

RECOMMENDATION ITU-R S.1593

Methodology for frequency sharing between certain types of homogeneous highly-elliptical orbit non-geostationary fixed-satellite service systems in the 4/6 GHz and 11/14 GHz frequency bands

(Question ITU-R 231/4)

(2002)

The ITU Radiocommunication Assembly,

considering

- a) that many fixed-satellite service (FSS) frequency bands may be used for both geostationary (GSO) and non-GSO satellite networks according to the Radio Regulations;
- b) that the technology advances necessary to allow the implementation of non-GSO FSS satellite systems capable of providing regional or worldwide service to small earth stations in a cost-effective manner are becoming available;
- c) that some non-GSO FSS systems are not designed to employ the interference mitigation technique of satellite diversity;
- d) that studies have shown that without the use of interference mitigation techniques, it will be impracticable for large numbers of non-GSO FSS systems to share the same frequency band when the systems are of significantly varying design;
- e) that studies have shown that multiple non-GSO FSS systems using only the mitigation technique of homogeneous design can share with each other in the same frequency bands;
- f) that for non-GSO FSS systems using a highly-elliptical orbit (HEO) design, the implementation of satellite diversity comes at a design cost and complexity that may make its use by such systems in sharing with other types of non-GSO FSS systems difficult;
- g) that multiple non-GSO FSS systems that operate in the 11/14 GHz and 4/6 GHz bands using an HEO design (e.g. USAKUS2 as described in Recommendation ITU-R S.1328) can employ geometric mitigation techniques to share with each other by several methods of satellite separation, including interleaving of satellites within orbital planes,

recommends

- 1 that in the 4/6 GHz and 11/14 GHz bands, the methodology presented in Annex 1 be used to perform analysis of frequency sharing between co-frequency, co-directional non-GSO FSS satellite systems of homogeneous sub-geosynchronous HEO design, i.e. the apogees, perigees, and inclinations of the systems are identical.

NOTE 1 – The methodology in Annex 1 may also be applicable to other types of non-GSO FSS systems. To determine whether the sharing prospects are different between multiple homogeneous non-GSO FSS systems of the type considered in Annex 1 and inhomogeneous non-GSO FSS systems, further study is required.

ANNEX 1

Methodology for sharing between certain types of homogeneous HEO non-GSO FSS systems in the 4/6 GHz and 11/14 GHz frequency bands

1 Introduction

The methodology presented in this Annex addresses sharing between certain types of homogeneous non-GSO FSS systems in the 4/6 GHz and 11/14 GHz frequency bands. This approach applies to systems that have homogeneous orbits; i.e. the apogee, perigee, and inclination are identical. The systems must have exactly the same ground tracks for the active portions of their orbits. The difference will come in the phasing of the satellites in the orbital track. The methodology applies to systems that are designed such that the portions of the orbit in which the satellites are either transmitting or receiving (active arcs) do not cross each other. The approach involves the interleaving of satellites within the same orbital ground track when sharing between multiple non-GSO FSS systems. It is applicable generally to non-GSO systems that employ HEO in which the satellites are only transmitting or receiving in a certain portion of the orbit. However, it may be applicable to other non-GSO systems provided that the active portions of the orbit do not cross each other. This approach eliminates in-line interference events since the active arcs do not cross. This means that there will be no need for complicated switching strategies in order to avoid in-line interference events and there will be no need to know the exact locations of the satellites in other constellations as they will be phased in such a way that there will always be a minimum separation between two satellites in adjacent systems. Appendix 1 to this Annex contains an example application of this methodology.

2 Description of methodology

The following Steps comprise this methodology:

Step 1: Select a minimum true anomaly separation angle between satellites in adjacent constellations.

This is the satellite separation angle between adjacent satellites in two constellations near apogee, when the satellites in adjacent constellations will be the closest to each other. At other locations in the active arc (or during any other portion of the orbit), satellites in adjacent systems will be further separated. The approach taken here is to select a minimum true anomaly separation angle between two satellites that are in adjacent constellations around the apogee. Since the apogee point is when the satellites are travelling at the slowest rate of speed, if the satellites in adjacent constellations are placed symmetrically around the apogee, this will be when the satellites would be closest to each other. Thus, the apogee will be chosen as the centre true anomaly and the true anomalies of the satellites in the two constellations will be equal to the true anomaly at apogee plus one-half the minimum true anomaly separation angle and the true anomaly at apogee minus one-half the minimum true anomaly separation angle. The resultant true anomalies (E) for the two satellites are given in equations (1) and (2):

$$E_1 = E(\text{apogee}) + \frac{\text{Separation angle}}{2} \quad \text{degrees} \quad (1)$$

$$E_2 = E(\text{apogee}) - \frac{\text{Separation angle}}{2} \quad \text{degrees} \quad (2)$$

Step 2: Determine the orbital locations (latitude, longitude and altitude) of the satellites that are located at the minimum true anomaly separation.

