RECOMMENDATION ITU-R M.1143-3*

System specific methodology for coordination of non-geostationary space stations (space-to-Earth) operating in the mobile-satellite service with the fixed service

(Questions ITU-R 201/8 and ITU-R 118/9)

(1995-1997-2003-2005)

Scope

This Recommendation describes methodologies and reference fixed system characteristics for implementation of the System Specific Methodology (SSM) of Appendix 5 of the Radio Regulations (RR), which allows a detailed assessment of the need to coordinate frequency assignments for non-geostationary (non-GSO) space stations (space-to-Earth) and receiving systems in the fixed service (FS). The Recommendation also describes a possible methodology for use in bilateral coordination of non-GSO mobile-satellite service (MSS) transmitting space stations with stations of the FS.

The ITU Radiocommunication Assembly,

considering

a) that certain space-to-Earth mobile-satellite service (MSS) allocations are shared on a co-primary basis with the fixed service (FS) in the range 1-3 GHz;

b) that non-geostationary-satellite orbit (non-GSO) MSS systems have individually unique system characteristics particularly in relation to orbital parameters, transmission characteristics, altitude, and elevation angle;

c) that consideration of the characteristics mentioned in *considering* b) may help in facilitating sharing with FS, when the thresholds set forth in the Radio Regulations (RR) are exceeded;

d) that analytical methods, interference criteria, and system characteristics exist describing the FS systems in the shared bands,

recommends

1 that when the thresholds set forth in RR Appendix 5 are exceeded, the system specific methodology described in Annex 1 be used to assess the need for coordination of non-GSO MSS networks (space-to-Earth) with FS assignments in the frequency bands 1 518-1 525 MHz, 1 525-1 530 MHz, 2 160-2 170 MHz, 2 170-2 200 MHz, 2 483.5-2 500 MHz and 2 500-2 535 MHz;

2 that, in detailed coordination, the methodology given in Annex 3 may be used to assess the level of interference into actual FS links.

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* The revision of this Recommendation was jointly prepared by Radiocommunication Study Groups 8 and 9, and any further revision will also be undertaken jointly.

Annex 1*

System specific methodology to be used by the standard computation program (SCP) in determining the need for coordination of non-GSO MSS systems in the space-to-Earth MSS allocations with the FS

1 Introduction

An administration with existing or planned terrestrial FS networks is considered to be potentially affected by emissions from non-GSO MSS space stations if the relevant coordination threshold criteria for analogue FS and/or digital FS systems given in RR Appendix 5 are exceeded.

The SCP needs to be developed for use in a detailed assessment of the need to coordinate frequency assignments to transmitting non-GSO MSS space-stations of one constellation (single-entry) with frequency assignments to receiving FS stations in a FS network of a potentially affected administration. The SCP takes into account more specific characteristics of the non-GSO MSS system and reference FS characteristics. Throughout this Annex, mention of FS characteristics are understood to imply reference characteristics. The specific reference FS systems of those given in Annex 2 to be used should correspond to the types of actual FS systems in use in the administration concerned.

The SCP requires as input a characterization of the reference FS system as well as that for the non-GSO MSS satellite system as described in § 2.

The SCP computes using the methodology as described in § 3 on the basis of the above data relevant statistics of interference caused by the non-GSO MSS constellation to the given reference FS system.

If the applicable maximum interference criteria given in § 4 are not exceeded then (unless otherwise subsequently advised by the administration responsible for the FS systems), coordination might not be necessary.

2 FS and MSS data requirements

2.1 Position of FS station and determination of worst FS pointing azimuth

For a given administration the SCP is exercised for a suitable sample of latitudes (e.g. every 5°) covering the latitude range covered by the territory of that administration. For a given non-GSO MSS constellation and for a victim FS station at a given latitude, it is possible to determine the worst azimuth pointing direction for the FS station in terms of maximum potential for receiving interference from the non-GSO constellation. The SCP is thus exercised for the worst FS trend-line azimuth pointing direction.

The formulae to be used for the calculation of the worst azimuth can be found in § 5 of Appendix 3 to Annex 1 of Recommendation ITU-R S.1257.

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* The standard computational programme needs to be further developed with joint participation of experts of Radiocommunication Study Groups 8 and 9. The methodology in this Annex may also need to be updated to reflect the results of this development work.

