RECOMMENDATION ITU-R M.1039-3

Co-frequency sharing between stations in the mobile service below 1 GHz and mobile earth stations of non-geostationary mobile-satellite systems (Earth-space) using frequency division multiple access (FDMA)

(Questions ITU-R 83/8, ITU-R 84/8 and ITU-R 201/8)

(1994-1997-2000-2006)

Scope

This Recommendation presents calculation methodologies to deal with the co-frequency sharing between stations in the mobile services below 1 GHz and mobile earth stations of non-geostationary mobile-satellite systems. A quick methodology to give an approximation of the interference is given as well as more precise calculations using detailed statistical methods.

The ITU Radiocommunication Assembly,

considering

a) that the spectrum allocated by the World Radiocommunication Conferences WARC-92, WRC-95 and WRC-97 for low-Earth orbit (LEO) mobile-satellite services (MSS) below 1 GHz, if shared with mobile services, must provide adequate protection from harmful interference;

b) that LEO MSS can provide beneficial radio-based services, including emergency alerting (see Note 1);

NOTE 1 – However, these services will not be identified as safety services as defined by the Radio Regulations.

c) that the use of LEO enables practical use of frequencies below 1 GHz by space stations;

d) that some coordination and channelization techniques used in fixed and mobile radio systems in bands below 1 GHz can lead to low Erlang loading on individual channels;

e) that dynamic channel assignment techniques are technically feasible and may provide a means of spectrum sharing between mobile services and low power, low duty cycle MSS;

f) that the non-GSO MSS users would operate throughout large geographic areas;

g) that the transmission of the mobile earth station (MES) are short bursts;

h) that the signal characteristics in the MSS below 1 GHz may allow co-channel sharing with mobile services;

j) that there is a need to determine MSS and MS sharing possibilities while considering the impact of MS transmissions into MSS satellite receivers;

k) that statistical modelling techniques can estimate the probability of interference to the MS from the MSS,

further considering

a) that, in many countries, the allocations to the mobile services are extensively used, and in some cases with periods of high traffic loading;

b) that a propagation model using scattering model for VHF band is provided by Recommendation ITU-R P.1546,

noting

a) that additional studies are required to determine whether the statistical models are fully applicable to maritime and aeronautical mobile services;

b) that the distribution of MES users may be concentrated into a specific area within the footprint of one satellite, taking into consideration geographical restriction;

c) that Recommendation ITU-R M.1184 provides technical characteristics of non-GSO MSS networks below 1 GHz that are considered appropriate for modelling and analysing sharing and potential interference between MES and stations in the mobile services,

recommends

1 that the analytic methodology described in Annex 1 can be used to provide a first approximation to the interference probability from non-GSO MSS MES to land mobile stations (LMS) generally in the same frequency band;

2 that a more precise calculation of the interference probability can be performed using the detailed statistical methods of either Annex 2 or Annex 3 to evaluate sharing between stations in the mobile services and FDMA non-GSO MES with primary allocations (Earth-to-space) in the same frequency band below 1 GHz;

3 that types of dynamic channel assignment techniques such as that described in Annex 4 could be used by non-GSO MSS systems (narrow-band) operating in MSS allocations below 1 GHz in bands to promote compatibility with terrestrial services.

Annex 1

An analytical methodology for calculating interference probability from non-GSO MSS earth station to LMS operating below 1 GHz

1 Introduction

This Annex describes an analytical methodology for calculating interference probability, considering potential interference from MES to base stations of the existing LMS station, and using a propagation model derived from the latest version of Recommendation ITU-R P.1546 (previously ITU-R P.370).

The proposed method may be used to evaluate the interference probability easily, and applies to any non-GSO MSS systems using FDMA. The employment of this method could facilitate the frequency sharing analysis between non-GSO MSS systems and the existing MS systems below 1 GHz.

2 Interference model between non-GSO MSS system and land mobile communications system

The frequency band 148-149.9 MHz allocated for Earth-to-space direction in the non-GSO MSS system is used as forward and return links in the land mobile communications systems. The operation of non-GSO MSS system in the frequency band 148-149.9 MHz could give rise to the following four interference cases between these two systems, as shown in Fig. 1:

(1) interference from MES of non-GSO MSS system to base station of the existing MS system;

(2) interference from MES to LMS of the existing MS system;

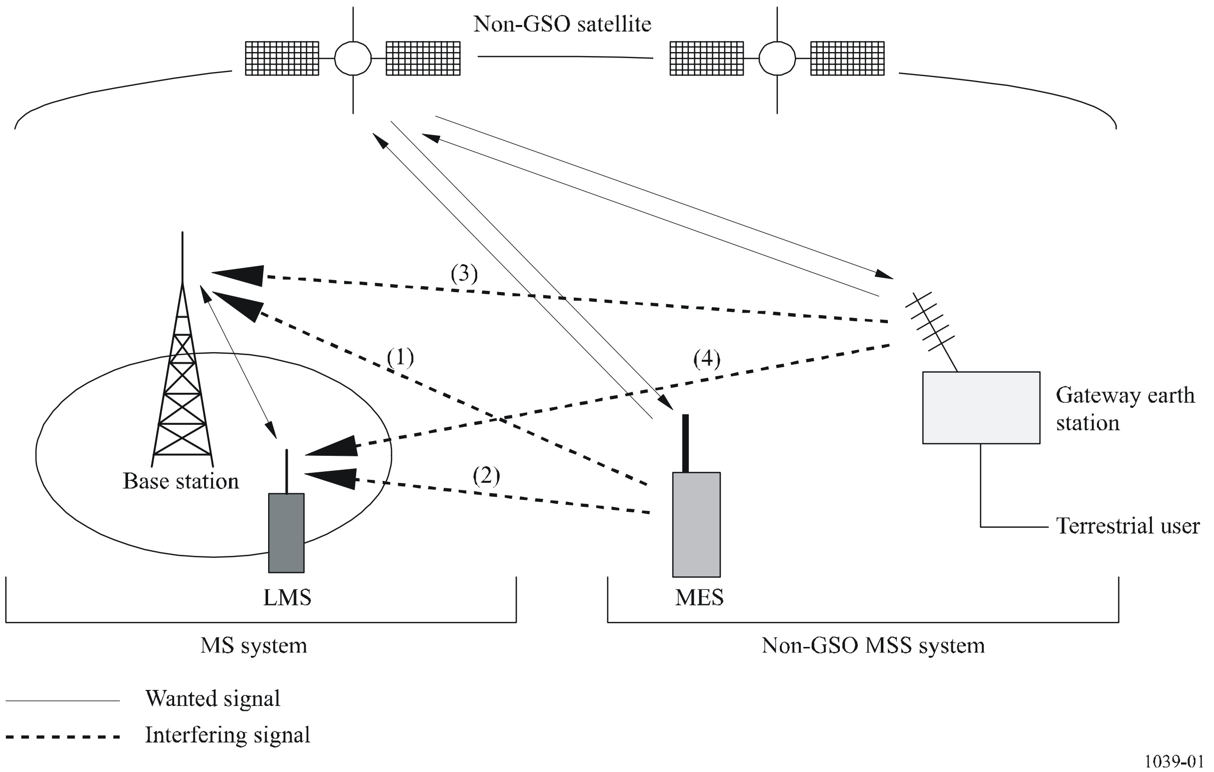
(3) interference from gateway earth station of non-GSO MSS system to base station;

(4) interference from gateway earth station to LMS.

Among these four interference cases, (1) and (2) are the interference paths from MES to the existing MS systems.

FIGURE 1

Interference model between non-GSO MSS and MS systems



This Annex describes the methodology for evaluating the interference probability in the interference paths (1) and (2).

For the interference paths (1) and (2), it is necessary to make an assessment of the existing systems in both of the following operation modes:

– the communications mode,

– the waiting mode.

The waiting mode is the case that no information is being exchanged between two stations, but the MS receivers are turned on to accommodate any call or information. When the MS system is in the waiting mode, the receiver, except for the receivers with use of tone squelch techniques, will have a squelch break during burst length +α (max. 450 ms +α, for example) emitted by MES with the interference probability mentioned hereunder.

The following presents the methodology for evaluating the interference probability occurring in the interference paths (1) and (2) as shown in Fig. 1, where the existing systems are both in the communications and waiting modes.

3 Propagation loss between MES and base station of MS system

Amongst the ITU-R texts, Recommendation ITU-R P.1546 describes the propagation loss in the VHF band from the antennas at high altitude. This Recommendation shows the experiments' results of the field strength of TV signals in the VHF band at the receiving station at *d* km away. The results are shown for various heights of antennas. For the above reasons, the propagation loss, required for obtaining the interference coordination distance between MES and the base station, is evaluated in this model on the basis of Recommendation ITU-R P.1546. Figure 2 shows the VHF propagation loss to the propagation distance for the various antenna heights obtained from the latest version of Recommendation ITU-R P.1546 (previously ITU-R P.370). In the computation of propagation loss shown in Fig. 2, 10% of the time values are used. For other frequency bands, Fig. 2 would need to be recalculated.

4 System parameters

Figure 3 shows the interference model from the MES to the base station and to the LMS of the existing MS system. The system parameters of the base station, LMS and MES used in the following consideration are summarized below. Suffix *i* indicates interfering system, *w* is interfered system, *t* is transmitter, and *r* is receiver. Also, *b* and *m* indicate base station and LMS, respectively.

4.1 MES parameter (interfering station):

– Transmission side
  - Transmission power: P_{it} (dBm)
  - Transmission antenna gain: G_{it} (dB)
  - MES antenna height: h_i (m)

4.2 Base station parameter (interfered station)

– Transmission side
  - Transmission power: P_{bwt} (dBm)
  - Transmission antenna gain: G_{bwt} (dB)
  - Transmission feeder loss: L_{bwt} (dB)
  - Base station antenna height: h_{bw} (m)

– Receiver side
  - Receiving antenna gain: G_{bwr} (dB)
  - Receiving feeder loss: L_{bwr} (dB)
  - Base station antenna height: h_{bw} (m)
  - Receiver sensitivity: C_b (dBm)
  - Required C/I: $(C/I)_{br}$ (dB)
  - Permissible interference level: I_b (dBm)
  - Squelch sensitivity: P_{bsd} (dBm).

FIGURE 2

Propagation loss in the VHF band (based on Recommendation ITU-R P.370)

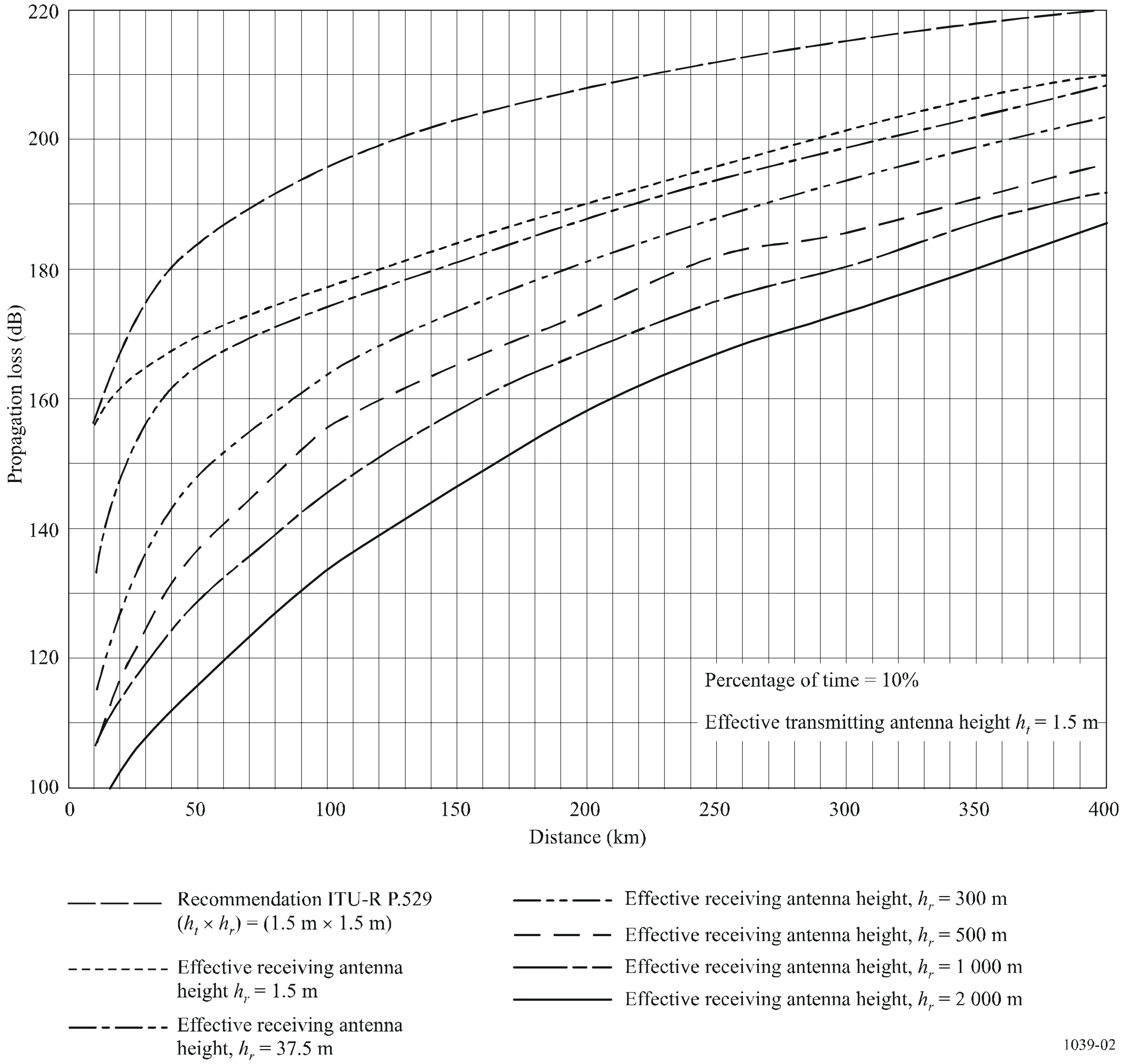
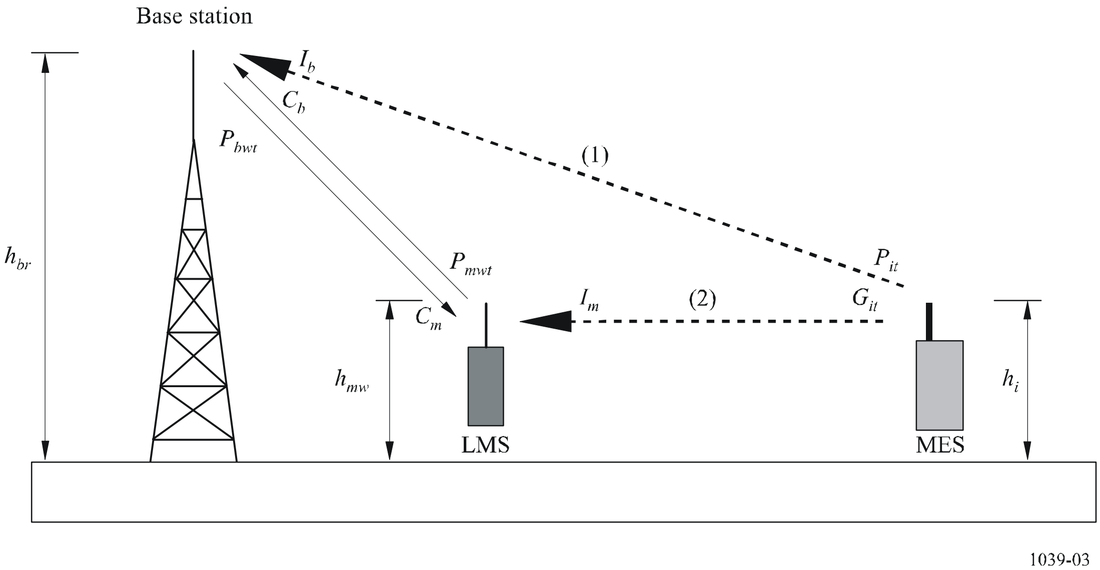


FIGURE 3

Interference model between MES and existing MS system



4.3 LMS parameter (interfered station)

– Transmission side
  – Transmission power: P_{mwt} (dBm)
  – Transmission antenna gain: G_{mwt} (dB)
  – LMS antenna height: h_{mw} (m)

– Receiver side
  – Receiving antenna gain: G_{mwr} (dB)
  – LMS antenna height: h_{mw} (m)
  – Receiver sensitivity: C_m (dBm)
  – Required C/I: $(C/I)_{mr}$ (dB)
  – Permissible interference level: I_m (dBm)
  – Squelch sensitivity: P_{msd} (dBm).

