



Recommendation ITU-R F.1107-2
(05/2011)

**Probabilistic analysis for assessing
interference into the fixed service from
satellites using the geostationary orbit**

F Series
Fixed service

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RECOMMENDATION ITU-R F.1107-2*

**Probabilistic analysis for assessing interference into the fixed service
from satellites using the geostationary orbit**

(1994-2002-2011)

Scope

This Recommendation provides methods for assessing sharing criteria for interference from satellites using the geostationary orbit into digital fixed wireless systems. Annex 1 provides the approach to calculate interference into digital systems, and provides an outline of a calculation methodology and includes examples and a software model to implement the methodology.

The ITU Radiocommunication Assembly,

considering

- a) that emissions from space stations operating in the geostationary orbit and sharing the same spectrum may produce interference in receiving stations of the fixed service (FS);
- b) that it may be impractical to coordinate between the many terrestrial stations and the many space stations, and that, therefore, sharing criteria should be established to preclude the need for detailed coordination;
- c) that in devising such sharing criteria, account needs to be taken of the operational and technical requirements of networks in the satellite service as well as of the requirements of the FS and measures available to them;
- d) that it has been determined that a probabilistic basis for developing sharing criteria results in a more efficient use of the spectrum than from criteria developed using worst case analysis;
- e) that it is difficult and burdensome to assemble sufficient statistically accurate information about real existing and planned terrestrial and satellite system stations;
- f) that computer simulations of FS and satellite services operating in the geostationary orbit can generate statistically accurate information suitable for determining sharing criteria for a wide variety of sharing scenarios,

recommends

- 1** that information derived from computer simulations of FS and satellite services operating from the geostationary orbit and using the same spectrum may be acceptable for developing sharing criteria;
- 2** that when developing sharing criteria with respect to digital systems in the FS, the material in Annex 1 to assess interference from FS into digital FS should be taken into account.

* This Recommendation should be brought to the attention of Radiocommunication Study Groups 4, 6 and 7.

Annex 1

Information for assessing the interference into digital fixed service systems from emissions of space stations operating in the geostationary orbit

1 Introduction

This Annex presents additional information that is necessary for assessing the interference into such FS systems employing digital modulation.

The methodology provides statistics for both the interference-to-noise ratio (I/N) values of individual stations and the fractional degradation of performance (FDP) values of routes. The methodology employed for assessing the route FDP as described in § 3 is only valid when the I/N of a receiver station of that route is not so large as to drive the receiver into a non-linear range. The user is therefore encouraged to assess the I/N per receiver statistics, as described in § 2, before assessing the FDP statistics on a multihop basis, as described in § 3.

This Annex applies to digital FS systems where multipath fading generally predominates and does not apply to those systems where precipitation attenuation generally predominates.

2 Station-by-station analysis

In the case of digital point-to-point (P-P) and point-to-multipoint (P-MP) FS systems, it is appropriate to evaluate interference in terms of FDP as defined for the time varying interference from non-geostationary satellites in Annex 3 to Recommendation ITU-R F.1108. As an analogy, when there is only one FS station, FDP_{hop} due to interference entries from geostationary satellites can be defined at the input of a receiver as follows, taking into account that the interference level is almost time-invariant:

$$FDP_{hop} = \frac{I}{N_T} \quad (1)$$

where:

- I : aggregate interference (W/MHz) from visible satellites into the FS receiver
- N_T : receiver thermal noise (W/MHz).

A methodology proposed in Appendix 2 of this Annex may be used for evaluating the I/N statistics.

When it is necessary to determine the effect of interference on digital FS receivers employing diversity, a different formula may be more appropriate for evaluating FDP_{hop} as described in Annex 4 to Recommendation ITU-R F.1108.

