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THE PROVISION OF SPECTRUM FOR FEEDER LINKS OF NON-GEOSTATIONARY MOBILE SATELLITES

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ABSTRACT

The possibility of sharing spectrum in the 30/20 GHz band between geostationary fixed-satellite systems and feeder-links of low-earth orbit (LEO) mobile-satellite systems is addressed, taking into account that ITU Radio Regulation 2613 would be a factor in such sharing. Interference into each network in both the uplink at 30 GHz and the downlink at 20 GHz is considered. It is determined that if sharing were to take place the mobile-satellite may have to cease transmission often for intervals up to 10 seconds, may have to use high-gain tracking antennas on its spacecraft, and may find it an advantage to use code-division multiple access. An alternate solution suggested is to designate a band 50 to 100 MHz wide at 28 and 18 GHz to be used primarily for feeder links to LEO systems.

INTRODUCTION

Recently a number of organizations have indicated the intention to implement non-geostationary (non-GSO) mobile satellites in the frequency range 1 to 3 GHz. Some of these systems would be located in low earth orbit (LEO) circular highly inclined orbits in the order of 1000 kilometres high, others in similar but higher orbits in the order of 10,000 kilometres high, and yet others in highly elliptical orbits with an apogee higher than geostationary altitude. The technical characteristics of these systems such as satellite EIRP and G/T, modulation and access technique, earth terminal characteristics, etc. may vary widely, according to the information provided by their proponents. Their common thread, from the perspective of this paper, is their need for feeder links to gateway stations in fixed-satellite bands above 3 GHz. This paper addresses that need for spectrum and orbit resources in the fixed-satellite service for feeder links for these non-GSO mobile satellites.

BACKGROUND

The satellite systems considered here are collectively known as "Big-LEO" mobile-satellite systems, even though some of them may be at higher altitudes than LEO or may be in elliptical orbits. A common characteristic in their need for feeder links is that spectrum in the frequency range 1 to 3 GHz is very much at a premium, even after the decisions of the 1992 World Administrative Radio Conference (WARC-92), and that by their very nature the systems are world-wide as distinct to national as many geostationary systems are. These two factors imply a need to implement the feeder links in a fixed-satellite band above 3 GHz that is accessible on a world-wide basis.

The problem that arises at this point is that Big-LEO feeder link systems do not share the spectrum very well with more conventional geostationary (GSO) fixed satellite (FSS) systems. At regular short periods of time the satellites are at the same angle as seen from a GSO/FSS system's earth station, and at different regular instants of time as seen from a LEO/MSS system's gateway or feeder-link earth station. At those instants of time one network may cause harmful interference into the other. It is this potential problem, and what to do about it, that is addressed in this paper.

Most GSO fixed-satellite networks to date are implemented in the 6/4 GHz bands or the 14/11 GHz bands on a world-wide basis, or in the 14/12 GHz bands for domestic systems in the Americas. The GSO in these bands is heavily used. To avoid the need to coordinate LEO/MSS feeder-link systems with these GSO systems, the trend is to concentrate on use of the 30/20 GHz bands for those LEO/MSS feeder-link systems, in bands that are not currently in wide-spread use. The problem with this approach is that the 30/20 GHz bands are being considered by fixed-satellite operators as the next band to be used, both because of its attractive technical characteristics for some applications and because lower bands are becoming congested in some areas. The situation from a LEO/MSS perspective is made more complex because of Radio Regulation 2614 of the International Telecommunications Union (ITU), as modified recently at WARC-92, which gives GSO/FSS systems a very strong advantage in any coordination discussions with any non-GSO system, including a feeder-link system of a LEO/MSS network. For this reason, a LEO/MSS operator may be making a very expensive mistake in assuming that prior notification of a LEO/MSS network would avoid the need to accommodate GSO/FSS networks at a later date.

The approach suggested here is that, instead, a way of accommodating both must be found before such coordination difficulties arise, either by finding ways to share the same bands or agreeing to use different bands.

