity) (numerical ratio)
- $G_r(\varphi_2)$: receiver gain (relative intensity) (numerical ratio)
- φ_1 : off bore-sight angle of the transmitter in the direction of the receiver (degrees)
- φ_2 : off bore-sight angle of the receiver in the direction of the transmitter (degrees)

- λ : wavelength of transmitter (m)
- R_i : length of the interfering path (m)
- k : Boltzmann's constant (1.38×10^{-23} W/(Hz · K))
- T : noise temperature (K)
- L_p : polarization isolation factor (numerical ratio ≥ 1).

If there is no range compensating power control on the links between the space station and the earth station, the only elements of equation (1) that are dependent variables for the time varying simulation are the receiver gain angle, the transmitter gain angle and the range between transmitter and receiver. To compute I_0/N_0 the range gain product can be multiplied by the constant:

$$\frac{P_t}{BW_{tx}} \frac{\lambda^2}{4\pi} \frac{1}{k T} \frac{1}{L_p}$$

For example the range gain product for space station 1 downlink into earth station 2 downlink is computed as (Fig. 1):

$$\frac{G_t(\varphi_1) G_r(\varphi_2)}{4\pi R_i^2} \quad (2)$$

For interference assessment from satellite networks with multiple ground terminals, the interference from all of the ground terminals (for the uplink case) or from all of the space stations (for the downlink case) must be combined to determine the total interference. The interference data can be combined at each simulation time step during the simulation, or by combining the data from a set of individual simulations. In either case the receive satellite antenna discrimination in the direction of each earth terminal must be considered when calculating the total uplink interference, $epfd_{\uparrow}$, and the receive earth station antenna discrimination in the direction of each non-GSO space station must be considered when calculating the total downlink interference $epfd_{\downarrow}$.

The $epfd$ is defined as the sum of the power flux-densities produced at a receive station of the interfered system, on the Earth's surface or in an orbit, as appropriate, by all the transmit stations within the interfering system, taking into account the off-axis discrimination of a reference receiving antenna assumed to be pointing in its nominal direction.

$$epfd = 10 \log_{10} \left(\sum_{i=1}^{i=N_a} 10^{P_i/10} \frac{G_t(\varphi_{1i})}{4\pi R_i^2} \frac{G_r(\varphi_{2i})}{G_{r_{max}}} \right) \quad (2a)$$

where:

- N_a : number of transmit stations in the interfering satellite system that are visible from the receive station of the interfered satellite system, considered on the Earth's surface or in an orbit as appropriate
- i : the index of the transmit station considered in the interfering satellite system
- P_i : RF power at the input of the antenna of the transmit station, considered in the non-GSO satellite system (dBW)

- $G_t(\varphi_{1i})$: transmit antenna gain of the station considered in the non-GSO satellite system in the direction of the receive station (relative intensity, numerical ratio)
- $G_r(\varphi_{2i})$: receive antenna gain of the receive station in the direction of the i -th transmit station considered in the non-GSO satellite system (relative intensity, numerical ratio)
- $G_{r_{max}}$: maximum gain of the receive station antenna (numerical ratio)
- φ_1 : off bore-sight angle of the transmit station considered in the non-GSO satellite system in the direction of the receive station
- φ_2 : off bore-sight angle of the receive station in the direction of the i -th transmit station considered in the non-GSO satellite system
- R_i : distance between the transmit station considered in the non-GSO satellite system and the receive station (m).

