RECOMMENDATION ITU-R M.1039-1

CO-FREQUENCY SHARING BETWEEN STATIONS IN THE MOBILE SERVICE BELOW 1 GHz AND FDMA NON-GEOSTATIONARY-SATELLITE ORBIT (NON-GSO) MOBILE EARTH STATIONS

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

(1994-1997)

Summary

In this Recommendation, a statistical calculation method is recommended to be used to evaluate sharing between MESs using FDMA and stations in the mobile service. A dynamic channel assignment technique is described in order to facilitate the sharing.

The ITU Radiocommunication Assembly,

considering

a) that the spectrum allocated by the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) 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), to a large community of travellers.

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 channelisation 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 mobile-satellite services;

f) that the users would operate throughout large geographic areas;

g) that the transmission of the MES are short bursts,

recommends

1 that the statistical calculation methods described in Annex 1 be used to evaluate sharing between mobile earth stations in the MSS using FDMA techniques and mobile services in the same frequency band;

2 that types of dynamic channel assignment techniques such as that described in Annex 2 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

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 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 can not 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) in the VHF frequency band a reference link model is given. Further study is required to evaluate an appropriate propagation model for other frequency bands below 1 GHz.

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

$$E = \frac{88\sqrt{P}}{\lambda\, d^2}\, h_t\, h_r \qquad (\mu\text{V/m})$$

where:

P : transmitted power (W)

h_t : transmitting antenna height (m)

h_r : receiving antenna height (m)

d : separation (km)

λ : wavelength (m).

Converting this expression from a field strength to a power flux-density from that transmitter incident at a distance d:

$$pfd(d) = \frac{\left(E \times 10^{-6}\right)^2}{120\,\pi}$$

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 m should be used. This accounts for the fact that LEO MSS transmitters are likely to be hand held 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:

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

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 realisable 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 $P_a(n)$.

The aggregate pfd incident at a mobile service receiver from a number of MES transmitters of equal power at a given distance can be expressed as:

$$pfd_t(d) = \frac{\left(88 \, \frac{\sqrt{e.i.r.p._{mes} \cdot N_t}}{\lambda \, d^2} \, h_t \, h_r \, \times 10^{-6} \right)^2}{120 \, \pi}$$

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:

$$P_s\left(d_i\right) = \frac{d_i}{norm}$$

with:

$$norm = \sum_{0}^{N_i} d_i$$

where:

N_i : total number of samples

d_i : discrete values of separation distance.

N_i should be selected such that $d_{max} / N_i \leq 0.5$ km to ensure adequate resolution in the model.

Filter isolation with respect to a MES transmission at the mobile station receivers must be calculated for 2.5 kHz offsets, at least from 0 to 12.5 kHz.

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 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 the following equation:

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

where:

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

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.

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

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.

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

APPENDIX 1

TO ANNEX 1

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.

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:

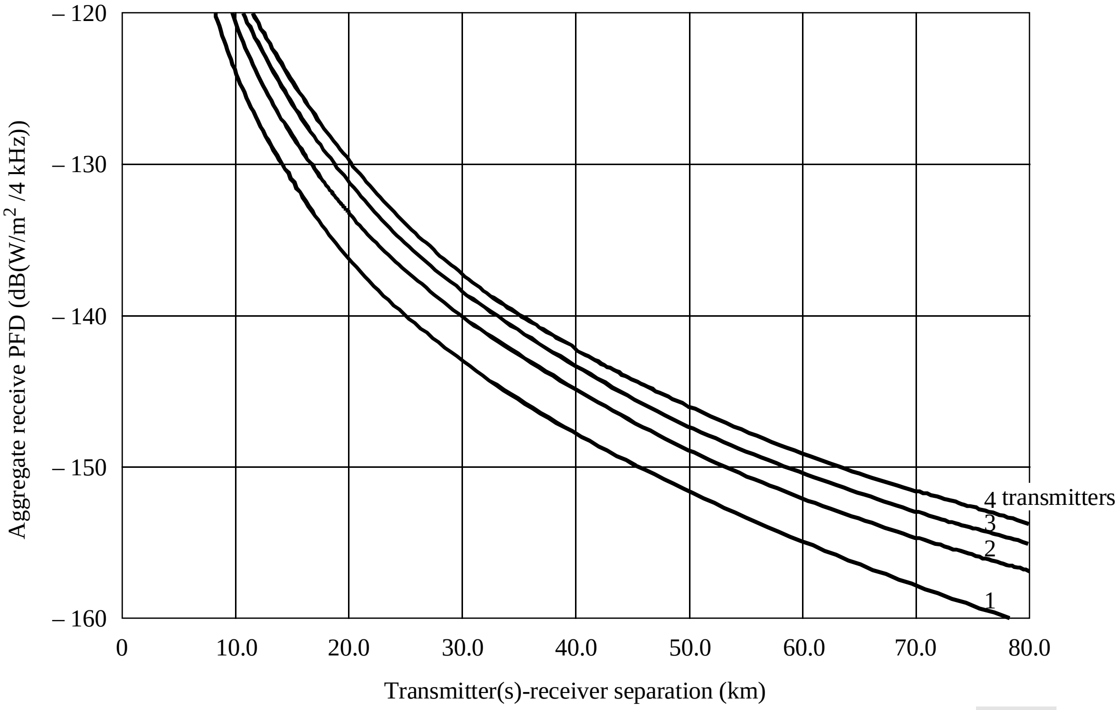
Separation (kHz)	Isolation (dB)
0	0
2.5	0
5.0	0
7.5	2
10.0	8
12.5	23

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 § 5 of Annex 1. Figure 1 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 1.

FIGURE 1

PFD as a function of distance



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From Fig. 1, a protection criteria of – 140 dB(W/m^2/4 kHz) would be exceeded by:

– one transmitter at a range of 25 km;

– two transmitters at a range of 30 km;

– three transmitters at a range of 33 km;

– four transmitters at a range of 35 km.

Thus the coordination contour would be defined as 35 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 § 6-9 of Annex 1.

