

RECOMMENDATION ITU-R S.1595

**Interference mitigation techniques to facilitate coordination between
non-geostationary fixed-satellite service systems in highly elliptical
orbit and non-geostationary fixed-satellite service
systems in low and medium Earth orbit**

(Question ITU-R 231/4)

(2002)

The ITU Radiocommunication Assembly,

considering

- a) that in some frequency bands non-geostationary orbit (non-GSO) satellite systems are required to coordinate with other non-GSO satellite systems if there is frequency overlap;
- b) that systems using highly elliptical orbits (HEO) have unique features, such as transmitting and receiving only during a long dwell time (normally around the apogee) of a single satellite over specific range of latitude and longitude, stable and predictable service arcs, and few satellites required to provide coverage over an entire hemisphere;
- c) that studies have shown, without the use of interference mitigation techniques, it will be impracticable for non-GSO systems to share the same frequencies and meet performance objectives;
- d) that studies have shown there are several different interference mitigation techniques that may allow non-GSO systems to share;
- e) that the effectiveness of a mitigation technique to decrease interference may be determined by an improvement in several different performance parameters, i.e. C/I , I/N or $C/(I + N)$;
- f) that if the clear sky C/N is large, of the order of 25 to 35 dB, typical ranges for allowable I/N values can have a negligible effect on clear sky-link performance, i.e. $C/(N + I)$ obtained with and without mitigation techniques;
- g) that, in the situation described in *considering* f), C/I may be a more useful parameter than I/N in evaluating the effectiveness of interference mitigation techniques;
- h) that, in situations other than those described in *considering* f), the use of I/N to evaluate the effectiveness of interference mitigation techniques may be more appropriate;

- j) that there are some non-GSO systems in operation in the fixed-satellite service (FSS) that have large clear-sky C/N values on the order of 25 to 35 dB;
- k) that Recommendation ITU-R S.1323 provides methodologies for determining maximum permissible levels of interference between non-GSO FSS systems;
- l) that the maximum permissible levels of interference discussed in Recommendation ITU-R S.1323 are based on an increase in the unavailability of the victim system/network,

recommends

- 1 that the mitigation techniques described in Annex 1 of this Recommendation should be considered for use to facilitate coordination between non-GSO FSS systems in HEO and non-GSO FSS systems in low Earth orbit (LEO) and medium Earth orbit (MEO) when coordination is required by No. 9.12 of the Radio Regulations (RR) (see Notes 1 and 2);
- 2 that non-GSO FSS systems with large clear-sky C/N requirements, on the order of 25 dB to 35 dB, may use as a starting point to interference assessment, C/I as a criterion to determine the effectiveness of interference mitigation techniques (see Note 3);
- 3 that a more thorough assessment of the effectiveness of mitigation techniques should also take into account the methodologies of Recommendation ITU-R S.1323.

NOTE 1 – Annex 2 shows that the mitigation techniques described in Annex 1 can have adverse operational impacts on the systems implementing them (e.g. coverage, capacity, etc.). The severity of these impacts vary with system characteristics.

NOTE 2 – The mitigation techniques of Annex 1 may also be applicable to sharing between non-homogeneous HEO systems. Further study is required to determine this applicability.

NOTE 3 – Other interference criteria may be more appropriate for non-GSO FSS systems with typical clear-sky C/N requirements.

ANNEX 1

Mitigation techniques

This Annex provides a summary of mitigation techniques that may be used by non-GSO systems to facilitate sharing between non-GSO systems in HEO and non-GSO systems in LEO and MEO. Four techniques for mitigating interference have been identified and studied. This Annex does not represent an exhaustive list of mitigation techniques, others may be identified in the future. These interference mitigation techniques and combinations thereof are useful to different degrees in facilitating sharing between non-GSO systems in HEO and non-GSO systems in LEO and MEO. Finding the optimum mitigation technique(s) to be applied between any two non-GSO FSS systems, one of which is a HEO, may, in some cases, best be able to be accomplished during inter-system coordination. Annex 2 provides an example of the results of simulations using these mitigation techniques.

1 Satellite diversity

An in-line event occurs when one interfering non-GSO satellite is directly between the wanted non-GSO earth station and the wanted non-GSO satellite. Satellite diversity means that in-line events are avoided by the interfering non-GSO system selecting another visible satellite (with available beams) whenever the current satellite approaches an in-line event with a satellite operating in another non-GSO FSS system. To accomplish this technique, an avoidance angle of X° in reference to the victim earth station is utilized. A cone of X° is placed around the link from the victim earth station and the victim satellite assigned to downlink to that earth station. As a satellite from the interfering system enters that cone, the interfering satellite is not allowed to transmit within the cell radius of the victim earth station.

