RECOMMENDATION ITU-R S.1325

SIMULATION METHODOLOGY FOR ASSESSING SHORT-TERM INTERFERENCE BETWEEN CO-FREQUENCY, CODIRECTIONAL NON-GEOSTATIONARY-SATELLITE ORBIT (GSO) FIXED-SATELLITE SERVICE (FSS) NETWORKS AND OTHER NON-GSO FSS OR GSO FSS NETWORKS

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

(1997)

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 § b) 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 networks are in circular orbits,

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 network;

2 that the output should be evaluated against an agreed set of common output statistics;

3 that the following Notes should be considered 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 – It should be assumed that the noise is thermal nature and is referenced to the total system noise power including the antenna thermal noise at the input to the demodulator.

NOTE 4 – There is need to develop a methodology for characterizing and calculating the long-term interference between non-GSO FSS and GSO FSS networks.

NOTE 5 – Annex 2 is the description and example of computational methodology.

NOTE 6 – Annex 3 provides a list of subjects for continuing work on this Recommendation.

ANNEX 1

Methodology for assessing short-term interference between co-frequency, codirectional non-GSO FSS networks and other non-GSO FSS 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	$\text{Uplink}_1 \rightarrow \text{Uplink}_2$ $\text{Downlink}_2 \rightarrow \text{Downlink}_1$
Earth station (Constellation 2)	$\text{Downlink}_1 \rightarrow \text{Downlink}_2$ $\text{Uplink}_2 \rightarrow \text{Uplink}_1$	None

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

$$\begin{aligned}\frac{I_0}{N_0} &= \frac{P_t}{BW_{tx}}\; G_t(\varphi_1)\; G_r(\varphi_2) \left(\frac{\lambda}{4\pi R}\right)^2 \frac{1}{k\,T}\;\frac{1}{L_p} \\ &= \frac{P_t}{BW_{tx}}\;\frac{\lambda^2}{4\pi}\;\frac{1}{k\,T}\;\frac{1}{L_p}\;\frac{G_t(\varphi_1)\; G_r(\varphi_2)}{4\pi R^2}\end{aligned} \qquad (1)$$

where:

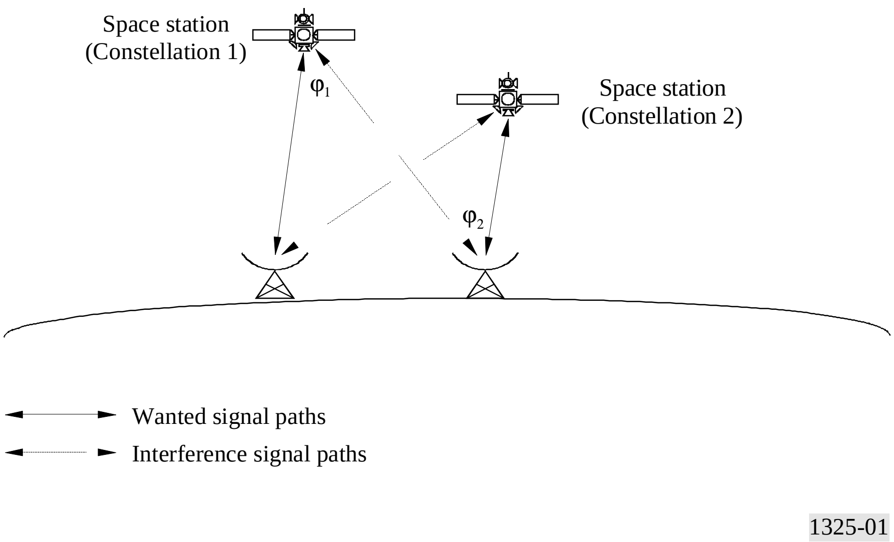
P_t :	available transmit power (W)
BW_{tx} :	transmit bandwidth (Hz)
$G_t(\varphi_1)$:	transmit gain (relative intensity)
$G_r(\varphi_2)$:	receiver gain (relative intensity)
φ_1 :	off bore-sight angle of the transmitter in the direction of the receiver
φ_2 :	off bore-sight angle of the receiver in the direction of the transmitter
λ :	wavelength of transmitter (m)
R :	range (m)
k :	Boltzmann's constant (1.38×10^{-23} J/K)
T :	noise temperature (K)
L_p :	polarization isolation factor.

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:

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

FIGURE 1

Interference geometry



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

$$\frac{G_t(\varphi_1)\ G_r(\varphi_2)}{4\pi\,R^2} \tag{2}$$

2 Simulation assumptions

2.1 Orbit model

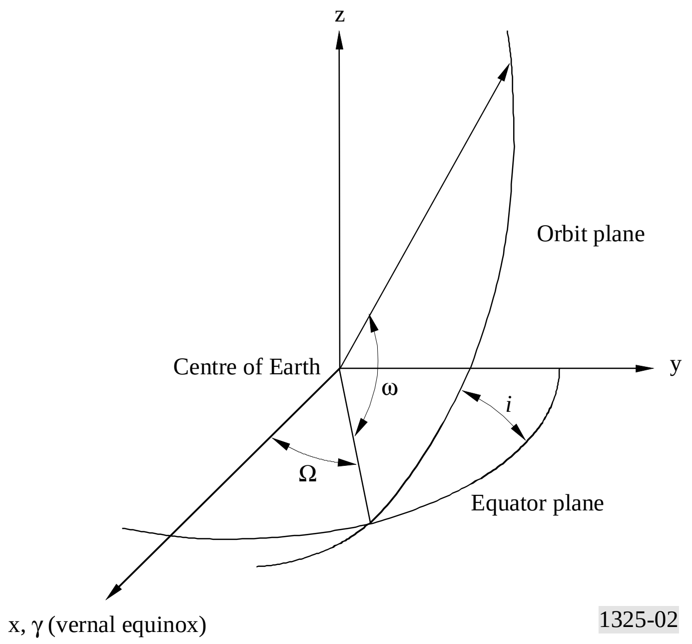
The orbit model to simulate the space stations in their orbits is for circular orbits only accounting for precession of the line of nodes in the equatorial plane due to asphericity of the Earth.

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 (γ, 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. $\vec{y} = \vec{z} \cdot \vec{x}$.