5 Computation of the interference coordination distance when the existing MS system is in the communications mode

5.1 Interference from MES to base station (path (1) in Fig. 3)

It is assumed that d_1 is the maximum distance between the base station and LMS that the transmitted signal from LMS can be received with the necessary S/N at the base station. This d_1 is equivalent to the radius of the service area of the existing MS system, namely, the circle with a radius of d_1 surrounding the base station represents the service area for the MS system. Under the assumptions above, and the sensitivity of the base station receiver being assumed as C_b, equation (1) is obtained:

$$C_b = P_{mwt} + G_{mwt} - L(d_1) + G_{bwr} - L_{bwr} \tag{1}$$

where:

P_{mwt}: LMS transmission power

G_{mwt}: LMS transmission antenna gain

$L(d_1)$: propagation loss along the distance of d_1 between the base station and LMS

G_{bwr}: base station receiving antenna gain

L_{bwr}: base station receiving feeder loss.

From equation (1), propagation loss between the base station and LMS is expressed by equation (2) and the propagation distance, d_1, can be obtained by using Fig. 2:

$$L(d_1) = P_{mwt} + G_{mwt} + G_{bwr} - L_{bwr} - C_b \tag{2}$$

The required $(C/I)_{br}$ at the base station can be given by equation (3):

$$(C/I)_{br} = C_b - I_b \tag{3}$$

where:

$(C/I)_{br}$: ratio of the required desired signal power to the interference signal power at base station

C_b: sensitivity of the base station receiver

I_b: permissible interference power from MES.

From equation (3), the permissible interference power level is expressed by equation (4):

$$I_b = C_b - (C/I)_{br} \tag{4}$$

Assuming that more than one non-GSO MSS system is operated in the same band, the permissible interference power level given in equation (4) will be shared by these non-GSO MSS systems. In the case of multiple non-GSO MSS systems operating in the same frequency band, equation (5) should substitute for equation (4):

$$I_b = C_b - (C/I)_{br} - \alpha \tag{5}$$

where α is the correction factor for the case of multiple operations of non-GSO MSS systems with use of the same frequency band. If each non-GSO MSS system could use the dedicated frequency band by using the band segmentation method, the permissible interference power level for each system can be given by equation (4).

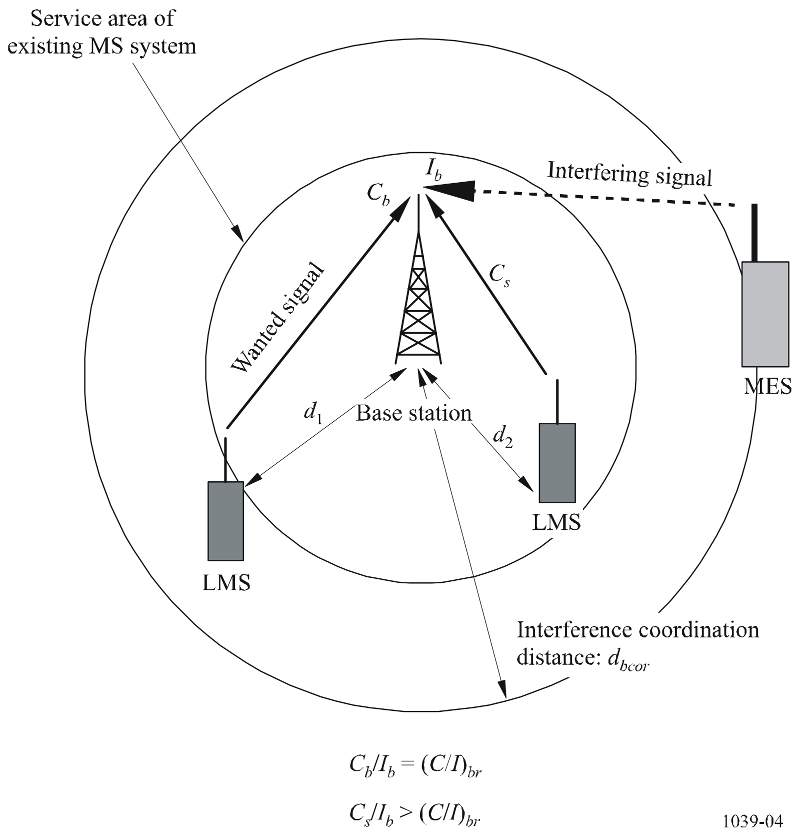
When the base station and MES are apart by the interference coordination distance, d_{bcor}, the interference signal power from MES would be received by the base station as the permissible interference power level, I_b. Therefore, equation (6) can be obtained. This relationship is shown in Fig. 4.

$$I_b = P_{it} + G_{it} - L(d_{bcor}) + G_{bwr} - L_{bwr} - I_{so} \tag{6}$$

where I_{so} represent the isolation in the case that the non-GSO MSS system adopts those channels interstitial between the existing system channels. Annex 2 shows the computer simulation results on the improvement of the adjacent channel isolation level in the interstitial channelling.

FIGURE 4

Interference coordination distance for base station in the communications mode



From equations (4) and (6), when the base station and MES are apart by the interference coordination distance, d_{bcor}, the propagation loss, $L(d_{bcor})$ is expressed by equation (7):

$$\begin{aligned} L(d_{bcor}) &= P_{it} + G_{it} + G_{bwr} - L_{bwr} - I_{so} - I_b \\ &= P_{it} + G_{it} + G_{bwr} - L_{bwr} - I_{so} - C_b + (C/I)_{br} \end{aligned} \quad (7)$$

From equation (7) and Fig. 2, d_{bcor} can be obtained which represents the interference coordination distance between the base station and MES when LMS of the existing system is communicating at the edge of the service area. In other words, it is assumed that all LMSs are operating at the edge of the service area. It is obviously understood from Fig. 4 that those LMSs nearer to the base station can secure higher S/N.

5.2 Interference from MES to LMS (path (2) in Fig. 3)

It is assumed that d_2 is the maximum distance between the base station and LMS and that the transmitted signal from the base station can be received with the necessary S/N at LMS. This d_2 is equivalent to the maximum distance for LMS to receive the signals from the base station with the necessary S/N.

Under the assumption above and the sensitivity of the LMS receiver being assumed as C_m, equation (8) can be obtained:

$$C_m = P_{bwt} + G_{bwt} - L_{bwt} - L(d_2) + G_{mwr} \quad (8)$$

where:

P_{bwt}: base station transmission power

G_{bwt}: base station transmission antenna gain

L_{bwt}: base station transmission feeder loss

$L(d_2)$: propagation loss in the distance d_2 between the base station and LMS

G_{mwr}: LMS receiving antenna gain.

From equation (8), the propagation loss between the base station and LMS can be expressed by equation (9):

$$L(d_2) = P_{bwt} + G_{bwt} - L_{bwt} + G_{mwr} - C_m \tag{9}$$

where:

$(C/I)_{mr}$: ratio of the required desired signal power to the interference signal power at LMS

C_m: LMS receiver sensitivity

I_m: permissible interference power.

This is expressed by equation (10):

$$(C/I)_{mr} = C_m - I_m \tag{10}$$

From equation (10), the permissible interference level, I_m, can be expressed by equation (11):

$$I_m = C_m - (C/I)_{mr} \tag{11}$$

In the case that more than one non-GSO MSS system is operated in the same band, the same correction factor defined in equation (5) is required to obtain the permissible interference power level for each non-GSO MSS system.

If LMS and MES are apart by the interference coordination distance, d_{mcor}, the interference power from MES would be received by LMS as permissible interference power, I_m, as shown in Fig. 5. This can be expressed by equation (12):

$$I_m = P_{it} + G_{it} - L(d_{mcor}) + G_{mwr} - I_{so} \tag{12}$$

From equations (11) and (12), $L(d_{mcor})$, the propagation loss of the interference coordination distance, d_{mcor}, can be expressed by equation (13):

$$\begin{aligned} L(d_{mcor}) &= P_{it} + G_{it} + G_{mwr} - I_{so} - I_m \\ &= P_{it} + G_{it} + G_{mwr} - I_{so} - C_m + (C/I)_{mr} \end{aligned} \tag{13}$$

From equation (13) and Fig. 2, d_{mcor} can be obtained which represents the interference coordination distance between LMS and MES. This coordination distance corresponds that LMS is communicating at the edge of the service area of the existing system. This assumption allows those LMS nearer to the base station to enjoy higher S/N, as illustrated in Fig. 5.

6 Computation of the interference coordination distance when the existing MS system is in the waiting mode

6.1 Interference from MES to base station (path (1) in Fig. 3)

As illustrated in Fig. 6, it is assumed that the base station would receive the interference power equal to its squelch sensitivity when MES emits at a distance, d_{bi}, from the base station. In this case, the distance, d_{bi}, represents the interference coordination distance between MES and the base station in the waiting mode. Where P_{bsd} is base station squelch sensitivity, equation (14) can be obtained:

$$P_{bsd} = P_{it} + G_{it} - L(d_{bi}) + G_{bwr} - L_{bwr} - I_{so} \tag{14}$$

$L(d_{bi})$ is the distance between the base station and MES that makes the base station receive the interference power equal to its squelch sensitivity. From equation (14) and Fig. 2, the interference coordination distance, d_{bi}, can be obtained.

6.2 Interference from MES to LMS (path (2) in Fig. 3)

As illustrated in Fig. 7, it is assumed that LMS would receive the interference power equal to its squelch sensitivity when MES emits at a distance, d_{mi}, from LMS. In this case, the distance, d_{mi}, represents the interference coordination distance between MES and LMS in the waiting mode. Where P_{msd} is MS squelch sensitivity, equation (15) can be obtained:

$$P_{msd} = P_{it} + G_{it} - L(d_{mi}) + G_{mwr} - L_{mwr} - I_{so} \tag{15}$$

$L(d_{mi})$ is the distance between LMS and MES that makes LMS receive the interference power equal to its squelch sensitivity. From equation (15) and Fig. 2, the interference coordination distance, d_{mi}, can be obtained.

FIGURE 5

Interference coordination distance for LMS in the communications mode

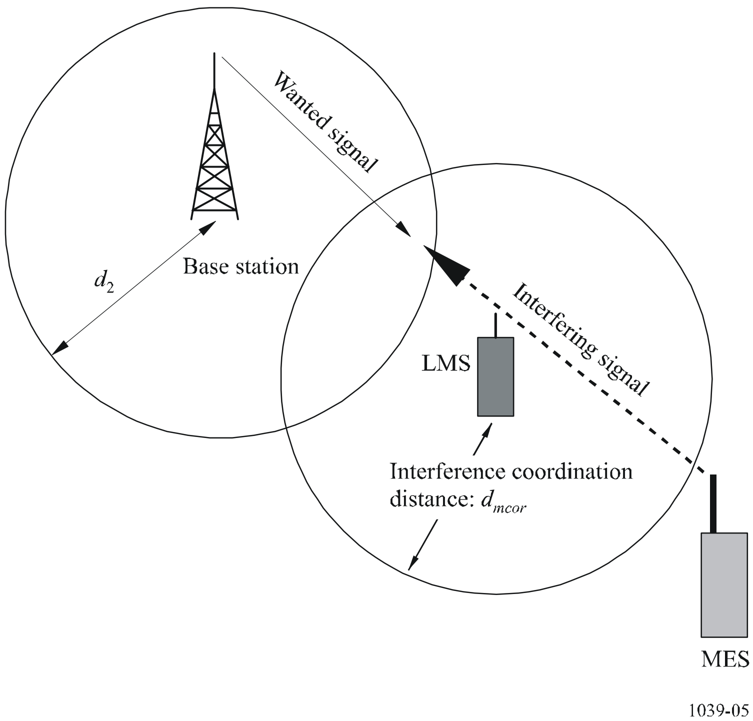


FIGURE 6

Interference coordination distance for base station in the waiting mode

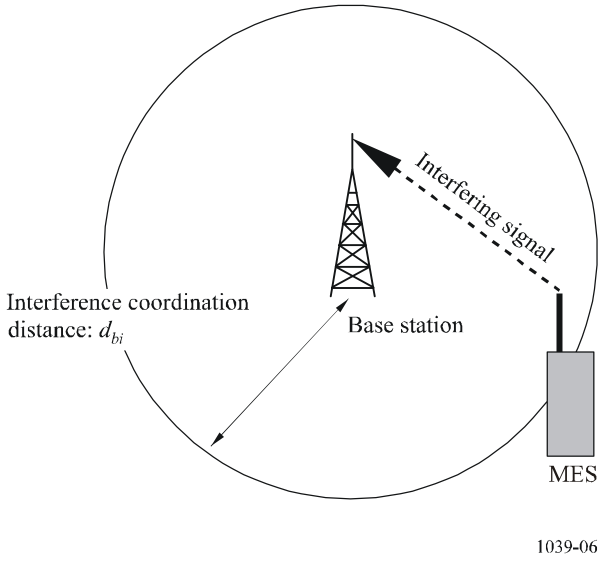
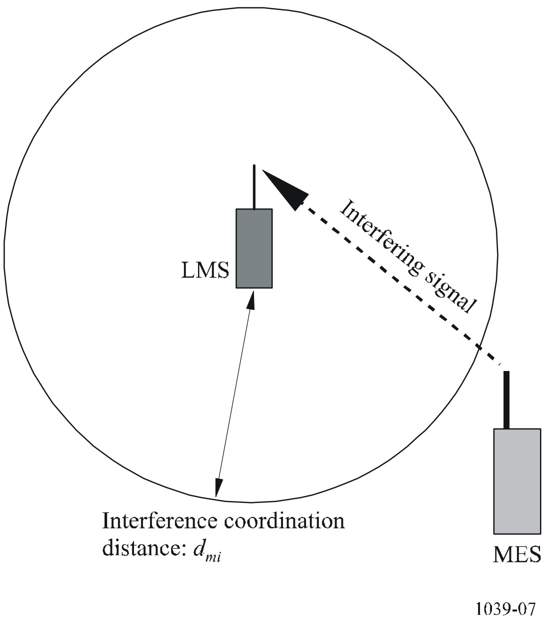


FIGURE 7

Interference coordination distance for LMS in the waiting mode



7 Evaluation of interference probability

In the previous sections, the methods are presented to evaluate the interference coordination distances for two potential interference paths between MES and the base station, and between MES and LMS, when the existing systems are in the communications mode and in the waiting mode, respectively. This section proposes the method for obtaining the probability of interference.