From the values for the true anomalies and the other orbital parameters for the system, it is then possible to calculate the eccentric anomaly (E_e), mean anomaly (E_m) and time (t) (relative to the time of the ascending node). From these values, it is possible to calculate the latitude, longitude and orbital altitude of the two satellites. The relevant equations for these calculations are as follows:

$$E_e = 2 \cdot \tan^{-1} \left(\tan \left(\frac{E}{2} \right) \sqrt{\frac{1-e}{1+e}} \right) \quad \text{degrees} \quad (3)$$

where e is the eccentricity of the orbit.

$$E_m = E_e - e \sin E_e \quad \text{degrees}^* \quad (4)$$

$$t = \frac{T}{360} \cdot (E_m - E_{ma}) + t_a \quad \text{s} \quad (5)$$

where:

T : period of the orbit

E_{ma} : mean anomaly at the ascending node time, t_a .

$$\text{long} = \tan^{-1}(\cos(i) \cdot \tan(\theta_p + E)) + \Lambda - \omega_e \cdot (t - t_a) \quad \text{degrees} \quad (6)$$

where:

i : inclination angle of the orbit (degrees)

θ_p : argument of perigee of the orbit (degrees)

Λ : longitude of the ascending node of the orbit (degrees)

ω_e : rotation rate of the Earth (degrees/s)

$$\text{lat}_{\text{geocentric}} = \sin^{-1}(\sin(i) \cdot \sin(\omega_p + E)) \quad \text{degrees} \quad (7)$$

The latitude calculated in equation (7) is the geocentric latitude. The geographical latitude can be derived from the geocentric latitude by using the formula in equation (8).

$$\text{lat}_{\text{geographical}} = \tan^{-1} \left(\frac{1}{(1 - J_\alpha)^2} \cdot \tan(\text{lat}_{\text{geocentric}}) \right) \quad \text{degrees} \quad (8)$$

where J_α is the factor for the Earth's oblateness.

* The solution to this equation has been developed using a trigonometric series developed by Lagrange.

$$Altitude = \alpha(1 - e \cdot \cos(E_e)) - R_e \quad \text{km} \quad (9)$$

where:

α : semi-major axis of the orbit (km)

R_e : radius of the Earth (km).

Step 3: Determine the locations of the other satellite systems that are within the same active arc based on the minimum true anomaly separation and the orbital parameters of the system.

The mean anomaly difference between the two satellites that are nearest to their apogee point allows for the computation of the time intervals between satellite passages over any point in the ground track. For example, if the mean anomaly difference between two satellites is 15° and the orbital period of both satellites is 8 h, then it will take $(E_m / 360) \times T = (15/360) \times 8 = 1/3 \text{ h} = 20 \text{ min}$ between passages of the two satellites past any point on the orbit. Since the satellites in the different constellations will follow the same ground tracks, this will allow for the calculation of the location of the satellites in the other constellations at the instant that the first two satellites are nearest to their apogee point (separated by the true anomaly separation) by simply adding or subtracting the time interval to the times for the first two satellites. For this example, if one satellite moves forward 20 min in the same orbital ground track, the next satellite (which is in another constellation) will be located at this point in the orbit when the original satellite is located at one-half the true anomaly separation past apogee. Using the time difference between the first two satellites (these times are calculated in Step 1), the time relative to time of the ascending node for each of the other satellites in the other systems may be found by simply adding the time difference to the time of the satellite that is past apogee or subtracting the time difference to the time of the satellite that is before apogee. Given the time (relative to the time of the ascending node) of the satellite in the next system, the mean anomaly, eccentric anomaly, true anomaly, latitude, longitude and altitude of that satellite can be found using the following equations:

From the new time, the mean anomaly can be calculated:

$$E_m = \frac{360}{T} \cdot (t - t_a) + E_{ma} \quad \text{degrees} \quad (10)$$

The eccentric anomaly is then found by applying an iterative solution to equation (4). The true anomaly is then calculated as:

$$E = 2 \cdot \tan^{-1} \left(\tan \left(\frac{E_e}{2} \right) \sqrt{\frac{1+e}{1-e}} \right) \quad \text{degrees} \quad (11)$$

The latitude, longitude and altitude of the satellite at this time can then be calculated using equations (6) through (9). The time interval is added to or subtracted from each new satellite until the time is reached where the satellite is not in the active arc. This process results in the locations of all of the satellites in the active arc.

