CEPT ECC
Electronic Communications Committee

ECC Report 322

Compatibility analysis (inter-service and intra service) for S-PCS below 1 GHz

approved 28 January 2022

0 EXECUTIVE SUMMARY

This Report contains the necessary studies for S-PCS for inclusion in ERC Decision (99)06, annex 2 [10].

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Explanation
CEPT	European Conference of Postal and Telecommunications Administrations
CMES	Customer Mobile earth stations
DCAAS	Dynamic Channel Activity Assignment System
ECC	Electronic Communications Committee
FDMA	Frequency Division Multiple Access
GCC	Gateway Control Center
GESs	Gateway Earth stations
IoT	Internet of Things
LBT	Listen Before Talk
LEO	low-Earth orbit
M2M	Machine-to-Machine
MEO	Medium Earth Orbit
MESs	Mobile Earth stations
MS	Mobile Station
MSS	Mobile Satellite Service
NCC	Network Control Center
PFSD	Power Flux Spectral Density
PMR	Private Mobile Radio
SFTSS	Standard frequency and time signal-satellite
TT&C	Telemetry, Tracking and Command
VHF	Very High Frequency
RR FN	ITU Radio Regulations footnote

1 INTRODUCTION

In order to harmonise the deployment of S-PCS (<1 GHz), ERC Decision (99)06 [10] states that compatibility analysis has to be performed by the operators of S-PCS (<1 GHz). This Report contains the relevant studies. The main body contains the list of affected services and the operational constraints for S-PCS (<1 GHz). ANNEX 1 contains systems description and inter-service studies. ANNEX 2 contains intra-service studies.

2 SERVICES TO CONSIDER FOR INTER-SERVICE COMPATIBILITY WITH MSS SYSTEMS

The inter-service compatibility studies and relevant standards any S-PCS<1 GHz needs to conduct and meet, respectively, in order to comply with ERC Decision (99)06, decides 5b [10], are provided in Table 1.

Table 1: Compatibility studies and technical standards for S-PCS<1 GHz[1]

Frequency band 148-150 MHz (Earth-space)	
Compatibility studies	Technical standards/Recommendations
Mobile services	Recommendation ITU-R M.1808 [1]
Radio astronomy services	Recommendation ITU-R P.452 [2]; Recommendation ITU-R RA. 769 [3]
Space Operation service	RR FN 5.218 and RR FN 5.219 [9] apply
Frequency band 137-138 MHz (space-Earth)	
Compatibility studies	Technical standards/Recommendations
Meteorological satellite services	Recommendation ITU-R 1026 [4]; Recommendation ITU-R SA. 1027 [5]
Radio astronomy services	Recommendation ITU-R S.1586 [6]; Recommendation ITU-RM.1583 [7]; Recommendation ITU-R RA.769 [3]; Recommendation ITU-R RA.1513 [8]
Mobile services	Annex 1 to RR Appendix 5
Frequency band 399.9-400.05 MHz (Earth-space)	
Compatibility studies	Technical standards/Recommendations
Radio astronomy services	Recommendation ITU-RP.452 [2]; Recommendation ITU-RRA.769 [3]
Frequency band 400.15-401 MHz (space-Earth)	
Compatibility studies	Technical standards/Recommendations
Radio Astronomy services	ITU-R Resolution 739 [23]; Recommendation ITU-R RA. 769 [3]; Report ITU-R SM.2091 [13]; Recommendation ITU-R RA.1631 [14]
Standard frequency and time signal satellite service	pfd protection limits for Tsykada, ICARUS, LEOTELCOM-1 and F-SAT-NG-8
MetAids systems	Recommendation ITU-R SA 1165-1 [15], Recommendation ITU-R RS 1263 [16]

[1] In the compatibility studies, the most recent versions of the recommendations available on 4 December 2020 were used.

3 OPERATIONAL CONSTRAINTS

In summary, the following operational constraints would ensure inter service and intra service compatibility services as indicated in ERC Decision (99)06 [10], without prejudice to requirements and precedence in the coordination at the ITU level.

3.1 OPERATIONAL CONSTRAINTS FOR HIBER

Table 2: Operational constraints

Operational Constraints for HIBER	
Up-link designated bands	399.9-400.05 MHz
Down-link designated bands	400.15-401 MHz
Multiple access method	CDMA
Modulation method	QPSK in transmitting and GFSK in receiving
Downlink e.i.r.p	12.5 dBW
Downlink duty cycle	400 milliseconds (typical) to a maximum of 1 second every 10 seconds, corresponding to a maximum duty cycle of 10%
Technique to avoid causing interferences from the downlink emissions	No more than 47 satellites (2/3 of the constellation) will operate with an elevated duty cycle of 10%, to stay below the 2% ITU interference threshold to protect the RAS. To protect the SFTSS systems in the frequency band 400.05-400.15, the lower portion of the frequency band 400.15-401 MHz will not be used by HIBER.
Maximum MESs e.i.r.p. spectral density	-6.0 dBW/(4 kHz) for 50 kcps,-9.0 dBW/(4 kHz) for 100 kcps
Technique to avoid causing interference from MESs	The MES transmits only when the satellite is visible. Sharing by channel and by time. Initially in one channel of 120 kHz in the uplink and 150 kHz in the downlink.
Maximum burst duration for MESs transmission	less than a half second to a maximum of 4 seconds.
Minimum time between bursts	Every 900 seconds
Maximum duty cycle per MESs	max transmission time of 4 seconds within the integration time of 15 minutes corresponds to a duty cycle of 0.4%

3.2 OPERATIONAL CONSTRAINTS FOR ARGOS KINEIS

Table 3: Operational constraints

Operational Constraints for ARGOS KINEIS	
Up-link designated bands	399.9-400.05 MHz
Down-link designated bands	400.15-401 MHz
Multiple access method	Uplink CDMA and FDMA Downlink: FDMA
Modulation method	Uplink: spread spectrum and narrow-band (PSK)

Operational Constraints for ARGOS KINEIS	
	Downlink: narrow band (PSK)
Downlink e.i.r.p	7.2 dBW
Downlink duty cycle	100%
Technique to avoid causing interferences from the downlink emissions	ARGOS KINEIS downlink transmitter rejection is specified so that the 2% ITU interference threshold to protect the RAS is met. The SFTSS falls within the spurious emissions domain of the 4 kHz ARGOS KINEISs downlink emissions bandwidth. Given the spurious emission requirements, SFTSS systems will be protected in the 400.05-400.15 MHz band.
Maximum MESs e.i.r.p. spectral density	Maximum beacon e.i.r.p. level will not exceed 5 dBW in the 399.9-400.05 MHz band. In effect, the beacon level will most of the time be largely below 5 dBW, and typically in the range -9 dBW to 0 dBW.
Technique to avoid causing interference from MESs	The MES transmits only when the satellite is visible.
Maximum burst duration for MESs transmission	About 1 second
Minimum time between bursts	30s
Maximum duty cycle per MESs	Typically, 0.01% and up to 0.3%

3.3 OPERATIONAL CONSTRAINTS FOR SWARM

Table 4: Operational constraints

<table>
<tr><th colspan="2">Operational constraints for SWARM</th></tr>
<tr><td>Uplink designated band</td><td>148-150.05 MHz</td></tr>
<tr><td>Downlink designated band</td><td>137-138 MHz
Not more than 4 SWARM satellites operating simultaneously over CEPT at any given time
Only one satellite per each 150 kHz in the above band operating simultaneously over CEPT</td></tr>
<tr><td>Multiple Access Method</td><td>CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance)</td></tr>
<tr><td>Modulation Method</td><td>Narrow band Frequency or Phase Modulation</td></tr>
<tr><td>Downlink e.i.r.p.</td><td>Limited to -1.55 dBW
Satellites shall cease emissions when their elevation with respect to the stations below is higher than 25°.
<table>
<tr><th></th><th>Longitude</th><th>Latitude</th></tr>
<tr><td>1</td><td>37.3 E</td><td>55.8 N</td></tr>
<tr><td>2</td><td>83.0 E</td><td>55.0 N</td></tr>
<tr><td>3</td><td>135.2 E</td><td>48.5 N</td></tr>
</table></td></tr>
<tr><td>Downlink duty cycle</td><td>Maximum: 10% (over 24 hours)
Typical: 5% (over 24 hours)</td></tr>
</table>

Operational constraints for SWARM	
Bandwidth	Not less than 41.7 kHz (uplink and downlink)
Maximum CMESs e.i.r.p. spectral density (uplink)	0 dBW/4 kHz
Technique to avoid causing interference from CMESs	Low duty cycle (<1%), low-power, and carrier sense multiple access (CSMA) media access control (MAC) protocol with Collision Avoidance (CSMA/CA) "listen before talk" (LBT); energy detection threshold near noise floor
Maximum burst duration for MESs transmission	1700 msec (in 149.9000-149.9500 MHz band) 500 msec (otherwise)

3.4 OPERATIONAL CONSTRAINTS FOR MYRIOTA

3.4.1 Operational constraints for MYRIOTA for UHF band

Table 5: Operational Constraints

UHF Operational Constraints for MYRIOTA (399.9–400.05 MHz and 400.15–401 MHz)	
Up-link designated bands	399.9–400.05 MHz
Down-link designated bands	400.15–401 MHz
Multiple access method	Uplink: Narrow band frequency hopping Downlink: narrow band FDMA
Modulation method	Uplink: FSK Downlink: FSK
Downlink e.i.r.p	400.15–401 MHz band: ▪ 4 kHz carrier: 10 dBW ▪ 20 kHz carrier: 8.5 dBW
Downlink duty cycle	400.15–401 MHz band: ▪ 4 kHz carrier: 10% in 5 s ▪ 20 kHz carrier: 20% in 5s
Technique to avoid causing interferences from the downlink emissions	400.15–401 MHz band: MYRIOTA downlink transmitters shall be designed to filter out of band emissions to at least level of -110 dBc, corresponding to a maximum peak e.i.r.p. of -100 dBW, in any 4 kHz bandwidth within the band 406.1-410 MHz to comply with the 2% data loss criteria in accordance with Recommendations ITU-R RA.769-2 [3] and ITU-R RA.1513 [8] for the protection of the Radioastronomy Service. To protect the SFTSS service in the frequency band 400.05-400.15 MHz, the lower 10 kHz (400.15–400.16 MHz) of this frequency band shall not be used. SFTSS: Standard frequency and time signal-satellite

Maximum MESs e.i.r.p. spectral density	IoT modules: 5 dBW/4kHz, maximum 4 kHz Micro-gateways: -2.96 dBW/4kHz, maximum 50 kHz
Technique to avoid causing interference from MESs	The MES transmits only when the satellite is visible.
Maximum burst duration for MESs transmission	262 ms
Minimum time between bursts	2 s
Maximum duty cycle per MESs	IoT modules: 0.5 % in 24 hours (typically 0.02%) Micro-gateways: 5.0% in 24 hours (typically 0.5%) Note: duty cycle is defined over all frequency hops.

3.4.2 Operational constraints for MYRIOTA for VHF band

Table 6: Operational constraints

VHF Operational constraints for MYRIOTA (137–138 MHz and 148.0–150.05 MHz)	
Up-link designated bands	148.0–150.05 MHz
Down-link designated bands	137–138 MHz
Multiple access method	Uplink and Downlink: narrow band FDMA
Modulation method	Uplink: FSK Downlink: FSK
Downlink e.i.r.p	137–138 MHz band: 4 kHz carrier: 1.5 dBW 20 kHz carrier: 8.5 dBW
Downlink duty cycle	137–138 MHz band: 4 kHz carrier: 10% in 5s 20 kHz carrier: 20% in 5s
Technique to avoid causing interferences from the downlink emissions	137–138 MHz band: When in visibility from the territory of Russian Federation: Reduce transmit power by up to 10 dB at elevations above 30.55o. Adjust transmit power at lower elevations to maintain a pfd on the ground of -140 dB(W/m2/4 kHz). At higher elevations, reduce downlink duty cycle to 0.25% and 0.5% for the 4 kHz and 20 kHz carriers, respectively to protect Aeronautical Mobile (OR), Reduce transmit power by up to 10 dB for all carriers and reduce downlink duty cycle to 0.006% for the 20 kHz carrier to protect Meteorological Satellite Service.
Maximum MESs e.i.r.p. spectral density	IoT modules: 5 dB(W/4kHz), maximum 4 kHz Micro-gateways: -0.97 dB(W/4kHz), maximum 250 kHz
Technique to avoid causing interference from MESs	The MES transmits only when the satellite is visible

VHF Operational constraints for MYRIOTA (137–138 MHz and 148.0–150.05 MHz)	
Maximum burst duration for MESs transmission	262 ms
Minimum time between bursts	2 s
Maximum duty cycle per MESs	IoT modules: maximum 0.5 % in 24 hours (typically 0.02%) Micro-gateways: maximum 5.0% in 24 hours (typically 0.5%)

4 CONCLUSIONS

This Report contains the compatibility analysis necessary for inclusion in ERC Decision (99)06, annex 2 [10]. Each system was considered, and the associated results are available in the relevant annexes.

ANNEX 1: DESCRIPTION OF MSS SYSTEMS AND INTER-SERVICE STUDIES

A1.1 DESCRIPTION OF LEOTELCOM-1

A1.1.1 General description

The LEOTELCOM-1 system is a narrow band FDMA constellation comprised of up to 48 satellites. The system is designed to operate in the frequency bands 137-138 MHz (space-to-Earth) and 148-149.9 MHz (Earth-to space). With full deployment, around 2 satellites will be visible at any time at a geographic location at a latitude of 50°. Each satellite is able to allow 6 MESs to transmit data bursts at the same time. The burst requires 5 kHz of bandwidth with a burst length of 55 milliseconds (typical) to about 500 milliseconds (maximum). The modulation scheme used is a symmetric differential phase shift keying. To minimise the probability of interference to terrestrial systems from MES uplinks, a dynamic channel activity assignment technique is used, which allows the satellite to assign unoccupied channels to S-PCS<1 GHz MES transmitters which are requesting an uplink for data bursts. Technical characteristics

The LEOTELCOM-1 system, named ORBCOMM, is a wide area, packet switched, two-way data communication system. Communications to and from Mobile Earth stations (MESs) and Gateway Earth stations (GESs) are accomplished through a constellation of low-Earth orbit (LEO) satellites. LEOTELCOM-1 Gateways are connected to dial-up circuits, private dedicated lines or the Internet.

The LEOTELCOM-1 system consists of a Network Control Center (NCC) that manages the overall system worldwide and three operational segments:

- A space segment consisting of up to 48 LEO Satellites;
- A ground segment consisting of GESs and control centers located throughout the world; and
- A subscriber segment consisting of MESs used by LEOTELCOM-1 system subscribers to transmit and receive information to and from the LEO Satellites.

RF communication within the LEOTELCOM-1 system operates in the Very High Frequency (VHF) portion of the frequency spectrum between 137 and 150 MHz. The LEOTELCOM-1 Satellites have a subscriber transmitter that provides a continuous 4800 or 9600 bps stream of packet data. Each Satellite also has multiple subscriber receivers that receive short bursts from the MESs at 2400 bps. The ORBCOMM System is capable of providing near real-time wireless data communications service around the world.

All communications within the LEOTELCOM-1 system must pass through a Gateway. A LEOTELCOM-1 Gateway consists of one Gateway Control Center (GCC) - the facility that houses the computer hardware and software that manages and monitors message traffic - and a GES. The GES provides the link between the Satellite constellation and an ORBCOMM GCC.

EXAMPLE: A typical messaging scenario will proceed, as shown in the following sequence, illustrated in Figure 1.

1. A LEOTELCOM-1 system subscriber enters a message in a subscriber communicator (an MES).
2. The MES transmits the message to the Satellite that receives, demodulates, reformats and retransmits the message to a GES.
3. The GES receives the message and sends it to a GCC over a dedicated connection.
4. The GCC re-sends it to its final destination using the access method (Dedicated access, dial-up access, e-mail, etc.) chosen by the subscriber.
5. The message is received at its destination.

A message from the home base to the subscriber follows the reverse route: Home base to the GCC, GCC to GES, GES to Satellite, and finally Satellite to the MES and user display. Even “direct” subscriber-to-subscriber transmissions must pass through an ORBCOMM Gateway.

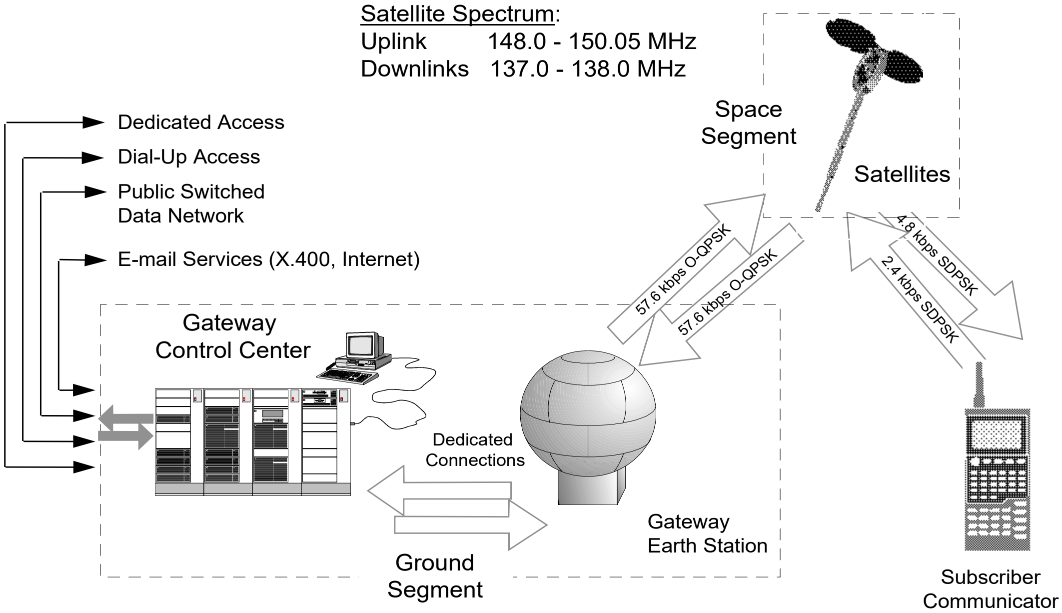

Figure 1: ORBCOMM System Overview

A1.1.2 LEOTELCOM 1 RF compatibility techniques

The 148.0-149.9 MHz band is heavily used by terrestrial systems. In order to operate, the LEOTELCOM-1 system must scan and identify channels within this band that are not being actively used during the 5 second scan duration. LEOTELCOM-1 has developed a Dynamic Channel Activity Assignment System (DCAAS) to identify channels being actively used by terrestrial services and to avoid those channels.

There is no way known for an FDMA system such as LEOTELCOM-1 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 the loss of MSS data.

The overall sharing approach used by LEOTELCOM-1 consists of four aspects:

- The DCAAS system avoids assigning active Mobile channels (e.i.r.p. toward the satellite > 0.1 W in 3 kHz) to MESs for uplink transmissions. The system scans the frequency band for inactive channels approximately every 5 seconds. The DCAAS system will not permit the MESs to transmit if there are no inactive channels available;
- 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;
- The short burst duration of LEOTELCOM-1 MES transmissions further minimises any interference effects;
- The structure of the MES message transmission session is such that even if interference does occur, it will not continue or re-occur.

More detailed descriptions of each of these aspects of LEOTELCOM-1's approach to interference avoidance are provided in the following sections. Each section is followed by sub-sections that summarise the results of analyses or tests that validate each aspect of the overall approach.

A1.1.2.1 DCAAS

The first level of the LEOTELCOM-1 uplink interference avoidance approach is the Dynamic Channel Activity Assignment System (DCAAS), which consists of a receiver and processing unit on the satellites. 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 is to avoid interfering with terrestrial receivers preventing MES transmissions on active mobile channels.

It is important to note that:

- A LEOTELCOM-1 MES can transmit only if it receives a downlink signal from the LEOTELCOM-1 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 next 5 seconds.

Figure 2 is a graphical representation of the various factors that affect the channel selection and implementation process described below.

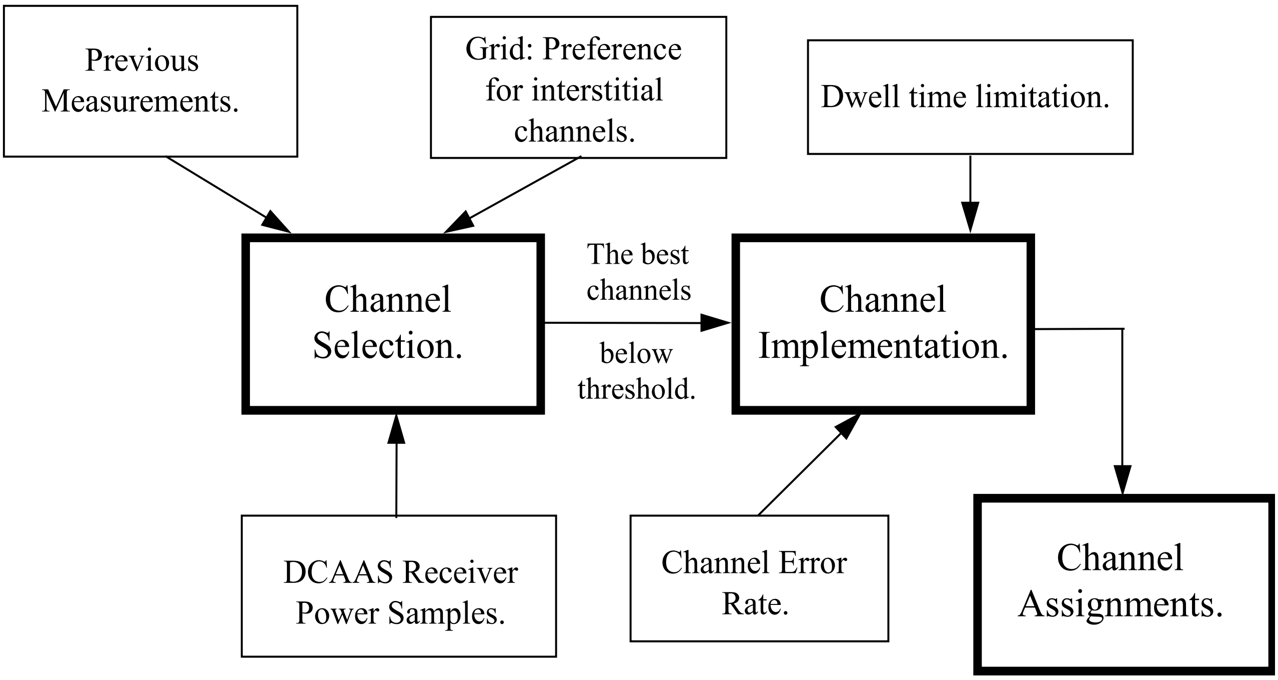

Figure 2: DCAAS Operation

A1.1.2.2 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 strict 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 several channelisation plans or grids. The LEOTELCOM-1 system is designed to give preference to channels spaced midway between these standard terrestrial emitters. This preference carries more weight in the channel selection algorithm than the quality factor, but less than the hard threshold decision;
- Quality Factor: The third channel selection criteria considers power sample measurements made over the previous 5 seconds 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 LEOTELCOM-1 proprietary 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 algorithm.

A1.1.2.3 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.

Under normal conditions of moderate to heavy traffic loading, the satellite will change the uplink channel to a different frequency in about 1-2 seconds if the bit error rate threshold on that channel is exceeded. Under light traffic loading conditions, there may be insufficient uplink signals to evaluate the bit error rate, and so the channel frequency will not be changed until the next DCAAS scan is completed, in a maximum of about 5 seconds plus a short processing time. During this time, however, there will be very few MES transmissions because the situation can only occur under very light traffic loading conditions.

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.

A1.1.2.4 Probability of DCAAS assigning an active channel

In some cases, the DCAAS receiver on the LEOTELCOM-1 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 LEOTELCOM-1 satellite, or ground reflection losses for the terrestrial mobile. In addition, the DCAAS monitoring system may not detect short burst low duty cycle terrestrial data traffic. 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. Att. 20 of WP8D/200 estimates a value for this probability of obstruction at 20%, based on the rate of service inability for cellular phones in Japan. This would seem to be an upper bound on the probability since it applies to a terrestrial path, while the Earth-to-space path between the Mobile transmitter and the LEOTELCOM-1 satellite would have a minimum elevation angle of 5º.

Additional factors reduce the probability of DCAAS assigning an active channel, but are difficult to quantify. These include the following:

- If the frequency band is heavily used by the terrestrial mobile services employing frequency re-use, there is a high probability that a second mobile transmitter visible to the LEOTELCOM-1 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 an LEOTELCOM-1 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;
- Also, if the Earth-to-space path from a mobile transmitter to an LEOTELCOM-1 satellite is blocked, there is higher probability that the MES is also blocked from the satellite, reducing the probability that an MES could be transmitting in that area;

- 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 and with the level of frequency re-use by the terrestrial services. LEOTELCOM-1 estimates the probability of DCAAS assigning an active channel to be considerably lower than the upper bound Japanese estimate.

A1.1.2.5 DCAAS tests

Tests performed independently by the German administration have verified that the initial two LEOTELCOM-1 satellites were able to detect and avoid terrestrial transmitters with an e.i.r.p. lower than 0.1 W.

A1.1.3 LEOTELCOM 1 data session

The structure of an LEOTELCOM-1 data session will also tend to reduce interference. Once power is applied, the MES automatically searches through an internally stored list of downlink channels. If the MES has not locked on to a satellite signal since power was applied and there is no satellite signal at any of the stored channels, a search of all possible channels in the 137 to 138 MHz band is conducted.

Once a satellite signal is found it must be received continuously for 2 seconds to begin a data transfer session. During this time, the MES receives the necessary control information. which includes the timing, the LEOTELCOM-1 Gateways connected to the Satellite, and the current uplink random access channels. The MES must receive this information before it can transmit data to the Satellite.

Figure 3 is a graphical representation of the data session process, which is described below.

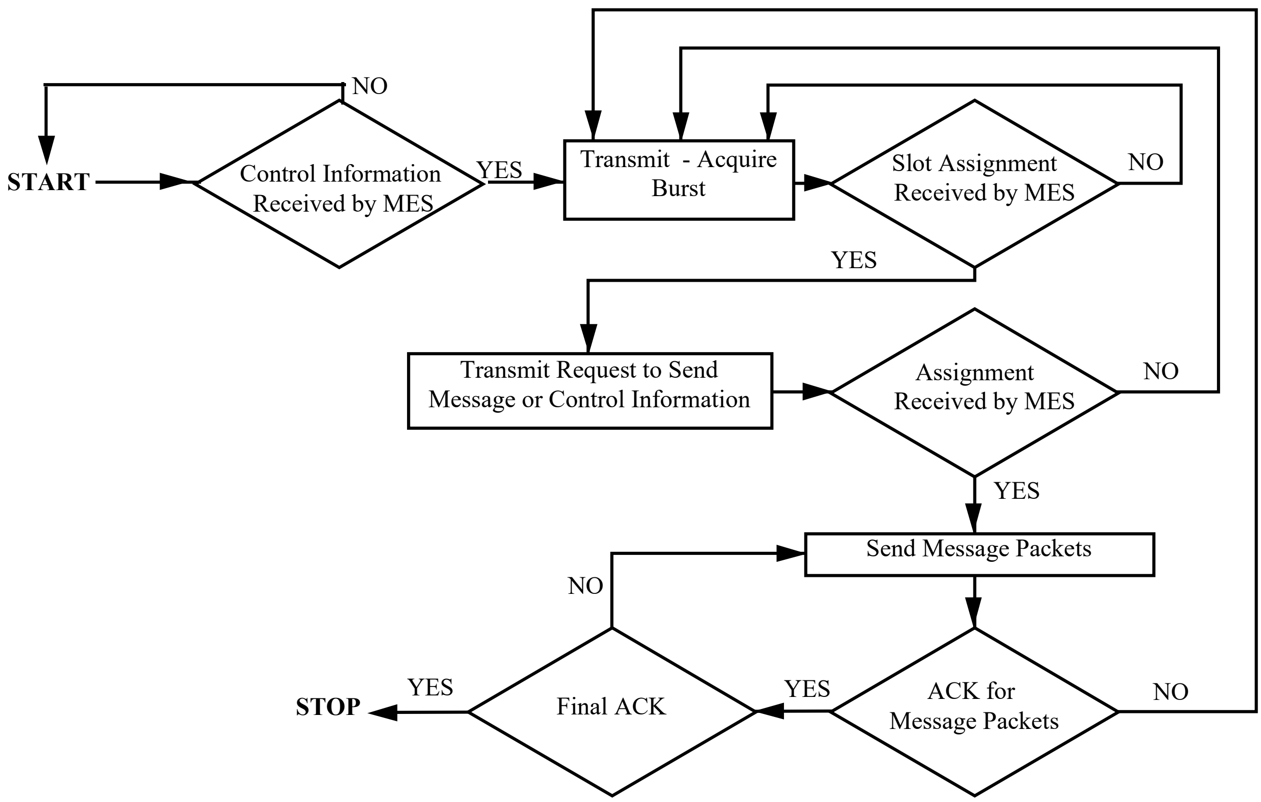

Figure 3: MES Data Transfer Session Flowchart

A1.1.3.1 Acquire/Communicate Burst Process

If the MES has a message to send, the MES-Originated data transfer session begins with a data transfer setup process called Acquire/Communicate. The MES first transmits an ultra-short acquire burst to initiate the data transfer setup process. The transmission frequency of the burst is randomly chosen from the list of available uplink random access channels provided by the satellite. This list of available channels changes frequently according to the DCAAS process.

The satellite will receive the acquire burst correctly if there is no interference and no time-overlapping bursts on the same receive channel within the 5000 km diameter Satellite footprint. Reception of the acquire burst by the satellite initiates a proprietary communications protocol/handshake between the satellite and the MES.

The acquire/communicate burst process can include either the transfer of a data report, which contains six bytes of user defined data, or a request to send a larger amount of data (referred to as a „Message Request“) and is, in total, less than 60 ms of transmit time.

As shown in Figure 3, whenever a longer burst is unsuccessful for any reason, the acquire burst is the next burst from the MES. This helps avoid harmful interference to a nearby terrestrial user.

A1.1.3.2 Sending Message Packets

Following a successful Message Request from an MES, the satellite responds with an assignment containing a time slot, an uplink frequency channel and the length of the first packets to be transmitted. The time slots and channels are selected by the satellite, which is also frequency hopping its receivers. The channels used for sending message packets are different than those used for random access, and can differ from packet to packet.

Following an MES message burst, the satellite sends an acknowledgment that also, if necessary, contains an assignment to send the next packet. This process continues until the message is completely and successfully transferred from the MES to the GSS. A long message may require multiple message burst transmissions.

A1.1.4 Inter-service studies

ERC Report 87 [17] has addressed the impact of narrowband FDMA MSS MESs of the LEOTELCOM-1 system on several types of terrestrial mobile systems and the radio astronomy service. ERC Report 87 indicated that, with the received threshold level of -128.5 dBm, the Dynamic Channel Activity Assignment System (DCAAS) is able to detect terrestrial transmissions with an e.i.r.p. of less than 0.1W. Additionally, ERC Report 87 addressed the impact of S-PCS<1 GHz MES (narrow band fashion) operating in adjacent channels to analogue PMR equipment.

For the conditions stated in these analyses, the probability of MSS MES interference into analogue PMR equipment operating with or without selective calling is sufficiently low such that studies conclude that sharing between non-trunked analogue PMR equipment and the MSS MES operating in narrow band fashion is feasible.

The results of initial field trials involving an analogue trunked MS system and the LEOTELCOM-1 system indicate the following:

- Burst transmissions from a single MES transmitting within the necessary receiver bandwidth of, and in the geographic proximity of, a terrestrial analogue voice mobile station attempting to establish a call to another terrestrial analogue voice mobile will prevent the terrestrial analogue voice mobile station from establishing its call;
- The tested analogue terrestrial base station configuration did not appear to demodulate MES transmissions, but instead, it appeared to treat these transmissions as noise.

These initial field trials led to a more detailed theoretical study. The further studies have concentrated on the compatibility between the LEOTELCOM-1 system and the trunked PMR schemes used in this band. A major study was commissioned to investigate the compatibility based on live data from several CEPT countries where available. This detailed study indicates that, under assumptions representing normal operating conditions, the interference potential is relatively low, about 0.1%. Under assumptions representing extreme operating conditions, the probability of interference to certain channels increases substantially therefore one administration is conducting additional studies to further quantify the interference potential.

An additional study of sharing between LEOTELCOM-1 MESs and the Radio Astronomy Service based on average and extreme potential interference situations indicates that the LEOTELCOM-1 MESs will not cause interference to radio astronomy observations. In addition, the radio astronomy community has concluded that LEOTELCOM-1 emissions are acceptable, provided the system complies with the standards and specifications given.

A1.1.4.1 Up-link

Based on the results of its study efforts, it was concluded that subject to the operational constraints given in this section, the probability of interference from LEOTELCOM-1 MESs to terrestrial analogue PMR base and mobile stations is sufficiently low that it is expected to result in little significant degradation of service availability.

Sharing between LEOTELCOM-1 MESs and mobile service systems, based on studies taking into account a LEOTELCOM-1 constellation of a maximum of 48 satellites and 6 receivers per satellite is possible and adequate interference protection will be afforded to other primary services if the following baseline operating constraints are placed on MES transmissions:

Table 7: Operational constraints on LEOTELCOM-1

System NAME : LEOTELCOM-1	
OPERATIONAL CONSTRAINTS	
Up-link designated bands	148-150.05 MHz
Down-link designated bands	137-138 MHz
Multiple access method	FDMA
Modulation method	Narrow band Frequency or Phase modulation
Maximum MESs e.i.r.p. spectral density	10 dBW/4 kHz
Technique to avoid causing interference from MESs	Dynamic channel avoidance assignment system (DCAAS as described in Recommendation ITU-R M 1039, annex 2 [25]) such that mobile earth stations avoid transmitting on the same frequency being actively used by terrestrial fixed or mobile stations.
Maximum burst duration for MESs transmission	500 msec
Maximum duty cycle for MESs	Not greater than 1% in any 15 minute period for any single channel
Maximum duty cycle for system control bursts	Not greater than 1% in any 15 second period for any single channel
All MES traffic with the exception of the system control bursts	Consecutive transmissions from a single earth station on the same frequency shall be separated by at least 15 seconds

Trunked mobile radio and data systems are more susceptible to MES interference. Depending on the nature of the affected terrestrial system it may be necessary for some Administrations to implement additional national measures.

A1.1.4.2 Down-link

In the frequency band 137-138 MHz (downlink), the LEOTELCOM-1 system does not exceed the applicable pfd threshold at the earth's surface established by Annex 1 of Appendix S5 (Rev. WRC-97 [9]), relevant at the time when the studies were performed, therefore no co-ordination is necessary with terrestrial services, and no further action is necessary.

A1.1.4.3 Sharing with the Radio Astronomy Service

The operations of LEOTELCOM-1 will not cause interference to the Radio Astronomy Service, based on the studies described in Annex 3.

A1.2 DESCRIPTION OF HIBER

A1.2.1 General description

HIBERBAND® (also abridged as HIBER in the text) is a system using low cost and low power transmitters to send small packets of data directly to its constellation of 70 small low-earth orbit ("LEO") nanosatellites. The system is designed to provides non-voice, non-geostationary ("NVNG") mobile satellite services ("MSS") in the 400.15-401 MHz (space-to-Earth) and 399.9-400.05 MHz (Earth-to-space) bands. The first two satellites of the constellation are already in orbit and are enough to cover 100% of the Earth's surface reliably, while providing high battery life (>10 years) and low connectivity cost with a maximum latency of 100 minutes. Interference between HIBER's satellites and those of other systems in this band is unlikely because the HIBER system will communicate only in short bursts of no more than 4 seconds while in view of a satellite passing overhead. Coordination with other users can be easily accomplished via sharing by channel and by time.

A1.2.2 Technical characteristics

A1.2.2.1 System Description

HIBER is composed of a fleet of communication nodes deployed with the assets, a satellite constellation at 600 kms of altitude, owned by HIBER and a supporting data processing infrastructure. HIBER consists of a modem based on our design and our proprietary firmware (embedded in all enabled devices), our own satellite constellation and our own data processing system. The topology of the HIBER network includes (see Figure 4):

- The application gathers data;
- The data is handed over to the modem, (typically) embedded in the device;
- The modem communicates and transmits the data to our satellite;
- The satellite stores all collected data;
- Once in view of a gateway, the data is forwarded back to Earth;
- From here, the messages are processed and stored for pickup or forwarded to the systems of the owner.

