REPORT ITU-R M.1179-1

Methodology for the derivation of interference and sharing criteria for the mobile-satellite services

(1990-2004)

1 Introduction

A mobile-satellite system can utilize a wide variety of channels in order to provide services that fulfil various communication needs of aircraft, ship or land mobile earth stations. Network control data, facsimile, video and voice communications channels may be provided. The performance and link characteristics associated with these channels may differ and consequently, the tolerance of each communication to interference may differ. This Report proposes a structured approach for developing interference and sharing criteria for the mobile-satellite services. The statistical aspects are reviewed and methodologies are described for the determination of maximum permissible total and single-entry interference power levels.

2 Statistical considerations

In mobile-satellite systems, the desired signal and noise power levels vary with operating and environmental conditions in such a manner that system performance is best portrayed as a statistical parameter. Interfering signal power levels vary for similar reasons. Consequently, interference criteria should be specified with two components:

– a threshold that defines a limit on interfering signal power; and
– a percentage of time and for land mobile-satellite service (LMSS), a percentage of locations, that defines the probability of exceeding the interference threshold. Criteria should be developed for at least two percentages of time and locations in order to control the variability of interference and absolute levels of performance.

"Long-term" criteria to establish the maximum permissible interference that should not be exceeded for more than *X*% of the time and if appropriate, for LMSS, *Y*% of locations. The percentages of time (and locations) correspond with those for the long-term performance objective (e.g. 10%-50%). These interference levels and the long-term desired signal and noise power levels define the long-term system performance.

"Short-term" criteria to establish the maximum permissible interference that should not be exceeded for more than a small percentage (*M*%) of the time (and, for LMSS, *N*% of locations).

Long- and short-term permissible interference criteria should be developed for both total interference (i.e. the total from all sources) and single-entry interference (i.e. from one source).

3 Basis for criteria on total interference

Performance objectives for communication circuits are specified in terms of baseband performance thresholds and associated percentages of time and locations for which the thresholds are to be exceeded. These objectives can be converted to ratios of the desired signal power to the sum of noise and equivalent-noise-like interfering signal powers. System link power budgets associated with the percentages of time and locations specified in the performance objectives can be computed for representative systems to determine the achievable performance in the absence of inter-system interference (e.g. as in Report ITU-R M.760). Furthermore, permissible levels of inter-system interference must be included in a statistical manner in these link power budgets in order to compare the required and achieved levels of performance. The following equation defines this relationship, assuming that the total effect of multiple interfering signals is noise-like.

$$\frac{C}{(N+I)_t}(p) = \left[\left(\frac{N}{C} + \frac{I}{C} \right)_{mob} + \left(\frac{N}{C} + \frac{I}{C} \right)_{fdr} \right]^{-1} (p) \tag{1}$$

where the symbols "*mob*" and "*fdr*" denote service link (i.e. 1.5/1.6 GHz link) and feeder link parameters, respectively, and:

- $C/(N+I)_t(p)$: ratio (numerical) of desired signal power to the total noise plus total interference power, to be exceeded for all but p% of the time and locations
- N/C: ratio (numerical) of total intra-system noise power to desired signal power (relates to performance achieved in the absence of inter-system interference)
- I/C: ratio (numerical) of aggregate interfering signal power to desired signal power.

The system performance in the absence of inter-system interference (i.e. N/C values in equation (1)) is limited by various intra-system performance degradations (e.g. receiver thermal noise, intermodulation noise, etc.). Additional intra-system degradations occur in systems employing frequency reuse (e.g. among satellite antenna spot beams). Thus, as has been the case for the fixed-satellite service, different interference criteria may be applicable to systems employing frequency reuse. In any case, the performance degradation attributed to the permissible level of interference should not exceed some fraction of the intra-system degradation in order to assure that the system designer and operator has good control over performance.

There is precedent in the Earth exploration-satellite and meteorological-satellite services for setting the long-term allowance for interference at 25% or more of the total noise plus interference power level. The fixed-satellite service (FSS), for which orbit and spectrum resources are in high demand and use, allows 35% of the long-term total noise in an FDM/FM telephone channel to result from inter-system interference, or 30% in the case of systems employing frequency reuse (Recommendations ITU-R S.353 and ITU-R S.466). These percentages are comprised of up to 10% from terrestrial fixed network interference and the remainder of 20% to 25% from fixed satellite network interference. However, in considering the use of such ratios of interference power to total noise plus interference power for the mobile-satellite services, the impact on performance and system capacity (for a given performance level) should be carefully evaluated.