3 Multi-hop P-P FS systems

For digital FS systems with n hops operating at frequencies where multipath fading generally predominates and acknowledging that, in general, the performance objectives for multi-hop P-P FS systems are specified on a route basis, two probabilistic assessment methods may be employed. One

is described in § 2 and another is to evaluate the FDP for the route defined as the ratio of total interference power to total noise power for one direction of a route as follows:

$$FDP_{route} = \frac{\sum_{k=1}^n (I_k)}{n \times N_T} \quad (2)$$

where I_k is the aggregate interference falling into the k -th receiver from visible satellites.

It should be noted that equation (2) is based on the assumptions that:

- the digital signal is regenerated at each repeater;
- the fading has Rayleigh characteristics.

It should also be noted that, for evaluating FDP_{route} for digital FS systems employing diversity, an appropriate formula different from equation (2) should be used. Further studies are required.

Although there are a variety of fading types, Rayleigh fading is regarded as the most severe fading encountered in line-of-sight paths and is a determining factor in the evaluation of FS system performance. The feature of Rayleigh fading is that the probability of 10 dB deeper fading, for example, becomes smaller by a factor of 1/10. Therefore, if there exists a time-invariant interference in a hop whose level is equal to the thermal noise level ($I/N = 0$ dB), the probability of severely errored seconds (or the probability of unavailable time) will become twice as much as that of the case where there is no interference.

The FDP concept has certain limitations, the most important assumption is that the FS receiver operation remains within a linear response range. If there is an exceptionally high level of interference so that the FS receiver operation falls into a non-linear response range, the FDP concept will not apply or will underestimate the effect of interference (see paragraph following equation (16) in Annex 3 to Recommendation ITU-R F.1108). However, as long as the FS receiver operation is maintained within a linear response range, equation (2) is valid for multi-hop FS digital systems.

The discussion in the preceding section does not result in a conclusion that only FDP should be evaluated on a route basis. Station basis evaluation of FDP will be also useful for understanding the effects of interference.

A typical hop distance of long haul systems is assumed to be 50 km, but a shorter hop distance may be appropriate for short haul systems, depending on various factors including the operating frequency and propagation effects. For example, in the case of an operating frequency in the 1-3 GHz range, random selection between specified limits (e.g. between 10 and 30 km) may be appropriate as typical hop distances.

FS routes under survey should be selected according to the Monte Carlo simulation approach with the route starting point randomly selected within a user specified test box identified by latitude and longitude limits.

In performing route analysis for digital systems subject to multipath fading, it may not be necessary that each individual hop meets the I/N criterion. The overall route performance, however, must meet the fractional degradation of performance criterion. This issue is explained below.

Where multipath is the dominant fade mechanism, Recommendation ITU-R P.530 relates the probability of an outage on a hop $P(hop\ outage)$ to the link thermal fade margin (TFM):

$$P(hop\ outage) = K \cdot d^{3.6} \cdot f^{0.89} \cdot (1 + |h_r - h_e|/d)^{-1.4} \cdot 10^{-TFM/10}$$

where:

- K : geoclimatic factor
- d : link length (km)
- f : frequency (GHz)
- h_r and h_e : transmit and receive antenna heights (metres above sea level or another common reference)
- TFM : thermal fade margin on a hop (dB).

$$TFM = 10 \log \left(\frac{C}{N_T} \right) - CNC$$

where:

$$10 \log \left(\frac{C}{N_T} \right): \text{ unfaded carrier-to-noise ratio } (C/N) \text{ (dB)}$$

CNC : value of C/N at which the performance criterion is just met (dB).

Setting

$$K \cdot d^{3.6} \cdot f^{0.89} \cdot (1 + |h_r - h_e|/d)^{-1.4} \cdot 10^{-CNC/10} = \gamma$$

Then:

$$P(\text{hop outage}) = \gamma \cdot N_T / C$$

Thus

$$P(\text{hop outage before satellite interference}) = \gamma \cdot N_T / C$$

$$P(\text{hop outage after aggregate satellite interference}) = \gamma \cdot (N_T + I) / C$$

where C , N_T and I are in consistent power units.