As seen from the control flow, the modem needs to know its exact location to be able to decide when it can transmit to the satellite. A lot of applications need a GPS location, such as tracking, so getting an exact location is not an issue. In the case of static (i.e. non-moving) use cases the customer can also set the current location through the modem API. This doesn't need to be a very exact location, anything within a few kilometres is precise enough, within a few 100 meter would be preferred.

The front-end is basically switching between TX and RX mode and is half duplex. The satellite broadcasts with a fixed interval, and during that time no modems should transmit. This assumes accurate synchronised time in the system. Modems with GPS already have accurate time and those without get a time update through every broadcast. This allows for precise timing of transmissions and it allows the whole network to switch between these modes synchronously.

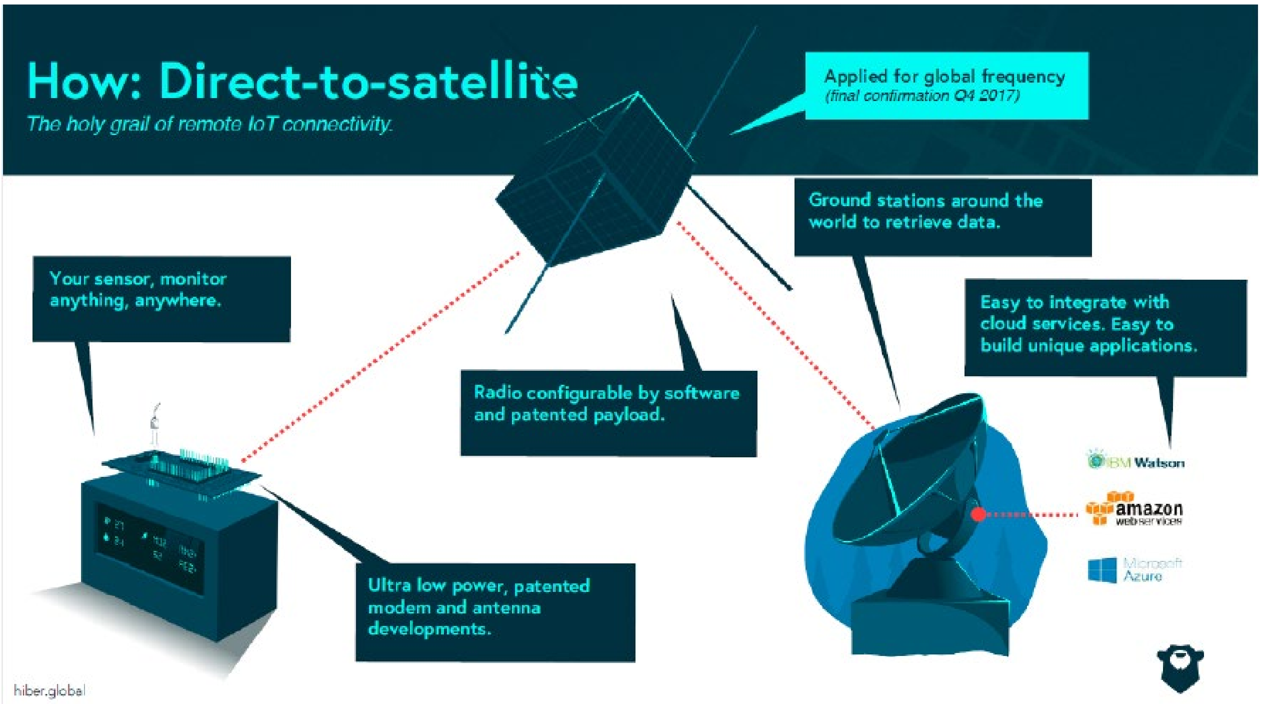

Figure 4: HIBER's overall architecture

A1.2.2.2 Access Scheme

The MES user terminals mainly use Code-division Multiple Access (CDMA) for random access as this scheme is known to better support asynchronous low power transmissions. The main feature of asynchronous CDMA is that each message sent by each terminal is spread over the available frequency bandwidth and multiplied by a long pseudo-random scrambling code. The fact that the messages of different terminals reach the satellite asynchronously allows the demodulator to distinguish them and recover each message by de-spreading it based on its time of arrival. Hence, the messages have a relatively high probability of getting successfully decoded even when they experience interference.

This tolerance to interference enables true random access at a single frequency without the need for synchronisation among different terminals nor for channel sensing before transmission. As a result, using asynchronous random access with CDMA eliminates the synchronisation overhead on the uplink channel and reduces the risk for system congestion caused by multiple access attempts.

To further decrease the risk of interference, the satellite will use the downlink to collectively instruct the terminals on the repetition period of their transmissions, which will maximise the probability that users will get their messages successfully decoded. By doing so, the satellite can actively maintain the traffic at the point of optimal efficiency, avoiding system congestion due to destructive interference to messages.

This traffic control is also extremely important from the viewpoint of reducing interference to other systems, by limiting access attempts to the strict minimum. Further, the low duty cycle described above together with the geographical distribution of the MES user terminals reduces to a minimum low the probability of signal interference.

In short, E-SSA proposes a signal cancellation method through which the power unbalance between transmission is less of a problem, even though it is a CDMA / spread spectrum signal.

A1.2.2.3 User Links

For the service uplink, in the frequency band 399.9-400.05 MHz, HIBER initially operates in one channel of 120 kHz, using Code Division Multiple Access (CDMA) spread spectrum. Yet, HIBER has the flexibility and spectral efficiency to operate with similar systems in this band by varying the bandwidth of their satellites' emissions as to potentially accommodate other users of the bands according to international coordination agreements. No intra sharing studies are needed regarding the frequency band 399.9-400.05 MHz (Earth-to-space) since there is no current utilization in Europe by any other system in this band that have followed the procedure as stated by the relevant European – CEPT regulatory framework. HIBER's proposed operations in the 399.9-400.05 MHz band is consistent with the ECA Table [22]. The MES user terminals can transmit uplink messages up to 1400 bits in size, and the duration of each transmission will be from less than a half second to a maximum of 4 seconds, depending on the bandwidth used and other factors. Even the longest possible transmission time of 4 seconds within the integration time of 15 minutes corresponds to a duty cycle of only 0.4%.

HIBER's broadcast service downlinks, in the frequency band in the band 400.15-401 MHz, initially operate in one channel of 150 kHz, using GFSK modulation. This link is used for broadcasting firmware updates and other broadcast data to the earth stations. Yet, HIBER has the flexibility and spectral efficiency to operate with similar systems in this band by varying the bandwidth of their satellites' emissions as to potentially accommodate other users of the bands according to international coordination agreements. HIBER will start transmitting between its satellites and ground stations once a day and will increase over time to approximately 100 times a day over four years. The length and intervals of such broadcasts are configurable by HIBER. The size of the transmissions could range from a few bytes to a few hundred kilobytes in intervals of 10 seconds. The duration of each broadcast transmission will be from 400 milliseconds (typical) to a maximum of 1 second every 10 seconds. These burst transmissions, within the integration time of 15 minutes, correspond respectively to duty cycles ranging from 4% to a maximum of 10%.

All HIBER satellites will be capable of instantaneous shutdown themselves and its associated mobile terminals on the ground, in compliance with ETSI EN 301 721 [20].

Table 8: HIBER's orbital parameters

Orbital Parameters										
# of satellites	70									
Altitude (km)	600									
Inclination (°)	97.8° for each plane									
Orbital Planes	8									
Satellite/Plane	7	7	7	7	7	7	7	7	7	7
Right ascension of ascending node (°)	0	18	36	54	72	90	108	126	144	162

Table 9: Subscriber uplink parameters

Subscriber Uplink	
Band (MHz)	399.9-400.05
Tx Power (W)	1 W
Tx e.i.r.p. (dBW)	5 dBW
Maximum Tx Antenna Gain	5 dBi at 0.4005 GHz
Antenna Pattern	Patch
Channel BW(kHz)	120 kHz
Rate (kbps)	4.17 kB/s
Polarisation	Linear / Circular (RHCP)
Sat Rx G/T (dB/K)	-28.00 dB/K
Maximum Rx Antenna Gain	2.5 dBi

Table 10: Subscriber downlink parameters

Subscriber Downlink	
Band (MHz)	400.15-401
Satellite Tx Power (W)	10 W
Satellite Tx e.i.r.p. (dBW)	12.5 dBi
Maximum Tx Antenna Gain	2.5 dBi
Antenna Pattern	(Note 1)
Channel BW(kHz)	150KHz
Rate (kbps)	25 kBit/s
Polarisation	RHCP
Subscriber Rx G/T (dB/K)	-38.9 dB/K
Maximum Rx Antenna Gain	5 dBi at 0.4005 GHz
Note 1: Radiation patterns for the Antenna of the HIBER modem Radiation patterns for the Satellite UHF Antenna	

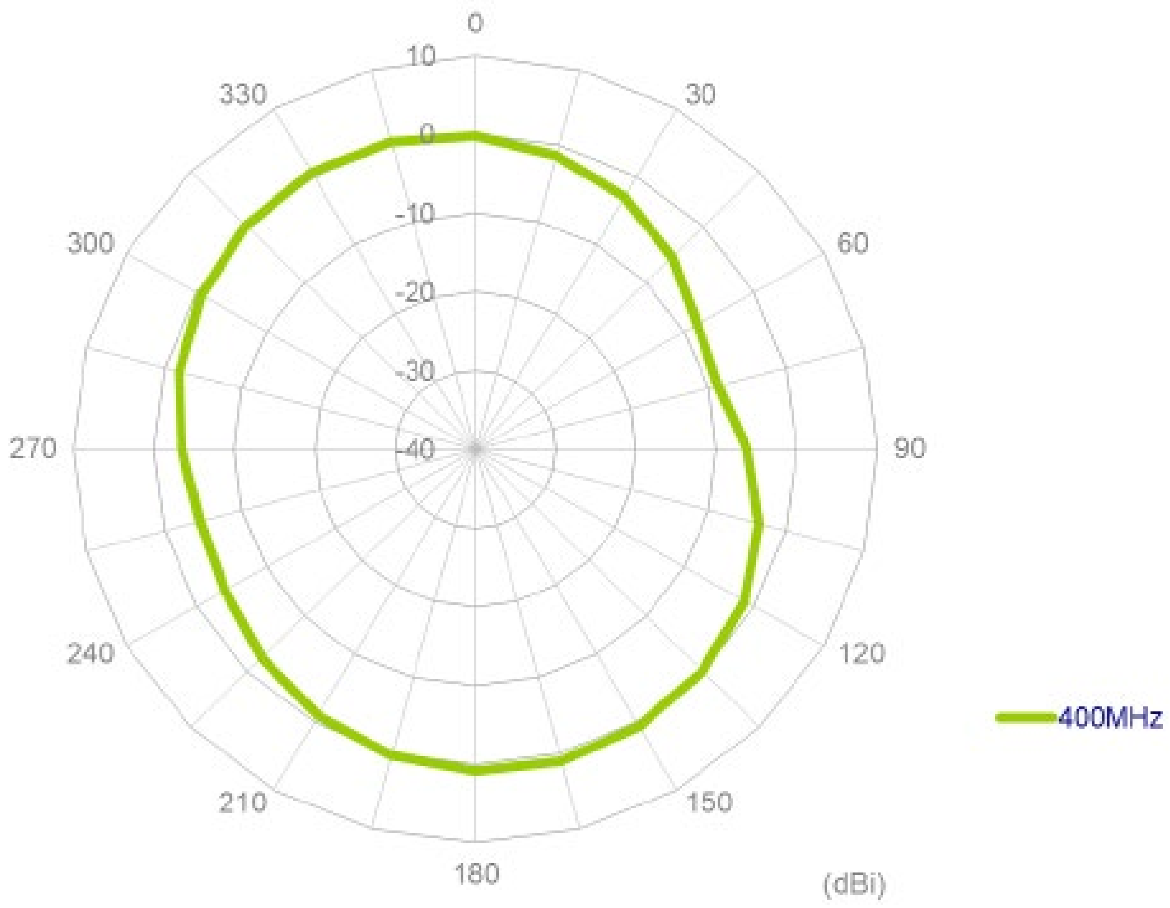

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Figure 5: Radiation pattern, MES, azimuthal plane

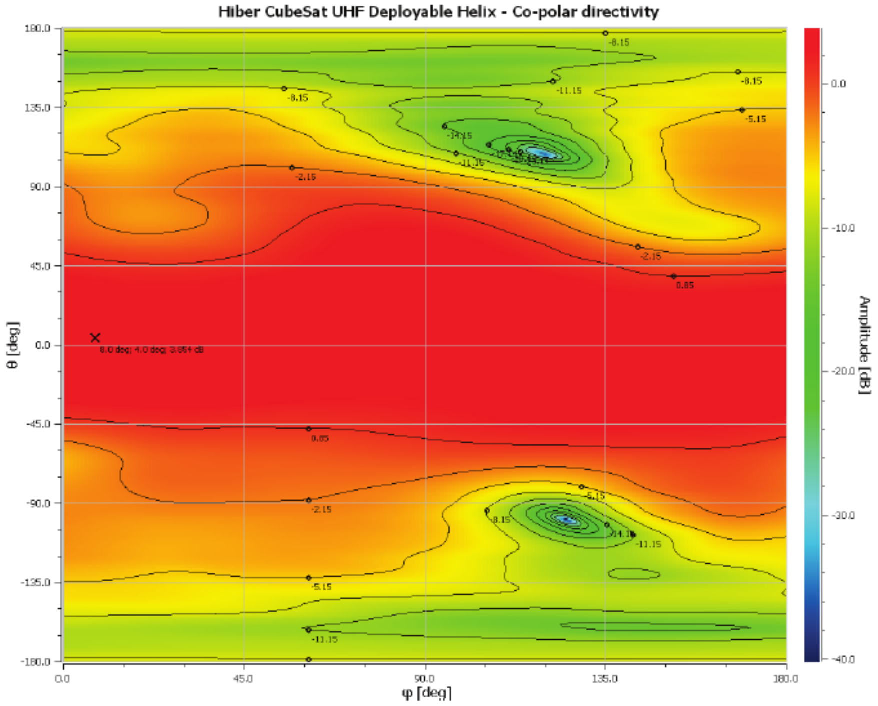


Figure 6: Satellite antenna radiation pattern, co-polar

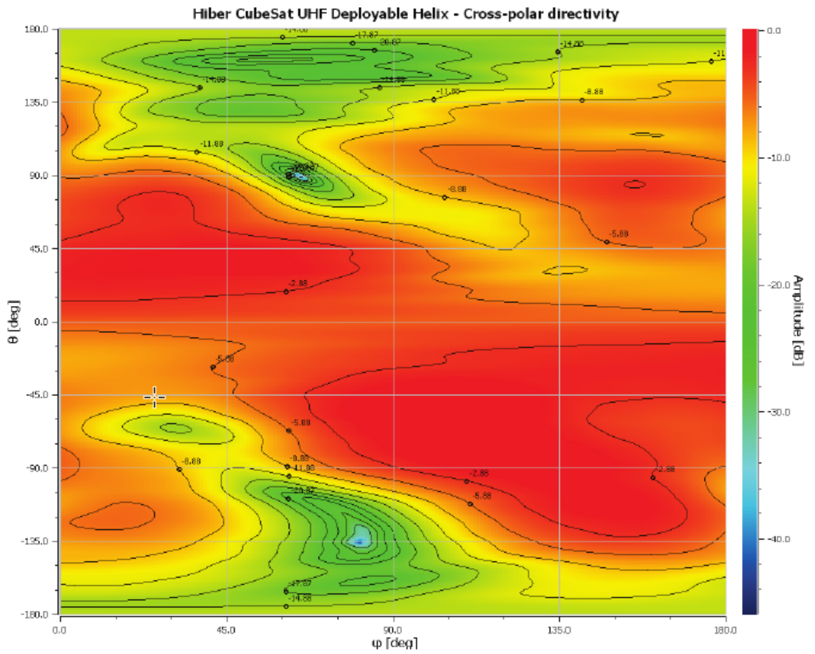


Figure 7: Satellite antenna radiation pattern, cross-polar

A1.2.3 Inter-service studies

HIBER uses the band 399.9-400.5 MHz for its up-link and the band 400.15-401 MHz for its down-link.

The following is an extraction from the EFIS database (https://efis.cept.org/) regarding the bands used by HIBER.

Table 11: HIBER adjacent and in-band frequencies

	Lower Frequency	Upper Frequency	Allocations	Applications
Adjacent	395 MHz	399.9 MHz	MOBILE	Defence systems/PMR/PAMR
HIBER UL	399.9 MHz	400.05 MHz	MOBILE-SATELLITE (EARTH-TO-SPACE)	PPDR
Adjacent	400.05 MHz	400.15 MHz	STANDARD FREQUENCY AND TIME SIGNAL- SATELLITE (400.1 MHZ) (400.1 MHz)	PPDR
HIBER DL	400.15 MHz	401 MHz	METEOROLOGICAL AIDS METEOROLOGICAL-SATELLITE (SPACE-TO-EARTH) MOBILE-SATELLITE (SPACE-TO-EARTH) SPACE OPERATION (SPACE-TO-EARTH) SPACE RESEARCH (SPACE-TO-EARTH)	PPDR/Sondes/Weather satellites/S-PCS
Adjacent	401 MHz	402 MHz	EARTH EXPLORATION-SATELLITE (EARTH-TO-SPACE) METEOROLOGICAL AIDS METEOROLOGICAL-SATELLITE (EARTH-TO- SPACE)	Sondes/Weather satellites/Active medical implants

Regarding the up-link component of the HIBER system, the band is exclusively allocated to the MSS, and there is no need to conduct in-band inter-service studies.

Regarding the down-link component of the HIBER system, the band is also allocated to the following services: meteorological aids, space operation (secondary), and meteorological-satellite service.

With regard to the band 400.05 MHz to 400.15 MHz it is agreed that under AI 1.2 of WRC-19 [9] that the band 400.02 MHz to 400.05 MHz will not have any uplink limits and will be within three years primarily be used by incumbent operators for high e.i.r.p./e.i.r.p TT&C operations and no longer by HIBER (and probably ARGOS). With a gap of 30 kHz between HIBER's future low power DCS operation it is highly unlikely that there will be any measurable out of band emission into 400.05-400.15 MHz from HIBER's future operation but instead quite likely emissions from incumbent TT&C operators operating in 400.02-400.05 MHz. This argument ought to address the out of band emission matter between HIBER's ITU filed 399.9-400.05 MHz and the 400.05 - 400.15 MHz band in the compatibility report

The TT&C component of HIBER has not been studied because it falls outside the scope of this Report, and it is considered that will be dealt with at the national level.

A1.2.3.1 Up-link

Regarding HIBER's MSS operations in the band 399.9-400.05 MHz, and according to Report ITU-R M.2359-0, the MSS terminals will not cause interference to the 406-406.1 MHz band, therefore protecting the Cospas-Sarsat system. Indeed, the characteristics of the MSS terminals in this band are similar to the PCM/FM data collection platforms as in ITU-R Report M.2359-0, table 5-1, taking into account the previous conclusion, and noting that this MSS band is further than the DCP band 401-403 MHz from the 406-406.1 MHz band, MSS terminals are therefore not likely to cause interference to the 406-406.1 MHz band.

The ECA table identifies the ECC Decision (08)05 [19] for "The harmonisation of frequency bands for the implementation of digital Public Protection and Disaster Relief (PPDR) narrow band and wide band radio applications in bands within the 380-470 MHz range" to affect the frequency band 399.9-400.05 MHz. However, PT FM44 is already aware that this seems to be an inconsistency that needs to be amended since the frequency band 399.9-400.05 MHz is not addressed by the ECC Decision (08)05 itself, nor by any of the frequency arrangements for mobile systems.

Pursuant to Agenda Item 1.2, considered at the World Radiocommunication Conference (WRC) in 2019, the relevant working parties under the ITU agreed to limit e.i.r.p. in this band to 5 dBW. HIBER's operations are envisaged to comply with the adopted limit by November 2022.

A1.2.3.2 Down-link

As provided by RR 5.264 [9], the pfd threshold indicated in Annex 1 of Appendix 5 of the ITU Radio Regulations shall be used as a coordination trigger in the 400.15-401 MHz band with respect to terrestrial services. That pfd threshold is -125 dBW/m2/4 kHz at the Earth's surface.

In Annex 1 of Appendix 5 of the ITU Radio Regulations limits are set to apply in the 400.15-401 MHz band. The following assumptions have been made:

- Channel bandwidth BWCh =150 kHz;
- Transmitter power Pt=10 W;
- Antenna gain G = 2.5 dBi;
- Distance to Earth R = 600 km;
- Bandwidth of interest BWmsr=4 kHz.

Under the assumptions provided above, the pfd is -129.79 dBW/m^2/4 kHz. This downlink pfd is less than the ITU-specified coordination trigger of -125 dBW/ m^2/4 kHz at the Earth's surface.

In the frequency band 400.15-401 MHz (downlink), HIBER will not exceed the applicable power flux density (pfd) threshold at the earth's surface established by Annex 1 of Appendix 5 (Rev.WRC-12) therefore, no co-ordination is necessary with terrestrial services, and no further action is necessary.

A1.2.3.3 Radio Astronomy service (RAS)

Radio astronomy observations in the 406.1-410 MHz band are carried out in several countries within the CEPT as indicated in Annex 3.

To safeguard radio astronomy services in the band 406.1-410 MHz, the International Telecommunications Union (ITU) provides limits on spurious emissions in this band via its Resolution 739 [23] and Recommendation RA.769 [3]. This section concludes spurious emissions of at most -227.7 dBm/Hz/m^2 (typical maximum -235.1 dBm/Hz/m^2 in 3.9 MHz), in compliance to the requirement of Recommendation RA.769 [3]. A full constellation analysis with 70 MK1 satellites shows that for 1.8% duty cycle, ITU-R Resolution 739 [23] is met. For 10% duty cycle, it is only met for limited latitude values, and a lowering of maximum duty cycle, constellation size, application of mitigation techniques and/or satellite redesign is recommended.

HIBER's mark 1 (MK1) satellites contain a space-to-earth communication system, dubbed the "broadcast" link which, among others, is used for synchronisation with the earth stations, the "communication nodes", and transfer of satellite based information. With this link, the satellites transmit GFSK modulated packets with a carrier frequency of 400.575 MHz at a baudrate 50 ksym/s (bandwidth roughly 100 kHz).

Laboratory measurements were carried out to determine the o.o.b. emissions of MK1 satellites. They are presented below.

INITIAL CALIBRATION

In order to measure the emissions of MK1 satellites, it was necessary to insert an attenuator in the measurement chain. The attenuator was measured to have a value of 30.1 dB with an excellent return loss. The SAW filter was seen to have an insertion loss of 1.6 to 1.8 dB in the band of interest, with a return loss smaller than -17 dB (see Figure 8). Rejection of the broadcast signal was found to be around 32 dB.

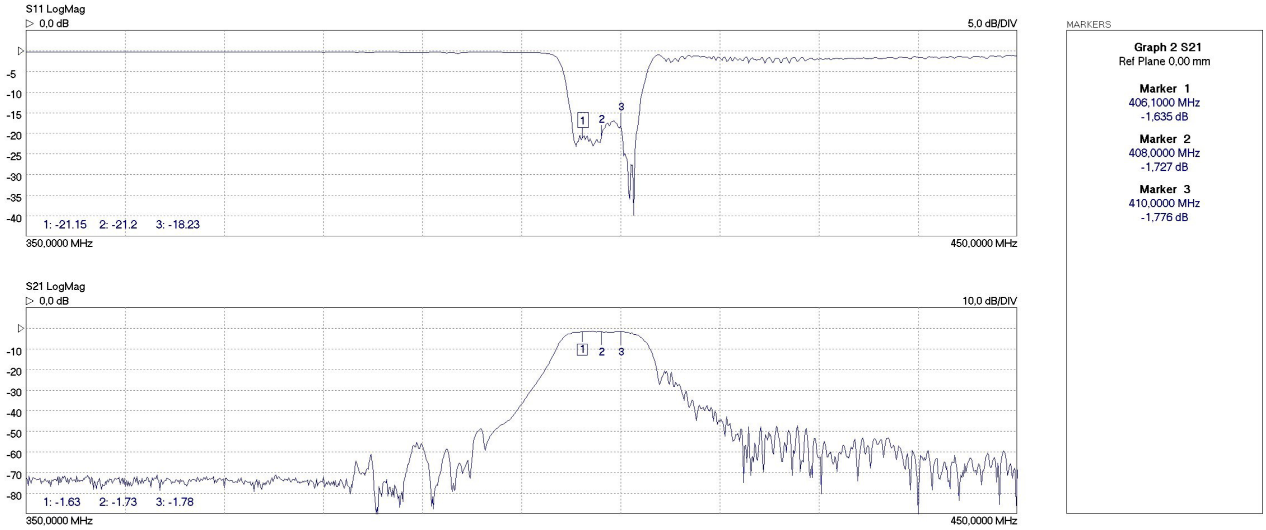


Figure 8: SAW filter scattering parameters

For the power measurement setup, the paths from payload to spectrum analyser, including all cabling and connectors, resulted in -30.6 dB transfer throughout the band of interest. For the spurious emissions setup, this was -32.4 dB at 306.1 MHz, -32.2 dB at 410 MHz.

POWER MEASUREMENT

The power of the broadcast packets after attenuation was measured to be 6.8 dBm. Taking the initial calibration into account, this results in 37.4 dBm at the output of the payload.

SPURIOUS EMISSIONS MEASUREMENT

The power spectral density (PSD) of the filtered signal, with max hold exposure of 2000 seconds, can be seen in Figure 8. The values -125.8 and -123.1 dBm/Hz were obtained at 406.1 and 410 MHz, respectively, resulting in path- compensated values of -93.4 and -90.8 dBm/Hz, respectively.

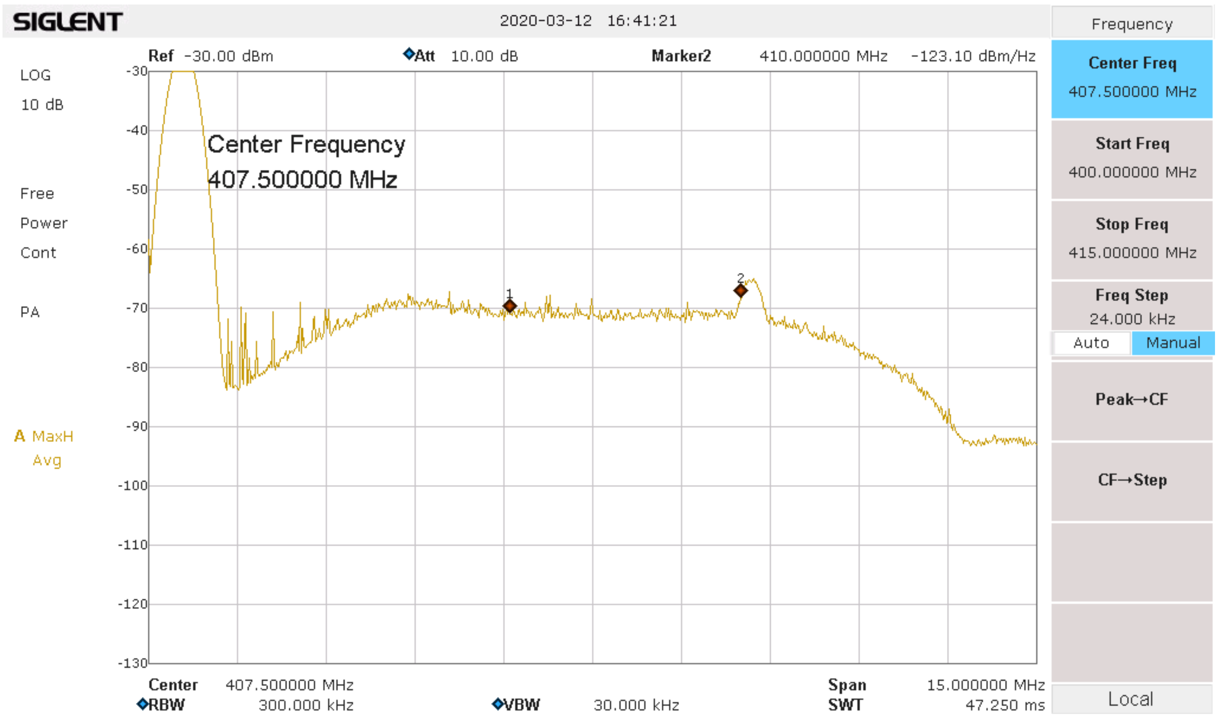


Figure 9: Power spectral density of spurious emissions

POWER FLUX SPECTRAL DENSITY ANALYSIS

In a simplified single satellite analysis, the upper-bound of the power flux spectral density (PFSD) of a single HIBER MK1 satellite is -235.1 dBm/Hz/m^2 for a duty cycle of 1.8%, and -227.7 dBm/Hz/m^2 for 10%, in conformity with Recommendation ITU-R RA.769 [3]. Subsequently, we move to a detailed full constellation analysis, where we prove that the average equivalent PFSD of the constellation stays below the target of -277.9 dBm/Hz/m^2 of ITU-R Resolution 739 [23] during at least 98% of time for 1.8% duty cycle. For 10% duty cycle, this is only valid for locations not too near the poles

a) Single satellite analysis

As preliminaries, and to better understand the situation when there are multiple satellites involved, we begin by computing the worst-case PFSD on the ground for a single satellite. The broadcast channel is not in continuous operation. Typical operation of this channel consists of a periodic transmission of a burst of 5 packets, with a total duration of 180 milliseconds and period of 10 seconds. This results in a duty cycle of 1.8% with an average spurious emission PSD given in log units by

$PSD_{spurious} = PSD_{spurious,full} + 10\log_{10}(0.018) =$ -110.8 dBm/Hz at 406.1 MHz
-108.2 dBm/Hz at 410.0 MHz

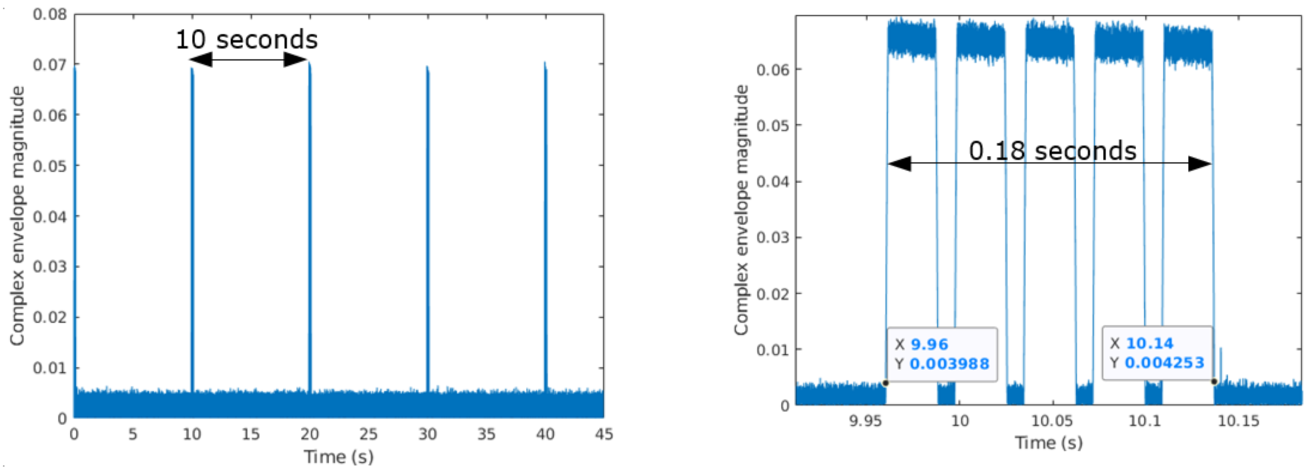


Figure 10: SDR recording of broadcast packets

The maximal gain of MK1 antennas was measured to be 2.5 dBi at the operating frequency of 400 MHz, which corresponds to 1.8 dBi RHCP gain. A drop of at least 2.3 dB at 406.1 MHz and 6.0 dB at 410 MHz was measured by the manufacturer, hence the transmitter gain values of $G_{t,max}$ = 0.2 and - 3.5dBi will be used, respectively.

The distance to an eventual radio telescope is taken to be the worst case value of d = 473.4 km, corresponding to a boresight situation, with HIBER-1 at is perigee and the radio telescope on the equator. The power flux spectral density is then (in log units)

$PFSD_{spurious} = PSD_{spurious} + G_t - 10\log10(4\pi\, d^2) =$ -235.1 dBm/Hz/m^2 at 406.1 MHz
-236.2 dBm/Hz/m^2 at 410.0 MHz

The worst value of -235.1 dBm/Hz/m^2 is taken. Recommendation RA.769 [3] imposes a limit of -189 dB(W/m^2) – 10log10(3.9×10^6) dBHz + 30 dB(mW/W) = -224.9 dBm/Hz/m^2 on this PFSD, which makes HIBER compliant with this recommendation, even in the measured and computed worst case scenario.

For the proposed maximal duty cycle of 10%, one can redo the computations by replacing 10log10(0.018) by 10log10(0.1). One arrives at -227.7 dBm/Hz/m2, still within the regulation.

b) Full satellite constellation analysis

Simulations were performed with different locations of the radio-telescope. The first location was set at coordinates (latitude, longitude) = (46.9, 2.4) degrees, in the middle of France, in accordance with ITU-R Report SM.2091-0 [13], but also at (50,0) degrees, as indicated by CRAF. The third location was (54.8222, 37.6314) degrees, corresponding to the Pushchino observatory in Russia. These locations were chosen in accordance with ITU-R Report SM.2091-0 [13], the Committee on Radio Astronomy Frequencies (CRAF), and the Russian Federation, respectively. Regarding the number of iterations, we use N_{trials} = 500. This number was determined beforehand to produce stable estimates of the 98th percentile of EPFSD (this is the EPFSD which is not exceeded more than 2% of the time). Regarding EPFSD internals, as transmitter gain, we use the radiation pattern of HIBER MK1 normalised to the values $G_{t,max}$ of Section 2.2.3.3, clause a. The receiving radio- telescope was modelled using ITU-R RA.1631 [14] with maximum gain $G_{r,max}$ = 53 dB and corresponding antenna diameter 104.46 meters (see Figure 11).

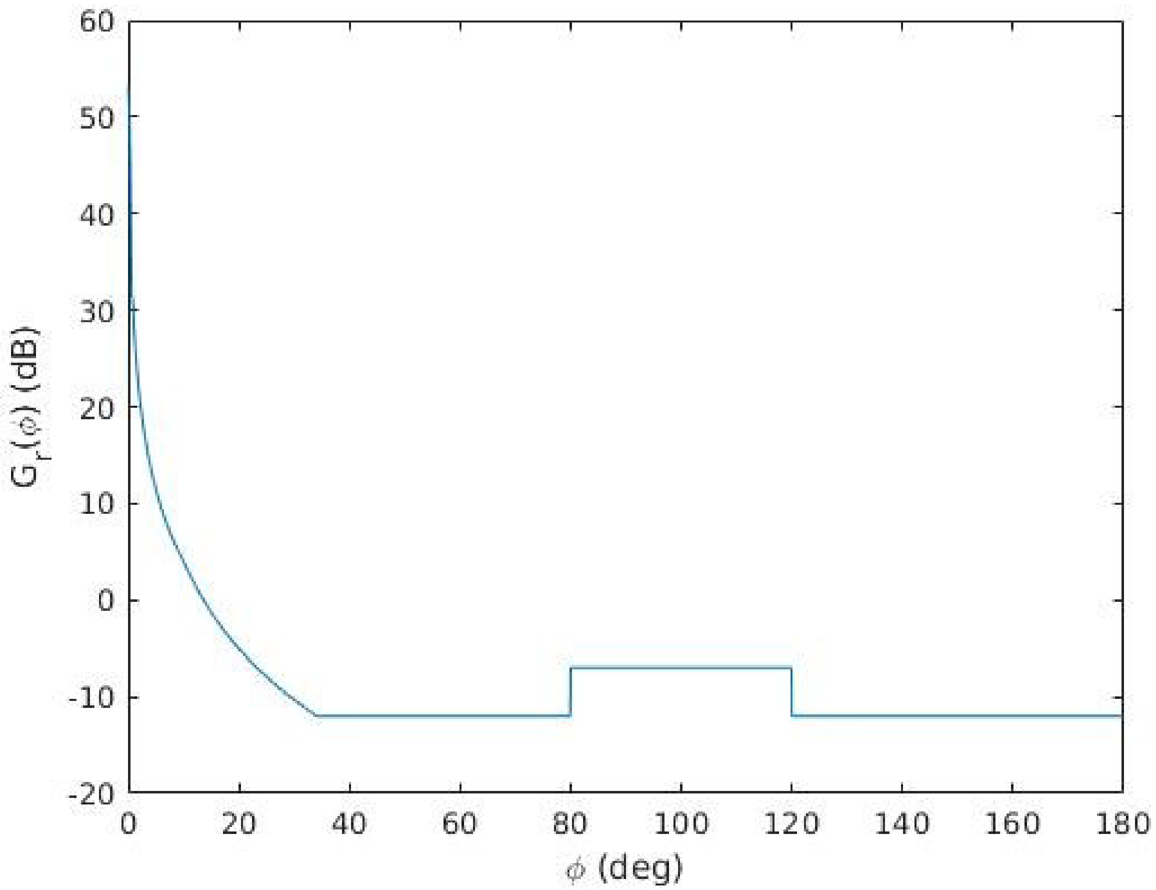


Figure 11: Prototype radio telescope gain according to ITU-R RA.1631 [14]

Finally, for the active and visible cells, the value PSD = $PSD_{spurious,full}$ + $10\log_{10}(d/0.1)$ is used, derived from the single satellite analysis, where we simulate duty cycles d = 1.8% and 10%. Note that an alternative to the $10\log_{10}(.)$ term to produce duty cycles lower than 10% would be to increase time resolution. Nevertheless, it was found that the latter did not produce significantly different results, but increased execution time significantly. Here, the frequency leading to the highest spurious e.i.r.p., which is 406.1 MHz was chosen.

