RECOMMENDATION ITU-R M.1315

METHODOLOGY FOR EVALUATING INTERFERENCE FROM NARROW-BAND MOBILE-SATELLITE NETWORKS TO SPREAD-SPECTRUM DIRECT-SEQUENCE MOBILE-SATELLITE NETWORKS OPERATING WITH SPACE STATIONS IN LOW-EARTH ORBIT AT FREQUENCIES BELOW 1 GHz

(Question ITU-R 83/8)

(1997)

Summary

Simplified and detailed methodologies are presented for evaluating the effect of narrow-band interfering signals on spread-spectrum communication channels. The methodologies allow a rapid comparison of the relative effects of changes to parameters of the desired and interfering signals, such as power level, bandwidth, and frequency offset, which may be investigated to facilitate sharing between narrow-band and spread-spectrum mobile-satellite networks.

The ITU Radiocommunication Assembly,

considering

a) that permissible levels of interference to spread-spectrum, direct-sequence networks operating in the low-Earth orbit mobile-satellite service (LEO MSS) should be based on performance objectives for that service;

b) that LEO MSS networks proposed for operation in shared frequency bands should be designed to accommodate limited interference from systems operating in the same bands, including other LEO MSS networks (both spread-spectrum and narrow-band),

recommends

1 that the detailed analysis methodology in Annex 1 be used for fully evaluating the degradation in performance of direct-sequence, spread-spectrum LEO MSS networks caused by narrow-band LEO MSS transmissions;

2 that the simplified methodology of Annex 2 be used to determine whether a potential interference condition exists between transmitters in a narrow-band LEO MSS network and receivers in a direct-sequence, spread-spectrum LEO MSS network.

ANNEX 1

Detailed methodology for assessing interference

1 Introduction

The performance of a spread-spectrum LEO MSS network can be degraded by the simultaneous operation of narrow-band transmitters in the same frequency band. Whilst it is of general interest to compute the bit-energy-to-noise density ratio, E_b/N_0, to estimate interference to a particular communication link, it is often sufficient to compute the carrier-to-noise density (CND) at the input to the receiver. In fact, without detailed knowledge of a particular receiving system, E_b/N_0 may be difficult or impossible to compute, whereas CND is relatively easy to compute. The effect of noise sources outside the network is easily expressed as a change to the CND, allowing easier comparison between alternative designs and frequency sharing arrangements.

Interference effects expressed as changes to CND are computed both for the worst case of an interfering transmitter being within the main lobe of a tracking antenna and for the more prevalent case of the interfering transmitter being in a side lobe of the tracking antenna.

2 Outline of the calculation procedure

Step A: Collection of network parameters:

- orbital parameters (altitude, constellation description),
- spacecraft radio parameters (power, bandwidth, antenna gain pattern, polarization),
- Earth station radio parameters (antenna, G/T).

Step B: Computation of the spread-spectrum CND network without external interference.

Step C: Computation of CND due to external interference in both main beam and side lobes for each simultaneously received interfering signal, including the effect of frequency offset.

Step D: Computation of overall CND ($C/(N_0 + I_0)$) for each interfering signal and of degradation to CND.

Step E: Computation of the overall CND degradation due to multiple–channel simultaneous interference entries.

3 Calculation steps (as defined in the above outline)

Step A: Collection of network parameters

To illustrate the calculation steps, two LEO MSS networks using the same downlink frequencies are assumed to have the parameters given in Table 1. It is assumed that the space station antennas are designed to compensate for the changing Earth-space basic transmission loss as the spacecraft rises, transits the sky, and sets. By assuming coupling into the main beam of the earth station, the computation can be made independent of receiver antenna gain. In the case of interference coming from a direction other than that of the main beam, the gain difference (or discrimination) between main and side lobes must be obtained (or a typical value must be assumed).

For this example, the spread-spectrum mobile earth station (user terminal) has a minimum elevation angle of 10° and an average elevation angle of 25° to its space station, and the feeder link (gateway) earth station operates with a 5° minimum elevation angle.

For the interfering transmitters in the narrow-band network, path loss values are required at the minimum elevation angle and the elevation angle which produces the maximum interfering signal.

Step B: Computation of spread-spectrum CND network without external interference

The overall CND of a communication network with a simple, frequency-translating transponder, is the reciprocal of the sum of the reciprocals of the CND values for the uplink and downlink. In the case of a multi-user spread-spectrum network of n users, additional noise in a particular user's link comes in the form of the carrier signals of the (n – 1) other users. The CND for both of the inbound links (user terminal-to-satellite and satellite-to-gateway earth station) are computed and the carrier to self-interference ratio (CND_s) is computed. These will be combined to form a CND value that can be used as a basis for comparison with values determined when out-of-network interference is present.

