RECOMMENDATION ITU-R SA.1158-3*

Feasibility of frequency sharing in the 1 670-1 710 MHz band between the meteorological-satellite service (space-to-Earth) and the mobile-satellite service (Earth-to-space)

(Question ITU-R 204/7)

(1995-1997-1999-2003)

The ITU Radiocommunication Assembly,

considering

a) that the World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (Malaga-Torremolinos, 1992) (WARC-92) has allocated the 1 675-1 710 MHz band on a primary basis in Region 2 to the mobile-satellite service (MSS) (Earth-to-space) and maintained the primary status of the meteorological-satellite (MetSat service) service (space-to-Earth);

b) that each of these two services may be provided by GSO satellite systems and non-GSO satellite systems;

c) that MetSat operators have agreed to separate the band 1 670-1 710 MHz into four sub-bands which are being used and are expected to continue to be used as follows:

1 670-1 683 MHz:	main earth stations at fixed locations for reception of raw image data, data collection data and spacecraft telemetry from GSO meteorological satellites;
1 683-1 690 MHz:	main earth stations at fixed locations for reception of raw image data, data collection and spacecraft telemetry from GSO meteorological satellites; user stations for direct readout from GSO meteorological satellites (GVAR and S-VISSR) (see Note 1);
1 690-1 698 MHz:	user stations for direct readout services from GSO meteorological satellites;
1 698-1 710 MHz:	user stations for direct readout services and prerecorded image data at main earth stations from non-GSO meteorological satellites;

d) that the 1 670-1 690 MHz band is and will continue to be used primarily but not exclusively by a limited number of main meteorological earth stations (command and data acquisition (CDA)) and the 1 683-1 690 MHz part of the band is and will continue to be used also by direct readout user stations (GVAR and S-VISSR);

e) that the portion 1 670-1 675 MHz of the band is used by very few main MetSat earth stations;

f) that there exist thousands of MetSat earth stations in the 1 690-1 710 MHz band, many of them using small antennas;

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[*] This Recommendation should be brought to the attention of the World Meteorological Organization (WMO) and Radiocommunication Study Group 8 (WP 8D).

g) that for different functions provided by the MetSat service, meteorological earth stations in the 1 690-1 710 MHz band and in the 1 683-1 690 MHz band can be fixed, mobile or transportable;

h) that Recommendation ITU-R SA.1027 provides sharing criteria for current MetSat systems using satellites in low-Earth orbit (LEO);

j) that Recommendation ITU-R SA.1161 provides sharing criteria for current MetSat systems using GSO satellites;

k) that MSS earth station transmitters are expected to be deployed near or within a MetSat service area;

l) that some operators of meteorological satellites plan to increase the channel bandwidths and revise the frequency assignment plans for new MetSat generations, which would make interleaving of meteorological and mobile-satellite channels impracticable;

m) that GSO MetSat space stations, which initially serve a certain area, may be relocated from time to time in order to provide coverage of another area;

n) that Annexes 1, 2, 3 and 4 provide a view pertaining to the technical sharing aspects of the MetSat and MSS services operating in the 1 670-1 710 MHz band;

o) that mobile-satellite techniques are either available or may be able to be developed to automatically and dynamically avoid transmissions from earth stations in the vicinity of receiving MetSat earth stations and that such techniques are described in Annex 3,

recognizing

1 that No. 5.377 of the Radio Regulations (RR) states that, in the band 1 675-1 710 MHz, stations in the MSS shall not cause harmful interference to, nor constrain the development of, the MetSat and meteorological aids services and that the use of this band shall be subject to coordination under RR No. 9.11A;

2 that studies (see Annex 1) have indicated that potential interference to meteorological earth stations from co-frequency MSS earth stations would be acceptable when the meteorological earth stations are protected by exclusion zones with radii of up to several hundred kilometres and appropriate technical measures are employed to avoid transmissions by mobile earth stations within the respective exclusion zones;

3 that the control of the mobile earth stations (MES) could be achieved with a location determination system forming part of the mobile-satellite system; this location determination may require a narrow-band signalling channel transmitted from the MES to the mobile satellite;

4 that studies indicate that interference from mobile-satellite service (MSS) earth station emissions in the band 1 670-1 675 MHz to meteorological earth stations would be acceptable with limited restrictions on MSS operations;

5 that studies conclude the complex challenge of MSS sharing in the band 1 683-1 690 MHz with the increasing number of GVAR and S-VISSR stations (see Note 1), especially transportable and future stations, would be extremely difficult;

6 that sharing in the band 1 690-1 710 MHz would not be feasible in view of the large number of MetSat earth stations, their generally unknown locations and the increasing use of the service, *recommends*

1 that MES possibly operating in part of the 1 670-1 690 MHz band do not transmit, except on a narrow-band signalling channel, inside the exclusion zones around main meteorological earth stations (CDA and primary data users station (PDUS)), taking into consideration the radii identified in *recognizing* 2, increased by the precision (km) of the position determination system referred to in *recognizing* 3 (see Note 2);

2 that mobile-satellite systems be equipped with demonstrated location determination capability, permitting the determination of the position of the mobile earth stations, in order to assure compliance with *recommends* 1;

3 that the narrow-band signalling channel, which may be required worldwide by certain location determination systems, be assigned in agreement with the meteorological operators concerned;

4 that the MSS could share the band 1 670-1 675 MHz with the MetSat service based on minor restrictions to ensure no worldwide impact on MetSat operations in the band 1 670-1 710 MHz.

NOTE 1 – GOES stands for geostationary operational environmental satellite; GVAR stands for GOES variable; VISSR stands for visual and infrared spin scan radiometer; S-VISSR stands for stretched VISSR;

NOTE 2 – The WMO is invited to inform the ITU, at regular intervals, of the geographical position of main meteorological earth stations.

Annex 1

Sharing analysis between the MetSat service and the MSS in the frequency bands 1 670-1 675 MHz and 1 683-1 690 MHz

1 Introduction

The ITU-R conducted an extensive series of studies regarding the potential sharing situation between the MSS and the MetSat service in the band 1 683-1 690 MHz or in the vicinity of this band. The band 1 683-1 690 MHz is mainly used by three different types of meteorological earth stations. While there are only a limited number of main MetSat earth stations deployed in all three ITU Regions, there are a large number of meteorological earth stations operated in Regions 2 and 3 and the locations of many of these stations are unknown. Some of them are also mobile (on ships and trucks) or transportable. During WRC-2000, it was also acknowledged that there is an increase in use of these stations in Regions 2 and 3 and that potential MSS operation should not constrain current and future development of the MetSat service as specified in RR No. 5.377.

Regarding meteorological earth stations, main stations with antenna diameters up to 15 m as well as data user stations such as GVAR and S-VISSR are operating in the band 1 683-1 690 MHz. Only a limited number of main stations operates in the band 1 670-1 675 MHz. Sharing and interference criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and MestSat services have been established in a number of ITU-R Recommendations. RR Appendix 7 and Recommendation ITU-R SA.1160 can be used for reference.

Recommendation ITU-R M.1184 provides information on mobile-satellite system characteristics to be used in sharing studies with other primary services in the range 1-3 GHz. As the interference to the MetSat stations is primarily determined by the amount of energy radiated towards the horizon and the troposphere, some degree of antenna discrimination will occur. Unless the MSS terminal actually operates at low elevation angles, the overall effect will be very similar to the systems using omnidirectional antennas. It has therefore been assumed that the mobile terminals operate in a way which results in very low gain around 0 dBi towards the horizon.

In view of the enormous differences that can arise from considering best and worst cases, it has been agreed between the relevant Radiocommunication Working Parties to use MSS, MetSat and shielding characteristics which disregard best and worst cases but consider a more representative typical sharing situation with some deviations to favourable and unfavourable sharing situations.