The results of the simulation can be seen under the Table 12, Figure 12 and Figure 13.

Table 12: Full constellation simulation: Global loss ratios with corresponding estimation standard deviations

Location \ Duty Cycle	1.8%	σ	10%	σ
France	0.78%	0.010%	1.94%	0.020%
CRAF	0.81%	0.013%	2.08%	0.023%
Pushchino	0.95%	0.013%	2.38%	0.028%

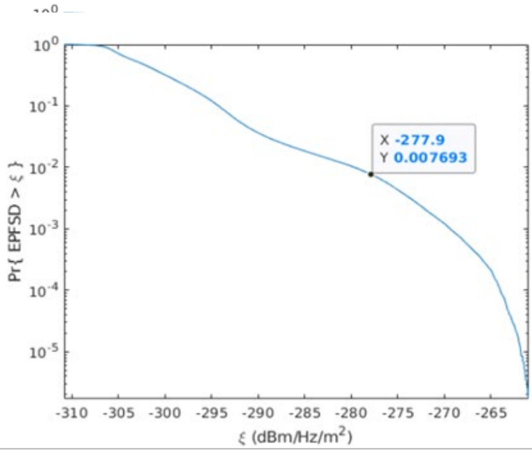
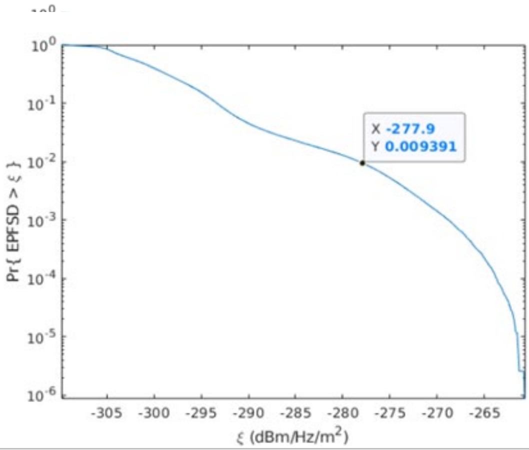
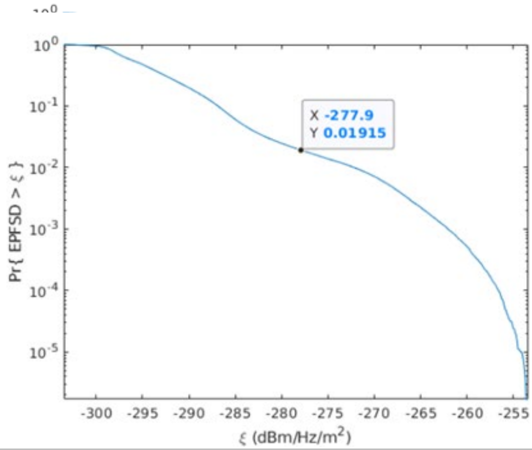
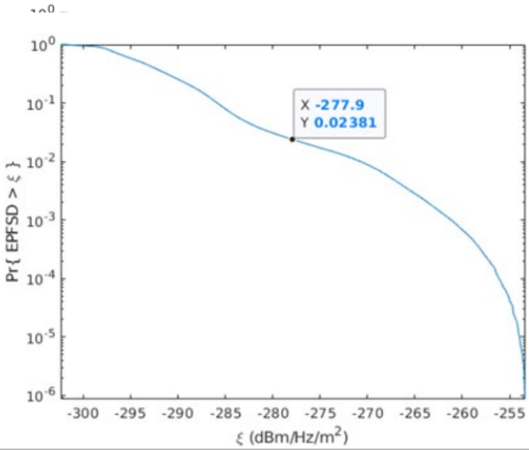
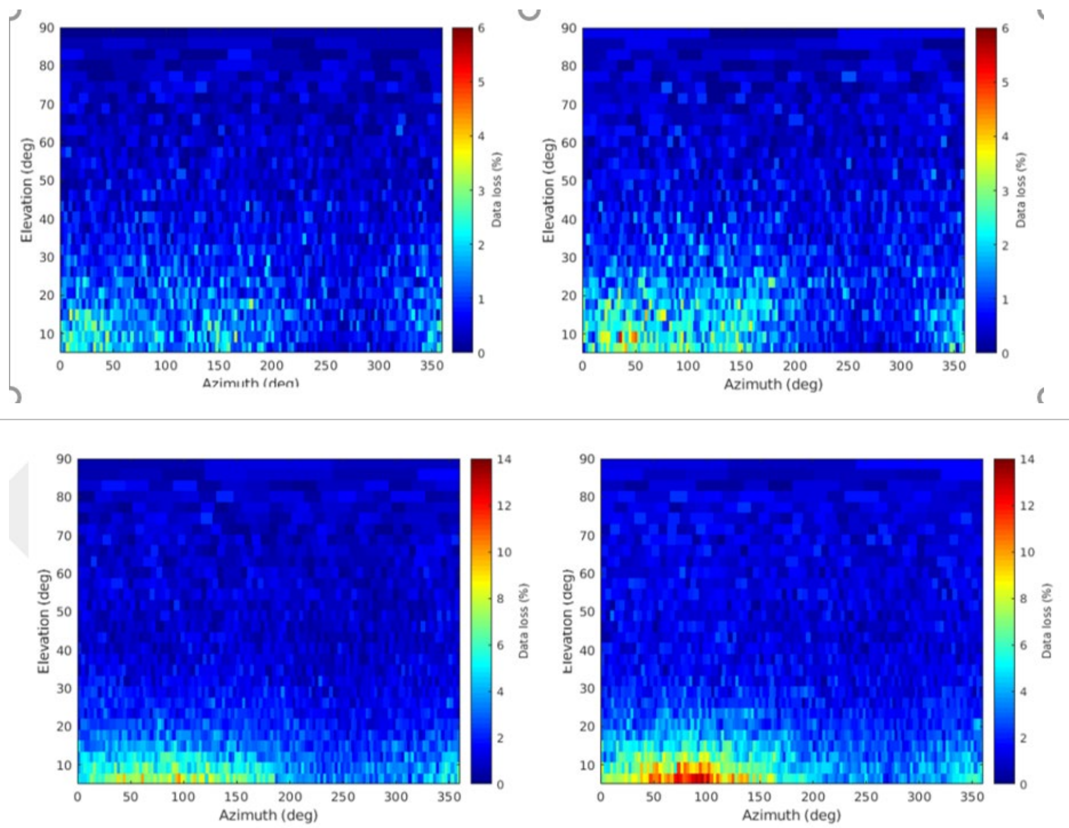
1.8%		
10%		
	France	Pushchino

Figure 12: Full constellation simulation: Complementary CDF

For 1.8% duty cycle, and according to ITU-R Resolution 739-1 [23], the loss ratios and CCDFs agree with regulatory limits not being exceeded more than 2% of the time. For 10%, this is only the case for the lower latitude. Also, the Figure 13 shows that most of the pollution is expected to occur in the low elevation region. As expected, the higher the latitude, the higher the experienced interference. This is the case since satellite visibility time increases as one gets closer to the poles. Hence, care must be taken with large duty cycles and radio telescopes near the poles.

1.8%

10%



France

Pushchino

Figure 13: Full constellation simulation: Loss ratios per cell

As it can be seen from the results, for the case of Pushchino mitigation techniques will have to be adopted.

c) Mixed duty cycles - HIBER's mitigation techniques

To push the values of Table 15 with duty cycle 10% under the regulatory limit of 2%, an alternative situation is proposed, where only a fraction of the constellation is allowed to have this elevated duty cycle. This is a reasonable assumption, since the 10% duty cycle scenario is only envisioned for transfer of large amounts of data to the communication nodes, like firmware updates. Clearly, not all satellites need to provide this data.

The simulation is repeated while restricting the satellite numbers multiple of 3 to have a duty cycle of 1.8%, while the remaining satellites keep 10% duty cycle. This results in 23 satellites with 1.8% and 47 satellites with 10% duty cycle (approximately one third and two thirds of the satellites, respectively). The results can be seen in Table 13 and Figure 14. With this configuration, all tested latitudes comply with the 2% norm of ITU-R Resolution 739 [23].

Table 13: Mixed duty cycle simulation: global loss ratios

Location \ Duty Cycle	Mixed	σ
France	1.58%	0.017%
CRAF	1.68%	0.021%
Pushchino	1.90%	0.024%

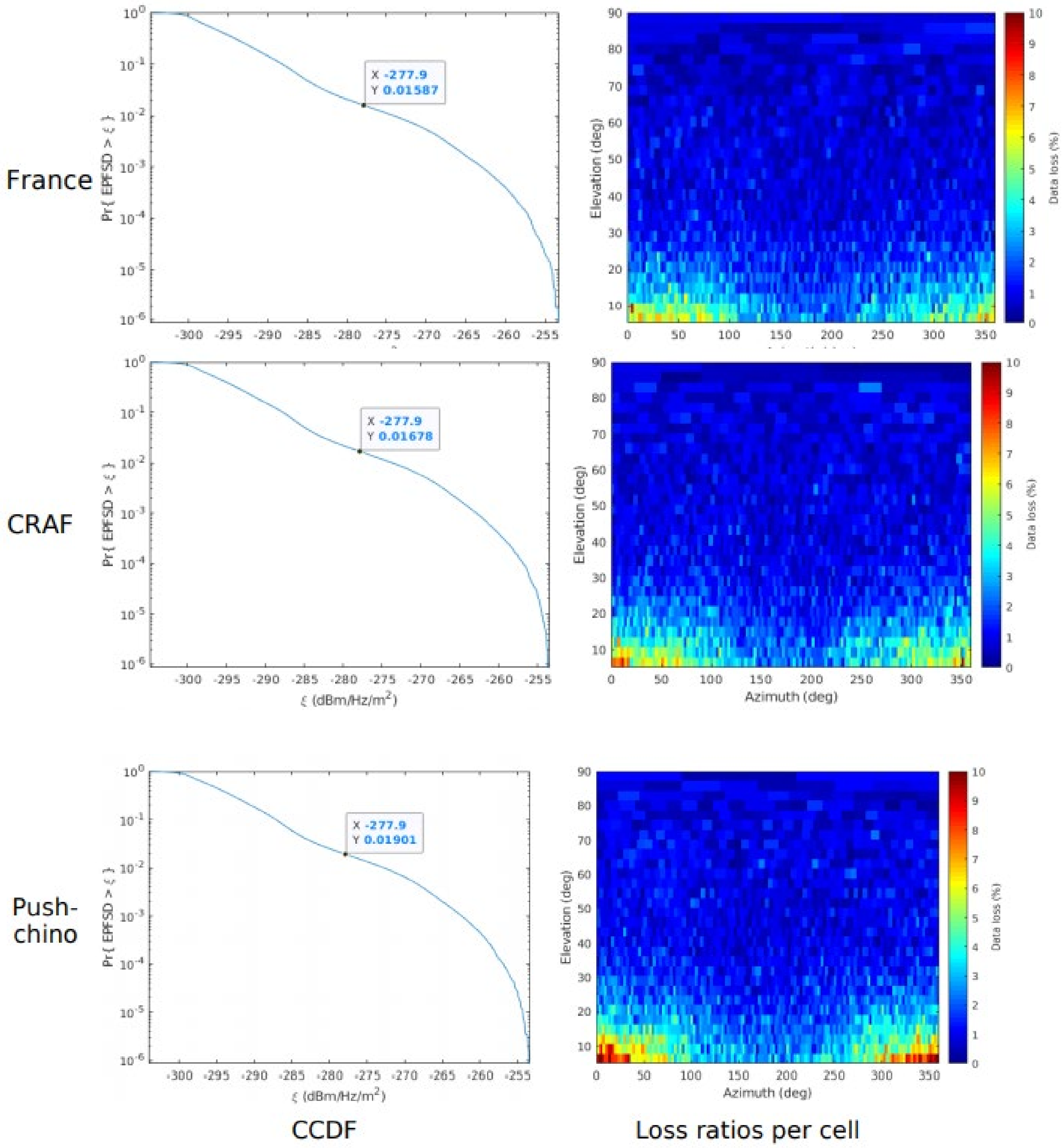


Figure 14: Mixed duty cycle simulation: Complementary CDF and loss ratios per cell

A1.2.3.4 Other existing services in the 400.15-401 MHz band

The 400.15-401 MHz band is allocated to the Meteorological Aids Service, Meteorological-Satellite Service (space-to-Earth), Mobile-Satellite Service (space-to-Earth), Space Research Service (space-to-Earth) on a co-primary basis and the Space Operation Service (space-to-Earth) on a secondary basis. There is no ITU-R Recommendation or other documentation providing technical characteristics, protection or sharing criteria for such systems with MSS operations in this specific frequency band.

A1.2.3.5 Standard frequency and time signal satellite (400.1 MHz)

Study 1

The standard frequency and time signal satellite (400.1 MHZ) service is allocated on a primary basis in the band 400.05-400.15 MHz.

The ITU does not stipulate limits on spurious emissions on the 400.05 to 400.15 MHz band allocated to Standard Frequency and Time Signal – Satellite (SFTSS) services. To ensure protection to the SFTSS is met, it was established a criterion on the interference- to-noise power spectral density ratio (I_0/N_0). The aim of this report is then to compare HIBER MK1's emissions in the SFTSS band to the limit values obtained using this criterion to determine protection of the SFTSS.

Assuming an example set of service stations summarised below, HIBER's studies conclude spurious emissions of at most - 193.7 dBm/Hz/m^2 (- 187.7 dBW/m^2 in 4 kHz), in compliance with the requirement of I_0/N_0 of at most -10 dB.

Table 14: SFTSS systems protection requirements

Network name	Admin	Receiver Gr/T (dB/K)	Limit PFSD (dBW/ m²/4 kHz)	Limit PFSD (dBm/m²/Hz)
TSYKADA	RUS	-23.0	-166.1	-172.1
LEOTELCOM-1	USA	-19.9	-169.2	-175.2
ICARUS	D	-44.8	-144.3	-150.3
F-SAT-NG-8	F	-27.0	-162.1	-168.1

The measured PSD of spurious emissions can be seen in Figure 15 (Markers are incorrectly placed. Correct values were read *a posteriori* from the exported data file, and those are the values used in this document). The values -135.8 and -132.2 dBm/Hz were obtained at 400.05 and 400.15 MHz, respectively, resulting in path-compensated values of -75.2 and -71.7 dBm/Hz, respectively.

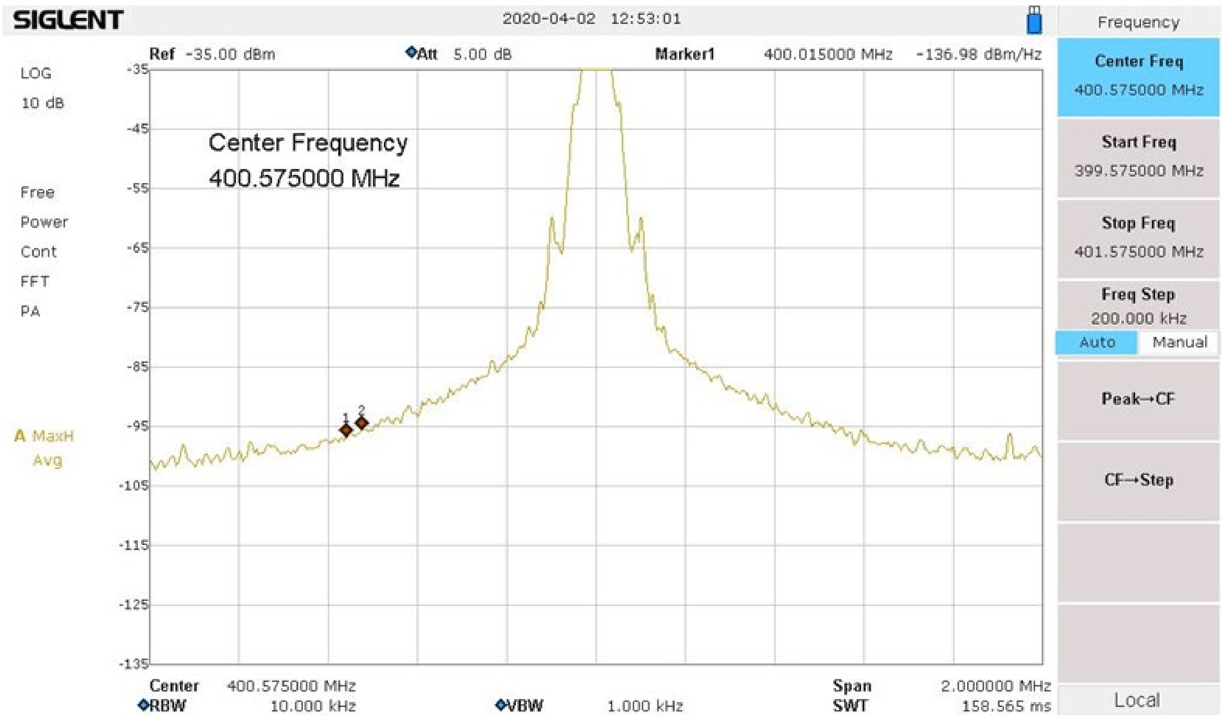


Figure 15: HIBER's PSD of spurious emissions

Single satellite scenario

Applying $PFSD_{spurious} = \frac{PSD_{spurious} \cdot G_t}{4\pi d^2}$ with the worst value of -71.7 dBm/Hz, with the worst case d = 473.4 km and G_t = 2.5 dBi, corresponding to 1.8 dBi RHCP gain, we obtain $PFSD_{spurious}$ = -193.7 dBm/m²/Hz, compliant even with the system with highest G/T of Table 14 by a large margin of 18.5 dB.

Multiple satellite scenario

Due to the large margin an upper estimate was found consisting of adding the powers of all satellites superimposed in the same most unfavourable position will suffice. This methodology will work for up to $10^{18.5/10}$ = 70.8 satellites, a number which is larger than the proposed maximum constellation size of 70 satellites. In other words, even if the 70 satellites were all emitting towards the most sensitive SFTSS receiver of the service stations summarised above and all with the lowest possible distance towards the receiver, the proposed criterion would still be met.

Study 2

The Standard frequency and time signal satellite (400.1 MHZ) service is allocated on a primary basis in the band 400.05-400.15 MHz. [Depending on the MSS (s-E) operation within a defined channel plan in the band 400.15-401 MHz, there may be two interference scenarios with SFTSS in the band 400.05-400.15 MHz (see Figure 16):

- The SFTSS signal frequency falls in the spurious emissions domain of the MSS (s-E) emissions (MSS (s-E) carrier is in the middle or in the upper part of MSS band);
- The SFTSS signal frequency falls in the out-of-band domain of the MSS (s-E) emissions (MSS (s-E) carrier is in the lower part of MSS band).

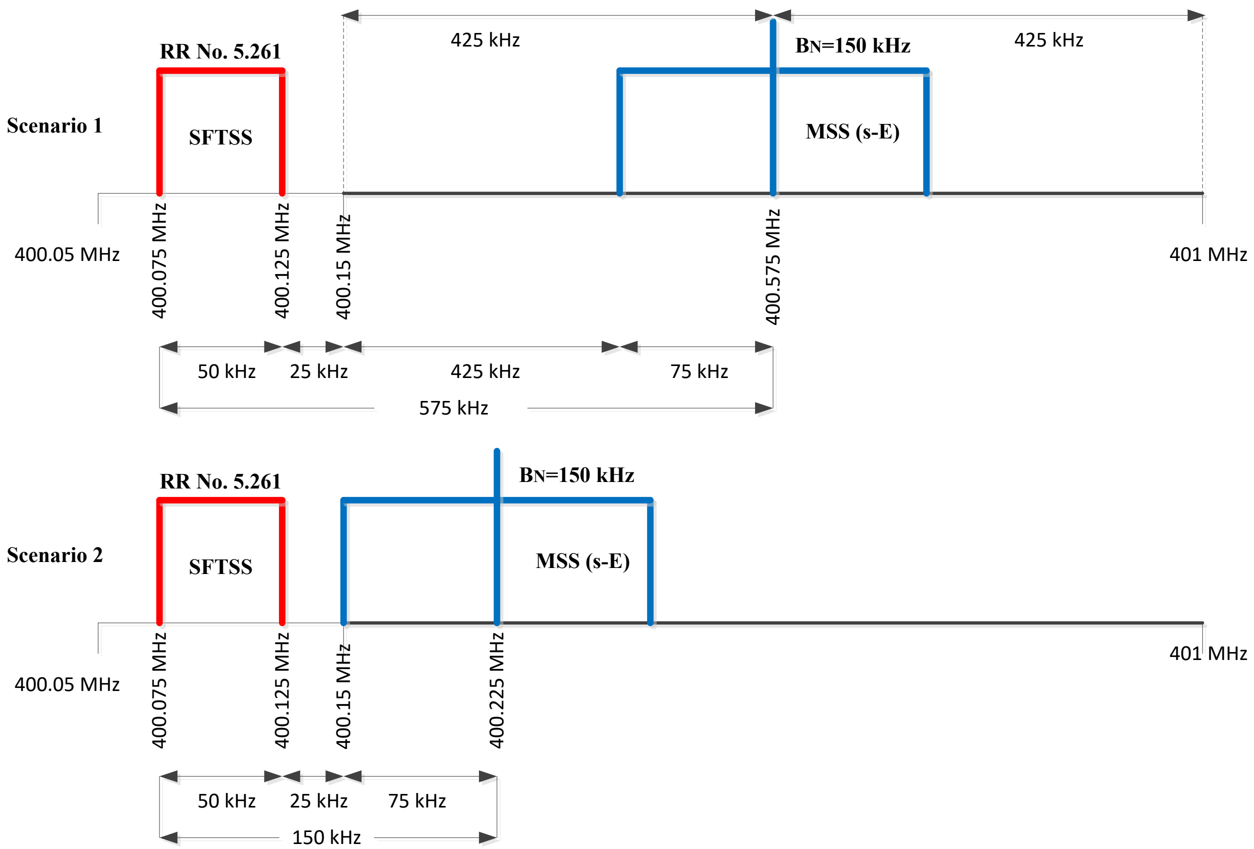


Figure 16: Interference scenarios with SFTSS

As it can be seen in Figure 16, the worst interference case (taking into account ChBW=150 kHz will be when MSS (s-E) carrier is 150 kHz away from the lower boundary of the SFTSS band (400.075 MHz).

In order to evaluate HIBER out-of-band emission PSD for the presented interference case, information about power spectral density of spurious and out-of-band emissions from section A1.2.3.3 was used (see Figure 17).

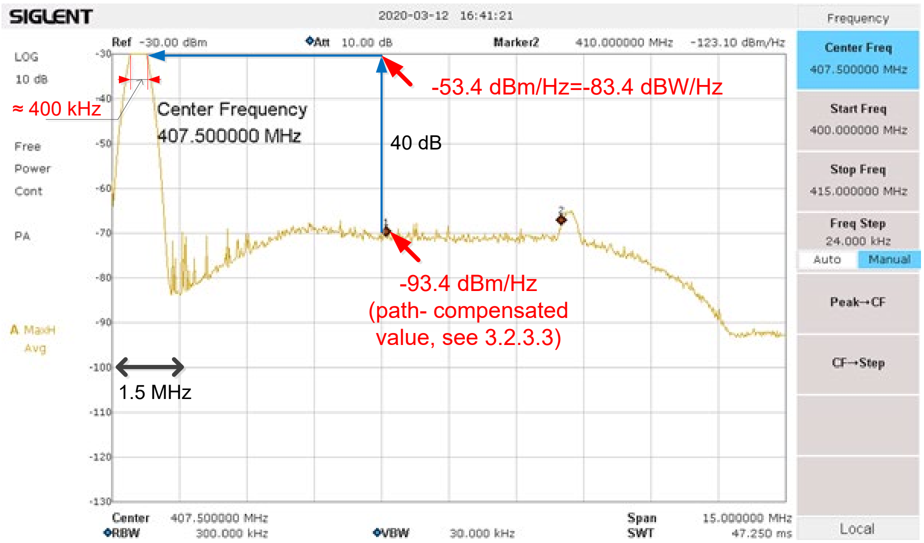


Figure 17: Power spectral density of spurious and out-of-band emissions (recalculation)

From the information presented the out-of-band emission PSD for the frequency offset from MSS (s-E) carrier of approximately 150-200 kHz (Scenario 2, see Figure 16) will not be lower than -53.4 dBm/Hz =-83.4 dBW/Hz or -47.4 dBW/4 kHz. For the frequency offset of approximately 550-600 kHz (Scenario 1, see Figure 16) PSD will be approximately 20 dB below or not lower than -73.4 dBm/Hz =-103.4 dBWHz or -67.4 dBW/4 kHz.

Simulation was performed (simulation time 30 days, simulation step 10 sec) to evaluate pfd within the adjacent band 400.05-400.15 MHz for two scenarios discussed (see Figure 16 and Figure 17). HIBER parameters were taken as presented in section A1.2.3.4 Orbital parameters from ITU-R filing HOL-MG-A006 were used. The receiving SFTSS ES was placed at a location with geographical coordinates 55N; 37E. The duty cycle was not taken into account.

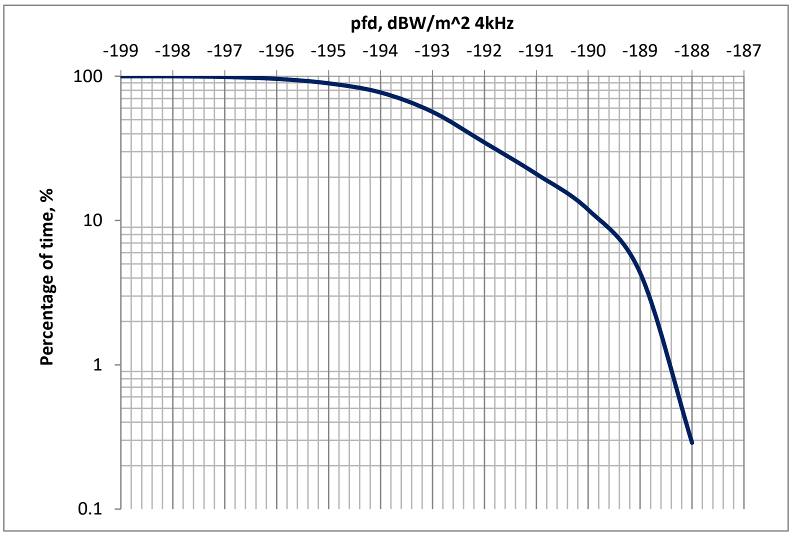


Figure 18: Power spectral density of spurious emissions, scenario 1

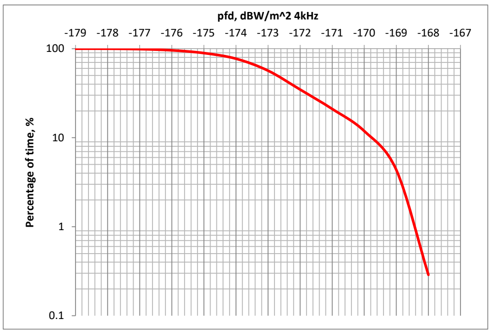


Figure 19: Power spectral density of out-of-band emissions, scenario 2

The following formula can be used to calculate the pfd value to protect SFTSS systems:

$$pfd = I - G - 10\ \log(\frac{\lambda^2}{4\pi}) \quad (1)$$

where:

- I: interference corresponding to the SFTSS system protection criterion (dBW);
- G: SFTSS system antenna gain (dBi);
- λ: wavelength (m)

For a given I/N criterion, interference can be represented as:

$I = \frac{I}{N} + N$ and N=kTB, then the formula for pfd in the reference band B=4 kHz takes the form:

$$pfd = \frac{I}{N} + 10\,log(\,kT4000) - G - 10\,log(\frac{\lambda^2}{4\pi})$$

The identified SFTSS network's characteristics are summarised as follows, and the right column provides the pfd value to meet an I/N of -10 dB protection criteria in the worst-case conditions.

Table 15: SFTSS systems and their protection requirement

Network name	Adm	Freq. min	Freq. max	Station class	Emission designator	E/S Rx Gain	E/S Noise temp	Worst case pfd (dBW/m²/4 kHz)
TSYKADA	RUS	400.075	400.125	EE	50K0G2D--	0	200	-166.1
LEOTELCOM-1	USA	400.075	400.125	EE	50K0G7D--	2	400	-165.1
		400.075	400.125	EE	50K0G7D--	6.1	400	-169.2
ICARUS	D	400.05	400.15	EY	5K00G1D--	-10	3000	-144.3
		400.05	400.15	EY	50K0G1D--	-10	3000	
F-SAT-NG-8	F	400.05	400.15	EY	50K0G7W--	0	500	-162.1
		400.05	400.15	EY	12K3G7W--	0	500	
		400.05	400.715	EY	1K00G7W--	0	500	

The simulated HIBER system pfd values within the adjacent band 400.05-400.15 MHz for scenario 1 are below pfd values calculated to protect the identified SFTSS systems with a margin of at least 19 dB (see Figure 18). For the identified scenario 2 and given assumptions pfd of out-of-band emissions could exceed the worst-case conditions value -169.2 dBW/m24 kHz up to 1.2 dB (see Figure 19).

This scenario 2 is not envisaged to be implemented and in such a case mitigation measures would need to be set in place.

A1.3 DESCRIPTION OF ARGOS KINEIS

A1.3.1 General description

The ARGOS KINEIS system aims at collecting data of all nature on a worldwide basis from small form factor, low-power devices, named “beacons”.

The ARGOS KINEIS system in composed of two kinds of satellites:

- A legacy component composed of ARGOS KINEIS payloads on board host satellites, generally polar orbiting MetSat satellites. Historically, the ARGOS KINEIS legacy payloads operate in the 401-403 MHz band. However, three ARGOS payloads with additional reception capabilities in the 399.9-400.05 MHz will be launched as hosted payloads in the 2020-2022 period. The first launch is scheduled during Summer 2020, with an ARGOS KINEIS s payload operating in the 399.9-400.05 MHz on board the Oceansat-3 satellite;
- The ARGOS KINEIS constellation. This constellation of 25 operational satellites will support the ARGOS service in both the 401-403 MHz band and the 399.9-400.05 MHz band, to provide continuity of service with respect to the legacy component and will provide better throughput and revisit performances. Each of the ARGOS KINEIS satellites embark an ARGOS KINEIS payload, and for some of them, a VHF maritime payload. The full deployment of the ARGOS KINEIS constellation is scheduled in 2022.

The beacons transmit at low duty cycle towards the visible ARGOS KINEIS satellites (constellation or legacy). Transmission may occur in the 399.9-400.05 MHz band or in the 401-403 MHz band, depending on the nature of the data. Once collected on board, the data are sent back to earth to the first visible “Ground station” encountered while the satellite is orbiting. ARGOS KINEIS will deploy around 20 stations worldwide, thereby ensuring that data are quickly delivered to the customers through the internet. This downlink data flow in the S band will also include the satellite payload and platform telemetry.

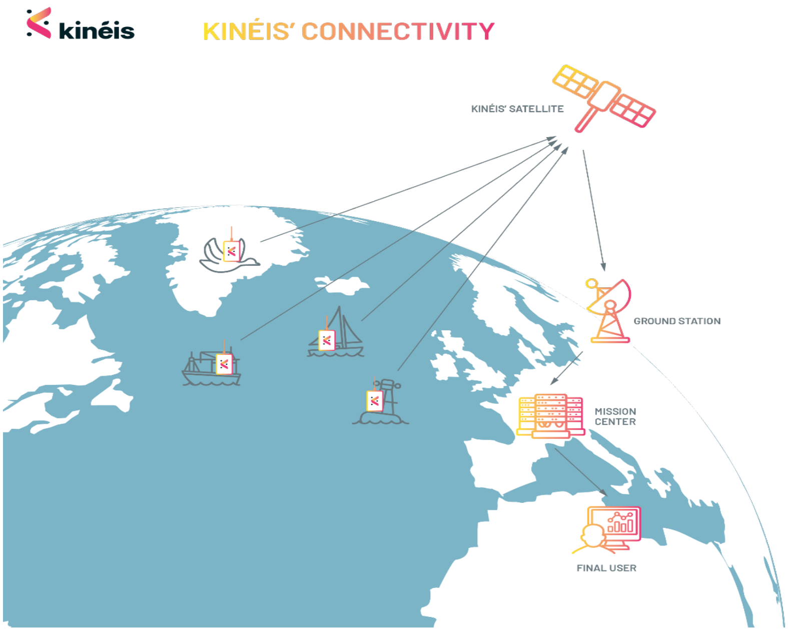


Figure 20: ARGOS KINEIS system architecture

The satellites have the capability to calculate GNSS-Free beacon position from the signal characteristics, thus enriching the data transmitted by the beacon, and avoiding loading the uplink messages with positioning information if not necessary. This also allows to minimise battery drain in the beacons.

Through the downlink at 400.15-401 MHz, the satellites may request a beacon to retransmit all or part of a message not properly received. Beacon control and updates, as well as Constellation Information Broadcasting, will also be executed in that band.

Each of the 20 planned ground stations include so-called “system beacons.” Such system beacons ensure the telecommand of the system as well as any communications to the customer beacons (e.g. control or upgrades and Constellation Information Broadcasting) and are operated in the 401-403 MHz band.

The ARGOS KINEIS constellation will be able to support the ARGOS legacy beacons, thereby providing continuity of services to the many environmental, meteorological and governmental organisations relying today on the ARGOS legacy service.

A1.3.2 Technical characteristics

The legacy component of the ARGOS KINEIS system is operated in the band 401-403 MHz on board of polar orbiting MetSat satellites. This frequency band does not fall in the purview of ERC Decision (99)06 [10] and therefore need not be considered here.

The other band for future payloads is 399.9-400.5, therefore the same considerations made for HIBER apply. The band is exclusively allocated to the MSS, and there is no need to conduct in-band inter-service studies. The ARGOS KINEIS constellation uses the same bands as the ARGOS legacy system (plus the S band for downlink, not considered in this study), so that the same considerations made for ARGOS KINEIS legacy system apply.

A1.3.3 Inter-service studies

A1.3.3.1 Up-link

The band 399.9-400.05 MHz is allocated solely to the MSS (Earth-to-space) in all ITU regions. Hence there are no compatibility studies to be carried out with respect to terrestrial services.

Regarding the inter service compatibility with search and rescue within the frequency band 406-406.1 MHz, it can be noted that according to Report ITU-R M.2359-0, no interference can be caused to the LEO/MEO/GSO search and rescue on board instruments. This report shows that the aggregation of data collection platforms in operation within the band 401-403 MHz is negligible. Since the waveforms envisaged for ARGOS KINEIS are very similar to the waveforms already used within the 401-403 MHz, and since the frequency band for ARGOS KINEIS is much smaller than the one for the 401-403 MHz and since the targeted frequency band for ARGOS KINEIS is lower, according to the results derived from Report ITU-R M.2359-0, it can be easily extrapolated from what is said above that the ARGOS KINEIS operations within the band 399.9-400.05 MHz will not cause interference to the LEO/MEO/GSO search and rescue on board instruments within the 406-406.1 MHz frequency band.