7.1 Probability of co-channel transmission of MS system and MES

Let P_I be the probability that a channel used by MS system has co-channel interference from an MES. P_I is evaluated by:

$$P_I = \sum_{i=0}^{m} \left(P(\text{Interference into MS} \mid i \text{ channels active}) \times P(i \text{ channels active}) \right) \tag{16}$$

where P (i channels active) indicates the probability that i channels are occupied by active MESs of the satellite system, and m is the maximum number of simultaneous operable channels for one non-GSO satellite. The worst-case evaluation of P_I can be made for the following conditions:

$$P\ (m \text{ channels active}) = 1$$

$$P\ (i \text{ channels active}) = 0 \qquad (i \neq m)$$

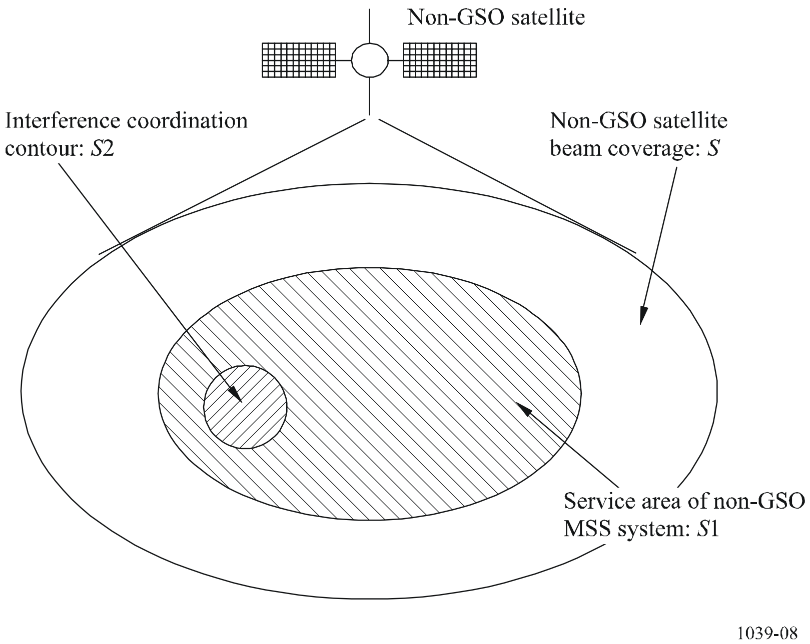
Under the assumption that MESs are uniformly distributed in the area of MSS coverage, the maximum number of simultaneous operable channels for one non-GSO satellite is given by equation (17):

$$m(S2) = m \times \frac{S2}{S1} \tag{17}$$

where $S1$ shows the service coverage of MSS systems, and $S2$ shows the interference coordination contour with a radius equal to the interference coordination distance. Figure 8 shows the relationship between the area of $S1$ and $S2$.

FIGURE 8

illustrative drawing for obtaining the probability that one MES is activated



This is because P (Interference into MS | i channels active) is largest when $i = m(S2)$. Therefore P_I at the worst case becomes:

$$P_I = P\left(\text{Interference into MS} \mid m(S2) \text{ channels active}\right) \tag{18}$$

If this assumption is too pessimistic, a factor η_L can be multiplied to take account of the percentage of time that the non-GSO MSS system is in use, i.e.:

$$P_I = P\left(\text{Interference into MS} \mid m(S2)\text{ channels active}\right) \times \eta_L \tag{19}$$

When assuming that the maximum number of available channels for non-GSO MSS system is M, the probability that one channel selected by MES out of $m(S2)$ channels would cause interference to the MS system using the same channel, η_c is given by equation (20):

$$\eta_c = \frac{m(S2)}{M} \times \gamma \tag{20}$$

where γ is the correction factor for the probability of MES channel selection. Since the activity of M channels is not often uniformly assigned due to the operation of dynamic channel activity assignment system (DCAAS), the maximum number of available channels would be considered with the correction factor.

By using equations (17) and (19), the probability, P_I, given in equation (18) can be obtained by equation (21):

$$\begin{aligned} P_I &= \eta_c \times \eta_L \\ &= \frac{m(S2)}{M} \times \gamma \times \eta_L = \frac{m}{M} \times \gamma \times \frac{S2}{S1} \times \eta_L \end{aligned} \tag{21}$$

In equation (21), the area of $S2$ can be obtained by using the interference coordination distance which is given by equations (7), (13), (14) and (15).

When the base station or LMS of the existing MS system is in the communications mode, the probability, P_I, can be given by equations (22) and (23), respectively:

Base station of MS system is in the communications mode

$$P_{bc} = \left(\frac{m}{M}\right) \times \gamma \times \eta_L \times \pi \times \frac{(d_{bcor})^2}{S1} \tag{22}$$

LMS of MS system is in the communications mode

$$P_{mc} = \left(\frac{m}{M}\right) \times \gamma \times \eta_L \times \pi \times \frac{(d_{mcor})^2}{S1} \tag{23}$$

When the base station or LMS of the existing MS system is in the waiting mode, the probability P_I can be given by equations (24) and (25), respectively.

Base station of MS system is in the waiting mode

$$P_{bw} = \left(\frac{m}{M}\right) \times \gamma \times \eta_L \times \pi \times \frac{(d_{bi})^2}{S1} \tag{24}$$

LMS of MS system is in the waiting mode

$$P_{mw} = \left(\frac{m}{M}\right) \times \gamma \times \eta_L \times \pi \times \frac{(d_{mi})^2}{S1} \tag{25}$$

7.2 Other parameters to be considered

For the evaluation of interference probability from MES to the existing system either in the communication mode or waiting mode, it is necessary to take the following parameters into consideration in addition to the probabilities, that a channel used by MS system has co-channel interference from a MES.

Parameter 1: Percentage of time that the existing system is in the communications mode

The percentage of time that the existing system is in the communications mode is assumed to be η_m. In practice, the existing system is usually operated in the one-way mode by using the press talk type terminal. In this case, the percentage of time for each direction of channel in communicating is 1/2 of η_m.

Parameter 2: Probability that DCAAS fails to detect the active channel used by the existing system

The DCAAS on-board satellite has a capability to detect all channels being used by the existing system; however, there might be a blockage between LMS and the satellite that disables the DCAAS to detect the signals transmitted from LMS. Taking into account this fact, the probability that DCAAS fails to detect the active channel being used by the existing system is assumed to be η_D.

Parameter 3: Satellite visibility factor in the case of multiple gateway earth stations

If more than one gateway earth station is installed in an area, the number of satellites increases so that MESs can access simultaneously, and the interference probability to the existing system also increases. η_G is assumed as the ratio of available number of channels with multiple gateway earth stations to a single gateway earth station.

Parameter 4: Number of interfering signals within the occupied bandwidth of the MS carrier

If the occupied bandwidth for the non-GSO MSS carrier is narrower than that for the MS carrier, a multiple interfering carrier would be observed in the wanted MS carrier occupied bandwidth. Under the assumption described above, the additional interference power level given by equation (26) might be considered in the calculation of C/I:

$$I = 10 \log \left(\frac{B_w}{B_i} \right) \tag{26}$$

where B_w and B_i are the occupied bandwidths for the MS carrier and MES carrier, respectively. Under the condition that non-GSO systems shall not assign more than one channel in each frequency grid allocated for the existing system, it is unnecessary to consider the additional interference power level given by equation (26).

Among the above-mentioned parameters, parameters 1 to 4 are required for the evaluation of interference probability when the existing system is in the communication mode, and parameters 3 and 4 are required for the evaluation of interference probability when the existing system is in the waiting mode.

7.3 Overall of interference probability

On the basis of what is presented in the above sections, the interference probability, P_t, for two potential interference paths from MES to the base station, and MES to LMS, both in the communications mode and in the waiting mode, are given by the following equations:

– Existing MS system is in the communications mode

$$P_t \text{ (base station)} = P_{bc} \times \eta_D \times \eta_G \tag{27}$$

$$P_t (LMS) = P_{mc} \times \eta_D \times \eta_G \tag{28}$$

It should be noted that the percentage of time of interference can be calculated by multiplying P_t by the factor η_m.

– Existing MS system is in the waiting mode

$$P_I \text{ (base station)} = P_{bw} \times \eta_G \tag{29}$$

$$P_I (LMS) = P_{mw} \times \eta_G \tag{30}$$

Annex 2

Methods and statistics for determining sharing between MSS earth station transmitters below 1 GHz and mobile stations

1 Introduction

The methods presented in this Annex describe a method to be used to determine if MSS earth station (MES) transmitters can share spectrum with mobile services. The methods described provide a basis for evaluating the effectiveness of power level limits for MES e.i.r.p. that may be established to allow sharing with mobile services (see Note 1).

NOTE 1 – In addition, the uplink transmissions from the MES have an optimum length for sharing with certain terrestrial voice services. It has been indicated this might be up to 500 ms. The duration of time over which such transmissions would take place is under study (1% in 1-15 min has been suggested).

2 Potential interference from MSS to mobile services

Mobile services in the VHF band are typically characterized by frequency modulated voice and data carriers assigned on a periodic channel grid. Channel spacings used include 6.25 kHz, 12.5 kHz, 15 kHz, 25 kHz and 30 kHz.

MSS systems below 1 GHz may use a dynamic channel assignment algorithm which allows the space station to identify those channels not occupied by the mobile stations which are sharing the spectrum. Thus it is expected that there will typically be significant frequency separation (15 kHz or less) between the MSS transmission and the mobile station receiver centre frequency. However, for the purposes of this methodology, the efficiency of the dynamic channel assignment process cannot yet be predicted; MSS uplink channel selection is therefore assumed to be randomly distributed in 2.5 kHz (see Note 1) steps within the mobile allocation.

NOTE 1 – This step size represents practical restrictions on synthesizer implementation with little loss in generality of the analysis.

3 Summary of the methodology

Several steps must be undertaken in order to determine the potential for harmful interference to mobile stations from MES transmitters. The methodology for so doing is outlined in this section. Detailed descriptions of each step are contained in the following sections.

3.1 Coordination contour

The first step is to determine a typical coordination contour around a mobile receiver to be protected. This is described by the range at which an MES transmitter or group of transmitters will produce a pfd in excess of a level determined to be a protection criteria. To perform this calculation one must know the following values:

$e.i.r.p._{mes}$:	maximum e.i.r.p. of the MES (W)
BW_{mes}:	signal bandwidth of the MES transmitter (Hz)
pfd_t:	pfd considered to be harmful (W/m^2)
N_t:	expected maximum simultaneous MES transmitters
$L(d)$:	propagation loss as a function of distance.

If it can be determined that the coordination contour is small enough as compared to the expected movements of mobile stations and MESs, then no further calculations are required. If the coordination contour is too large for this determination to be made, the following steps must be executed.

3.2 Calculation of threshold exceedance probability

Probabilistic techniques are used to determine the percentage of time that the protection pfd will be exceeded at a particular mobile station receiver. If this "exceedance probability" is low enough, exceeding the protection level is not considered to be harmful interference.

3.2.1 Geographic area for the calculation

The first step is to determine an area over which transmissions from MESs will contribute significantly to the statistics of received pfd at the mobile receiver. If too large an area is used, the subsequently calculated exceedance probability is likely to be understated. This area is typically described by a radius corresponding to the protection contour described above.

3.2.2 Single transmitter pfd probability density function

Given an area over which the calculation is to be performed, one then calculates a discrete probability density function (see Note 1) for the expected values of pfd at a mobile receiver. This is a two-step process, beginning with the establishment of a random variable describing the probability distribution of MES to mobile receiver range. The probability of a particular pfd is then evaluated as that associated with the range which, in combinations with the MES e.i.r.p., propagation model and potential filter isolation, produces that pfd.

NOTE 1 – The probability density function (PDF) for a random variable defines the probability weight for each of the values that the random variable can take on. The integral of the probability density function is unity. If one constructs a new function for each of the values that the random variable can take on by integrating the probability density function from minus infinity to that random variable value, one has created the cumulative distribution function.

3.2.3 Multi-carrier pfd probability density function

The resulting probability density function of pfd applies when a single MES transmitter is activated. The probability density functions for pfd associated with two or more MES transmitters are derived from the single carrier probability density function using a convolutional method described in § 7.

3.2.4 Probability that MES transmitters are activated

The resulting pfd distributions must be conditioned by the actual probability that one or more MES transmitters are active within the area of the receiver to be protected. These probabilities are traffic level dependant and are typically described by the Poisson distribution. This portion of the calculation is dependant on the type of access scheme chosen for the MSS system, however the maximum transmission probabilities have been bounded by assuming very efficient use of available channels by the MSS operator.

3.2.5 Exceedance probability

Actual exceedance probability depends on the share of MSS system traffic originating within the protection contour of the mobile receiver. Typically the ratio of MSS space station coverage area to the area described by the protection contour is 0.1% or less. Because the actual distribution of system traffic cannot be determined in advance of system operation, the method described for calculation of exceedance probability shows how to make this factor a parameter. This will facilitate understanding of the impact of expected traffic levels on the potential for harmful interference to a mobile station.

3.2.6 Exceedance probability versus actual interference

The calculated exceedance probability actually overstates the potential for harmful interference for the following reasons:

– it assumes that each mobile link is always active, either transmitting or receiving;

– it assumes that each mobile receiver is operating at its maximum range (minimum performance threshold) with no additional link margin; however power control may be employed in some systems, eliminating this effect;

– it discounts the fact that dynamic channel assignment techniques used by MSS systems will avoid active receiver frequencies;

– many MES transmissions will be short bursts which may not open squelch on many receivers and may not be audible if they occur during talker activity on speech channels, however if the channel is used for data or signalling performance it may be degraded no matter how short the burst.

4 Reference propagation model

For purposes of evaluating the potential of interference from LEO MSS uplink transmitters to mobile stations (MS) or base stations (BS) a reference link model is given for frequency bands below 1 GHz.

The predicted propagation loss is a function of transmitter/receiver separation distance and the received field strength can be modelled, to first order as:

$$E(1\ \text{kW}) = 70 - 40\log(d) - 10\log(f) + 20\log(h_1\,h_2) - 10\log(0.02\,p)\,[1 - \exp(-0.1d)]^2 \quad \text{dB}(\mu\text{V/m}) \tag{31}$$

where:

f: frequency in the range 20 to 1 000 MHz

d: path length in the range of 1 to 600 km

h_1, h_2: effective antenna heights (m) for the transmitting and receiving antennas, respectively, each having a minimum value of 1 m, with the product ($h_1\ h_2$) limited to a maximum value of 300 m^2

p: percentage of time for which the field strength will be exceeded, in the range 1 to 50%

where E is evaluated for a power of 1 kW radiated from a half-wave dipole (32.15 dBW e.i.r.p.) and E must not exceed the free-space value, E_{fs}, given in dB(μV/m) by:

$$E_{fs}(1\ \text{kW}) = 107 - 20\log(d) \qquad \text{dB}(\mu\text{V/m}) \tag{32}$$

The calculated field strength must be modified to account for the e.i.r.p. of the MES by:

$$E = E(1\ \text{kW}) + (P_{mes} - 32.15)$$

where:

P_{mes}: e.i.r.p. of the MES (dBW).

