RECOMMENDATION ITU-R SF.1601-1

Methodologies for interference evaluation from the downlink of the fixed service using high altitude platform stations to the uplink of the fixed-satellite service using the geostationary satellites within the band 27.5-28.35 GHz

(Questions ITU-R 218/9 and ITU-R 251/4)

(2002-2005)

Scope

This Recommendation provides methodologies for the interference evaluation from the downlink of the fixed service (FS) using high altitude platform stations to the uplink of the fixed-satellite service using the geostationary satellites within the band 27.5-28.35 GHz. The methodology for interference evaluation in Annex 2 and *recommends* 2 referring to Annex 2 were newly added as well as a new Appendix to Annex 1 to provide an example of application of the methodology contained in Annex 1.

The ITU Radiocommunication Assembly,

considering

a) that new technology utilizing high altitude platform stations (HAPS) in the stratosphere is being developed;

b) that WRC-97 made provisions for operation of HAPS within the fixed service (FS) in the bands 47.2-47.5 GHz and 47.9-48.2 GHz;

c) that since the 47 GHz bands are more susceptible to rain attenuation in those countries listed in Nos. 5.537A and 5.543A of the Radio Regulations (RR), the frequency range 18-32 GHz has been studied for possible identification of additional spectrum in ITU-R;

d) that since the 47 GHz bands are more susceptible to rain attenuation in certain countries, WRC-2000 made a provision for the use of HAPS in the FS in the bands 27.5-28.35 GHz and 31.0-31.3 GHz in certain countries under the condition that it does not cause harmful interference to, nor claim protection from, other types of FS systems or other co-primary services (RR Nos. 5.537A and 5.543A);

e) that Resolution 145 (WRC-03) urgently requested studies on technical, sharing and regulatory issues in order to determine criteria for the operation of HAPS in the bands 27.5-28.35 GHz and 31.0-31.3 GHz;

f) that the band 27.5-28.35 GHz is allocated to the fixed-satellite service (FSS) (Earth-to-space direction) on a primary basis;

g) that there is a need for methods to evaluate the interference from transmissions in the HAPS-to-ground direction within the band 27.5-28.35 GHz that could be caused to receivers of FSS satellites in the geostationary orbit,

recommends

1 that the methodology contained in Annex 1 may be used to assess the level of interference from the HAPS-to-ground (downlink) transmission in the FS to the Earth-to-space (uplink) of the FSS using GSO satellites within the frequency band 27.5-28.35 GHz;

2 that administrations may consider Annex 2 as a method to estimate the e.i.r.p. of transmissions in the HAPS-to-ground direction within the band 27.5-28.35 GHz that would cause a given increase in the interference-to-noise ratio (*I*/*N*) of receivers of FSS satellites in the GSO orbit.

Annex 1

A methodology for interference evaluation from the downlink of the FS using HAPS to the uplink of the FSS using GSO satellites within the band 27.5-28.35 GHz

1 Introduction

This Annex provides a methodology for interference evaluation from the FS using HAPS to a GSO satellite system in the FSS within the band 27.5-28.35 GHz. This band is used for the Earth-to-space (uplink) direction by the GSO/FSS system.

2 A methodology for interference evaluation

2.1 Interference from a HAPS system

Figure 1 shows the analysis model assumed for the evaluation of interference from a HAPS system to a GSO satellite. The interference power level in 1 MHz, $I(g,h,b,r)$ due to a spot beam of a HAPS, received by a GSO satellite (g) is calculated using equation (1):

$$I(g,h,b,r) = P^H(b) - F_{loss} + G^H{}_{tx}(\varphi(g,h,b)) - FSL(g,h) + G^S{}_{rx}(\varphi(h,g,r)) \qquad \text{dB(W/MHz)} \quad (1)$$

where:

- $P^H(b)$: transmitter power in 1 MHz (dB(W/MHz)) at the input of HAPS antenna for the beam (b)
- F_{Loss}: feeder loss (dB)
- $\varphi(g,h,b)$: discrimination angle (degrees) at the HAPS (h) between the pointing direction of a HAPS spot beam (b) and the GSO satellite (g)
- $G^H{}_{tx}(\varphi(g,h,b))$: transmitter antenna gain (dBi) of the HAPS (h) for off-axis angle $\varphi(g,h,b)$
- $FSL(g,h)$: free space loss (dB) between the GSO satellite (g) and the HAPS (h)
- $\theta(h,g,r)$: discrimination angle (degrees) at the GSO satellite (g) between the pointing direction of a GSO FSS reference point (r) and a HAPS (h), see Fig. 2
- $G^S{}_{rx}(\theta(h,g,r))$: receiver antenna gain (dBi) of the GSO satellite (g) for off-axis angle $\theta(h,g,r)$.