The ECA Table [22] identifies ECC Decision (08)05 “The harmonisation of frequency bands for the implementation of digital Public Protection and Disaster Relief (PPDR) narrow band and wide band radio applications in bands within the 380-470 MHz range » as pertinent for the band 399.9-400.05 MHz. However, none of the frequency arrangements for mobile systems, including PPDR, include the band 399.9-400.05 MHz.

Based on the above, no specific measures are necessary to ensure compatibility with terrestrial services.

The ARGOS KINEIS beacons operating uplink transmissions in the 399.9-400.05 MHz band are also capable to protect Radio astronomy sites. The radio telescopes use highly directive antennas, with low gain towards transmitters located on Earth. In addition, terrain often provides significant path attenuation.

The ARGOS KINEIS beacons transmit at low power levels, typically in the range -9 dBW to 0 dBW and never more than 5 dBW. The low duty cycle further reduces the interference impact as Radio astronomy observations are made over large integration times.

The ARGOS legacy system beacons are operated for decades in the band 401-403 MHz with similar technical characteristics than the beacons intended for operation in the band 399.9-400.05 MHz. The band 401-403 MHz is located closer to the Radio astronomy band 406.1-410 MHz than the 399.9-400.05 MHz, nevertheless no interference issue for the Radio astronomy has been reported.

A1.3.3.2 Down-link

As provided by RR 5.264, the pfd threshold indicated in Annex 1 of Appendix 5 of the ITU Radio Regulations shall be used as a coordination trigger in the 400.15-401 MHz band with respect to terrestrial services. That pfd threshold is -125 dBW/m2/4 kHz at the Earth's surface.

In order to demonstrate compliance with this value, the following table provides the pfd for a satellite in the ARGOS KINEIS ARGOS-Kinéis system for the whole range of satellite transmit off-axis angles with Earth visibility (elevations ranging from 0 to 90°). In all cases, the pfd on Earth is below the prescribed power flux density threshold.

Table 16: pfd values, ARGOS KINEIS system, as a function of off-axis angle

Off-axis angle (°)	0.0	9.0	18.0	27.0	36.0	45.0	52.0	59.0	64.0	65.2
Elevation (°)	90.0	80.1	70.1	60.0	49.6	38.8	29.7	19.2	7.9	0.0
Gain (dBi)	-3.96	-3.4	-2.6	-1.7	-0.6	0.9	2.2	3.5	4.1	4.2
Power (dBW/4 kHz)	3	3	3	3	3	3	3	3	3	3
e.i.r.p. (dBW/4 kHz)	-0.96	-0.4	0.4	1.3	2.4	3.9	5.2	6.5	7.1	7.2
Range (km)	650.0	658.9	687.2	739.4	826.4	971.8	1163.5	1525.3	2201.4	2948.5
Spreading loss (dB)	127.3	127.4	127.7	128.4	129.3	130.7	132.3	134.7	137.8	140.4
Flux (dBW/m²/4 kHz)	-128.2	-127.8	-127.3	-127.1	-126.9	-126.8	-127.1	-128.2	-130.7	-133.2

As a consequence of the above, the ARGOS KINEIS system is compatible with terrestrial services in the 400.15-401 MHz band.

A1.3.3.3 Compatibility between ARGOS KINEIS and Standard Frequency Time Signal Satellite radio Service in the frequency band 400.05-400.15 MHz

The SFTSS (Standard Frequency and Time Signal – Satellite) Service is allocated in Article 5 of the Radio Regulations on primary basis in the band 400.05-400.15 MHz. In accordance with footnote 5.261, emissions shall be confined in a band of +/- 25 kHz about the standard frequency 400.1 MHz.

There is no identified Recommendation ITU-R or Report providing characteristics or protection criteria for SFTSS. However, some satellite networks contain assignments in this service (class of station EE or EY) in the band 400.05-400.15 MHz. Their characteristics may be used to assess adjacent band compatibility with the ARGOS KINEIS system downlink operations within the adjacent 400.15-401 MHz MSS allocation.

The following formula permits to calculate the pfd value (dBW/m²/4 kHz) to meet a given I/N criterion into earth station with an antenna gain Grx and a noise temperature N:

$$pfd_{\left(\frac{dBW}{m^2}/4kHz\right)} = \left(\frac{I}{N}\right) - 38.55 + 20 * Log(f_{MHz}) - G_{rx} - 228.6 + 10 * Log(T * 4000) \qquad (2)$$

The identified SFTSS networks characteristics are summarised as follows, and the right column provides the pfd value to meet an I/N of -10 dB in the worst case conditions.

Table 17: SFTSS networks characteristics with protection requirements

Network name	Adm	Freq. min	Freq. max	Station class	Emission designator	E/S Rx Gain	E/S Noise temp	Worst case pfd (dBW/m²/4 kHz)
TSYKADA	RUS	400.075	400.125	EE	50K0G2D--	0	200	-166.1
LEOTELCOM-1	USA	400.075	400.125	EE	50K0G7D--	2	400	-165.1
		400.075	400.125	EE	50K0G7D--	6.1	400	-169.2
ICARUS	D	400.05	400.15	EY	5K00G1D--	-10	3000	-144.3
		400.05	400.15	EY	50K0G1D--	-10	3000	
F-SAT-NG-8	F	400.05	400.15	EY	50K0G7W--	0	500	-162.1
		400.05	400.15	EY	12K3G7W--	0	500	
		400.05	400.15	EY	1K00G7W--	0	500	

The ARGOS KINEIS system will comply with the pfd threshold of -125 dBW/m²/4 kHz with the band 400.15-401 MHz. The SFTSS signal frequency fall in the spurious emissions domain of the ARGOS KINEIS emissions for which a prescribed 46 dBc attenuation is required. In the 400.05-400.15 MHz band the pfd produced by the ARGOS KINEIS spurious emissions will therefore be lower than -125-46 = -171 dBW/m²/4 kHz, hence below the worst case pfd values calculated to protect the identified SFTSS systems.

A1.3.3.4 Compatibility with Radio astronomy in the band 406.1-410 MHz (general considerations)

The band 406.1-410 MHz is allocated to Radio astronomy service and is used for continuum observations integrated throughout the band.

The ARGOS KINEIS transmitter in the band 400.15-401 MHz is implementing filtering to reject at least 46 dBc with respect to in-band level, in compliance with Appendix 3 of the Radio Regulations. The actual emissions of the ARGOS KINEIS payload in the 406.1-410 MHz band will actually be much lower than the prescribed 46 dBc rejection.

The transmission bandwidth is narrow, 4 kHz maximum, and the natural decay of the signal is steep, considering that the Radio astronomy band is distant of at least 3.9 MHz from the ARGOS KINEIS carrier frequency.

The ARGOS KINEIS payload will transmit a single carrier, which limits the generation of intermodulation products in the output amplifier.

By design, the ARGOS KINEIS payload shall limit its out-of-band emissions in the adjacent band 401-403 MHz where simultaneous beacon signal reception shall be ensured. This design feature de facto protects the Radio astronomy band located a few MHz further.

The ARGOS KINEIS payload is designed to meet a maximum spurious emission levels of -80 dBm in any 1 kHz bandwidth within the band 406.1-410 MHz.

In the following sections, compliance with the pfd values of Recommendation ITU-R RA.769-2 [3] and the epfd values of ITU-R Resolution 739 [23] are shown.

A1.3.3.5 Compliance with Recommendation RA.769-2 for ARGOS KINEIS

Recommendation ITU-R RA.769-2, table 1 [3] sets a detrimental interference pfd threshold of -189dBWm²/3.9 MHz in the band 406.1-410 MHz.

The following table provides an evaluation of the flux provided by an ARGOS KINEIS payload transmitting at its specified spurious level across the whole 406.1-410 MHz frequency band, for different angles of arrival on Earth.

Table 18: pfd (spurious) produced by ARGOS KINEIS payloads in band 406.1-410 MHz

Off-axis angle (°)	0	9	18	27	36	45	52	59	64	65.2
Elevation (°)	90	80.1	70.1	60	49.6	38.8	29.7	19.2	7.9	0
Gain (dBi)	-3.96	-3.4	-2.6	-1.7	-0.6	0.9	2.2	3.5	4.1	4.2
Power (dBm/1 kHz)	-80	-80	-80	-80	-80	-80	-80	-80	-80	-80
EIRP (dBm/kHz)	-83.96	-83.4	-82.6	-81.7	-80.6	-79.1	-77.8	-76.5	-75.9	-75.8
Range (km)	650	658.9	687.2	739.4	826.4	971.8	1163.5	1525.3	2201.4	2948.5
Spreading loss (dB)	127.3	127.4	127.7	128.4	129.3	130.7	132.3	134.7	137.8	140.4
Flux (dBW/m²/3.9 MHz)	-205.3	-204.9	-204.4	-204.2	-204.0	-203.9	-204.2	-205.3	-207.8	-210.3
RA.769 (dBW/m²/3.9 MHz)	-189.0	-189.0	-189.0	-189.0	-189.0	-189.0	-189.0	-189.0	-189.0	-189.0
Margin (dB)	16.3	15.9	15.4	15.2	15.0	14.9	15.2	16.3	18.8	21.3

This table shows that the pfd value defined in Recommendation ITU-R RA.769-2, table 1 [3] is met by a margin above 15 dB. Actually, the margin will be higher since the spurious emissions of the satellite Payload will be below the 80dBm/kHz limit in average across the 406.1-410 MHz band.

A1.3.3.6 Compliance with Resolution 739 requirements for ARGOS KINEIS

ITU-R Resolution 739 [23] sets epfd limits to be respected by satellite systems in active services in certain RAS frequency bands. Specifically, MSS systems for which Advanced Publication information has been received after the entry into force of the WRC-07 operating in the band 400.15-401 MHz band shall be designed not to exceed an epfd value of -242 dBW/m²/3.9 MHz for more of 2% of measurement windows of 2000s in the band 406.1-410 MHz.

A simulation of the ARGOS KINEIS constellation has been made in accordance with the method described in ITU-R M.1583 [7], and summarised below:

- the RAS antenna is assumed to be located centrally in CEPT (15°E, 50°N)[2];
- the sky is divided in 2334 cells, each of approximately 9° solid angle as described in Recommendation ITU-R M.1583, annex 2.

100 successive simulation trials were made.

For each of 100 trial, the ARGOS KINEIS constellation of 20 active satellites was propagated for a period of 2000s with a random time start and a time resolution of 1 second. The average epfd was calculated over the 2000s window taking into account the RAS antenna gain towards each visible satellite and the satellite "spurious" e.i.r.p. towards the RAS site. The epfd calculation is made for each of the 2334 sky cells: at each

[2] For polar orbit systems, given the geometry of the constellation, the cumulative impact is expected to be the greatest at the poles, and to lessen with lower latitudes, However, when considering traffic patterns of the network, this may not be the case any longer.

of the 100 trial, the RAS antenna is set at a random pointing within the considered sky cell. As indicated in ITU-R Resolution 739 [23], only the RAS pointings at or above 5° elevation were considered.

At the end of the 100 trials, the percentage of 2000s time windows for which the prescribed pfd value is exceeded is calculated for each skycell, and then averaged over the sky.

The resulting dataloss from the simulation is 1.44 %, which is below the 2% target.

This means that the -80dBm/kHz specification for the ARGOS KINEIS payload adequately protect the Radio astronomy in the band 406.1-410 MHz.

Actually, the compliance should meet with a higher margin, as the payload is expected operate better than the specification in average across the 406.1-410 MHz band.

A1.4 DESCRIPTION OF SWARM

A1.4.1 General description

WARM Technologies, Inc. (SWARM) is a U.S. corporation that has United States Federal Communications Commission (FCC) authorisation to launch and operate an innovative constellation of 150 small two-way communications satellites in the non-voice, non-geostationary (NVNG) Mobile-Satellite Service (MSS) very-high frequency (VHF) bands in Low Earth Orbit (LEO). SWARM has filed via the USA before the ITU and a coordination request has been published under the name USASAT-NGSO-7 in Special Section CR/C 4998 in BR IFIC 2901 on 6 August 2019.

SWARM will provide global data services for small Internet of Things (IoT) and Machine-to-Machine (“M2M”) to industry, government, non-profit, and research and development users. SWARM will provide satellite data services for the agriculture, logistics, connected cars, and maritime industries, as well as pipeline monitoring, weather monitoring, animal tracking, disaster detection, remote backhaul, scientific research, and emergency response applications. By leveraging advances in small satellite technology and the increased availability of launch opportunities, SWARM’s system will be deployed rapidly and will provide connectivity at far lower costs than have been previously possible. The SWARM satellite system will be providing connectivity on a global basis, not only to sensors on fixed devices, but also to mobile earth stations, which will move across borders within Europe and outside of Europe.

The satellite service transmits a narrow-band waveform operating within the 137-138 MHz (space-to-Earth) and 148-150.05 MHz (Earth-to-space) VHF MSS bands. With full deployment, approximately a dozen satellites will be visible at a given geographic location. The majority of SWARM’s satellites are in polar orbits and see each place on earth four times a day. These satellites will be allocated across uplink and downlink sub-bands so that the total number of satellites on any particular sub-band will be lower than the total number of visible satellites. SWARM’s satellites are deployed in nine orbital planes. The length, interval, data rate, bandwidth, and frequency of broadcasts from satellites and user terminals are configurable. The transmissions are sent using specific predefined channels using the F1D digital modulation type.

SWARM’s system does not operate exclusive feeder uplink and downlink channels within its requested frequency assignment. Instead, customer data will be transferred between SWARM’s ground stations and satellites on the uplink and downlink frequencies. SWARM does not propose to designate channels for the exclusive purpose of telemetry, tracking, and command (TT&C). TT&C operations will be conducted on in-band links within the uplink and downlink frequencies. Command signals will be issued from SWARM’s mission control centers and uplinked to the satellites from various ground stations that SWARM operates. Note that SWARM will not provide voice services.

A1.4.2 Technical characteristics

The characteristics of the satellites are the following:

- Number: 150 (replenished as needed);
- Size: ¼ unit (11cm x 11 cm x 2.8 cm);

- Lifetime: average of 4 years (between 2.5 to 12.2 years).

The orbital parameters are:
- Altitude 450 to 550 km;
- Inclination 0 to 98 degrees;
- Orbital Period 92 to 96 minutes.

The uplink frequencies (Earth-to-space) are:
- 148.2500-148.5850 MHz;
- 148.6350-148.7500 MHz;
- 149.9000-149.9500 MHz.

The downlink frequencies (space-to-Earth) are:
- 137.0250-137.1750 MHz;
- 137.3275-137.3750 MHz;
- 137.4725-137.5350 MHz;
- 137.5850-137.6500 MHz;
- 137.8125-138.0000 MHz.

The following table gives the emission parameters.

Table 19: SWARM emission parameters considered in thre studies

Parameters	Downlink	Uplink
Necessary bandwidth	Adjustable from 41.7 to 125 kHz	Adjustable from 41.7 to 125 kHz
Emission designator	F1D	F1D
Maximum e.i.r.p.	-1.55 dBW	0.55 dBW
Space station antenna	0 dBi, RHCP	2.1 dBi, Linear (Vertical)
Data rate	0.91 kbps (adjustable from 0.05 to 5.4 kbps)	0.91 kbps (adjustable from 0.05 to 5.4 kbps)
Typical duty cycle	5%	0.1%
Maximum duty cycle	10%	1.0%

A1.4.2.1 Limits on Re-Transmission of Signal

SWARM's satellites employ on-board processing and do not utilize "bent-pipe" transponders. Signals received by a satellite that originate from SWARM user terminals and ground stations are demodulated and processed. An appropriate response is then generated, modulated, and transmitted by the satellite. Unknown or incompatible signals received by a satellite are ignored and do not result in a transmission response, ensuring that signals originating from sources outside of the SWARM network are not re-transmitted.

A1.4.2.2 Cessation of Emissions

Each satellite can be turned off upon telecommand from a SWARM ground station. Each SWARM satellite has a hardware and software watchdog timer that resets the satellite if the satellite enters an anomalous condition or is subject to an upset from radiation (total ionizing dose or single event upset). Each SWARM satellite is also programmed with a 48-hour "dead-man's switch," which turns the satellite off every 48 hours.

Each SWARM satellite must receive a “heartbeat” command from a SWARM earth station once every 48 hours to remain on and continue transmitting.

A1.4.2.3 Geographic Distribution and Duty Cycle

A number of factors contribute to the low likelihood that SWARM’s transmissions will cause interference with other users in the band or in neighbouring bands. First, SWARM’s anticipated customer deployments (including remote agriculture, livestock monitoring, and energy applications) are largely located outside of urban areas and are geographically separated from other users. SWARM’s IoT data services are designed to send short and infrequent bursts of data rather than continuous transmissions (e.g. once per day). It is expected that most devices will transmit far less than 1% of the time (e.g. 0.01%). At full deployment, SWARM expects an approximate density of one mobile earth station per 10 square km.

A1.4.2.4 Mechanism for Interference Avoidance

The SWARM network consists of three components: 1) customer mobile earth stations (CMES), 2) space stations, and 3) gateway earth stations. Each is designed to limit out-of-band emissions to prevent interference with operations in adjacent bands, as well as terrestrial networks, satellite networks, radio astronomy services (RAS), and government operations. In addition, SWARM’s system architecture and specific design choices are designed to reduce or eliminate interference. These include a low transmit power, low duty cycle, and carrier sense multiple access/collision avoidance (CSMA/CA) “listen-before-talk” (LBT) protocols.

SWARM uses a Carrier-Sense Multiple Access media access control (MAC) protocol with Collision Avoidance (CSMA/CA). With CSMA, a transmitter on the ground uses a “listen-before-talk” protocol and verifies the absence of other traffic before transmitting on a given channel. SWARM's CMES listen for both SWARM network transmissions as well as any other transmission from any other network on the particular channel. This means that a SWARM's customer mobile and gateway earth stations avoid transmitting on the same frequency being actively used by terrestrial fixed or mobile stations. SWARM transmitter, using a carrier-sensing mechanism, determines whether another transmission is in progress before initiating a transmission. If a carrier is sensed, the transmitter waits for the transmission in progress to end before initiating its own transmission. Therefore, using the CSMA/CA protocol, multiple carriers on the ground can send and receive on the same channel. There is inherently a low probability of signal collision because of the low duty cycle (typically much less than 1%) and distributed geography of the anticipated customer deployments. CSMA/CA protocols are commonly used in many spectrum sharing environments (e.g. Wi-Fi) and have a track record of successful operations, both technically and in the marketplace.

SWARM employs a CSMA/CA technique on board of the MES. SWARM's CMES remain in a listen-only mode until a satellite communicates with them. This means that no unnecessary transmissions are sent. Prior to any transmission, the CMES listens on its intended operational frequency and takes a measurement of received signal strength (RSSI). Should the channel be in use, either from a terrestrial service or another mobile satellite service (including other CMES on SWARM's network), then the CMES uses the distributed coordination function (DCF) and a random backoff duration to retry transmission. These techniques are also employed in the IEEE 802.11 MAC Protocol, which must successfully overcome high interference environments. If a channel remains busy as determined by the RSSI for a certain number of attempts after backoff, then the CMES either waits to initiate upon receiving another request from a satellite or changes its operational frequency to a different available channel. The energy detect (ED) threshold is used to detect any type of RF transmissions during the clear channel assessment (CCA). The ED threshold used by SWARM is 3 dB higher than the local noise floor (e.g. for 41.7 kHz, this is approximately -128 dBm, depending on local conditions). The bandwidth of SWARM's transmissions are small (e.g. 41.7 kHz) and of short duration (e.g. 500 msec). The result of all of these techniques and features is a very small probability of interference with terrestrial systems and also with other devices on SWARM's own network.

The comparison with the system LEOTELCOM-1 is for information only and should not be a basis for conclusions on compatibility studies.

Table 20: A comparison of the operational constraints of SWARM and existing LEOTELCOM-1 system

OPERATIONAL CONSTRAINTS COMPARISON		
	SWARM	LEOTELCOM-1
Uplink designated bands (no spectrum overlap between systems)	Bands: 148.2500-148.5850 MHz 148.6350-148.7500 MHz 149.9000-149.9500 MHz	Bands: 148.0000-148.2500 MHz 148.7500-149.9000 MHz 149.9500-150.0500 MHz
Downlink designated bands (no spectrum overlap between systems)	Bands: 137.0250-137.1750 MHz 137.3275-137.3750 MHz 137.4725-137.5350 MHz 137.5850-137.6500 MHz 137.8125-138.0000 MHz	Bands: 137.1875-137.2625 MHz 137.2750-137.3250 MHz 137.4275-137.4525 MHz 137.4475-137.4725 MHz 137.5350-137.5850 MHz 137.6500-137.7500 MHz 137.7875-137.8125 MHz
Multiple Access Method	CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance)	FDMA
Modulation Method	Narrow band Frequency or Phase Modulation	Narrow band Frequency or Phase Modulation
Maximum CMES e.i.r.p.	0.55 dBW	11 dBW
Maximum CMES e.i.r.p. spectral density	0 dBW/4 kHz	10 dBW/4 kHz
Technique to avoid causing interference from CMESs	Low duty cycle (<1%), low-power, and carrier sense multiple access (CSMA) media access control (MAC) protocol with Collision Avoidance (CSMA/CA) “listen before talk” (LBT); energy detection threshold near noise floor in 148-150.05 MHz	Dynamic channel avoidance assignment system (DCAAS as described in Recommendation ITU-R M 1039, annex 4 [25]) such that mobile earth stations avoid transmitting on the same frequency being actively used by terrestrial fixed or mobile stations
Maximum burst duration for MESs transmission	1700 msec (in 149.9000-149.9500 MHz band) 500 msec (otherwise)	500 msec
Maximum duty cycle for MESs and system control	Not greater than 1% in any 15 minute period for any single 41.7 kHz channel in an operational sub-band	Not greater than 1% in any 15 minute period for any single channel
Maximum duty cycle for system control bursts	N/A	Not greater than 1% in any 15 second period for any single channel

A1.4.3 Inter service studies

The space operations and space research services are primary in the 137-138 MHz band. There is no ITU Recommendation or other documentation providing technical characteristics, protection or sharing criteria for such systems with MSS operations in this specific frequency band.

The satellite service transmits a narrow-band waveform operating within the 137-138 MHz (space-to-Earth) and 148-150.05 MHz (Earth-to-space) VHF MSS bands.

The following is an extraction from the EFIS database (https://efis.cept.org/) regarding the bands used by SWARM for the downlink.

Table 21 ITU allocations

BAND	Lower Frequency	Upper Frequency	Allocations	Applications
Adjacent	136 MHz	137 MHz	AERONAUTICAL MOBILE (R)	Aeronautical communications
Used by SWARM for DL	137 MHz	137.025 MHz	METEOROLOGICAL-SATELLITE(SPACE-TO-EARTH) MOBILE MOBILE-SATELLITE(SPACE-TO-EARTH) SPACE OPERATION(SPACE-TO-EARTH) SPACE RESEARCH(SPACE-TO-EARTH)	Aeronautical military systems/Land military systems/Satellite systems (military)/Land mobile/Weather satellites/S-PCS
	137.025 MHz	137.175 MHz	METEOROLOGICAL-SATELLITE (SPACE-TO-EARTH) MOBILE Mobile Satellite(space-to-earth) SPACE OPERATION(SPACE-TO-EARTH) SPACE RESEARCH(SPACE-TO-EARTH)	S-PCS/Weather satellites/Land mobile/Land military systems/Satellite systems (military)/Aeronautical military systems
	137.175 MHz	137.825 MHz	METEOROLOGICAL-SATELLITE(SPACE-TO-EARTH) MOBILE MOBILE-SATELLITE(SPACE-TO-EARTH) SPACE OPERATION (SPACE-TO-EARTH) SPACE RESEARCH (SPACE-TO-EARTH)	Aeronautical military systems/Land military systems/Satellite systems (military)/Land mobile/Weather satellites/S-PCS
	137.825 MHz	138 MHz	METEOROLOGICAL-SATELLITE (SPACE-TO-EARTH) MOBILE Mobile-Satellite(space-to-Earth) SPACE OPERATION(SPACE TO EARTH) SPACE RESEARCH(SPACE TO EARTH)	Weather satellites/S-PCS/Satellite systems (military)/Land mobile/Land military systems/Aeronautical military systems
Adjacent	138 MHz	143.6 MHz	AERONAUTICAL MOBILE (OR) LAND MOBILE Space Research (space-to-Earth)	Aeronautical military systems/Land military systems/Maritime military systems/Land mobile/Non-specific SRDs

As it can be seen, for the downlink of SWARM the following inter-service sharing studies need to be performed:

- Meteorological satellite;
- Space operation;

- Space research;
- Mobile

The space operation and space research were not considered in the studies because they are secondary in the band.

Regarding the up-link component of SWARM (band: 148-150.5), the following allocations and uses are provided in EFIS table:

Table 22: ITU Region 1 table for SWARM uplink

Band	Lower Frequency	Upper Frequency	Allocations	Applications
Adjacent	146 MHz	148 MHz	MOBILE	PMR/PAMR
SWARM UL	148 MHz	149.9 MHz	MOBILE MOBILE-SATELLITE (EARTH-TO-SPACE)	PMR/PAMR/S-PCS
	149.9 MHz	150.05 MHz	MOBILE MOBILE-SATELLITE (EARTH-TO-SPACE)	S-PCS/PMR/PAMR
Adjacent	150.05 MHz	153 MHz	MOBILE EXCEPT AERONAUTICAL MOBILE RADIO ASTRONOMY	PMR/PAMR/Radio astronomy

From Table 22, it follows that the service to be considered in inter-service studies for the UL component of SWARM is the Mobile service.

A1.4.3.1 Up-link studies

RR N. 5.221 [9] lists a number of administrations, including 40 CEPT countries, in which stations of the MSS in the frequency 148-149.9 MHz shall not cause harmful interference to, or claim protection from stations of the fixed or mobile service.

It is noted that ECC Report 181 [21] has sufficiently investigated this situation where interference mitigation is performed in time (because of a low duty cycle below 1%) and in the frequency domain (due to techniques such as LBT, CSMA/CA, DAA, DCAAS). Systems also adopt a maximum limit for the individual transmission duration and bandwidth as well as setting a minimum off time in-between any such transmissions. It is important to understand that the concept of sharing is based on all MSS systems in one band employing these techniques in an equivalent way, that is adhering to blanket parameters. ECC Report 181 has sufficiently investigated the situation (e.g. low duty cycle, LBT, CSMA, etc) and is the basis for the sharing scheme that SWARM has implemented in its systems both to avoid interference to other potential MSS operators in the same band as well as to other devices on the same network.

The satellites and CMES devices are capable of operating with a variety of emissions designators to meet the diverse needs of customers, and SWARM plans to vary the bandwidth of channels on which CMES devices transmit and receive to best serve customer needs, maximise spectral efficiency, and conform to regulatory requirements.

Uplink spectrum masks for SWARM CMES emissions comply with the limits set forth in U.S. 47 CFR 25.202(f). The figures reflect SWARM's nominal initial plan for communications links, which consists of channels with a necessary bandwidth of 41.7 kHz and an assigned bandwidth of 50.0 kHz to account for Doppler shift and frequency tolerance. Transmissions using alternative emissions designators will also comply with the emissions mask requirements shown for each frequency band. In addition, the carrier frequency of each

SWARM satellite will be maintained within 0.002% of the reference frequency. In the 148-149.9 MHz band, SWARM CMES are co-frequent with PMR/PAMR land mobile radio systems. Note that no such systems operate in 149.9-149.95 MHz. SWARM completed a study based on ITU-R M.1808-1 [1] for cases where the CSMA/LBT protocol either (1) does not detect a transmission in progress, (2) begins before a PMR/PAMR transmission begins, or (3) is within 10 kHz frequency separation of a PMR/PAMR channel.

A list of PMR/PAMR victim system parameters are considered per the recommendation in Table 23.

Table 23: Victim parameters: Land Mobile Base Station

Victim parameters: Land Mobile Base Station		
Centre frequency	149.025	MHz
Bandwidth	12.5	kHz
Antenna Gain (dBi)	2.15	dBi
Antenna Height	30	m
Radiation Pattern	Omni	
Noise Figure	12	dB

A summary of the results follows in Table 24.

Table 24: Minimum recommended separation.

Separation distance to protect Land Mobile Base Station		
	Typical CMES DC	Maximum CMES DC
Co-Frequency	3.91 km	7.58 km
10 kHz Frequency Separation	0.58 km	0.98 km

Standoff distances presented here are worst case due to the fact that the study assumes maximum gain in the direction of the victim. Also, if CMES and LMR systems operate further than 10 kHz, the separation distance will only decrease.

Note that the standoff distance is just one of three techniques used to avoid interference in the mobile and fixed service terminals. First, the LBT/CSMA protocol avoids occupying a channel in use by other networks. No interference is expected in this scenario. Second, for cases when SWARM transmissions begin on a clear channel that later becomes used by another system, the SWARM transmission are short (< 500 msec) and infrequent (<1% duty cycle). Thus, the probability of denying access to other systems is very low. Third, SWARM's CMES will attempt to move to channels further than 10 kHz away from any detected operational systems. Finally, the standoff distance is offered to Administrations who request additional protection from particular systems. SWARM plans to support Customer Mobile Earth Station (CMES) operating between 148-150.05 MHz. The satellites and CMES devices are capable of operating with a variety of emissions designators to meet the diverse needs of customers, and SWARM plans to vary the bandwidth of channels on which CMES devices transmit and receive to best serve customer needs, maximise spectral efficiency, and conform to regulatory requirements.

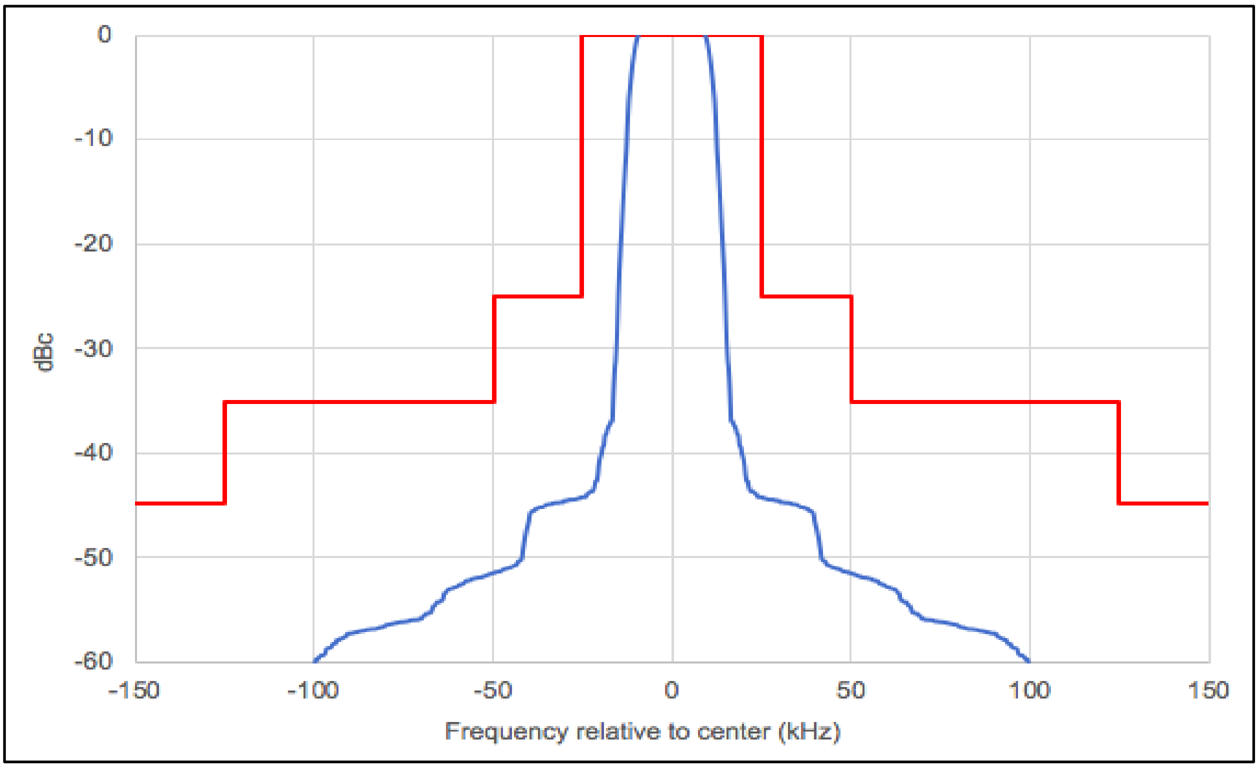


Figure 21: Example emission mask for the 149.000-149.950 MHz band. SWARM's transmit signal is shown in blue, while the required mask from the FCC is shown in red

A1.4.3.2 Compatibility with the Radio Astronomy Service (RAS) in the frequency band 150.05-153 MHz

See Annex 3 with the studies of compatibility with the RAS.

A1.4.3.3 Down-link

SWARM's downlink (space-to-Earth) operations will be conducted in the 137-138 MHz band from satellites in orbits with altitudes of 450-550 km. Power flux density (pfd) calculations were therefore conducted for a satellite operating at orbital altitudes of 550, 500, and 450 km to reflect the range of potential pfd values.

Pfd values for a SWARM satellite as a function of elevation angle are specified below. Table 25 represents a worst-case (highest pfd) scenario. The pfd values do not account for additional real-world losses that will result in further attenuation of the pfd level at the Earth's surface. The pfd values were calculated with the following parameters:

- Necessary bandwidth: 41.7 kHz;
- Maximum downlink e.i.r.p.: -1.55 dBW;
- Maximum antenna gain: see Table 25;
- Orbital altitude: 450, 500, or 550 km.

Table 25: pfd values as a function of elevation angle[3]

Elevation angle	Max. Gain (dBi)	Max. pfd (dBW/m2/4 kHz)		
		450 km orbit	500 km orbit	550 km orbit
0°-5°	-3.5	-152.0	-152.6	-153.1
5°-10°	-3.4	-150.0	-150.7	-151.3
10°-15°	-3.3	-148.2	-149.0	-149.6
15°-20°	-3.1	-146.5	-147.3	-148.0
20°-25°	-2.8	-145.0	-145.8	-146.6
25°-90°	0.0	-135.8	-136.7	-137.5

According to the ITU provision from Annex 1 to Appendix 5 space stations transmitting in the 137-138 MHz band require coordination with terrestrial services only if the pfd produced by the space station exceeds -125 dBW/m2/4 kHz at the Earth's surface. The pfd plots in Figure 22 show that SWARM's satellite transmissions will not exceed this threshold in any angle of arrival for any operational altitude.

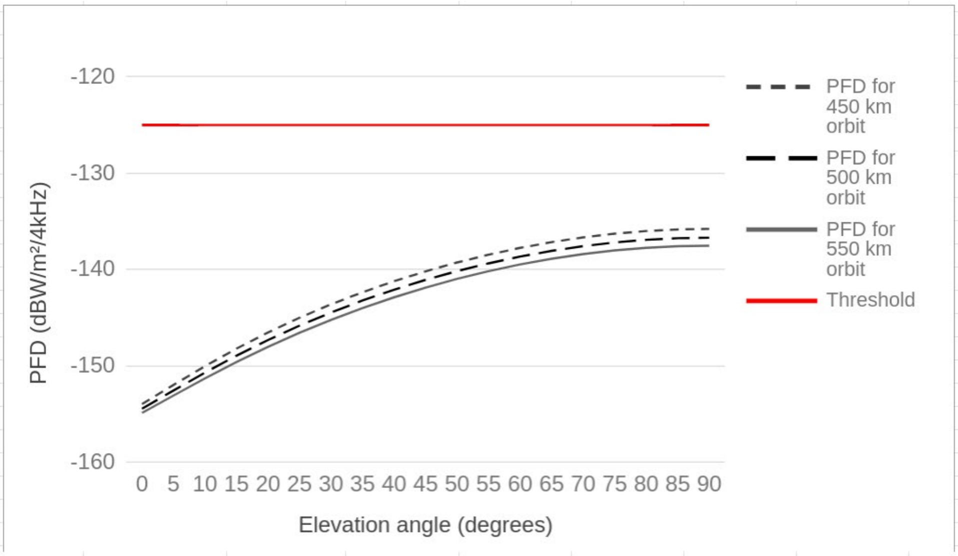


Figure 22: pfd at the Earth's surface as a function of elevation angle

However, the same provisions in Annex 1 to ITU RR [9] Appendix 5 state that as of 1 November 1996 coordination of a space station of the MSS (space-to-Earth) with respect to the aeronautical mobile (OR) service is required if the pfd produced by this space station at the Earth's surface exceeds -140 dBW/m2/4 kHz. A list of administrations in which the frequency band 137-138 MHz is allocated to the aeronautical mobile (OR) service on a primary basis can be found in ITU RR Nr. 5.206.