THE POTENTIAL PROBLEM

Let us suppose that a LEO/MSS feeder-link system and a GSO/FSS system are using the same frequency bands within the range 27.5 to 30 GHz in the Earth-to-space direction (the uplink), and within the range 17.7 to 20.2 GHz in the space-to-Earth direction (the downlink). As seen from the Earth the FSS satellite is fixed, and the LEO/MSS satellite is rapidly moving. Eventually, for a short period of time, the two satellites and the LEO/MSS earth station will be in approximately a straight line, and at other short periods of time the two satellites and the GSO/FSS earth station will be in a straight line. At these instants there may be harmful interference between the two networks, either in the uplink or in the downlink, or both, depending on the technical characteristics of the two networks. (See Figures 1 to 4.)

The problem can thus be broken down into its four components:

1. interference in the uplink from the GSO satellite into the LEO satellite;
2. interference in the uplink from the LEO satellite into the GSO satellite;
3. interference in the downlink from the GSO satellite into the LEO satellite; and
4. interference in the downlink from the LEO satellite into the GSO satellite.

If the two types of satellite networks are to share the same spectrum in the uplink or in the downlink, or in both directions, their characteristics must be such that they can share with widely varying characteristics of the other type of network, because each network may have to share the band with a number of networks of the other type. This observation applies particularly to a LEO/MSS network, which may have to share the spectrum at different instants with a large number of GSO/FSS networks in different parts of the world. This is based on the high frequency-reuse factor of the GSO by GSO/FSS networks, and an eventual high GSO/FSS satellite population in these bands, as there currently is in the lower 6/4 GHz and 14/11 or 14 12 GHz bands.

ANALYSIS APPROACH

Two approaches were considered in doing the necessary analysis of the above potential problem. One approach considered was to analyze in detail the sharing between particular GSO/FSS networks and particular LEO/MSS networks to determine the carrier-to-interference levels, technical constraints, etc for each pair of GSO and LEO networks. There were several problems in adopting that approach. One problem would have been the need to follow detailed changes in the design of both types of network, a difficult task in itself. A second problem would have been that despite the large amount of work required, the results would be dated by any future changes to either network. The third problem, perhaps the most serious, would have been that the approach would not necessarily lead to general conclusions regarding use of the 30/20 GHz bands by the two types of networks.

A second approach, the one adopted here, was to analyze the sharing possibility without making any more assumptions about either the GSO or the LEO network than necessary, and when necessary use appropriate CCIR Recommendations to model the networks. The objective of the analysis is not to estimate precisely the magnitudes of the interferences between the networks, but rather to determine whether sharing between the GSO and LEO networks is easy, whether measures can and should be taken to permit sharing, or whether sharing is impossible and so separate frequency bands will be necessary for the two classes of network.

Because of the existence of ITU Regulation 2614, it is assumed in this analysis that if sharing of the same frequency band is to take place between a GSO/FSS system and a LEO/MSS system it is the latter that must adapt its characteristics to make the sharing possible.

ANALYSIS

In carrying out an analysis of the compatibility of the two classes of network, as discussed above, each of the four modes of interference are considered in turn, and constraints put on the relationship between system parameters at each stage. An inconsistency between these various constraints would indicate an inability to share the band.

In each of the four interference modes one can use the link equations

$$C = EIRP_d - FSL_d + G(\phi)_d \qquad \ldots(1)$$

$$I = EIRP_i - FSL_i + G(\phi)_i \qquad \ldots(2)$$

where

* EIRP is signal effective isotropic radiated power,
* FSL is free-space loss of the signal
* L_r is rain loss of the signal
* $G(\phi)$ is antenna gain at an angle ϕ off boresight
* C is the received strength of the desired signal
* I is the received strength of the interfering signal
* d refers to the desired signal, and
* i refers to the interfering signal.

These are rather simple versions of the well-known satellite link equation, not taking account of implementation margins, antenna losses, rain margins, etc. However, "ball-park" results are sought here, not fine-tuning of a result.