In terms of I_0/N_0 , $epfd$ can be expressed as:

$$10^{epfd/10} = \sum_i P_i \frac{G_t(\varphi_{1i})}{4\pi R_i^2} \frac{G_r(\varphi_{2i})}{G_{r_{max}}} \quad epfd \text{ (dB(W/(m}^2 \cdot \text{Hz))), } P_i \text{ (W/BW)} \quad (2b)$$

$$10^{epfd/10} = \sum_i \frac{P_{t_i}}{BW_{tx}} \frac{G_t(\varphi_{1i})}{4\pi R_i^2} \frac{G_r(\varphi_{2i})}{G_{r_{max}}} \quad epfd \text{ (dB(W/(m}^2 \cdot \text{Hz))), } P_{t_i} \text{ (W)} \quad (2c)$$

$$10^{epfd/10} = \sum_i \frac{P_{t_i}}{BW_{tx}} \frac{G_t(\varphi_{1i})}{4\pi R_i^2} \left(\frac{\lambda^2}{4\pi} \frac{1}{k T} \frac{1}{L_p} \right) \frac{G_r(\varphi_{2i})}{G_{r_{max}}} \left/ \left(\frac{\lambda^2}{4\pi} \frac{1}{k T} \frac{1}{L_p} \right) \right. \quad (2d)$$

where $epfd$ is in dB(W/(m² · Hz)), P_{t_i} is in W, and BW_{tx} is the transmit bandwidth in Hz.

Substituting I_0/N_0 (equation (1)):

$$10^{epfd/10} = \sum_i \frac{I_{0i}}{N_0} \left/ \left(G_{r_{max}} \frac{\lambda^2}{4\pi} \frac{1}{k T} \frac{1}{L_p} \right) \right. \quad (2e)$$

so:

$$epfd = 10 \log \left[\sum_i \frac{I_{0i}}{N_0} \left/ \left(G_{r_{max}} \frac{\lambda^2}{4\pi} \frac{1}{k T} \frac{1}{L_p} \right) \right. \right] \quad (2f)$$

$$epfd = 10 \log \left(\sum_i \frac{I_{0i}}{N_0} \right) - \frac{G_{r_{max}}}{T} - 10 \log \left(\frac{\lambda^2}{4\pi} \right) - 228.6 + 10 \log (L_p) \quad \text{dB(W/(m}^2 \cdot \text{Hz))} \quad (2g)$$

2 Simulation assumptions

2.1 Orbit model

The orbit model to simulate the space stations in their orbits is for circular orbits only accounting for precession of the line of nodes in the equatorial plane due to asphericity of the Earth.

2.1.1 Discussion

The orbit model represents satellite motion in a geocentric inertial coordinate frame shown in Fig. 2. The origin of this inertial frame is at the centre of the Earth. The x-axis points to the first point in the constellation Aries (i.e., vernal equinox), the z-axis is the mean rotation axis of the Earth, and the y-axis is determined as the cross product of the unit vectors in the z and x direction, i.e. $\vec{y} = \vec{z} \times \vec{x}$.

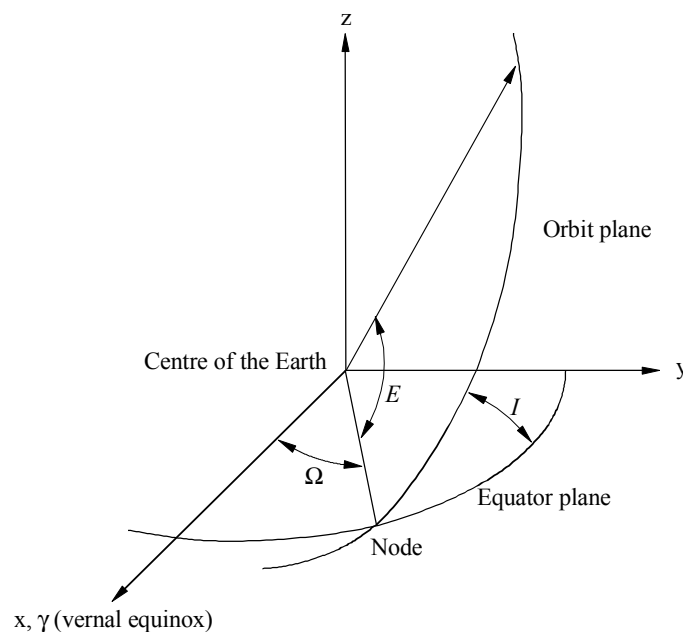
The orbital model is based on Newton's equation of motion for a satellite orbiting a perfectly spherical Earth in a circle. The characteristics of this motion that make it easy to model is that the satellite orbital radius and velocity are constant. These parameters are connected by Newton's second law. The equation of motion is:

$$\frac{m_{sv} v^2}{r} = \frac{G M_e m_{sv}}{r^2} \quad (3)$$

where:

- m_{sv} : mass of the space station
- v : constant velocity of the space station
- G : Newtonian gravitational constant ($6.673 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$)
- r : radius of orbit
- M_e : mass of the Earth ($5.974 \times 10^{24} \text{ kg}$).

FIGURE 2
Representation of Keplerian orbital elements



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Equation (3) can be written in the form:

$$v^2 = \frac{G M_e}{r} = \frac{G M_e}{R_e^2} \frac{R_e^2}{r} \quad (4)$$

where R_e is the radius of a perfectly spherical Earth (6378 km). Since at the surface of the Earth:

$$mg = \frac{G M_e m}{R_e^2} \quad (5)$$

where g is the acceleration due to gravity at the surface of the Earth is:

$$g = \frac{G M_e}{R_e^2} = 9.806 \text{ m/s}^2 \quad (6)$$

we find that (4) can be written as:

$$v^2 = g \frac{R_e^2}{r} \quad (7)$$

or:

$$v = R_e \sqrt{\frac{g}{r}} \quad (8)$$

The period of the orbit, T , is given by the expression:

$$T = \frac{2\pi r}{v} = \frac{2\pi}{R_e} \sqrt{\frac{r^3}{g}} \quad (9)$$

These equations completely describe the dynamics of circular orbit motion about a perfectly spherical Earth.

The description of this motion in the geocentric coordinate system shown in Fig. 2 is based on specifying the satellite position using the Keplerian orbital parameters. These variables are defined as:

- Ω : the right ascension of the ascending node (RAAN) of the orbit. The angle as measured from the x-axis in the equatorial plane (x-y plane).
- I : the inclination of the orbit. The angle as measured from the equatorial plane to the orbital plane of the space station.
- E : the argument of latitude (true anomaly). The angle as measured from the line of nodes to the radius vector at the position of the space vehicle.

It should be noted that the true anomaly is a function of the angular position of the space station at time t_0 and the angular velocity of the space station. It can be expressed as:

$$E = E_0 + \omega t \quad (10)$$

where:

- E_0 : angular position of the space station at time t_0 (rad)
- ω : angular velocity of the space station (rad/s)
- $= v/r$.

To account for orbital precession the RAAN of the orbit is also a function of the RAAN at time t_0 and the orbital precession rate. It can be expressed as:

$$\Omega = \Omega_0 + \Omega_r t \quad (11)$$

where:

Ω_0 : RAAN of the space station at time t_0 (rad)

Ω_r : orbital precession rate of the space station (rad/s).

$$\Omega_r = -\frac{3}{2} J_2 \cos(I) R_e^2 \frac{\sqrt{r\mu}}{r^4} \quad (12)$$

where:

μ : Earth attraction constant ($3.986 \times 10^5 \text{ km}^3/\text{s}^2$)

J_2 : second harmonic Earth potential constant ($1\,082.6 \times 10^{-6}$).

The representation of the space station position in terms of the geocentric inertial coordinate system is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = r \begin{bmatrix} \cos \Omega \cos E - \sin \Omega \cos I \sin E \\ \sin \Omega \cos E + \cos \Omega \cos I \sin E \\ \sin I \sin E \end{bmatrix} \quad (13)$$

The representation of the space station velocity in terms of the geocentric inertial coordinate system, ignoring the relatively long-term variation in Ω , is:

$$\begin{bmatrix} dx / dt \\ dy / dt \\ dz / dt \end{bmatrix} = r\omega \begin{bmatrix} -\cos \Omega \sin E - \sin \Omega \cos I \cos E \\ -\sin \Omega \sin E + \cos \Omega \cos I \cos E \\ \sin I \cos E \end{bmatrix} \quad (14)$$

2.1.2 Perturbations

For GSO satellites:

The orbit inclination of the satellite

The slight inclination of the satellite orbit may occur for satellites that have been in orbit for a period of time. A deviation generally takes place, with a limit in the deviation not to be exceeded.