The required separation distances are to a significant extent a function of the elevation angle and terrain shielding. The elevation angle ranges between 3° and 90° for stations receiving data from GSO satellites. Main stations will not operate at elevation angles of less than 5°. Shielding for main stations is in general quite good because of typical deployment in remote locations. However, user stations are often deployed on top of buildings with an unobstructed view of the surroundings.

2 System characteristics assumed for the analyses

The characteristics shown in Table 1 have been adopted to represent a range of MSS and MetSat systems. The parameter values have been chosen to represent favourable, typical and unfavourable sharing conditions, and do not necessarily represent the best-case or worst-case conditions.

TABLE 1

System parameters used in sharing studies between the MetSat service and the MSS

	Favourable sharing case	**Typical sharing, Case 1**	**Typical sharing, Case 2**	**Unfavourable sharing case**
MSS characteristics				
Maximum e.i.r.p. per channel (dBW)	3.5	21	17	10.9
Maximum antenna gain (dBi)	0	16.5	10	Not applicable
Channel data rate (kbit/s)	23.4	732	5.6	4.5
Allocated bandwidth (channel spacing) (kHz)	31.24	200	12.5	6
Average antenna gain towards horizon (dBi)	1	0	0	0
Average e.i.r.p. towards horizon (dBW)	3.5	4.5	7	6.9
Average e.i.r.p. density towards horizon (dB(W/4 kHz))	–5.4	–12.5	2.1	5.1
Antenna height of MES above ground level (m)	2	2	2	10

TABLE 1 (*end*)

	Favour-able sharing case	**Typical sharing, Case 1**	**Typical sharing, Case 2**	**Unfavourable sharing case**
MSS characteristics (Cont.)				
Average obstacle height in vicinity of MES (m)	90	50	50	10
Distance of obstacle to MES (km)	10	10	10	5
Satellite beamwidth (degrees)	0.7	1.5	7	2
Percentage of transmitting MES (%)	60	75	75	90
Polarization discrimination (dB)	3	3	3	3
MetSat characteristics for main stations				
Antenna diameter (m)	15	15		15
Antenna centre height above ground level (m)	15	20		25
Minimum antenna elevation angle (degrees)	20	15		10
Permissible long-term interference level (20%) (dB(W/4 kHz))	–182	–182		–182
Permissible short-term interference level (dB(W/4 kHz))	–178	–178		–178
Percentage of time for short-term interference(1) (%)	0.011	0.011		0.011
Receiver bandwidth (kHz)	5 200	5 200		30
Obstacle height in vicinity of main station (m)	200	150		25
Distance of obstacle to main station (km)	10	10		10
Typical radio climatic zone for main station	A2	A2		A1
MetSat characteristics for user stations				
Antenna diameter (m)	3.6	3.6		3.6
Antenna centre height above ground level (m)	5	25		50
Minimum antenna elevation angle (degrees)	20	15		5
Permissible long-term interference level (dB(W/4 kHz))	–180	–180		–180
Permissible short-term interference level (dB(W/4 kHz))	–175.3	–175.3		–175.3
Percentage of time for interference (%)	0.025	0.025		0.025
Receiver bandwidth (kHz)	6 000	4 200		4 200
Obstacle height in vicinity of user station (m)	50	25		0
Distance of obstacle to user station (km)	10	10		Not applicable
Typical radio climatic zone for user station	A2	A1		A1

(1) This percentage applies to the aggregate interference from all MES.

Combinations of the above system assumptions should be considered. For studies addressing adjacent band interference, Recommendation ITU-R SA.1160 shall be taken into account regarding protection criteria for small user stations with antenna diameters between 1.2 and 2.4 m. For out-of-band emissions of MES terminals, Recommendation ITU-R M.1480 shall be referred to.

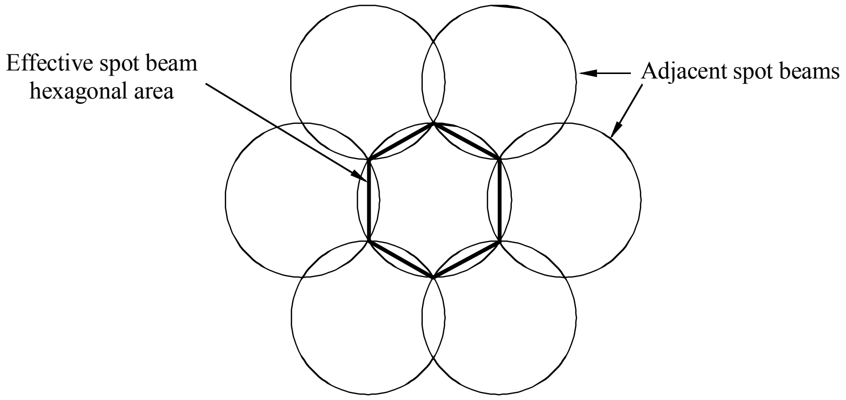
3 Analysis methodology

3.1 MES density

This section presents an analysis where, based on system parameters, a number of operating MESs are considered. Therefore, the MES distribution and density must be calculated for each of the sharing cases. The first step in the analysis is to determine the size of the spot beam projected on the Earth's surface. For simplicity, it will be assumed that the spot beam centreline is perpendicular to the Earth's surface and the surface area within the spot beam is approximately flat. Adjacent spot beams will overlap. To further simplify the analysis, the area of each spot beam will be converted to a regular hexagon. This can be done since either spot beam can service an MES within the overlap area (refer to Fig. 1). For the MES density calculation, the overlap areas may be divided evenly between the overlapping beams.

FIGURE 1

Conversion of circular spot beams to effectively equal hexagonal areas



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The area of the hexagon is given by:

$$A = (h * \tan(\theta / 2)^2 (3\sqrt{3}) / 2$$

where:

h: GSO altitude (km)

θ : spot beamwidth (degrees).

TABLE 2

Effective square area of spot beams on Earth's surface for cases listed in Table 1

Sharing case	Spot beam width (degrees)	Effective area (km^2)	Frequency reuse factor
Favourable Case	0.7	1.25×10^5	7
Typical Case 1	7.0	1.25×10^7	2
Typical Case 2	1.5	5.77×10^5	7
Unfavourable Case	2.0	1.03×10^6	7

The next step is to determine the MES density within the service area under consideration (analysis area). Since the spot beams are smaller or nearly equal to the exclusion zone sizes, the required analysis area is larger than the spot beam footprints. All three sharing cases defined in Table 1 provide the receive antenna beamwidth (satellite beamwidth), the channel spacing (allocated bandwidth) and the system loading factor (percentage of transmitting MES). From these values the transmitting MES density can be calculated. The transmitting MES density can then be used to determine the number of transmitting MES within a chosen analysis area.

The maximum number of available channels for MES that can be co-channel with the MetSat station is calculated by dividing the channel spacing into the MetSat Station bandwidth. Since channels cannot be easily reused between adjacent spot beams, the assumption was made that spot beams reusing channels must be separated by at least one spot beam. Analysis was conducted using a frequency reuse factor of 7.

One further consideration is that each sharing case has a load factor specified. Therefore, the total number of available channels per spot beam should be reduced by the load factor to provide the actual number of MES operating at any time within a spot beam.

The number of operating MESs using frequencies within a single spot beam can be calculated from:

$$n = (1/F) * (BW_{metsat} / S_{stm}) * L$$

where:

F: frequency reuse factor

n: number of transmitting MESs per spot beam

BW_{metsat}: bandwidth of the MetSat receiver

S_{mes}: MES channel spacing

L: MSS system load factor.