2.2 Analogue FS system data

It is assumed that there are M = 13 co-frequency analogue stations on a route centred at a given latitude with a trend-line corresponding to the worst azimuth for the given non-GSO MSS constellation. The routes span a distance of D = 600 km with stations spaced exactly d = 50 km apart. The azimuth angle for each station is specified by the given worst azimuth trend-line angle and a variable angle that is uniformly distributed between $V = \pm 12.5°$. Each FS station is assumed to use a high gain antenna pointed at the next station at an elevation angle of 0°. The point-to-point FS station antenna gain conforms to the antenna pattern having averaged sidelobe levels as defined in Recommendation ITU-R F.1245.

The characteristics of the reference analogue FS system are taken to be as given in Appendix 2 to Annex 2, or if available, as obtained from FS data notified by the administration to the Radiocommunication Bureau (BR) and filed in the BR database.

2.3 Digital FS system data

Only one digital FS receiver is required for the analysis as opposed to a complete route. The FS station is positioned at a given latitude pointing in the worst azimuth direction. The FS station is assumed to use an antenna at an elevation angle of 0°. The FS station antenna gain conforms to the antenna pattern having averaged sidelobe levels as defined in Recommendation ITU-R F.1245.

The characteristics of the reference digital FS system are taken to be as given in Appendix 1 to Annex 2, or if available, as obtained from FS data notified by the administration to the BR and filed in the BR database.

2.4 Non-GSO MSS data

Full information on the following parameters is required to characterize non-GSO/MSS networks:

– centre frequency,
– number of spot beams,
– maximum power of one satellite,
– spot beam characteristics.

The detailed list of parameters is given in Appendix 1 to Annex 1.

Full information is required on the maximum e.i.r.p. density/4 kHz and 1 MHz in any active beam of any satellite with potential carrier frequency overlap with the assumed FS receiver at all sample points during the time that any given satellite is visible to the FS system. This information should implicitly reflect the intra-satellite and inter-satellite frequency reuse plans as well as satellite spot beam traffic loading taking into account the expected geographical distribution of traffic for the MSS system.

In general if a code division multiple access/frequency division multiple access (CDMA/FDMA) access scheme is employed on the non-GSO MSS constellation, then potentially all beams of all visible satellites may operate co-frequency. However if a time division multiple access (TDMA)/FDMA or FDMA access scheme is employed on the non-GSO MSS constellation, then only a subset of beams on visible satellites will operate co-frequency.

Part 1 of Appendix 2 to Annex 1 provides a default/baseline methodology for modelling satellite spot beam loading. Part 2 of Appendix 2 to Annex 1 provides a detailed methodology for modelling of satellite spot beam loading for CDMA and TDMA systems in cases where the necessary traffic data for the MSS system is made available. Since projections of MSS traffic data for that system are required, the application of Part 2 of Appendix 2 to Annex 1 methodology will normally require consultation with concerned administrations.

For all types of non-GSO MSS systems (TDMA, FDMA, or CDMA), all visible satellites of the constellation should be considered in the computation of aggregate interference to the victim FS station, but traffic should be distributed among these satellites.

3 Methodology for calculating interference

The SCP simulates the interference into the FS network from the non-GSO satellite constellation(s) as follows.

3.1 Calculation loop

The programme calculates the position and velocity vectors of the satellites of the non-GSO satellite system and stations of FS system at each time instance.

At each time sample the SCP calculates the total interfering power at each victim FS station from all active spots from all visible and appropriately selected MSS satellites. If the FS receiver bandwidth does not completely overlap the MSS signal the interfering power is then scaled by the bandwidth factor. In the analogue case, this interfering power is scaled to 4 kHz.

The aggregate interference power from all active spot beams of all visible satellites visible to the FS station(s) is determined using the following equation:

$$I = \sum_{k=1}^{M} \sum_{i=1}^{N} \sum_{j=1}^{S} \frac{E_{jk}}{L_{ik}} G^3\left(\alpha_{ijk}\right) G^4\left(\theta_{ik}\right) \frac{B_w}{B_{ij}} \frac{1}{F_k} \frac{1}{P_{ijk}\, A} \qquad (1)$$

where:

- I: interference power (W)
- i: 1 of N satellites being considered in the interference calculation for the k-th FS station
- j: 1 of S active spot beams on the visible selected MSS satellite with frequency overlap to the current FS station receiver, taking account of the satellite spot beam frequency reuse pattern
- k: 1 of M FS stations on a FS route
- E_{jk}: maximum e.i.r.p. density per reference bandwidth input to the antenna for the j-th active spot beam in its boresight direction of the i-th visible selected satellite (W/reference bandwidth)
- B_{ij}: reference bandwidth for the interfering signal from the j-th active spot beam of the i-ths visible selected satellite (kHz)
- $G^3(\alpha_{ijk})$: antenna discrimination of the j-th active spot beam of the i-th visible selected satellite towards the k-th FS station
- α_{ijk}: angle between the boresight pointing vector j-th active spot beam of the i-th visible selected satellite to the k-th FS station (degrees)
- L_{ik}: free space loss at the given reference frequency from the i-th visible selected satellite to the k-th FS station
- $G^4(\theta_{ik})$: k-th FS station's antenna gain in the direction of the i-th visible selected satellite
- θ_{ik}: angle between the k-th station's antenna pointing vector and the range vector from the k-th station and the i-th visible selected satellite (degrees)
- B_w: receiver bandwidth of the victim FS station (4 kHz or 1 MHz)

A: averaging factor to take into account MSS carrier frequency, power or time variability

F_k: feed loss for the k-th FS station

P_{ijk}: polarization advantage factor between j-th spot beam of the i-th MSS satellite and k-th FS station.

The averaging factor A may be applicable to reflect dynamic frequency, time or power variations in MSS traffic levels in a given reference bandwidth (due to, for example, use of voice activation, duty cycle, power control, etc. as appropriate for the concerned non-GSO MSS system). Further study is required in this respect.

The polarization advantage P_{ijk} is to be used only if the i-th MSS satellite is within the 3 dB beamwidth of the k-th FS station antenna and the k-th FS station is within the 3 dB beamwidth of the j-th spot beam of the i-th MSS satellite. P_{ijk} can be calculated according to the formula of Note 7 of Recommendation ITU-R F.1245.

An improvement of the simulation run time can be obtained by excluding from the interference calculation beams for which α_{ijk} is greater than a given "exclusion" angle.

3.2 Size and number of steps in the calculation loop

On the one hand the duration of the program must be as quick as possible so that the user does not have to wait a long time for the results, on the other hand it is necessary to have enough samples at appropriate time intervals to have accurate results, taking into account all the interference received at the receiver of the fixed station.

3.2.1 Time increment

The following formulae are used, and the derivation of the formulae are fully detailed in Appendix 3 to Annex 1. As the satellite speed is about the same at the equator and at higher latitudes, the calculation of simulation time step Δt is made for a satellite at the equator taking into account the Earth's rotation, satellite inclination and FS station antenna elevation. The worst azimuth for fractional degradation of performance (FDP) or the azimuth of horizontal movement is not used in calculation of Δt.

$$\omega = \sqrt{(\omega_s \cos I - \omega_e)^2 + (\omega_s \sin I)^2}$$

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

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

where:

ω: satellite angular velocity in Earth fixed coordinates (geocentric geo-synchronous reference coordinate system)

ω_s: satellite angular velocity in space fixed coordinates (geocentric helio-synchronous reference coordinate system)

ω_e: Earth rotation angular velocity at the equator

I: satellite orbit inclination

θ_ε: geocentric angle between FS station and satellite

R: Earth radius

h: satellite altitude

ε: FS antenna elevation angle

φ_{3dB}: FS station 3 dB beamwidth

N_{hits}: number of hits in FS station 3 dB beamwidth (N_{hits} = 5)

Δt: simulation time step.

3.2.2 Precession rate and total simulation time

As time evolves, the subsatellite point of an MSS satellite circular orbit traces out a path on the surface of the Earth. After a number of complete orbits, this path will return to the same, or almost the same, point on the surface of the Earth. The elapsed time for this occurrence is the repeat period of the satellite. For some constellations, a repeat period can be defined based on another satellite of the constellation returning to the same point. In these cases the elapsed time between the two occurrences can be taken as the repeat period of the constellation.

Some constellations have short repeat periods of several days (typically less than one week) whereas other constellations have very long periods, such as many months. These great differences require special consideration because FS systems must meet performance requirements in any month. Two ways of handling these discrepancies were identified.

For constellations with repeating periods of less than one week, the solution could be to use the repeating period of the constellation as the total simulation time and to run the program for several values of the right ascension (initial position of the ascending node of orbital plane number 1) ranging from a longitude of 0° to a longitude equalling the angular distance between two consecutive orbital planes. This would ensure that the worst case from the FS point of view would be identified. Further study is needed to assess the value of the longitude incremental step, which is related to the number of time increments during which a satellite is within the main beam of a FS station (see § 3.2.1).