If it is assumed that:

- each hop is designed to have a similar nominal probability of outage before satellite interference;
- hop fades are independent and sufficiently rare that the outage probabilities may be added,

then the net nominal probability of outage for the route is:

$$P(\text{route outage}) = \Sigma (P(\text{hop outage}))_{\text{number of hops in route}}$$

Thus, the fractional increase in the probability of a route outage due to a degraded fade margin on each hop within the route is simply:

$FDP(\text{route outage})$

$$\begin{aligned} &= \frac{P(\text{route outage with interference}) - P(\text{route outage without interference})}{P(\text{route outage without interference})} \\ &= \frac{\Sigma (\gamma \cdot (N_T + I) / C) - \Sigma (\gamma \cdot N_T / C)}{\Sigma (\gamma \cdot N_T / C)} \\ &= \frac{\Sigma I}{\Sigma N_T} \end{aligned}$$

i.e. the route FDP is the total route interference power divided by the total route noise power:

$$= \frac{\sum I}{n \cdot N_T} \quad \text{as a power ratio}$$

$$= 100 \frac{\sum I}{n \cdot N_T} \quad \%$$

Thus the FDP approach for the assessment of the impact of interference on a FS route and the usage of percentages (rather than dB) is appropriate.

In P-MP systems, most links are single hop therefore equation (1) would apply. In P-P systems, multihop deployments are typical, therefore equation (2) will apply.

4 P-MP FS systems

Interference to hub stations in P-MP systems should be evaluated according to § 2 in the case of digital modulation, but it should be noted that these stations employ omnidirectional or sectoral antennas. Reference radiation patterns in the elevation plane for such antennas are described in Recommendation ITU-R F.1336. If appropriate, the effect of downward beam tilting of the antennas may be evaluated in the interference assessment.

Interference into subscriber stations in P-MP FS systems should also be evaluated according to § 2 in the case of digital modulation. For this case, it is generally assumed that the azimuthal directions of subscriber station antennas are uniformly distributed over 0°-360° noting that, in general, orbit avoidance is not feasible for these systems.

5 Test area

A large number of FS routes and stations (to ensure stability and convergence of the statistics) are randomly distributed in latitude, longitude and azimuth in a user-defined test area. To ensure a uniform exposure to all arrival angles, the test area longitude dimension should be an integral multiple of the satellite spacing in the case of uniformly spaced satellites and the latitude dimension of the test area should be sufficiently large. Alternatively, the test area can be defined to encompass an administration's territory so that parameters specific to that administration's systems may be evaluated. In this case, the satellite locations may be specified.

6 Satellite constellation

A full orbit of equally spaced satellites is usually assumed when investigating a new satellite service. Alternatively, user-defined satellite locations should be accommodated. Another option would permit random locations within a specified orbital arc.

The model should permit orbit avoidance in those situations where this technique is practical for the FS. In general, ubiquitous deployment FS systems cannot take advantage of this technique.

7 pfd mask

All satellites are assumed to transmit the maximum levels allowed by the assumed pfd mask. This is a conservative assumption with respect to the level of interference. The mask consists of straight-line segments of pfd versus arrival angle (from 0° to 90°). The model should allow multiple segments to be specified.

Statistical pfd masks to account for satellite service area coverage's may also be derived. Further studies are required.

8 FS parameters

The noise figure (or thermal noise floor) and feeder loss common to all FS stations in the computer simulation must be specified. In addition, the common antenna gain and pattern must be specified. The following default patterns could be included in an antenna file for selection by the user, for example:

- Recommendation ITU-R F.1245, *recommends* 2, for P-P systems co-polar with the interferers.
- Recommendation ITU-R F.1245, Note 7, for P-P systems with linear/circular discrimination in main beam-to-main beam coupling conditions.
- Recommendation ITU-R F.1245, Annex 1, for P-P systems with a sine squared structure in the side lobes.
- Recommendation ITU-R F.699 for P-P systems co-polar with the interferers.
- Recommendation ITU-R F.1336 for P-MP systems hub station antennas.
- Recommendation ITU-R F.1336 for P-MP systems subscriber station antennas.