The deviation of the antenna beam from its nominal pointing direction

The following factors contribute to the total variation on the area on the surface of the Earth illuminated by the satellite beam:

- variations on satellite station-keeping;
- variations caused by the pointing tolerances, which become more significant for coverage areas with low angles of elevation;
- effect of yaw error, which increases as the beam ellipse lengthens.

The effect of these possible variations should be assessed on a case-by-case basis, since their total effect on the area covered will vary with the geometry of the satellite beam, and it would not be reasonable to indicate a single value of shift on the area covered for all situations.

For non-GSO satellites, the exact longitude precession rate would be affected by a slight drift due to longitudinal station-keeping errors. This effect should be modelled and integrated in the simulations.

2.2 Consideration of polarization isolation

The polarization isolation factor, L_p , is the amount of polarization isolation that can be assumed between the transmitter and receiver (see Annex 4).

2.3 Operational assumptions

2.3.1 Non-GSO earth stations location

The identification of beams used at any given location and time from a non-GSO satellite is dependent on both the tracking strategy and the location of non-GSO earth stations. The tracking strategies are described in § 2.3.2. The following sections describe techniques to determine non-GSO earth station locations. The non-GSO systems should use the most accurate approach that applies to their system.

The simulation requires geographical location of the non-GSO earth stations on the Earth's surface which could operate co-frequency, co-polarized. In some cases information on the number and exact location of non-GSO earth stations may be unavailable.

If every non-GSO earth station whose uplink and/or downlink would interfere with the uplink and/or the downlink of a given victim earth station is modelled, the running time of the simulation may become excessive. In many cases it will be possible to limit the number of non-GSO earth stations included in the model, and thus substantially reduce the simulation runtime, without significant loss of accuracy in the epfd statistics computed. In most cases, the links to and from non-GSO earth stations nearest to the victim earth station will make the largest contributions to the epfd, and the contributions of links to and from other non-GSO earth stations will be progressively smaller as their distance from the victim earth station increases. One way of minimizing the necessary time of a definitive simulation is to perform an initial short run with a limited number of non-GSO earth stations disposed symmetrically around the victim earth station, and then add a concentric ring of non-GSO earth stations and perform a further short run, and repeat this process until the epfd statistics produced by successive short runs do not increase significantly. Use the resulting model for the definitive simulation.

2.3.1.1 Known distribution of non-GSO earth stations

There are cases where the exact locations of all the non-GSO earth stations are known. In those cases, the non-GSO systems should use those locations, which constitute the most accurate configuration of their system.

2.3.1.2 Uniform distribution of non-GSO earth stations

Each cell is assumed to have a uniform distribution of non-GSO earth stations.

For the purpose of the simulation, the non-GSO earth stations' position could be specified with regard to a predicted number of the earth stations located on a unit Earth area in a specific geographical region.

The distribution of non-GSO earth stations should be done uniformly on the Earth's surface, knowing the density of co-frequency, co-polarized non-GSO earth station per km², and the average distance between the centre of the cells created by the non-GSO system.

To produce the uniform distribution of non-GSO earth stations for the uplink, the following method should be used:

Step 1: Calculate the number, n_{es} , of actual operating non-GSO earth stations that the representative earth station will represent using:

$$n_{es} = d_{es} \cdot d_{es} \cdot \sigma_{es}$$

where:

d_{es} : average distance between the co-frequency, co-polarized non-GSO earth stations (km)

σ_{es} : density of co-frequency, co-polarized non-GSO earth station per km².