The link performance can be degraded to levels associated with a performance threshold by fading of desired signals or by increases of the interfering signal levels. Performance margins should be designed so that interference does not degrade link below the performance objectives.

4 Development of the interference budget

4.1 Budgeting between feeder links and service links

Fixed-satellite service allocations are typically used for feeder links; thus, each half of a channel (uplink or downlink) is subject to different interference environments and may have different interference criteria.

Short-term interference considerations also affect the C/N and C/I requirements of mobile-satellite circuits. Short-duration shadowing and multipath effects may control the C/N and C/I budgets, in the service link at 1.5/1.6 GHz, especially for networks in the land mobile-satellite service. As well, if feeder links above 10 GHz are used short-term fading due to rain attenuation may control the feeder-link noise and interference budgets.

A fundamental design consideration in developing mobile-satellite systems is that the net *C*/*N* (including *C*/*I* contributions) should be largely established by the service links; i.e. the feeder links should only provide a small degradation (trade-offs in system design, e.g. to take into consideration the very low availability of feeder link e.i.r.p. in the space-to-Earth direction in early systems, have necessitated compromising this design consideration).

4.2 Criteria for service links

The desired signal power levels at 1.5/1.6 GHz generally experience wide and rapid variations. The same is true of interfering signals at these frequencies, which generally vary independently of the desired signals. Thus, given the performance requirement for a service link (i.e. derived using equation (1), the performance objective, and the budgeting between feeder and service links), the permissible aggregate interference level could be determined in a statistical analysis of desired and interfering signals. Further, given an assumed number of interferers, a statistical analysis could be performed to determine permissible single entry levels of interference. Annex 1 describes how these interference budgets could be determined. A description of coordination thresholds for these links is discussed in Annex 3.

4.3 Criteria for the feeder links

In the feeder downlink, the desired signal power level generally experiences the same variations as the service uplink signal when the transponder is used in the quasi-linear region. Therefore, the methodology used for the feeder downlink should be similar to that for the service uplinks.

In the feeder uplinks, where the desired signal is within about 1 dB of its mean value for large percentages of the time (e.g. >95%), simplifying assumptions can be made in deriving the interference criteria. Specifically, the permissible "long-term" total interference power levels can be based on analyses of performance expected for the mean value of the desired signal. The "short-term" interference criteria can be established from an analysis of "unfaded" performance because of the small joint probability of interference increasing to levels experienced for only small percentages of time while the desired signal is also faded to levels existing for only small percentages of time. Annex 2 provides a method for determining feeder uplink interference criteria based on these assumptions.

Annex 1

Derivation of interference criteria for service links operating at 1.5/1.6 GHz and feeder downlinks

1 Introduction

Mobile-satellite systems operating in the 1.5/1.6 GHz portion of the spectrum will need to accommodate a large range of service requirements that include both analogue and digital modulation techniques, a variety of bandwidths and data rates, and a variety of transmitter power levels. There are significant variations in the e.i.r.p., bandwidth and performance margins among the various channels used in the service links provided in mobile-satellite systems. Each type of link should be evaluated separately. However, it is anticipated that several types of links will be seen to have similar interference criteria.

2 Interfering services to be considered

Interference to the service links of a mobile-satellite system operating in the 1.5/1.6 GHz bands will be caused by emissions of space stations and mobile earth stations operating in other mobile-satellite systems. Interference to the service links operating in certain portions of the 1.5/1.6 GHz bands will also be experienced from emissions of systems in the fixed service operating in specific geographical areas. Interference to feeder downlinks can be experienced from other services operating in these bands.

3 Propagation factors

The service link signals of mobile-satellite systems are primarily affected by reflection and scattering from the surrounding terrain (e.g. the ground, the oceans and buildings), by shadowing from obstructions (e.g. buildings and trees) along the Earth-space path, and by diffraction from nearby obstacles. These links are also affected, but to a much lesser extent at 1.5/1.6 GHz, by the ionosphere, the troposphere, and by precipitation. Recommendations ITU-R P.680 and ITU-R P.681 describe the propagation effects experienced in maritime and land environments at frequencies above 100 MHz, respectively. Aeronautical environments are also being studied in Recommendation ITU-R P.682. Of the three types of operating environments, the propagation effects on land mobile-satellite links are the most severe.