The transmitting MES average density is calculated by dividing the number of transmitting MES per spot beam by the spot beam area:

$$D = n / A$$

where:

D: transmitting MES density (MES/km^2)

n: number of transmitting MES per spot beam

A: area of spot beam (effective square) (km^2).

TABLE 3

Transmitting MES density for cases listed in Table 1

MSS system	**Number of transmitting MES: *n*** (favourable-typical-unfavourable main station)	**Average transmitting MES density: *D* (MES/10^6 km^2)**	**Number of transmitting MES: *n*** (favourable-typical-unfavourable user station)	**Average transmitting MES density: *D* (MES/10^6 km^2)**
MSS favourable	14.3/17.8/0.12	114/142/9.83	16.5/14.4/17.3	131/115/138
MSS typical 1	2.23/2.79/0.02	3.86/4.83/0.033	2.57/2.25/2.7	4.46/3.9/4.68
MSS typical 2	125/156/1.08	9.91/12.4/0.08	144/126/151	11.4/10/12
MSS unfavourable	74/93/0.64	72/91/109	86/75/90	83.6/73.1/87.7

3.2 MetSat station horizon antenna gain

For determination of the interference from an aggregation of MESs, it is appropriate to use an antenna gain pattern which is representative of the average side-lobe level. In order to compensate for the fact that the pattern in RR Appendix 7 is likely to overestimate the average gain of the meteorological antenna towards a potentially large number of interferers, it is considered that a combination between the pattern given in Recommendation ITU-R F.1245 and RR Appendix 7 would be more appropriate. For the MetSat stations the antenna pattern using both Recommendations ITU-R F.699 (RR Appendices 7 and 8) and ITU-R F.1245 are used. For each value of off-axis angle, the gain is taken as the average of the values given by Recommendations ITU-R F.699 and ITU-R F.1245. A single value of horizon antenna gain can be determined by taking into account the MetSat earth station elevation angle and azimuth angle. For each azimuth angle, the average horizon antenna gain is determined using the side-lobe patterns described above. Each value of horizon antenna gain (dBi) is converted to a linear power ratio and the average value determined.

The antenna gain specified in Recommendation ITU-R F.699, as well as RR Appendix 7 (and RR Appendix 8), for a ratio between the antenna diameter and the wavelength of less than or equal to 100, is determined by the following equation:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \qquad \text{for} \quad 0 < \varphi < \varphi_m$$

$$G(\varphi) = G_1 \qquad \text{for} \quad \varphi_m \leq \varphi < 100\frac{\lambda}{D}$$

$$G(\varphi) = 52 - 10\log\frac{D}{\lambda} - 25\log\varphi \qquad \text{for} \quad 100\frac{\lambda}{D} \leq \varphi < 48^\circ$$

$$G(\varphi) = 10 - 10\log\frac{D}{\lambda} \qquad \text{for} \quad 48^\circ \leq \varphi \leq 180^\circ$$

where:

G_{max}: maximum antenna gain (dBi)

$G(\varphi)$: gain (dBi) relative to an isotropic antenna

φ: off-axis angle (degrees)

D: antenna diameter

λ: wavelength

$\left.\begin{matrix} D \\ \lambda \end{matrix}\right\}$ expressed in the same unit

G_1: gain of the first side lobe = $2 + 15 \log (D/\lambda)$

$$\varphi_m = \frac{20\,\lambda}{D}\sqrt{G_{max} - G_1} \qquad \text{degrees}$$

$$\varphi_r = 12.02\ (D/\lambda)^{-0.6} \qquad \text{degrees}$$

In cases where the ratio between the antenna diameter and the wavelength is less than or equal to 100, the following equation is given by Recommendation ITU-R F.1245:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \qquad \text{for} \quad 0 \leq \varphi < \varphi_m$$

$$G(\varphi) = 39 - 5\log(D/\lambda) - 25\log\varphi \qquad \text{for} \quad \varphi_m \leq \varphi < 48°$$

$$G(\varphi) = -3 - 5\log(D/\lambda) \qquad \text{for} \quad 48° \leq \varphi < 148°$$

For each value of off-axis angle, the gain is taken as the average of the values given by Recommendations ITU-R F.699 and ITU-R F.1245 in linear terms.

A single value of horizon antenna gain is determined by the following steps.

Step 1: Taking into account the MetSat earth station elevation angle, the off-axis angle for each azimuth angle around the MetSat earth station is determined.

Step 2: For each azimuth angle, the average horizon antenna gain is determined using the side-lobe patterns described above.

Step 3: Each value of horizon antenna gain (dBi) is converted to a linear power ratio and the average value determined.

The effective gain used in the calculations is then half of the linear sum of both components. Table 4 shows the results for the various elevation angles used in the calculations.

TABLE 4

Average mean antenna gain for meteorological stations

Elevation angle	**Meteorological main station (dBi)**	**Meteorological user station (dBi)**
5° (unfavourable case for user stations)	(–0.3)	5.1
10° (unfavourable case for main stations)	–4.6	(0.9)
15° (typical case)	–6.8	–1.3
20° (favourable case)	–8.1	–2.7

It is also advisable to take into account the actual antenna gain towards the tropospheric scatter medium. Recommendation ITU-R P.452 was originally developed for coordination of fixed service links where the elevation of the antenna was limited to angles close to the horizon and where the antenna gain towards the troposphere was generally decreasing with increasing elevation angle. This is not the situation for antennas with increasing gain towards higher elevation angles. The actual antenna gain of both antennas towards the troposphere should be taken into account and could be estimated as follows: A mean height of the troposphere can be assumed around 5 000 m and the mean elevation angle towards the troposphere is then determined by this height and the middle of the distance between transmitter and receiver. For the MetSat stations, the gain values in Table 4 can be interpolated to derive the mean average gain of the antenna towards the troposphere. The contribution from the MES antenna is generally much less significant because of their usually low gains and high elevation pointing angles.

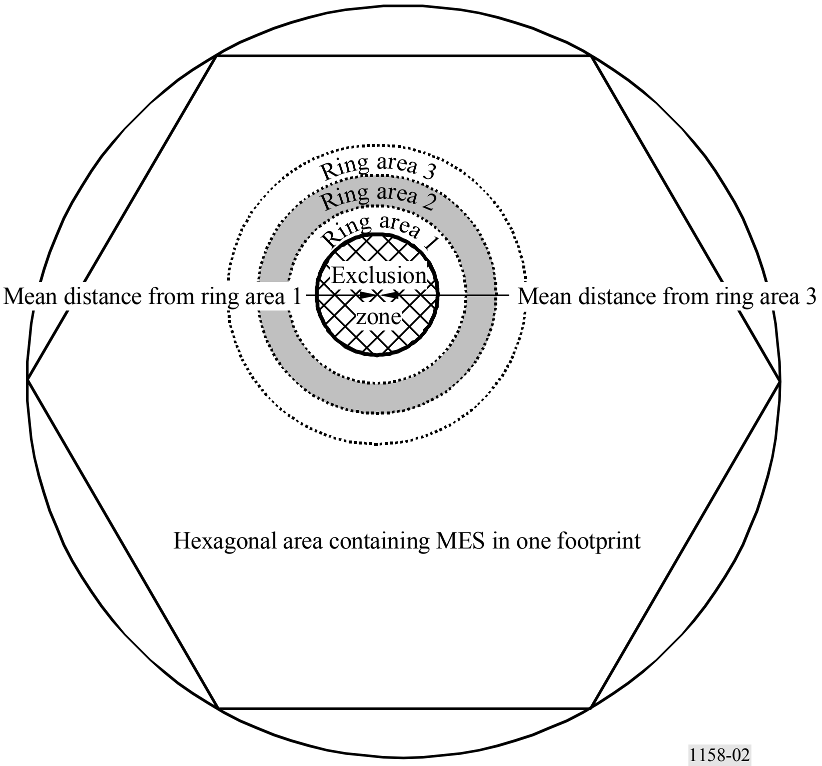
3.3 Analysis areas

In order to model the effects of a number of MES around a MetSat station, an analysis area must be established that is sufficiently large to encompass all the MES locations that could contribute to interference.