For constellations with very long repeat periods, using this period as the total simulation time could lead to correspondingly long central processing unit (CPU) running time. Furthermore the paths on the Earth surface would be uniformly distributed and the longitude resolution (longitudinal distance between two neighbour paths) would be unnecessarily small. In such cases one should use an artificial precession rate which would lead to a longitude resolution of the same order of magnitude as the longitude incremental step described in the previous case. The artificial precession rate would induce an artificial constellation period, significantly shorter than the real one, thus reducing the CPU running time. However, it is necessary to evaluate simulation results for several one month periods within the repeat cycle to assess the variability of the FDP on a month-to-month basis.

4 Applicable interference criteria

4.1 Analogue FS

The SCP calculates the interference statistics based on the aggregate interference noise power accumulated over all stations as calculated at each sample point. The interference statistics indicate the probability that the aggregate received interference noise power exceeds a given interference level.

The simulation described in Annex 2 of Recommendation ITU-R F.1108, which is based in part on the methodology of Recommendation ITU-R SF.766, may be used for this purpose with the following parameters:

N_t: thermal noise power introduced in a 4 kHz telephony channel at a station = 25 pW psophometrically weighted at a point of zero relative level (pW0p)

T: station receiving system noise temperature (K)

L_f: feeder loss (dB).

In order to assess if coordination is triggered or not, the distribution of interference power is compared with respect to the two point interference objective mask, consisting of a long-term and a short-term interference objective given in Recommendation ITU-R SF.357.

4.2 Digital FS system

For the digital FS case the SCP calculates the FDP for the digital station as in Annex 3 of Recommendation ITU-R F.1108:

$$FDP = \sum_{I_i = min}^{max} \frac{I_i \, f_i}{N_T} \tag{2}$$

where:

I_i: interference power in FS receiver bandwidth B_w

f_i: the fractional period of time that the interference power equals I_i

N_T: station receiving system noise power level

$= k \, T \, B_w$

where:

k: Boltzmann's constant

T: station receiving system noise temperature (K)

B_w: FS receiver bandwidth (usually FDP is calculated in a 1 MHz reference bandwidth).

In order to assess if coordination is triggered or not with respect to digital FS systems, the computed FDP is compared with respect to the applicable criterion of 25%.

Appendix 1
to Annex 1

List of parameters for the MSS

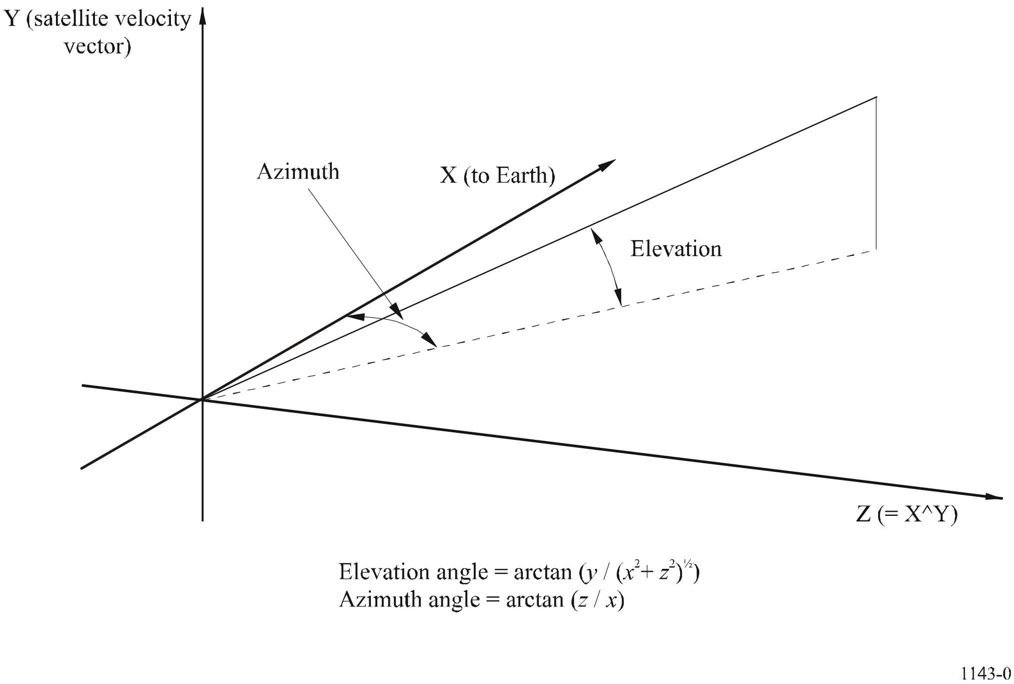
– Orbit parameters:
  - orbit radius (km),
  - inclination (degrees),
  - number of planes,
  - number of satellites per plane,

  - phasing of satellites between two consecutive planes (degrees),
  - ascending node longitude of one plane at time 0,
  - angles between planes (if not specified, planes are evenly distributed).