Then to perform the interference calculation, an equivalent e.i.r.p. level should be affected to each equivalent non-GSO earth station as follows:

Step 2: Calculate e.i.r.p. to use for each representative non-GSO earth station using:

$$e.i.r.p._{rep} = e.i.r.p._{es} + 10 \log_{10} n_{es}$$

where:

$e.i.r.p._{rep}$: e.i.r.p. for a representative non-GSO earth station (dBW)

$e.i.r.p._{es}$: e.i.r.p. per non-GSO earth station (dBW)

n_{es} : number of actual operating non-GSO earth stations.

$$e.i.r.p._{es} = P_t + G_t$$

where:

P_t : transmit power of the non-GSO earth station (dB)

G_t : gain of the non-GSO earth station in the direction of the non-GSO satellite (dBi).

Step 3: For every distance d_{es} in latitude and distance d_{es} in longitude within the GSO service area, locate a representative non-GSO earth station radiating with $e.i.r.p._{rep}$.

2.3.1.3 Probabilistic distribution of non-GSO earth stations

Assigning positions of non-GSO earth stations could be based on a probabilistic rule. Resource allocations can be continually chosen randomly or may be determined globally before the simulation is initiated (e.g. as a function of geography, or time). An initial random seed should be used to allow the simulation to be repeated under the same conditions.

2.3.1.4 Distribution of non-GSO earth stations based on population

Published population densities over the Earth's surface can be used to determine the geographic distribution of non-GSO earth stations. Tracking strategies should be weighted more heavily toward earth stations that have higher population densities.

2.3.1.5 Distribution of non-GSO earth stations based on typical demand

The distribution of non-GSO earth stations is likely to be dependent on the type of service provided (e.g. target market can be rural or city). If a more accurate model of the distribution of non-GSO earth stations is known then it should be used.

2.3.2 Tracking strategy

2.3.2.1 GSO arc avoidance

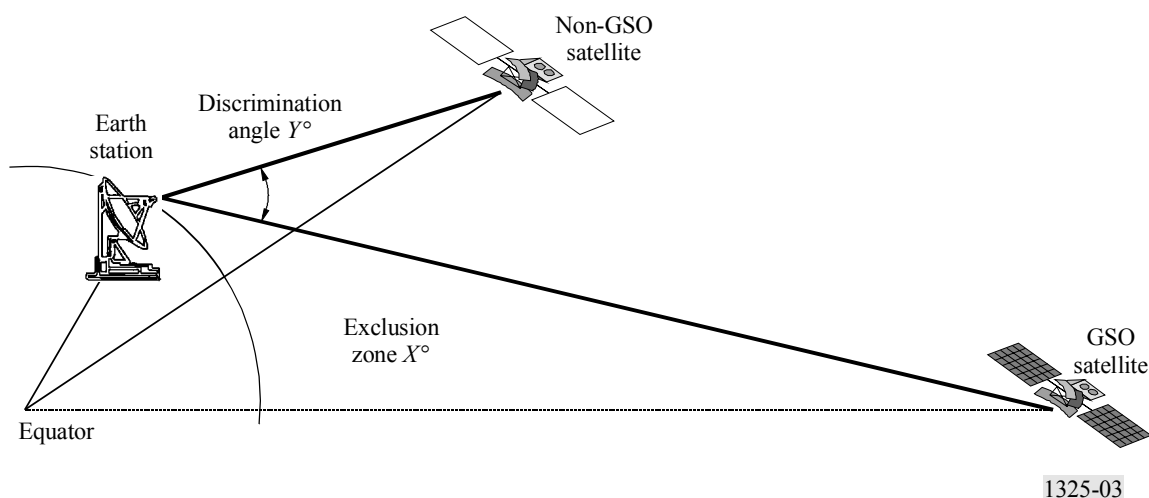
Some non-GSO systems have been designed to reuse the frequency already heavily used by GSO systems. This frequency reuse is feasible thanks to several techniques. Some of them are described below.