The spectrum masks for downlink transmissions from SWARM satellites in each downlink frequency band are shown below. These spectrum masks demonstrate that SWARM's satellites comply with the out-of-band emission limitations specified in U.S. 47 Code of Federal Regulations Section §25.202(f). In addition, the carrier frequency of each SWARM satellite will be maintained within 0.002% of the reference frequency.

[3] Note that pfd values were calculated using the necessary bandwidth (41.7 kHz) to account for the worst-case (highest pfd) scenario

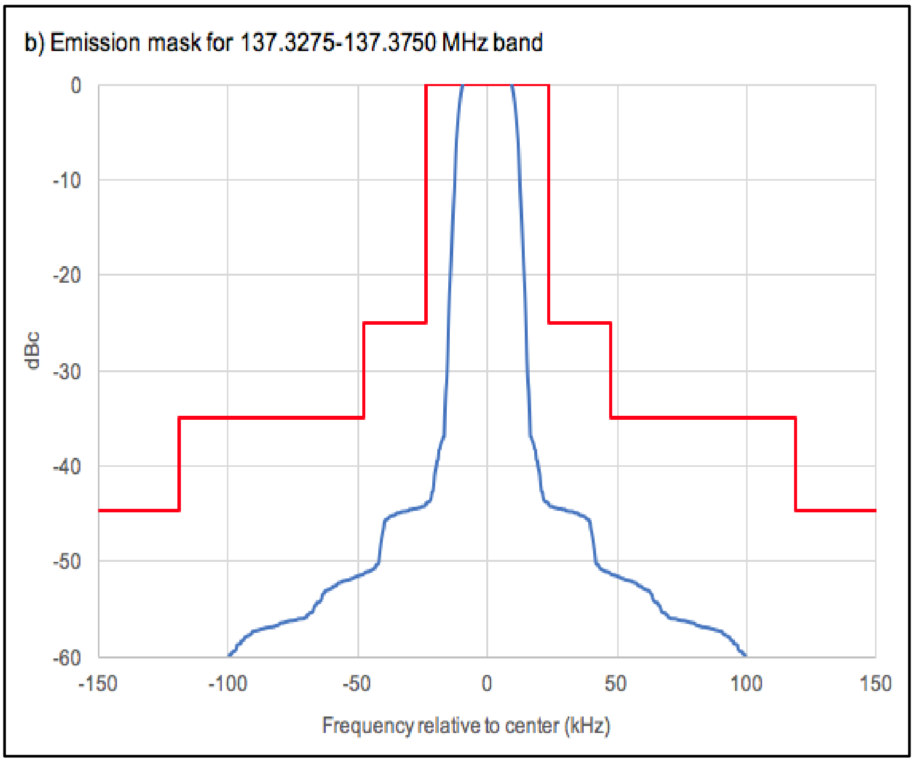


Figure 23: Example emission mask for 137.3275-137.3750 MHz band. SWARM's signal is shown in blue

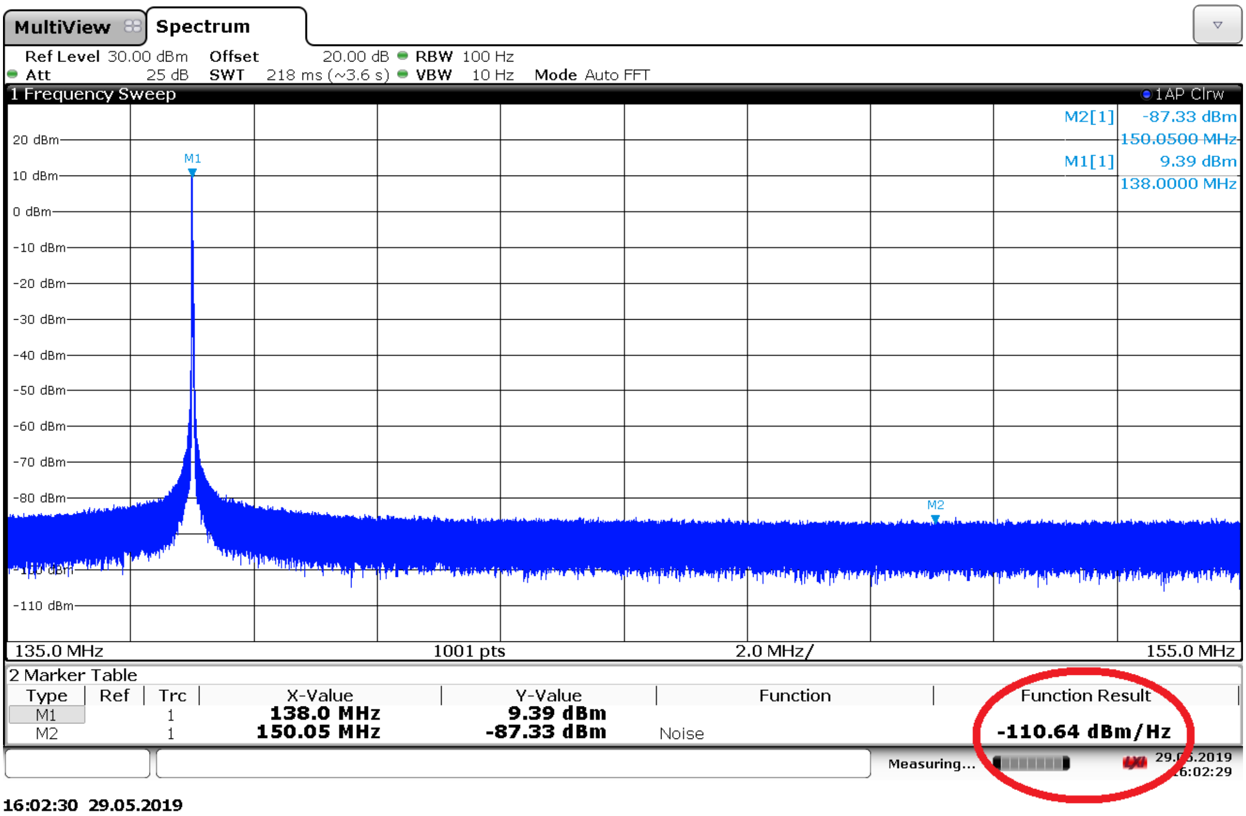


Figure 24: Measurements of SWARM's out-of-band emissions into the RAS band

A combination of spectral roll-off and filtering combine to provide at least -100 dBc roll-off in the RAS band 150.05-153. For uplink, the combination results in a roll-off of at least -70 dBc. These results are inputs to ANNEX 3.

Recent German Administration measurements of the VHF downlink in 137-138 MHz demonstrated an overall modest spectrum utilization at this stage (see Figure 25).

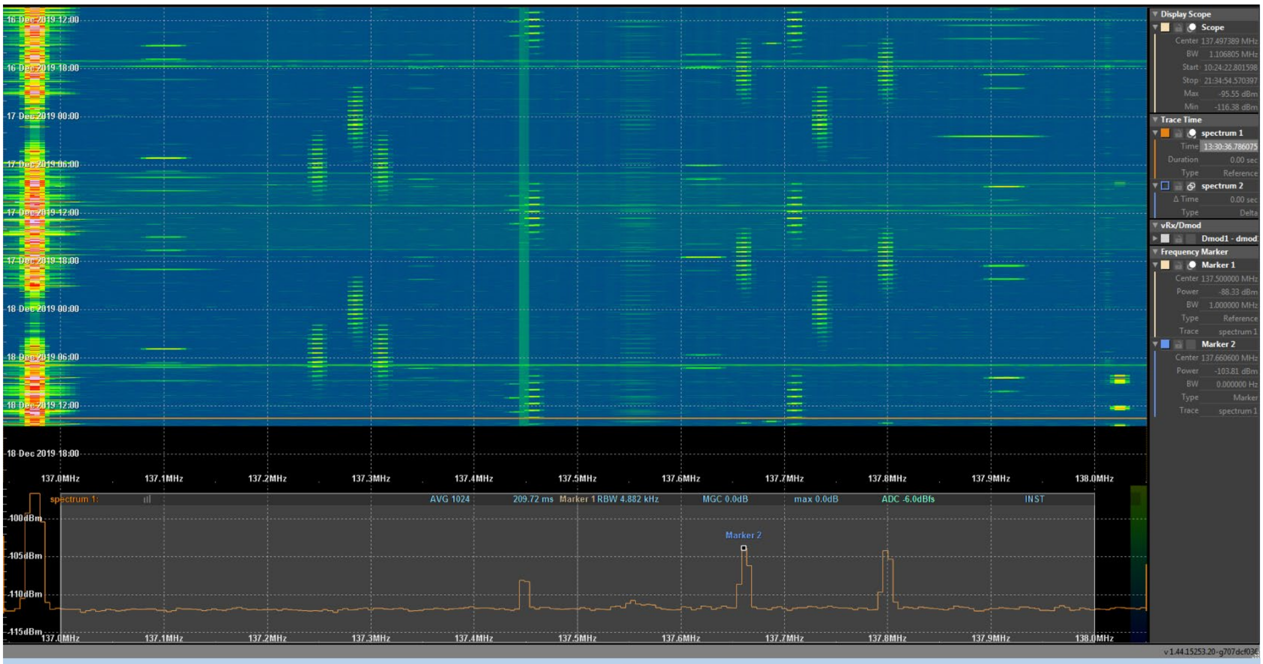


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Figure 25: Sample measurements of spectrum occupancy in the VHF band

The spectrum utilization was recorded in 12/2019 over a duration of 48 hours several times. The maximum duration of individual MSS transmissions on the downlink did not exceed 779 s. The minimum off time in between was at least 1996 s (this was measured with much higher resolution in time). These measurements suggest that up to 99% of the downlink (137-138 MHz) can be used by other MSS transmissions.

A1.4.3.4 Compatibility with the MetSat systems/METEOR-3M system, study 1

Russian satellite system METEOR-3M (with the same name for ITU publication) is operating within the 137-138 MHz band under the Meteorological Satellite Service. This band is used for downlink. Thus, the victims are the earth stations.

There are three similar earth stations receiving in the 137-138 MHz band in Moscow, Novosibirsk and Khabarovsk. Their locations are provided in Table 26.

Table 26: Locations of METEOR-3M earth stations operating in 137-138 MHz band

Earth station location (number)	Longitude	Latitude
Moscow (1)	37.3 E	55.8 N
Novosibirsk (2)	83.0 E	55.0 N
Khabarovsk (3)	135.2 E	48.5 N

All earth stations have the same characteristics, covering 137-138 MHz band and using crossed dipole for low gain (0 dBi, this antenna was used in simulations) and high gain Yagi (10 dBi). Protection criteria from ITU-R Recommendation SA.1026-5 is [4]: the interfering signal power is -142 dBW in the reference bandwidth 150 kHz to be exceeded no more than 20% of the time (long-term protection criterion) and -136 dBW in the reference bandwidth 150 kHz to be exceeded no more than 0.0125% of the time (short-term protection criterion).

Additional mitigation techniques were proposed by SWARM to be included in the study:

- Downlink spectrum subband limits. In the following subbands, SWARM will limit one satellite per channel to downlink over CEPT
  - 137.0250-137.1750 MHz
  - 137.3275-137.3750 MHz
  - 137.4725-137.5350 MHz
  - 137.5850-137.6500 MHz
  - 137.8125-138.0000 MHz
- Total emitting satellites over CEPT: typically, four (4) SWARM satellites emitting over CEPT at any given time
- Downlink power: the downlink power will be reduced from 1.5 W to 0.7 W
- Downlink duty cycle: the downlink duty cycle is 10% maximum (per satellite) and 5% typical (per satellite)
- Downlink bandwidth: the downlink bandwidth will be 41.7 kHz (or greater) in any channel

To simulate the conditions above in studies, the following assumptions were made:

1. To respect downlink duty cycle, each satellite has 5 to 10% (uniformly distributed) chance to be activated.

2. As reference bandwidth is 150 kHz and SWARM decided to limit one satellite per channel to downlink over CEPT in all operating bands it was supposed that 41.7 kHz channels are adjacent to each other to fill reference bandwidth.

3. Downlink power was reduced from 1.5 W to 0.7 W, which should gain instant benefit of 3 dB better margin.

In the simulation in a given instant of time, one channel can be used by one satellite at the time and a satellite is emitting over one channel only. The simulation was carried out for approximately 35 days with a time step of 10.01 seconds. CDFs for three METEOR-3M earth stations (see Table 26) are presented in the three figures below.

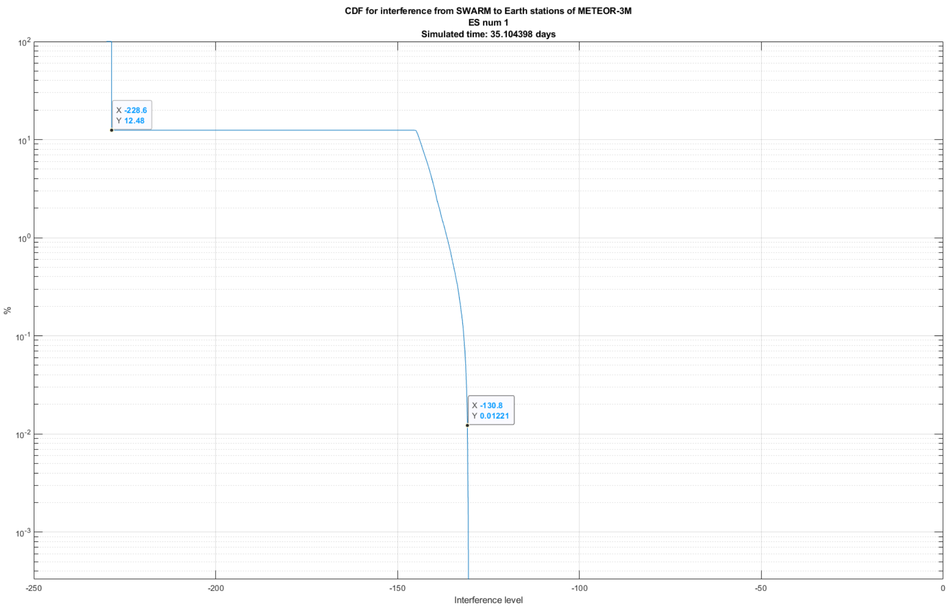


Figure 26: CDF for Moscow METEOR-3M Earth station

As could be seen in Figure 26, the long-term interference protection criterion is met but the short-term interference criterion is exceeded by 5.2 dB.

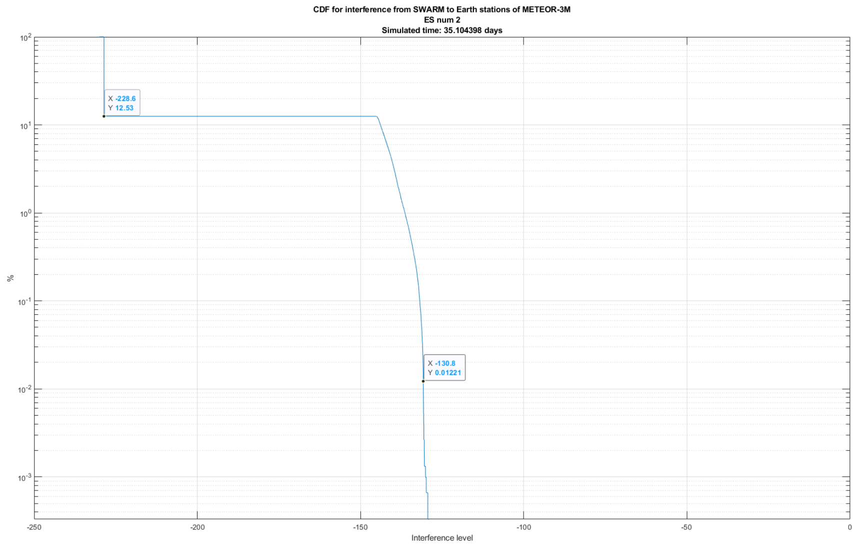


Figure 27: CDF for Novosibirsk METEOR-3M earth station

As could be seen on Figure 27, the long-term interference protection criterion is met but the short-term interference criterion is exceeded by 5.2 dB.

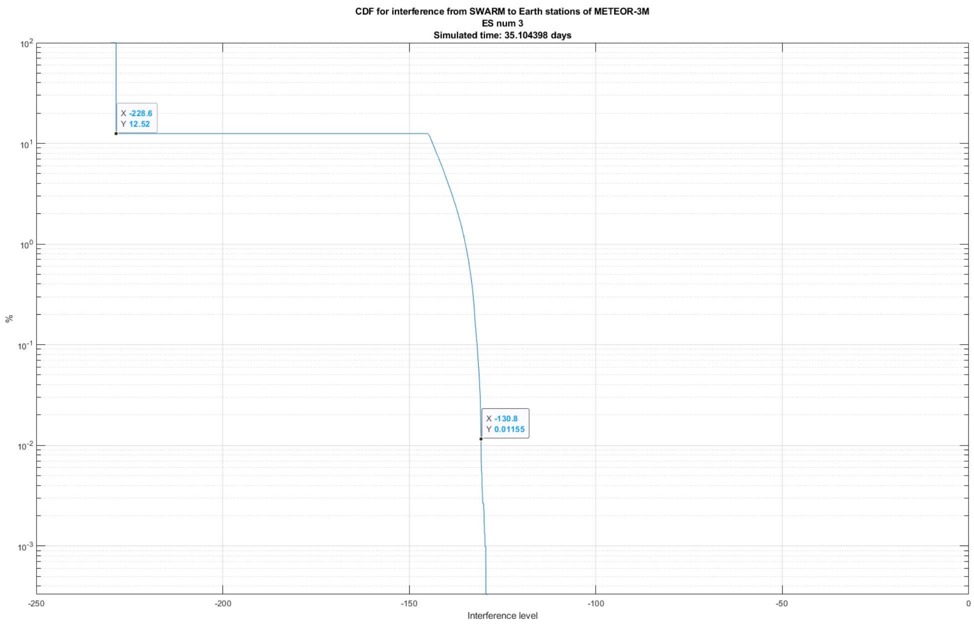


Figure 28: CDF for Khabarovsk METEOR-3M earth station

As could be seen on Figure 28, the long term interference protection criterion is met but the short-term interference protection criterion is exceeded by 5.2 dB.

The Maximum exceedance of the protection criterion is therefore 5.2 dB.

In order to compensate for the 5.2 dB exceedance of the protection criterion, the following additional mitigation techniques are proposed for one-satellite-per-channel bands:

- Possible usage of wider bandwidth with same e.i.r.p. For example, if minimum bandwidth of 125 kHz would be used instead of 41.7 kHz it would give extra 4.77 dB;
- To further enhance compatibility maximum duty cycle could be reduced to typical.
- In order to avoid interference a possible mitigation technique could be that the satellites cease emissions when they are in view of the three stations mentioned above and their elevation with respect to them is higher than 25°.

It should be also noted as this study shows that compatibility requires several combined mitigation techniques, the manufacturing tolerance should be also studied to guarantee the protection of the MetSat service.

A1.4.3.5 Compatibility with the MetSat systems/METEOR-3M system, study 2

The study is a feasibility/sensitivity study for informational purposes.

The aggregate interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services can be found in the Recommendation ITU-R SA.1026-5 [4]. The long- and short-term interference thresholds for protecting the Earth exploration-satellite and meteorological-satellite services are summarised in Table 27 .

Table 27: Interference criteria for Earth exploration-satellite and meteorological-satellite earth stations using spacecraft in low-Earth-orbit

Frequency band	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 0.0125% of the time. (This value is based on the 99.9% performance requirement in Recommendation ITU-R SA.1159)
137-138 MHz	−142 dBW per 150 kHz	−136 dBW per 150 kHz
Note 1: The interfering signal powers (dBW) in the reference bandwidths are specified for reception at elevation angles ≥ 25°; in all other cases the minimum elevation angle is 5°. Source: ITU-R SA.1026-5 [4]		

For this study, the interfering signal power values into the METEOR-3M earth stations were calculated for a range of SWARM satellite elevations between 5° and 90° at altitudes of 450 km and 550 km using the satellite power level reduced by the appropriate slant range propagation loss. The calculations were performed for a single SWARM satellite. The pfd levels were obtained for both high (10 dBi) and low (0 dBi) METEOR-3M earth station antenna gains. The location of interest was chosen for the Moscow earth station (37.3 E, 55.8 N).

In the first step, it appears that the long- and short-term interference thresholds into the high gain METEOR-3M earth station from a SWARM satellite is exceeded for all satellite elevations (based on only on the power calculation). The amount of power excess is consistent with Study 1. For the satellite altitude of 450 km, the long- and short-term interference thresholds for low-gain earth stations are exceeded for satellite elevations above 25° and 40°, respectively. At 550 km, the excess in the long- and short-term interference thresholds for low-gain earth stations occur at 25° and 50°, respectively. In the case of high-gain earth stations the interference thresholds are exceeded for all satellite elevations computed.

Because the ITU-R SA. 1026-5 [4] involves both a power level and a threshold exceedance time percentage, SWARM proposes mitigation techniques to limit the total interference levels to within those deemed acceptable in the recommendation for certain time periods. For a more realistic interference analysis, the amount of interference should be calculated when considering both the duty cycles of both SWARM and METEOR-3M satellites along with the visibility of SWARM satellites over the METEOR-3M stations. When SWARM's satellites are constrained both in their downlink duty cycle and in their frequency use, both the short- and long-term interference criteria are satisfied such that the percentage of time for the calculated power excess remains below the threshold of ITU-R SA.1026-5 [4].

With this in mind, an effective and possible mitigation method to avoid interference to the METEOR-3M earth stations is the implementation of “geo fencing” on the SWARM satellites, in the sense that the satellites will be commanded to cease transmissions (space-to-Earth) when between certain elevations over the geographical location of these earth stations. Additionally, it can be arranged that only one visible SWARM satellite transmits in one available operational sub-band at each time to prevent the potential for two simultaneous satellite transmissions into the METEOR-3M antenna.

To demonstrate that the interference thresholds are met when taking into consideration the duty cycle and the frequency band plan, Table 28 (SWARM satellite altitude of 450 km) and Table 29 (SWARM satellite altitude of 550 km) suggest that when the duty cycles of the SWARM and METEOR-3M satellites as well as the duration of visibility of a SWARM satellite over a METEOR-3M earth station are taken into account, the time percentage of power excess remains below the limits provided in ITU-R SA.1026-5 [4]. For the calculations in Table 28 and Table 29,the satellite access times were determined using the STK software. The simulation period was performed over one year. For both the short- and long-term interference thresholds and for the various scenarios involving satellite altitudes, elevations, duty cycles, and high/low gain earth stations, the percentage of time for the calculated power excess remains below the threshold of ITU-R SA.1026-5.

Table 28: Analysis for the percentage of time for interference threshold for a SWARM satellite at 450 km orbit

Elevation	Max. visibility time duration	Access over year per one SWARM satellite		SWARM duty cycle	METEOR-3M Duty cycle	Total access time percentage
25°	4.5 minutes	217000 sec	0.6881%	10%	18%	0.0124%
50°	1.8 minutes	41800 sec	0.1325%	10%	18%	0.0024%
Full visibility		1659232 sec	5.26%			

Table 29: Analysis for the percentage of time for interference threshold for a SWARM satellite at 550 km orbit

Elevation	Max. visibility time duration	Access over year per one SWARM satellite		SWARM duty cycle	METEOR-3M Duty cycle	Total access time percentage
25°	3.5 minutes	157300	0.4988%	10%	18%	0.0090%
40°	2.2 minutes	56130	0.1780%	10%	18%	0.0032%
Full visibility		1355675	4.30%			

A1.4.3.6 Compatibility with the RAS

See ANNEX 3.

A1.4.3.7 Compatibility with AMS(OR) in the CEPT countries listed in RR FN.5.206 [9]

In a number of CEPT countries, as specified in RR No. 5.206, the 137-138 MHz band is allocated to the aeronautical mobile service on a primary basis and Annex 1 to RR Appendix 5 suggests a threshold pfd limit of -140 dBW/m2/4 kHz for space stations of the MSS below 1 GHz for coordination with the AMS(OR). However, in bilateral coordination, some CEPT countries have confirmed that a limit of -125 dBW/m2/4 kHz would sufficiently protect their AMS applications.

Introduction

Systems and networks operating in the AMS are used for airborne data-links to support remote sensing, etc., applications.

Operational deployment

Aeronautical mobile data links are operated between aeronautical stations and aircraft stations, or between aircraft stations equipped with AMS data links and can be deployed anywhere within a country whose administration has authorised their use in accordance with regulations.

AMS data links includes transmission from and to, either aircraft stations or a ground terminal considered as an aeronautical station. These transmissions could use bidirectional air to ground links, or relay through another airborne platform using an air to air data link. Links can be either simplex or duplex. The link lengths vary greatly in these applications. Although some of the link lengths may be relatively short, many of the link lengths approach the radio line of sight distance. The operational altitude of airborne platforms equipped with these AMS data links can vary up to 20000 m.

The ground terminals may be at a permanent location or they may be transportable. Transportable ground terminals can be moved to meet operational needs and the duration of use while it remains at a particular location is dependent upon operational requirements.

A single ground terminal may simultaneously support several aircraft stations at the same time via different links.

Technical characteristics of aeronautical mobile systems

Typical technical characteristics for representative airborne data links for the frequency range 137-138 MHz are provided in Table 30.

Table 30: Typical technical characteristics of representative AMS systems operated in the frequency range 137-138 MHz

Parameter	Units	Typical AMS System Airborne	Typical AMS System Ground	
Tuning range	MHz	137-138	137-138	
Bandwidth (3 dB)	MHz	0.006 / 0.01 / 0.025/ 0.15	0.006 / 0.01 / 0.025/ 0.15	
Noise figure	dB	2.5	2.5	
Thermal noise level	dBm	–134.4 to –120.5	–134.4 to –120.5	
Antenna				
Antenna type		Omnidirectional	Omnidirectional	Directional
Antenna gain	dBi	3	3	8.2
Polarisation		RHCP or LHCP	RHCP or LHCP	RHCP or LHCP

Parameter	Units	Typical AMS System Airborne	Typical AMS System Ground	
Antenna pattern		Not applicable	Not applicable	Uniform distribution refer to Recommendation ITU-R M.1851
Horizontal beamwidth	Degrees	360	360	70
Vertical beamwidth	Degrees	120	120	70

Protection criteria

An increase in receiver effective noise of 1 dB would result in significant degradation in communication range. Such an increase in effective receiver noise level corresponds to an I/N ratio of about −6 dB. This represents the required protection criterion for the AMS systems from interference due to another radiocommunication service. If multiple potential interference sources are present, protection of the AMS systems requires that this criterion is not exceeded due to the aggregate interference from the multiple sources.

Determination of a pfd levels for the protection of AMS and compatibility analysis

The pfd level corresponding to the AMS long term interference protection criteria may be expressed as follows:

$$pfd = I + L - G - 10\ \log\left(\frac{\lambda^2}{4\pi}\right) \tag{3}$$

where:

- I: interference spectral density corresponding to the protection criterion of the AMS station (dBW/Hz);
- L: feeder loss (dB);
- G:antenna gain towards the MSS station (dBi);
- λ: wavelength (m).

This equation may be directly used to determine the worst case in terms of long-term interference to the AMS systems.

The interference spectral density corresponding to the protection criterion of I/N=-6 dB for the parameters presented in Table 31 (Noise figure=2.5 dB) is -208 dBW/Hz.

The pfd level calculations in the 4 kHz reference are presented below:

Table 31: pfd levels for the protection of AMS stations

Interference spectral density, dBW/Hz	Feeder loss, dB	Antenna gain, dBi	Spectral pfd, dB(W/(m2·Hz))	pfd, dB(W/(m2·4 kHz))
AMS airborne receiver				
-208	1	0	-202.8	-166.8
AMS ground based receiver				
-208	1	3	-205.8	-169.8

Interference spectral density, dBW/Hz	Feeder loss, dB	Antenna gain, dBi	Spectral pfd, dB(W/(m2·Hz))	pfd, dB(W/(m2·4 kHz))
-208	1	8.2	-211	-175

Pfd values for a SWARM satellite as a function of elevation angle are specified in A1.4.3.3 (see Table 25).

Power flux density evaluations above represent the worst case interference scenario (static analyses with assumption of maximum pfd for 100% of time). In order to take into account the mobile nature of services as well as actual duty cycles for the downlink transmissions a dynamic simulation was performed.

Following MSS (s-E) parameters were used in the dynamic study:

- Emission type: 125KF1D;
- Maximum e.i.r.p.: -1.55 dBW;
- Maximum antenna gain: 0 dBi, RHCP;
- Typical duty cycle 5% (per satellite over 24 hours); Maximum duty cycle 10% (per satellite over 24 hours);

Table 32: Antenna pattern

Off-axis angle (degree)	0	40	65	70	75	80	85	90
Elevation (degree)	90	50	25	20	15	10	5	0
Gain (dBi)	0	0	-2.8	-3.1	-3.3	-3.4	-3.5	-3.5

Table 33: Orbit information

ORBIT	Number OF SATELLITES	RIGHT ASC. ANGLE	INCLINATION ANGLE	PERIOD DAYS HOURS MINUTES			APOGEE VALUE EXPONENT		PERIGEE VALUE EXPONENT	
1	20	0	45	0	1	34	450	0	450	0
2	20	0	10	0	1	35	500	0	500	0
3	12	105	97.4	0	1	35	500	0	500	0
4	16	127	97.4	0	1	35	500	0	500	0
5	16	228	97.4	0	1	35	500	0	500	0
6	18	332	97.4	0	1	35	500	0	500	0
7	16	54	97.6	0	1	36	550	0	550	0
8	16	168	97.6	0	1	36	550	0	550	0
9	16	234	97.6	0	1	36	550	0	550	0

All types of AMS stations are considered but due to the fact that interfering MSS satellite is located in the back lobe of the airborne station receiving antenna communicating with its ground station and also taking into account attenuation by the aircraft fuselage, the worst case of the receiving AMS ground station was assessed. The receiving AMS ground station was placed at a location with geographical coordinates 55N; 36E. Simulations were performed for the 100% AMS operation time and for the case of using for AMS links the same duty cycle of 5% as for MSS (s-E) operations. The simulation time is 15 days and simulation step is 10 sec.

At the first stage of analyses a probability distribution of the pfd produced by MSS satellites at the AMS ground station location for the given assumptions was obtained (see Figure 29).

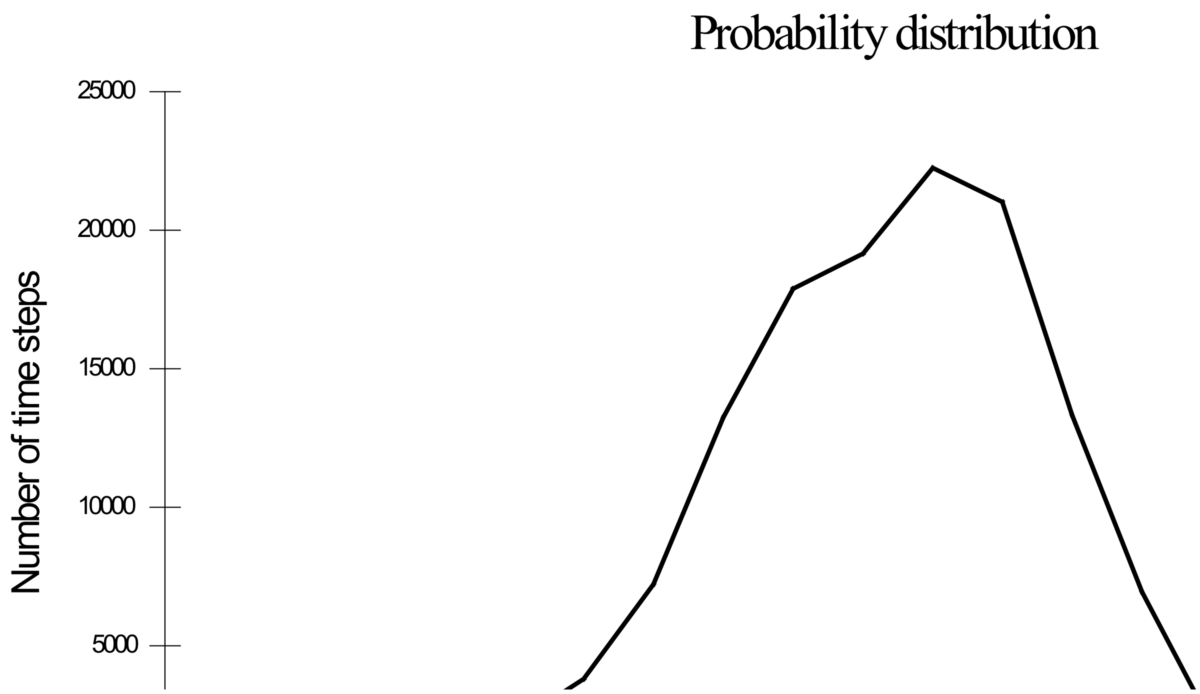


Figure 29: Probability distribution of pfd value for the given assumptions

The average obtained pfd value is -144.109 dB(W/(m2 4 kHz) and standard deviation is 2.202 dB. These values are below -140 dB(W/(m2 4 kHz) defined as a threshold in RR [9]. The obtained values are average; therefore, it is necessary to determine the probability of deviation upward.

At the next stage of analyses CDFs of pfd were obtained taking into account different duty cycle modes (see Figure 30 and Figure 31).

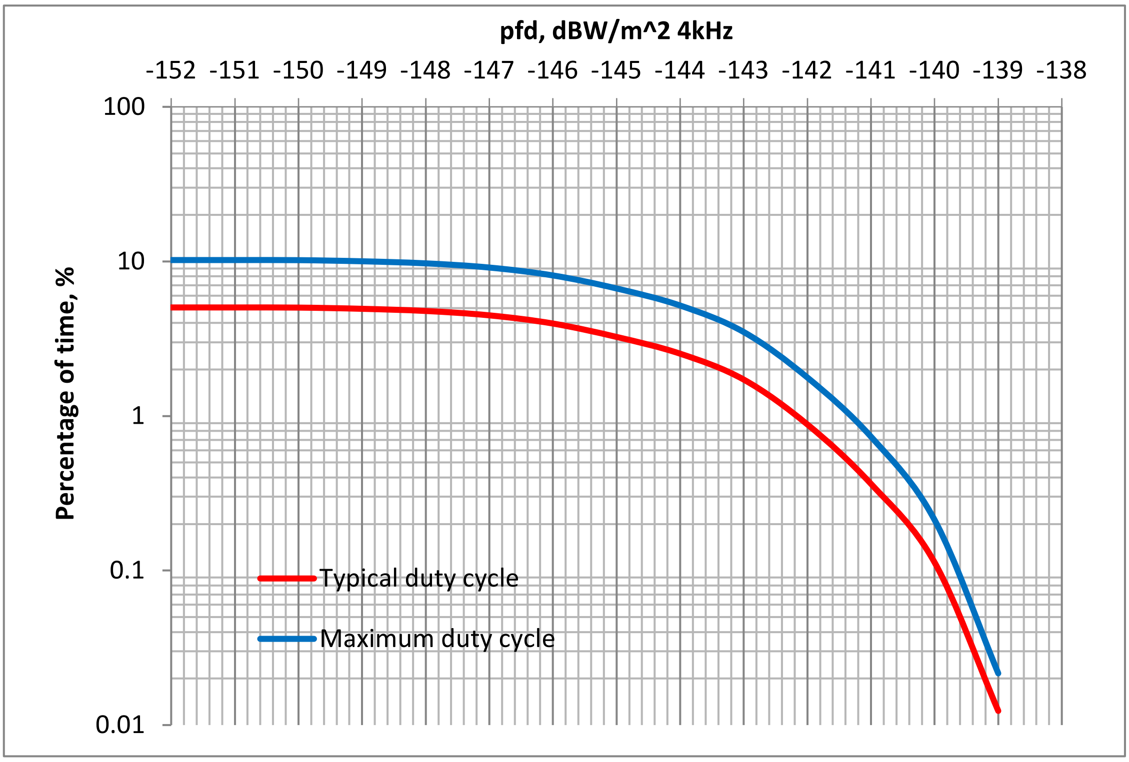


Figure 30: Pfd distribution function for the typical and maximum MSS (s-E) duty cycles

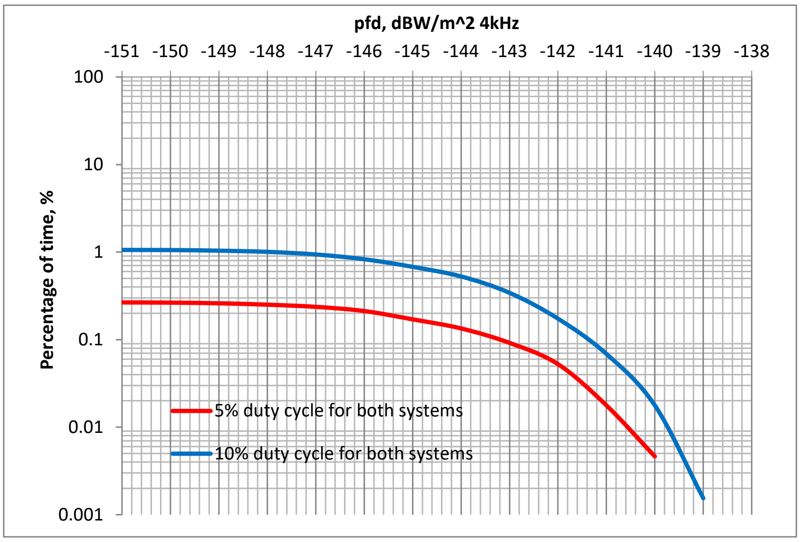


Figure 31: Pfd distribution function for both MSS (s-E) and AMS duty cycle modes

Performed dynamic simulation showed that when using 10% MSS (s-E) duty cycle the probability of exceeding the threshold level of -140 dB(W/(m2 4 kHz) is 0.2% and for the 5% duty cycle such probability will be 0.1%. If one takes into account the possible duty cycle of AMS links, then the probability of producing higher pfd than the threshold pfd at the location of an operating receiving ground station varies from 0% to 0.0015%.