FIGURE 1

Interference evaluation model from a HAPS to a GSO satellite

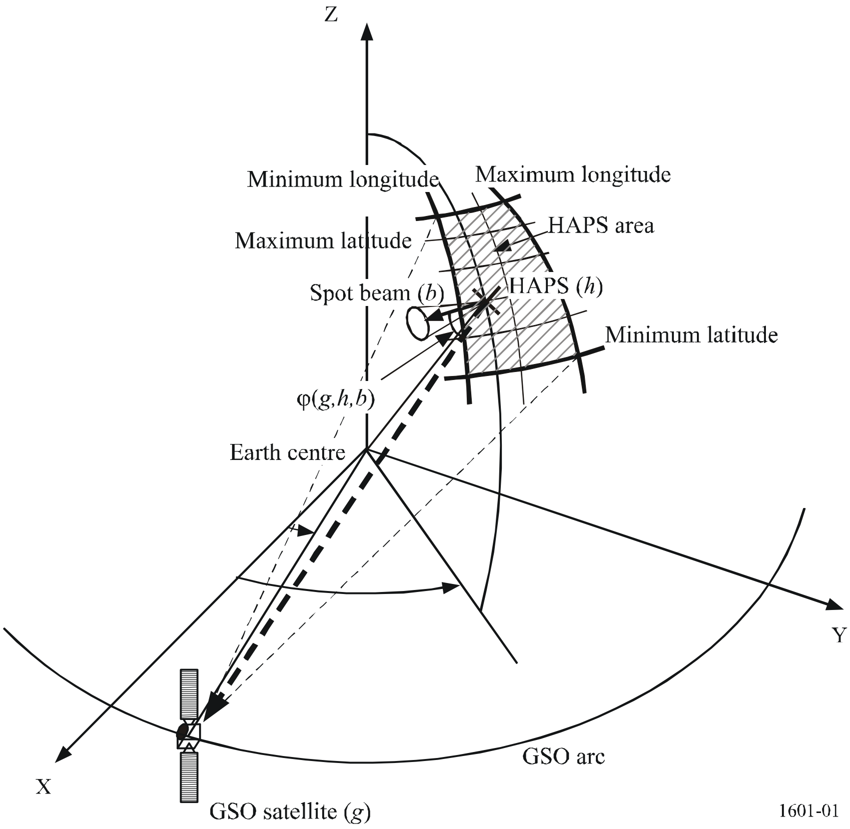
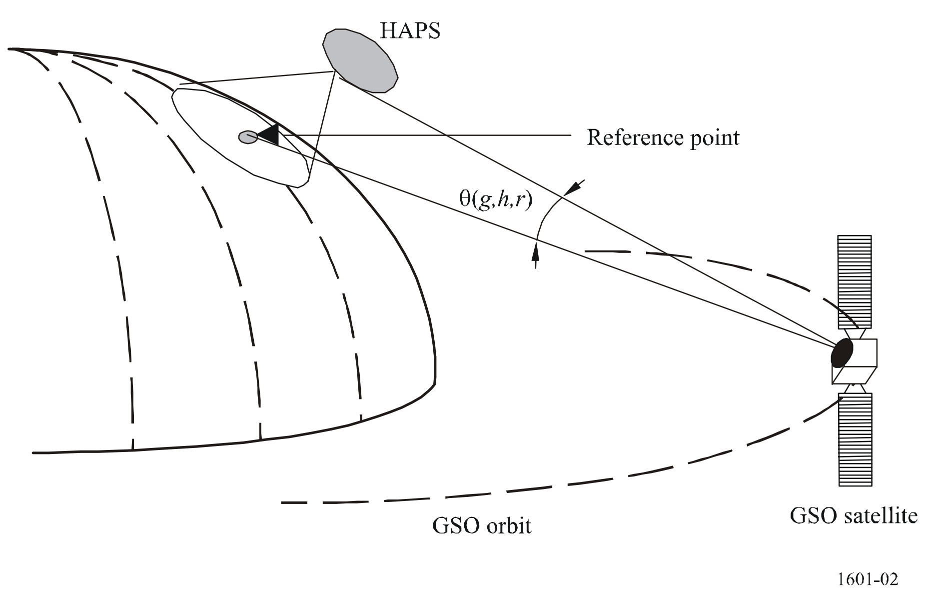