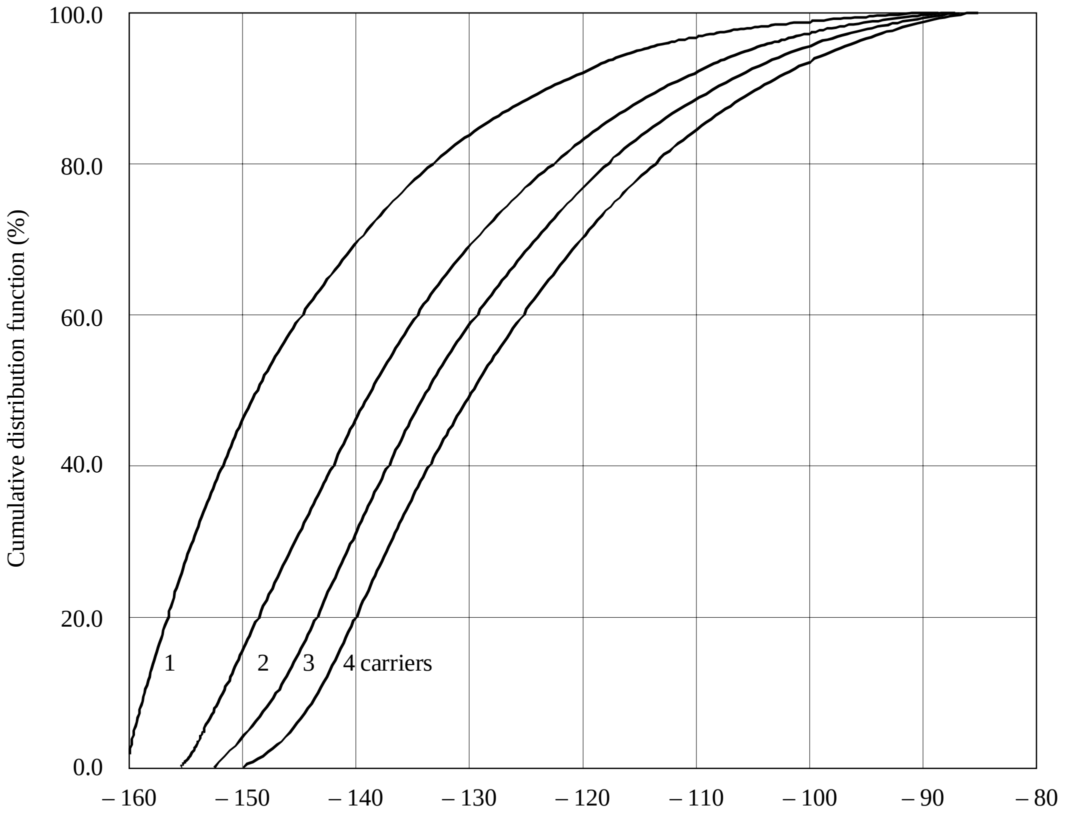
3 PFD distributions

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. 2 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 – 160 dB(W/m^2/4 kHz). Note that the results are shown as cumulative distribution functions.

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.

FIGURE 2

Interference power distribution



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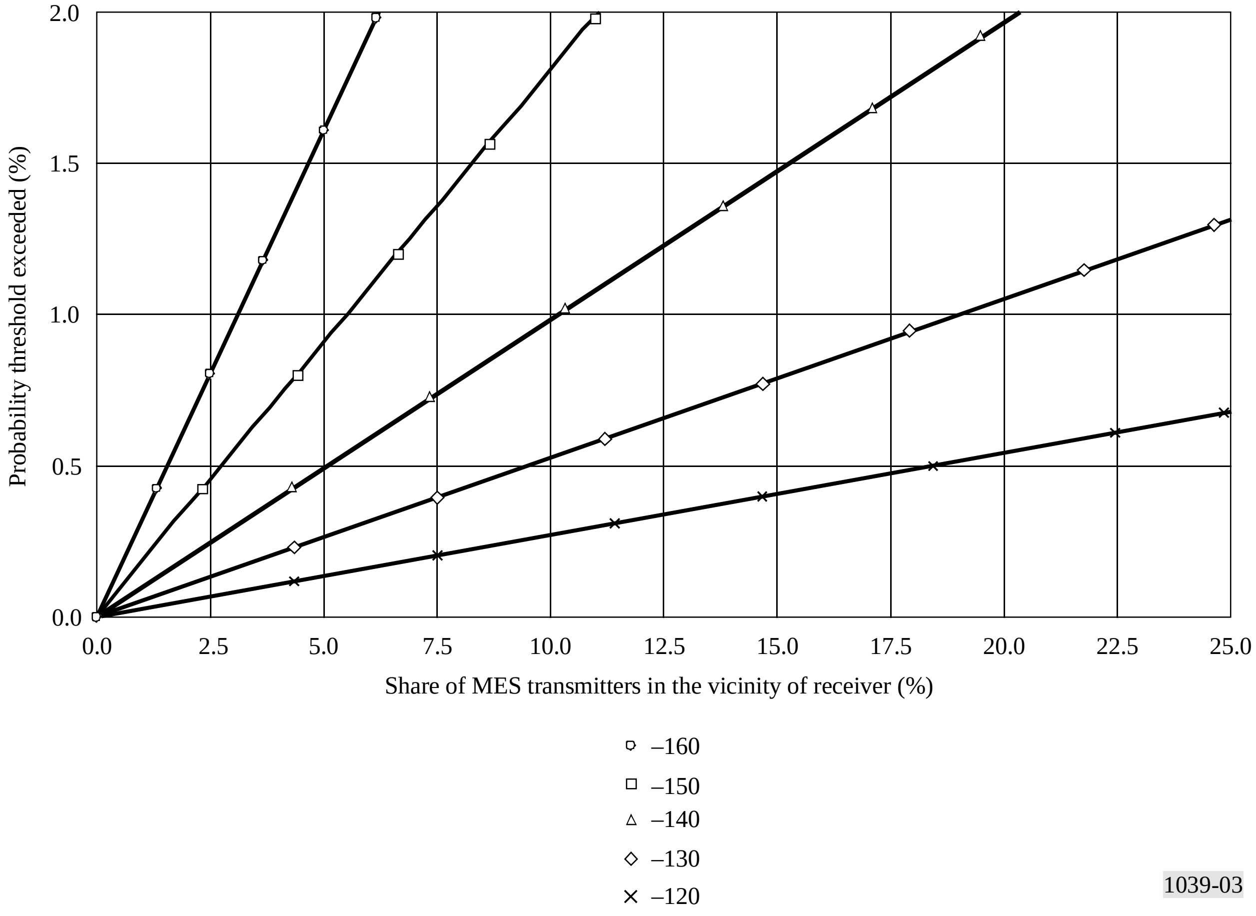
4 Interference probability