Uplink Interference from a LEO System into a GSO System

It is assumed here that the GSO/FSS system is carrying QPSK traffic with forward error correction, requiring a carrier to interference plus noise ratio C/(I+N) of about 10 dB. If CCIR Recommendation 523 is to hold, I should be about 12 dB below N, and so C/I should be about 22 dB. If we consider the transient worst case of the LEO earth station pointing toward the GSO satellite, in the same direction as the LEO satellite momentarily, as in Figure 1, ϕ is zero in (1) and (2). This requires a boundary condition of

$$EIRP_{gso,up} - EIRP_{leo,up} > 22 \text{ dB}. \qquad \ldots(3)$$

A variation of the LEO system's operation, if it could not or did not wish to meet the constraint of (3), would be to cease transmissions during the time that it was pointing towards the GSO satellite. If one assumes

* that the LEO earth station antenna diameter was 2 meters, a fairly large antenna with a diameter-to-wavelength ratio of 200 at 30 GHz,
* that transmission is interrupted while the GSO satellite is in the LEO earth station antenna's main beam,
* the LEO satellite is at an altitude of about 1,000 km,
* the earth station elevation angle

is 30°, a fairly high angle in Canada when pointing towards the GSO, and

* the earth-station-antenna model of Appendix 28 of the Radio Regulations applies

then the LEO earth station would have to cease operation for periods in the order of 6 to 10 seconds, and by so doing would be able to increase the LEO earth station by about 17 dB over that specified by equation (3).

Uplink Interference from a GSO System into a LEO System

The EIRP of a LEO earth station can be considerably lower than that of an earth station of a GSO/FSS system, if the space station antenna gains in the two systems are similar. This is because of the lower altitude and so smaller free-space-loss in the LEO system's transmission path. If the LEO slant range in the direction of the GSO at an elevation angle of 30° was 2,000 km., the difference in EIRP may be in the order of 12.5 dB. (If such were the case, 12.5 dB of the 22 dB of Equation (3) could be met in this way.)

The lower value of the LEO system's EIRP presents a problem, however, in terms of the C/I in the LEO system during the transient condition that the LEO and GSO satellites and a GSO earth station are in a straight line. (See Figure 2.) If the LEO system's modulation and access are say QPSK and TDMA, it would need a C/I during these transient conditions (lasting 6 to 10 seconds) of at least 15 dB. With an EIRP differential of about -12 dB, there is a need to improve the LEO's interference immunity by in the order of 27 dB. One way to meet that objective would be to place the LEO gateway stations in remote locations and have a LEO satellite antenna discrimination $\{G(0) - G(\phi)\}$ in the order of 27 dB. This would require both high-gain tracking antennas on the LEO satellite and LEO/MSS gateway stations in remote locations, both at considerable cost.

If the LEO system's access technique were CDMA these constraints could be relaxed. If that system had a CDMA bandwidth improvement factor of say 30 dB, and carried 100 massages simultaneously, its transient C/I could be as low as -12 dB, the EIRP differential due to the range difference. There would still be the need to meet the constraint in equation (3), but if CDMA were used uplink interference into the LEO system may not be a problem.

Downlink Interference from a LEO System into a GSO System

In this case the interference would be from the LEO satellite into the GSO/FSS receiving earth station. The earth stations of the GSO/FSS system may be quite small, requiring large GSO satellite EIRP's, or they may be in the order of 2 to 4 meters in diameter, similar to those of the LEO gateway stations. Thus similar power-flux-densities (pfd's) on the Earth's surface must be expected from the two systems. However, in the transient situation in which the two satellites and the GSO receiving earth station are in a straight line (see Figure 3) the GSO/FSS system would require a C/I of about 22 dB, the same as that considered for uplink interference into the GSO system. The only measures available to the LEO system operator to meet this constraint is to place its receiving gateway stations at remote locations and use large tracking satellite antennas to not illuminate areas where GSO earth stations might be, or to cease transmission from the satellite when the LEO satellite is in the path between the GSO satellite and its earth station, or some combination of these two techniques. The problem with the latter technique is that there may be a very large number of GSO earth stations, particularly in the top 500 MHz of the 30/20 GHz band where there is no need to share with terrestrial networks.

Downlink Interference from a GSO System into a LEO System

As discussed above, the pfd's of the two systems are expected to be similar, or the pfd of the GSO system might be higher if a large number of earth terminals with small receiving antennas were used. This would not be a problem for a LEO system that employed

CDMA, but a LEO system that used TDMA or FDMA would have to interrupt operation when its satellite, its earth station, and the GSO satellite were in a straight line as indicated in Figure 4. These interruptions would be in the 6 to 10 second range, the same as that experienced to combat uplink interference.