FIGURE 2

Geometric model of the reference point for a GSO satellite



To calculate the discrimination angle at a GSO satellite, a reference point must be established for the calculations. The reference point is selected as a specific location on the surface of the Earth. It is then assumed that the boresight of the spot beam antenna of the GSO satellite is always directed to the reference point, regardless of the orbital location of the spacecraft. In cases where the reference point is not visible to the GSO satellite, then it is assumed that the reference point is moved to another point under the condition that the elevation angle toward the GSO satellite is the minimum value. Figure 2 shows the geometric model of the example including the reference point.

Based on an operational scenario of the HAPS system in which a HAPS can transmit multiple carriers in each spot beam, it is assumed that HAPS downlink multiple carriers could exist in the entire receiver bandwidth at the GSO satellite. The aggregate interference from a HAPS system is expressed as I_{single} and calculated as a sum of the spectral density $I(g,h,b,r)$ of all the possible spot beams of the HAPS which could use the same frequency as shown in equation (2).

$$I_{single} = 10 \log\left(\sum_{h=1}^{h_n} \sum_{b=1}^{b_n} 10^{I(g,h,b,r)/10} \right) \quad \text{dB(W/MHz)} \qquad (2)$$

where b_n indicates the number of spot beams which could use the same frequency and h_n indicates the number of HAPS which one HAPS system consists of.

Once the interference level received by the FSS has been assessed, the I/N ratio can be assessed as follows:

$$I/N_{single} = I_{single} - N = I_{single} - 10 \log(k\, T_{sat}) - 60 \qquad (3)$$

where:

- I/N_{single}: interference-to-thermal noise ratio (dB)
- N: thermal noise power of satellite receiver in 1 MHz (dB(W/MHz))
- k: Boltzmann's constant (W/(K · Hz))
- T_{sat}: system noise temperature of a GSO/FSS satellite (K).

The calculated aggregate interference level would then be compared with an appropriate interference threshold in order to determine if the HAPS system is causing harmful interference to the FSS.

2.2 Interference from multiple HAPS systems

Situations could arise in which several operational HAPS systems could cause interference to a certain GSO satellite. The aggregate interference from multiple HAPS systems is expressed as $I_{multiple}$ and derived from the sum total of each interference level from each HAPS system to the GSO satellite as shown in equation (4).

$$I_{multiple} = 10 \log\left(\sum_{s=1}^{s_n} \sum_{h=1}^{h_n} \sum_{b=1}^{b_n} 10^{I(g,h,b,r)/10} \right) \quad \text{dB(W/MHz)} \qquad (4)$$

where s_n indicates the number of HAPS systems. The other terms are as described above for the case of interference from a single HAPS system.

For an exact evaluation of a multiple HAPS situation, the characteristics of each HAPS system should be used in the calculations. In the absence of such information for one or more of the systems, an approximate indication of the resulting interference can be obtained by using the characteristics of a reference HAPS system in the calculations.

Once $I_{multiple}$ has been found, it can be used instead of I_{single} in equation (3) in order to assess the impact of the interference upon the FSS.

2.3 Downlink power control

The interference from HAPS downlink to GSO/FSS uplink is maximum under the condition of maximum transmission power of HAPS downlink or under the rain condition. When using downlink power control in HAPS system, aggregate transmission power of HAPS downlink can be reduced under clear-sky conditions. As a result, the interference received at the FSS spacecraft is reduced in clear-sky conditions.

2.4 Input parameters

Interference studies applying the methodology of this Annex should use actual characteristics of FSS and HAPS systems under consideration if available. In their absence, the following values may be used:

2.4.1 HAPS characteristics

See Recommendation ITU-R F.1569.