TABLE 1

Typical parameters of example non-GSO MSS networks operating below 1 GHz

Network	Spread-spectrum (SS) network	Narrow-band (NB) network
Orbital parameters		
– Altitude (km)	1 000	775
– Number of satellites	24	32
– Number of orbits (satellites/orbit)	6 (4 satellites)	4 (8 satellites)
– Satellite separation, degree	90	45
Operational parameters		
Inbound Link (user–satellite):		
– Emission designation	905KG1D	Not applicable (the two example networks use different uplink frequencies)
– Frequency (MHz)	148.4245	
– Chip rate (kHz)	614.4	
– Maximum e.i.r.p. (dBW)	3.5	
– Number of users	12	
– Receiver G/T (dB(K^{-1}))	–30	
– Path loss for minimum link (dB)	144.7 (10° minimum elevation angle)	
– Path loss for average link (dB)	141.1 (25° average elevation angle)	
Inbound Link (satellite–gateway):		
– Emission designation	905KG1D	5K00G1D
– Frequency (MHz)	137.5	137-138
– Maximum e.i.r.p. (dBW)	–14	7
– Path loss for minimum link (dB)	145.3 (5° elevation angle)	143.9 (5° elevation angle)
– Path loss for average link (dB)	140.7 (25° elevation angle)	140.4 (19° elevation angle)
– Path loss for maximum pfd (dB)	139.5 (32° elevation angle)	136 (42° elevation angle)
– Channel spacing (kHz)	–	10
– Antenna gain (dB)	16	–
– Side lobe gain (dB)	1	–
– Polarization	Left hand circular	Right hand circular
– Receiver G/T (dB(K^{-1}))	–19.2	–

GSO: geostationary-satellite orbit.

In the equations below, the variables are defined as follows:

n: number of simultaneous users

C: carrier power (dBW)

N: noise power (dBW)

N_0: noise density (dB(W/Hz))

I: interference power (dBW)

I_0: interference density (dB(W/Hz))

BW: bandwidth

X: polarization isolation (dB)

$e.i.r.p.$: effective isotropic radiated power (dBW)

G: gain (dB)

G_{diff}: gain difference between the desired and interfering antennas (dB)

T: noise temperature (dBK)

G/T: $10 \log g/t$
where g and t are $10^{0.1G}$ and $10^{0.1T}$ (dB(K^{-1}))

CND_u: uplink carrier-to-noise density at the antenna aperture (dB(Hz))

CND_d: downlink carrier-to-noise density at the antenna aperture (dB(Hz))

CND_s: carrier-to-noise density of network self-interference at the antenna aperture (dB(Hz))

CND_o: overall carrier-to-noise density (dB(Hz))

$L(\text{angle})$: loss ($L(\text{angle}) = 10 \log (4 \pi\, d(\text{angle})^2)$

$d(\text{angle})$: slant range of a spacecraft at a specified elevation angle (km).

For purposes of illustration, it is assumed that we are analysing the effect of (n–1) "average" users at 25° elevation on one "desired" user at a minimal-link elevation of 5°.

For the uplink (desired user):

$$\begin{aligned} CND_u &= e.i.r.p. - L(10°) + G/T - (-228.6) \\ &= 3.5 - 144.7 + (-30) - (-228.6) \\ &= 57.4 \text{ dB(Hz)} \end{aligned} \tag{1}$$

For the downlink:

$$\begin{aligned} CND_d &= e.i.r.p. - L(5°) + G/T - (-228.6) \\ &= -14 - 145.3 + (-19.2) - (-228.6) \\ &= 50.1 \text{ dB(Hz)} \end{aligned} \tag{2}$$

For the self-interference on the uplink:

$$\begin{aligned} CND_s &= e.i.r.p. - L(10°) - \big(e.i.r.p. + 10 \log (n-1) - L(25°) - 10 \log BW\big) \\ &= 3.5 - 144.7 - (3.5 + 10.4 - 141.1 - 59.6) \\ &= 45.6 \text{ dB(Hz)} \end{aligned} \tag{3}$$

The overall CND for the network operating with n users and no external interference is the reciprocal of the sum of the reciprocals of these three values:

$$\begin{aligned} CND_o &= -10 \log \big(10^{-0.1 CND_u} + 10^{-0.1 CND_d} + 10^{-0.1 CND_s}\big) \\ &= -10 \log \big(1.82 \times 10^{-6} + 9.77 \times 10^{-6} + 2.78 \times 10^{-5}\big) \\ &= 44.1 \text{ dB(Hz)} \end{aligned}$$

Thus, when this example spread-spectrum communication network operates, it has a 44 dB(Hz) CND. If at this noise level there is a 5 dB operating margin, then any additional interference which reduces the overall CND below 39 dB(Hz) will cause the network to operate in a degraded manner.