The statistics of propagation loss depend on the local environment. Theoretical studies and measurements made for links show that multipath signals are Rayleigh distributed. The mean power of the multipath signals relative to the power of the unattenuated line-of-sight (LoS) signal is dependent on the antenna radiation pattern, the elevation angle of the antenna, and the characteristics of the physical media from which the multipath signals are scattered. If the receiving antenna does not completely discriminate against the multipath signal and the LoS signal is not severely attenuated, then the distribution of the envelope of the received signal may be modelled by the Rice-Nakagami distribution function. Measurements have also shown that the distribution of the LoS signal power under conditions of shadowing (e.g. by trees or other obstacles) is suitably approximated by a log-normal distribution. Thus, for all environments, the statistical variation of the envelope of the received signal may be modelled as a compound process. The fluctuations of the instantaneous received signal power can be modelled as a Rice-Nakagami process in which the amplitude of the "constant" signal is assumed to be a log-normal process. A rather comprehensive discussion of the mathematical details of this compound process is given in Recommendation ITU-R P.1057.

However, it should be noted that those mathematical models might not be accurate enough, especially in the region of extremely high or low signal levels where the probability of occurrence of such levels is very low.

Interfering signal levels will be affected by similar propagation factors. Nevertheless, the LoS interference level can be used as a representative value for most of the time in cases where we consider the interference from other mobile-satellite networks, provided that the elevation angle of the desired and interfering signal paths are not too low (e.g. $<5°$).

In considering short-term interference criteria, short-term increases of the interference levels due to multipath mechanisms should be taken into account, especially in cases where the mobile earth station is over the sea. Increases of up to 5 dB over the LoS level may be experienced from such effects.

The analyses should take into account the effects of differences between the elevation angles of the desired and interfering signals or the earth station antenna discrimination and the consequential differences in the distribution functions of desired and interfering signals. Elevation angles must be considered when the sharing criteria are applied, but the effects of earth station antenna discrimination can be encompassed in the interference criteria. Furthermore, the effect of intra-system noise must be included.

The total interference levels can be determined by convolution of the probability density functions of the assumed individual interference entries. These relationships between required performance and aggregate and single entry interference levels can be used to determine the permissible levels of interference to service links.

Annex 2

Derivation of permissible single-entry interference criteria for feeder uplink

1 Allocation of interference criteria among space and terrestrial services

Earth-to-space frequency allocations used for the mobile-satellite services, generally require sharing among mobile-satellite systems, sharing with systems in terrestrial services and, in some cases, sharing with systems in other space services. An initial division of the short-term (enhanced) and long-term (near-median) interference criteria can be made to establish separate interference budgets for the space service and terrestrial service. This procedure facilitates the determination of appropriate sharing criteria and coordination thresholds for space and terrestrial systems, which are generally present in differing numbers and which might-pose interference potentials of different severity. The following equations can be used for this subdivision:

$$I_s(x) = I(x) \cdot \frac{A_s}{100} \tag{2}$$

$$I_t(x) = I(x) - I_s(x) \tag{3}$$

where:

- I_s: interference (W) budget for space service
- I_t: interference (W) budget for terrestrial service
- A_s: per cent of total interference power budget allocated to the space service
- $I(x)$: total permissible level of interference power (W) to be exceeded for no more than x% of the time, where x is associated with the long-term performance objective.

$$I_s(p_s) = I(p) - I_t(x) \tag{4a}$$

$$I_s(p_t) = I(p) - I_s(x) \tag{4b}$$

$$p_s = p(a_s/100) \tag{5a}$$

$$p_t = p - p_s \tag{5b}$$

where:

- p: percentage of time associated with the short-term interference criterion
- p_s: percentage of time that space services may exceed the interference threshold

p_t: percentage of time that terrestrial services may exceed the interference threshold

a_s: portion (%) of the percentage of time p allocated to the space services

$I(p)$: total interference power (W) to be exceeded for no more than p% of the time (i.e. short-term interference criterion).

In equations (2) and (3), the long-term interference criteria are subdivided on a power basis among space and terrestrial service interference categories. This is justified in that these long-term space and terrestrial interference levels can be expected to be present simultaneously.

The short-term interference criteria are subdivided in equations (4) and (5) on a percentage-of-time basis among space and terrestrial service interference categories. Short-term enhanced interference levels are not likely to occur simultaneously for both space and terrestrial services owing to the uncorrelated mechanisms that cause these enhancements. However, the interference from the space services at its long-term level must be considered when the short-term interference budget is established for the terrestrial services; likewise, from the terrestrial services to the space services. Thus, in equations (4a) and (5a) the long-term interference associated with the space service is assumed to be additive with the short-term interference associated with the terrestrial service.