Converting this expression from a field strength to a pfd from that transmitter incident at a distance, d:

$$pfd(d) = \frac{(E \times 10^{-6})^2}{120\,\pi} \qquad \text{W/m}^2 \tag{33}$$

where E is in µV/m.

For the purpose of evaluation the potential of interference from a LEO MSS transmitter to a mobile station, an antenna height product of the order of 10 m² should be used. This accounts for the fact that LEO MSS transmitters are likely to be handheld or vehicle mounted, rather than tower mounted. For the case of base stations in the mobile service, a larger product should be used as appropriate. In the case of airborne receivers or MSS transmitters, larger products should also be used.

5 Probability of multiple MES transmissions

As noted in § 3.1, the potential for interference will be dependant on the expected number of simultaneous MES transmitters which can contribute to the aggregate pfd incident at the mobile service receiver. Random access protocols (see Note 1) allow for occasional multiple simultaneous transmissions on the same frequency and as such represent the upper limiting case on the potential for aggregate interference to a mobile station receiver. The probability of simultaneous transmitters is evaluated using the Poisson distribution:

$$P_a(n) = \frac{\Lambda^n}{n!} \cdot \mathrm{e}^{-\Lambda} \tag{34}$$

where:

n: number of simultaneous transmitters

Λ: average transmissions per unit time.

NOTE 1 – Many random access protocols are referred to as "ALOHA" protocols, a specific type of random access protocol.

The particular type of random access protocol chosen will determine the appropriate value of Λ. The use of slotted random access protocols allows the highest value of carried traffic, a theoretical maximum of 36.8%; practical upper bounds are around 30%. This is double the value of traffic and value of Λ as compared to a simple un-slotted technique. Systems must be designed to operate within the throughput constraint of the random access protocol to maintain their quality of service. Thus while short periods of traffic loading in excess of the stability values may be seen, it is reasonable to assume that systems will need to operate below these values in order to retain their users.

A value of $\Lambda = 0.4$ in the expression for the Poisson distribution yields practically realizable peak loading levels for the slotted random access protocol. Table 1 demonstrates the probability of 0, 1, 2, ..., 6 simultaneous transmitters for a value of $\Lambda = 0.4$. One can see from this Table that the probability of more than four simultaneous transmitters is 0.00001. Thus an appropriate value for N_t is 4, however, consideration may be given to using other values.

TABLE 1

Representative MES transmission probabilities

n	$P_a(n)$	$C_a(n)^{(1)}$	$1 - C_a(n)$
0	0.670320	0.670320	0.329680
1	0.268128	0.938448	0.061552
2	0.053626	0.992074	0.007926
3	0.007150	0.999224	0.000776
4	0.000715	0.999939	0.000061
5	0.000057	0.999996	0.000004
6	0.000004	1.000000	0.000000

(1) $C_a(n)$: cumulative distribution function of $P_a(n)$.

6 Evaluation of single carrier pfd probability distribution

The single carrier pfd probability distribution is evaluated from two basic assertions: that the propagation loss between the MES and the mobile service receiver is dependant upon distance and that the probability distribution of all possible separations is known. For the former, refer to § 4 for the propagation loss model. For the latter, a uniform density of MES (terminals/m^2) is used. More complicated distributions could be used but they would implicitly assume that some feature of the mobile service receiver, an uncorrelated phenomenon with respect to the placement of MESs, had some influence on the MES distribution.

It is straightforward to demonstrate that a uniform density of MES produces a unit ramp probability density function for the random variable describing the separation between the MESs and the mobile service receiver. This discrete probability density function is constructed in the following manner:

$$P_s(d_i) = 2d_i / R^2 \tag{35}$$

where:

d_i: discrete values of separation distance

R: radius of the coordination distance surrounding the mobile receiver (km).

Filter isolation with respect to a MES transmission at the mobile station receivers must be calculated for 2.5 kHz offsets from the operating frequency of the mobile receiver.

An array is created with the index corresponding to pfd values and the array values corresponding to probability values. This array has all values set to zero.

Each value of distance in the separation probability density is used to calculate a pfd attenuated by the frequency-offset isolation at each of the 2.5 kHz positions. The probability value associated with the distance is divided by the number of separate filter isolation calculations and added to the probability value already associated with the calculated pfd. This is repeated over all statistically significant values of distance to create the complete probability distribution function. This calculation is expressed in equation (36):

$$\sum_{i=0}^{N_i} \sum_{j=0}^{N_f} P_{pfd}\left(\frac{pfd(d_i)}{A_j}\right) += \frac{P_s(d)}{N_f} \tag{36}$$

where:

A_j: filter isolation $j \times 2.5$ kHz from the mobile receiver centre frequency

N_f: number of frequency channels used by the MSS system.

The expression "+ =" refers to adding the right side of the expression to the existing contents of the variable on the left side of the equation.

7 Evaluation of multi-carrier pfd probability distribution

Multi-carrier pfd probability distributions are evaluated in an iterative manner beginning with the single carrier pfd distribution derived above. This is based on the principle that the pfd distribution for each MES transmitter is the same and that MES transmissions are statistically independent.

The process of the pfd generation is described algorithmically as it is only practical to generate the distributions with the aid of a computer. It is considered that two pfd distributions exist in discrete form as an array of values, known as P_{pfd1} and P_{pfd2}. Note that the pfd values are referenced via the index to the array and the probability value associated with an individual pfd is the value in the array at that index.

A third array, P_{pfd3}, is created with sufficient index range to accommodate pfd values ranging from the lowest value among the input distributions to the sum of the highest values in the input distributions. This third array has all its values set to zero. The following expression is then executed for all values of the index pointers to produce the joint pfd distribution.

$$\sum_{i=0}^{I_{max}} \sum_{j=0}^{J_{max}} P_{pfd3}(pfd_i + pfd_j) \; + = \; P_{pfd1}(pfd_i) \cdot P_{pfd2}(pfd_j) \qquad (37)$$

Thus the distribution of pfd for two carriers is derived in this manner from the single carrier distribution. Multi-carrier distributions are derived from an appropriate combination of distributions for lesser number of carriers. For example, a five carrier distribution can be derived from combining 2 and 3 carrier or 4 and 1 carrier distributions according to the method described above.

8 Determination of MES transmission probability

The probability of one or more MES transmitters being on a given unit of time is evaluated using the Poisson distribution. The formula for this is described in § 5. This allows the pfd probability distribution for n carriers to be conditioned by the actual probability that n transmitters will be active. The shape of a particular Poisson distribution is determined by the variable Λ, often referred to as traffic intensity.

Traffic intensity levels relevant to the determination of interference potential from MSS systems are evaluated in terms of the share of the total traffic transmitted to the MSS space station that is generated within the local region of the mobile station to be protected. Recalling that practical system implementations limit the maximum value for Λ in the Poisson distribution to 0.4, the answer to the impact of a given percentage share of the total traffic is achieved by reducing the maximum value of Λ by the same percentage.

For example, if the traffic generated in the local area of the mobile station was expected to be in the same proportion as the ratio of the local area to the total area of a typical LEO satellite beam (0.002), then a value of $\Lambda = 0.0008$ should be used. In practice, one should add up to a factor of 50 to account for geographic peaking effects.

9 Calculation of exceedance probability

The preceding statistical derivations can be combined to determine the exceedance probability for particular pfd thresholds and levels of local MES traffic intensity. It is recommended that the expression contained in this section be evaluated for a range of these parameters, because of the range of uncertainty that exists for each. The following expression should be used to determine the value of exceedance probability to be associated with these parameters.

$$P_e(\Lambda, \tau) = \sum_{i=1}^{N_t} \frac{\Lambda^n}{n!} \cdot \mathrm{e}^{-\Lambda} \cdot \left(1 - \sum_{-\infty}^{\tau} P_{pfdn}(pfd)\right) \tag{38}$$

Appendix 1
to Annex 2

Example application of the calculation methodology

1 Introduction

This Appendix shows an example of application of the methodology contained in this Recommendation. The particular type of MES under consideration has the following relevant characteristics:

– maximum e.i.r.p.: 9 dBW
– modulation bandwidth: < 4 kHz
– transmit frequency: around 150 MHz
– MSS operational bandwidth: around 2 MHz.

A description of the dynamic channel assignment technique proposed for MSS systems operating below 1 GHz is given followed by the results of the calculations described in the methodology.

The example assumes the following isolation between the MES transmitter and the MS receiver for frequency offsets near the operating frequency of the mobile receiver. For MES transmissions displaced in a frequency greater than 12.5 kHz from the mobile receiver frequency an isolation of 23 dB is assumed.

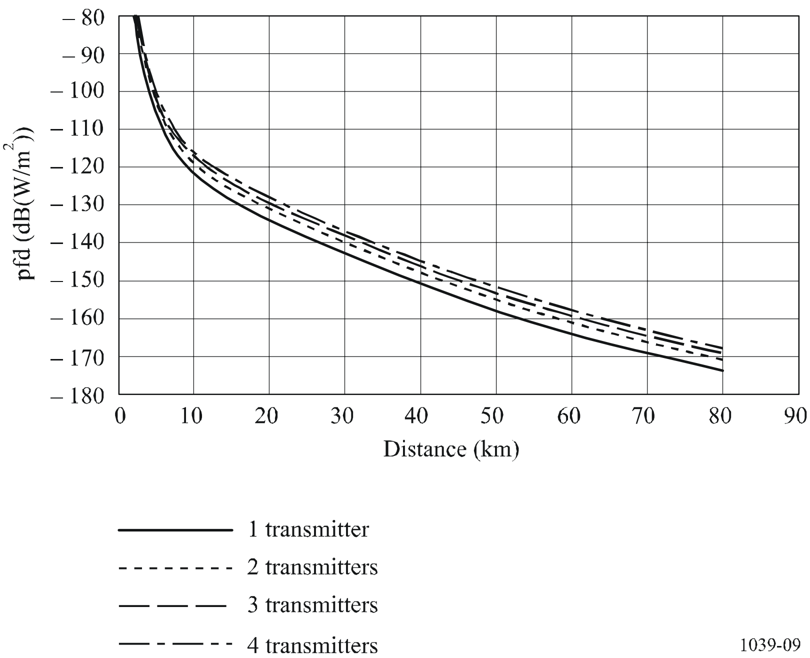
Separation (kHz)	Isolation (dB)
0	0
2.5	0
5.0	0
7.5	2
10.0	8
12.5	23

2 Protection contour calculation

Given a propagation loss model and a maximum MES transmitted e.i.r.p., one can calculate the pfd as a function of distance as described in § 4 of Annex 2. A value of $p = 1\%$ is used in this example. Figure 9 depicts the pfd as a function of distance for one to four simultaneous MES transmitters. Four is the value selected for N_t, the expected maximum number of transmitters on a particular frequency, as described in § 5 of Annex 2.

FIGURE 9

pfd as a function of distance



From Fig. 9, a protection criteria of –140 dB(W/(m^2 · 4 kHz)) would be exceeded by:

– one transmitter at a range of 27 km;

– two transmitters at a range of 30 km;

– three transmitters at a range of 32 km;

– four transmitters at a range of 34 km.

Thus the coordination contour would be defined as 34 km for a protection criteria of –140 dB(W/(m^2 · 4 kHz)).

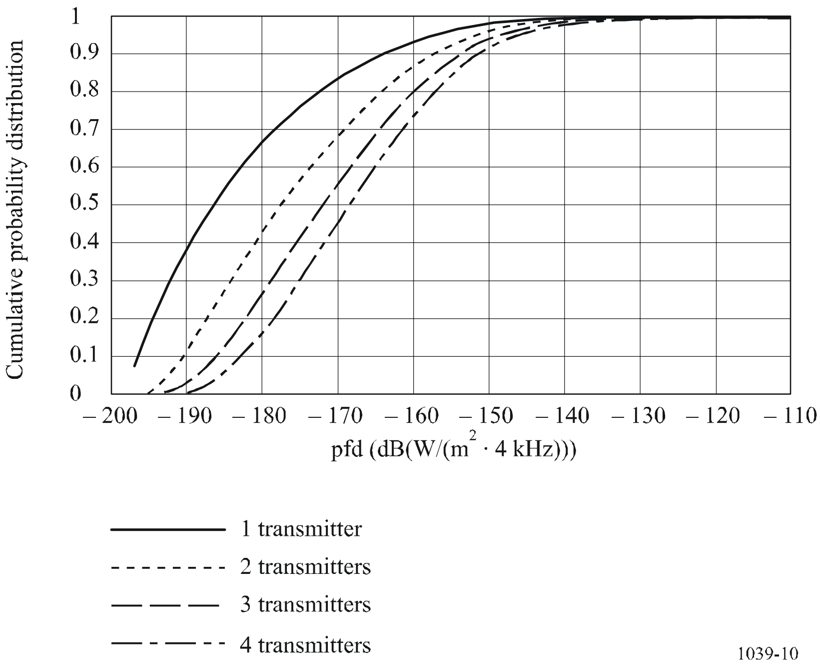
In the cases where it is possible for the protection criteria to be exceeded, one must determine the likelihood of that occurrence. This is done using the probabilistic analysis described in § 6 to 9 of Annex 2.

3 Pfd distributions

The results of the derivation of a pfd probability distribution, based on a 9 dBW transmitted e.i.r.p. from the MES are shown in Fig. 10 for 1, 2, 3, and 4 carriers. This distribution was made over a coordination contour of 80 km, the value which is chosen for a protection criteria of –150 dB(W/(m^2 · 4 kHz)). Note that the results are shown as cumulative distribution functions. The lowest pfd in the cumulative distribution function are of the order of –197 dB(W/(m^2 · 4 kHz)). This value is a combination of the –174 dB(W/(m^2 · 4 kHz)) pfd derived from the propagation model and the 23 dB frequency offset isolation.

FIGURE 10

pfd cumulative probability distributions for 1, 2, 3 and 4 MES transmitters



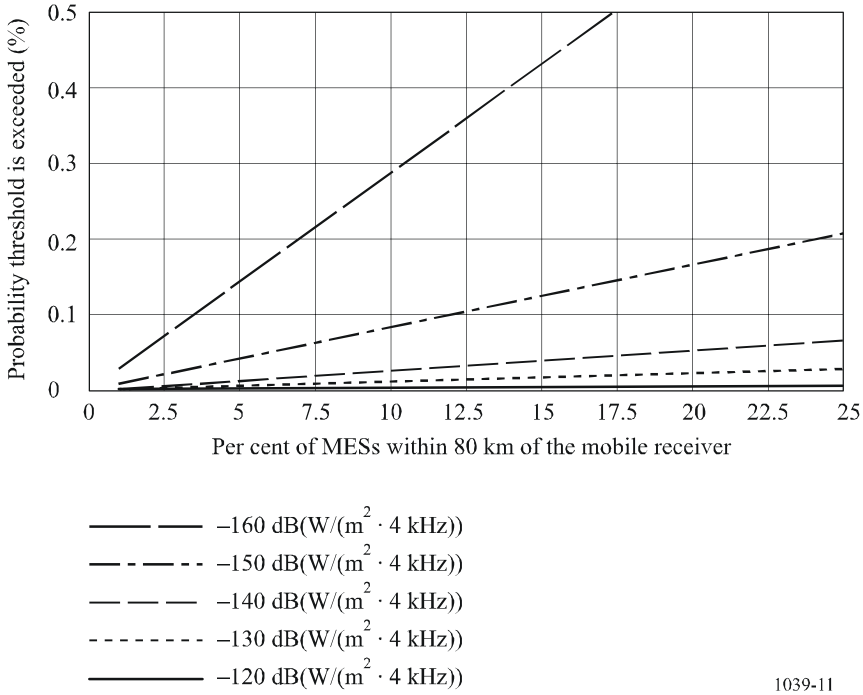
One can determine the probability that a power flux-density protection criteria will not be exceeded when *n* transmitters are active by obtaining the cumulative distribution function valued for that power flux-density for *n* carriers. The probability that the threshold is exceeded is one minus this value. This probability that interference may occur must be conditioned by the probability that *n* transmitters are active as described in the next section.