2.3.2.1.1 GSO arc avoidance based upon the latitude

In order to decrease the interference level, some systems use a technique that allows to avoid coupling between the main beam of their satellites and the main beam of the GSO earth station. An exclusion zone is defined by $\pm X^\circ$ with respect to the equatorial plane. When a non-GSO satellite enters the exclusion zone, the traffic of the beam where there is main beam coupling is handed over to another satellite that is not in the zone.

In addition to that, those systems have been designed such that there is a minimum discrimination angle at the earth station of at least Y° between the GSO satellites and the non-GSO satellites.

FIGURE 3



This technique is often used by MEO systems.

2.3.2.1.2 GSO arc avoidance based upon angle between non-GSO satellite and GSO arc

The GSO arc protection implemented by other systems consists of switching off the beams when any earth point within a cell sees an angular separation between the GSO arc and a non-GSO satellite of less than α° .

The value of α is system dependent, but it is generally taken equal to 10° .

2.3.2.1.3 GSO arc avoidance based upon the system design

Some systems have implemented their own technique, depending on the design of their system. There can be many different types of GSO satellite protection.

2.3.2.2 Non-GSO space station selection

There are several different satellite selection strategies which non-GSO system operators may employ. Studies have shown that the choice of the selection strategies affects the medium to long-term interference levels. Non-GSO system operators may use different selection strategies to reduce the interference into other systems. Some of the selection strategies are listed below in the following subsections.

2.3.2.2.1 Space station selection based upon longest dwell time

The space station selection process discussed in this section is based on establishing a link to the satellite in view of the non-GSO earth station for the longest period of time. This process will minimize the number of hand-offs of the data flow. If a satellite system is designed to have multiple satellites in view of the earth station for an extended period of time, then an additional constraint may be imposed to optimize on interference avoidance or diversity.

It is assumed that the earth station, associated with a constellation, tracks the corresponding space station once it has a communication link established. When this space station is beyond the minimum elevation angle it is assumed that the next space station can be acquired before the next simulation time step. If more than one space station can be acquired at the next time step, the algorithm to select the next space station is based on the vector from the earth station to the potential space station, $\vec{r}$, and the unit vector in the direction of the space stations velocity, $\vec{v}$. The selection criterion is to minimize the dot product of $\vec{r}$ and $\vec{v}$:

$$\begin{aligned} & (\vec{r} \cdot \vec{v})_{min} \\ & \text{i.e. the minimum value of all satellites} \\ & \text{above minimum elevation} \end{aligned} \tag{15}$$

This selection procedure is shown in Fig. 4. The top view representation shows the space station velocity vector, denoted by $\vec{v}_1$ directed towards the earth station. The dot product is negative, so space station number 1 is selected over the other space station (see Annex 4).

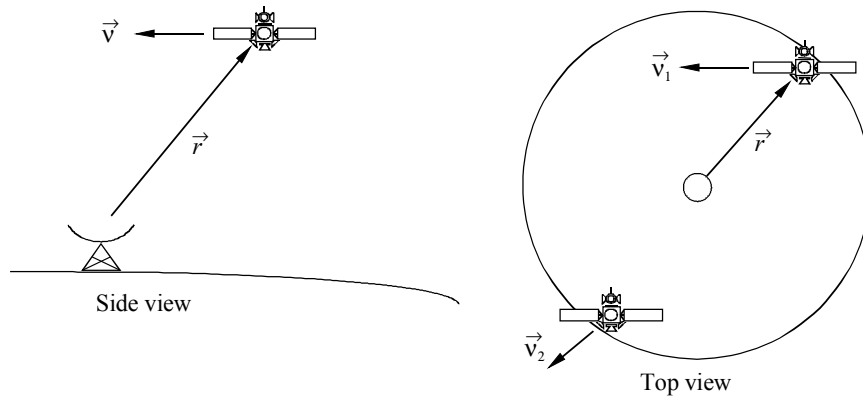
2.3.2.2.2 Space station selection based upon highest elevation angle

This selection strategy will require a higher number of hand-offs than longest dwell time but may be used to improve link performance for the non-GSO system. Active satellites are selected if it has the highest elevation angle from a non-GSO earth station and an available transponder. There are two possible hand-over techniques for highest elevation angle:

- the satellite with the highest elevation angle is always selected as the active satellite;
- the highest elevation satellite is selected once the active satellite drops below a minimum elevation angle.