2.4.2 FSS input characteristics

– T_{sat}: 500 K

– Antenna beamwidth (small stations): 0.3°

– Antenna beamwidth (hub stations): 2°

– Antenna gain: Recommendation ITU-R S.672, Annex 1, (L_s = –20 dB)[1].

Appendix 1
to Annex 1

An example of the application of the methodology of Annex 1

1 Interference model

It is assumed a HAPS system consisting of a number of HAPS platforms is operating in a rectangular area as shown in Fig. 3. A platform located at the centre of the area is the reference point in this example calculation and all other platforms are deployed on the plane which is perpendicular to the line connecting the reference point and its nadir point on the Earth. When the reference point is taken as the origin of the x-y coordinates on that plane, it is assumed that the HAPS platforms are placed at every lattice point in the area which has the coordinates of (L_x, L_y), ($L_x - L_y$), ($-L_x$, L_y) and ($-L_x$, $-L_y$). Also assuming that the numbers of HAPS platforms are n_x and n_y as counted on the x and y axes, respectively, then the total number of platforms, n_t, in consideration becomes $n_x \times n_y$ (n_x and n_y are odd numbers). In this deployment model, the separation distance

[1] Recommendation ITU-R S.672 provides design objectives for spacecraft antenna designers. Providing objectives for a shaped beam is not possible for typical cases as there is no knowledge of the FSS service area. A specific roll-off performance of L_s = –10 dB may be used so as to characterize the shaped beam case. Further study is required on the roll-off performance.

between neighbouring HAPS are expressed as d_x and d_y as measured along with the x and y axes, respectively. The d_x and d_y are given by $2L_x/(N_x – 1)$ and $2L_y/(N_y – 1)$, respectively.

It is also assumed that the GSO satellite to be interfered is positioned in the direction of the assumed x axis and the satellite antenna is always pointed to the reference point. The angle α in Fig. 4 is defined as the elevation angle of the satellite at the reference point measured from the x-y plane.

The aggregate interference from the n_T HAPS platforms are evaluated in terms of the interference to satellite noise power ratio, *I*/*N*, of the GSO satellite as a function of the elevation angle, αfor combinations of typical HAPS deployment and satellite characteristics.