4 Interference probability

The actual probability of interference to a particular receiver depends upon the total share of the MSS traffic occurring within the local area of the receiver. Figure 11 indicates the share of traffic which must originate in the local area of the mobile receiver to produce a given interference probability. For example, if the established protection criteria is a pfd of −130 dB(W/(m^2 · 4 kHz)), 90% of the total population of MESs would have to be within 80 km of the receiver before the probability of interference would exceed 1%.

FIGURE 11

Probability that threshold is exceeded as a function of the percentage of the MSS users population within 80 km of the mobile receiver



An additional way of looking at these results is that the MSS system operating with orbital altitudes of the order of 700 to 900 km will have a single satellite service area about 5 000 km in diameter. The 80 km radius area discussed in this example is $(80 \times 2/5\,000)^2 = 0.1\%$ of the satellite service area. If the MESs were uniformly distributed within the service area it would be expected that 0.1% of the MES would be within the 80 km area surrounding the mobile receiver and that, from Fig. 11, an interference criteria of –130 dB(W/(m^2 · 4 kHz)) would be exceeded only 0.0001% of the time. If the population of MESs were distributed such that the 80 km area surrounding the mobile receiver arbitrarily contained 20 times the value of the uniformly distributed MESs, then the −130 dB(W/(m^2 · 4 kHz)) criteria would still be exceeded only 0.0022% of the time. The conclusion is that the probability of exceeding a –130 dB(W/(m^2 · 4 kHz)) criteria is very small even given very conservative assumptions used for MES distributions.

Annex 3

Statistical modelling of frequency sharing between stations in the MS and non-GSO MSS earth stations with primary allocations (Earth-to-space) below 1 GHz

1 Introduction

This Annex describes methods that model MSS earth station transmitters sharing spectrum with MS. Statistical models are given for potential interference to MS receivers from MSS earth station transmitters, and for availability of Earth-to-space channels when the MSS is frequency sharing with MS systems.

Mobile services in the bands below 1 GHz are typically characterized by voice and data carriers that may be analogue or digitally modulated and are assigned on a periodic channel grid. Channel spacings used include 6.25 kHz, 12.5 kHz, and 25 kHz. The MSS systems that would frequency share would conduct Earth-to-space transmissions using short-term signal bursts on an intermittent basis with a low duty cycle. Annex 2 of this Recommendation notes that burst lengths might be up to 500 ms and that the time duration of 1% in 1-15 mins has been suggested. MSS systems below 1 GHz may use a dynamic channel assignment algorithm (as described in Annex 4, for example) which allows the space station to identify those channels not occupied by the mobile stations which are sharing the spectrum. A receiver in the satellite monitors the entire shared frequency band and determines which segments of the spectrum are currently being used by the MS system or for non-GSO MSS uplinks. With the band-scanning receiver on board the satellite, there is very little chance for interference from MES to mobile service receivers. There are, however, several circumstances where the dynamic channel assignment technique would fail to identify an active MS channel:

– MS power level below the detection threshold of the satellite band-scanning receiver;

– blockage on the path from the MS transmitter to the satellite so the received signal level is not high enough to be detected;

– an MS transmitter begins operation on a channel during a MSS transmission on what had previously been measured as a clear channel.

The methodology in § 2 to this Annex provides calculation of the probability of interference to an MS receiver from MES transmissions within a single MSS system, without the dynamic channel assignment technique being used.

The other possibility for mutual interference is MS transmissions interfering into the MSS space station receiver. With the MSS band scanning receiver identifying clear Earth-to-space channels for MES use, this type of interference can be avoided. Paragraph 3 to this Annex provides a statistical method that can be used to provide assurance of finding a sufficient number of clear channels to carry the MSS Earth-to-space transmissions. However, there remains the possibility of an MS transmitter beginning operation on a previously clear channel during the short interval of an MES transmission on that channel, and thereby potentially causing interference into the space station receiver.

2 Statistical modelling of interference from non-GSO MSS MESs into mobile service stations

The following statistical model determines the probability of interference without dynamic channel assignment being used. This worst-case assumption provides an upper bound on the actual probability of interference for a single non-GSO MSS network with dynamic channel assignment.

The input parameters are:

a) Mobile service channelization plan (25, 12.5 or 6.25 kHz)

Used to determine mobile link centre frequency and receiver IF bandwidth as shown in Table 2.

TABLE 2

Typical mobile service channelization plans

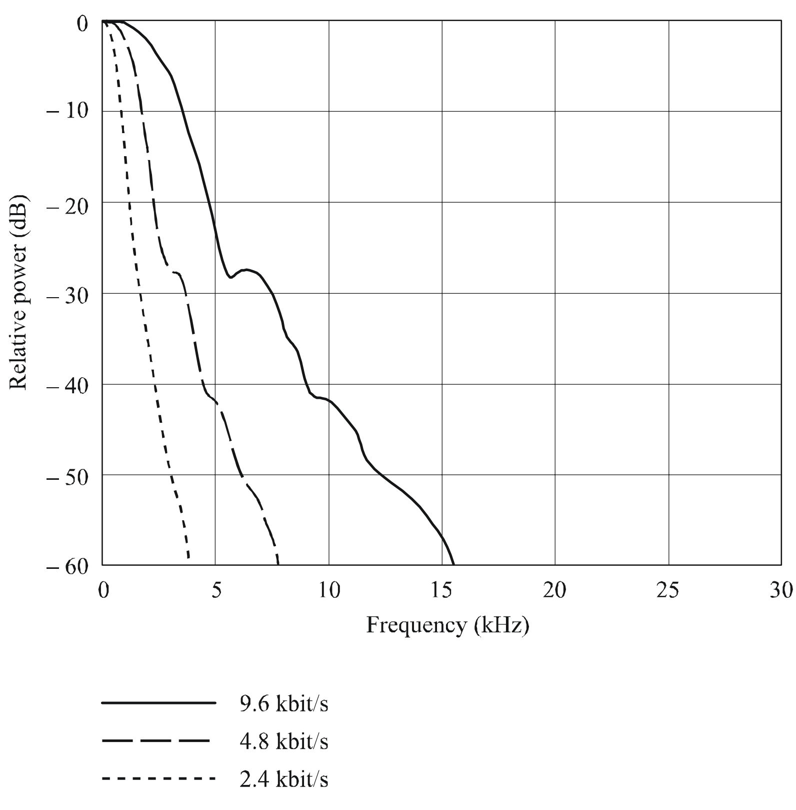
Channelization plan (kHz)	IF bandwidth (kHz)
25	16
12.5	8
6.25	4

b) MES uplink data rate (9.6, 4.8, or 2.4 kbit/s)

Used to determine the MES transmit spectrum as shown in Fig. 12 and transmit power as shown Table 3.

FIGURE 12

MES transmit signal masks



Note 1 – These masks are shown for offset-QPSK modulation. Other types may be used. When an ITU-R recommended template is developed, the recommended signal mask should be used.

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TABLE 3

Example MES transmit powers

Data rate (kbit/s)	Transmit power [(1)] (W)
9.6	7
4.8	3.5
2.4	1.75

(1) Transmit power that provides needed satellite received power in the Earth-to-space channel.

c) MES distribution (uniform or clustered)

The uniform distribution models the MESs as uniformly distributed over the land area within the MSS satellite uplink beam. The clustered distribution places the MESs within the satellite beam with probability density roughly proportional to population density.

d) MES channel selection (random or interstitial)

For the random selection algorithm, the MSS uplink channels are selected randomly on a 2.5 kHz grid across the entire frequency band to be shared (1 MHz, for example). For the interstitial algorithm, the MSS uplink channels are restricted to interstitial frequency locations between the mobile service channels.

For a given set of input parameters, a sufficient number of 1/2-s trials are performed to ensure that the computed probability of interference is reliable. (The number of trials is deemed sufficient when doubling the number of trials does not change the probability of interference significantly.) For each 1/2-s trial the following steps are performed:

Step 1: A mobile service transmitter location is randomly selected as the centre of one of the 20 most populous cities within the MSS satellite uplink beam. (The number of most populous cities may be adjusted to be representative of the population distribution within the MSS satellite uplink beam. Typical satellite beam coverage area is 12 million km^2.)

Step 2: The mobile service receiver location is randomly selected using a circular mass distribution from 0 km to edge of coverage (R_C) from the transmitter location. (The circular mass distribution defines the MS receiver to be equally likely to be positioned anywhere within the circular coverage area.)

Step 3: A mobile service link centre frequency, CF_{MS}, is randomly selected in a 1 MHz bandwidth based on the input mobile service channelization plan.

Step 4: The mobile service receiver IF bandwidth, B_{IF}, is determined from the input channelization plan.

Step 5: The distance between the MS transmitter and the MS receiver, d_{MS}, is computed.

Step 6: One hundred and twenty-eight active MESs are randomly selected each 1/2 s within the satellite beam using the input distribution, either uniform or clustered. This corresponds to over 22 million MES transmissions per day from the beam coverage area, which assumes that the non-GSO MSS system is operating at 100% of theoretical capacity. This is another worst-case assumption. (The number of active MESs is chosen to supply the number of uplink transmissions that fill the non-GSO MSS system to design capacity. This number would vary with different MSS network designs.)

Step 7: The distances, $d_{MES\text{-}MS}$, from each of the MESs to the mobile service receiver are computed.

Step 8: Centre frequencies, CF_{MES}, are randomly selected in a 1 MHz band for each of the MESs using the input selected method, uniform or interstitial.

Step 9: The MES effective isotropic radiated power spectrum, $e.i.r.p._0(f)$, is determined based on the input data rate.

$e.i.r.p._0(f)$: normalized power spectral density for the MES transmissions, a mathematical representation of the appropriate curve in Fig. 12.

Step 10: The carrier-to-noise-plus-interference ratio is computed as follows:

$$C/(N+I) = \frac{\dfrac{10^{PR/10} \times k\,T\,B_{IF} \times (R_C)^4}{d_{MS}^4}}{k\,T\,B_{IF} + \displaystyle\int_{CF_{MS}-\frac{B_{IF}}{2}}^{CF_{MS}+\frac{B_{IF}}{2}} \sum_{MESs} \frac{\beta e.i.r.p._0(CF_{MES}-f)}{d_{MES-MS}^4}\,\mathrm{d}f} \tag{39}$$

where:

PR: protection ratio for MS receiver (dB)

k: Boltzman's constant (1.38×10^{-23} J/K)

T: MS receiver noise temperature (K)

B_{IF}: MS receiver IF bandwidth (Hz)

R_C: distance from MS base station to edge of coverage (m)

d_{MS}: distance (m) between MS transmitter and MS receiver

CF_{MS}: centre frequency of MS channel (Hz)

$MESs$: number of active MES transmitters

β: $(h_{MES})^2 \times h_{MS}^2 \times g_{MS} \times p_{MES} \times D_{MS}$

- h_{MES}: height of MES antenna (m)
- h_{MS}: height of MS receive antenna (m)
- g_{MS}: numerical gain of MS receive antenna
- p_{MES}: MES transmitter power (W)
- D_{MS}: polarization discrimination factor of MS receiver antenna against MES signals (numerical factor, less than or equal to one)

$e.i.r.p._0(f)$: MES effective isotropic radiated power spectral density as defined in Step 9 above (W/Hz)

CF_{MES}: centre frequency of individual MES transmitter (Hz)

f: frequency (Hz)

$d_{MES\text{-}MS}$: distance from MES transmitter to MS receiver (m).

The $C/(N+I)$ equation uses the propagation model in equation (31) with median field strength levels, that is, with $p = 50\%$.

Step 11: If $C/(N+I)$ is less than the design threshold of the MS receiver, then the trial is deemed to have resulted in interference.

The probability of interference is computed as the ratio of the number of trials resulting in interference divided by the total number of trials. This result is the probability of interference to the MS receiver if it were to be receiving transmissions continuously.

For cases with low MS traffic loading, the probability of interference to the MS receiver is reduced by the Erlang factor for the channel.

Modelling $C/(N+I)$ with values of p other than 50% requires modification of equation (39) to account for variations in path loss with p and distance as given in the propagation model in equation (31).

3 Modelling of interference from mobile service stations into non-GSO MSS satellites

Narrow-band non-GSO MSS networks will use dynamic channel assignment techniques to avoid channels being actively used by mobile service stations. Thus as long as the dynamic channel assignment system correctly identifies all active MS channels, the non-GSO MSS uplinks will begin transmissions only on channels that are clear of potentially interfering mobile service station transmissions. This model examines if there would be a sufficient number of unused, clear channels available to support non-GSO MSS operations.

The simulation determines the number of mobile service stations in the satellite beam that can operate in the shared spectrum and still allow an average of at least six channels per satellite for the non-GSO MSS uplinks. This worst-case assumption provides a lower bound on the number of mobile service stations that can operate in the shared spectrum while still allowing the non-GSO MSS network to operate at 36% of theoretical capacity. (The number of uplink channels per satellite is chosen to allow the satellite to operate at design capacity.)

The input parameters are:

a) Mobile service channelization plan (25, 12.5 or 6.25 kHz)

Used to determine MS station centre frequency grid, and mobile service transmit spectrum as shown in Fig. 13.

b) MES uplink data rate (9.6, 4.8, or 2.4 kbit/s)

Used to determine the non-GSO MSS uplink centre frequency grid as shown in Table 4.

c) Amount of shared spectrum (1 MHz or 5 MHz)

d) Mobile service station average activity factor (0.01, 0.003, 0.001, or 0.0003 E).