An exclusion area is placed around the MetSat earth station at a distance *d*. Three concentric rings are drawn each with outer radius *d* (*n*/2 + 1) where *n* is the ring number.

FIGURE 2

Model for assessment of number of transmitting MES



Within each ring the number of MESs is determined from the area of the ring and the average density. In typical operation, MESs will not be evenly distributed throughout the footprint but will be concentrated in areas of high demand. To account for this, the average number of MESs is multiplied by 1.5. This may not be appropriate for rings 2 and 3, if the exclusion area is a large proportion of the MSS footprint. The interference contribution from each ring is estimated by calculating the path loss to a point midway between the inner and outer radii of each ring and increasing the interference from a single MES by 10 log N_n where N_n is the number of MESs in each ring. Furthermore, to account for the possibility of MESs moving from inside the exclusion area to outside the area, it is assumed that 50% of the average number of MESs in the exclusion area transmit from the boundary. This percentage is reduced to 35% in the case of unfavourable MetSat and shielding situations as the exclusion zone is then significantly increasing.

3.4 Interference calculation

The propagation model is based on an implementation of Recommendation ITU-R P.452 for a latitude of 45°. For the ducting model only one MES shall be taken into account. For transmissions from the edge of the exclusion zone, the minimum number of MES to be taken into account shall be 1. The total aggregate interference within the receiver bandwidth is compared with the permissible interference level, scaled to the receiver bandwidth. The size of the exclusion zone is adjusted until the predicted interference just meets the permissible level.

For cases involving radio-climatic zone A1, it can be assumed that 50% of the propagation path falls within zone A2 in order to avoid a worst-case assumption.

Using the number of MESs within each ring and at the edge of the exclusion zone, and the propagation losses for the associated distances for the exclusion zone edge and the ring mean distance, the cumulative interference from each exclusion zone and ring can be calculated. The formula for the cumulative interference (non-ducting conditions) is:

$$P_i = 10 \log\left(10^{(P_e 10)} + 10^{(P_1/10)} + 10^{(P_2/10)} + 10^{(P_3/10)}\right)$$

where:

P_e: cumulative interference power from the MESs at the edge of the exclusion zone

P_1: cumulative interference power from the MESs in ring 1

P_2: cumulative interference power from the MESs in ring 2

P_3: cumulative interference power from the MESs in ring 3.

The values for P_e are calculated using:

$$P_e = e.i.r.p._{mes} - L_e + G_{metsat} + 10 \log (N_e) - L_{pol}$$

where:

$e.i.r.p._{mes}$: MES e.i.r.p. towards the horizon (from Table 1)

L_e: path loss for distance from MetSat earth station to exclusion zone edge

G_{metsat}: MetSat average antenna gain towards horizon (from Table 4)

N_e: number of MESs operating at exclusion zone edge

L_{pol}: polarization loss (from Table 1).

The values for P_n, under non-ducting conditions, are calculated using the equation below, where n is the ring number (1, 2, or 3):

$$P_n = e.i.r.p._{mes} - L_n + G_{metsat} + 10 \log (N_n) - L_{pol}$$

where:

$e.i.r.p._{mes}$: MES e.i.r.p. towards the horizon (from Table 1)

L_n: path loss for distance from MetSat earth station to ring n mean distance

G_{metsat}: MetSat average antenna gain towards horizon (from Table 4)

N_n: number of MESs operating in ring n

L_{pol}: polarization loss (from Table 1).

The values for interference power, P, under ducting conditions with a single MES, are calculated using the following equation:

$$P = e.i.r.p._{mes} - L_n + G_{metsat} - L_{pol}$$

where:

$e.i.r.p._{mes}$: MES e.i.r.p. towards the horizon (from Table 1)

L_n: path loss for distance from MetSat earth station to the MES (exclusion zone radius)

G_{metsat}: MetSat average antenna gain towards horizon (from Table 4)

L_{pol}: polarization loss (from Table 1).

4 Summary of results

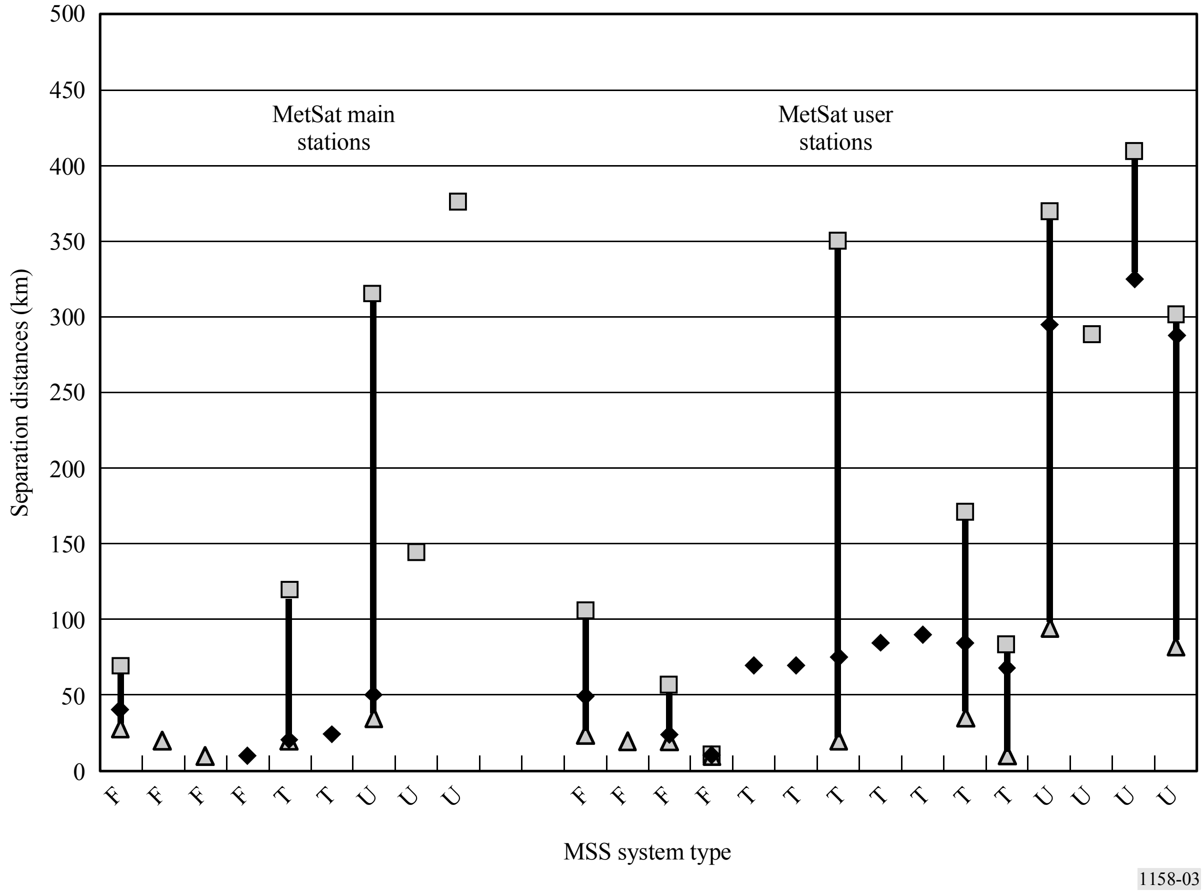
4.1 Summary on separation distances

Figure 3 gives an overview of the separation distances required for MetSat main and user stations obtained from four study contributions to the ITU-R. The lower triangle represents the separation distances for the favourable (F) case and the upper rectangle the separation distances for the unfavourable (U) case. The diamonds in-between are the separation distances for the typical (T) cases.