In addition, the algorithm should accept user-defined patterns that could consist, for example, of a main lobe defined by the 3 dB beamwidth with the discrimination varying as the square of the off-axis angle and the transition to a piecewise linear side-lobe region (on a logarithmic off-axis angle scale). These user-defined patterns could be entered into an antenna pattern file library for future applications.

9 Other considerations

9.1 Interference criteria

For bands where the fading is controlled by multipath, Recommendation ITU-R F.758 states that, in principle, the interference level relative to receiver thermal noise should not exceed -10 dB (or -6 dB). In the case of digital FS systems, these values correspond to a FDP_{hop} of 10% (or 25%), respectively. It is recommended that, if possible, the -10 dB value be adopted. However, in certain difficult sharing situations, it was found extremely difficult to apply the -10 dB requirement from the viewpoint of facilitating frequency sharing. For example, Recommendations ITU-R M.1141 and ITU-R M.1142 dealing with frequency sharing between FS systems and space stations (geostationary or non-geostationary) in the MSS in the 1-3 GHz range are based on the -6 dB requirement.

In a statistical interference assessment, it is necessary to establish a certain allowable percentage of stations or routes for which the aggregate interference may exceed the interference criterion. It is preferable that this percentage should be as small as possible, but, in certain difficult sharing situations, it was found extremely difficult to adopt a very small allowable percentage. For example in such situations, 10% of FS receivers under survey might be prepared to accept interference exceeding the preferred interference criterion. In a similar manner, a certain allowable percentage of routes for which the fractional degradation of performance may exceed the FDP criterion may be defined.

Thus two pairs of performance criteria are specified:

Receiver I/N objective	Per cent of receiving stations allowed to exceed receiver objective
Route FDP objective	Per cent of routes allowed to exceed route objective

Either or both of these performance criteria pairs may be applicable in a given situation.

9.2 Propagation attenuation

Minimum propagation attenuation due to atmospheric gases for use in frequency sharing studies between FS systems and satellites in various space services is given in Recommendations ITU-R SF.1395 and ITU-R F.1404.

9.3 Slightly inclined orbits

Satellite service to near omnidirectional antennas permits the satellite operators to take advantage of the fuel savings afforded by relaxed North-South station keeping and allows the satellites to employ slightly inclined orbits. This causes the interference arrival angles to terrestrial networks to vary on a daily basis, in effect extending the orbital arc below the static radio horizon for part of the time and increasing the arrival angle (and hence the pfd) of interference of satellites above the horizon for another part of the time. A simple mechanism for evaluating this effect is to modify, for calculation purposes, the latitude of the FS station: nominal station latitude, nominal station latitude plus maximum orbit inclination, and nominal station latitude less maximum orbit inclination can be determined.

10 Output results

The probability distribution functions of the aggregate I/N or FDP for the individual FS stations (FDP_{hop}) and of the route FDPs (FDP_{route}) are the required outputs. Optional outputs include $\{I/N, \text{azimuth}\}$, $\{I/N, \text{arrival angle}\}$ for presentation in scatter diagrams. The latter output is useful in synthesizing a pfd mask. These optional outputs require no additional processing since the parameters are already computed.

Appendix 1 to Annex 1

Software model for probabilistic interference assessment on a multi-hop P-P basis

1 Introduction

In frequency bands where the probabilistic interference methodology is intended to be exercised, the FS is the existing service while the satellite service is the unknown incoming system. It is thus logical, when assigning parameters in the software model, to fix as many of the FS parameters as possible and to vary the satellite parameters.