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 3 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), 20% of the total population of mobile earth stations would have to be within 80 km of the receiver before the probability of interference would exceed 1%.

FIGURE 3

Interference possibility



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ANNEX 2

Dynamic channel assignment technique

1 Introduction

Mobile satellite systems below 1 GHz can use a technique called dynamic channel activity assignment system (DCAAS) to allow mobile earth stations to communicate effectively in the presence of nearly co-channel uplink interference from mobile transmitters. The technique allows the MSS uplink channels to be re-assigned (of the order of every 10 s) in response to statistical time variation of channel use by mobile transmitters.

The dynamic channel assignment algorithm begins with a scan of the entire uplink band by the satellite using a step size and measurement bandwidth typically equal to the modulation bandwidth of the LEO MSS uplink carrier. The instantaneous power level as seen at the satellite in each potential channel is recorded. This set of measurements is combined with past measurements in a weighted time average for each potential channel. This weighted average takes into account the short and long-term statistics of talker and calling activity. The channels are then ranked from most to least desirable in terms of the potential for interference.

Each satellite periodically updates the list of channels to be used by the mobile earth stations. A list containing a portion of the channels found to be usable is transmitted to the MESs. A MES chooses from this list when initiating an uplink transaction. Control of the remaining usable channels is retained by the system to be used in channel assignments to MESs.

2 Description of DCAAS implementation

Basically each satellite of the non-GSO MSS constellation is monitoring the band 148-149.9 MHz. In the case of a particular constellation, it is scanning the band at 5 s increments on a continuous basis. The system described below has now been implemented on the network LEOTELCOM-1 (ORBCOMM) network in the MSS allocation at 148-149.9 MHz.

The heart of the 148-149.9 MHz uplink interference avoidance technique is the DCAAS.

This system is based on a scanning receiver capable of measuring the interference power across the entire band, in small bandwidth increments, every 5 s or less. This interference information is processed on board the satellite to yield a list of the best uplink channels, prioritized in terms of interference power expected in the channel on the next scan. The channels selected by DCAAS are picked from a stored set of possible uplink channels maintained in the satellite according to the prioritized list. Each satellite will contain a different list of possible uplink channels, avoiding satellite-to-satellite uplink interference situations within the system. In actual operation with the first two satellites, the DCAAS system has been able to predict which channels will be interference free on the next band scan with an accuracy of better than 98%.

3 Technical description

This section provides a technical description of the characteristics associated with the DCAAS technique.

The system uses a channel plan with 2.5 kHz spacing, compared to the mobile services grid used in the United States of America and many other countries, which have transmitters and receivers spaced on 25 kHz centres. The channels labelled “0” and “10”, in Fig. 4, represent channels on the United States mobile grid. The curve shows the probability of a channel being assigned for use by a user transmission. The figure shows that over the period of 1993, the DCAAS would not have selected a frequency directly on the 25 kHz mobile grid.

3.1 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.