  For elliptical orbits:
  - argument of perigee,
  - mean anomaly,
  - mean motion and epoch.
- Number of spot beams
- Maximum power of one satellite (W)
- Spot beam characteristics:
  - azimuth angle (degrees) (see Fig. 1),
  - elevation angle (degrees) (see Fig. 1),
  - major axis (degrees),
  - minor axis (degrees),
  - major axis to azimuth (degrees),
  - maximum antenna gain (dBi),
  - antenna pattern: for example characterized by a parabolic roll-off with a floor, any of the applicable World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Utilizing It (Geneva, 1988) (WARC ORB-88) or the World Broadcasting-Satellite Administrative Radio Conference (Geneva, 1977) (WARC BS-77) satellite antenna patterns, or as given in Recommendation ITU-R S.672,
  - maximum beam e.i.r.p. (dBW) in 4 kHz and 1 MHz,
  - maximum beam bandwidth (kHz),
  - mean beam e.i.r.p. (dBW) in 4 kHz and 1 MHz,
  - mean beam bandwidth (kHz),
  - minimum beam e.i.r.p. (dBW) in 4 kHz and 1 MHz,
  - minimum beam bandwidth (kHz),
  - polarization,
  - centre frequency of the beam (MHz).

FIGURE 1

Non-GSO reference frame and azimuth/elevation angle definition



Appendix 2
to Annex 1

Part 1

Each spot beam of each satellite is to be assumed to have frequency overlap with the FS receiver and to be loaded to a level given by a random variation between the maximum and mean traffic loading levels.

NOTE 1 – The mean MSS traffic loading for any spot beam is obtained by dividing the total instantaneous maximum satellite traffic capacity by the number of spot beams on the satellite.

Part 2

A major factor in the calculation of the level of interference into FS systems from a MSS system is the e.i.r.p. per spot beam on the satellite. The SCP methodology described in Annex 1 is based on the e.i.r.p. of each beam being selected at random between the MAX and the MEAN levels. A better assessment of the level of the MSS signal into the FS could be made by taking into account traffic loading on the satellite.

While the traffic level per beam varies according to demand, certain constraints will limit the e.i.r.p. per spot beam such as:

– total loading that can be carried by one particular spot beam;

– total loading that can be carried by one particular satellite.

Traffic models should take into account concerns that traffic levels in a particular spot beam could be higher than the average, while not resulting in unrealistic situations such as when all spot beams of all satellites are operating fully loaded.

Two basic methodologies, pending the technology access, are used to calculate e.i.r.p. per spot beam based on input data.

Methodology for TDMA system

Input data is defined by dividing the world into equally sized cells in latitude and longitude. Each cell has parameters associated with it that can be used to calculate the level of traffic within that cell at any time during the simulation. These parameters would be supplied by the MSS operators based on predicted demand. The traffic can then be allocated to spot beams, potentially shared between multiple visible satellites, taking into account total traffic allowed per beam and satellite.

Methodology for CDMA system

The level of traffic in each country is defined as one of high, medium or low. These parameters would be supplied by the MSS operators based on predicted demand. The spot beam that covers each country is then loaded with an e.i.r.p. based upon this traffic level, taking into account total traffic allowed per beam and satellite.

The details of the steps of the two methodologies are described in following sections.

Step 1: Traffic methodology for TDMA system

Traffic levels are determined from two sources:

– a geographic traffic file, specified as a grid containing for each (latitude, longitude) cell a peak traffic level and a "busy hour offset" which is the difference in times at which the peak traffic occurs in the cell and in the following diurnal traffic variation file;

– a diurnal traffic variation file, containing the normalized variation of the traffic level against time over one day.

As the proposed platform for SCP is a PC, a suitably practical size of traffic file is 5° of latitude by 5° of longitude.

The traffic level is calculated as follows:

a) the current simulation time and the station position give the local time. This gives a baseline time offset to be used in connection with the diurnal traffic variation file;

b) the geographic traffic file gives the additional busy hour offset for this particular cell;

c) the total time offset (i.e. sum of baseline and busy hour offsets) is used to get the percentage of traffic in the cell from the diurnal variation file:
   - For the geographic traffic file, variables are stored as:
     - offset in minutes from local time;
     - number of carriers active at busiest hour.
   - For the diurnal traffic variation file, variables are stored as:
     - offset in minutes from time zero;
     - percentage of busy hour, so the scale is from 0 to 100.