DISCUSSION

As indicated in the above analysis of the four interference modes, simultaneous use of a block of spectrum by a GSO/FSS system and a LEO/MSS feeder-link system would be quite difficult. Given the existence of ITU Regulation 2613, it would result in severe constraints being imposed on the LEO/MSS system designer and its operator. These include placement of LEO gateway stations at remote locations with associated backhaul costs, regular interruption of the operation of the LEO feeder-link system for intervals as long as 10 seconds, and the inclusion of high-gain tracking antennas on LEO/MSS spacecraft. The use of CDMA rather than TDMA or FDMA would ease some of the problems, particularly those into the LEO system, but would not solve the problems of interference into the GSO system and so the other constraints may have to be implemented whatever access scheme is used.

A technique that may be applicable in higher latitudes for LEO/MSS systems with inter-satellite links between the satellites is to recognize that the location of the LEO satellite may cause an interference problem, and at that point in time switch operations to a different satellite rather than interrupting the user traffic for up to 10 seconds. However, that would be a complex that could only be implemented by some MSS operators, ie. those with inter-satellite links in their networks.

There is an alternative regulatory solution that should be considered, given the fairly serious sharing problems with potentially expensive solutions discussed briefly above: that is the designation of a separate relatively small band in both the uplink and downlink directions in the 30/20 GHz frequency range that would be used for LEO/MSS systems. In those bands Regulation 2613 would not apply, and GSO system operators would be encouraged to not use the bands. The sharing of the band by different LEO/MSS systems has not been analyzed here, but it is believed that this sharing problem is easier to solve than one in which GSO/FSS systems have to be taken into account.

Initial consideration of this possibility indicates that bands in the order of 50 MHz to 100 MHz in width would be adequate for the LEO/MSS feeder-link application. These bandwidths are only 2% to 4% of the 2.5 GHz wide 30/20 GHz FSS bands, and their designation could avoid a very difficult sharing problem with large associated costs. Frequency bands at 18 GHz and 28 GHz are being considered in Canada for this purpose.

Because a LEO/MSS system is by its very nature a global system, agreement on the use of frequencies for its feeder links would have to be reached on a world-wide basis. If sharing with GSO/FSS systems were contemplated the sharing consultations would be complex because sharing would be necessary between a LEO/MSS system and many GSO/FSS systems. In contrast, if the LEO/MSS systems were to use a separate designated band, this band would have to be agreed globally through action of the ITU. Because LEO/MSS systems are currently being designed and feeder-link frequencies for those systems chosen, and because these frequencies cannot easily be changed once they are chosen, the subject requires urgent attention.

In summary, it is concluded that LEO/MSS feeder-link systems could not be easily coordinated with GSO/FSS systems in the same frequency band. Further, it would be very difficult to design and operate a LEO/MSS feeder-link system such that interference into both the LEO/MSS system and the GSO/FSS system are at acceptable levels. Because of ITU Regulation 2613, the onus is on the LEO/MSS operator to ensure that such interference does not occur. **The designation of uplink and downlink fixed-satellite bands for LEO/MSS feeder links in the 30/20 GHz frequency range is seen as the basis for solution of this potential problem.**