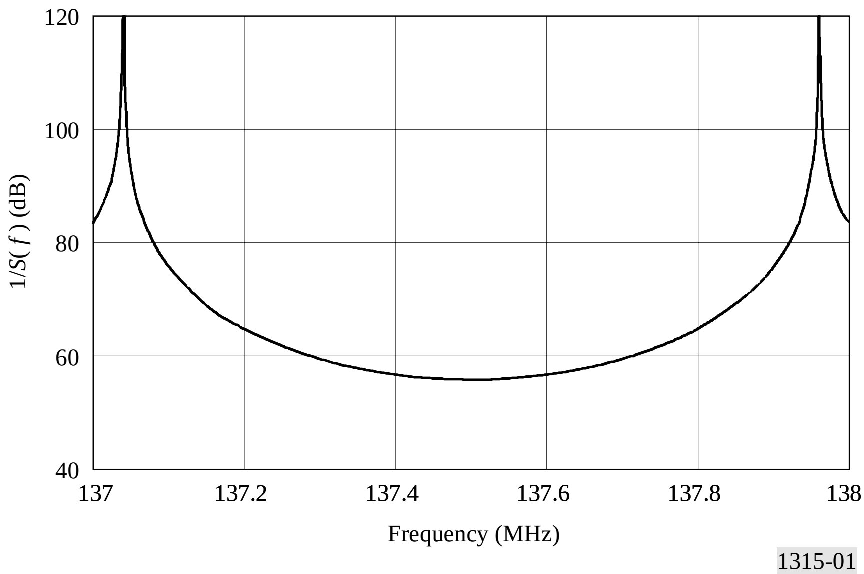
Step C: Computation of CND due to external interference in both main beam and side lobes for each/simultaneously received interfering signal, including the effect of frequency offset

As the desired and interfering spacecraft rise, transit the sky, and set, they will sometimes be in the same direction as viewed from the feeder link earth station antenna (i.e., both in the main beam). More often, the interfering satellite will be radiating its signal into a side lobe of the feeder link earth station antenna. The CND_i, the interference contribution to the overall CND, is computed for both cases. For the case of cross-polarized interfering and desired networks, allowances of 13 dB for polarization isolation in the victim feeder link earth station antenna main-beam direction and 8 dB in other directions are assumed. From Table 1, we see that there is a gain difference of 15 dB between the main and side lobes of the victim antenna.

In addition, it is necessary to perform the entire calculation for at least two carrier frequencies of the narrow-band network, since the CND contribution of a narrow-band signal into a direct-sequence spread-spectrum network is related to the relative offset of the narrow-band carrier from the spread-spectrum centre frequency. This offset relationship is given by the inverse of the "shape factor" of the spread-spectrum signal and is shown graphically for the example spread-spectrum signal as Fig. 1.

FIGURE 1

Inverse shape factor for minimum-shift keyed spread-spectrum modulation



The carrier-to-noise density contribution of a narrow-band interfering signal to a direct-sequence spread-spectrum channel is proportional to the ratio of the total powers of the desired signal and the interfering signal, and inversely proportional to the "shape factor" of the spread-spectrum signal. Thus, for a minimum-shift keyed spreading code of chip rate *Rc*, the CND_i of an interfering signal having frequency offset (f–f_0) is given by equation (4):

$$CND_i \ = \ 10 \log \left[\frac{P_s}{P_j} \ \times \ \frac{1}{S(f \ - \ f_0)} \right] \tag{4}$$

where:

- CND_i : carrier-to-interference density at the antenna aperture (dB(Hz))
- P_s : power of desired signal at the antenna aperture
- P_j : power of the interfering signal, including polarization effects, at the antenna aperture
- $S(f - f_0)$: Shape factor for spread-spectrum signal of chip rate *Rc*:

$$S(f \ - \ f_0) \ = \ \frac{16}{\pi^2 \ Rc} \ \times \ \frac{(\cos(2\pi(f \ - \ f_0)/Rc))^2}{(1 \ - \ 16 \ \times \ ((f \ - \ f_0)/Rc)^2)^2} \tag{5}$$

where:

- f : frequency (Hz)
- f_0 : center frequency (Hz)
- Rc : spread-spectrum chip rate (Hz).