FIGURE 13

Mobile service station transmit signal masks

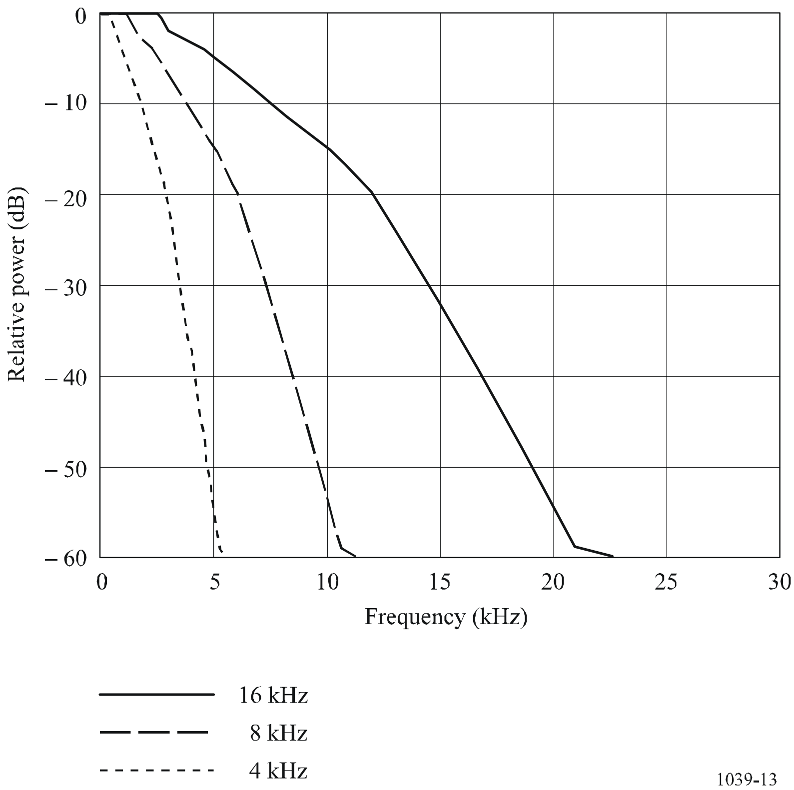


TABLE 4

Typical MES uplink channel bandwidths

Data rate (kbit/s)	Channel bandwidth (kHz)
9.6	15
4.8	10
2.4	5

For each set of input parameters, the following steps are performed:

Step 1: The initial number of mobile service stations is set to 1 000.

Step 2: The mobile service stations are randomly distributed across the area covered by the satellite uplink beam.

Step 3: The mobile service transmitter effective isotropic radiated power spectrum, $[e.i.r.p._0(f)]_{MS}$ is determined based on the input mobile service channelization plan,

where:

$$[e.i.r.p._0(f)]_{MS} = e.i.r.p._{MS} \times PSD_0(f) \tag{40}$$

$e.i.r.p._{MS}$: effective isotropic radiated power of the mobile service station

$PSD_0(f)$: normalized power spectral density for the MS transmissions, a mathematical representation of the appropriate curve in Fig. 13.

Step 4: The non-GSO MSS satellite system uplink channel bandwidth, BW, is determined based on the input MES uplink data rate.

Step 5: For each trial, the non-GSO MSS satellite constellation is randomly rotated in time, and a sufficient number of trials are performed to ensure that the computed number of mobile service stations is reliable. The following steps are performed:

Sub-step 1: For each mobile service station, a transmit centre frequency, CF_{MS}, is randomly selected in the input amount of shared spectrum, 1 MHz or 5 MHz, based on the input mobile service channelization plan.

Sub-step 2: For each mobile service station and for each non-GSO MSS satellite the Doppler frequency shift, $\Delta f_{Doppler}$, is computed taking account of the relative velocities of the transmit and receive equipments. The Doppler shift observed at a receiver is given by:

$$\Delta f_{Doppler} = (v/c)\, F_0 \tag{41}$$

where:

$\Delta f_{Doppler}$: Doppler shift (Hz)

v: relative velocity between the transmitter and the receiver (m/s)

c: speed of light (3×10^8 m/s)

F_0: transmit frequency (Hz).

Sub-step 3: For each non-GSO MSS satellite and for each non-GSO MSS uplink channel centre frequency, CF_{CH}, in the input amount of shared spectrum, the interference-to-noise ratio is computed as follows:

$$(I/N)_{CH} = \frac{\varepsilon}{BW} \cdot \int_{CF_{CH} - \frac{BW}{2}}^{CF_{CH} + \frac{BW}{2}} \sum_{MSs} \Big(e.i.r.p._0 (CF_{MS} + \Delta f_{Doppler} - f) \Big)_{MS} \, \mathrm{d}f \tag{42}$$

where:

$$\varepsilon = (G/T)_{SAT} / [(Alt_{SAT} \times F \times (4\pi/c))^2 \times k \; BW] \; D_{SAT} \tag{43}$$

where:

$(G/T)_{SAT}$: MSS satellite antenna on-axis gain (numerical value) divided by receiver system noise temperature (K^{-1})

Alt_{SAT}: altitude of satellite (m)

F: channel centre frequency (Hz)

c: speed of light (3×10^8 m/s)

k: Boltzman's constant (1.38×10^{-23} J/K)

BW: MSS satellite receiver bandwidth (Hz)

D_{SAT}: polarization discrimination factor of MSS satellite receiver antenna against MS signals (numerical factor, less than or equal to one).

The I/N equation uses the space propagation model.

Sub-step 4: For each non-GSO MSS satellite, the number of clear channels is computed as the sum of those with $I/N < 10$ dB.

Step 6: If the minimum of the computed numbers of clear channels is greater than six, then the number of mobile service stations is increased by 1 000 and the above procedure is repeated starting at step 2.

Step 7: The process is completed when the maximum number of MS stations that still allows for six clear channels is found.

Appendix 1 to Annex 3

Example applications of the statistical models

1 Introduction

This Appendix shows examples of application of the two statistical models contained in Annex 3 of this Recommendation.

The example non-GSO MSS network used has the following characteristics: 48 satellites in eight orbital planes inclined 50° to the equator; each plane contains six equally spaced satellites in 950 km altitude circular orbits; narrow-band frequency division multiplexing for the Earth-to-space transmissions; operation in a store-and-forward mode; transmissions within 500 ms frames containing digital packets; satellite use of a band scanning receiver to implement a DCAAS that assigns unused channels to earth stations for uplink transmissions; operation at 149 MHz; MES antenna 1.5 m height, with vertical polarization and 0 dBi gain; and uplink data rates of 2.4, 4.8, and 9.6 kbit/s. It is assumed that the one MSS system is operating at maximum capacity over a specific geographic area, (for this example, 22 million Earth-to-space packet transmissions per day over the contiguous United States of America).

LMS are modelled with the following characteristics: analogue, frequency modulation system (or digitally modulated, binary-FSK system); a vertically polarized antenna having 0 dBi gain towards the satellite; minimum received signal power assumed to be –140 dBW; and channel bandwidths of 6.25, 12.5 and 25 kHz with low Erlang loading on individual channels. The technical characteristics used in the model are for certain LMS systems operating in the bands below 1 GHz. For the frequency sharing analyses, LMS systems are modelled as operating in the 20 most populous cities in the United States of America.

2 Potential interference from non-GSO MSS earth stations into LMS

The distance between the LMS and its base station is modelled by a circular mass distribution from 0 to 20 km with 20 km corresponding to threshold received power. The protection ratio for the LMS receiver is set at 10.7 dB, and its noise temperature is 3 890 K. LMS receiver antenna height is 3.22 m. The LMS receiver antenna and the MES transmit antenna have the same polarization, so the polarization discrimination factor is set equal to 1.0. Both uniform and clustered distributions of MSS earth stations are considered. One hundred and twenty-eight active MESs are used in the simulation. A 1 MHz shared frequency band is assumed with both random and interstitial uplink channel selection algorithms considered.

With the parameter values selected the $C/(N+I)$ equation becomes:

$$C/(N+I) = \frac{\dfrac{10^{3.204}}{d_{MS}^4}}{10^{-15.07} + \displaystyle\int_{CF_{MS}-\frac{B_{IF}}{2}}^{CF_{MS}+\frac{B_{IF}}{2}} \sum_{MESs} \frac{10^{2.815} \times e.i.r.p._0(CF_{MES}-f)}{d_{MES\text{-}MS}^4} \, \mathrm{d}f} \tag{44}$$

Table 5 shows the upper bound probability of interference computed by the simulation program for the range of parameters examined. (The probabilities calculated using the model are the probabilities of interference with the DCAAS system not used. Hence they are upper bound values on the probability of interference. The actual probabilities of interference with DCAAS in use would be the probabilities in Table 5 multiplied by the probability of the DCAAS system not detecting an active channel, 10^{-3}, 10^{-4}, or less, for example.) The significance of the raw probabilities may be difficult to interpret, so they have been converted to mean time between interference events as shown in Table 6. The mean times between interference events in Table 6 are obtained from the reciprocal of the probability in Table 5×0.5 s, the period of the MES transmissions used in the model. The results in Tables 5 and 6 are for the condition that the LMS is operating continuously. Table 7 shows the mean time between interference events for a typical land mobile user with 0.01 E of traffic.

TABLE 5

Probability of interference

		Uniform distribution		Clustered distribution	
Land mobile channelization (kHz)	MES uplink data rate (kbit/s)	Random selection	Interstitial selection	Random selection	Interstitial selection
25	9.6	0.00038	0.000055	0.0013	0.00020
	4.8	0.00025	0.0000058	0.00088	0.000022
	2.4	0.00016	0.00000093	0.00052	0.0000034
12.5	9.6	0.00023	0.00019	0.00075	0.00064
	4.8	0.00012	0.000020	0.00039	0.000069
	2.4	0.000067	0.0000024	0.00023	0.0000084
6.25	9.6	0.00014	0.00015	0.00049	0.00051
	4.8	0.000094	0.00011	0.00032	0.00037
	2.4	0.000066	0.000074	0.00023	0.00026

TABLE 6

Worst-case (smallest) mean time between interference events

		Uniform distribution		Clustered distribution	
Land mobile channelization (kHz)	MES uplink data rate (kbit/s)	Random selection (min)	Interstitial selection	Random selection (min)	Interstitial selection
25	9.6	22	3 h	7	42 min
	4.8	34	24 h	10	7 h
	2.4	50	150 h	16	41 h
12.5	9.6	36	44 min	11	13 min
	4.8	70	7 h	22	120 min
	2.4	130	60 h	36	17 h
6.25	9.6	60	55 min	17	17 min
	4.8	90	75 min	26	23 min
	2.4	130	120 min	36	32 min

TABLE 7

Mean time between interference events for typical push-to-talk user (0.01 E)

		Uniform distribution		Clustered distribution	
Land mobile channelization (kHz)	MES uplink data rate (kbit/s)	Random selection (h)	Interstitial selection	Random selection (h)	Interstitial selection
25	9.6	37	10 days	11	69 h
	4.8	56	100 days	16	26 days
	2.4	83	21 months	27	68 days
12.5	9.6	60	73 h	18	22 h
	4.8	120	29 days	36	200 h
	2.4	210	8 months	60	71 days
6.25	9.6	100	92 h	28	28 h
	4.8	150	130 h	43	38 h
	2.4	210	190 h	60	53 h

For land mobile channelizations, MES uplink data rates, and other parameters that are different from those used in this example, interpolation may be used to determine approximate values of probabilities of interference and mean times between interference events.

3 Potential interference from LMS into non-GSO MSS satellites

The model of section 3 of Annex 3 of this Recommendation performs a simulation to determine the number of LMS within the MSS satellite uplink beam that can operate in the shared spectrum and still provide an average of at least six channels per satellite for the MSS uplinks. The average per satellite assumption is worst case, since the average over all of the visible satellites will be greater than the average per satellite, and thus provides a lower bound on the number of LMS that can operate in the shared spectrum. The satellite footprint is roughly the size of the contiguous United States of America, 12 million km^2. Additional technical parameter values needed for this example are:

MSS satellite $G/T = -30.1$ dB(K^{-1})

LMS antenna gain = 6 dBi in horizontal direction and 0 dBi towards the satellite.

The MSS satellite receiver antenna is assumed to have no polarization discrimination against the LMS signals so the polarization discrimination factor is set equal to 1.0.

With the parameter values chosen, the I/N equation becomes:

$$(I/N)_{CH} = \frac{10^{6.25}}{BW} \cdot \int_{CF_{CH} - \frac{BW}{2}}^{CF_{CH} + \frac{BW}{2}} \sum_{MSs} \left(e.i.r.p._0 (CF_{MS} + \Delta f_{Doppler} - f) \right)_{MS} \mathrm{d}f \qquad (45)$$

Four LMS average activity factors were considered, 0.01, 0.003, 0.001, and 0.0003 E (Erlang is a measure of traffic intensity. In this context it is a measure of the LMS utilization). These correspond to averages of 432, 130, 43, and 13 min/month of LMS transmissions, respectively. Assuming a 0.4 voice activity factor, the equivalent conversation times are 1 080, 325, 108, and 33 min/month. Note that the averages are over the entire population of LMS and over the entire month.

Table 8 shows lower bounds on the number of LMS in the contiguous United States of America operating in 1 MHz of shared spectrum computed by the simulation program for the range of parameters examined.

TABLE 8

Lower bound number of LMS in 1 MHz of shared spectrum

		LMS average activity factor			
Land mobile channelization (kHz)	MES uplink data rate (kbit/s)	0.01 E	0.003 E	0.001 E	0.0003 E
25	9.6	12 000	38 000	120 000	380 000
	4.8	17 000	55 000	170 000	550 000
	2.4	23 000	77 000	230 000	770 000
12.5	9.6	16 000	52 000	160 000	520 000
	4.8	24 000	80 000	240 000	800 000
	2.4	35 000	120 000	350 000	1.2 million
6.25	9.6	18 000	60 000	180 000	600 000
	4.8	35 000	120 000	350 000	1.2 million
	2.4	58 000	190 000	580 000	1.9 million

Table 9 shows the lower bounds assuming 5 MHz of shared spectrum. The lower bounds are significantly greater than 5 times those for 1 MHz of shared spectrum.

TABLE 9

Lower bound number of LMS in 5 MHz of shared spectrum

		LMS average activity factor			
Land mobile channelization (kHz)	MES uplink data rate (kbit/s)	0.01 E	0.003 E	0.001 E	0.0003 E
25	9.6	110 000	370 000	1.1 million	3.7 million
	4.8	125 000	420 000	1.3 million	4.2 million
	2.4	170 000	570 000	1.7 million	5.7 million
12.5	9.6	115 000	380 000	1.2 million	3.8 million
	4.8	190 000	630 000	1.9 million	6.3 million
	2.4	255 000	850 000	2.6 million	8.5 million
6.25	9.6	120 000	400 000	1.2 million	4.0 million
	4.8	230 000	770 000	2.3 million	7.7 million
	2.4	450 000	1.5 million	4.5 million	15 million

For parameter values not presented in the Tables, interpolation may be used to determine approximate values of the lower bound numbers.

Annex 4

Use of the dynamic channel assignment technique for frequency interference avoidance

1 Introduction

This Annex describes a technique used by non-GSO MSS networks to detect open channels in terrestrial service systems operating in the same frequency band and that can then identify them for use for uplink transmissions by an MES of the MSS system. While the details of the DCAAS given in this Annex are those used in the LEOTELCOM-1 network, other MSS networks are planning to use similar-band scanning systems that operate generally according to the same principles, but may differ in their specific implementations.

Such a technique provides a demonstrated basis for interference avoidance to other co-frequency primary terrestrial services in the same band. The name used to describe this technique is DCAAS, and has been implemented successfully on the LEOTELCOM-1 MSS satellite network. Test information is also included.