FIGURE 3

Interference evaluation model

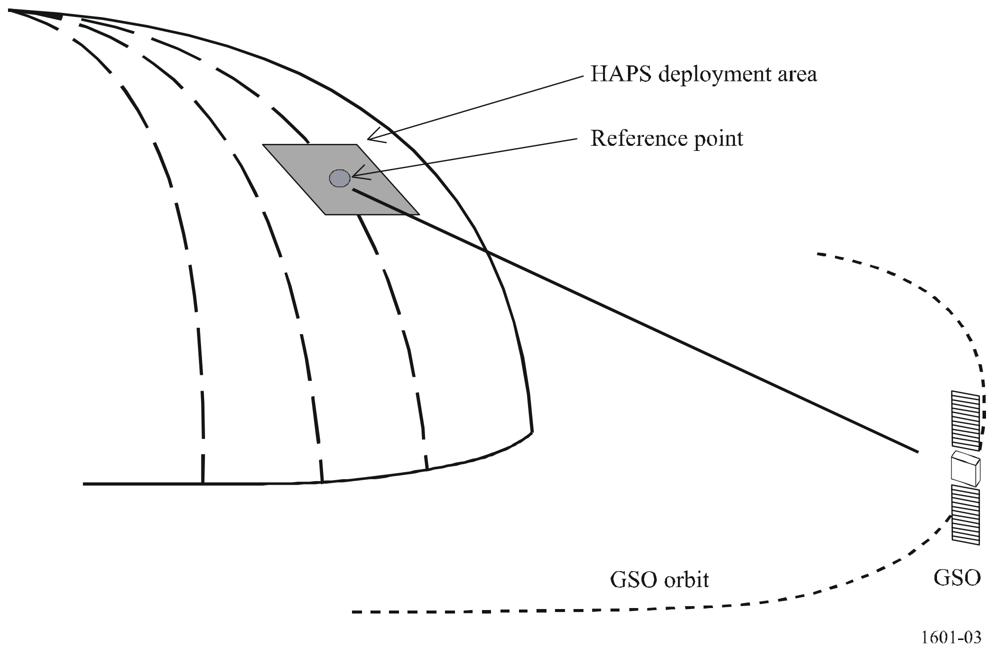
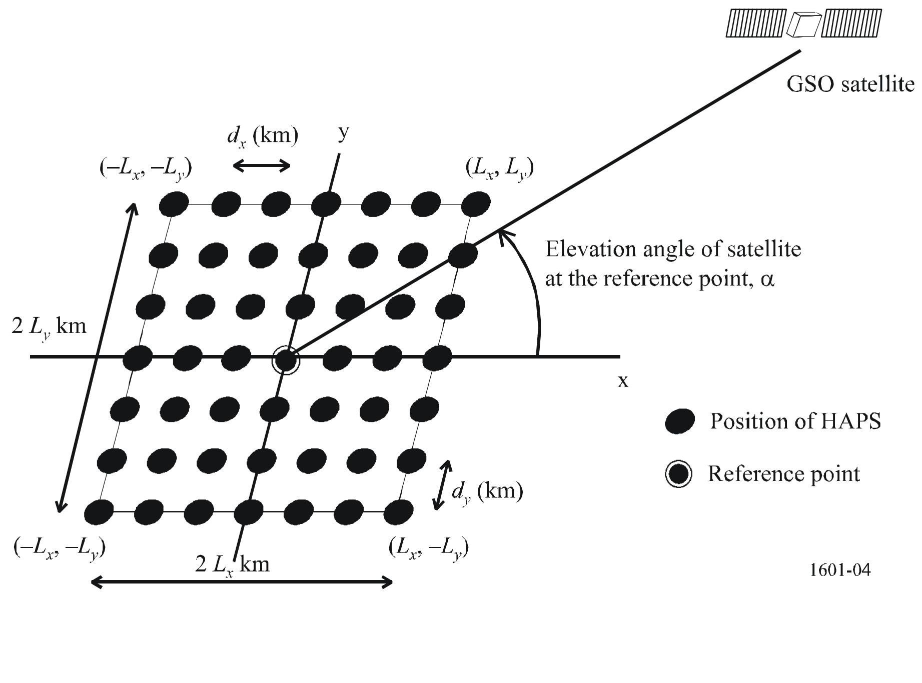


FIGURE 4

HAPS deployment model



2 HAPS characteristics

Typical parameters of HAPS systems at the 28 GHz band are given in Recommendation ITU-R F.1569. Table 1 shows the parameters used for the calculations.

TABLE 1

HAPS characteristics

Parameters	HAPS-1	HAPS-2
Altitude of HAPS (at the reference point) (km)	20	20
Aggregate e.i.r.p. of a HAPS sideward or backward(1)	–5 dBW in 20 MHz bandwidth	–5 dBW in 20 MHz bandwidth
Length of HAPS deployment area (2 L_x) (km)	1 000	600
Width of HAPS deployment area (2 L_y) (km)	1 000	600
Number of HAPS on x axis (n_x)	11	9
Number of HAPS on y axis (n_y)	11	9
Total number of HAPS (n_T)	121	81
Distance between HAPS on x axis (d_x) (km)	100	75
Distance between HAPS on y axis (d_y) (km)	100	75

(1) The practical model with the 397 spot beams shown in Fig. 3 of Recommendation ITU-R F.1569.

3 GSO satellite characteristics

The parameters of the GSO satellite are shown in Table 2.

TABLE 2

GSO satellite characteristics

Parameters	GSO-1	GSO-2
System noise temperature (K)	500	500
Antenna half-power beamwidth (degrees)	0.3	2
Antenna side-lobe level (dB) (L_s in Annex 1 of Rec. ITU-R S.672-4)	–20	–20
Antenna peak gain(1) (dBi)	55.0	38.5

(1) Calculated using the equation of G_{max}(dBi) = 44.5 – 20 log θ (θ is a –3 dB beamwidth (degrees)).

4 Calculation results

Figures 5 and 6 indicate the calculated I/N of the GSO satellite.