Step 4: Determine the number of satellites and, thus, systems that are in the active arc.

This is a simple process of just adding the number of satellites determined in Step 3 to be within the active arc based on the minimum true anomaly separation. In some cases, the satellite entering the active arc and the one leaving the active arc will be of the same system. In these cases, the total number of systems within the active arc will be the total number of satellites minus one.

Step 5: Select one satellite to be in the wanted satellite system and calculate the interference from each of the other satellite systems into the wanted system for both the uplink and the downlink and calculate the aggregate interference from all of the interfering systems into the wanted system.

After selection of the wanted satellite, the earth station location for the wanted system is selected. This selection can be done randomly or a worst-case earth station location can be used. For the uplink, the off-axis angle for the interfering earth station antenna is calculated (this is the angle between the direction toward the satellite this earth station is communicating with and direction to the wanted satellite). For the downlink, the off-axis angle for the wanted earth station antenna is calculated (this is the angle between the direction toward the wanted satellite and the direction toward the satellite in the interfering system). The interference contributions from each of the interfering systems into the wanted system are calculated using equation (12) for the uplink and equation (13) for the downlink.

$$I_{\uparrow} = P_{ES} + G_{ES,t}(\theta_i) - (32.45 + 20 \log(f_{\uparrow} \cdot d_{\uparrow})) + G_{s,r} \quad \text{dBW} \quad (12)$$

$$I_{\downarrow} = P_s + G_{s,t} - (32.45 + 20 \log(f_{\downarrow} \cdot d_{\downarrow})) + G_{ES,r}(\theta_w) \quad \text{dBW} \quad (13)$$

where:

P_{ES} : transmitted power of the interfering earth station (dBW)

θ_i : interfering earth station off-axis angle (degrees)

$G_{ES,t}(\theta_i)$: gain of the interfering earth station antenna in the direction of the wanted satellite (dBi)

$f_{\uparrow}$: frequency of the uplink (MHz)

$d_{\uparrow}$: distance between the interfering earth station and the wanted satellite (km)

$G_{s,r}$: receiving antenna gain of the wanted satellite (dBi)

P_s : transmitted power of the interfering satellite (dBW)

$G_{s,t}$: transmitting antenna gain of the interfering satellite (dBi)

$f_{\downarrow}$: frequency of the downlink (MHz)

$d_{\downarrow}$: distance between the interfering satellite and the wanted earth station (km)

θ_w : wanted earth station off-axis angle (degrees)

$G_{ES,r}(\theta_w)$: gain of the wanted earth station antenna in the direction of the interfering satellite (dBi).

The aggregate interference is calculated using equation (14).

$$I_{aggregate} = 10 \log \sum_1^n 10^{\frac{I_n}{10}} \quad \text{dBW} \quad (14)$$

where:

n : number of interfering satellite systems

I_n : interference contribution of the n -th system.

Step 6: Calculate the resultant $C/(I + N)$ due to the aggregate interference from these multiple interfering systems for both the uplink and the downlink into the wanted system link budget and calculate the total link $C/(I + N)$. Determine if the system meets its required performance criteria. It is noted that another interference evaluation methodology, such as I/N or $\Delta T/T$ may be used in place of $C/(I + N)$.

The resultant $C/(I + N)$ for the uplink and downlink are calculated using equations (15) and (16).

$$I + N = 10 \log \left(10^{\frac{I_{aggregate}}{10}} + 10^{\frac{N}{10}} \right) \quad \text{dBW} \quad (15)$$

$$\frac{C}{I + N} = C - (I + N) \quad \text{dB} \quad (16)$$

where:

N : noise power density and is equal to $k T B$

where:

k : Boltzmann's constant

T : receiver noise temperature of either the wanted satellite or the wanted earth station (K)

B : bandwidth (Hz).

The total $C/(I + N)$ for the entire link is calculated using equation (17).

$$\left(\frac{C}{I + N} \right)_{total} = -10 \log \left(\sum 10^{-\left(\frac{C}{I + N} \right)_{\uparrow} / 10} + 10^{-\left(\frac{C}{I + N} \right)_{\downarrow} / 10} + 10^{-\left(\frac{C}{I + N} \right)_{other} / 10} \right) \quad \text{dB} \quad (17)$$