FIGURE 2

Representation of Keplerian orbital elements



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:

$$\frac{m_{sv}\, v^2}{r} = \frac{G\, M_E\, m_{sv}}{r^2} \tag{3}$$

where:

m_{sv}: mass of the space station

v: constant velocity of the space station

G: Newtonian gravitational constant (6.673×10^{-11} N · m^2/kg^2)

r: radius of orbit

M_E: mass of the Earth (5.974×10^{24} kg).

Equation (3) can be written in the form:

$$v^2 = \frac{G\, M_E}{r} = \frac{G\, M_E}{R_E^2}\, \frac{R_E^2}{r} \tag{4}$$

where R_E is the radius of a perfectly spherical Earth (6 378 km). Since at the surface of the Earth:

$$m\, g = \frac{G\, M_E\, m}{R_E^2} \tag{5}$$

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

$$g = \frac{G\, M_E}{R_E^2} = 9.806 \text{ m/s}^2 \tag{6}$$

we find that (4) can be written as:

$$v^2 = g \frac{R_E^2}{r} \tag{7}$$

or:

$$v = R_E \sqrt{\frac{g}{r}} \tag{8}$$

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

$$T = \frac{2\pi r}{v} = \frac{2\pi}{R_E} \sqrt{\frac{r^3}{g}} \tag{9}$$

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.
- a : the 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:

$$a = a_0 + at \tag{10}$$

where:

- a_0 : angular position of the space station at time t_0
- a : 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:

$$\Omega = \Omega_0 + bt \tag{11}$$

where:

- Ω_0 : RAAN of the space station at time t_0
- b : orbital precession rate of the space station (rad/s)

$$b = 2.018 \; e - 6 \left(\frac{r}{R_E} \right)^{-3.5} \quad \cos \text{i} \tag{12}$$

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

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = r \begin{bmatrix} \cos\Omega \;\; \cos\omega - \sin\Omega \;\; \cos i \;\; \sin\omega \\ \sin\Omega \;\; \cos\omega + \cos\Omega \;\; \cos i \;\; \sin\omega \\ \sin i \;\; \sin\omega \end{bmatrix} \tag{13}$$

2.2 Antenna parameters

2.2.1 Earth station and non-GSO space 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,

– Radio Regulations (RR) Appendix 29 [S8],

– Recommendation ITU-R S.465,

– Recommendation ITU-R S.672.

2.2.2 GSO space station antenna patterns

While the GSO space station may employ shaped antenna beam patterns, the antenna pattern for the GSO space station is not required for the simulation. The required parameters are the GSO space station receive/transmit gain in the direction of the non-GSO earth station. This is because location of the non-GSO earth station is constant relative to the GSO space station, therefore the receive/transmit gain of the GSO space station is constant in the direction of the non-GSO earth station.

2.3 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 3).

2.4 Operational assumptions

2.4.1 Non-GSO space station selection

The space station selection process discussed in this section is based on establishing a link to the satellite in view of the earth station for the longest period of time. This process will minimize the number of 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 1 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 criteria is:

$$\min_{\substack{\text{All satellites above} \\ \text{minimum elevation}}} \quad \vec{r} \cdot \vec{v} \tag{14}$$

This selection procedure is shown in Fig. 3. The top view representation shows the space station, denoted by $\vec{v}_1$ travelling towards earth station therefore the dot product is negative and it is selected over the other space station. (See Annex 3).

2.4.2 Power control on range

Power control on a non-GSO space station is to account for differences in the range (between the earth station and the space station). This section describes an algorithm to perform power control on range. The concept for power control on range is for the transmitting station to reduce/increase its transmit power as the receiver is getting closer/further to 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:

$$P_r = \frac{P_t(R)}{BW_{tx}} \; G_t(0) \left(\frac{\lambda}{4\pi \; R_w} \right)^2 \tag{15}$$

where R_w is the length of the wanted signal path (i.e. distance between earth station and space station of constellation 1) and $P_t(R)$ 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:

$$C_0/N_0 = \frac{P_r(R)\ G_{rw}(0)}{k\ T_w} = \frac{P_t(R)}{BW_{tx}}\ \frac{G_t(0)\ G_{rw}(0)}{k\ T_w}\left(\frac{\lambda}{4\pi\ R_w}\right)^2 \tag{16}$$

where:

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

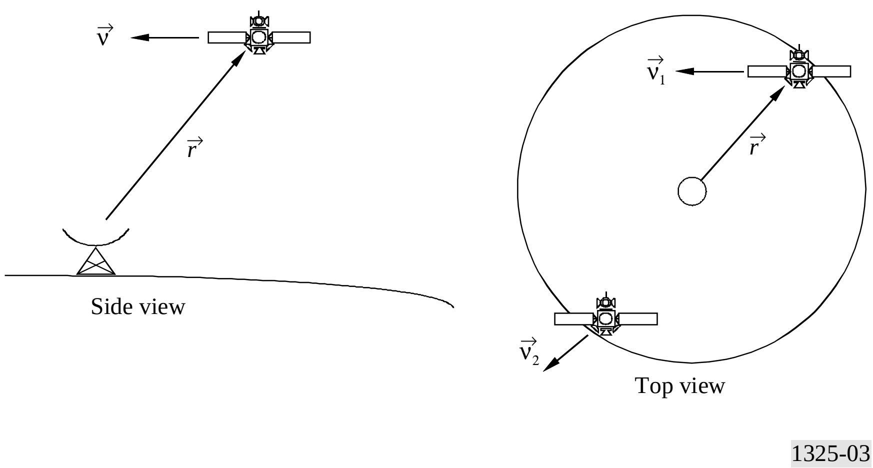
T_w: wanted receiver noise temperature.

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

$$\begin{aligned} I_0/N_0 &= \frac{P_t(R)}{BW_{tx}}\ G_t(\varphi_1)\ G_r(\varphi_2)\left(\frac{\lambda}{4\pi\ R}\right)^2 \frac{1}{k\ T}\ \frac{1}{L_p} \\ &= P_r\ \frac{G_t(\varphi_1)\ G_r(\varphi_2)}{G_t(0)}\left(\frac{R_w}{R}\right)^2 \frac{1}{k\ T}\ \frac{1}{L_p} \end{aligned} \tag{17}$$

FIGURE 3

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



2.5 Input data

The required input parameters for each of the two communication systems are:

2.5.1 Orbit parameters

– Number of space stations

– Number of planes

  – Orbit altitude

  – Inclination of plane

  – Right ascension of the ascending node

  – Anomaly of first space station in each plane (all other space stations in the plane are equally spaced).