Satellite diversity implies performing a handover (switching) process due to reselecting the satellite for interference avoidance. Satellite diversity may require a complex process involving cooperation among the systems involved. This mitigation technique requires extensive knowledge of the location of both non-GSO systems satellites and inherently reduces the service capacity of the mitigating satellite system.

To use satellite diversity as an interference mitigation technique, it is necessary for the interfering non-GSO FSS system to be designed to have a sufficient number of satellites with enough beams per satellite capable of serving a given earth station location simultaneously. Not all non-GSO systems meet these criteria.

2 Satellite selection strategies

The algorithm chosen for satellite selection by a given non-GSO FSS system may enhance the ability of that system to share with other non-GSO FSS systems. In general, earth stations will communicate with the satellite that is at the highest elevation. If a system chooses to use a different tracking technique, such as selecting the satellite that has the largest angular discrimination with respect to the satellites of other non-GSO FSS systems, the sharing situation may improve with the expense of added complexity and/or reduced capacity in system operation. This mitigation technique requires extensive knowledge of the location of both satellite systems.

3 Earth station site diversity

In some cases, it may be possible to use earth station site diversity as a mitigation technique. This technique involves separating the earth stations so that when an in-line event occurs the interfering satellite is not pointed toward the victim earth station but is pointed toward another earth station further away. This ensures that there is no main beam-to-main beam interference, rather it is side lobe to main beam interference thus reducing the amount of interference. The fewer earth stations involved the more practical this becomes. This mitigation technique reduces the number of earth stations a non-GSO system could use and restricts the location of those earth stations. Therefore the capacity on the ground and the ability to serve certain areas are reduced but not necessarily the capacity on the satellite.

4 HEO apogee avoidance

HEO apogee avoidance uses a concept similar to the GSO arc avoidance technique proposed by several non-GSO systems which intend to operate in the bands 17.8-18.6 GHz and 19.7-20.2 GHz where protection of the GSO networks by non-GSO systems is required by RR Article 22. This concept uses the fact that an HEO apogee service arc can be defined based on the fact that many HEO systems use an inclination of approximately 63° and an argument of perigee of 270° or 90° . Many HEO systems employ this common inclination because for inclined elliptical orbits the argument of perigee changes due to the non-uniform gravitational pull of the Earth. Lunar and solar gravitation are secondary causes for movement in the argument of perigee. For an HEO type orbit it is necessary to keep the argument of perigee stable so that the operational portion of the orbit (or where the satellite dwells the longest) is consistently in the same place above the Earth. The formula for rate of change of the argument of perigee is:

$$\dot{\omega} = \frac{4.982}{(1-e^2)^2} \left(\frac{R_e}{a} \right)^{3.5} (5 \cos^2 i - 1) \quad \text{degrees/day}$$

where:

$\dot{\omega}$: rate of change of the argument of perigee

e : eccentricity of the orbit

R_e : radius of the Earth

a : semi-major axis of the orbit

i : inclination of the orbit.

When the inclination of the orbit is equal to 63.4° or 116.6° the argument of perigee remains constant since at these angles $\cos^2 i = 1/5$ and $\dot{\omega}$ is zero. Therefore, for any satellite orbit semi-major axis and eccentricity, if the inclination is 63.4° , then the argument of perigee (and therefore the apogee service arc) is constant and well defined. A northern HEO apogee service arc is defined when the argument of perigee for the HEO orbit is 270° . A southern HEO apogee service arc is created when the argument of perigee for the HEO orbits is 90° .

If the HEO system has known earth station locations then the beams on the LEO or MEO satellite could be directed away from those earth stations when the LEO or MEO satellite is within the HEO apogee service arc. If the HEO systems has ubiquitous earth stations then the LEO or MEO satellite would have to direct the beams away from all earth station locations for which there might be

an in-line event when the LEO or MEO satellite is in the HEO apogee service arc. This redirection of beams would then avoid in-line conjunction, and thus reduce the interference to acceptable levels between the two non-GSO satellites without having to have extensive knowledge of the location of the HEO satellites. This mitigation technique inherently reduces the service capacity for the mitigating satellite system. Redirecting the beams away from several known earth station locations would have less impact on the interfering systems satellite coverage capability than redirecting the beams away from all of the possible earth station locations with the ubiquitous case.