It is obvious from the methodology that the I/N of the GSO satellite largely depends on the peak gain of the antenna of the GSO satellite when the antenna is pointed towards the interference source. An antenna with the narrow beamwidth (0.3°) receives more interference when the reference point has lower elevation angles because the number of the HAPS within the main beam is limited at the high elevation angles and increased at the lower elevation angles. On the other hand, an antenna with the wider beamwidth (2°) receives less interference because of lower antenna gain and the interference level is rather constant because it almost covers the entire HAPS deployment area within the main beam even for the high elevation angles. The interference level mainly depends on the propagation distance of the interference signal. For these cases results show that the *I*/*N* of the GSO satellite is less than –20 dB (1%) for both GSO satellite cases under usual operating condition where the earth stations are assumed to have elevation angles of 20° or higher against the satellite.

FIGURE 5

HAPS-1 model (121 HAPSs with 100 km interval)

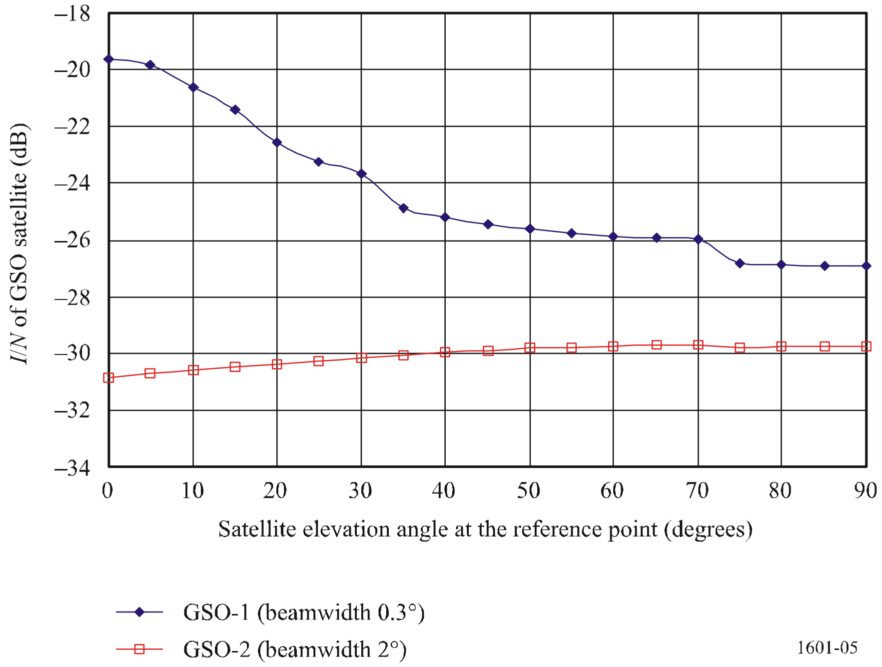
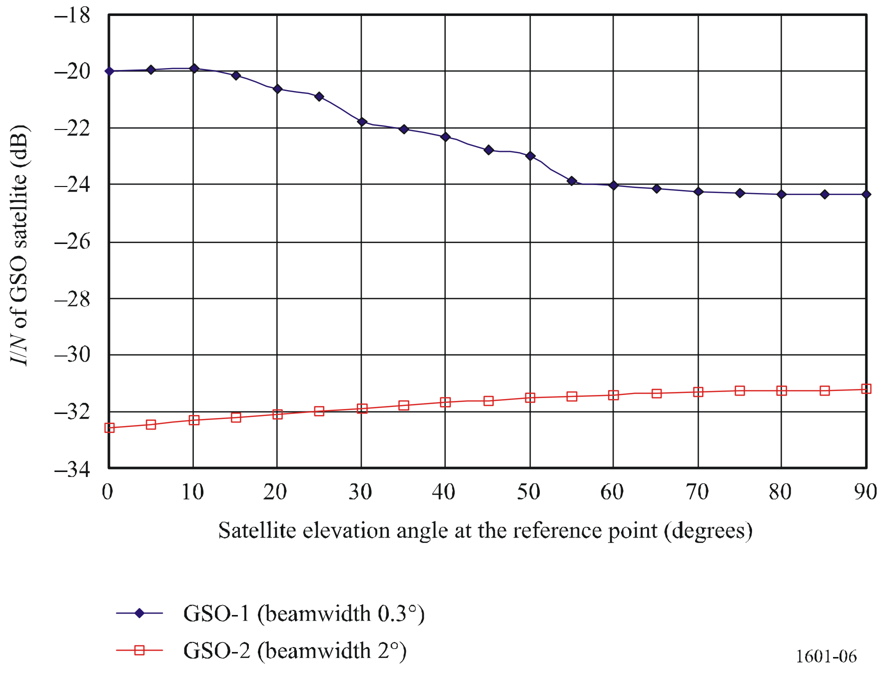