2.5.2 Antenna parameters

– Space station

  If non-GSO system:

  – Antenna pattern
  – Maximum transmit gain (dBi)
  – Maximum receive gain (dBi)

  If GSO system:

  – Transmit gain (dBi) in direction of non-GSO earth station
  – Receive gain (dBi) in direction of non-GSO earth station

– Earth station

  – Antenna pattern
  – Maximum transmit gain (dBi)
  – Maximum receive gain (dBi)
  – Location (latitude, longitude).

2.5.3 Operational and computational parameters

– Minimum elevation angle for communication
– Simulation time start
– Simulation time end (see § 2.7)
– Simulation time increment (see § 2.7)
– Precession (see § 2.7)
– If non-GSO system and power control on range is used: the desired receiver power density at the input to the wanted antenna (dB(W/Hz)).

2.6 Output data

The raw output data of the simulation is a time history of the interference to noise level (I_0/N_0) versus time. This data can be analysed to obtain the following information:

– A plot of the interference to noise level, I_0/N_0 (dB), as a function of the per cent time (on a logarithmic scale) that this level is exceeded.
– A time history of a peak interference event (I_0/N_0 versus time).
– The number of events and duration of those events that the interference to noise level is above a pre-defined level. For example let the pre-defined level be –1 dB, then in this case an event starts when the interference level is above –1 dB and ends when it falls below –1 dB, the time that this event is above the –1 dB level is the duration of the event. This will give an indication of how long the interference level will be above a particular level.

2.7 Calculation of the total simulation time, simulation time increment and precession

2.7.1 Introduction

The calculation method described in this section may be used for simulation when the interference is from non-GSO satellite to GSO FSS earth station or from non-GSO earth station to GSO FSS satellite. Calculation methods for other interference cases and for elliptical orbits need further study (see Annex 3).

2.7.2 Simulation time increment

For accurate results the simulation time increment should be as short as possible, but on the other hand the total simulation time should be reasonable. For comparable accuracy in different simulations the time steps can be related to the antenna beamwidth of the interfered systems.

Satellite speed in Earth-fixed coordinates depends on the sub-satellite point latitude but the variation can be neglected for this purpose and the highest speed at equator can be used in the calculation. The angular speed of the satellite, as seen from a point on Earth, is highest when the satellite is moving directly towards or away from that point. The angular speed can be calculated by the following equations:

$$a = \sqrt{(a_s \cos I - a_e)^2 + (a_s \sin I)^2}$$

$$\theta_\varepsilon = \arccos\left(\frac{R}{R + h} \cos \varepsilon\right) - \varepsilon$$

$$\Delta t = \frac{\varphi_{3\,dB}}{N_{hits}\, a} \frac{\sin \theta_\varepsilon}{\cos \varepsilon}$$

where:

- a: satellite angular velocity in Earth-fixed coordinates (geocentric geosynchronous reference coordinate system)
- a_e: Earth rotation angular velocity at the equator
- a_s: satellite angular velocity in space fixed coordinates (geocentric heliosynchronous reference coordinate system)
- I: satellite orbit inclination
- θ_ε: geocentric angle between the interfered earth station and the satellite sub-point when it is at the main beam axis of the earth station
- R: Earth radius
- h: satellite altitude
- ε: earth station antenna elevation
- $\varphi_{3\,dB}$: earth station 3 dB beamwidth
- N_{hits}: number of hits in interfered station 3 dB beamwidth ($N_{hits} = 5$)
- Δt: simulation time increment.

2.7.3 Precession and total simulation time

A satellite of a non-GSO constellation on a circular orbit traces out a path on the Earth's surface. After a time, which is specific to the system, the satellite or another satellite of the constellation returns to the same or practically to the same point. The time between these two cases is the repeat period of the constellation. The repeat periods of different constellations are from a few days to several months.

Total simulation time and the precession should be such that the distribution of the satellite paths along a latitude line is even and there are enough traces passing through the interfered station beamwidth. For a compromise between accuracy and simulation programme run time the number of passes through the area should be the same as the number of hits during one pass (see simulation time increment).

If the repeat period is so short that there will not be the required number of passes through the area, the programme is run for several values of the initial right ascension of the node. The angle between the initial ascensions of the node should correspond to the required spacing between the passes through the area and the number of program runs should be such that the initial right ascensions of one plane reaches the corresponding initial point of the next plane.

If the repeat period is so long that the number of passes through the area is unnecessarily high an artificial precession which gives shorter repeat period can be used. In this case the satellite e.i.r.p. should not be time dependent.

The effect of fractional relation between a cycle of time depending variation of satellite e.i.r.p. and satellite passes through the area needs further study.