Lower pfd levels (below the threshold of -140 dB(W/(m2 4 kHz)) may be more likely to be created (for example, -150 dB(W/(m2 4 kHz) with probability from 0.2% to 1% depending on assumptions), while the indicated percentages correspond to short-term criteria, tolerances in absolute values of which are larger than according to the long-term criteria indicated.

In summary, given the pfd levels of the SWARM satellites at different altitudes and taking into account the duty cycles, it can be concluded that interference into AMS remains within the threshold pfd limit suggested in Annex 1 to RR. Appendix 5 [9].

A1.5 DESCRIPTION OF MYRIOTA

A1.5.1 General description

MYRIOTA is an established global provider of satellite-based IoT services. Through its global headquarters in Australia, MYRIOTA Pty Ltd has authorisation from the Australian Government to operate a constellation of up to 208 two-way communications satellites in Low Earth Orbit (LEO) to utilise the VHF and UHF frequency bands of the Mobile Satellite Service (MSS).

MYRIOTA has designed a novel communications protocol that uses a Software Defined Radio (SDR) and advanced signal processing to allow very large numbers of low power signals from user terminals to be received on the same frequency channel. MYRIOTA enables secure low-cost communications for Internet of Things (IoT) devices anywhere on the planet using patented techniques for massive scale direct-to-orbit communications. MYRIOTA's system brings a cost-effective data communication technology to a new class of users with operations that require direct-to-orbit access to small amounts of data from numerous low-power devices.

MYRIOTA's direct-to-orbit IoT connectivity platform allows modules to communicate directly with low earth orbit (LEO) satellites and provides affordable access to location data and other data collected by sensors using devices with a battery life of several years.

MYRIOTA's system enables millions of terrestrial IoT modules – associated with sensors or other devices – to transmit small data messages direct-to-orbit, without requiring a gateway between the device and satellite.

Examples of applications that MYRIOTA's system can provide include:

- Environment: Weather monitoring; water flow sensing; oceanography; soil monitoring; natural resource management;
- Agriculture: Water security; livestock tracking; sensor telemetry; soil moisture probes; weather stations; feral animal trapping;
- Resource sector: Asset tracking and monitoring; predictive maintenance; process optimisation;
- Utilities: Smart grid; meter reading; infrastructure management; remote alerts and control;
- Transport and Logistics: Asset tracking and monitoring; end-to-end freight; route planning and optimisation; intelligent transport.

The satellite service operates within the VHF and UHF MSS frequency bands, including 137-138 MHz (space-to-Earth), 148-150.05 MHz (Earth-to-space), 399.9-400.05 MHz (Earth-to-space), and 400.15-401 MHz (space-to-Earth).

There are three categories of terrestrial station anticipated to be used for MYRIOTA's system, as shown in Figure 32 and Figure 33 that follow:

- IoT Modules - provide MYRIOTA's advanced nanosatellite transceiver for secure data transfer and a system for sophisticated power management. They allow Original Equipment Manufacturers to add global IoT connectivity, and reliable, long battery life to their devices for a wide range of mobile applications;
- International ground stations - backhaul data to and from the satellite constellation to provide connectivity to the Internet, and also perform telemetry, tracking, and control ("TT&C") functions;
- Low-cost micro-gateways - also backhaul data to and from the satellite constellation, augmenting the international ground station network and providing low latency connectivity to the Internet. Each micro-gateway includes a MYRIOTA radio for nanosatellite connectivity.

MYRIOTA's IoT modules communicate with the NGSO constellation at given times as the satellites pass overhead. The IoT modules wait to transmit only when a satellite is visible, which leads to extended battery lifetime. Their emissions are low power (< 1 Watt), low bandwidth (< 4 kHz), and low duty cycle (< 0.02%). This means the IoT modules are small and inexpensive, with long battery life, supporting a myriad of different applications in the context of the Internet of Things.

The VHF and UHF downlink is used to broadcast updates to IoT modules. It also enables ability to command individual IoT modules, e.g. to cease transmissions, if required.

Operation of Telemetry, Tracking and Control (TT&C) shall be performed from ground stations at various global locations using S Band spectrum: 2025-2110 MHz (Earth-to-space) and 2200-2290 MHz (space-to-Earth). In the future, MYRIOTA may also consider using other frequency bands for this purpose, including those allocated in VHF and UHF.

The user data uplinked from the IoT modules is downlinked using S Band frequencies (2200-2290 MHz) or X Band (8025-8400 MHz) to ground stations in various global locations. Data arriving at ground stations is delivered via the Internet to MYRIOTA's cloud hub, where a customer portal provides users with access to their data.

Data may also be transferred between IoT modules and MYRIOTA's cloud system via micro-gateways in CEPT countries, using 148-150.05 MHz and 399.9-400.05 MHz for uplink; 137-138 MHz and 400.15-401 MHz for downlink.

Note that MYRIOTA will not provide voice services in Europe.

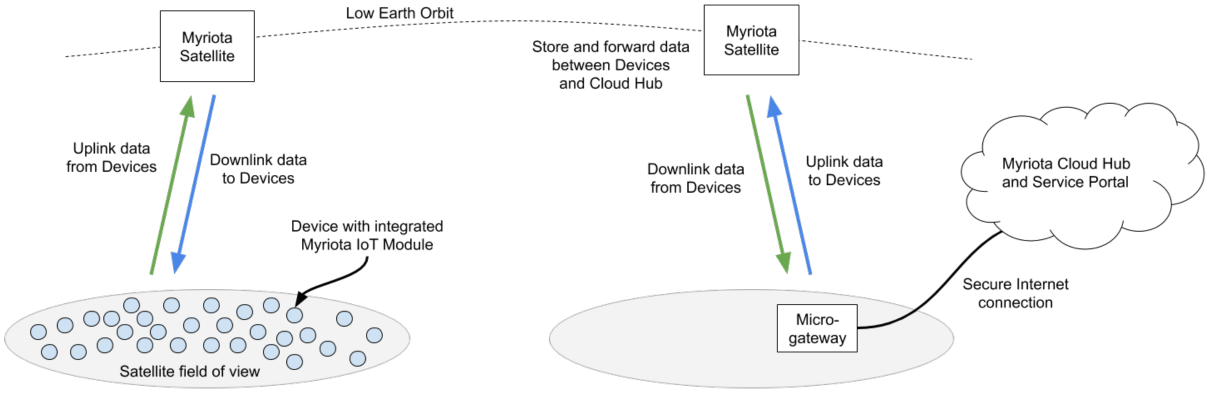


Figure 32: MYRIOTA System Architecture (IoT device and micro-gateway data flow)

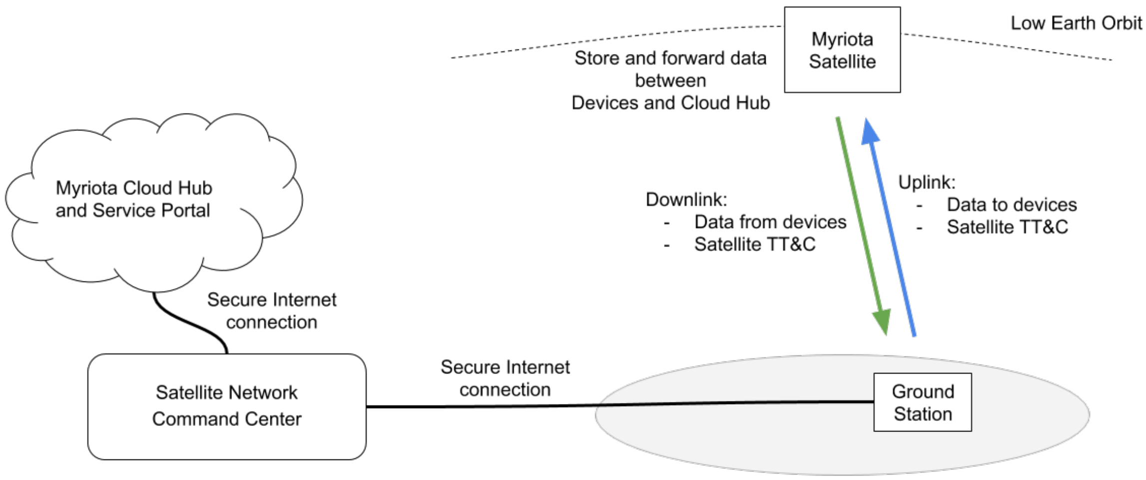


Figure 33: MYRIOTA System Architecture (Operations and ground station data flow)

A1.5.2 Technical characteristics

Table 34 outlines the frequency bands to be used by MYRIOTA satellites:

Table 34: MYRIOTA satellite frequency bands

Frequency range	Direction	Typical operating bandwidth per transponder
137-138 MHz	space-to-Earth	20 kHz transmit
148-149.9 MHz	Earth-to-space	50 kHz receive
149.9-150.05 MHz	Earth-to-space	50 kHz receive
399.9-400.05 MHz	Earth-to-space	50 kHz receive
400.15-401 MHz	space-to-Earth	20 kHz transmit

MYRIOTA's satellite system for service will consist of a total of 52 satellites, within 16 orbital planes:

- 12 satellites in sun synchronous orbits, in 6 planes;
- 40 satellites at 54° inclined orbit, in 10 planes.

Orbital altitudes of all satellites will be launched between 450 to 600 km.

MYRIOTA has filed via the Australian Administration and a coordination request has been published under the ITU name MNSAT in Special Section CR/C 4735 in BR IFIC 2878 on 4 September 2018. The complete satellite constellation will consist of at least 26 satellites that will be replenished. But the system may employ up to 52 satellites to provide MYRIOTA's service. The satellites will be launched at various altitudes between 450-600 km, and inclination angles ranging 0°- 98°. The orbital parameters provided to CEPT are a subset of the envelope MYRIOTA's satellite constellation outlined in its ITU filings. For example, the MNSAT filing enables 208 satellites at orbital altitudes ranging from 400-850 km, and inclination angles ranging 0°- 98.9°.

MYRIOTA also intends to employ other existing ITU filings to provide its service in CEPT countries. At present, MYRIOTA has purchased satellite communications assets from exact Earth Ltd, including hardware and access to the ITU filing ADS. MYRIOTA's satellite system will provide service to CEPT countries using both ITU filings MNSAT (for UHF and VHF bands) and ADS (for UHF band). Note that 6 of the 52 satellites in MYRIOTA's constellation will be from the ADS filing. All 52 satellites will operate at altitudes below 600 km. MYRIOTA has no intention of operating satellites outside this altitude range.

The studies presented in this Report consider orbital height of 600 km. Conclusions reached for the altitude of 600 km are valid for heights below 600 km as a satellite closer to Earth will have a smaller field of view, therefore less impact on Earth.

Table 35: MYRIOTA Satellites Orbital Parameters

Orbital plane ID	Number of satellites per plane	Inclination of the orbital plane	Orbital period (minutes)	Apogee (km)	Perigee (km)	Right ascension of the ascending node
1	2	97.69	97	600	600	0
2	2	97.69	97	600	600	30
3	2	97.69	97	600	600	60
4	2	97.69	97	600	600	90
5	2	97.69	97	600	600	120
6	2	97.69	97	600	600	150
7	4	54	97	600	600	0
8	4	54	97	600	600	36
9	4	54	97	600	600	72
10	4	54	97	600	600	108
11	4	54	97	600	600	144
12	4	54	97	600	600	180
13	4	54	97	600	600	216
14	4	54	97	600	600	252
15	4	54	97	600	600	288
16	4	54	97	600	600	324

There are two types of terrestrial stations anticipated to be used for MYRIOTA's system: the IoT module, and micro-gateway.

A1.5.3 UHF parameters

A1.5.3.1 Uplink parameters (UHF band)

The uplink operational parameters are outlined in Table 36:

Table 36: Uplink parameters (UHF band)

TYPE OF STATION	OPERATING PARAMETER	TYPICAL	MAXIMUM
IoT Modules UHF 399.9-400.05 MHz	Maximum e.i.r.p.	< -3 dBW	5 dBW
	Transmit power	-3 dBW	0 dBW
	Occupied bandwidth (99% of emission power)	4 kHz	4 kHz
	Duty cycle	< 0.02%	0.50%
	Modulation	MSK (FSK modulation index ½)	MSK (FSK modulation index ½)
Micro-gateways UHF 399.9-400.05 MHz	Maximum e.i.r.p.	< 5 dBW	5 dBW
	Transmit power	-3 dBW	0 dBW
	Occupied bandwidth (99% of emission power)	25 kHz	50 kHz
	Duty cycle	< 0.50%	5.00%
	Modulation	FSK	FSK

Table 37: IoT module uplink (UHF band)

IoT module uplink (UHF)		
Parameter	Value	Notes
Typical duty cycle	0.02%	
Maximum duty cycle	0.50%	
Maximum individual transmission time	262 ms	
Minimum off time in between emissions	2 s	There may be more than one emission per satellite pass. IoT modules only transmit when within footprint of MYRIOTA satellite
Time period of duty cycle	1 day (24 hours)	
Parameter	Value	Notes
Frequency hopping dwell time	262 ms	

IoT module uplink (UHF)		
Occupied bandwidth of emission (99% of power)	4 kHz	
Hopping bandwidth	UHF: Up to 150 kHz	The hopping bandwidth depends on the frequency range permitted to operate. UHF: If assigned 150 kHz of the 399.9-400.05 MHz allocation, MYRIOTA IoT modules will hop over the entire 150 kHz range. MYRIOTA's IoT modules are reconfigurable in the field, and can perform frequency hopping over several non-contiguous frequency allotments.
Duty cycle relation to frequency hopping	Duty cycle is defined over all hops	Duty cycle is the transmit duty cycle of the device (regardless of frequency). Due to the narrow emission bandwidth (4 kHz) of MYRIOTA's IoT module, a larger permitted frequency hopping bandwidth will result in lower probability of occupying the same frequency.

Typical operation is for the IoT applications, for the majority of time. Many applications using MYRIOTA's IoT modules are expected to be battery powered, with battery life related to the transmit power and number of transmissions; therefore, there is motivation to operate with the minimum necessary transmit power and duty cycle. There will be some applications and situations that may require the maximum transmit power and duty cycle.

In terms of channel spacing and bandwidth, MYRIOTA’s IoT modules employ frequency hopping with 4 kHz narrow band emissions that can operate within any given range or multiple ranges within the 399.9-400.05 MHz frequency bands. The IoT modules do not use predefined channels. Due to the flexibility of MYRIOTA’s system, the IoT modules can be updated via the MSS downlink to modify the ranges of frequencies allowed to operate.

MYRIOTA IoT modules will typically operate with e.i.r.p. below -3 dBW, for the UHF MSS frequency band. This will be typical operation for most applications, and due to varying antenna gain, the e.i.r.p. in a given direction will be far less than this most of the time. Some applications may require IoT modules to transmit at higher power or may be connected to an antenna with higher gain. However, the e.i.r.p. of IoT modules will never exceed 5 dBW, for UHF band.

The micro-gateways will remain within the 5 dBW e.i.r.p. limit for the UHF MSS frequency band. Due to the flexibility of MYRIOTA’s system, the micro-gateways can be updated with regulatory permissions, including e.i.r.p. limits depending on their location and the location of surrounding terrestrial services. Emissions of MYRIOTA ground stations will comply with the spectrum mask limits set forth in US 47 CFR 25.202(f).

In the band 399.9-400.05 MHz, MYRIOTA can configure the length, interval, data rate, bandwidth, and frequency of transmissions from earth stations in its system. MYRIOTA’s system will be able to share these bands with other systems without causing harmful interference. Both IoT modules and micro-gateways transmit only when a MYRIOTA satellite is overhead, significantly reducing the times during which there is a risk of interference. All of MYRIOTA’s terrestrial stations in the 399.9-400.05 MHz band will operate with less than 5 dBW e.i.r.p. MYRIOTA’s IoT modules will operate with typical transmit duty cycle less than 0.02%, and occasionally with duty cycle of up to 0.5%. They employ frequency hopping across the intended band, with a narrow emission bandwidth of less than 4 kHz. MYRIOTA’s micro-gateways will typically operate with transmit duty cycle less than 0.5% and occasionally up to 5%, with emission bandwidth ranging from 25-250 kHz. Since the micro-gateways are far less numerous than other devices communicating with MYRIOTA satellites in this band, their slightly higher duty cycle will have a negligible effect on the spectrum environment. These operating characteristics give MYRIOTA the ability to share the entire uplink frequency range with other satellite systems also operating in the same bands, as well as the ability to operate in various portions of the frequency bands designated for use. The time period for the station's duty cycle is 24 hours.

MYRIOTA's MESs employ frequency hopping with a maximum dwell time of 262 ms and a minimum off time between emissions of 2 seconds. The hopping bandwidth is configurable so that the entire available bandwidth can be used. In addition, the transmit duty cycle is defined per device, regardless of the frequency of operation or frequency hopping arrangements. MYRIOTA's system will employ feeder link earth stations using S-band uplink (2025-2110 MHz), as well as S-band downlink (2200-2290 MHz) and X-band downlink (8025-8400 MHz).

A1.5.3.2 Downlink parameters (UHF band)

Examples of MYRIOTA's downlink operational parameters are outlined in Table 38:

Table 38: Downlink parameters (UHF band)

Parameters	UHF band	
Bandwidth	4 kHz	20 kHz
Satellite altitude [km]	600	600
Transmit bandwidth [kHz]	4	20
Transmit power [dBW]	10	8.5
Typical Antenna Gain [dBi] (Omnidirectional antenna)	0	0
e.i.r.p. over given bandwidth [dBW]	10	8.5
Maximum e.i.r.p. density [dBW / 4 kHz]	10	1.5
Duty cycle	10%	20%

Table 39: Satellite downlink (UHF band)

Satellite downlink (UHF band)		
	Value	Notes
Duty cycle per individual satellite	10% 20%	0.5 second every 5 seconds 1 second every 5 seconds
Length of individual transmissions	0.5 second 1 second	
Off time in between transmissions	4.5 seconds 4 seconds	
Frequency hopping	No plan to implement frequency hopping	Depending on noise sources and developing congestion in Europe, MYRIOTA may implement frequency hopping

These example downlink parameters apply to UHF band. MYRIOTA's satellites have the flexibility to control the transmit power according to satellite altitude. Ideally, MYRIOTA will deploy all satellites at 600 km altitude, however some satellites may be subject to orbital parameters determined by launch providers. Operating parameters of the satellites will be adjusted so that the received signal power on the surface of the Earth is the same, regardless of orbital height. For that reason, in the studies presented here, the orbital height of 600 km was considered but the conclusions reached are valid for heights of 450 km as well.

Omni directional satellite antennas are used for the studies, with max gain shown in Table 39. MYRIOTA's satellites will be steered for solar pointing purposes (charging battery). Therefore, the antenna gain in the direction of the Earth's surface can vary. The satellites will have dual polar linear antennas for UHF, and the spacecraft will be operated such that the gain in nadir direction is close to maximum for the majority of time.

In the band 400.15-401 MHz, MYRIOTA's system has the flexibility and spectral efficiency to be able to operate harmoniously with other users of the bands. MYRIOTA's satellites can vary channel bandwidth through on-board processing, and dynamically control their emissions across the entire frequency ranges to accommodate sharing arrangements with other users of these bands. MYRIOTA downlink emissions can range in bandwidth between 4-20 kHz and operate within the entire MSS allocation or any portion thereof designated for use. MYRIOTA downlink emissions can employ frequency hopping to move through the assigned band, or operate with a defined channel plan, using either multiple contiguous channels or a fragmented channel arrangement. MYRIOTA can also configure the length, interval, data rate, bandwidth, and frequency of transmissions of satellites in its system. The flexibility of the software defined radio on board MYRIOTA's satellites will enable MYRIOTA to share spectrum by coordinating usage and/or time of operations. It is important to note that the time reference for MYRIOTA's downlink duty cycle is 5 seconds.

A1.5.3.3 Downlink out-of-band emissions

This section describes measurements of MYRIOTA's downlink out-of-band emissions. The output power from MYRIOTA's satellite at 400.55 MHz was set to 36.63 dBm, or -0.37 dB(W/4 kHz). An attenuator was used to reduce this power across the entire 400-410 MHz band, and a notch filter was inserted at the carrier frequency to prevent overloading the spectrum analyser. The frequency response of the notch/LNA is shown in Figure 34. Between 406.1-410 MHz, the notch/LNA produced gain, which amplifies the unwanted emissions and makes the results appear worse. This gain ranges between 2.2 dB to 6.38 dB and is compensated for in the results. However, this gain is assumed to be only 2.2 dB as a conservative approach.

Measurement of noise was only performed during transmission 'on time', thus without any benefit from duty cycle. The resulting measurements assume always on transmission and are shown in Figure 35. The measured noise power over 3.9 MHz is compensated by 2.2 dB to account for notch/LNA gain, and then converted to 4 kHz reference bandwidth, which results in -111.29 dBm (per 4 kHz). Compared to the input power of -0.37 dBm (per 4 kHz), this means attenuation of at least 110.92 dBc is achieved across the 406.1-410 MHz band.

The results here presented are for the UHF band, but a similar out-of-band attenuation value can be assumed for the VHF band due to the similarity between the MYRIOTA payloads in both bands. In addition, the frequency separation between the MYRIOTA downlink and the RAS band in the VHF spectrum is more than twice the separation in the UHF band. If a spectral roll off of -110 dBc/4 kHz was measured in the UHF band with a 5.1 MHz separation between the transmit and the interference bands, more roll off can be expected in the VHF band, with a 12.05 MHz frequency separation.

Table 40: Parameters and results

Parameters	Results
Output power of satellite (no attenuator, no notch)	36.63 dBm
Input power to measurement notch/LNA (over 4 kHz bandwidth)	-0.37 dBm
Attenuation from notch/LNA at carrier frequency 400.57 MHz	22.97 dB
Carrier power after notch/LNA	-23.34 dBm (calculated) -23.53 dBm (measured)

Notch/LNA gain	2.2 dB (at 406.1 MHz) 6.38 dB (at 410 MHz) (lower gain value used as worst case)
Transmission on time	1100 ms
Measured noise power (over 3.9 MHz bandwidth)	-79.2 dBm
Calculated noise power after compensating for 2.2 dB notch/LNA gain	-81.4 dBm (over 3.9 MHz) -111.29 dBm (over 4 kHz)
Ratio of noise power to carrier power	-110.92 dBc (4 kHz reference)

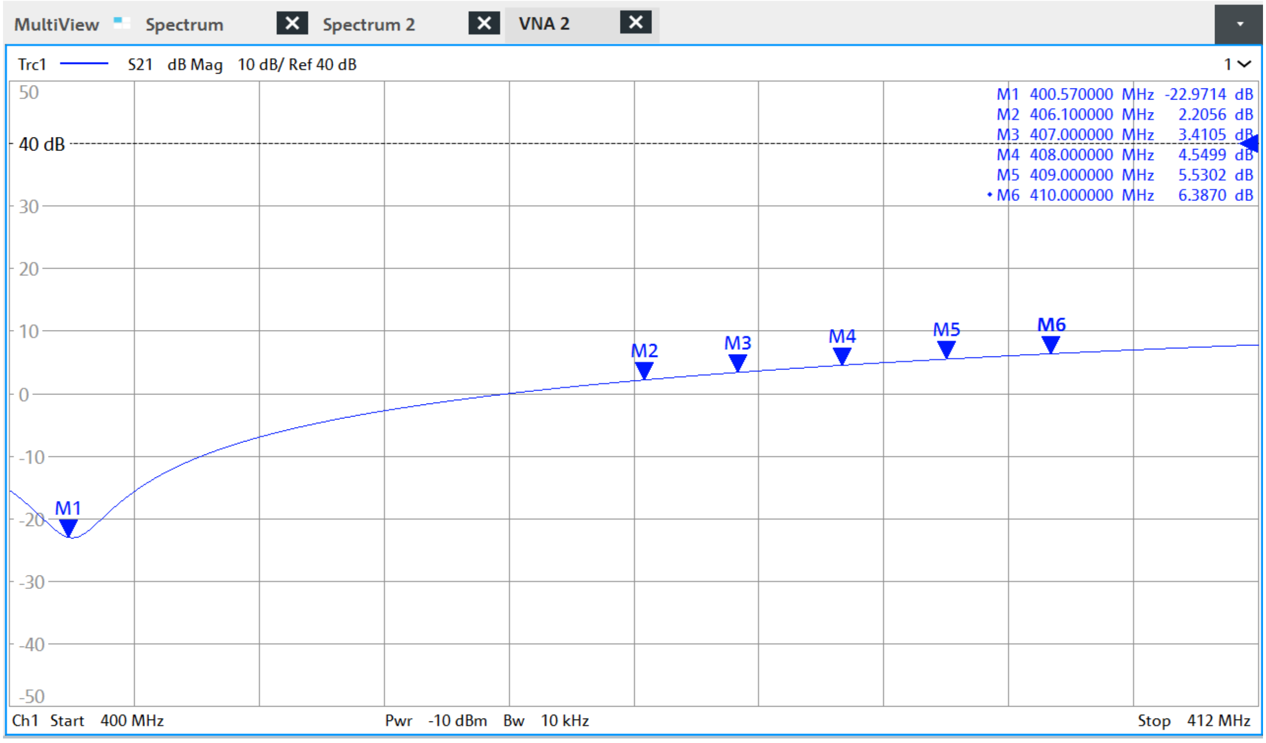


Figure 34: Notch filter with 23 dB attenuation at the carrier; and between 2.2 dB to 6.38 dB gain over RAS frequency range

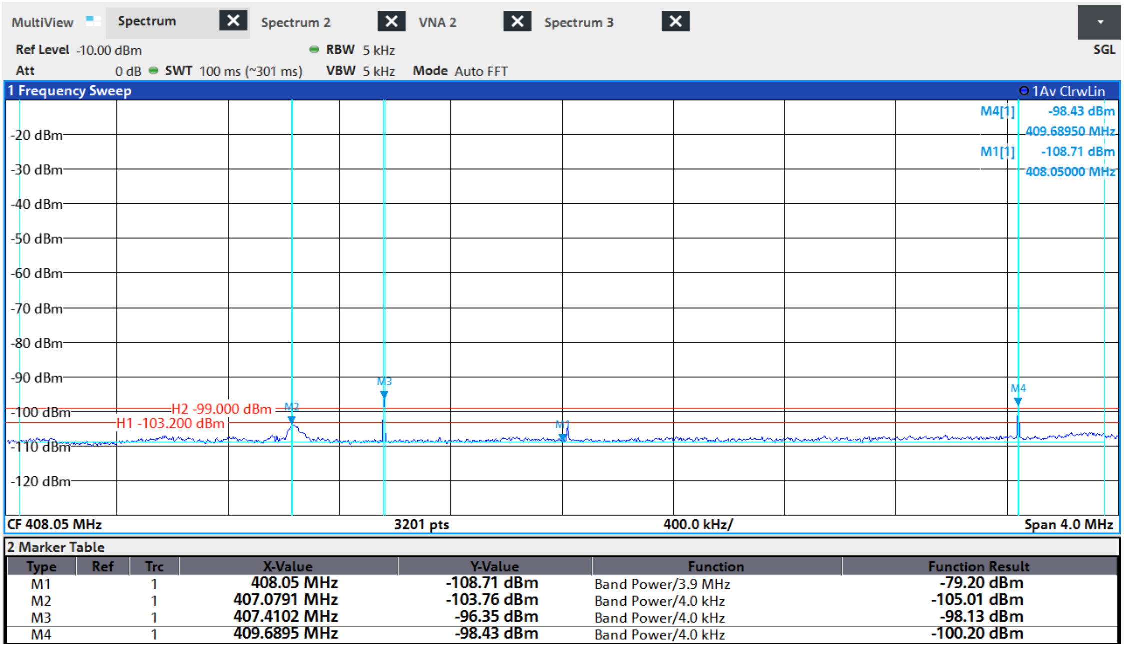


Figure 35: Test measurement over RAS frequency range. Marker M1 measured total power across the 3.9 MHz range as -79.2 dBm, from which an amplification of 2.2 dB was discounted

A1.5.4 VHF parameters

A1.5.4.1 Uplink parameters (VHF band)

The uplink operational parameters are outlined in Table 41:

Table 41: Uplink parameters (VHF band)

TYPE OF STATION	OPERATING PARAMETER	TYPICAL	MAXIMUM
IoT Modules VHF 148-150.05 MHz	Maximum e.i.r.p.	< -3 dBW	5 dBW
	Transmit power	-3 dBW	0 dBW
	Occupied bandwidth (99% of emission power)	4 kHz	4 kHz
	Duty cycle	< 0.02%	0.50%
	Modulation	MSK (FSK modulation index ½)	MSK (FSK modulation index ½)
Micro-gateways VHF 148-150.05 MHz	Maximum e.i.r.p.	< 5 dBW	10 dBW
	Transmit power	-3 dBW	10 dBW
	Occupied bandwidth (99% of emission power)	25 kHz	250 kHz
	Duty cycle	< 0.50%	5.00%
	Modulation	FSK	FSK

Table 42: IoT module uplink (VHF band)

Type of station	Operating parameter	Typical	Maximum
IoT Modules VHF 148-150.05 MHz	Maximum e.i.r.p.	< -3 dBW	5 dBW
	Transmit power	-3 dBW	0 dBW
	Occupied bandwidth (99% of emission power)	4 kHz	4 kHz
	Duty cycle	< 0.02%	0.50%
	Modulation	MSK (FSK modulation index ½)	MSK (FSK modulation index ½)
Micro-gateways VHF 148-150.05 MHz	Maximum e.i.r.p.	< 5 dBW	10 dBW
	Transmit power	-3 dBW	10 dBW
	Occupied bandwidth (99% of emission power)	25 kHz	250 kHz
	Duty cycle	< 0.50%	5.00%
	Modulation	FSK	FSK

Typical operation is IoT applications,for the majority of time. Many applications using MYRIOTA's IoT modules are expected to be battery powered, with battery life related to the transmit power and number of transmissions; therefore, there is motivation to operate with the minimum necessary transmit power and duty cycle. There will be some applications and situations that may require the maximum transmit power and duty cycle.

In terms of channel spacing and bandwidth, MYRIOTA's IoT modules employ frequency hopping with 4 kHz narrow band emissions that can operate within any given range or multiple ranges within the 148-150.05 MHz frequency band. The IoT modules do not use predefined channels. Due to the flexibility of MYRIOTA's system, the IoT modules can be updated via the MSS downlink to modify the ranges of frequencies allowed to operate.

MYRIOTA IoT modules will typically operate with e.i.r.p. below -3 dBW, for VHF MSS frequency band. This will be typical operation for most applications, and due to varying antenna gain, the e.i.r.p. in a given direction will be far less than this most of the time. Some applications may require IoT modules to transmit at higher power or may be connected to an antenna with higher gain. However, the e.i.r.p. of IoT modules will never exceed 5 dBW, for VHF band.

For the VHF MSS band, micro-gateways may occasionally operate with e.i.r.p. up to 10 dBW. Due to the flexibility of MYRIOTA's system, the micro-gateways can be updated with regulatory permissions, including e.i.r.p. limits depending on their location and the location of surrounding terrestrial services. This ensures MYRIOTA's responsible use of the VHF MSS band and does not impose any risk of harmful interference to terrestrial services. Emissions of MYRIOTA ground stations will comply with the spectrum mask limits set forth in US 47 CFR 25.202(f).

In the band 148-150.05 MHz, MYRIOTA can configure the length, interval, data rate, bandwidth, and frequency of transmissions from earth stations in its system. MYRIOTA's system will be able to share these bands with other systems without causing harmful interference. Both IoT modules and micro-gateways transmit only when a MYRIOTA satellite is overhead, significantly reducing the times during which there is a risk of interference. Earth stations in the 148-150.05 MHz frequency band will typically operate with less than 5 dBW e.i.r.p. but may operate higher. MYRIOTA's IoT modules will operate with typical transmit duty cycle less than 0.02%, and occasionally with duty cycle of up to 0.5%. They employ frequency hopping across the intended band, with a narrow emission bandwidth of less than 4 kHz. MYRIOTA's micro-gateways will typically operate with transmit duty cycle less than 0.5% and occasionally up to 5%, with emission bandwidth ranging from 25-250 kHz. Since the micro-gateways are far less numerous than other devices communicating with MYRIOTA satellites in this band, their slightly higher duty cycle will have a negligible effect on the spectrum environment.

These operating characteristics give MYRIOTA the ability to share the entire uplink frequency range with other satellite systems also operating in the same bands, as well as the ability to operate in various portions of the frequency bands designated for use. The time period for the station's duty cycle is 24 hours.

MYRIOTAs MESs employ frequency hopping with a maximum dwell time of 262 ms and a minimum off time between emissions of 2 seconds. The hopping bandwidth is configurable so that the entire available bandwidth can be used. In addition, the transmit duty cycle is defined per device, regardless of the frequency of operation or frequency hopping arrangements. MYRIOTA's system will employ feeder link earth stations using S-band uplink (2025-2110 MHz), as well as S-band downlink (2200-2290 MHz) and X-band downlink (8025-8400 MHz).

A1.5.4.2 Downlink parameters (VHF band)

Examples of MYRIOTA's downlink operational parameters are outlined in Table 43.

Table 43: Downlink parameters (VHF band)

	UHF		VHF	
Bandwidth	4 kHz	20 kHz	4 kHz	20 kHz
Satellite altitude [km]	600	600	600	600
Transmit bandwidth [kHz]	4	20	4	20
Transmit power [dBW]	10	8.5	1.5	8.5
Typical Antenna Gain [dBi] (Omnidirectional antenna)	0	0	0	0
e.i.r.p. over given bandwidth [dBW]	10	8.5	1.5	8.5
Maximum e.i.r.p. density [dBW / 4 kHz]	10	1.5	1.5	1.5
Duty cycle	10%	20%	10%	20%

Table 44: Satellite downlink (VHF band)

Satellite downlink (VHF band)		
	Value	**Notes**
Duty cycle per individual satellite	10% 20%	0.5 second every 5 seconds 1 second every 5 seconds
Length of individual transmissions	0.5 second 1 second	
Off time in between transmissions	4.5 seconds 4 seconds	
Frequency hopping	No plan to implement frequency hopping	Depending on noise sources and developing congestion in Europe, MYRIOTA may implement frequency hopping.

These example downlink parameters apply to VHF band. MYRIOTA's satellites have the flexibility to control the transmit power according to satellite altitude. Ideally, MYRIOTA will deploy all satellites at 600 km altitude, however some satellites may be subject to orbital parameters determined by launch providers. Operating parameters of the satellites will be adjusted so that the received signal power on the surface of the Earth is the same, regardless of orbital height. For that reason, in the studies presented here, the orbital height of 600 km was considered but the conclusions reached are valid for heights of 450 km as well.

Omni directional satellite antennas are used for the studies, with max gain shown in Table 44. MYRIOTA's satellites will be steered for solar pointing purposes (charging battery). Therefore, the antenna gain in the direction of the Earth's surface can vary. The satellites will have dual polar linear antennas for VHF, and the spacecraft will be operated such that the gain in nadir direction is close to maximum for the majority of time.