FIGURE 6

HAPS-2 model (81 HAPSs with 75 km interval)



Annex 2

A methodology for the calculation of the e.i.r.p. transmissions from HAPS in the HAPS-to-ground direction within the band 27.5-28.35 GHz that would cause a given increase in the *I*/*N* of receivers of FSS geostationary satellites

1 Introduction

The measure of interference used in this method is the *I*/*N* of the FSS receiving system. The determinative interference characteristics of the FSS receiving system are its antenna gain and system noise temperature.

This method can be used to estimate the e.i.r.p. density of transmissions from HAPS in the HAPS-to-ground direction that could cause a given increase in the *I*/*N* of FSS receiving systems in the GSO orbit.

2 Description of the method

The first step of the method is to calculate the given increase in interference-to-noise ratio, *I*/*N*, by determining the noise power in the assumed receiving system noise power density in 1 MHz.

$$N = k\,T\,B \tag{5}$$

where:

- k: Boltzmann's constant (W/(K · Hz))
- T: FSS receiving system noise temperature (K)
- B: reference bandwidth (1 MHz).

Next, the assumed *I*/*N* is used to determine the interference power (dB(W/MHz)).

$$I = N + I/N \tag{6}$$

Then the power flux-density (PFD) that would produce the assumed interference at the GSO orbit is calculated:

$$\text{PFD} = I - G_R + 20 \log (f) + 21.45 \qquad \text{dB(W/(m}^2 \cdot \text{MHz))} \tag{7}$$

where:

- G_r: effective gain (dBi) of the FSS receive antenna in the direction of the interfering HAPS platforms,
- f: frequency of transmission (GHz).

Then, the total e.i.r.p. from all HAPS transmissions that would produce this PFD at the GSO is

$$(\text{e.i.r.p.})_{total} = \text{PFD} + 10 \log(4\pi \cdot d^2) \qquad \text{dB(W/MHz)} \tag{8}$$

where d is the distance (m) between the HAPS platform and the FSS satellite.

In principle:

$$(\text{e.i.r.p.})_{total} = 10 \log \sum_{j=1}^{n} 10^{-0.1(\text{e.i.r.p.})_i} \qquad \text{dB(W/MHz)} \tag{9}$$

where:

$(e.i.r.p.)_j$: e.i.r.p. from the j-th HAPS platform

n: number of interfering HAPS platforms.

Assuming for simplicity,

$$(e.i.r.p.)_{average} = (e.i.r.p.)_{total} - 10 \log(n) \qquad \text{dB(W/MHz)} \qquad (10)$$

the average e.i.r.p. from each HAPS platform can be approximated.

3 Interference levels from typical HAPS systems

The interference that could be caused by HAPS systems to FSS satellites in the geostationary orbit can be determined by comparing the e.i.r.p. in the side and back lobes of the HAPS transmitting antennas with the e.i.r.p.s resulting from the calculation above.

Appendix 1 to Annex 2

An example of the application of the methodology of Annex 2

1 Introduction

The two FSS systems described in Annex 1, § 2.4.2 above are considered in these example calculations. One system, receiving from major hub stations, employs a receiving antenna beamwidth of 2° and a gain of 39 dBi. The other system, receiving from ubiquitous, small, user terminals is assumed to have a beamwidth of 0.3°, and a gain of 55.4 dBi. Both kinds of systems are assumed to have receiving system noise temperatures of 500 K, which is taken as being representative of sensitive receivers that have been identified for implementation.

This example assumes a dense deployment of HAPS systems. In the case of an FSS GSO satellite with a 2° beam antenna, it is assumed that interfering signals from as many as 100 HAPS platforms will be received. Some of those signals will be received at or near maximum main-beam gain, others will be received with lesser gain. This example assumes that signals from the 100 HAPS platforms will each be received with an average FSS antenna gain of 1 dB below its maximum, that is, with a gain of 38 dBi.