Once the percentage of traffic has been calculated, this percentage is multiplied by the maximum number of carriers at busiest hour in the traffic file for this cell to get the total number of carriers in the traffic cell for this time step (the number of carriers can be multiplied by the carrier bandwidth to get the bandwidth required for this traffic cell).

The next step is to allocate the traffic for a particular cell to one or more satellites. For the LEO-F system there are typically between 2 and 4 satellites visible with differing elevation angles. For each satellite the traffic is assumed to be allocated to the beam with footprint nearest the centre of the traffic cell. The following two algorithms have been implemented:

– *In proportion to elevation*

  In this case the traffic is allocated to satellites according to elevation angle. Hence with two satellites with elevation angles 30° and 60°, twice as much traffic would go to the higher elevation satellite as to the lower.

– *In proportion to elevation, with highest satellite loaded first*

  This algorithm skews the traffic to high elevation angles, based on the principle that the blocking is elevation angle dependent, and that there is a linear relationship, i.e.: probability of non-blocking ~ elevation angle/90°.

  Then traffic will be allocated to the visible satellites based on the principle that the higher elevation satellite is selected first.

  If e is the elevation angle/90°, then:

  $p_1 = e_1$ for satellite 1

  $p_2 = (1 - e_1)\, e_2$ for satellite 2

  $p_3 = (1 - e_1)\,(1 - e_2)\, e_3$ for satellite 3, etc.

  The ratio of total traffic allocated to satellite n is:

$$T_n = p_n / \Sigma p_i$$

If some traffic remains unallocated after application of one of the above algorithms, this traffic will be allocated to other satellites.

Step 2: Traffic methodology for CDMA system

For each step of the simulation and for each satellite in view of the FS station, the simulation calculates the traffic load in each spot beam and then calculates the e.i.r.p.

There are three levels of traffic: no traffic, low traffic and high traffic.

The traffic in each spot beam is determined based on a cell-by-cell traffic table and a diurnal variation.

According to the traffic level, the subprogram determines the power in each spot of a satellite (the power is referred to the total CDMA bandwidth):

– no traffic → $Pspot_{min}$

– low traffic → $Pspot_{mean}$

– high traffic → $Pspot_{max}$

For instance, the values for the LEO-D system would be:

$$Pspot_{max} = \frac{Psat_{max}}{4}$$

$$Pspot_{mean} = \frac{Psat_{max}}{24}$$

$$Pspot_{min}\text{, power needed for signalling} = 4 \times \frac{Pspot_{max}}{50} = \frac{Psat_{max}}{50}$$

Then the simulation calculates the total transmitted power for the satellite; if it is higher than the maximum transmitted power $Psat_{max}$, the total transmitted power is set at $Psat_{max}$ and the power in each spot beam is reduced by the same factor.

Finally, the subprogram calculates the e.i.r.p. from each spot beam i towards the FS station:

$$\text{e.i.r.p.}_i\,(\theta, \varphi) = P_i \cdot G_i\,(\theta, \varphi)$$

Appendix 3
to Annex 1

Time increment calculation

Derivation of formulae

All angles in the following equations are given in radians, if not indicated to be in degrees, and velocity values in rad/min, if not indicated otherwise.

In all cases in this Appendix the geocentric angle means angle in spherical coordinate system which has origin on the Earth's centre. It should be noted that if two points on Earth at equator have a longitude difference of 1°, the distance is 1° in geocentric angle, but at higher latitudes the same longitude difference corresponds to a smaller geocentric angle; at 60° latitude it would be 0.5°.

An angle (e.g. for movement or intersection of antenna beam) at orbit shell is different for geocentric angle and for an angle as seen from the surface of the Earth. The ratio between those angles depends on the altitude of the orbit shell and also on the direction of the movement (if the movement is e.g. horizontal or vertical (= "towards")).

A geocentric coordinate system may be either fixed to Earth and so rotating with Earth, or the axis directions may be fixed to space. In the latter coordinate system satellite orbit plane is nearly stationary; only precession is turning it.

When satellite velocity, as seen from a given point on Earth, needs to be calculated, the Earth rotation has to be taken into account if better than rough results are needed. The Earth velocity to be used is the real velocity of a point at Earth surface which is a subpoint for a point (e.g. link antenna beam intersection or satellite) at orbit shell. At the equator the Earth velocity as a geocentric angle is about 360°/d, but at pole 0°. So it depends on the latitude of the area:

$$\omega_e' = (\cos L) \cdot \omega_e \tag{3}$$

where:

ω_e: Earth rotation velocity at equator

L: latitude of the area.