ANNEX 2

Description and example of computational methodology

1 Introduction

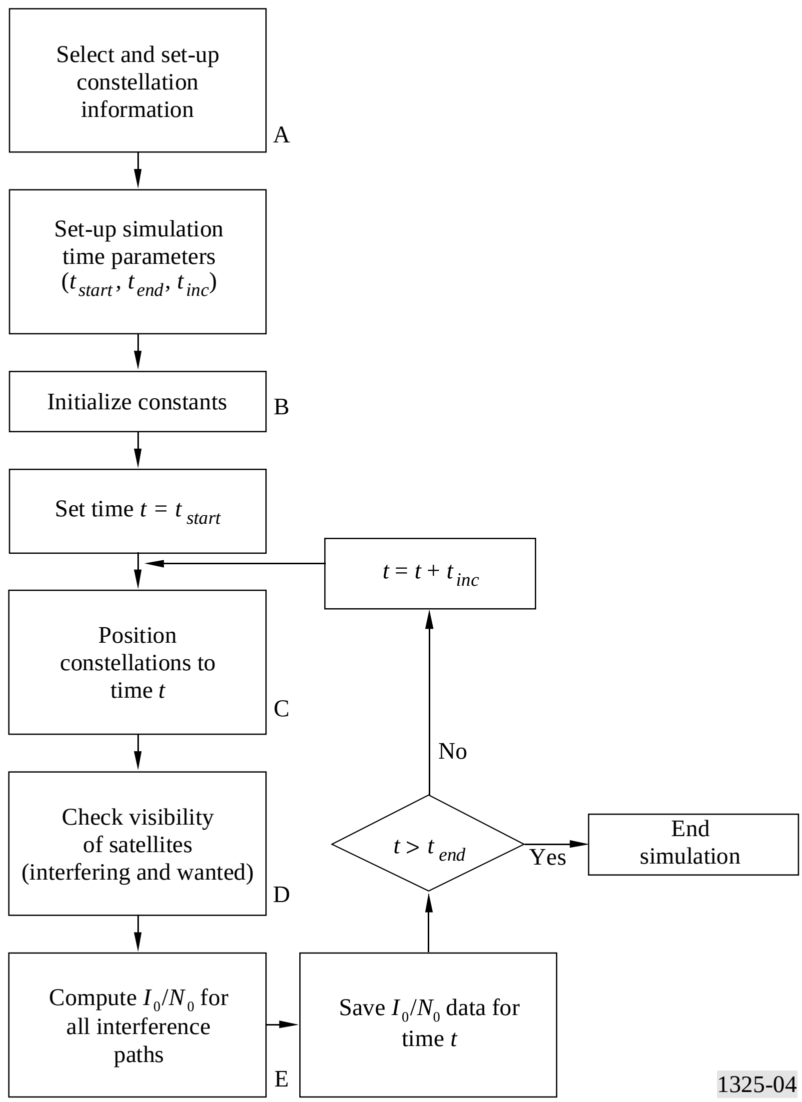
The methodology described in Annex 1 is intended to be implemented via a computer program. This Annex outlines one such implementation along with a demonstration of an example of the results obtained using the geometric analysis defined in Annex 1 to interference analysis between a non-GSO system and a GSO satellite system

2 Description of computation methodology

Shown in Fig. 4 is a top level description of an implementation, the blocks labelled A, B, C, D, E will be treated in more detail. To maximize efficiency this implementation computes interference from the four possible interference scenarios under consideration (Annex 1, § 1) at the same time. A data evaluation process evaluates the I_0/N_0 versus time data for each of the four scenarios, this evaluation process is not considered in this Annex.

FIGURE 4

Implementation of methodology



2.1 Block A – Constellation selection and set-up

Information about the constellations to be simulated are defined in this section of the program see Fig. 4, block A. For this implementation the relevant data required by § 2.5 of Annex 1 is stored in a database and recalled for the simulation for each of the two constellations that are to be simulated. This portion of the program may also allow for variances from the standard set of parameters, such as a different antenna patterns, modification of the location of the earth station associated with each constellation or the peak antenna gains associated with each antenna. For this discussion call the two constellations that are to be simulated Const_1 and Const_2.

This section of the program allocates and initializes the memory required to simulate the constellation. This memory is made of data structures that holds information about the position of the constellation, the velocity of the constellation, and pointing vectors of each satellite of the constellation (antenna boresight information). See Annex 1, § 2.1 for the relevant initial information that needs to be configured for a simple orbit model.

Required data for each earth station is also allocated memory and initialized for each station associated with the constellations. The data structure of the earth station keeps track of which satellite of the wanted constellation the earth station is currently communicating with, the locations of possible interfering satellites, and the minimum required elevation angle that the earth station can communicate (which is related to the maximum range to a satellite for communication to occur and also stored in the data structure). The initial satellite that the earth station is in communication with is also initialized in this portion of the program.

2.2 Block B – Initialize program constants

To promote efficient use of resources, constants of the simulation are factored out of the equation used to compute I_0/N_0. For example consider equation (1), the variables of this equation that do not change with respect to time (assuming that power control on range is not employed, § 2.4.2 of Annex 1) are:

P_t: available transmit power (W)

BW_{tx}: transmit bandwidth (Hz)

λ: wavelength of transmitter (m)

k: Boltzmann's constant (1.38×10^{-23} J/K)

T: noise temperature (K)

L_p: polarization isolation factor.

Therefore, for each interference path the following four constants can be computed before the simulation starts to step on each time increment:

TABLE 1

Link constants of simulation

Interference path	Constant
Const_1 downlink → Const_2 downlink	$C_{12d} = \frac{P_{t\,1d}}{BW_{tx\,1d}} \frac{\lambda^2}{4\pi} \frac{1}{k\,T_{2d}} \frac{1}{L_{p\,12d}}$
Const_1 uplink → Const_2 uplink	$C_{12u} = \frac{P_{t\,1u}}{BW_{tx\,1u}} \frac{\lambda^2}{4\pi} \frac{1}{k\,T_{2u}} \frac{1}{L_{p\,12u}}$
Const_2 downlink → Const_1 downlink	$C_{21d} = \frac{P_{t\,2d}}{BW_{tx\,2d}} \frac{\lambda^2}{4\pi} \frac{1}{k\,T_{1d}} \frac{1}{L_{p\,21d}}$
Const_2 uplink → Const_1 uplink	$C_{21u} = \frac{P_{t\,2u}}{BW_{tx\,2u}} \frac{\lambda^2}{4\pi} \frac{1}{k\,T_{1u}} \frac{1}{L_{p\,21u}}$

In this Table the subscript 1d corresponds to constellation 1 downlink, 2d corresponds to constellation 2 downlink, 1u corresponds to constellation 1 uplink and 2u to constellation 2 uplink. The polarization isolation factor corresponds to the transmit/receive combination, i.e. 12d indicates the polarization isolation between the downlink transmitter of constellation 1 to the downlink transmitter of constellation 2.

Once these constant factors are computed then for efficiency in the program the following equations are used to compute the I_0/N_0 level in each time step (block E).