ANNEX 2

Results from simulations using mitigation techniques

1 System characteristics

The dynamic simulations of this study were performed using data provided in RR Appendix 4 coordination information, Recommendation ITU-R S.1328 and through other contributions to ITU-R. Five systems are characterized by the information found in Table 1: two LEO systems, two MEO systems and one HEO system. For all systems, the satellite selection strategy for nominal operations is assumed to be highest elevation angle, unless otherwise stated for a mitigation technique. The USCSID-P system is modelled such that the satellites do not transmit to any earth station when the subsatellite latitude of the HEO satellite is below 35° in order to protect the GSO arc. This GSO avoidance technique is a typical HEO operational characteristic and is not intended to reflect the actual characteristics of USCSID-P.

The earth station locations of each system were modelled as concentric circles around a co-located earth station with the victim non-GSO system. The distance between earth stations was based on the beamwidth of the satellite downlink such that the non-GSO system would not cause self interference. For the HEO system only one earth station was modelled because the earth stations for this system are very far apart and multiple earth stations would not have any cumulative effect on the results of the simulations.

TABLE 1
System characteristics

Characteristic	USCSID-P	LEOSAT-1	LEOSAT-2	USAMEO-2	USAMEO-3
Number of satellites	8	288	63	15	20
Number of planes	8	12	7	3	4
Number of satellites per plane	1	24	9	5	5
Plane spacing (degrees)	45	15.36	51.43	120	90
Inclination (degrees)	63	84.7	48	50	55
Orbit altitude (km)	Apogee = 39 400 Perigee = 1 000	1 375	1 400	10 355	10 352
Inter-plane phasing (degrees)	$45^*(j-1)$ $j = 1, 3, 5, 7$ $45^*(j+1)$ $j = 2, 4, 6, 8$	Random	28,57	24	0
Minimum earth station elevation angle (degrees)	3	40	16	25	30
<i>Downlink transmission parameters</i>					
Carrier bandwidth (MHz)	3 200	500	35	222	133.47
Power control	No	No	Yes	No	No
Earth station receive peak gain (dB)	70 and 59.5	34.1	34.2	51.7	35.9
Earth station receive antenna pattern	Rec. ITU-R S.1428	Rec. ITU-R S.1428	Rec. ITU-R S.1428	Rec. ITU-R S.1428	Rec. ITU-R S.1428
Earth station receive antenna diameter (m)	20 and 6	0.3	0.35	2.2	0.36
Earth station receive noise temperature (K)	255	288	678.4	259.6	192
Satellite transmit peak gain (dB)	51	34.7 to 35.7	34.3	41.28	44.6
Satellite transmit antenna pattern	Rec. ITU-R S.672	−0.5 edge of coverage, −25 near side lobe, −30 far side lobe	Rec. ITU-R S.672 $L_N = -25$ dB	Rec. ITU-R S.672 $L_N = -25$ dB	Rec. ITU-R S.672 $L_N = -25$ dB
Satellite transmit e.i.r.p. (dBW)	70	53.9	37.22	42.5	60.34
Number of co-frequency co-polarized transmit beams	1	8	260	24	20
Number of earth stations modelled	1	91	91	91	91

2 Analysis

Simulations were run to determine the effectiveness of the different mitigation techniques and to understand the impact of these mitigation techniques on the individual systems analysed. Interference, in the form of C/I , is compared to a given threshold. For these simulations the threshold was set arbitrarily at $C/I = 20$ dB. For a large clear sky C/N such as 35 dB, rain could lower the C/N to approximately 20 dB. The effect of rain includes signal attenuation, an increase in the earth station receiver noise temperature, and (if dual polarization) an increase in cross-polarization interference. A C/N of 20 dB combined with C/I of 20 dB gives a $C/(N + I)$ of 17 dB, which is considered sufficient for link performance in this study. The C/I threshold chosen does not reflect the actual C/I threshold of any of the systems modelled and could be refined using the criterion specified in Recommendation ITU-R S.1323 (10% aggregate reduction in unavailability). Additionally, the joint probability of fading and interference should be considered. However, for this analysis, interference is considered acceptable if the resulting C/I value equals or exceeds 20 dB.

The impact of a given mitigation technique is measured by the decrease in the number of satellites in the mitigating system available to service a given area. Another type of impact, which is not included in this study, is the increase in the amount and complexity of switching required in implementing the mitigation techniques. However, it should be noted that the HEO system modelled is not designed for complex switching. The satellites of USCSID-P have only a single beam and although the mitigation technique of satellite diversity is modelled in these simulations, USCSID-P is not capable of performing the switching required to implement this mitigation technique.