In the band 137-138 MHz, MYRIOTA's system has the flexibility and spectral efficiency to be able to operate harmoniously with other users of the bands. MYRIOTA's satellites can vary channel bandwidth through on-board processing, and dynamically control their emissions across the entire frequency ranges to accommodate sharing arrangements with other users of these bands. MYRIOTA downlink emissions can range in bandwidth between 4-20 kHz and operate within the entire MSS allocation or any portion thereof designated for use. MYRIOTA downlink emissions can employ frequency hopping to move through the assigned band, or operate with a defined channel plan, using either multiple contiguous channels or a fragmented channel arrangement. MYRIOTA can also configure the length, interval, data rate, bandwidth, and frequency of transmissions of satellites in its system. The flexibility of the software defined radio on board MYRIOTA's satellites will enable MYRIOTA to share spectrum by coordinating usage and/or time of operations. It is important to note that the time reference for MYRIOTAs downlink duty cycle is 5 seconds.

A1.5.5 Inter service studies (UHF band)

A1.5.6 Uplink (399.9-400.05 MHz (Earth-to-space))

The band 399.9-400.05 MHz is only allocated to the MSS (Earth-to-space) in the ITU Radio Regulations. Therefore, there is no need for compatibility studies in this band with other services.

A1.5.6.1 Protection of Mobile Services

The ECA Table [22] identifies ECC Decision (08)05 "The harmonisation of frequency bands for the implementation of digital Public Protection and Disaster Relief (PPDR) narrow band and wide band radio applications in bands within the 380-470 MHz range" as pertinent for the band 399.9-400.05 MHz. However, none of the frequency arrangements for mobile systems, including PPDR, include the band 399.9-400.05 MHz.

A1.5.6.2 Protection of Radio Astronomy

MYRIOTA's UHF uplink transmissions between 399.9–400.05 MHz are separated by 5.05 MHz from the 406.1–410 MHz RAS allocation. Note that MYRIOTA will carefully manage the deployment location of micro-gateways such that they avoid interference potential to RAS facilities.

For MYRIOTA's IoT modules, there are several reasons why they are unlikely to cause harmful interference:

- There is a low probability of an IoT module operating in proximity to RAS facilities for a prolonged period of time;
- Over the intended operating frequency ranges, typical e.i.r.p. of an IoT module will be less than -3 dBW in the direction of RAS site;
- Emissions outside the intended operating frequency ranges will be significantly reduced over any 4 kHz measured bandwidth through front-end filtering compared to the emission at frequency of operation.

Using the operating parameters of MYRIOTA's terrestrial stations, it is possible to calculate the necessary separation distance from a RAS site in order to comply with the protection criteria of Table 45. First step is to calculate the minimum path loss between the two systems, based on the transmission parameters of the MYRIOTA Earth stations and the maximum allowable interference to the RAS site. Then, using the propagation model described in ITU-R P.452 [2], the minimum distance that corresponds to a path loss equal to or higher to the minimum path loss calculated is computed. This minimum distance is the required separation distance between a MYRIOTA Earth station and a RAS site.

Table 45: RAS parameters

UHF Parameter	Value	Unit
RAS centre frequency	408.05	MHz
RAS bandwidth	3.9	MHz
Pfd threshold	-255	dB(W/m2/Hz)
Interference limit	-203	dBW

Table 46 outlines the required separation distances for typical and maximum operation of MYRIOTA terrestrial stations in the UHF band, using attenuation of 65 dBc over the RAS operating frequency range. The antenna gain of the radio astronomy station was assumed to be 0 dBi, as indicated in Recommendation ITU-R RA.769-2 [3].

Table 46: Minimum separation distances between RAS site and UHF MYRIOTA IoT modules/ Micro-Gateways

Minimum separation distances	
MYRIOTA IoT modules	
Worst case	9.03 km
Typical	3.4 km
MYRIOTA Micro-Gateways	
Worst case	8.56 km
Typical	4.8 km

Despite these precautionary features, if a specific RAS site is nonetheless susceptible to interference, MYRIOTA can utilise its geofencing technology to prevent IoT modules from transmitting within certain distances of a given location. MYRIOTA can even send messages instructing specific terrestrial stations to cease transmission should interference concerns arise. Accordingly, using such measures, MYRIOTA will protect RAS facilities operating in the UHF band from harmful interference from unwanted emissions.

A1.5.6.3 Protection of the Cospas-Sarsat system

The 406-406.1 MHz frequency band is exclusively allocated to the mobile-satellite service, which is currently used by the Cospas-Sarsat system. Report ITU-R M.2359-0 outlines the uplink operational parameters of data collection platforms in the 401-403 MHz frequency range. MYRIOTA's IoT modules and micro-gateways operating in the 399.9-400.05 MHz range will use transmit power lower than the values presented in Table 5 - 1 of the Report. Furthermore, the 399.9-400.05 MHz range has at least 5.95 MHz frequency separation with the 406-406.1 MHz range, which is significantly more than that of data collection platforms operating between 401-403 MHz. The Report concludes that the Cospas-Sarsat system is protected from interference from data collection platforms in the 401-403 MHz, and the same conclusion is valid for MYRIOTA's IoT modules and micro-gateways operating within 399.9-400.05 MHz, even when operating at maximum transmit power.

A1.5.7 Downlink (400.15-401 MHz (space-to-Earth))

A1.5.7.1 Coordination with terrestrial systems

For the UHF frequency band, MYRIOTA’s 20 kHz downlink transmissions comply with the -125 dB(W/m2/4 kHz) pfd threshold for coordination with terrestrial systems. When accounting for duty cycle, MYRIOTA‘s 4 kHz downlink transmissions will meet an average pfd on the Earth’s surface of less than -125 dB(W/m2/4 kHz). Without taking into account the duty cycle MYRIOTA 4 kHz downlink emissions do not comply with the threshold for the protection of terrestrial services. Due to its flexibility, MYRIOTA’s system can adjust its transmission parameters to comply with this threshold and protect terrestrial systems, if necessary. Any exceedance of pfd limit shall be subject to an agreement with the concerned administration in CEPT.

Table 47: MYRIOTA’s ground pfd

Parameter	Maximum operation	Alternate operation example	Unit
Orbital height	600	600	km
Bandwidth	4	20	kHz
Transmit power	10	8.5	dBW
Duty cycle	10	20	%
Antenna gain towards ground	0	0	dBi
e.i.r.p. towards ground	10	8.5	dBW
e.i.r.p. density (1 kHz)	3.98	-4.51	dB(W/1kHz)
e.i.r.p. density (4 kHz)	10.00	1.51	dB(W/4 kHz)
PFD density	-116.56	-125.04	dB(W/4 kHz/m2)
PFD density with duty cycle	-126.56	-132.03	dB(W/4 kHz/m2)
PFD threshold	-125	-125	dB(W/4 kHz/m2)
Margin with duty cycle	-1.56	-7.03	dB
Margin without duty cycle	8.44	- 0.04	dB

A1.5.7.2 Protection of Radio Astronomy

For the protection of RAS systems in the band 406.1-410 MHz, the data loss in an integration time of 2000s must not exceed the value of 2%. According to Recommendation ITU-R RA.769-2 [3], the interference pfd threshold above which there is data loss at a RAS site is -189 dB(W/m2) in the UHF band. To compute the data loss, the method described in Recommendation ITU-R M.1583-1 [7] is used. According to this recommendation, the sky is divided into grid of cells and the RAS station receiver is pointing to a random location inside each cell. The interfering MSS constellation is simulated for 2000s for a number of iterations and the interference statistics are collected for all cells and iterations. The antenna pattern described in Recommendation ITU-R RA.1631 [14] is used for the RAS station. The results of the studies are provided in Figure 36 and Figure 37.

In all simulated cases, a spectral roll off of -110 dBc was applied to MYRIOTA’s in-band transmissions to calculate the out-of-band power in the RAS band. It is concluded that MYRIOTA adequately protects the Radio astronomy in the band 406.1-410 MHz.

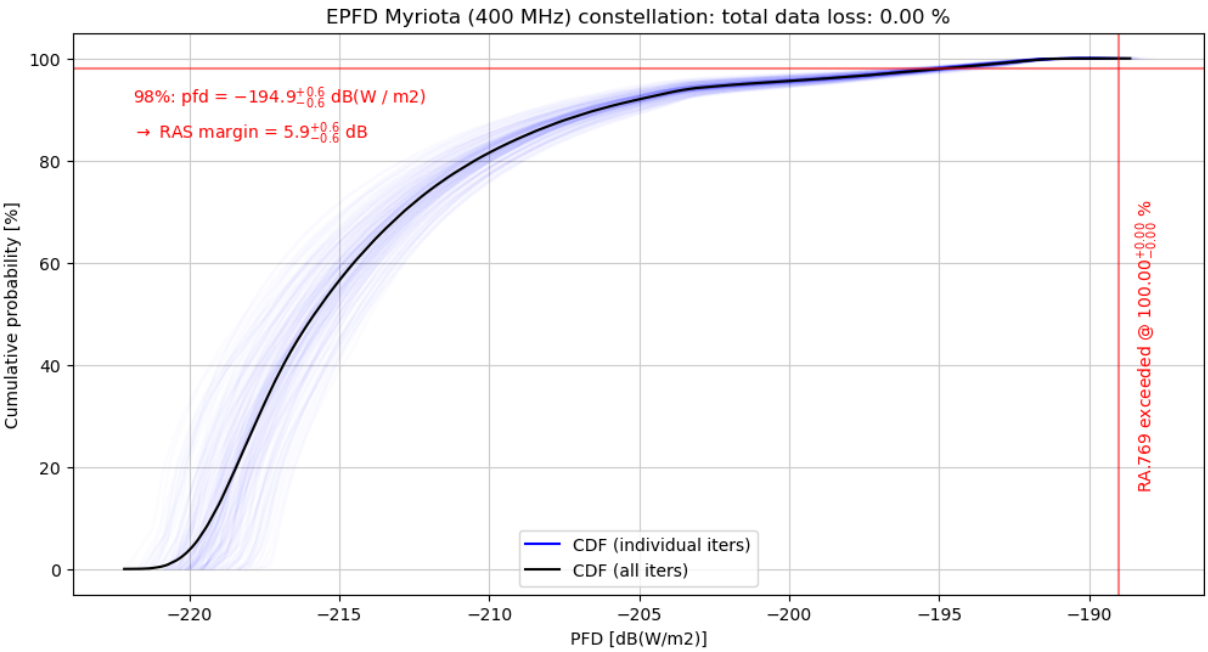


Figure 36: Data loss distribution for 4 kHz carrier

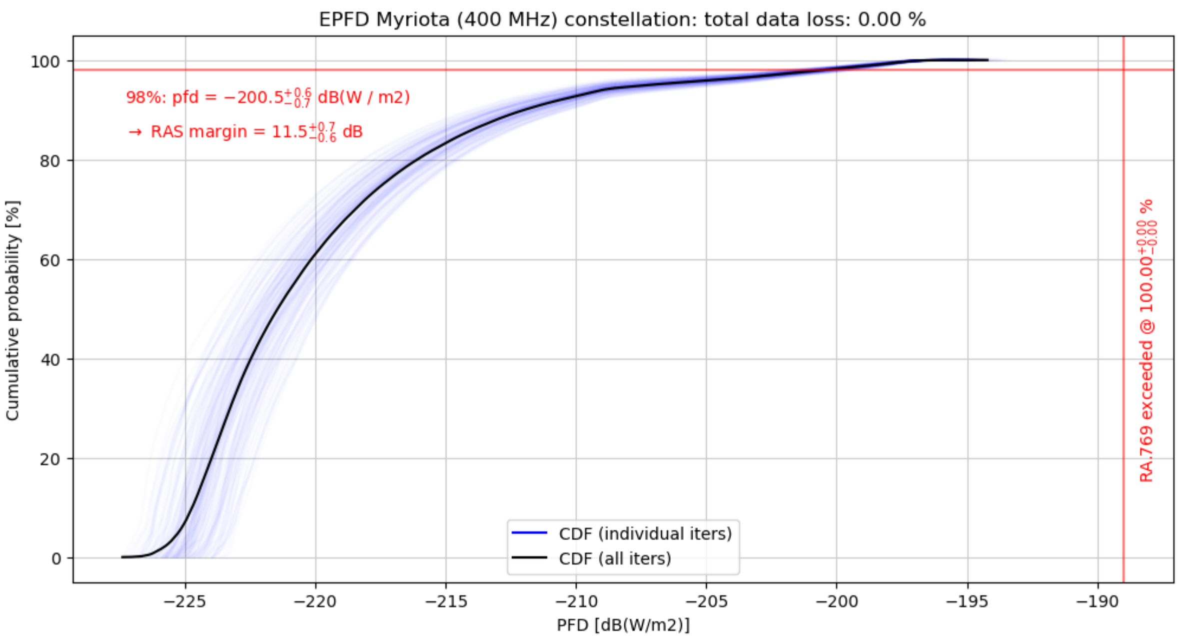


Figure 37: Data loss distribution for 20 kHz carrier

A1.5.7.3 Standard frequency and time signal satellite (400.1 MHz)

The SFTSS (Standard Frequency and Time Signal-Satellite) Service is allocated in Article 5 of the Radio Regulations on a primary basis in the band 400.05-400.15 MHz. In accordance with footnote 5.261, emissions shall be confined in a band of +/- 25 kHz about the standard frequency 400.1 MHz.

There is no identified Recommendation ITU-R or Report providing characteristics or protection criteria for SFTSS. However, some satellite networks contain assignments in this service (class of station EE or EY) in the band 400.05-400.15 MHz. Their characteristics can be used to assess adjacent band compatibility with MYRIOTA downlink operations within the adjacent 400.15-401 MHz MSS allocation.

The following formula permits to calculate the pfd value (dBW/m²/4 kHz) to meet a given I/N criterion into an Earth station with an antenna gain Grx and noise temperature N:

$$pfd_{(\frac{dBW}{m^2}/4kHz)} = \left(\frac{I}{N}\right) - 38.55 + 20 * Log(f_{MHz}) - G_{rx} - 228.6 + 10 * Log(T * 4000)$$

The identified SFTSS network's characteristics are summarised as follows, and the right column provides the pfd value to meet an I/N of -10 dB in the worst-case conditions.

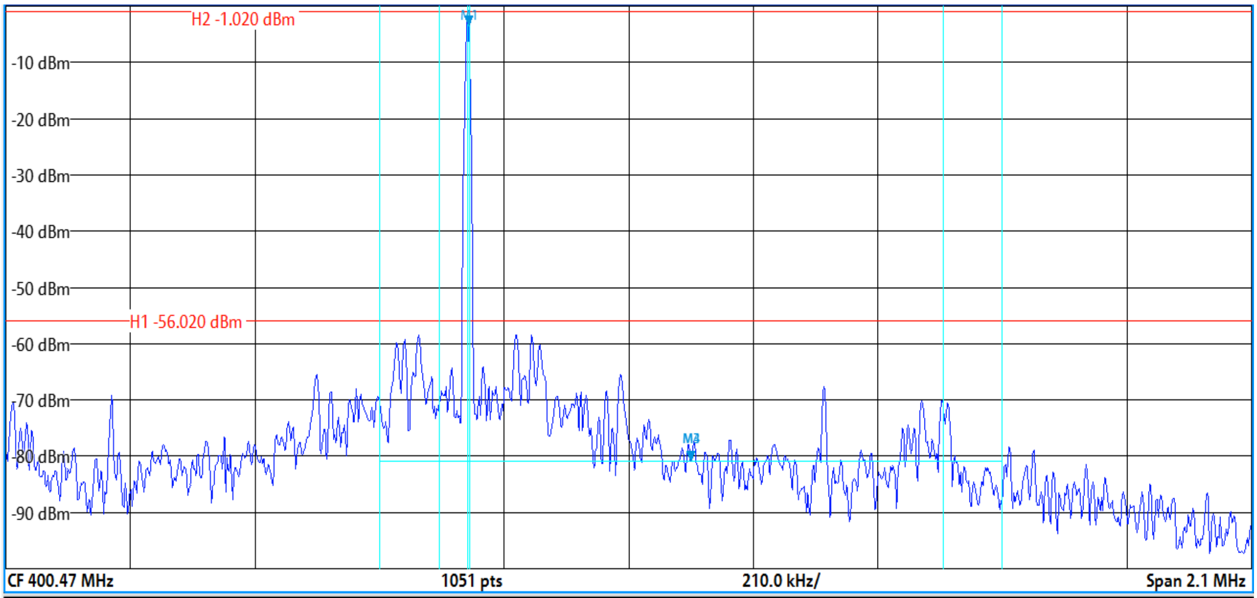
Table 48: SFTSS network's characteristics

Network name	Adm	Freq min	Freq max	Station class	Emission designator	E/S Rx Gain	E/S Noise temp	Worst case PFD (dBW/m²/4 kHz)
TSYKADA	RUS	400.075	400.125	EE	50K0G2D--	0	200	-166.1
LEOTELCOM-1	USA	400.075	400.125	EE	50K0G7D--	2	400	-165.1
		400.075	400.125	EE	50K0G7D--	6.1	400	-169.2
ICARUS	D	400.05	400.15	EY	5K00G1D--	-10	3000	-144.3
		400.05	400.15	EY	50K0G1D--	-10	3000	
F-SAT-NG-8	F	400.05	400.15	EY	50K0G7W--	0	500	-162.1
		400.05	400.15	EY	12K3G7W--	0	500	
		400.05	400.15	EY	1K00G7W--	0	500	

MYRIOTA will employ the necessary guard bands so that there is sufficient frequency separation to protect SFTSS from MYRIOTA satellite emissions. For example, MYRIOTA's 20 kHz emissions require attenuation of at least 44.2 dBc to ensure the pfd produced on the Earth's surface in the 400.05-400.15 MHz range is below -169.6 dBW/m²/4 kHz, which is sufficient to protect SFTSS. To reach this attenuation, MYRIOTA will apply a guard band from the 400.15 MHz boundary. MYRIOTA's 4 kHz emissions require attenuation of at least 52.64 dBc to protect SFTSS, which is achievable with frequency separation from the 400.15 MHz boundary. The measurements in Figure 38 show that a guard band of 10 kHz is sufficient to guarantee these levels of attenuation.

Given the orbital parameters of MYRIOTA's system, there will be several satellites in view of any point on the Earth's surface in Europe. However, the duty cycle of each of MYRIOTA's satellites is no more than 20%. MYRIOTA can control its satellite emissions to ensure that their aggregate effect does not exceed the required pfd limit to protect SFTSS.

In addition, Figure 38 shows measurements for MYRIOTA's UHF downlink out of band emissions. The image shows the narrow 4 kHz emission transmitting at centre 400.2 MHz achieves at least -53 dBc attenuation by the 400.15 MHz boundary to protect SFTSS. However, MYRIOTA can get much closer to the 400.15 MHz boundary as the tests show that when transmitting at 400.16 MHz the attenuation is close to 53 dBc. For the 4 kHz emission, transmitting at centre 400.162 MHz would ensure at least 53 dBc attenuation by the 400.15 MHz boundary. Similar results can be expected to the 20 kHz emissions, given the fact that the transmit bandwidth is larger but the necessary attenuation is lower than for the 4 kHz emissions.



2 Marker Table

Type	Ref	Trc	X-Value	Y-Value	Function	Function Result
M1		1	400.2 MHz	-3.42 dBm	Band Power/4.0 kHz	-4.08 dBm
M3		1	400.575 MHz	-80.93 dBm	Band Power/1.05 MHz	-2.42 dBm
M4		1	400.575 MHz	-80.93 dBm	Band Power/850.0 kHz	-2.42 dBm

Figure 38: MYRIOTA's UHF downlink out of band emissions

A1.5.7.4 Other existing services in the 400.15-401 MHz band

The 400.15-401 MHz band is allocated to the Meteorological Aids Service, Meteorological-Satellite Service (space-to-Earth), Space Research Service (space-to-Earth) on a co-primary basis, and the Space Operation Service (space-to-Earth) on a secondary basis. There is no Recommendation ITU-R or other documentation providing technical characteristics, protection or sharing criteria for such systems with MSS operations in this specific frequency band.

With regards to the Meteorological Aids Service, the Australian administration will coordinate the MNSAT downlink emissions with the French administration under RR 9.14 [9] for the protection of the meteorological aids service in the band 400.15-401 MHz. The coordination is for the frequency assignments registered by France into the MIFR and subject to PFD threshold of -125 dB(W/m²/4kHz) or the use of the Recommendation ITU-R RS.1262 when the threshold is exceeded.

A1.5.8 Inter-service studies (VHF band)

A1.5.8.1 Uplink (148-149.9 MHz (Earth-to-space))

In the band 148-150.05 MHz, MYRIOTA can configure the length, interval, data rate, bandwidth, and frequency of transmissions from earth stations in its system. MYRIOTA's system will be able to share these bands with other systems without causing harmful interference. Both IoT modules and micro-gateways transmit only when a MYRIOTA satellite is overhead, significantly reducing the times during which there is a risk of interference. All of MYRIOTA's earth stations in the 148-150.05 MHz frequency band will typically operate with less than 5 dBW e.i.r.p., but may operate higher.

A1.5.8.2 Protection of Radio Astronomy

MYRIOTA's VHF uplink transmissions between 148–150.05 MHz are adjacent to the 150.05–153 MHz allocation of RAS. Note that MYRIOTA will carefully manage the deployment location of micro-gateways such that they avoid interference potential to RAS facilities.

For MYRIOTA's IoT modules, there are several reasons why they are unlikely to cause harmful interference:

- There is a low probability of an IoT module operating in proximity to RAS facilities for a prolonged period of time;
- Over the intended operating frequency ranges, typical e.i.r.p. of an IoT module will be less than -3 dBW in the direction of RAS site;
- Emissions outside the intended operating frequency ranges will be significantly reduced over any 4 kHz measured bandwidth through front-end filtering compared to the emission at frequency of operation.

Using the operating parameters of MYRIOTA's terrestrial stations, it is possible to calculate the necessary separation distance from a RAS site in order to comply with the protection criteria of Table 49. First step is to calculate the minimum path loss between the two systems, based on the transmission parameters of the MYRIOTA earth stations and the maximum allowable interference to the RAS site. Then, using the propagation model described in ITU-R P.452 [2], the minimum distance that corresponds to a path loss equal to or higher to the minimum path loss calculated is computed. This minimum distance is the required separation distance between a MYRIOTA earth station and a RAS site.

Table 49: RAS parameters

VHF Parameter	Value	Unit
RAS centre frequency	151.525	MHz
RAS bandwidth	2.95	MHz
PFD threshold	-259	dB(W/m2/Hz)
Interference limit	-199	dBW

The following table outlines the required separation distances for typical and maximum operation of MYRIOTA terrestrial stations in the VHF band, using attenuation of 65 dBc over the RAS operating frequency range. The antenna gain of the radio astronomy station was assumed to be 0 dBi, as indicated in Recommendation ITU-R RA.769-2 [3].

Table 50: Minimum separation distances between RAS site and VHF MYRIOTA IoT modules/ Micro-Gateways

Minimum separation distances	
MYRIOTA IoT modules	
Worst case	19.1 km
Typical	3.4 km
MYRIOTA Micro-Gateways	
Worst case	23.4 km
Typical	5.8 km

Despite these precautionary features, if a specific RAS site is nonetheless susceptible to interference, MYRIOTA can utilise its geofencing technology to prevent IoT modules from transmitting within certain distances of a given location. MYRIOTA can also send messages instructing specific terrestrial stations to cease transmission should interference concerns arise. Accordingly, using such measures, MYRIOTA will protect RAS facilities operating in the VHF band from harmful interference from unwanted emissions.

A1.5.8.3 Protection of Mobile Services

As provided by RR 5.221 [9], stations of the mobile-satellite service in the frequency band 148-149.9 MHz shall not cause harmful interference to, or claim protection from, stations of the fixed or mobile services. In addition, according to RR 5.219, the use of the band 148-149.9 MHz by the mobile-satellite service is subject to coordination under 9.11A.

In the VHF band, MYRIOTA's uplink transmissions share spectrum with PMR and PAMR land mobile systems. The parameters and protection criteria used for these systems in this study were taken from Recommendation ITU-R M.1808-1 [1] and shown in Table 51.

Table 51: Land mobile systems (base stations) parameters

Parameter	Value	Unit
Protection criterion (I/N)	-6	dB
Centre frequency	149.025	MHz
Bandwidth	12.5	kHz
Antenna gain (dBd)	0	dBd
Antenna gain (dBi)	2.15	dBi
Antenna height	30	m
Radiation pattern	Omnidirectional	
Noise figure	12	dB
Noise temperature	300	K

The recommended separation distance between MYRIOTA's stations and Land Mobile stations is shown in Table 52. To calculate these values, the minimum coupling loss between the two systems was calculated and the associated separation distance determined, using the propagation model described in ITU-R P.1546. This was calculated for the co-channel scenario where a MYRIOTA station overlaps in frequency with a Land Mobile station; and, for the scenario where there is 10 kHz frequency separation between the two systems. If the two systems operate in channels more than 10 kHz apart, MYRIOTA's emissions into the land mobile service channel will be attenuated by at least 55 dB, and the recommended physical separation distances are significantly reduced.

For this analysis, the transmit antenna gain was assumed to be 0 dBi for MYRIOTA's stations in the direction of the horizon (direction towards Land Mobile station). In practice, the gain towards the horizon is expected to be far below 0 dBi for the majority of MYRIOTA' stations, which would further reduce the distance values shown in Table 52.

Neither duty cycle nor clutter losses were considered in the calculation leading to the values in Table 52.

Table 52: Minimum recommended separation distance to protect Land Mobile base stations

VHF IoT Modules	Recommended Distance (Co-channel scenario)	Recommended Distance (10 kHz frequency separation)
Typical operation	2.19 km	0.35 km
Maximum operation	5.48 km	0.44 km
VHF Micro-gateways	Recommended Distance (Co-channel scenario)	Recommended Distance (10 kHz frequency separation)

VHF IoT Modules	Recommended Distance (Co-channel scenario)	Recommended Distance (10 kHz frequency separation)
Typical operation	4.59 km	0.47 km
Maximum operation	11.20 km	0.83 km

A1.5.9 Downlink (137-138 MHz (space-to-Earth))

In the band 137-138 MHz, MYRIOTA's system has the flexibility and spectral efficiency to be able to operate harmoniously with other users of the bands. MYRIOTA's satellites can vary channel bandwidth through on-board processing, and dynamically control their emissions across the entire frequency ranges to accommodate sharing arrangements with other users of these bands. MYRIOTA downlink emissions can range in bandwidth between 4-20 kHz and operate within the entire MSS allocation or any portion thereof designated for use. MYRIOTA downlink emissions can employ frequency hopping to move through the assigned band, or operate with a defined channel plan, using either multiple contiguous channels or a fragmented channel arrangement. MYRIOTA can also configure the length, interval, data rate, bandwidth, and frequency of transmissions of satellites in its system. The flexibility of the software defined radio on board MYRIOTA's satellites will enable MYRIOTA to share spectrum by coordinating usage and/or time of operations.

A1.5.9.1 Coordination with terrestrial systems

For the VHF frequency band, MYRIOTA's downlink transmissions comply with the -125 dB(W/4 kHz/m2) pfd threshold for coordination with terrestrial systems. Due to its flexibility, MYRIOTA's system can adjust its transmission parameters to comply with this threshold and protect terrestrial systems, if necessary. Both the transmission power and the bandwidth can be adjusted to reduce the pfd generated by MYRIOTA's downlink transmissions.

Table 53: MYRIOTA's ground pfd

Parameter	4 kHz carrier	20 kHz carrier	Unit
Orbital height	600	600	km
Bandwidth	4	20	kHz
Transmit power	1.5	8.5	dBW
Duty cycle	10	20	%
Antenna gain towards ground	0	0	dBi
e.i.r.p. towards ground	1.5	8.5	dBW
e.i.r.p. density (1 kHz)	-4.52	-4.51	dB(W/1kHz)
e.i.r.p. density (4 kHz)	1.5	1.51	dB(W/4 kHz)
PFD density	-125.06	-125.04	
PFD density with duty cycle	-135.06	-132.03	dB(W/4 kHz/m2)
PFD threshold	-125	-125	dB(W/4 kHz/m2)
Margin with duty cycle	-10.06	-7.03	dB
Margin without duty cycle	-0.06	- 0.04	dB

A1.5.9.2 Compatibility with AMS(OR) in the CEPT countries listed in RR N.5.206 [9]

As provided by RR 5.206 [9], the 137-138 MHz band is allocated to the aeronautical mobile service on a primary basis. Annex 1 to RR Appendix 5 of the ITU Radio Regulations shall be used as a coordination trigger. That PFD threshold is -140 dBW/m2/4 kHz at the Earth's surface.

In some CEPT administrations listed in RR. 5.206 [9], the 137-138 MHz band is allocated to the aeronautical mobile service on a primary basis with a coordination PFD threshold of -140 dBW/m2/4 kHz at the Earth's surface. As shown in Table 54, the PFD level produced by MYRIOTA emissions is ordinarily above -140 dBW/m2/4 kHz for elevation angles above 30.55 degrees. Radio Regulations defines coordination procedures for the operation of MSS to ensure compatibility, including with the Aeronautical Mobile Service in the same band. To comply with the PFD provisions, interference mitigation techniques are proposed which are only applicable in countries where necessary. The studies are not coordination and equally are not regulation. ECC studies and Decisions are intended to assist harmonisation, but they do not override national licensing and authorisation, or rights under Radio Regulations.

As part of the mitigation technique, MYRIOTA satellites will reduce their transmission power by up to 10 dB when covering the territory of the Russian Federation at elevations above 30.55 degrees. Table 54 summarises MYRIOTA's downlink transmit power and PFD as function of the elevation angle. For elevations above 30.55 degrees, reductions in duty cycle will guarantee the protection of AMS systems, as is discussed further ahead.

Table 54: MYRIOTA's transmit power as a function of elevation

Worst case PFD vs elevation					
Geometry		20 kHz carrier		4 kHz carrier	
Elevation (deg)	Distance (km)	MYRIOTA Tx Power (dBW)	PFD (dB(W/4 kHz/m2))	MYRIOTA Tx Power (dBW)	PFD (dB(W/4 kHz/m2))
10	1931.6	3.70	-140.00	-3.29	-140.00
20	1392.2	0.86	-140.00	-6.13	-140.00
30	1075.1	-1.39	-140.00	-8.38	-140.00
30.55	1061.9	-1.50	-140.00	-8.49	-140.00
40	882.3	-1.50	-138.39	-8.50	-138.40
50	760.8	-1.50	-137.11	-8.50	-137.12
60	683.2	-1.50	-136.17	-8.50	-136.18
70	634.9	-1.50	-135.54	-8.50	-135.55
80	608.4	-1.50	-135.17	-8.50	-135.18
90	600.0	-1.50	-135.04	-8.50	-135.06

With the transmit power reductions proposed above, MYRIOTA satellites will always comply with the -140 dB(W/m2/4 kHz) pfd threshold for coordination with AMS systems at elevations below 30.55 degrees. For higher elevations, MYRIOTA satellites will reduce their duty cycle in order to maintain the percentage of time at which the threshold is exceeded below or close to the value of 0.2%. To estimate the necessary duty cycle reduction, dynamic simulations of MYRIOTA's system interference to an AMS ground station were performed. In the simulation, an AMS ground station was positioned at 55N36E with an omnidirectional 0 dBi antenna while the entire MYRIOTA constellation was simulated, using the parameters and orbital characteristics presented in the previous section.

The results, shown in Figure 39 were obtained for a MYRIOTA downlink duty cycle of 0.25% and 0.5% for the 4 kHz and 20 kHz carriers, respectively. The 20 kHz transmissions exceed the -140 dB(W/m2/4 kHz) for only 0.2% of the time, approximately.

Table 55 shows MYRIOTA's duty cycle at elevations above 30.55 degrees to protect the AMS, while Table 56 shows the percentage of time the pfd threshold is exceeded for all the analysed cases.

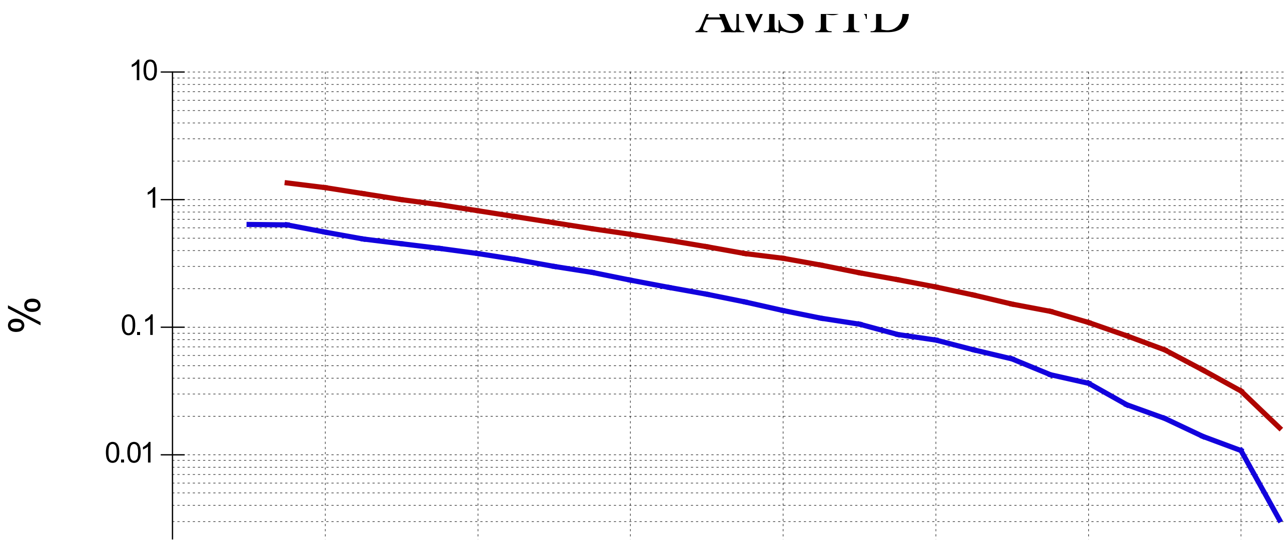


Figure 39: PFD statistical distribution for AMS duty cycle of 100%

Table 55: MYRIOTA's duty cycle at elevations above 30.55 degrees to protect the AMS

Carrier Bandwidth	MYRIOTA Duty Cycle
4 kHz	0.25%
20 kHz	0.5%

Table 56: PFD threshold exceedance

Carrier Bandwidth	PFD Threshold Exceedance
4 kHz	0.079%
20 kHz	0.21%

With regards to Aeronautical Mobile (OR) Service, the Australian administration will coordinate the MNSAT downlink emissions with the French administration under RR 9.14 [9] for the protection of the aeronautical mobile (OR) service in the band 137-138 MHz. The coordination is for the frequency assignments registered by France into the MIFR and subject to Annex 1 of the Appendix 5 of RR.

A1.5.9.3 Protection of Radio Astronomy

For the protection of RAS systems in the band 137-138 MHz, the data loss in an integration time of 2000s must not exceed the value of 2%. According to Recommendation ITU-R RA.769-2 [3], the interference pfd threshold above which there is data loss at a RAS site is -194 dB(W/m2) in the VHF band. To compute the data loss, the method described in Recommendation ITU-R M.1583-1 [7] is used. According to this recommendation, the sky is divided into grid of cells and the RAS station receiver is pointing to a random location inside each cell. The interfering MSS constellation is simulated for 2000s for a number of iterations and the interference statistics are collected for all cells and iterations. The antenna pattern described in

Recommendation ITU-R RA.1631 [14] is used for the RAS station. The results of the studies are provided in Figure 40 and Figure 41.