Similarly, in the case of an FSS GSO satellite with a 0.3° beam, which will see many fewer HAPS platforms than a 2° beam, it is assumed that interfering signals from as many as three HAPS platforms will be received, and that they will be received at different gain levels on the antenna pattern. This example assumes that signals from the three HAPS platforms will each be received with an average FSS antenna gain of 1 dB below its maximum, that is, with a gain of 54.4 dBi.

The distance between the GSO and the closest HAPS platform is taken as the altitude of the GSO and the 20 km height of HAPS platforms (35 788 – 20 = 35 768 km).

2 Interference to 2° beamwidth FSS hub station beams

Half-power beamwidth: 2.0°

Peak satellite antenna gain: 39 dBi

Average receiving antenna gain from all interfering HAPS platforms: 39 – 1 = 38 dBi

Assumed number of interfering HAPS platforms within the 2° beamwidth: 100

Receiving system noise temperature: 500 K

Reference bandwidth: 1 MHz

Therefore, the receiving system noise power:

$$N = k\,T\,B = -228.6 + 10\log(500) + 10\log(10^6) = -141.61 \qquad \text{dB(W/MHz)} \qquad (11)$$

Assuming the interference power in this example calculation is 1% of the noise power, the I/N will be 10 log (0.01) = –20 dB. Then:

$$I = N + I/N = -141.61 - 20 = -161.61 \qquad \text{dB(W/MHz)} \qquad (12)$$

The PFD that will produce that interference power at the orbit is:

$$\text{PFD} = (-161.61 - 38 + 29 + 21.45) = -149.2 \qquad \text{dB(W/(m}^2 \cdot \text{MHz))} \qquad (13)$$

Then:

$$(\text{e.i.r.p.})_{total} = -149.2 + 162.1 = 12.92 \qquad \text{dB(W/MHz).}$$

If that aggregate interference power is apportioned among 100 HAPS platforms, each such platform would be limited to 12.92 – 10(log 100) = 12.92 – 20 = –7.08 dB(W/MHz).

3 Interference to 0.3° beamwidth FSS small user terminal beams

Half-power beamwidth: 0.3°

Peak satellite antenna gain: 55.4 dBi

Average receiving antenna gain from all interfering HAPS platforms: 55.4 – 1 = 54.4 dBi

Assumed number of interfering HAPS platforms within the 0.3° beamwidth: 3

Receiving system noise temperature: 500 K

Reference bandwidth: 1 MHz.

Therefore, as above, the receiving system noise power, N = –141.61 dB(W/MHz), the maximum interference power, I = –161.61 dB(W/MHz).

The PFD producing that interference power will be:

$$\text{PFD} = (-161.61 - 54.4 + 29 + 21.45) = -165.6 \qquad \text{dB(W/(m}^2 \cdot \text{MHz))} \qquad (14)$$

Then:

$$(\text{e.i.r.p.})_{total} = -165.6 + 162.1 = -3.5 \qquad \text{dB(W/MHz)}$$

If that aggregate interference power is apportioned among 3 HAPS platforms, each such platform would be limited to –3.5 – 10(log 3) = –3.5 – 4.77 = – 8.27 dB(W/MHz).

4 Interference levels from typical HAPS systems

The maximum interference from the side and back lobes of HAPS downlink transmissions at 28 GHz can be calculated from the HAPS system parameters given in Recommendation ITU-R F.1569.

A HAPS platform transmitter, designed to serve user terminals having elevation angles as low as 26°, under rainy conditions, would have an output power of 1.8 dBW, with a bandwidth of 150 MHz, a feeder link loss of 0.5 dB, and an antenna having a gain of 16.4 dBi. That results in a maximum e.i.r.p. of 17.7 dBW per 150 MHz, or 17.7 – 10 log 150 = (17.7 – 21.7) = –4 dB(W/MHz).

However, the antenna gain in the direction of the far side and back lobes, will be at least 10 dB below isotropic. Therefore, the e.i.r.p. of a HAPS platform towards the GSO is (–4 – 16.4 –10) = –30.4 dB(W/MHz).

For the examples given in Sections 2 and 3 above, the e.i.r.p. toward the GSO is well below the levels from individual HAPS-to-ground transmissions of –7.08 dB(W/MHz) or –8.27 dB(W/MHz), that would result in an *I*/*N* of less than 1% in FSS satellites with 2.0° or 0.3° antenna beams.