The following example table for shape factors is computed from the equation (5) and is shown in Fig. 1. The centre frequency is 137.5 MHz and the chip rate is 614.4 kHz.

TABLE 2

Offset (kHz)	Inverse Shape Factor (dB)
0	55.79
50	56.00
100	56.66
150	57.78
200	59.43
250	61.71
300	64.80
350	69.10
400	75.72
450	92.54

For this example, the following CND values for a single interfering downlink signal are computed for frequency offsets of zero and 250 kHz (about 1/4 the spreading bandwidth).

The interference CND in the spread-spectrum receiving antenna main beam is:

For $(f - f_0) = 0$:

$$\begin{aligned} CND_{main_{dB}} &= SS_{power_{dB}} - NB_{power_{dB}} - 10 \log S(0) \\ &= (e.i.r.p._S - L(5°)) - (e.i.r.p._I - L(5°) - X) - 10 \log S(0) \qquad (6) \\ &= (-14 - 145.3) - (7 - 143.9 - 13) + 55.8 \\ &= 46.4 \text{ dB(Hz)} \end{aligned}$$

For $(f - f_0) = BW/4$:

$$\begin{aligned} CND_{main_{dB}} &= SS_{power_{dB}} - NB_{power_{dB}} - 10 \log S(BW/4) \\ &= (e.i.r.p._S - L(5°)) - (e.i.r.p._I - L(5°) - X) - 10 \log S(250000) \qquad (7) \\ &= (-14 - 145.3) - (7 - 143.9 - 13) + 61.7 \\ &= 52.3 \text{ dB(Hz)} \end{aligned}$$

Interference CND caused by one interfering signal impinging on a spread-spectrum receiving antenna side lobe is (assuming the interference source is producing its maximum-pfd):

For $(f - f_0) = 0$:

$$\begin{aligned} CND_{side_{dB}} &= SS_{power_{dB}} - NB_{power_{dB}} - 10 \log S(0) \\ &= (e.i.r.p._S - L(5°)) - (e.i.r.p._I - L(42°) - X - G_{diff}) - 10 \log S(0) \qquad (8) \\ &= (-14 - 145.3) - (7 - 136 - 8 - 15) + 55.8 \\ &= 48.5 \text{ dB(Hz)} \end{aligned}$$

For $(f - f_0) = \text{BW}/4$:

$$\begin{aligned} CND_{side_{dB}} &= SS_{power_{dB}} - NB_{power_{dB}} - 10 \log S(BW/4) \\ &= (e.i.r.p._S - L(5°)) - (e.i.r.p._I - L(42°) - X - G_{diff}) - 10 \log S(250000) \qquad (9) \\ &= (-14 - 145.3) - (7 - 136 - 8 - 15) + 61.7 \\ &= 54.4 \text{ dB(Hz)} \end{aligned}$$

Step D: Computation of overall CND ($C/(N_0 + I_0)$) *for each interfering signal and of degradation to CND*

The overall impact of the frequency division multiple access (FDMA) carrier for the four cases considered above is:

– Interference in main beam, zero frequency offset:

$$CND = -10 \log (10^{-0.1(44.0)} + 10^{-0.1(46.4)})$$
$$= 42.0 \text{ dB(Hz)} \qquad (44.0 - 42.0 = 2.0 \text{ dB degradation})$$

– Interference in side lobe, zero frequency offset:

$$CND = -10 \log (10^{-0.1(44.0)} + 10^{-0.1(48.5)})$$
$$= 42.7 \text{ dB(Hz)} \qquad (3 \text{ dB degradation})$$

– Interference in main beam, 250 kHz frequency offset:

$$CND = -10 \log (10^{-0.1(44.0)} + 10^{-0.1(52.3)})$$
$$= 43.4 \text{ dB(Hz)} \qquad (0.6 \text{ dB degradation})$$

– Interference in side lobe, 250 kHz frequency offset:

$$CND = -10 \log (10^{-0.1(44.0)} + 10^{-0.1(54.4)})$$
$$= 43.7 \text{ dB(Hz)} \qquad (0.3 \text{ dB degradation})$$

In this example, for which the spread-spectrum network is assumed to have a 5 dB operating margin, the spread-spectrum network will still operate even when the interfering signal has no offset and is in the main beam of the spread-spectrum receiving antenna.