In this model, an area coverage approach is combined with statistical interference analyses of a set of individual stations and routes. The primary satellite deployment is a uniformly spaced deployment of satellites with uniform pfd masks. This deployment may be assumed for simplicity noting that this is a conservative approach. User-defined satellite locations or random deployment could be options. Simple straight line, smooth spherical earth, geometry is assumed.

2 Input parameters for model

2.1 Satellite parameters

- pfd mask {arrival angle break points/pfd levels}; linear segments assumed, number of break points user specified, common to all satellites.
- Uniform geostationary-satellite orbit spacing (must be an integer divisor of 360°), full orbit; (optionally, defined orbit locations can be input or satellites can be randomly located in a specified orbital arc).
- Orbit inclination (e.g. 0° or 5°), applies to all satellites.

2.2 FS performance criteria

- Required protection level (e.g. $FDP_{route} = 10\%$ or 25% , station $I/N = -10$ dB or -6 dB).

2.3 FS test area parameters

- Longitude limits, latitude limits.
- Atmospheric loss model (selection from a menu relating atmospheric loss to be applied to the interference power based on arrival angle and geoclimatic region, zero if none).
- Refraction model (selection from a menu of models relating maximum refraction angles, latitude, and geoclimatic region, zero if none).
- Rain fade model if applicable i.e. if rain fading is to be applied to the interference power (selection from a menu of the rain fade levels to be applied, the arrival angle, and off-axis angle dependencies, and geoclimatic region, zero if none).

(Further study is required to generate suitable menus of the above models of low arrival angle phenomena based on ITU-R Recommendations bearing in mind that, in general, these phenomena affect only near-worst-case exposures in a substantial way and that these exposures are reduced in significance by the probabilistic approach.)

2.4 FS station parameters

- Orbit avoidance angle (zero if none).
- Number of routes in victim area:
 - Minimum and maximum number of hops per route: the resulting total number of stations ($\Sigma_{all\ routes}$ (number of stations per route)); should be as large as computer memory and speed limitations allow.
 - Minimum and maximum hop lengths (not required for single station analysis).
 - Maximum azimuth variation about route trend line (not required for single station analysis).

- Station parameters, different types of station require separate runs. Within a run, the following parameters are common to all stations:
 - Antenna gain and pattern (from built-in list (including options such as linear to circular discrimination and side lobe structure), facility for entering other antennas into list should be provided).
 - Feeder loss.
 - Noise figure.
 - Elevation angle distribution quantized function (e_{i-1} to e_i , probability). Assume a maximum of 100 pairs of elevation angle range and probability of occurrence values for each distribution ($i = 1$ to I_{elev_max}) noting that different types of station will probably have different elevation angle statistics (large antennas are usually employed where high gain is required to compensate for the high losses of long path lengths, long path lengths imply low elevation angles). The elevation angle distribution should be symmetric about zero degrees elevation.

3 Parameter selection process

Set up a hundred-entry weighted list (to correspond to percentage values) for the elevation angle distribution. A uniformly distributed random pointer selects the elevation angle of each station.

(The symbol “ $\Rightarrow < 1 >$ ” indicates the start of loop 1; “ $RANDx$ ” = uniformly distributed random number between 0 and 1.)

- $\Rightarrow < 1 >$ Choose route starting points and trend lines (randomization of parameters):
- $latitude = latitude(min) + RAND1 * (latitude(max) - latitude(min));$
 - $longitude = longitude(min) + RAND2 * (longitude(max) - longitude(min));$
 - $trend_line_azimuth = RAND3 * 360$ if only one direction of transmission is subject
 $= 90 + RAND3 * 180$ if both directions of transmission are subject to satellite interference from the same satellite service; the “go” direction route (trend line azimuth 90° through 180° to 270°) is reversed for the “return” direction of transmission (270° through 0° to 90°) and the larger of the two degradations determines the route performance;
 - $number\ of\ hops = hop(min) + RAND4 * (hop(max) - hop(min)).$

(For single-station analysis only (i.e. minimum number of hops = maximum number of hops = 1), the trend line azimuth is the station azimuth and the station is assumed to be a receiver.)