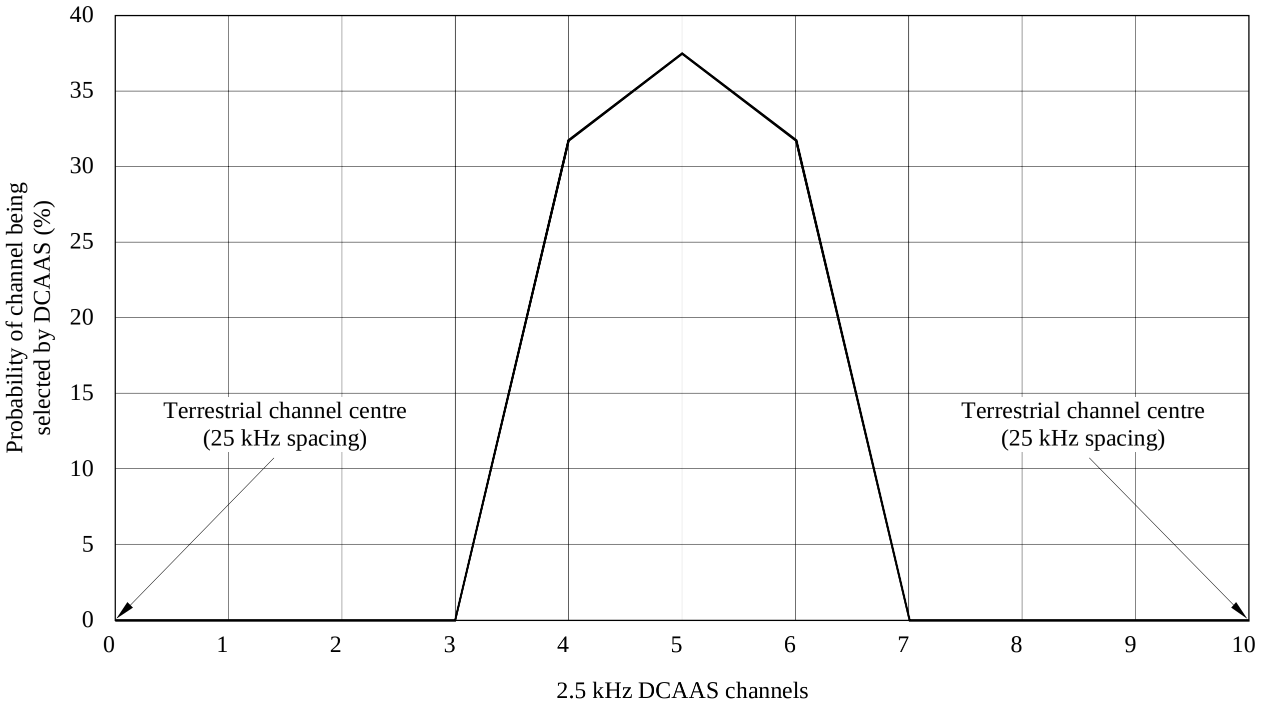
Once recognized within the system, the subscriber may transmit either a single communication packet of 15 bytes or a request to transmit a longer message.

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, or 108 bytes at 2 400 bit/s, 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.

FIGURE 4

Frequency selections made by DCAAS



Based on simulations using a full year of frequency occupancy data collected from CDS satellite