TABLE 2

I_0/N_0 computation using link constants

Interference path	Interference level
Const_1 downlink → Const_2 downlink	$I_0/N_0 = \mathrm{C}_{12d} \dfrac{G_{t\,1d}(\varphi_1)\,G_{r\,2d}(\varphi_2)}{4\pi\left(R_{12d}\right)^2}$
Const_1 uplink → Const_2 uplink	$I_0/N_0 = \mathrm{C}_{12u} \dfrac{G_{t\,1u}(\varphi_1)\,G_{r\,2u}(\varphi_2)}{4\pi\left(R_{12u}\right)^2}$
Const_2 downlink → Const_1 downlink	$I_0/N_0 = \mathrm{C}_{21d} \dfrac{G_{t\,2d}(\varphi_1)\,G_{r\,1d}(\varphi_2)}{4\pi\left(R_{21d}\right)^2}$
Const_2 uplink → Const_1 uplink	$I_0/N_0 = \mathrm{C}_{21u} \dfrac{G_{t\,2u}(\varphi_1)\,G_{r\,1u}(\varphi_2)}{4\pi\left(R_{21u}\right)^2}$

In this Table for example in the Const_1 downlink → Const_2 downlink path the variables are:

$G_{t\,1d}(\varphi_1)$: transmit gain of Const_1 downlink transmit antenna (relative intensity)

$G_{r\,2d}(\varphi_2)$: receiver gain of Const_2 downlink receive antenna (relative intensity)

R_{12d}: range between Const_1 transmitter (downlink) to Const_2 receiver (downlink) (m).

This section requires modification when power control on range is performed by one or both of the constellations under study.

2.3 Block C – Position constellation to time *t*

For each time step before any calculation of interference levels the position of the constellation is required to be computed. For this example the orbit model described in Annex 1, § 2.1 is employed. The velocity vector and position vector of each satellite is computed and stored in the data structure defined in block A of the simulation. The range between the earth station and the satellites of the constellation it is trying to communicate with is also computed in this step.

2.4 Block D – Check visibility of satellites (interfering and wanted)

This section determines which satellite is communicating to the earth station. First the satellite that the earth station was communicating with in the previous time step is checked to see if the earth station is able to continue communication (i.e. the range between the earth station and the satellite is compared to the maximum possible range a satellite can be to continue communications, if larger then the communications need to be established with an new satellite). If communication with a new satellite needs to be established, then the algorithm shown in Annex 1, § 2.4.1 is used to select a new satellite for communication with the earth station.

Once each earth station has computed which satellite it is communicating with, the parameters associated with the interference between the satellite systems can be computed. This requires computing the range of the four interference paths and the off-axis angles associated with the interference paths (see Fig. 1).

2.5 Block E – Compute I_0/N_0 for all interference paths

The computation of the interference levels are now possible because all relative information has been computed in previous steps. The interference level for four interference paths between the two constellations are performed in this section (Annex 2, Table 2). The interference levels are stored for later analysis.

3 Example of non-GSO and GSO interference methodology

This section demonstrates an example of the results obtained using the geometric analysis defined by this methodology to interference analysis between a non-GSO system and a GSO satellite system. The example presented in this Annex is for the LEO-A system and a GSO system. The input parameters for the constellations are in Table 3.

TABLE 3

Non-GSO and GSO simulation input parameters

Input parameter	Non-GSO	GSO
Number of space stations	66	1
Number of planes	6	1
Orbit altitude (km)	780.6	35 785.4
Inclination (degrees)	84.6	0
Right ascension of ascending node (degrees)	0.0; 31.6; 63.2; 94.8; 126.4; 158.0	261
Anomaly of first space station in each plane (degrees)	0.0; 16.35; 2.6; 18.95; 5.2; 21.55	0
Minimum elevation (degrees)	5	–
Space station antenna pattern	RR Appendix 29 [S8]	–
Space station maximum transmit gain (dBi)	26.9	41.5(1)
Space station maximum receive gain (dBi)	30.1	41.5(2)
Earth station north latitude (degrees:min:s)	33:26:54	
Earth station west longitude (degrees:min:s)	112:04:24	
Earth station antenna pattern	RR Appendix 29 [S8]	
Earth station maximum transmit gain (dBi)	56.3	44.5
Earth station maximum receive gain (dBi)	53.2	43.0

(1) Space station transmit gain towards non-GSO earth station, 41.5 dBi is edge of coverage gain for narrow spot beam.

(2) Space station receive gain towards non-GSO earth station, 41.5 dBi is edge of coverage gain for narrow spot beam.

Table 4 shows the radio-frequency parameters for non-GSO and GSO links. The missing portions of the table is information that is not required for the simulation. The GSO system no power control on range is employed, therefore the P_r row is not required, similarly for the non-GSO system employing power control on range P_t, BW_{tx} and P_t/BW_{tx} are not required.

The results shown in Figs. 5-10 are for a simulation over 49 days sampled every 2 s. This results in over 2.1 million sample points.

TABLE 4

System radio-frequency parameters

Parameter	Non-GSO space station	Non-GSO earth station	GSO space station	GSO earth station
P_t (dBW)	–	–	12.5	–5.2
BW_{tx} (MHz)	–	–	125	0.5
P_t/BW_{tx} (dB(W/Hz))	–	–	–68.5	–62.2
P_r (dB(W/Hz))	–216.1	–243.6	–	–
L_p	1	1	1	1
Transmit λ (m)	0.0154	0.0103	0.0154	0.0103
T (K)	1 295.4	731.4	575	275

Shown in Figs. 5 and 6 is the interference ratio versus the per cent time that level occurs. Figure 5 shows the interference ratio of the non-GSO network into the GSO network, Fig. 6 shows the interference ratio of the GSO network into the non-GSO network.

Shown in Figs. 7 and 8 is the number of events and duration of those events that the interference ratio is greater than a pre-specified level. Figure 7 is effect of the non-GSO network into the GSO network when an event is defined as occurring when I_0/N_0 is above –16 dB, Fig. 8 is the effect of the GSO network into the non-GSO network when an event is defined as occurring when I_0/N_0 is above –1 dB.

Shown in Figs. 9 and 10 is the time history of the interference ratio for interference from the GSO uplink into the non-GSO uplink. These graphs are shown during a period of time that the interference level reaches it peak. Figure 9 is over a time scale of 1 h, the tics on the time axis are shown every 15 min. Figure 10 examines the peak interference event shown in Fig. 9.