FIGURE 3

Summary of separation distance calculations for main and user stations

Separation distance ranges for MetSat stations



4.2 Summary on coordination distances

Several contributions have also been received regarding the required coordination distances. RR Appendix 7 contains the methodology and parameters to determine the coordination area for MES with respect to MetSat earth stations. Because the procedures are well established within RR Appendix 7, it is considered sufficient just to summarize the conclusions of the relevant studies. For operation of MSS in the territory of one administration, it would be necessary to coordinate with MetSat stations operated by other administrations if the MetSat earth station is located within the coordination area of the MSS terminals. The coordination area is the service area of the MES extended by the coordination distance. The available study results show that for the most favourable climatic zone, A2, the required coordination distances are often in excess of several hundred kilometres and would cause a significant coordination burden for the MSS. The extent of the coordination burden would depend on the number and location of MetSat stations affected. The problem increases for coastal areas where coordination distances above 1 000 km could be required in a few cases. Also the separation distances could increase beyond the numbers shown above. Coordination would also be required between MSS and MetSat earth stations within the territory of a given administration but would be a domestic rather than an international matter.

5 Conclusions

ITU-R has conducted several studies regarding separation distances required between MSS and MetSat earth stations, considering in particular GVAR/S-VISSR earth stations. The studies have been based on a range of MSS system characteristics and a range of different deployment scenarios of MetSat Main and GVAR/S-VISSR stations. An attempt was made to avoid best and worst-case assumptions by considering system and shielding assumptions ranging from favourable to unfavourable conditions. The studies revealed that shielding conditions had the most significant impact on the required separation distances. The following results were obtained for a range of MSS system parameters where the terms "favourable, typical and unfavourable" refer primarily to the MetSat deployment and shielding conditions. The lower separation distances are mainly due to favourable MSS parameters whereas the higher separation distances are obtained for unfavourable MSS parameters:

TABLE 5

	MetSat main stations: favourable-unfavourable MSS	**GVAR/S-VISSR stations: favourable-unfavourable MSS parameters**
Favourable conditions (km)	< 20-35	20-100
Typical conditions (km)	< 20-45	35-300
Unfavourable conditions (km)	75-320	70-370

At this point in time, GVAR MetSat stations are mostly deployed in many Region 2 countries and S-VISSR MetSat stations are mostly deployed in many Region 3 countries. In Region 1 countries there are a few MetSat GVAR/S-VISSR stations. More than 15 MetSat Main stations are deployed throughout all three Regions. It is expected that the MetSat service will make more extensive use of this band in the future. However, there are also transportable GVAR/S-VISSR stations in Regions 2 and 3. Exclusion zones are required but cannot be practically established around transportable earth stations that may be periodically relocated.

Sharing the band 1 683-1 690 MHz would require the establishment of geographical separation between MSS earth stations and co-frequency MetSat stations. There are currently more than 15 main earth stations operated in all three Regions and more than 400 registered data user stations operated mostly in Regions 2 and 3, with some also in Region 1. The number of registered data user stations is increasing and the actual number of existing stations is expected to be in excess of 1 000. The studies concluded that, even though feasible in some areas of the world, implementation of sharing would be subject to such practical constraints and limitations for the MSS that it should not be considered suitable for providing MSS spectrum on a global basis.

Available studies have concluded that the actual required separation distances are typically 70-105 km, but can be up to 400 km. This would in some cases cause large service areas not being available to the MSS; rendering typical features of this service such as global or regional coverage as well as unrestricted mobility, unavailable without the use of selectable frequency agility. Resolution 227 (CMR-2000) also recognizes that the use of the data user stations is on the increase and given the implications of RR No. 5.377, this would mean an unpredictable risk for any MSS operator to lose service areas in addition to those unavailable today. As an additional system burden, the MES locations would have to be determined with sufficient accuracy to comply with the required separation distances. However, there are current operational MSS systems that implement spot beam configurations (150-300 spot beams), frequency reuse and position determination capabilities. In combination with spectrum availability outside of the band 1 683-1 690 MHz, selectable frequency agility would increase the possibility of sharing this band between the MSS and MetSat service.

In addition to in-band interference in the band 1 683-1 690 MHz, the problem of adjacent band interference to thousands of meteorological earth stations operating in the band 1 690-1 698 MHz requires either a guardband below 1 690 MHz or a limitation of out-of-band emissions. Studies have shown that the out-of-band emission limits contained in Recommendation ITU-R M.1480 (and proposed revisions to this Recommendation), if extended to MESs operating in 1 683-1 690 MHz, could be adequate to protect MetSat earth stations operating above 1 690 MHz. Further study may be required.

Annex 2

TABLE 6

Information on worldwide MetSat systems

MetSat system	Function	Frequency (MHz)	RF bandwidth (MHz)	e.i.r.p. (dBW)
GMS (GSO)	Sensor	1 681.600	20.000	27.0
	S-VISSR	1 687.100	6.000	25.0
	WEFAX1	1 691.000	0.260	17.0
	WEFAX2	1 691.000	0.032	7.0
	Ranging 1	1 684.000	1.000	17.0
	Ranging 2	1 688.200	1.000	–4.5
	Ranging 3	1 690.200	1.000	–4.5
	Data collection platform (DCP) report	1 694.500	0.400	4.0
	Telemetry	1 694.000	0.400	10.0
FY-2 (GSO)	Raw Image Data	1 681.6	20	27
	S-VISSR	1 687.5	2	25.5
	WEFAX	1 691.0	0.260	21
	Ranging 1	1 690.5	1	18
	Ranging 2	1 686.5	1	3
	Ranging 3	1 684.5	1	3
	DCP report	1 709.5	1	9
	Telemetry	1 702.5	0.4	15
	Sensor W/B	1 676.000	5.000	19.0
	Sensor raw image	1 681.600	25.000	27.9
	Sensor multi	1 681.478	0.500	19.0
	Sensor mode AAA	1 685.700	5.000	19.0

TABLE 6 (*end*)

MetSat system	**Function**	**Frequency (MHz)**	**RF bandwidth (MHz)**	**e.i.r.p. (dBW)**
GOES (GSO)	Ranging 1	1 684.000	1.000	27.9
	Ranging 2	1 688.200	1.000	27.9
	Ranging 3	1 690.200	1.000	27.9
	Direct readout	1 687.100	3.500	27.9
	WEFAX	1 691.000	0.026	27.9
	Telemetry	1 694.000	0.020	19.0
	DCP report 1	1 694.450	0.400	19.0
	DCP report 2	1 694.500	0.400	21.1
	DCP report 3	1 694.800	0.400	19.0
METEOSAT-MOP (GSO)	DCP reports	1 675.281	0.435	12.5
	Telemetry	1 675.929	0.030	5.0
	Sensor	1 686.833	5.300	10.7
	Ranging 1	1 691.000	0.660	21.3
	Ranging 2	1 694.500	0.660	21.3
	Fax high resolution 1	1 691.000	0.660	21.3
	Fax high resolution 2	1 694.500	0.660	21.3
	WEFAX1	1 691.000	0.026	21.3
	WEFAX2	1 694.500	0.026	21.3
	MDD	1 695.770	0.720	9.0
	HRIT	1 695.150	1.960	18.4
	LRIT	1 691.000	0.660	16.6
METEOSAT-MSG (GSO)	Telemetry (DCP)	1 675.281	0.750	14.5
	Image raw data	1 686.833	6.000	15.9
	HRIT	1 695.150	4.000	22.4
	LRIT 1	1 691.000	2.000	19.8
	LRIT 2	1 695.150	2.000	19.8
GOMS (GSO)	Sensor	1 685.000	5.000	23.0
	WEFAX1	1 671.48 1 690.8	0.018	18.8
	WEFAX2	1 674.48 1 691.4	0.018	18.8
	Fax high resolution 1	1 672.48 1 691.0	0.0024	12.3
	Fax high resolution 2	1 673.48 1 691.2	0.0024	12.3
	DCP 1	1 697.0	2.000 (300 × 3 kHz)	9.7
	DCP 2	1 688.5	1.000 (100 × 10 kHz)	12.0
Typical LEO MetSat	Worst case	1 698-1 710	3.000	9.0