Choose station locations:

- first station location is the same as the route starting point; the first station is assumed to be a transmitting station in this context unless there is only one station in the route.
- $\Rightarrow < 2 >$ for second and subsequent stations in route:
- $azimuth = trend_line_azimuth + (2 * RAND5 - 1) * \max\ hop_azimuth_variation;$
 - $elevation\ angle = \text{mid value of range pointed to by “Nearest_integer}\{100 * RAND6\}”$
- Check if orbit avoidance applies (noting that stations with elevation angles above zero may intercept orbit above the horizon). If avoidance applies and station main beam direction is within the avoidance angle, reject station, go to $< 2 >$;
- $hop\ length = hop\ length(min) + RAND7 * (hop\ length(max) - hop\ length(min));$
 - determine latitude and longitude of station.
- If station is outside test area, reject station location. Go to $< 2 >$.

Repeat for all hops in route. Go to < 2 >.

Repeat for all routes in the specified area. Go to < 1 >; note that, if interference in both directions of transmission is to be assessed, the “return” direction of the route has the reverse list of station locations, complement azimuths and complement elevation angles from the “go” direction route parameters.

Store set of FS station parameters $\{\{FS\}\} = \{\{type\} (antenna\ gain\ and\ pattern, noise\ figure, feeder\ loss), route\ number, station\ location(latitude, longitude), azimuth, elevation\ angle\}\}$.

For equally spaced satellites, the constellation reference longitude is expressed relative to the mid longitude of the test area “ $long_{mid}$ ”. Generate satellite locations.

- $satellite\ longitude\ long_m = long_{mid} + m \cdot (360 / number_of_satellites),$
 $m = 0\ to\ (number_of_satellites - 1)$

For randomly located satellites:

- $satellite\ longitude\ long_m = min\ arc\ longitude + RAND8 \cdot (max\ arc\ longitude - min\ arc\ longitude)$
- ⇒ <3> For each route
- ⇒ <4> For each station in route
- ⇒ <5> For each satellite in constellation.
- compute nominal arrival angle to satellite, compute arrival angles at maximum and minimum excursions of orbit inclination allowing for refraction;
- if any of these arrival angles are more negative than the refraction angle attach “ignore” marker for future computations. If all of these arrival angles are more negative than the refraction angle, go to <5> to select next satellite, else
- compute off-axis angles, antenna gains, compute maximum of the three $I/N|_{single\ entry}$ values {as power ratios} taking account of atmospheric attenuation (function of arrival angle) and rain fade (function of off-axis angle and arrival angle) if appropriate.

Go to <5>, next satellite

- compute $I/N|_{aggregate} = \sum_{all\ satellites} (I/N|_{single\ entry}), I/N|_{station} = 10 \log(I/N|_{aggregate})$ (dB)
 NOTE 1 – Appendix 2 to this Annex describes the derivation of $I/N|_{aggregate}$ in greater detail.

Go to <4>, next station in route

- compute $FDP_{route} = \sum_{all\ stations} (I/N|_{aggregate})/n$ sum over all stations n in route.