DIAGRAMS OF INTERFERENCE CONDITIONS

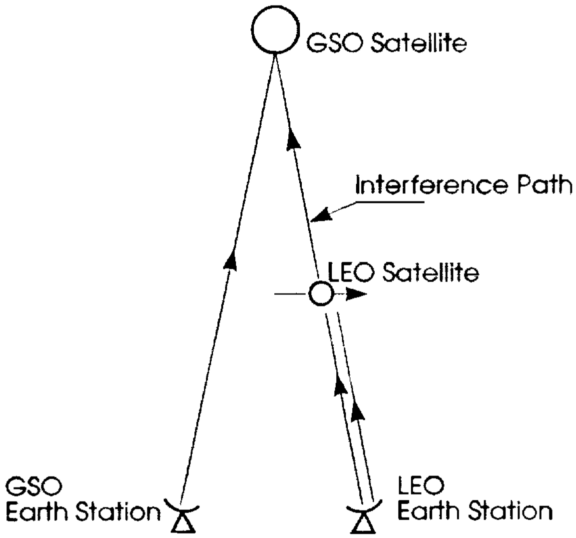

Figure 1
Uplink LEO Interference into GSO

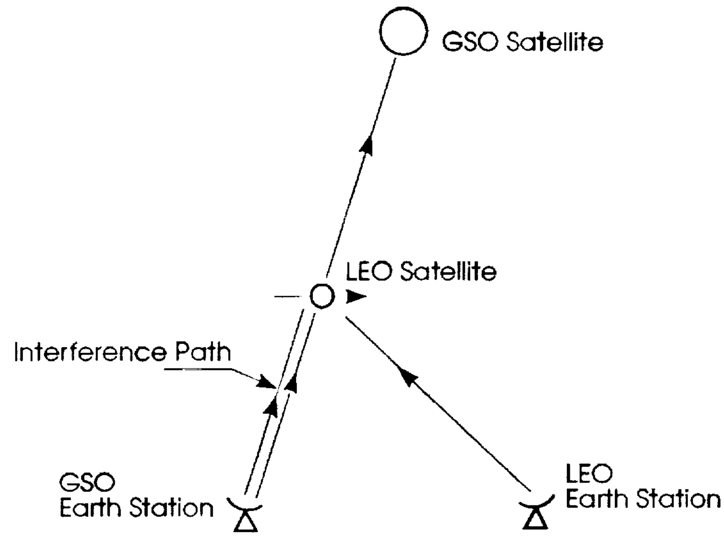

Figure 2
Uplink GSO Interference into LEO

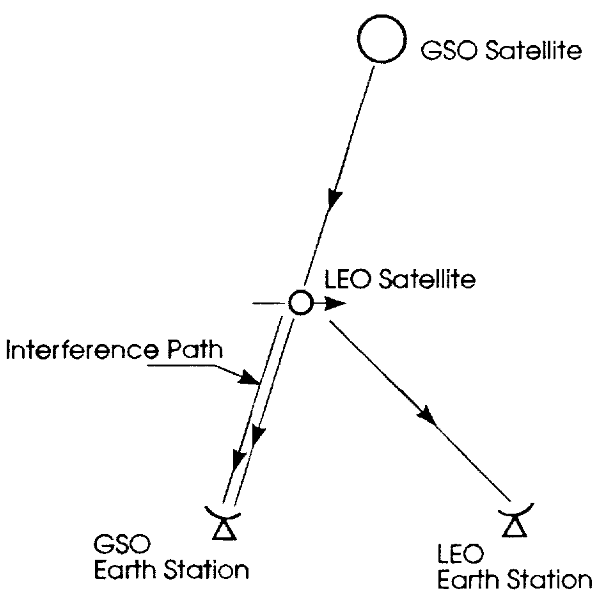

Figure 3
Downlink LEO Interference into GSO

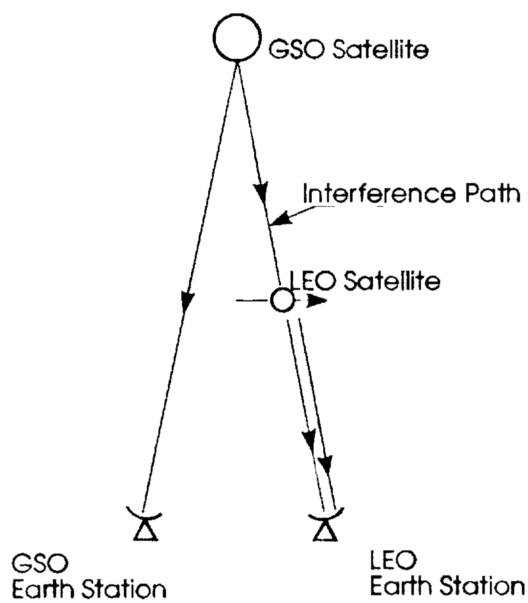

Figure 4
Downlink GSO Interference into LEO