Annex 3

Sharing techniques for MSS and MetSat earth stations in the 1675-1690 MHz frequency band

A number of techniques have been studied by the ITU-R to enhance the capability to share the radio spectrum between mobile or mobile-satellite systems and systems of other services. The basic problem addressed in these studies is that when the mobile service or MSS shares a frequency band with another service, the mobile station or the mobile-satellite earth station has been assumed to be operating anywhere in the service area of the victim system, whilst transmitting at the same frequency as the victim unit receives. Thus, these studies found that within the service area, the mobile or MSS earth station could cause harmful interference to stations of the other service.

These mobile or MSS earth stations must be assumed to be used by persons not accustomed to taking measures to avoid harmful radio interference between stations. For that reason the techniques implemented to control the magnitude of the interference within agreed-to limits must function without action being required by the user of the mobile or MSS earth station. Several such techniques that could be applied to limit the interference from a transmitting MSS earth station into a receiving MetSat earth station are described briefly here. The techniques which can be employed individually or jointly are:

– frequency assignment by location,

– beacon-actuated protection zones,

– interference avoidance by frequency selection,

– using frequencies in an MSS beam coverage area only when the MetSat earth stations are not using them (i.e., time sharing with MetSat priority).

1 Frequency assignment by location

1.1 Method of assuring adequate frequency-distance separation (for the fixed exclusion zone case)

Using an interference-free signalling channel, the mobile earth station reports its location to the network operations centre (this capability is inherent in some planned non-GSO MSS systems). Interference-free working channels are then assigned, based on a computer “look-up” table indicating the frequencies whose use will not cause interference in the reported location and a list of frequencies not already assigned in the beam coverage area. The “look-up” table is based on known location and frequency assignments for the MetSat earth stations.

1.2 Comments

– MSS signalling channels that will not cause harmful interference must be available for use throughout each MSS satellite coverage area.

– MSS earth stations must inherently have, or be equipped with, position determination capabilities.

- MSS earth station location must be known by the network control centre prior to being assigned a service channel.
- Software and a database for assignment based on MSS earth station location must be integrated with the provisions for other channel assignment algorithms.
- The network control computer system should be able to maintain acceptable network access delay.

2 Beacon-actuated protection zones

2.1 A flexible method of assuring adequate frequency-distance separation

A beacon transmitter is co-located with each MetSat receiving earth station to be protected with minimum acceptable frequency offsets between the beacon and the MetSat earth station receiver. The MSS earth station uses the beacon signal to determine whether it is in a restricted-frequency zone. This information is conveyed to the network operation centre, which assigns a channel that will not cause interference for use in the restricted-frequency zone when necessary.

2.2 Comments

- MSS signalling channels that will not cause harmful interference must be available for use throughout each MSS satellite coverage area.
- Beacons must be installed (practical only if there are a small number of receivers to be protected) at each MetSat earth station to be protected.
- MSS earth stations must be equipped with beacon-signal processing capabilities.
- MSS earth stations location (or the specific beacon zone the MSS earth station is within) must be known by the network operation centre prior to channel assignment.
- Software and a database for assignment based on MSS earth station location in relation to specific beacons must be integrated with the provisions for other channel assignment algorithms.
- The network control computer system should be able to maintain acceptable network access delay.
- The technique also may facilitate time sharing.

3 Interference avoidance by frequency selection

3.1 Method to avoid interference to MetSat earth station types with many installations

The above interference avoidance techniques are appropriate for the case where only a few MetSat earth stations are used to receive signals from a MetSat (e.g., raw image data). However, these techniques are not suitable for the case where there are hundreds or thousands of small earth stations used in meteorological data distribution, e.g., for WEFAX, high resolution picture transmission (HRPT) etc. These frequencies may be different for different MetSat systems and moreover, there may be some MetSat data distribution services that may not become ubiquitous.

These data distribution channels are generally quite narrow. Interference to these ubiquitous MetSat earth stations is avoided by having the MSS system not use the frequencies employed by the MetSat data distribution channels and a suitable guardband around them.

3.2 Comments

- MSS signalling channels that will not cause harmful interference must be available.
- Because the data distribution channels have a narrow bandwidth, the diminution of frequencies and capacity to an MSS system will probably be acceptable.
- For non-GSO MSS systems, their network control centres must have the capability to recognize and adopt flexible frequency assignment protocols because different MetSat systems with different coverage areas may employ different frequencies and bandwidths for their data distribution channels.
- Some parts of the world may not ubiquitously install small meteorological data distribution earth stations. MSS earth stations may be useful in such areas.

4 Using frequencies in an MSS beam coverage area only when the MetSat earth stations are not using them

4.1 Time sharing of frequencies

This is an old idea that has been in use in the MetSat field by non-GSO space stations for some time. That is, a non-GSO space station only serves a small part of the Earth's surface at any instant of time. Thus, the same frequencies employed by the space station at that time can be employed on the rest of the world's surface at that time. In other words, time-share the use of the frequencies at all locations on the surface of the Earth between non-GSO MetSats and MSS systems.

4.2 Comments

- MSS signalling channels that will not cause harmful interference must be available.
- In the case at hand, there is a potential for interference from the MetSat space stations into the receivers of the MSS space stations. That concern is discussed in Annex 1.
- The MSS network control centre must keep track of orbital locations and coverage of its own as well as the non-GSO MetSat space stations.
- This technique may be used in conjunction with the beacon and fixed exclusion zone methods described above.
- Good liaison channels must be established between MSS and MetSat system operators.
- For multibeam MSS systems, this method may be used on a beam-by-beam basis.

Annex 4

Sharing considerations for the sub-band 1 698-1 710 MHz based on the time separation concept

1 Introduction

This Annex addresses sharing aspects between the MetSat service and the MSS in the sub-band 1 698-1 710 MHz. Studies within the ITU-R concluded that sharing based on distance separation would not be feasible in this sub-band due to the very high number of receiving earth stations and their generally unknown positions. Currently around 1 000 HRPT earth stations are registered with the WMO. It is expected that this number will significantly increase in future, as this band is the prime expansion band for new non-GSO MetSat systems.

As an alternative to distance separation, the concept of time-sharing has been proposed based on some indications that a limited amount of bandwidth might be available on that basis depending primarily on the beam size of the mobile satellite. However, it was also recognized, that the continuous real-time coordination burden involving between 10 and 20 meteorological satellites operated by different administrations or international organizations coupled with disabling the use of large parts of the spectrum at irregular time intervals would not render such a sharing concept practical. It was concluded that further study would be necessary with respect to very narrow beam systems as they may have some sharing potential. Technical characteristics of MSS systems to be used for sharing studies are contained in Recommendation ITU-R M.1184.

2 Meteorological satellite system characteristics

Several LEO meteorological satellites are currently operating in the band 1 698-1 710 MHz. Of particular interest is the planned medium-term deployment of such systems taking into account RR No. 5.377 which stipulates, amongst others, that the MSS shall not constrain the development of the meteorological satellite service. System characteristics have been collected from various administrations and international organizations which can be considered representative for the next series of LEO meteorological satellites already deployed or planned to be deployed within the next decade.