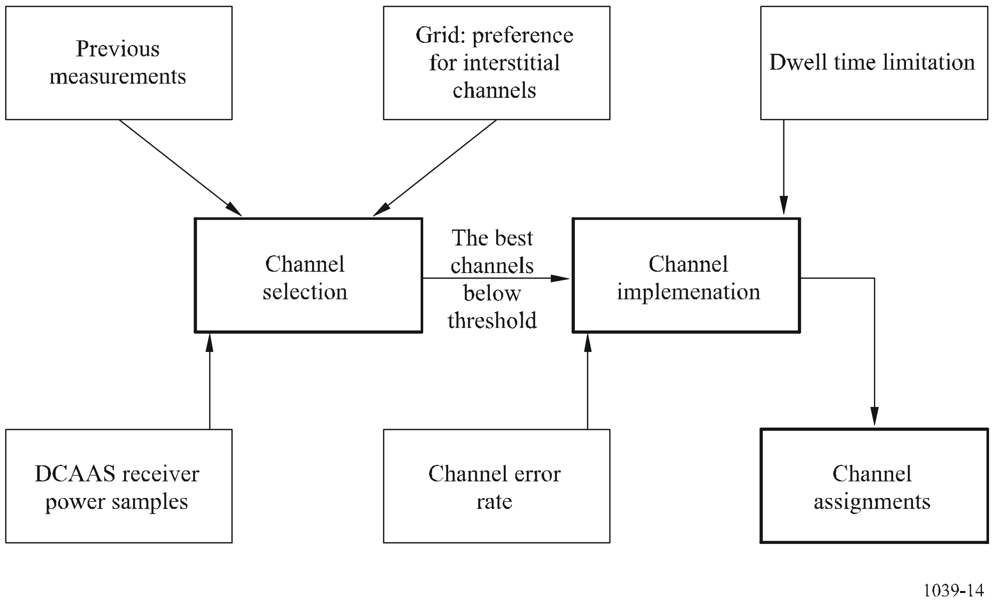
2 DCAAS operation

The DCAAS, consists of a receiver and processing unit on all the satellites (see Fig. 14) in the constellation. The DCAAS scans the MES uplink band for terrestrial transmissions in 2.5 kHz intervals, identifies channels which are not in use and assigns these channels for uplink use by the MESs. The objective of this process is to avoid MES transmissions interfering with terrestrial receivers, i.e. preventing MES transmissions on active mobile channels.

Figure 14 is a graphical representation of the various factors that affect the channel selection and implementation process carried out by the DCAAS operation.

FIGURE 14

DCAAS operation



2.1 Channel selection

There are three inputs to the algorithm that identify the preferred channels available on each scan:

– *Power sampling* – The first selection criterion involves power sampling. One satellite receiver operates in DCAAS mode and scans all channels in the selected operating range. Channels for which the power samples fall below a specific threshold are declared to be potentially available. The power sample threshold determination is a hard decision and thus carries the highest weight of the channel selection criteria.

– *Grid preference* – The second channel selection criteria is referred to as the grid preference. Around the world there are many wireless systems (including paging and cellular systems) which are assigned channels on a 20, 25 or other kHz channelization plan or grid. The satellite system is designed to give preference to channels spaced midway between these standard terrestrial, channelizations. This preference carries more weight in the channel selection algorithm than the quality factor, but less than the hard threshold decision. While all potential uplink channels are investigated by the DCAAS system, channels lying on known terrestrial grids are investigated last.

– *Quality factor* – The third channel selection criteria considers power sample measurements made over the previous several band scans and is referred to as the quality factor. The quality factor is a measure of the current and past power levels of the channel, as determined by an algorithm.

Once all factors are taken into account, the preferred channels are selected from the available channels and passed to the channel implementation portion of the DCAAS system.

It is important to note that:

– an MSS can transmit only if it receives a downlink signal from the satellite telling it which uplink channels may be used;

– if the DCAAS system cannot find an inactive channel at a particular point in time, DCAAS will not permit the MESs to transmit.

In addition to scanning for inactive channels, the DCAAS processor predicts which of the available channels are most likely to be available for the immediate short-term future.

2.2 Channel implementation

Once the channel selection process determines the preferred channel frequencies, the channel implementation process assigns these channels for random access (acquire/communicate transmissions) and reservation channel (messaging transmissions) use. The remaining channels go into a reserve pool. The reserve pool is used if a channel dwell limiting timer expires for the random access receivers, or if the performance measurement thresholds (error rates) are exceeded.

Four conditions regulate channel switching for the satellite receivers:

– exceeding the error rate threshold of a random access receiver;

– exceeding the error rate threshold of a reservation receiver;

– channel selection process using new DCAAS scan data shows power level exceeding the quality factor threshold on the currently assigned channel;

– expiration of the channel dwell limiting timer, if enabled.

If there are few MESs transmitting to a satellite, the time for a satellite to change the uplink channel in use to a different frequency will depend on the correlation between the start of an interference event detected at the satellite and the DCAAS scan process. The DCAAS process, as implemented by one system operator, has a repeat time of approximately 5 s.

If there are many MESs transmitting to a satellite, the time for a satellite to change the uplink channel to a different frequency is designed to be rapid if the error rate threshold on that channel is exceeded.

As can be seen, DCAAS uses the data from the current scan to identify channels which appear to be inactive, then combining the information from the current scan with information from previous scans, makes a prediction as to which of these available channels are likely to remain inactive.

2.3 Message lengths

Within the frequency agile system constellations, a subscriber can make only two types of transmissions: a short burst, or access request, on the random access channel or a longer messaging transmission burst, on a messaging channel. Each messaging burst is specifically controlled as to the frequency and duration of the transmission. Under DCAAS control, the frequency of the random access channel will change at frequent intervals, always staying on a channel least occupied by any terrestrial user.

Once recognized within the system, the subscriber may transmit either a single communication packet of 15 bytes or a request to transmit a longer message.

If a longer message transmission is requested, the subscriber transmits a request for access to a messaging channel and provides the total length of the message to be transmitted. This channel request is itself a 15 byte, 50 ms long, packet. The maximum message length, i.e. number of bytes, to be transmitted by the user in a single burst is then relayed back to the subscriber along with a specific transmit frequency obtained from the DCAAS process. This maximum allowable message length will be used to control the maximum transmission length of the subscriber message to less than 450 ms to 500 ms on a single transmission frequency. Since the initial subscriber-to-satellite handshake takes place on a channel being used as a random access order wire, the subscriber message will be transmitted on a different frequency.

If the maximum allowable message length is shorter than the subscriber's total message, the message will be transmitted in several bursts. The transmission frequency of each subscriber burst is controlled by the DCAAS process on the satellite and will be on a different frequency. In this way the maximum time that a subscriber can transmit on a single frequency will be controlled.

3 DCAAS probability considerations

3.1 Probability of assigning an active channel

In some cases, the DCAAS receiver on the satellite may not be able to see terrestrial mobile transmitters due to an obstruction, such as a building, along the Earth-to-space path between the mobile transmitter and the satellites. In this case, the DCAAS receiver might not sense the mobile transmitter, and therefore might assign that active channel to an MES transmitter. The probability of this occurring will vary depending on location and local topography.

Other factors which affect the probability of DCAAS assigning an active channel, but which are difficult to quantify include the following:

– If the frequency band is heavily used by the terrestrial mobile services employing frequency reuse, there is a high probability that a second mobile transmitter visible to the satellite is also using that same channel, thereby preventing DCAAS from assigning that channel.

– If the Earth-to-space path from a mobile transmitter to a satellite is blocked, there is a certain probability that the terrestrial path between the MES and the mobile receiver is also blocked. It can be expected that in areas where the probability of blockage on the Earth-to-space pass is highest, the probability of blockage on the terrestrial path is also high.

– The predictive algorithm in the DCAAS processor will evaluate the probability that its available channels will remain interference free until the next scan is complete. This takes into account data from recent scans, so that a channel used by a terrestrial mobile transmitter that suddenly vanishes behind an obstruction will probably not be assigned for use if other channels are available.

Taking into account all of these factors to obtain a single probability for DCAAS assigning an active channel would be an extremely difficult task, and the probability would change from one geographic area to another. However, the interference calculations in which this probability would be used require only an order of magnitude estimate. For these reasons, the probability of DCAAS failure is estimated to be very low.

3.2 Probability of an MES transmitting near a mobile receiver

If the DCAAS system does not see a terrestrial mobile transmitter, and happens to assign that channel to MES transmissions, this may result in interference to the mobile receiver, depending on a number of factors including the distance between the MES and the mobile receiver, the number of MESs and the probability that an MES is transmitting at the same time as the mobile is receiving. This subject is addressed in Annexes 1, 2, and 3.

4 Summary of interference avoidance due to the DCAAS technique

WARC-92 allocated the bands 137-138 MHz (downlink) and 148-149.9 MHz (uplink) to the MSS. These bands are also shared with terrestrial services. The DCAAS techniques operate to permit transmissions of the MES (satellite) in such a way as to avoid interference to other users in the band 148-149.9 MHz. However, it is accomplished through use of the downlink transmissions as well.

Specifically, the 148-149.9 MHz band is heavily used by terrestrial systems. In order to operate effectively, the MSS system must scan and identify channels within this band which are not being actively used during the few second scan duration. It is impossible for an FDMA MSS satellite system to operate in the 148-149.9 MHz band without some scheme, such as DCAAS. Any attempt to receive on a channel being actively used by a terrestrial transmitter would result in interference to the satellite and a total loss of MSS data.

4.1 Aspects of the sharing approach

The DCAAS identifies channels being actively used by terrestrial services and avoids those channels. The sharing approach used exploiting this technique consists of five aspects:

– The system as implemented by one operator scans the frequency band for inactive channels every 5 s. The DCAAS system will not permit the MESs to transmit if there are no inactive channels available. The DCAAS system avoids assigning active mobile channels (e.i.r.p. toward the satellite > 0.1 W in 7.5 kHz) to MESs for uplink transmissions.

– Should the DCAAS system inadvertently assign an active channel, there is a very low probability that a transmitting MES is sufficiently near to a receiving mobile unit to be detected.

– If a channel selected by DCAAS receives interference, DCAAS will quickly select a different channel.

– The short burst duration of MES transmissions further minimizes any interference effects.

– The structure of the MES message transmission is such that even if interference does occur, it will not continue or reoccur.

This Annex has described the DCAAS technique. The basic principles of the DCAAS technique can be implemented in a variety of ways. For example, the LEO-L MSS system design uses a digital dynamic channel assignment technique that performs fast Fourier transform (FFT) processing in the satellite to simultaneously view the entire uplink band and to identify clear uplink channels for assignment to MSS subscriber terminals. The FFT band-scanning receiver allows the MSS uplink channels to be re-assigned (of the order of every 0.5 s) in response to measured channel availability. The expected response varies as a function of frequency and bandwidth. For example, the band-scanning receiver in the LEO-L design can detect a 0.5 s duration, 460 MHz frequency, 2.5 kHz bandwidth, 3.5 mW transmit power signal anywhere in the satellite footprint with 99.9% probability. For a 16 kHz signal the sensitivity is 22 mW. At 149 MHz the transmit power sensitivities are 0.4 mW and 2.3 mW, for 2.5 kHz and 16 kHz signals, respectively. These sensitivities allow the non-GSO MSS uplinks to avoid channels that are in use by the LMS systems, and band sharing between the non-GSO MSS below 1 GHz and the LMS is feasible to the extent allowed by usage congestion.

5 Demonstration of avoidance of interference

5.1 Initial tests simulation

In many countries the principal occupants of the uplink frequency band are terrestrial mobile systems. The DCAAS is specifically designed to avoid occupied channels within the band. By determining which channels are unoccupied and assigning these clear channels to the subscriber mobile earth terminals, the system will meet this criteria. Figure 15 shows the probability of channel selection of the DCAAS algorithm. The algorithm was run in a simulation that was based on a full year of frequency occupancy data collected by the communications demonstration satellite (CDS). The CDS collects scan data on the 148-149.9 MHz band from an altitude of 750 km. The CDS satellites were low orbit experimental satellites designed to collect information on the terrestrial use of the 148-149.9 MHz uplink band. The satellites gathered data for approximately two years from altitudes of 750 km.

FIGURE 15

Frequency selections made by DCAAS

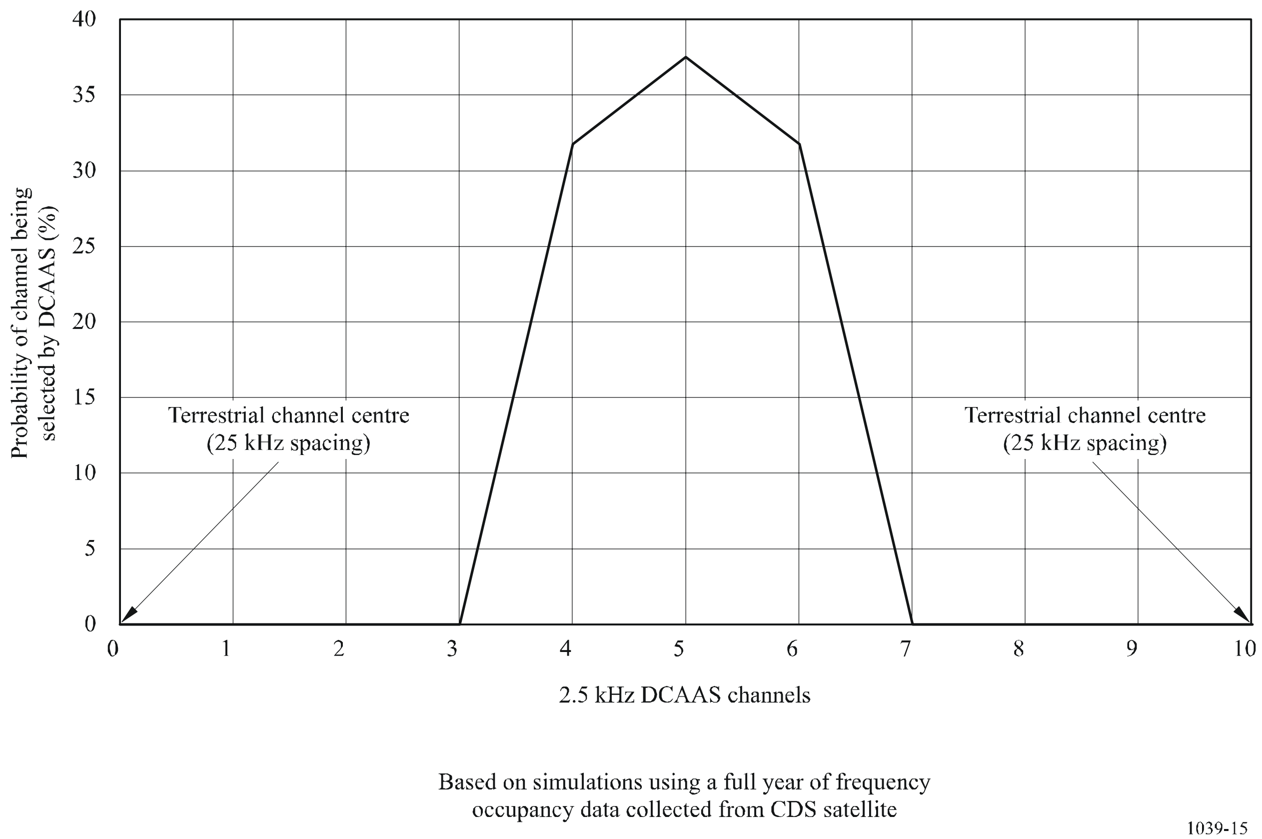
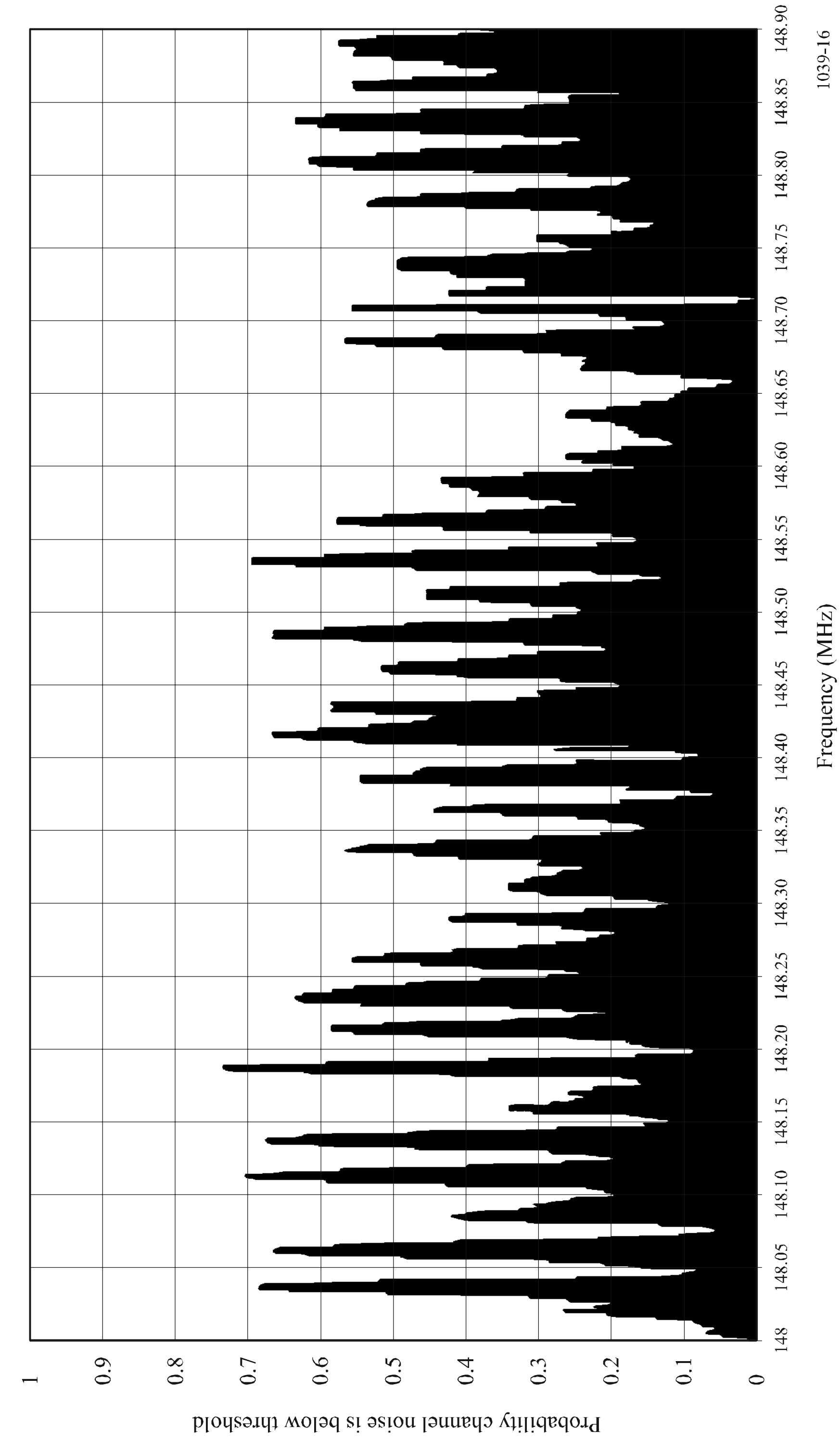