Step E: Computation of overall CND degradation due to multiple-channel simultaneous interference entries

LEO MSS constellations often require more than one simultaneously operating downlink channel on different frequencies. Thus, the cumulative effect of these interfering signals must be computed to determine the total degradation to the spread-spectrum downlink signal. The same principal may apply to the uplinks of narrow-band networks. The total CND caused by j interferers is represented by equation (10):

$$CND_{tot} \, (j \text{ interferers}) = -10 \log \left(10^{-0.1 CND_o} + \Sigma_j \, (10^{-0.1 CND_j})\right) \tag{10}$$

The example narrow-band (NB) network has a 32-satellite constellation, so there is always at least one satellite above the horizon, and as many as four satellites can be above the horizon. In the case of four interfering satellites above the horizon, one in the main beam and three in the side lobes of the victim network, the overall CND would be computed as illustrated below.

Assuming that the frequency offsets are: +250 kHz, –250 kHz, +100 kHz and –100 kHz relative to the spread-spectrum signal carrier frequency, and assuming that the interferer in the main beam is at a 100 kHz offset:

$$\begin{aligned} CND_{tot} \, (4 \text{ interferers}) &= -10 \log \left(10^{-0.1(44.0)}\right) + && \text{(self-interference)} \\ &\quad + 10^{-0.1(47.3)} + && \text{(interferer in main lobe at 100 kHz offset)} \\ &\quad + 10^{-0.1(49.4)} + && \text{(interferer in side lobe at 100 kHz offset)} \\ &\quad + 2 \times 10^{-0.1(54.4)} && \text{(two interferers in side lobe at 250 kHz offset)} \\ &= 41.1 \text{ dB(Hz)} && \text{(a 2.9 dB degradation)} \end{aligned}$$

If all 4 interferers were in the side lobe, the total CND would be:

$$CND_{tot} \, (\text{all 4 in side lobe}) = 41.5 \text{ dB(Hz)} \qquad \text{(a 2.5 dB degradation)}$$

In this example, one additional NB network in the same band as the spread-spectrum network nearly depletes the available link margin, and little additional interference (from other networks operating in the band, for instance) could be accommodated without beginning to degrade the spread-spectrum network's performance. The benefit derived from operating narrow-band sources of potential interference away from the centre frequency of a spread-spectrum signal is clearly shown.

ANNEX 2

Simplified methodology for assessing interference

The methodology in Annex 1 can be simplified by substituting the "Simplified Step C", below, for "Step C" in Annex 1. If the overall interference appears significant using this simplified method, Steps C, D, and E should be repeated using Step C as presented in Annex 1.

Simplified Step C: Simplified technique for computing approximate CND due to interference

The simplified CND calculation outlined below serves as a quick method for computing and comparing the relative effect of various interference sources. The example of this simplification (assuming the example networks of Annex 1) shows that the simplified methodology may yield results that are nearly the same as those obtained by the detailed methodology.

By making the assumption that the spectral density of the spread-spectrum signal is uniform across its bandwidth (i.e., a rough approximation), we can compute CND as follows:

Interference in antenna main beam:

$$\begin{aligned} CND_{main} &= e.i.r.p._S - L(5°) - (e.i.r.p._I - L(5°) - 10 \log BW - X) \\ &= –14 - 145.3 - (7 - 143.9 - 59.6 - 13) \\ &= 50.2 \text{ dB(Hz)} \end{aligned}$$

Interference in antenna side lobe:

$$\begin{aligned} CND_{side} &= e.i.r.p._S - L(5°) - (e.i.r.p._I - L(42°) - 10 \log BW - X - G_{diff}) \\ &= –14 - 145.3 - (7 - 136 - 59.6 - 8 - 15) \\ &= 52.3 \text{ dB(Hz)} \end{aligned}$$

The total CND values for these two cases are the following:

Interference in main beam:

$$\begin{aligned} CND &= –10 \log \left(10^{–0.1(44.0)} + 10^{–0.1(50.2)}\right) \\ &= 43.1 \text{ dB(Hz)} \qquad \text{(versus 42.0 to 43.4 dB(Hz) using the detailed method)} \end{aligned}$$

Interference in side lobe:

$$\begin{aligned} CND &= –10 \log \left(10^{–0.1(44.0)} + 10^{–0.1(52.3)}\right) \\ &= 43.4 \text{ dB(Hz)} \qquad \text{(versus 42.7 to 43.7 dB(Hz)).} \end{aligned}$$