Some other administrations have plans for similar systems but detailed characteristics are currently not available. It may be fair to assume that in the medium- to long-term future between 20 and 25 meteorological satellites will be deployed worldwide. Most operators will have at least two satellites in orbit simultaneously. It may consequently be assumed that between 10 and 20 satellites will operate in the band 1 698-1 710 MHz at any time in the future. The possible frequency reuse will put a limit on the number of satellites and every spectral gap will sooner or later be used. Already now, careful planning is necessary in order to minimize interference.

For the purpose of this study, it was assumed that 14 satellites would use this band within the next decade. Seven satellites have been taken from the ones already operating or in the design stage with a limit of two per administration or international organization. Five additional ones are intended as placeholders for other administrations without firm plans yet or administrations possibly having more than two satellites simultaneously in orbit. The satellite characteristics used for the simulations are given in Table 7.

TABLE 7

Meteorological satellite data used for the simulation

Satellite	**Orbit height (km)**	**Inclination (degrees)**	**Lower frequency (MHz)**	**Upper frequency (MHz)**
FY-1	870	98.7	1 698	1 703
	870	98.7	1 705.5	1 710
METOP	827	98.7	1 698.75	1 703.25
	827	98.7	1 704.75	1 709.25
SPOT	822	98.7	1 703	1 705
METEOR	1 020	99.6	1 698.5	1 701.5
	1 020	99.6	1 703.5	1 706.5
NOAA	850	98.7	1 698.75	1 703.25
	850	98.7	1 704.75	1 709.25
ADMIN1-A	840	98.7	1 698	1 702
ADMIN1-B	840	98.7	1 702	1 706
ADMIN2-A	840	98.7	1 702	1 706
ADMIN2-B	840	98.7	1 706	1 710
ADMIN3	840	98.7	1 706	1 710

It shall be noted that most of these MetSat satellites transmit in addition a much wider signal to their corresponding CDA stations when in field of view. Such stations are generally located at high latitudes with contact times between 6% and 13% per orbit. MSS spot beams pointing above medium latitudes will therefore encounter additional operational constraints not covered by this study.

Meteorological satellite earth stations are normally receiving data at elevation angles above typically 5° but have to support occasionally satellite passes with lower elevation angles. It also happens frequently, that data are received until the meteorological satellite loses line-of-sight. In addition, the initial signal acquisition and data synchronization process requires some time and is normally initiated as soon as the satellite is expected to come into line-of-sight. Interference during this period can be very harmful. Furthermore, the position uncertainty of the meteorological satellite increases with the time interval between localization procedures. Some safety margin is therefore required with respect to inaccuracies regarding the orbital position of meteorological satellites. For the above reasons, it was assumed that protection of the HRPT station would be required during the entire period when the satellite is visible, i.e. for elevation angles down to 0°. This will in practice result in an operational elevation angle of approximately 5° as stipulated in Recommendation ITU-R SA.1026. Consequently, a MES shall not transmit when an HRPT station is in line-of-sight of its corresponding meteorological satellite.

3 Mobile-satellite system characteristics

This study is based on technical characteristics of MSS systems to be used for sharing studies. The information contained in Recommendation ITU-R M.1184 lists a number of GSO and non-GSO systems. For the GSO systems, beamwidths between 1° and 17° have to be considered with corresponding 3 dB mobile service areas ranging between 1 million km^2 and 217 million km^2. Three systems have been selected for the simulations with a minimum beamwidth of 1°, a medium beamwidth of 6° and a maximum beamwidth of 17°.

For the non-GSO mobile-satellite systems, a selection of a subset out of the eleven systems was necessary. Systems A, B and G have been chosen in order to have a representative spread of orbital heights, inclination angles and beamwidths. For these systems, the service area covered by one antenna footprint lies in the range between 180 000 km^2 and 8 400 000 km^2. Table 8 summarizes the MSS characteristics used for this study. It must be noted that systems based on code division multiple access (CDMA) utilize in general rather high chip rates which require the availability of a large portion of the bandwidth of 12 MHz.

TABLE 8

Mobile-satellite characteristics used for the simulation

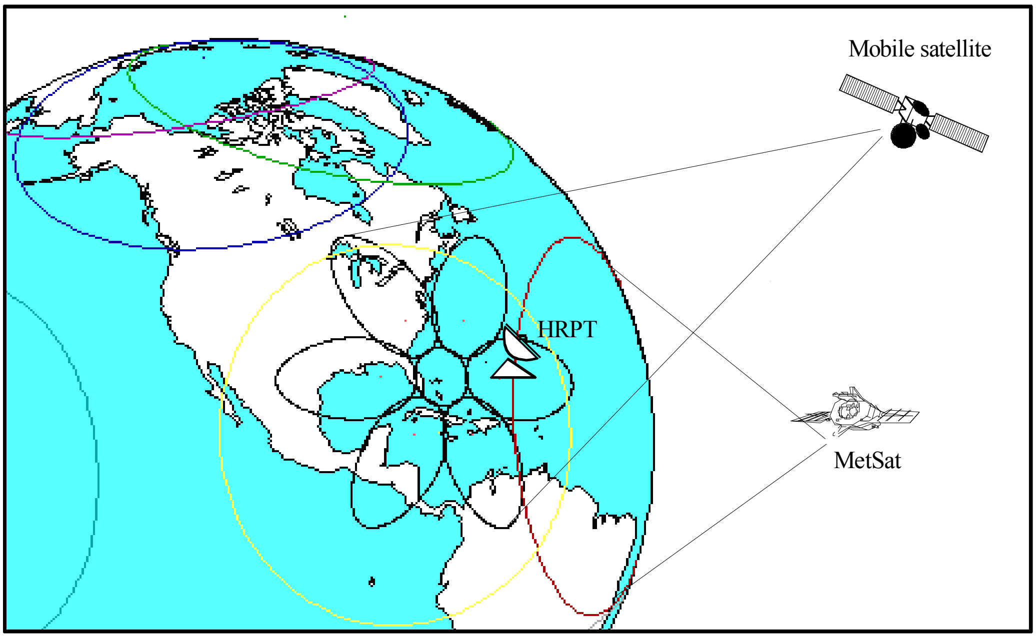
	INMARSAT-M	GSO-A	GSO-C	LEO-A	LEO-B	LEO-G
Orbit altitude (km)	36 000	36 000	36 000	780	10 355	1 500
Inclination angle (degrees)	1	1	1	86	50	74
Beamwidth (degrees)	17	1	6	34	13	95
Number of beams	1	180	7	48	37	6
RF channel spacing (kHz)	10	Not applicable	6	42	Not applicable	50
Modulation bandwidth (kHz)	8	8 330	4.7	32	2 500	5 800
Maximum beam size (km^2)	215×10^6	–	–	700 000	1 000 000	8 400 000

4 Simulation and technical analysis

The sharing assessment is based upon a computer simulation involving 14 meteorological satellites and one mobile system satellite. The orbital heights for the meteorological satellites are between 827 km and 1 020 km with a typical inclination around 99°. The mobile system satellites are a subset of those given in Recommendation ITU-R M.1184. For the non-GSO ones, systems A, B and G were selected and for the GSO systems, systems A (GSO-A) and C (GSO-C) as well as the INMARSAT-M system (GSO-M) have been selected. The geometrical constellation is illustrated in Fig. 4.