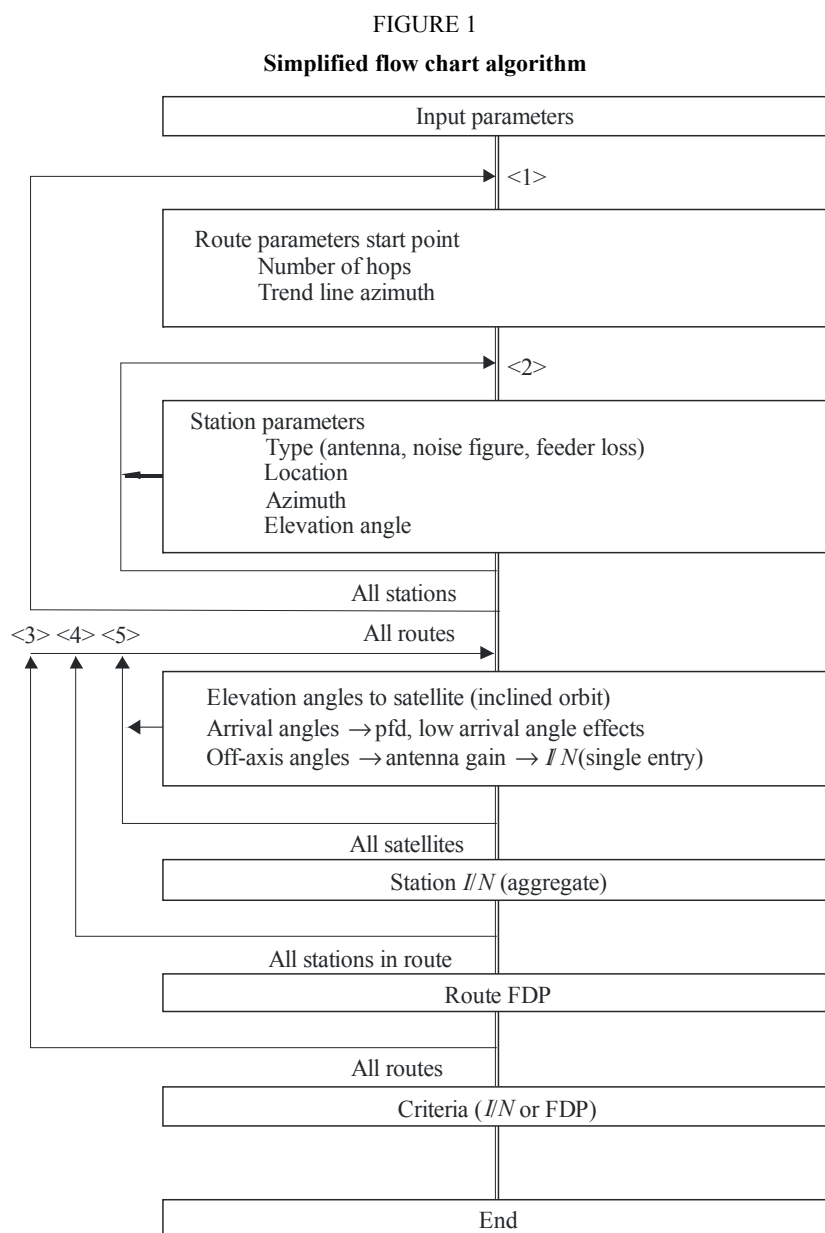
Go to <3>, next route

- generate probability distribution function (pdf) of station $I/N|_{aggregate}$ values by creating an ordered list of values from high to low, numbering the list of entries, i.e. $(j, I/N|_j : j = 1\ to\ J)$ then $\{100 \cdot j/J\}$ is the percentile corresponding to $I/N|_j$ whereby all subsequent stations have a performance better (less) than $I/N|_j$. Generate pdf of route FDP in a similar fashion;
- determine from the pdfs,
 - the per cent of stations or routes as appropriate at the associated performance criterion (“%stations_at_ $I/N|_{criterion}$ ” and “%routes_at_ $FDP_{criterion}$ ”); and
 - the value of I/N or FDP as appropriate at the defined percentage of stations or routes, respectively (“ $I/N|_{at_P_{station}}$ ” and “ $FDP_{at_P_{route}}$ ”);

- output the station I/N and route FDP probability distribution functions: $\{I/N \text{ value, probability } I/N \text{ is exceeded}\}$: $\{\text{FDP value, probability FDP is exceeded}\}$ for presentation as a graph. Output the above derived values: “%stations_at_ $I/N_{\text{criterion}}$ ”, “%routes_at_ $\text{FDP}_{\text{criterion}}$ ”, “ $I/N_{\text{at_P}_{\text{station}}}$ ” and $\text{FDP}_{\text{at_P}_{\text{route}}}$ ”.