When satellite diversity is applied, the same selection should be made on the number of satellite required by the diversity: the next satellite chosen would be the second highest elevation satellite, then the third would be the third highest elevation, etc.

FIGURE 4
Selection criteria for the next space station from the earth station to establish a communication link



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2.3.2.2.3 Space station selection based upon largest separation angle from the GSO arc

Non-GSO systems may choose satellites based upon the farthest separation angle from the look angle to the GSO arc. This reduces the level of interference generated by the non-GSO satellites into a GSO earth station but has some drawbacks. It may result in a less than optimum link performance and also require a large amount of hand-offs.

2.3.2.2.4 Space station selection based upon typical resource allocation

Non-GSO systems should choose to provide a more typical resource allocation if it is different from the three mentioned above.

2.3.3 Power control on range

Power control on a non-GSO space station is to account for differences in the range R (between the earth station and the space station). This section describes an algorithm to perform power control on range. The concept of power control on range is for the transmitting station to reduce or increase its transmit power as the receiver moves towards or away from the transmitter, i.e. the received power is kept constant. The required input parameter for the simulation is the desired receiver power density at the input to the wanted antenna, P_r (dB(W/Hz)). This receive power can be expressed as:

$$P_r = \frac{P_t(R_w)}{BW_{tx}} G_{tw}(0) \left(\frac{\lambda}{4\pi R_w} \right)^2 \quad (16)$$

where R_w is the length of the wanted signal path (i.e. distance between earth station and space station of constellation 1) and $P_t(R_w)$ is the transmit power required to close the link. P_r can be related to the carrier to noise level at the wanted receiver by:

$$C_0/N_0 = \frac{P_r(R_w) G_{rw}(0)}{k T_w} = \frac{P_t(R_w)}{BW_{tx}} \frac{G_{tw}(0) G_{rw}(0)}{k T_w} \left(\frac{\lambda}{4\pi R_w} \right)^2 \quad (17)$$

where:

$G_{rw}(0)$: maximum wanted receive gain of the wanted antenna

$G_{tw}(0)$: maximum wanted transmit gain of the wanted antenna

T_w : wanted receiver noise temperature.

When power control on range is considered, the equation to compute the interference level can be expressed as:

$$\begin{aligned} I_0 / N_0 &= \frac{P_t(R_i)}{BW_{tx}} G_{t_i}(\varphi_1) G_{rw}(\varphi_2) \left(\frac{\lambda}{4\pi R_i} \right)^2 \frac{1}{k T} \frac{1}{L_p} \\ &= P_r \frac{G_{t_i}(\varphi_1) G_{rw}(\varphi_2)}{G_{t_i}(0)} \left(\frac{R_w}{R_i} \right)^2 \frac{1}{k T} \frac{1}{L_p} \end{aligned} \quad (18)$$