As the latitude of the area depends on the latitude of the observation site and on the observation azimuth, also the velocity is dependent on those.

The velocity of satellite in Earth fixed coordinates is vector sum of Earth velocity and satellite velocity in space fixed coordinate system. The value of vector sum depends on the angle α between the satellite path and the latitude lines. The angle is the same as inclination I if the satellite is above the equator but 0 at the highest latitude of the satellite (if not 90°). The angle is:

$$\alpha = \arccos \frac{\cos I}{\cos L} \tag{4}$$

So the real geocentric angular velocity is:

$$\omega = \sqrt{(\omega_s \cdot \cos\alpha - \omega_e')^2 + (\omega_s \cdot \sin\alpha)^2} \tag{5}$$

where:

ω_s: satellite angular velocity in space fixed coordinates.

The geocentric angle between the observation point and observed area at orbital shell is:

$$\theta_\varepsilon = \arccos\left(\frac{R}{R + h} \cos\varepsilon\right) - \varepsilon \tag{6}$$

where:

ε: elevation of the observed area.

If the satellite moves forming a geocentric angle of Δθ, then the movement β as seen from observation point, if satellite is moving **horizontally**, is for small angles:

$$\beta = \frac{\cos\varepsilon}{\sin\theta_\varepsilon} \Delta\theta \tag{7}$$

and if the satellite is moving **vertically**, is for small angles:

$$\beta = \frac{-\cos\varepsilon}{\sin\theta_\varepsilon} \sqrt{1 - (k \cdot \cos\varepsilon)^2} \; \Delta\theta \tag{8}$$

$$k = \frac{R}{R + h} \tag{9}$$

If γ is the angle between satellite path and horizon, the angle β would be:

$$\beta = \frac{\cos \varepsilon}{\sin \theta_\varepsilon} \Delta\theta \sqrt{1 - (k \cdot \cos \varepsilon \cdot \cos \gamma)^2} \tag{10}$$

The satellite speed, as seen from the observation point, is highest when the satellite is moving horizontally. Therefore that direction and equation (7) are used for further calculations.

If the angle β is satellite movement during one calculation time step Δt, the required angle may be calculated by:

$$\beta = \frac{\varphi_{3dB}}{N_{hits}} \tag{11}$$

The small geocentric angle for satellite movement during one time step is:

$$\Delta\theta = \Delta t \cdot \omega \tag{12}$$

Combining equations (7), (10) and (11) gives:

$$\Delta t = \frac{\varphi_{3dB}}{N_{hits}\,\omega} \frac{\sin \theta_\varepsilon}{\cos \varepsilon} \tag{13}$$

If elevation is zero then using $\varepsilon = 0$ in equation (6) and substituting to equation (12) gives:

$$\Delta t = \frac{\theta_{3dB}}{N_{hits}\,\omega} \sqrt{1 - \left(\frac{R}{R+h}\right)^2} \tag{14}$$

ω: satellite angular velocity in Earth fixed coordinates (Earth centred, rotating)

ω_e: Earth rotation velocity at equator

ω_s: satellite angular velocity in space fixed coordinates (Earth centred, inertial)

I: satellite orbit inclination

θ_ε: geocentric angle between FS station and satellite

R: Earth radius

h: satellite altitude

ε: FS antenna elevation

φ_{3dB}: FS station 3 dB beamwidth

N_{hits}: number of hits in FS station 3 dB beamwidth

Δt: simulation time step.

Annex 2

Reference characteristics of fixed service systems in the 1-3 GHz band for use in sharing analyses with other services

1 Introduction

The following Appendices provide the characteristics of FS systems, operating in the 1-3 GHz band, which can be used to perform analysis of sharing between stations in the FS and other services. Where applicable both typical and the most sensitive parameters are detailed.

Appendix 1 – Characteristics of digital point-to-point systems

Appendix 2 – Characteristics of analogue point-to-point radio-relay systems

Appendix 3 – Characteristics of reference point-to-multipoint systems.

It should be noted that digital FS systems are typically more sensitive to interference than analogue systems and that new installations of FS systems will primarily be digital.

It should be further noted that the parameters for troposcatter systems are detailed in Recommendation ITU-R F.758, Table 6 for 1.7-2.45 GHz band, and Table 7 for the 2.45-2.69 GHz band.