FIGURE 5

Interference from non-GSO network into GSO network

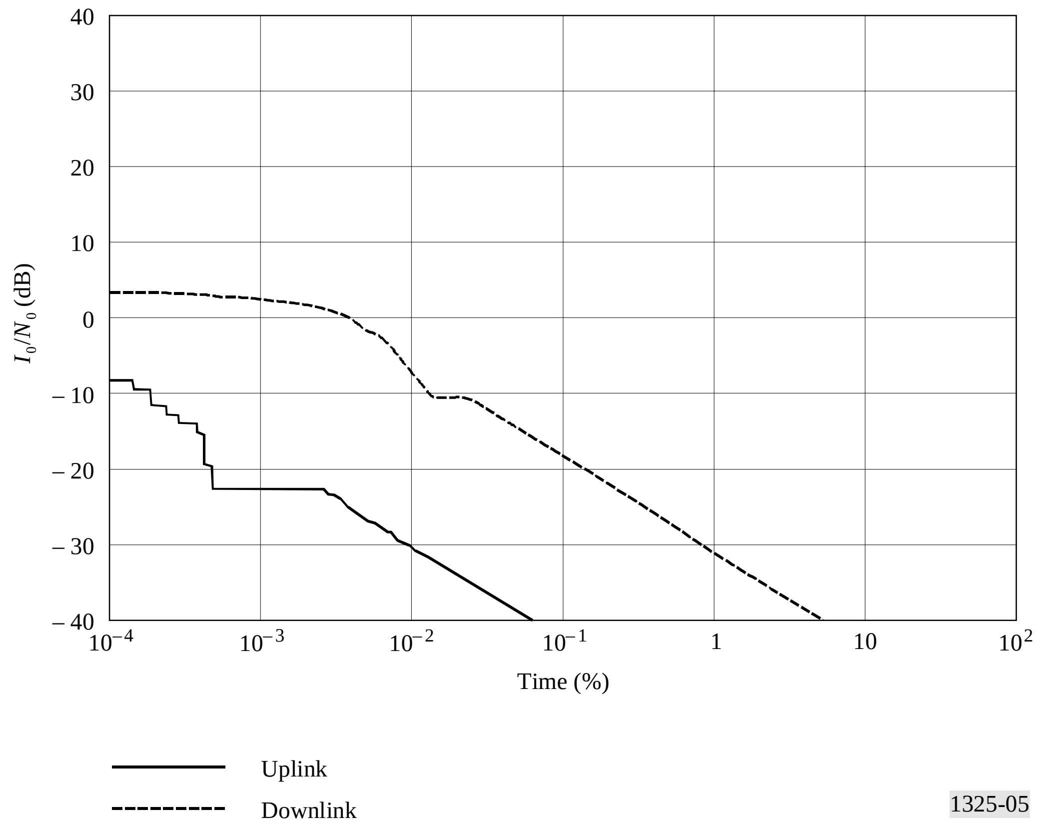


FIGURE 6

Interference from GSO network into non-GSO network

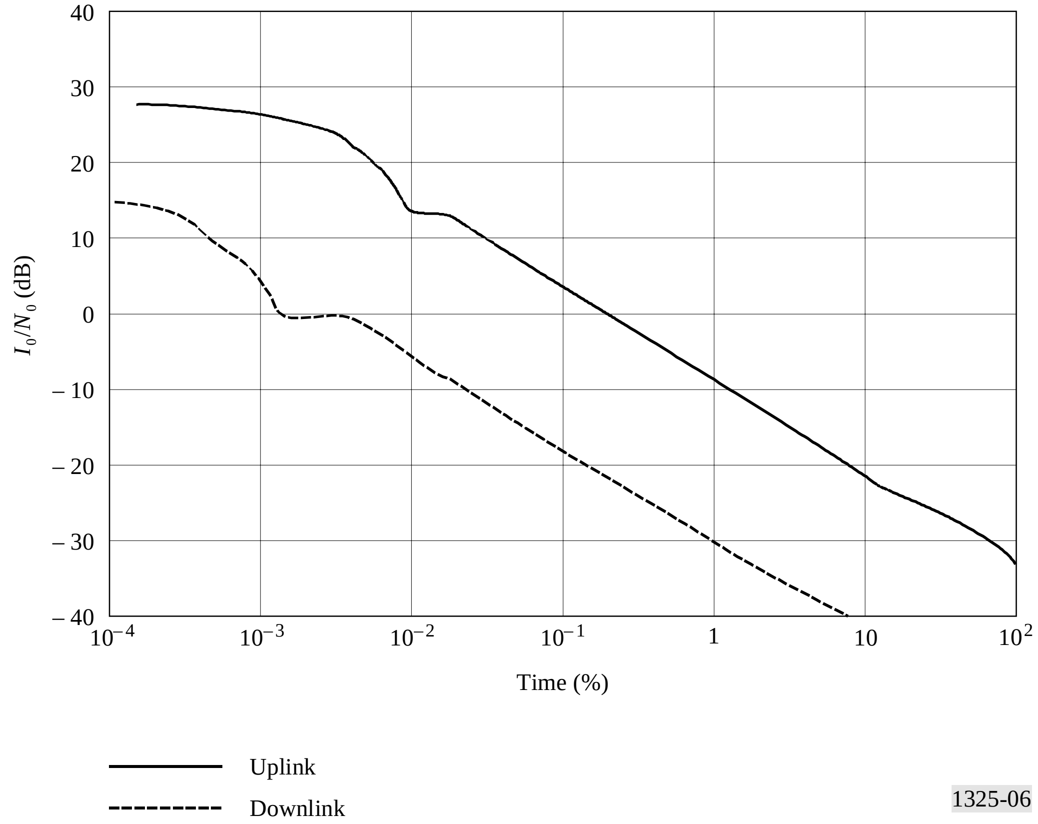


FIGURE 7

Duration of interference events from non-GSO network into GSO network

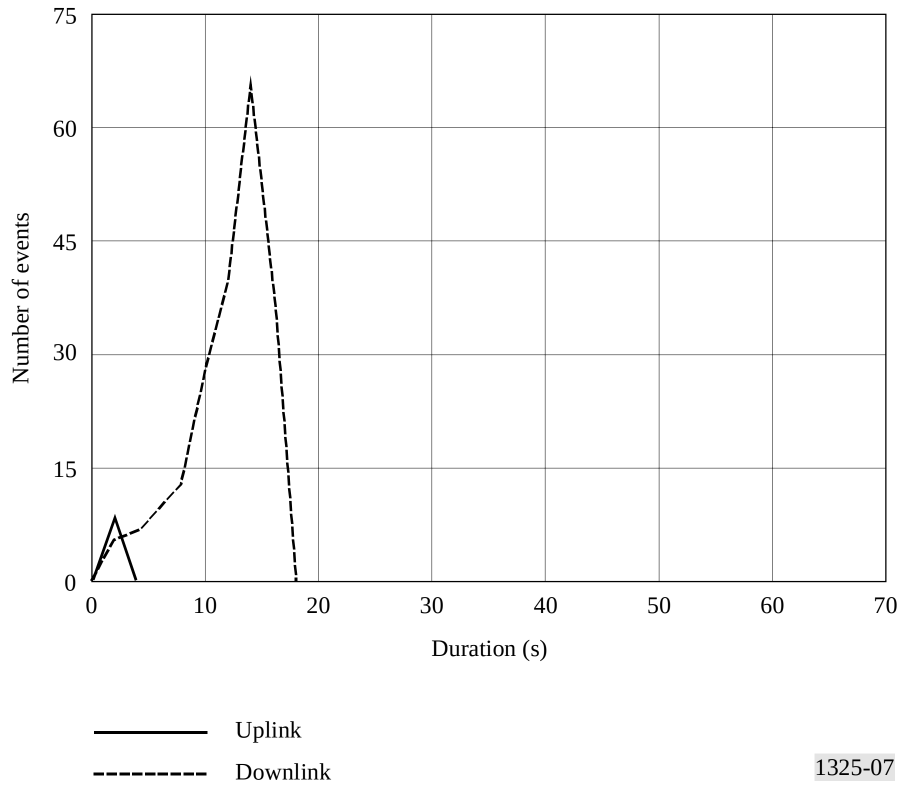


FIGURE 8

Duration of interference events from GSO network into non-GSO network

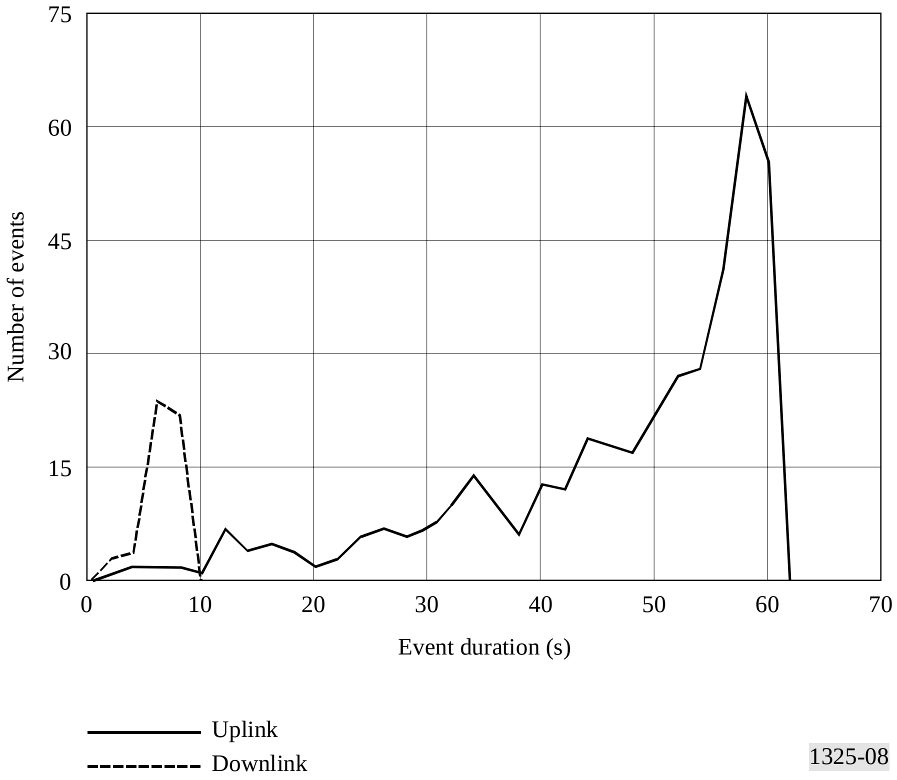


FIGURE 9

Time history of interference from GSO network into uplink of non-GSO network

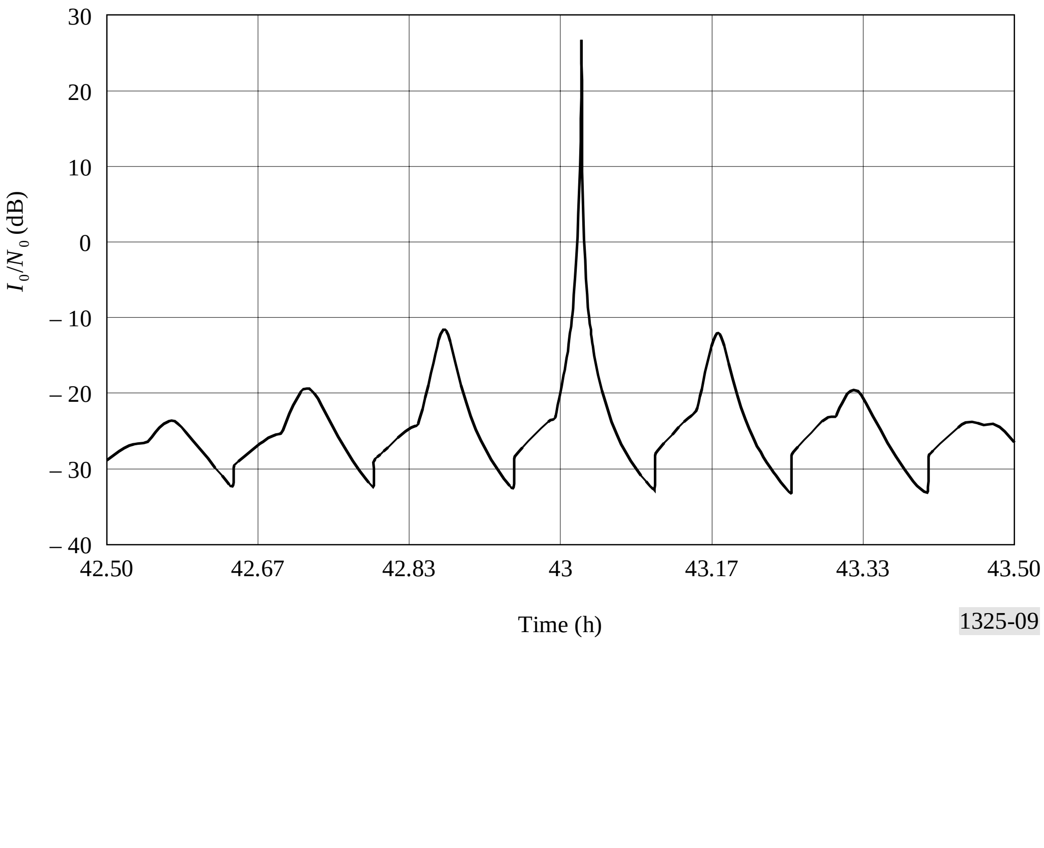
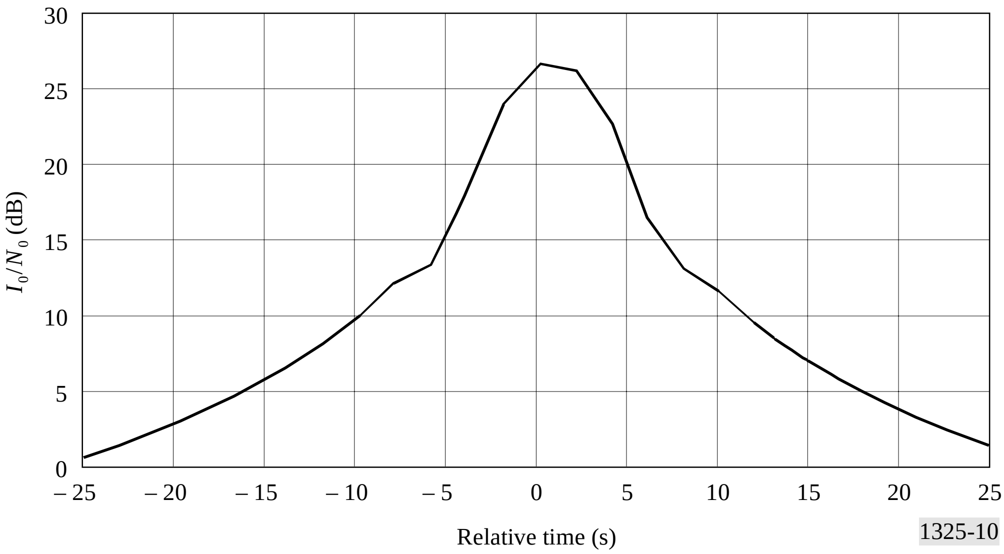


FIGURE 10

Detail of peak event from Fig. 9, centred at time t = 43 h, 74 s



3.1 Validation of interference results

To confirm that the interference levels computed in § 3 are within bounds of what is expected a comparison with a known check point is desired. A convenient check point is to compare the maximum interference levels shown in Figs 5 and 6 with the interference level computed when the non-GSO satellite is directly in line with the path between the GSO earth station and the GSO satellite. Shown in Table 5 is the interference computation for the case of the non-GSO network interfering with the GSO network. The peak values of Fig. 5 and the interference value computed in Table 5 are the same.