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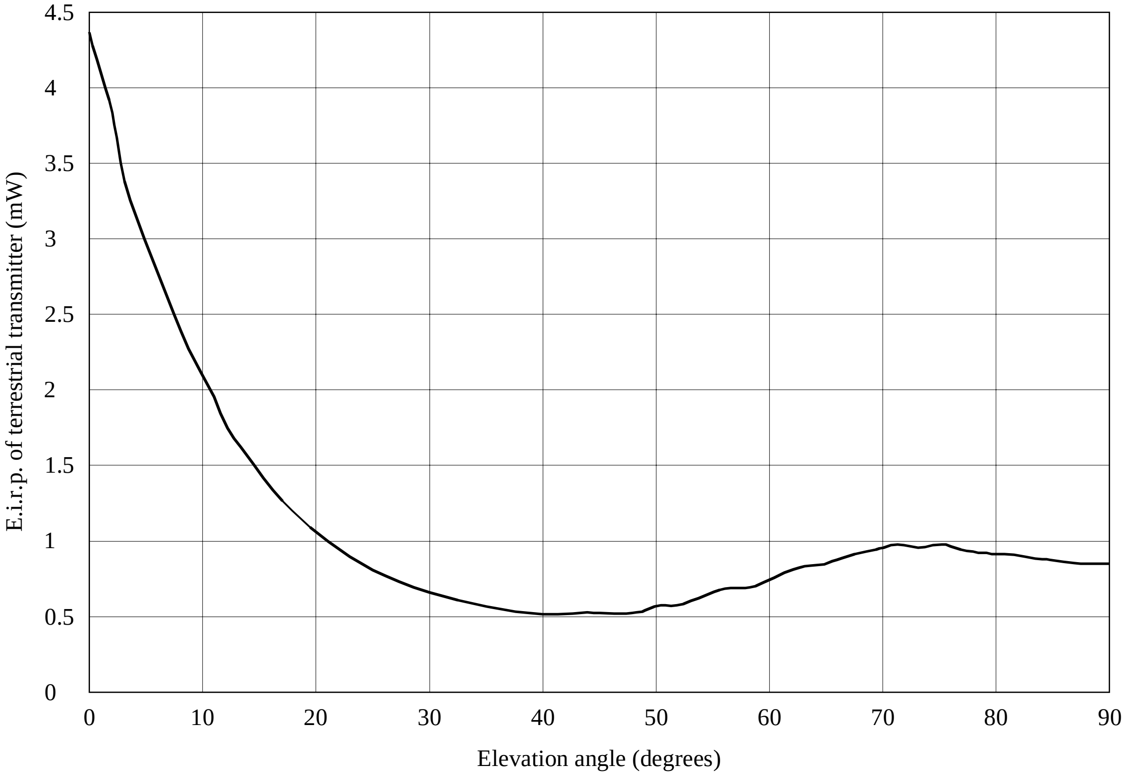
3.2 DCAAS sensitivity

The receivers on the satellites have a noise floor of – 137 dBm in a 2.5 kHz bandwidth. This comes about from the 2 dB receiver noise figure, the 1.6 dB loss between the antenna and the receiver, a near omni-directional antenna gain and a 480 K antenna temperature. The DCAAS process will detect, and can avoid, any terrestrial transmitter signal that is received more than 1 to 2 dB above this level. The terrestrial transmitter effective isotropically radiated power (e.i.r.p.) required to be received at – 135 dBm at the satellite is a function of the satellite elevation angle (see Fig. 5).

FIGURE 5

Terrestrial transmitter e.i.r.p. “seen” and avoided by ORBCOMM DCAAS system



E.i.r.p. needed to generate a signal level of – 135 dBm
in DCAAS receiver (2.5 kHz receive filter)

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As shown in Fig. 6, the DCAAS system can sense terrestrial transmitters with powers on the order of 1 to 5 mW depending on the relative position of the satellite and the terrestrial transmitter. Terrestrial transmission on the order of 5 to 10 mW should always be detected and avoided.

4 Avoidance of interference

A non-GSO MSS system using the DCAAS technique now has two satellites of its constellation in orbit. These have been carrying out developmental testing to determine that the DCAAS system is working as expected.

In many countries the principal occupants of the 148-149.9 MHz frequency band are government terrestrial mobile systems. The DCAAS is specifically designed to avoid occupied channels within the 148-149.9 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 7 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 band. The satellites gathered data for approximately two years from altitudes of 750 km.