Appendix 1 to Annex 2

Characteristics of digital point-to-point systems

TABLE 1

Characteristics of reference digital point-to-point system for SCP calculations

Capacity	45 Mbit/s
Modulation	64-QAM
Antenna gain (dB)	33
Transmit power (dBW)	1
Feeder/multiplexer loss (dB)	2
e.i.r.p. (dBW)	32
Receiver IF bandwidth (MHz)	10
Receiver noise figure (dB)	4
Receiver input level for a bit error ratio (BER) of 1×10^{-3} (dBW)	–106

QAM: quadrature amplitude modulation.

Fixed service antenna pattern

Recommendation ITU-R F.1245 should be used.

Appendix 2
to Annex 2

Characteristics of analogue point-to-point radio-relay systems

The types of analogue point-to-point systems operating in the 1-3 GHz band comprise telephony, FM-TV and ENG links. A reference set of characteristics has been extracted from Tables 5, 6 and 7 of Recommendation ITU-R F.758, Table 1 of Recommendation ITU-R F.759 and from Recommendation ITU-R SF.358 which details the analogue hypothetical reference circuit currently used for ITU-R sharing studies.

Typical FS analogue characteristics operating in the 1-3 GHz band

Antenna pattern: Recommendation ITU-R F.1245

Antenna gain: 33 dBi

e.i.r.p.: 36 dBW

Receiver noise figure (referred to input of receiver): 8 dB

Hop length: 50 km

Number of hops: 12.

Appendix 3
to Annex 2

Characteristics of reference point-to-multipoint systems

Typical characteristics: see Table 2.

Antenna pattern: for the omnidirectional antenna pattern and the outstation antenna pattern, the reference pattern described in Recommendation ITU-R F.1336 should be used.

NOTE 1 – In application of the SCP, the use of P-MP reference FS system parameters for the 2 170-2 200 MHz is not required.

TABLE 2

Typical characteristics

Parameter	Central station	Outstation
Antenna type	Omni/Sectoral	Dish/Horn
Antenna gain (dBi)	10/13	20 analogue 27 digital
Feeder/multiplex loss (dB)	2	2
e.i.r.p. (maximum) (dBW) – analogue – digital	 12 24	 21 34
Receiver IF bandwidth (MHz)	3.5	3.5
Receiver noise figure (dB)	3.5	3.5

Annex 3

Possible methodology for use in bilateral coordination

If the non-GSO MSS system parameters exceed the threshold criteria given in RR Appendix 5, or referred to in this Recommendation detailed bilateral coordination will be required between the concerned administrations. In this step, actual FS parameters could be used. One possible methodology which could be used in bilateral coordination is described below in this Annex.

1 Description of a possible methodology

The cumulative distribution function (CDF) of $C/(N+I)$ on analogue or digital FS systems is evaluated. The time varying interfering carrier power from the non-GSO MSS satellite is estimated at each FS receiver using orbital dynamic simulation taking into account the non-GSO MSS satellite antenna characteristics and traffic loading modelling.

The time varying wanted received FS carrier at each FS receive station is evaluated using the FS transmission characteristics in conjunction with a model of multipath fading. If considered appropriate by both parties, Recommendation ITU-R P.530 could be used. At each simulation time step the per hop C/N and C/I are evaluated and aggregated to give the end-to-end $C/(N+I)$. The CDF of $C/(N+I)$ can then be compared directly with the applicable performance objectives for the concerned FS system to evaluate whether the degradation caused by the non-GSO MSS satellite unacceptably degrades the performance.

2 Interference criteria

This analysis would apply to both analogue and digital FS systems.

Recommendation ITU-R F.393, which refers to the total noise allowance in an analogue radio-relay system, is used as the criterion to assess the interference impact into analogue FS systems.

Recommendations ITU-R F.695, ITU-R F.696 and ITU-R F.697 specify network performance objectives (NPO) (error performance objectives and availability) for the existing digital systems in high, medium and local grade of the integrated services digital network (ISDN) in terms of required BER for various percentages of time. The procedure for new digital FS systems based on Recommendations ITU-R F.1397 and ITU-R F.1491 requires further study.

Additionally, consideration should be given to including in the total noise, N, an allowance for intra-system and intra-service interference within the fixed service as well as contributions from other co-primary (non-MSS) services. The value of this allowance should be determined by the concerned parties. It should be noted that Recommendation ITU-R F.1094 specifies the maximum allowable value of error performance and availability degradation to digital FS systems.