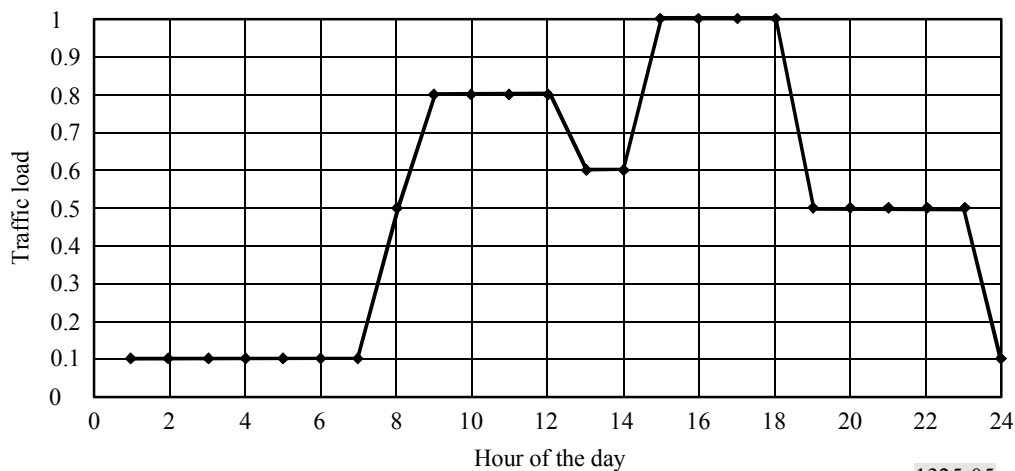
2.3.4 Traffic

2.3.4.1 Time varying nature of the traffic

The time varying nature of the interference created by a non-GSO system into a GSO network or non-GSO system should be taken into account for accurate modelling of the interference. The traffic variation is a function of the local time at the non-GSO earth station. The transmit power per carrier of a non-GSO system which use code division multiple access (CDMA) varies as a function of the traffic load on the specific carrier, then the transmit power per carrier may vary during the time of the day following the traffic demand. This feature is specific to CDMA.

A reference traffic model is proposed. If the non-GSO system has a model that more accurately represents its service demand, it may choose to use it instead of the referenced one given in Fig. 5.

FIGURE 5
Traffic model



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The traffic coefficient is taken into consideration in the maximum transmit power.

$$P_t = P_{max} \times C_{traffic}$$

where:

- P_t : transmit power (W)
- P_{max} : maximum transmit power (W)
- $C_{traffic}$: traffic coefficient dependent on the local time.

The traffic coefficients are only applicable to CDMA mode.

It is noted that non-GSO traffic load might be correlated with the GSO traffic, depending on the type of services offered by the two systems. Interference during time periods when GSO traffic is very low will not likely have the same effect on the GSO network performance. If the GSO satellite is also using CDMA, epfd statistics calculated taking into account non-GSO traffic variations could lead in some cases to results that might not correspond integrally to interference statistics observed by GSO operators during busy hours.

2.3.4.2 Geographical dependence of the traffic

The referenced traffic model given in the previous section is only dependent on the time. The traffic statistics may also vary with geographic location, target markets and other factors. In order to be more precise, an additional traffic model depending on the geographic location, target markets and other factors may be needed. Nevertheless, this model will vary with the types of services offered by the systems, the system itself and the country considered.

If a non-GSO system has a traffic model that more precisely represents its service demand depending on the geographical locations and target market, it may be used. If no precise data is available, the traffic demand could be considered identical everywhere on the Earth, which remains a conservative assumption. In that case, the traffic model used could be time-dependent only.

2.4 Antenna parameters

2.4.1 GSO earth station antenna parameters

The antenna pattern for the earth station is an input parameter to the simulation. Suggested patterns include, but are not limited to, the following:

- measured antenna patterns;
- RR Appendix 8;
- Recommendation ITU-R S.465;
- Recommendation ITU-R S.580;
- Recommendation ITU-R S.1428.

Recommendation ITU-R S.1428 has been developed in order to take into account a more accurate, though conservative, description of the shape of the pattern so that it can be used more realistically in interference calculations involving non-GSO FSS systems.

2.4.2 Non-GSO space station antenna parameters

In order to perform interference analysis, non-GSO satellite multiple beam antennas should be modelled using either of the following patterns, subject to availability, proposed in Recommendation ITU-R S.1528:

- measured antenna patterns;
- proposed reference antenna patterns;
- an analytical function which models the side lobes of the non-GSO satellite.