FIGURE 16

Probability of interference-free channels



5.2 Demonstration tests

One administration recently undertook a test programme to evaluate the non-GSO MSS satellite receiver sensitivity and DCAAS capabilities in detecting the noise power or occupancy of channels due to either high noise, or an analogue voice land mobile carrier, within the 148-149.9 MHz band. A demonstration test set (DTS) ran several tests over a two-day period. These tests took place during a number of good (high elevation) satellite passes that occurred over a two-day period, where on average there were 6-8 good passes per day.

Three types of tests were conducted:

– the satellite receiver sensitivity tests;

– DCAAS switching under normal conditions and switching when the DTS simulates a land mobile transmission in the assigned channel;

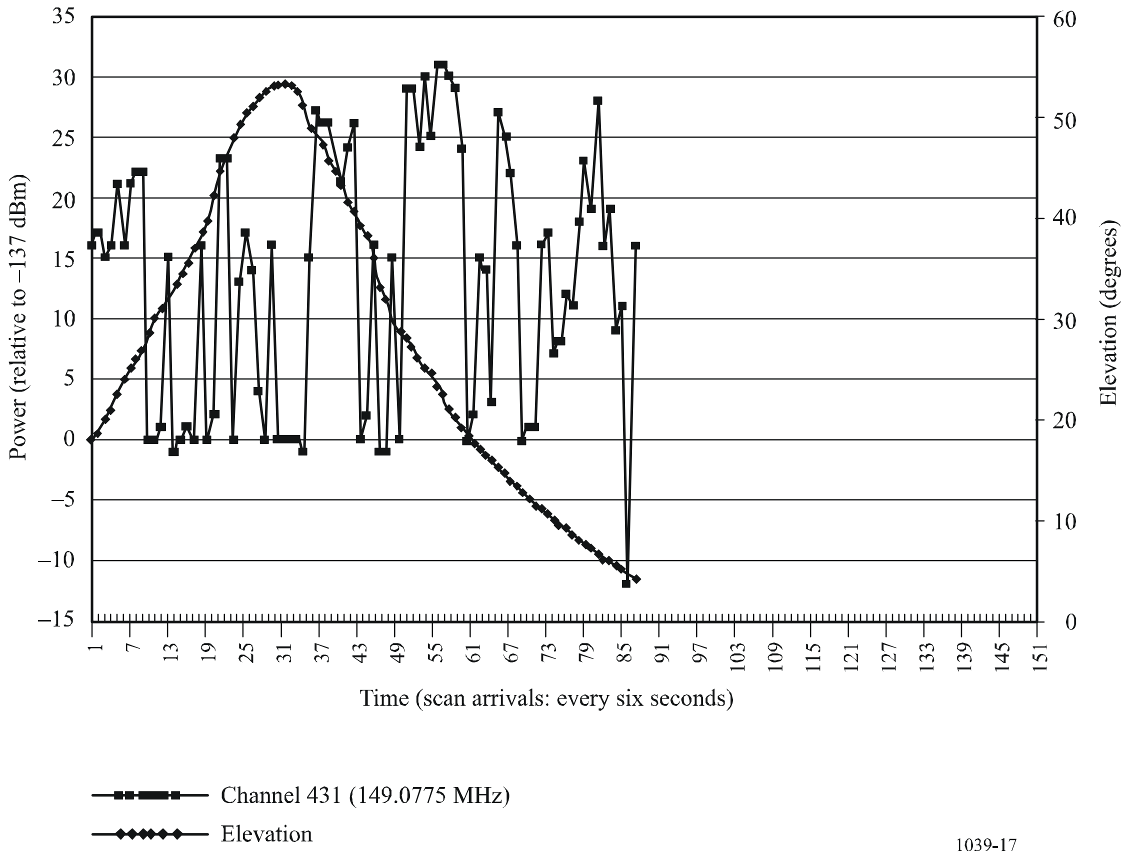
– the DTS simulating an MES interferer transmitting co-channel with an analogue voice land mobile system.

5.2.1 Satellite receiver sensitivity tests

The DTS was configured to receive the downlink scan data from the satellite. The scan data indicated the spectrum noise (power) level across the 148-149.9 MHz band which the satellite could observe within its 3 000 mile diameter coverage area. The scans verified the sensitivity of the satellite receivers as they detected the high power paging transmitters used by the administrations' paging networks, and the mobile base station transmissions utilized by the administration to transmit a 5 W carrier at various satellite elevation angles during the satellite pass. The mobile base station carrier was detected by the satellite and is shown in Fig. 17, where the carrier was on at satellite elevations of 50° and 30°, and turned off at 45° and 20°. The satellite Rx noise level was confirmed to be approximately –137 dBm within the 2.5 kHz receiver channel bandwidth. This noise level was sufficient to easily detect a 500 mW LMS transmitter.

FIGURE 17

Received power at space vehicle

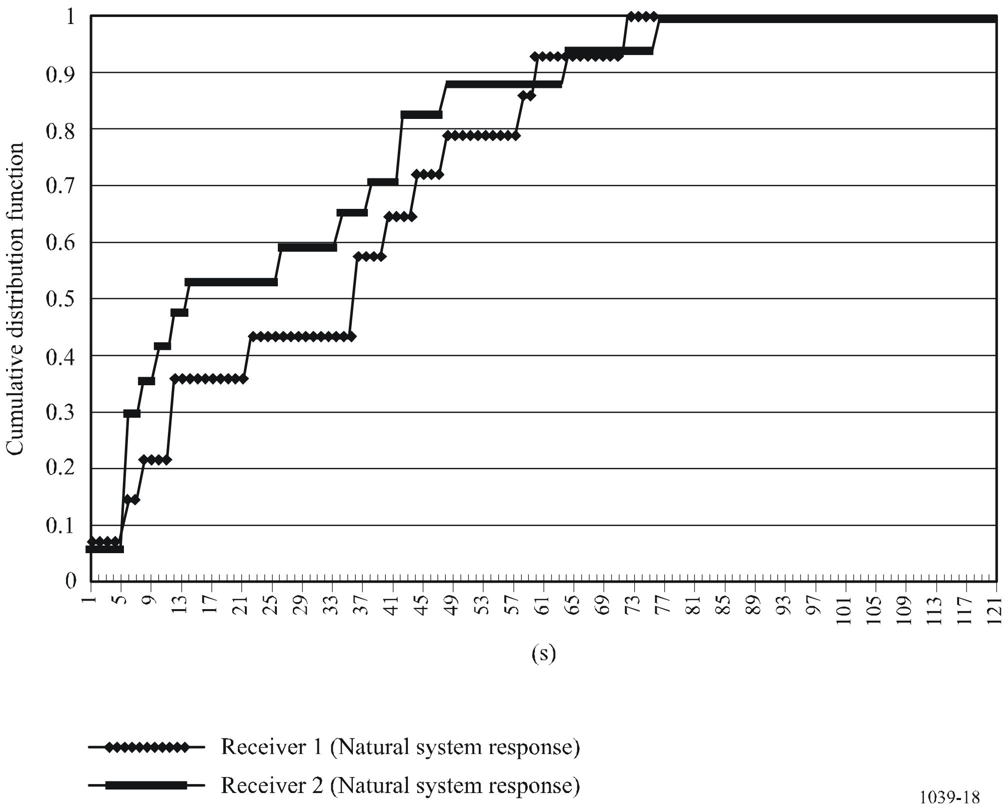


5.2.2 DCAAS testing

During the DCAAS testing the DTS was first configured to monitor the switching of the assigned uplink channels, where the actual spectrum occupancy controlled the DCAAS switching. This is shown in Fig. 18 where the cumulative distribution for the switching of receive channels 1 and 2 showed 60% of the time the channel switching occurred after 30 s. The next test simulated an interfering land mobile transmitter or high noise power interferer occurring into the assigned receiver channel on the satellite. This so-called stress test of DCAAS occurs by setting up the DTS to receive the assigned uplink channel information from DCAAS, much like an MES however instead of sending acquisition transmissions the DTS generated a random noise signal on that channel.

FIGURE 18

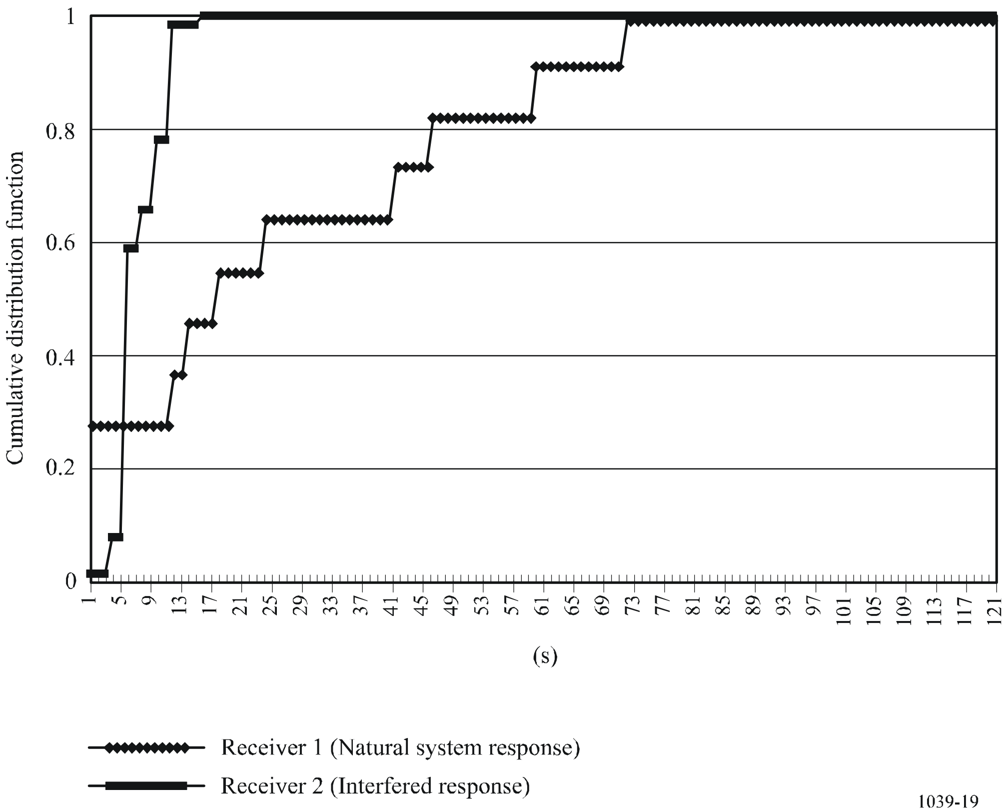
Distribution of selected channel durations



The tests verified that DCAAS would switch the assigned receiving channel after a single scan, (approximately 6 s) 60% of the time, and after 2 scans (approximately 12 s) over 90% of the time, see Fig. 19.

FIGURE 19

Distribution of selected channel durations



5.2.3 Interference into land mobile systems

The interference tests with the land mobile systems consisted of configuring the DTS to simulate MES data burst transmissions of 3 ms, 50 ms, 100 ms, and 450 ms. The power of these transmissions could be varied from 10-30 dBm. The following results were observed:

– co-channel MES transmission bursts do not open the tone squelch on land mobile receivers;

– co-channel MES transmissions of 3.3 ms data bursts are too short to open the mobile receiver carrier squelch or interfere with conversations in progress;

– mobile receivers with carrier squelch will observe squelch breaks if an MES transmits longer co-channel data bursts (50 ms) within approximately 25 km, depending on terrain blockage and the sensitivity of the mobile receiver, which is consistent with the expected coordination distances assumed in other sections of this Recommendation;

– it was noted that the actual impact of the DTS transmissions into land mobile calls would occur when calls are in progress. In these tests the DTS bursts were perceptible for 50 ms and 100 ms co-channel MES data bursts, and breaks in the received message will occur for 450-500 ms data bursts. It was observed that the degree of subjective effect of the DTS bursts is a function of the wanted carrier to interference (*C*/*I*), which is directly related to the distance of the mobile receiver from the MES relative to the distance from the land mobile transmitter. The probability distribution is described in other sections of this Recommendation.