Values for the-interference power apportionment (I_s and I_t) and time apportionment (p_s and p_t) in equations (2) to (5) should be selected so as to correspond with the relative interference levels that can be expected from a typical environment of terrestrial and space service interferers in order to minimize constraints resulting from adoption of sharing criteria.

2 Considerations for the establishment of sharing criteria

2.1 Single-entry interference criteria

Subdivisions of the total interference and time allowances for space and terrestrial interferers can be made to establish appropriate permissible levels of interference from individual interferers (i.e. "single entry" interference). Equations (6) and (7) can be used for this purpose:

$$I_{x'}(x) = \frac{I_x(x)}{n} \tag{6}$$

$$I_{x'}(p_{x'}) = \frac{I_x(p_x)}{y_n} - \left(I_{x'}(20) \cdot \frac{1-y}{y} \right) \tag{7a}$$

$$p_{x'} = \frac{p_x}{y_n} \tag{7b}$$

where prime (') parameters denote single-entry values and:

$I_x(x)$: total permissible interference power level (W) budgeted for space or terrestrial services to be exceeded for no more than X% of the time

$I_x(p_x)$: total permissible interference power level (W) budgeted for space or terrestrial services to be exceeded for no more than p_x% of the time

n: effective number of space or terrestrial interferers

y: the fraction of interferers at an enhanced level, $0 < y < 1$.

Equations (6) and (7) are similar in nature to equations (2) to (5). Long-term interference allowances are subdivided on a power basis and short-term interference allowances are subdivided on a percentage-of-time basis. In equation (7), only some of the interference entries are assumed to be enhanced to their short-term values and are, therefore, uncorrelated. While these interference entries are at an enhanced level, all other entries are assumed to be at their long-term levels. The sum of these long-term levels is assumed to be ($n - yn$) times the long-term single entry interference allowance.

Annex 3

Coordination thresholds and sharing criteria for 1.5/1.6 GHz links*

1 Coordination among satellite systems

Potential interference among satellite systems is examined in the course of coordination under RR Article 9 to determine what, if any, design or operating constraints are necessary to ensure that interference will remain below acceptable levels. Single entry permissible interference levels define the minimum acceptable levels of interference for use in coordination. RR Appendix 8 prescribes a method for determining when this coordination should be conducted. Coordination is triggered when a small increase in link noise temperature is predicted under worst-case conditions (i.e. a 6% increase). As a practical matter, the low discrimination of mobile earth station antennas at 1.5/1.6 GHz would almost always trigger coordination under this procedure, provided that a mobile earth station from one system has LoS visibility to the satellite of the other system. Thus, this visibility condition appears to be a practical approach for determining when coordination should be conducted among mobile-satellite systems operating at 1.5/1.6 GHz, except when the satellite coverage areas are completely separated.

2 Interference caused to satellite receiver by terrestrial stations

Criteria for sharing near 1.6 GHz among transmitting stations in the terrestrial services and receiving space stations can be developed from the aggregate long-term permissible level of interference budgeted for this interaction (see Annex l to Report ITU-R M.1173).

Coordination is not used as a method for governing this interference interaction. Instead, applicable sharing criteria have the form of e.i.r.p. and antenna input power and pointing limits on the terrestrial stations. The aggregate interference from terrestrial stations can be expected to have a low temporal variability, thus assuring that the relatively stringent long-term interference criteria will dominate the sharing when the method of Annex l is applied. These sharing criteria have been developed for other bands on the basis of assumptions as to the deployment and characteristics of the terrestrial stations.

* See also RR Appendix 7.

3 Coordination distances

Criteria for sharing between mobile earth stations and terrestrial stations can be developed in accordance with the protection area concept. The high temporal variability of propagation losses over terrestrial signal paths generally requires that both short-term and long-term interference criteria be applied. Coordination areas can be computed for land and ship mobile earth stations using the method of RR Appendix 7. For aircraft earth stations, coordination areas can be constructed using coordination distances based on LoS propagation paths between the aircraft and terrestrial station. Assuming that an aircraft earth station may be operated at altitudes as high as 12 km, and that the refraction of the atmosphere causes a 4/3 effective Earth radius, the LoS distances would be 450 km and 900 km with respect to other stations on the ground or in an aircraft, respectively. Allowing for somewhat higher atmospheric refractivity, the coordination distances for aircraft should be taken to be 500 km and 1 000 km for sharing with terrestrial stations located on the ground and in aircraft, respectively. Further study of coordination distances is required.