The simulations were run for 100 days at 0.5 s intervals. The scenarios modelled examined interference into USCSID-P small and large earth station antennas from LEOSAT-1, LEOSAT-2, USAMEO-2, and USAMEO-3. Interference from USCSID-P into the LEO and MEO systems was also examined. The following are some additional assumptions used in the simulations:

- A satellite selection strategy of highest elevation angle criteria was used at each non-GSO earth station to select a non-GSO satellite for nominal operations.
- If the satellite at the highest elevation angle was not available due to mitigation techniques or all the beams were servicing other earth stations then the next highest satellite was chosen.
- If no satellites were available for the interfering system due to mitigation techniques or all beams were servicing other earth stations (i.e. there was no interference event), the C/I was set to a large number so that the statistics were not skewed.
- The sample LEO and MEO systems plan to have ubiquitously deployed earth stations. This was modelled by placing a grid of earth stations around the central LEO/MEO earth station, which was co-located with a single HEO earth station.

- The LEO and MEO earth stations were spaced in a grid around the HEO earth station. The cell size and the distance required for frequency reuse are what determined the distance between the LEO and MEO earth stations. The earth stations were aligned in concentric circles centred at the HEO earth station.
- Only one non-GSO satellite beam was able to transmit to one non-GSO cell.

Four mitigation techniques were modelled in this study: satellite diversity, earth station site diversity, satellite selection criteria and HEO apogee avoidance. All of the mitigation techniques were examined with the LEO and MEO protecting the HEO and the HEO protecting the LEO and MEO, except for HEO apogee avoidance. HEO apogee avoidance technique, with respect to the HEO protecting the LEO and MEO, was examined in the sense that if the LEO or MEO system uses HEO apogee avoidance what are the benefits to them regarding interference from the HEO.

2.1 Satellite diversity

Satellite diversity is a mitigation technique that is not generally available for use by satellite systems that utilize HEOs, as most such systems are not designed to have multiple satellites with multiple beams per satellite capable of simultaneously serving a given earth station location. Even so, there is nothing inherent in the definition of a HEO or any orbit that precludes the use of satellite diversity.

Table 2 lists the characteristics of several HEO systems. Upon examining this Table, note that the operating portion of most of these orbits is quite small. The systems are designed such that as one satellite is leaving the operational portion of the orbit, another satellite is entering. Generally these systems operate on the assumption that only one satellite is in the defined operational window for the major portion of time.

Dual satellite coverage for an HEO orbit is generally not required in order to provide continuous coverage. A constellation, implementing HEO orbits, designed to have many satellites visible or accessible to an earth station for more than a short period of time would depart from the natural characteristics of the HEO orbit. Therefore, satellite diversity does not seem to be the optimum mitigation technique for HEO systems because this would require HEO systems to be designed to work with a larger operational window, decreased minimum elevation angle, more complex earth stations and to add additional satellites to the constellations. The use of a larger operational window could increase interference to GSO satellites. A decrease in minimum elevation angle would increase the complexity of the earth station tracking. Adding satellites to the constellation would increase cost and complexity. It should be noted that, these impacts are generally applicable to any non-GSO system. However, these measures could increase the possibility to coordinate with other non-GSO systems.

To develop the proper avoidance angle as illustrated in Fig. 1, several simulations were run to determine the most appropriate avoidance angle to just allow the C/I threshold to be met. Satellite diversity takes advantage of the antenna gain discrimination that an earth station antenna can provide.

TABLE 2
Orbital parameters of HEO systems

System	1	2	3	4	5	6
Apogee altitude (km)	35 970	44 640.5	Approximately 39 000	35 800	52 700	40 000
Perigee altitude (km)	4 500	26 931.5	500	35 800	18 900	31 600
Eccentricity	0.59	0.21	0.74	0 (circular)	0.4	0.1
Orbital period	Approximately 12 h	23 h 56 min	11.97 h	23 h 56 min	23 h 56 min	23 h 56 min
Orbital inclination (degrees)	50	42.5	63.43	63.4	60	40
Operating portion of orbit	4 h before apogee to 4 h after apogee	4.5 h before apogee to 3.5 h after apogee	3.5 h around apogee	(See Note 1)	4 h	6 h
Number of satellites in constellation	3 or 4	3 or 4	7	(See Note 1)	6	4

TABLE 2 (*continued*)

System	7	8	9	10	11	12
Apogee altitude (km)	50 400	52 400	20 180	34 800	39 300	27 470
Perigee altitude (km)	21 200	19 200	20 180	20 600	1 075	310
Eccentricity	0.347	0.393	0	0.55	0.72	0.67
Orbital period	23 h 56 min	23 h 56 min	Approximately 12 h	Approximately 12 h	Approximately 12 h	Approximately 8 h
Orbital inclination (degrees)	63.4	63.4	63.4	45	63.4	45
Operating portion of orbit	6 h	4 h	2 h	8 h	6 h	4 h
Number of satellites in constellation	4	6	12	3	4	6