4 Commentary

A flow chart of the above process is given in Fig. 1.



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The test criterion “ $I/N_{\text{at_P}_{\text{station}}}$ ” indicates by how much the pfd mask may need to be reduced. For example, assuming the original low arrival angle pfd level to high arrival angle pfd level transition is to be maintained, if the acceptable performance is 90% of stations should have an I/N less than or equal to -10 dB and if the test criterion “ $I/N_{\text{at_P}_{\text{station}}}$ ” (dB) exceeds this value, the pfd mask should be reduced by the difference $\{I/N_{\text{at_P}_{\text{station}}} - (-10)\}$ to meet the criterion.

Similarly, if the acceptable performance is 90% of routes should have a FDP less than or equal to 25% and if the test criterion “FDP_at_P_{route}” (%) exceeds this value, the pfd mask should be reduced by the difference $\{10 \log((\text{FDP_at_P}_{\text{route}}/100)) - 10 \log(0.25)\}$ to meet the criterion.

A scatter diagram of the calculated I/N values against arrival angle would permit a different transition to be developed if required.

It should be fairly straightforward to input an actual database of FS receive stations and/or a known satellite constellation instead of the random set of stations and the uniform constellation in order to obtain a real-life picture if required. Allowance for these options would have to be made in the data input routines of course.

Appendix 2 to Annex 1

Derivation of $I/N_{\text{aggregate}}$ for individual FS receivers

The methodology is based on the following algorithm:

- considering a given spacing between geostationary satellites, $Long_{ref} = 360/nb_sat$
- considering a given pfd mask applicable to each geostationary satellite;
- considering a given latitude and longitude of the FS system:
 - for each FS pointing azimuth (varying from 0° to 360°);
 - for each satellite constellation relative longitude ($\Delta long$ varying from 0° to $Long_{ref}$);
- calculation of the aggregate interference at the FS receiver entrance from all visible geostationary satellites;
- calculation of the resulting I/N at the FS receiver:

$$\frac{I}{N}(azimuth, \Delta long) = \frac{1}{N} \sum_{i=1}^{vis} \left(pfd_i(\Delta long) + G(\theta_i(azimuth, \Delta long)) + 10 \log \left(\frac{\lambda^2}{4\pi} \right) - FL \right)$$

where:

- $\frac{I}{N}(azimuth, \Delta long)$: resulting aggregate I/N from all visible geostationary satellites at the FS receiver, $\Delta long$ being the relative longitude of the satellite constellation and $azimuth$ the pointing azimuth of the FS station antenna
- $pfd_i(\Delta long)$: pfd at the FS station from visible geostationary satellite i
- $\theta_i(azimuth, \Delta long)$: off-axis angle between the FS antenna pointing direction and the direction under which the i -th satellite is seen from the FS station (in the case of hub stations of P-MP systems $\theta_i(azimuth, \Delta long)$ should be replaced by $elev_i(\Delta long)$ which is the difference between the pointing elevation of the FS antenna and the elevation under which the i -th satellite is seen. Where directional FS stations have elevation angles other than zero, the off-axis angle is modified accordingly

- $G(\theta)$: gain of the FS antenna for the off-axis θ
 λ : wavelength
 FL : FS feeder loss
 vis : number of visible satellites from the FS station
 N : FS receiver thermal noise.

This enables one to determine a table of I/N values (or FDP) at the FS receiver station as a function of the pointing azimuth of the FS station and relative longitude of the satellite constellation, and hence a probability density function of the FS station I/N or FDP_{hop} or route FDP_{route} (all routes located within a given test area) for a given pfd mask and geostationary satellite spacing.