FIGURE 4

Illustration of exclusion zone for the mobile satellite



1158-04

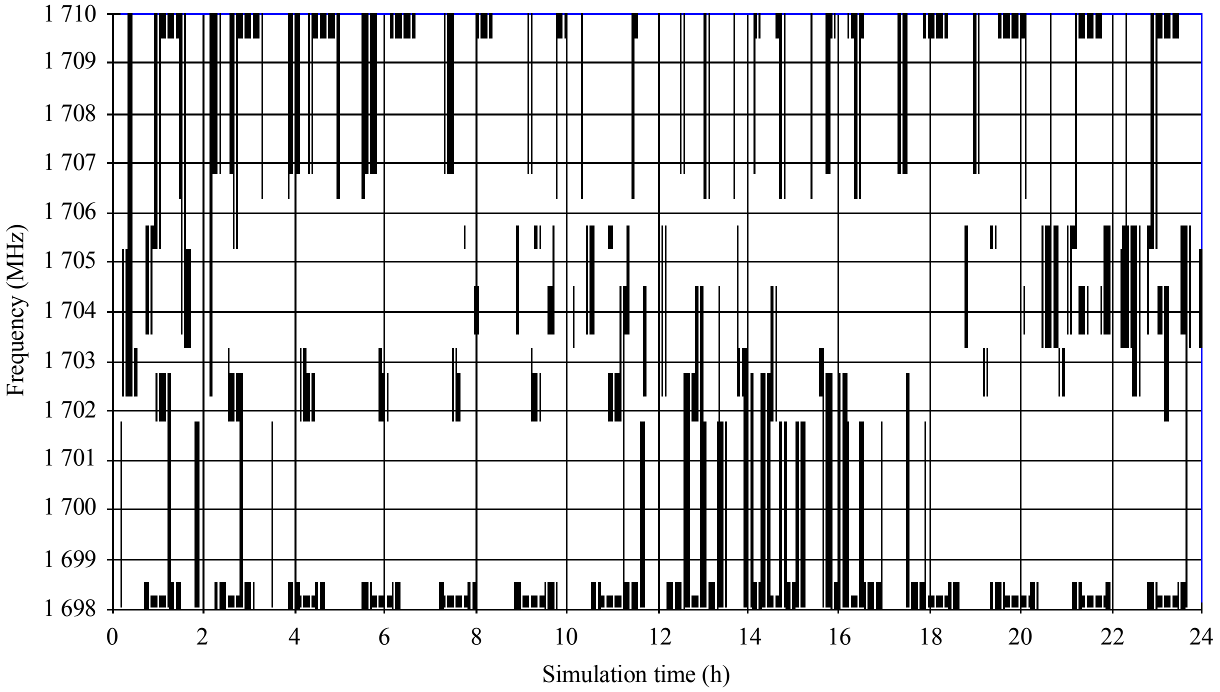
When an HRPT station is within the service area of a mobile satellite antenna beam, and when a meteorological satellite is in field of view of the HRPT, the bandwidth used by the meteorological satellite is not available for mobile terminals within the service area as long as any potential HRPT could receive data. It can be seen that in this example, the MSS footprint intersects with two service areas of meteorological satellites and that the corresponding frequency bands cannot be used. It can also be seen that the beams with some distance to the sub-satellite point covers significantly larger area resulting in a higher outage time. During the simulation, only the beam with the most northern centre point has been selected. As the simulations are very time consuming, only 24 h have been assessed with samples taken every 30 s.

From all available simulation results, the GSO system case with a 6° (two-sided) service area angle (GSO-C) has been selected as a representative case. Figure 5 shows the available spectral gaps in the full frequency range as a function of simulation time.

Figure 6 shows the total available bandwidth. It shall be noted that any given bandwidth is usually available only in several slots which are changing over time. It can be seen that the available bandwidth is rather limited and switches rapidly over time and frequency. Other mobile systems show similar results.

FIGURE 5

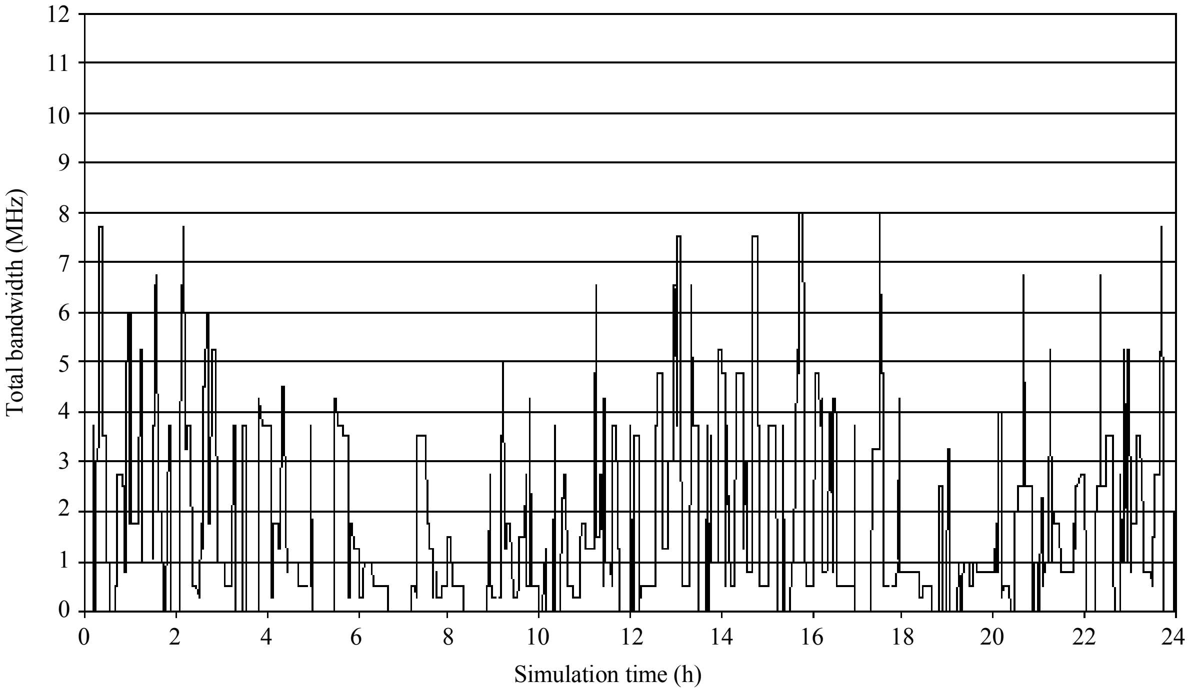
Available spectral gaps for mobile system GSO-C



1158-05

FIGURE 6

Total available bandwidth for mobile system GSO-C



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5 Summary

At irregular time intervals, the available bandwidth drops to zero MHz which is equivalent to a total traffic interruption. This would exclude any voice communications. Only narrow-band, short duration type of data transmissions may be feasible.

MSS systems using CDMA would not be able to operate as bandwidths of several MHz are hardly ever available.

The available bandwidth can switch within minutes between less than 1 MHz and more than 10 MHz as well as between different sub-bands within the range 1 698-1 710 MHz requiring frequent interruption and relocation of mobile frequency channels.

Continuous real-time coordination involving between 10 and 20 active MetSat satellites operated by different administrations or international organizations would be required coupled with increased requirements for rather precise orbit determination of the meteorological satellites.

All simulations are based on 14 MetSats only. In view of the rapid growth of satellite projects worldwide, and taking into account RR No. 5.377 regarding unconstrained deployment of future meteorological systems, a significantly higher number of MetSats would result in basically no available spectrum even for very narrow-beam systems.

MSS systems with spot beams towards higher northern latitudes will encounter additional operational constraints when meteorological satellites transmit wideband signals to their corresponding CDA stations.

In view of the above results, it can be concluded that the sharing potential is very limited and complex. Considering the expected future increase of meteorological systems and their protection as stipulated in RR No. 5.377, this sub-band cannot be considered practical for sharing between the MetSat service and the MSS.