TABLE 5

In-line computation of interference level from GSO network into non-GSO network

	Non-GSO uplink into GSO uplink	Non-GSO downlink into GSO downlink
P_r (dB(W/Hz))	–216.1	–243.6
Wanted path length (km)	998.7	998.7
Wanted path loss (dB)	–181.7	–178.4
Wanted transmit gain (dBi)	56.3	26.9
P_t/BW_{tx} (dB(W/Hz))	–90.7	–92.4
Wanted transmit gain (dBi)	56.3	26.9
Interference path length (km)	37 165.8	998.7
Interference path loss (dB)	–213.1	–178.4
L_p	1	1
Receive gain (dBi)	41.5	43.0
I_0 (dB(W/Hz))	–206.0	–200.6
Receiver noise, T (K)	575	275
N_0 (dB(W/Hz))	–201.0	–204.2
I_0/N_0 (dB)	–5.0	3.6

Shown in Table 6 is the interference computation for the GSO network interfering with the non-GSO network. The peak values of Fig. 6 and the interference value computed in Table 6 are the same.

TABLE 6

In-line computation of interference level from GSO network into non-GSO network

	GSO uplink into non-GSO uplink	GSO downlink into non-GSO downlink
P_t/BW_{tx} (dB(W/Hz))	–62.2	–68.5
Transmit gain (dBi)	44.5	41.5
Interference path length (km)	998.7	37 165.8
Interference path loss (dB)	–181.7	–209.6
L_p	1	1
Receive gain (dBi)	30.1	53.2
I_0 (dB(W/Hz))	–169.3	–183.4
Receiver noise, T (K)	1 295.4	731.4
N_0 (dB(W/Hz))	–197.5	–200.0
I_0/N_0 (dB)	28.2	16.6

ANNEX 3

Continuing work programme

The following is an outline for further work on this Recommendation.

1) Adjust the run time to be that of the first repetition of the non-GSO subsatellite ground track when the other network is a GSO, and/or provide a discussion of the initial conditions and suitable run time for various constellations to insure an unbiased statistical output.

2) Include a discussion of the appropriate time step selection for various constellations. This would be a function of the constellation altitude(s) and antenna size (beamwidth).

3) Further study is required to define the amount of isolation that can be assumed between the transmitter and receiver due to differing polarization. These studies should account for items such as atmospheric effects and systems that use phase comparative methods for tracking antennas.

4) Use of space station selection techniques when multiple satellite are in view of an earth station. Include a discussion of other techniques under consideration by other operators that may address interference avoidance or diversity techniques.