FIGURE 6

Typical CDS scan

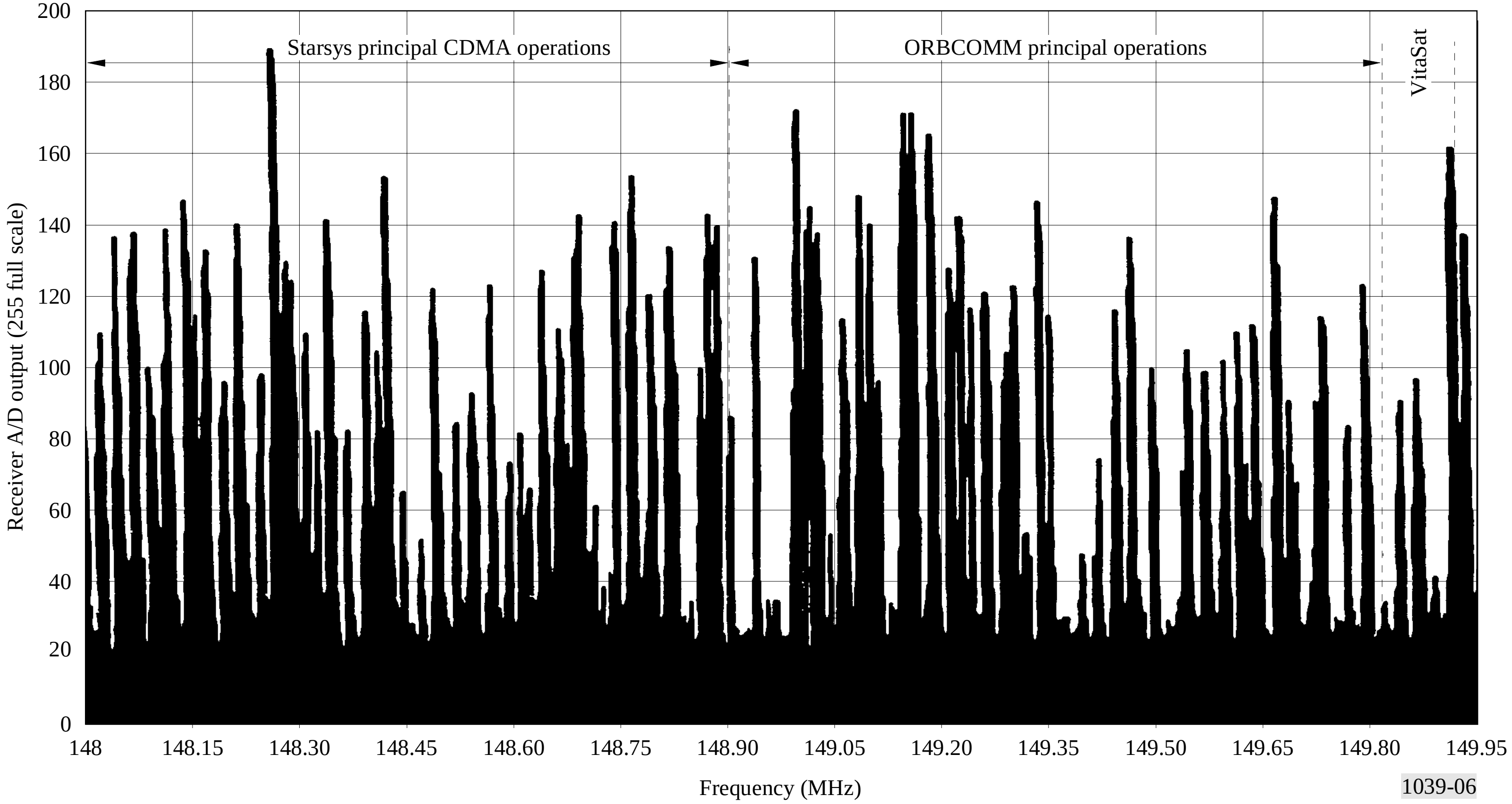
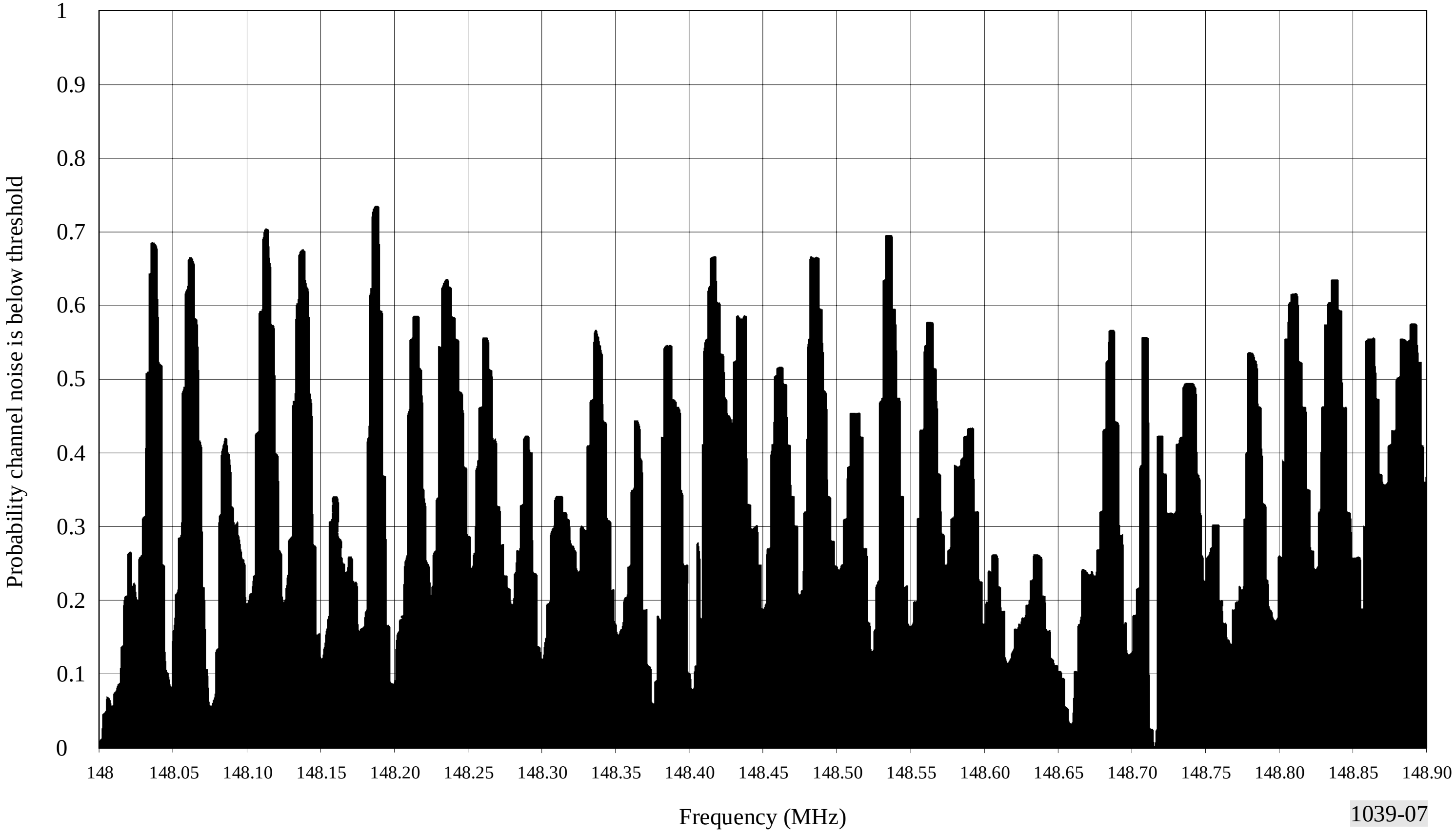


FIGURE 7

Probability of interference-free channels



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5 Summary

The DCAAS is a technique which optimizes the ability of non-GSO-MSS systems operating on frequencies below 1 GHz to operate co-frequency with terrestrial services such as fixed and mobile. It demonstrates that FM type non-GSO MSS systems in the band 148-149.9 MHz which utilize this technique can optimally share co-frequency with the other primary services in the band, to the extent allowed by usage congestion and probability of interference free-channels similar to the one shown in Fig. 7.