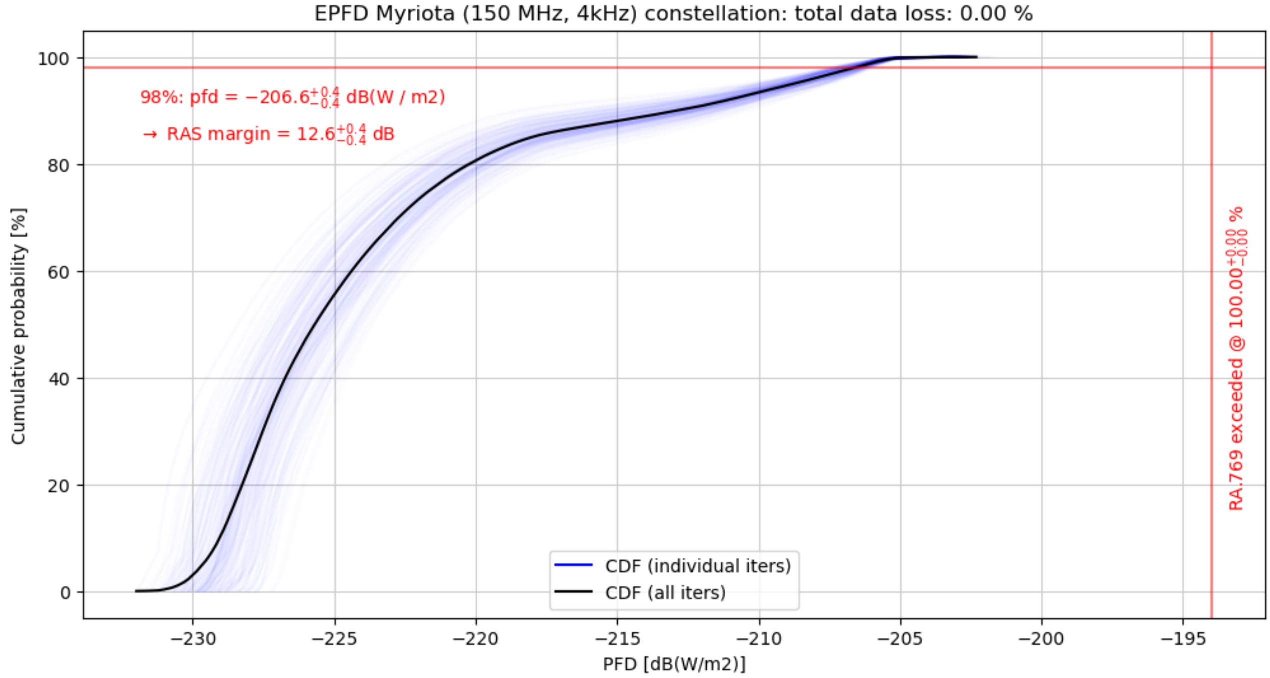


Figure 40: PFD distribution in the RAS band for MYRIOTA's 4 kHz emissions

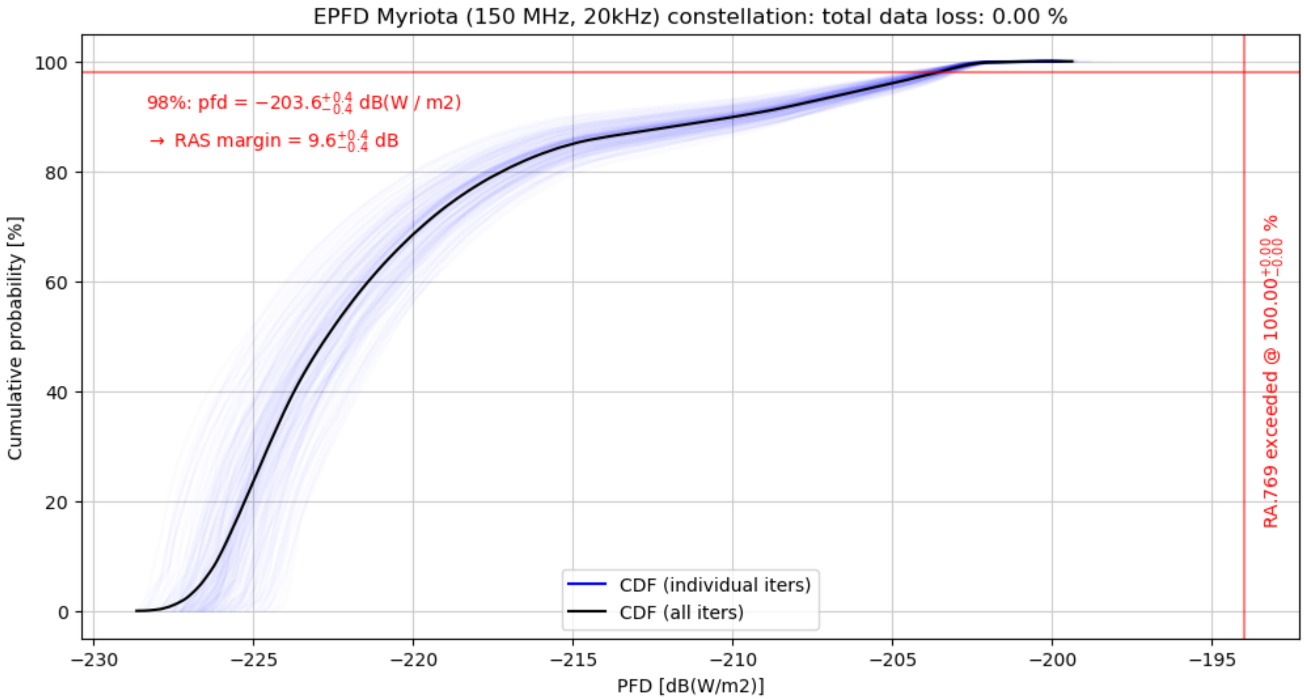


Figure 41: PFD distribution in the RAS band for MYRIOTA's 20 kHz emissions

In all simulated cases, a spectral roll off of 110 dBc was applied (see section A1.5.9.3) to MYRIOTA's in-band transmissions to calculate the out-of-band power in the RAS band. It is concluded that MYRIOTA adequately protects the Radio astronomy in the band 150.05–153 MHz.

A1.5.9.4 Protection of Meteorological Satellite Services

The Meteorological Satellite service is allocated on the 137-138 MHz band on a primary basis. Compatibility studies were conducted, in order to determine the level of interference generated by MYRIOTA's satellite stations into Meteorological Satellite receiving Earth stations in Russia. The Recommendation used for the parameters is ITU-R SA.1026 [4] and ITU-R SA. 1027 [5]. The parameters used for the victim station are shown in Table 57:

Table 57: MetSat Earth Station parameters

Parameter	Value – VHF	Unit
Long-term protection criterion (I)	-142.00	dBW
Long-term time allowance	20.00	%
Short-term protection criterion (I)	-136.00	dBW
Short-term time allowance	0.0125	%
Centre frequency	137.50	MHz
System	B	
Bandwidth	150.00	kHz
Antenna gain	0.00	dBi
Antenna pattern	Omnidirectional	

Dynamic aggregate interference simulations were performed. For this study, MYRIOTA's constellation of 52 satellites was simulated and the interference generated at the meteorological satellite earth station was estimated, considering the orbital characteristics and the duty cycle of the interferer stations. The simulated MetSat earth stations are positioned in Russia. The propagation model considered between the two systems is described in ITU-R P.525 with the addition of fading loss from Recommendation ITU-R P.618 and atmospheric attenuations taken from Recommendation ITU-R P.676. A power reduction of 10 dB was applied to the MYRIOTA satellites to account for the interference mitigation technique to protect the METEOR-3M earth stations in Russia. Note that the interference mitigation techniques proposed are only applicable invisibility of the three MetSat earth stations (listed below), considered in this study, which are located in Russia.

Table 58: Locations of METEOR-3M earth stations operating in 137-138 MHz band

Earth station location (number)	Longitude	Latitude
Moscow (1)	37.3 E	55.8 N
Novosibirsk (2)	83.0 E	55.0 N
Khabarovsk (3)	135.2 E	48.5 N

The transmission cycle of the simulated satellites is independent, meaning that at a random time step each satellite has a chance of causing interference to the MetSat station equal to the satellite's duty cycle regardless of whether other satellites are active or not. For that reason, there is a chance that more than one, or even none, satellites will be causing interference to the MetSat simultaneously. In addition, each satellite transmit only one carrier at a time, so that the total transmissions of a MYRIOTA satellite fit into a single 4 or 20 kHz bandwidth.

A total of 20 days was simulated in time steps of 30 seconds, in a configuration shown in Figure 42. The complementary cumulative distribution function of the interference measured at the victim station is shown in Figure 43. In this scenario, the protection criteria (for both short-term and long-term) is met for the 4 kHz transmissions but not for the 20 kHz transmissions.

Figure 42: Simulation scenario for interference analysis between MYRIOTA and Meteorological Satellite earth station in Moscow

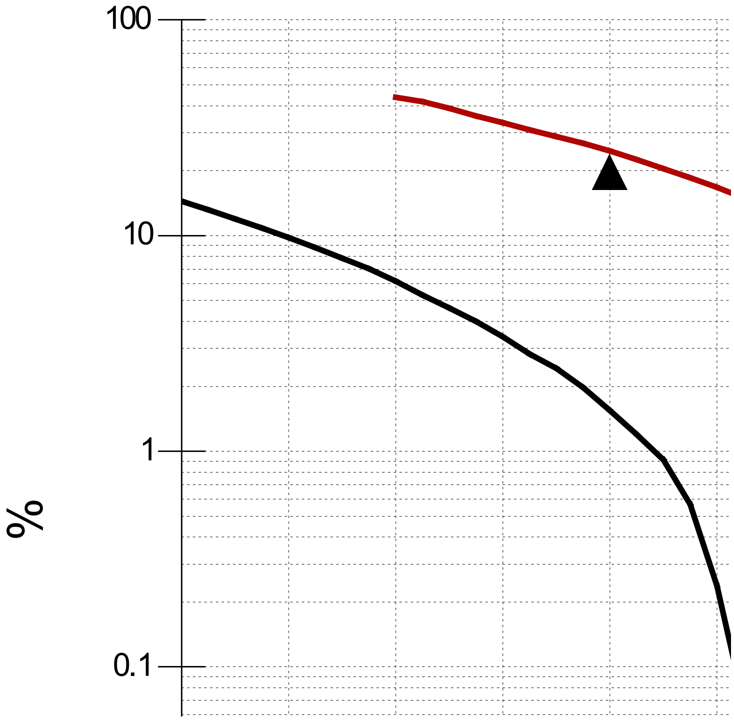


Figure 43: Interference at the Moscow Meteorological Satellite Earth station considering protection criteria from ITU-R SA.1026 [4]

On a second analysis, the METEOR-3M constellation was also simulated, in order to evaluate the impact of MYRIOTA's interference when the Meteorological Satellite stations are overhead the receiving earth station. In this scenario, the meteorological satellite earth station is only a victim of interference when it is in line of sight of a meteorological satellite. When a satellite is not passing over, the meteorological satellite earth station is inactive and therefore not a victim of interference. The complementary cumulative distribution function of the interference measured at the victim station is shown in Figure 44. Considering the entire constellation, the victim station is only receiving data and, consequently interference, when there is a meteorological satellite overhead. Thus, the long-term criterion is met for the 20 kHz carrier, but the short-term criterion is not met. The short-term exceedance margin for the 20 kHz carrier is in the order of 5 dB.

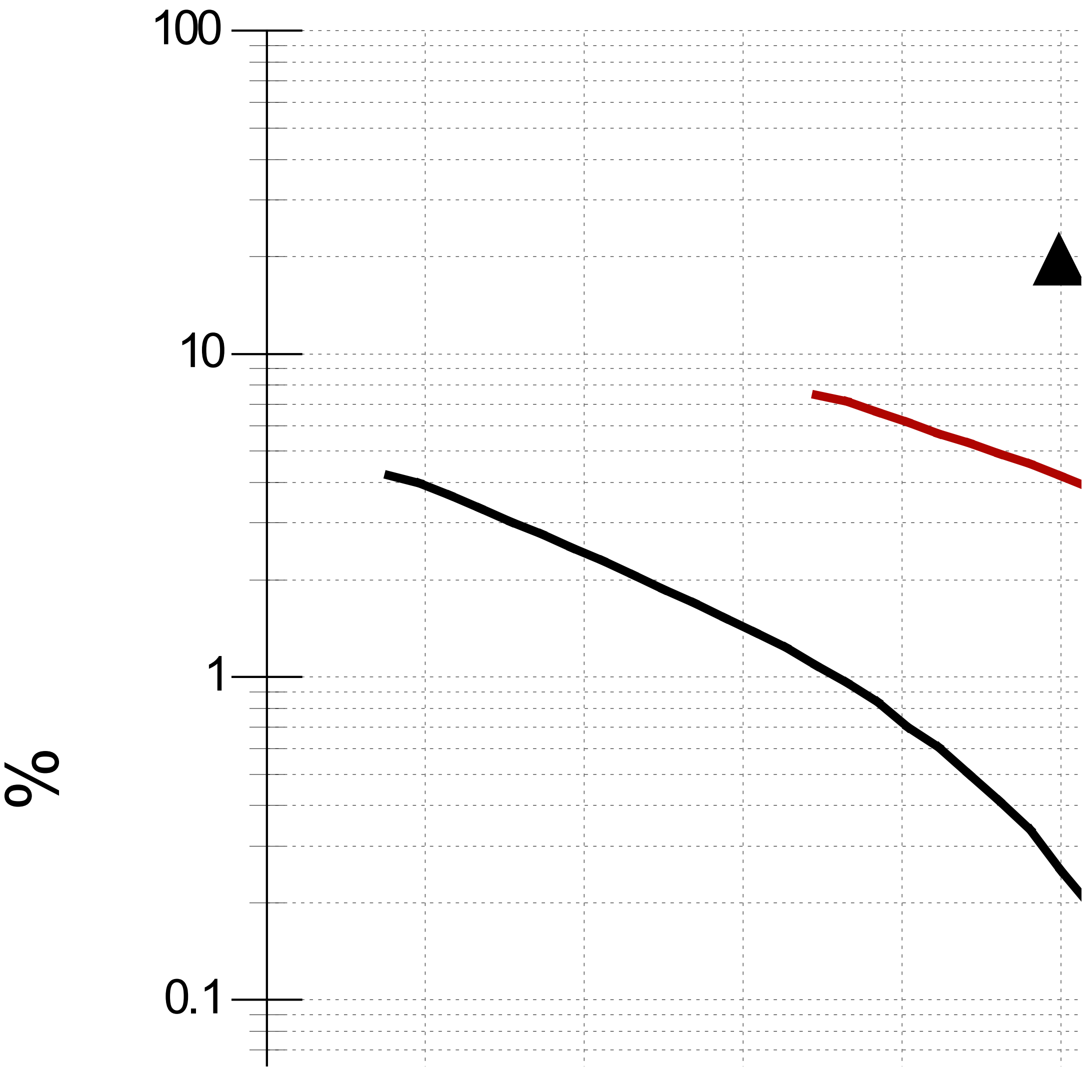


Figure 44: Interference at Moscow Meteorological Satellite Earth station when transmitting constellation is simulated considering protection criteria from ITU-R SA.1026 [4]

The 4 kHz carrier complies with both the short and long-term protection criteria, while 20 kHz carrier only complies with the long-term criterion if the Moscow MetSat station is considered to be active only when a METEOR-3M satellite is visible. Thus, a duty cycle reduction of the 20 kHz carrier is necessary. In Figure 45, the duty cycle of the 20 kHz carrier was reduced to 0.08% for the case where the MetSat earth station is always active and to 0.45% for the case MetSat earth station is only active when a METEOR-3M satellite is visible. Hence, MYRIOTA can reduce the transmit power by 10 dB, for both carriers, and reduce the duty cycle to 0.45%, for the 20 kHz carrier, when in sight of a MetSat earth station in Russia in order to avoid interference.

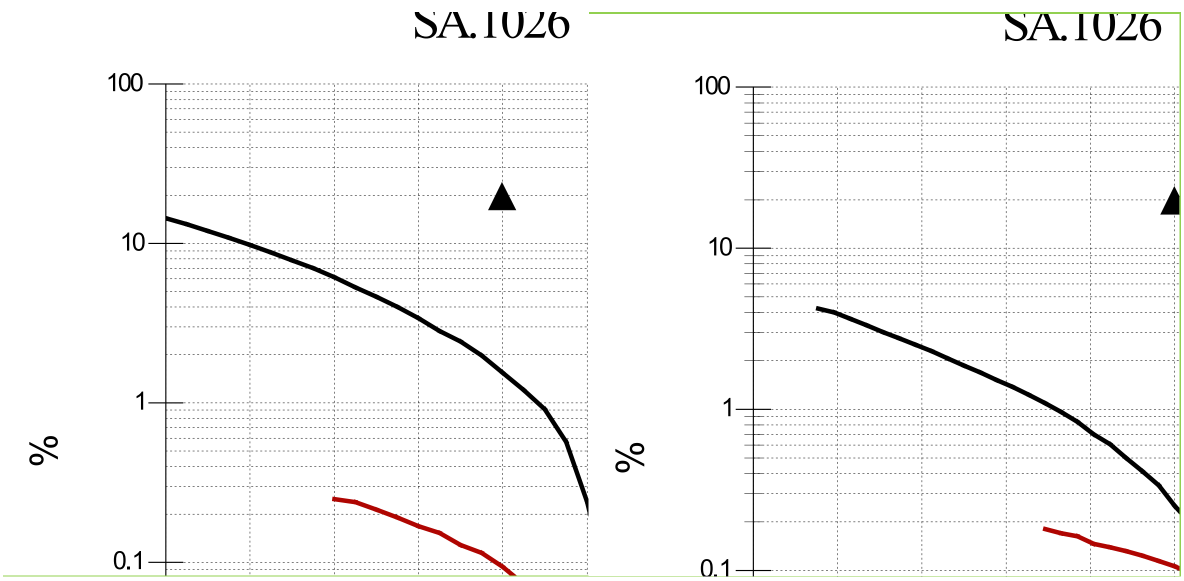


Figure 45: Interference distribution when Moscow MetSat station is always active (left) and when it is only active when a METEOR-3M satellite is visible (right) with duty cycle reduction considering protection criteria from ITU-R SA.1026 [4]

The effectiveness of the proposed mitigation techniques was also analysed for MetSat earth stations located in Novosibirsk and Khabarovsk, with results shown below. For Novosibirsk, a duty cycle reduction to 0.04%, when the MetSat station is considered to be always on, and 0.13%, when it is only active when a METEOR-3M satellite is overhead, is necessary. For Khabarovsk, those values are 0.035% and 0.13% respectively.

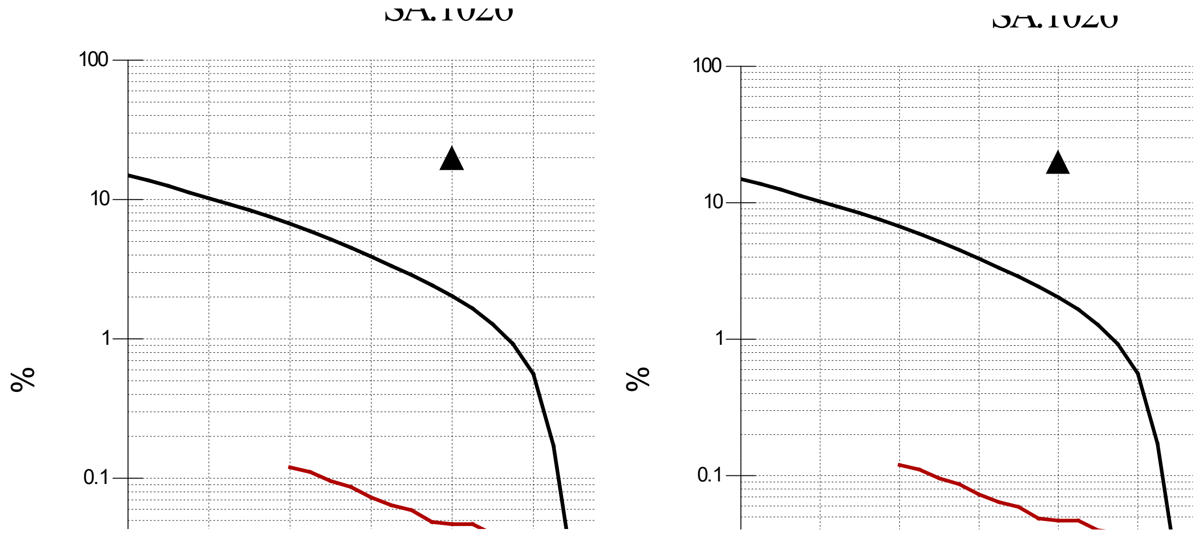


Figure 46: Interference distribution when Novosibirsk MetSat station is always active (left) and when it is only active when a METEOR-3M satellite is visible (right) with duty cycle reduction considering protection criteria from ITU-R SA.1026 [4]

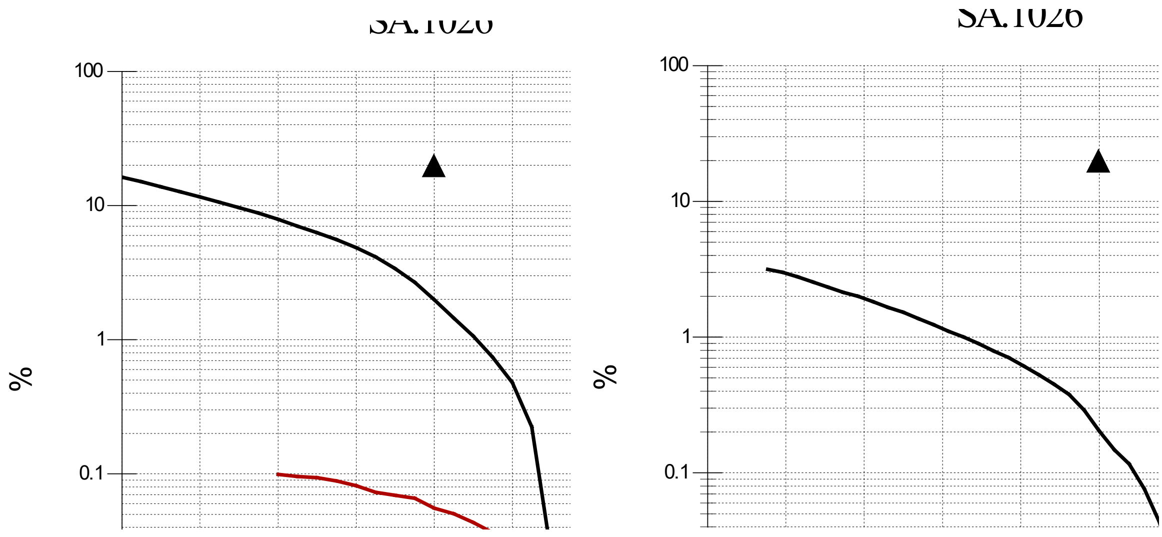


Figure 47: Interference distribution when Khabarovsk MetSat station is always active (left) and when it is only active when a METEOR-3M satellite is visible (right) with duty cycle reduction considering protection criteria from ITU-R SA.1026 [4]

Results considering the protection criteria described in Recommendation ITU-R SA.1027 [5] were also generated. The Recommendation defines a long-term protection criterion of -147 dBW at a time percentage of 20% and –137 dBW at 0.0031% of the time. The results below analyse the necessary duty cycle reduction to protect the MetSat system from MYRIOTA’s downlink interference. No duty cycle reduction is necessary for the 4 kHz carrier, but the 20 kHz carrier needs its duty cycle reduced to 0.008% in the case in which the Moscow MetSat station is always active and 0.05% when it is only active when a meteorological satellite is overhead. For the Novosibirsk MetSat station, those numbers are 0.006% and 0.055% respectively. For Khabarovsk they are 0.0065% and 0.05% respectively.

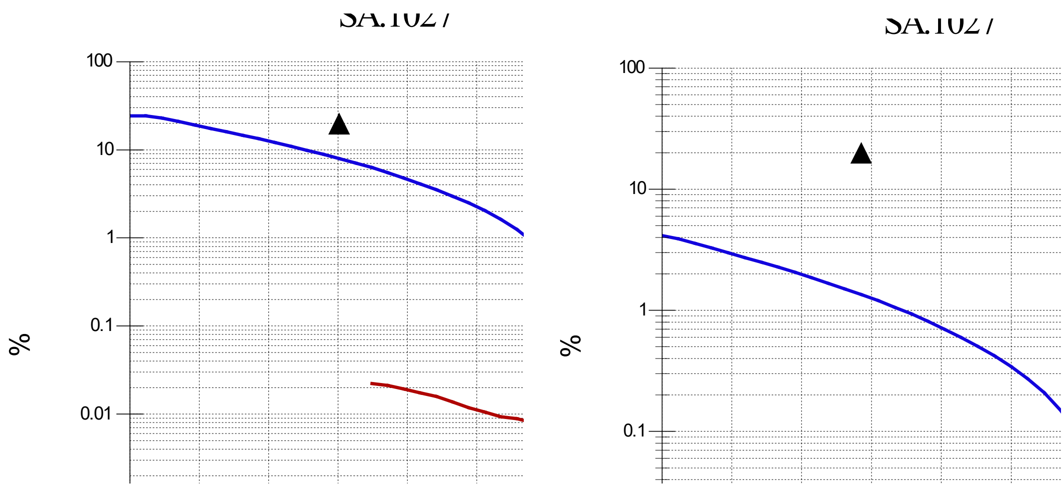


Figure 48: Interference distribution when Moscow MetSat station is always active (left) and when it is only active when a METEOR-3M satellite is visible (right) with duty cycle reduction considering protection criteria from ITU-R SA.1027 [5]

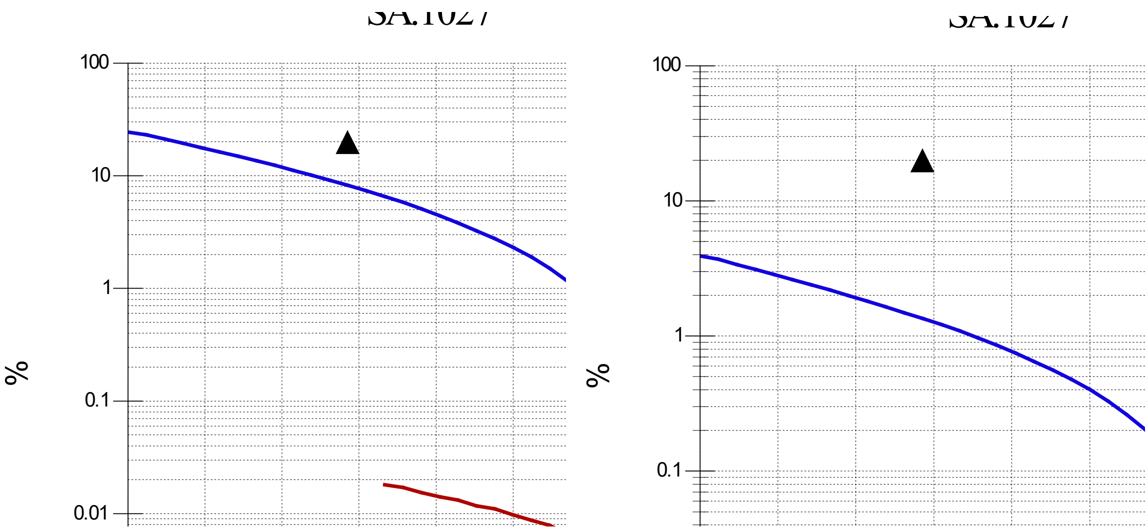


Figure 49: Interference distribution when Novosibirsk MetSat station is always active (left) and when it is only active when a METEOR-3M satellite is visible (right) with duty cycle reduction considering protection criteria from ITU-R SA.1027 [5]

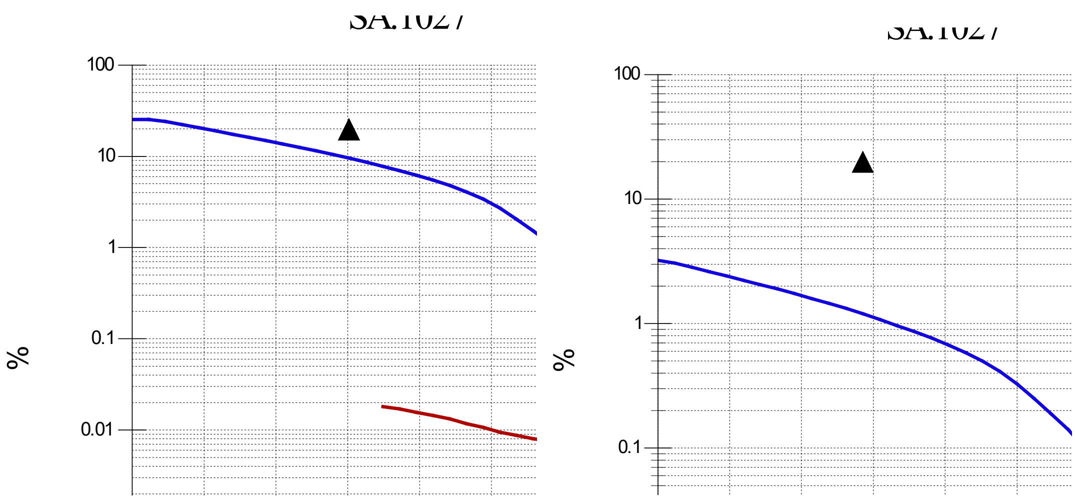


Figure 50: Interference distribution when Khabarovsk MetSat station is always active (left) and when it is only active when a METEOR-3M satellite is visible (right) with duty cycle reduction considering protection criteria from ITU-R SA.1027 [5]

Table 59 summarises the necessary duty cycle of 20 kHz emissions for the short-term protection of MetSat earth stations. Combined with a 10 dB power reduction, the duty cycles shown in the Table will guarantee that the interference measured at the victim MetSat stations are not subject to harmful interference. For the 4 kHz carrier, the 10 dB power reduction is sufficient to protect the MetSat. It is important to note that Recommendation ITU-R SA.1026 [4] states that “interference criteria are specified with respect to the percentage of time of reception by the earth station”. The results consider both scenarios: when the MetSat earth station is always active; and when the MetSat station is active only when a meteorological satellite is visible. Both results are kept for information purposes. The most stringent duty cycle values based on Recommendation ITU-R SA.1027 [5] (the value of 0.006% for when the MetSat Novosibirsk earth station is always active) will be used to derive the mitigation techniques imposed on the MYRIOTA system to protect METSAT earth stations in Russia.

Table 59: Necessary duty cycle of 20 kHz emissions for the short-term protection of MetSat earth stations

MetSat station:	SA.1026 [4]		SA.1027 [5]	
	Always active	Active when satellite is visible	Always active	Active when satellite is visible
Moscow	0.08%	0.45%	0.008%	0.05%
Novosibirsk	0.04%	0.13%	0.006%	0.055%
Khabarovsk	0.035%	0.13%	0.0065%	0.05%

In order to verify that a duty cycle of 0.006% can protect all three considered earth stations, further study was carried out for 5.3 days with time steps of 0.01 seconds resulting in 45809992 ticks simulated. With a minimum margin of 0.3 dB the 0.006% duty cycle ensures compatibility with considered MetSat earth stations and should be used when in their visibility. Figure 51, Figure 52 and Figure 53 depict these results.

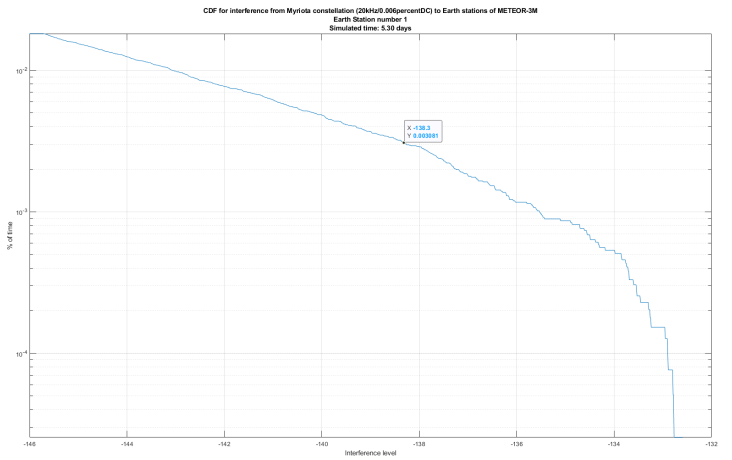


Figure 51: Interference distribution at Moscow station for MYRIOTA downlink duty cycle of 0.006%

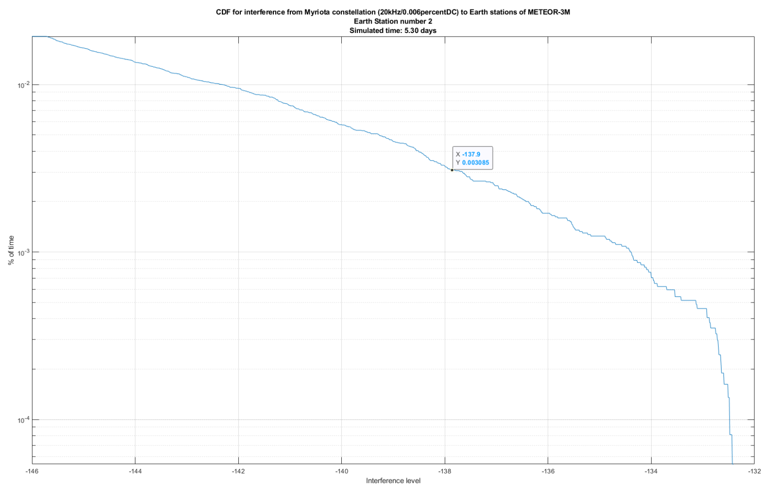


Figure 52: Interference distribution at Novosibirsk station for MYRIOTA downlink duty cycle of 0.006%

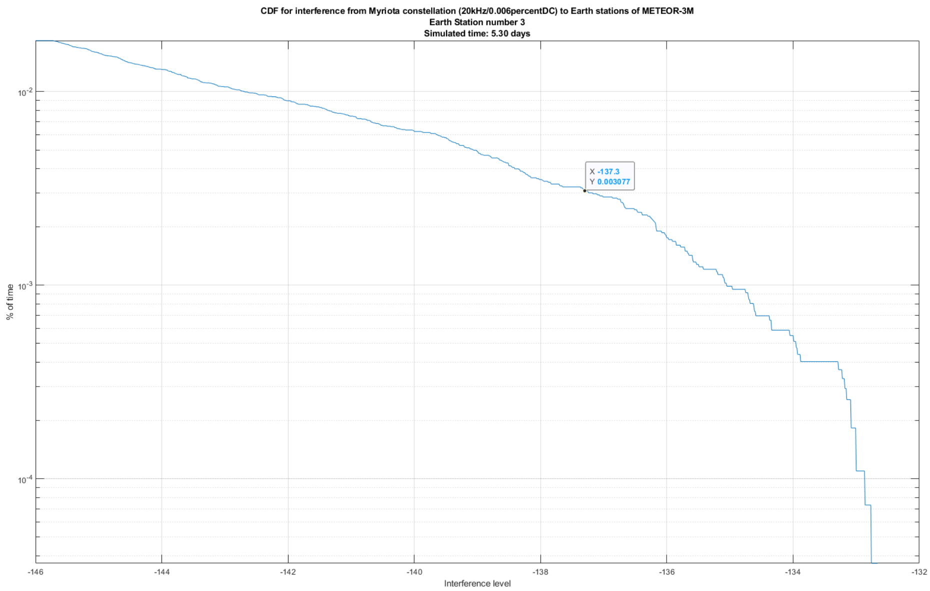


Figure 53: Interference distribution at Khabarovsk station for MYRIOTA downlink duty cycle of 0.006%

The 137-138 MHz band is allocated to the Space Research Service (space-to-Earth) and Space Operation Service (space-to-Earth) on a secondary basis, these are not studied.

A1.6 DESCRIPTION OF FLEET

This section presents provisional characteristics for the FLEET system. The information provided here is currently only used in this Report to assess compliance with the RAS protection limits in the aggregate studies contained in ANNEX 3.

A1.6.1 General description

FLEET SPACE is an international satellite system operator which is providing IoT and M2M services through its NGSO satellite constellation, the deployment of which started in 2018 and will continue during 2020 and beyond.

FLEET SPACE is developing a combined satellite and ground segment network focused on industrial IoT, which aims to address the enterprise end of the market, where companies deploy thousands of sensors over a wide area. FLEET's technology enables these companies to address and manage these large numbers of sensors.

The FLEET SPACE network will consist of:

- Up to 145 nanosatellites;
- Gateway ground stations around the globe. FLEET SPACE has constructed one gateway satellite ground station in South Australia, has rights of use for gateway ground stations in Italy and Spain. FLEET SPACE will expand the number of its own gateway ground stations over time;
- FLEET SPACE has developed a terrestrial network component called a Portal. The Portal provides:
  - Uplink and downlink communications to FLEET SPACE nanosatellites.
  - A LoraWAN network, connecting up to 1000 sensors within its wide area network catchment. This could be within a radius of up to 15 kilometres, depending on the topography of the area;
  - An edge platform for applications, plus a data analytics capability for processing the sensor data received.

The FLEET SPACE key components and system architecture are shown in the figure below:

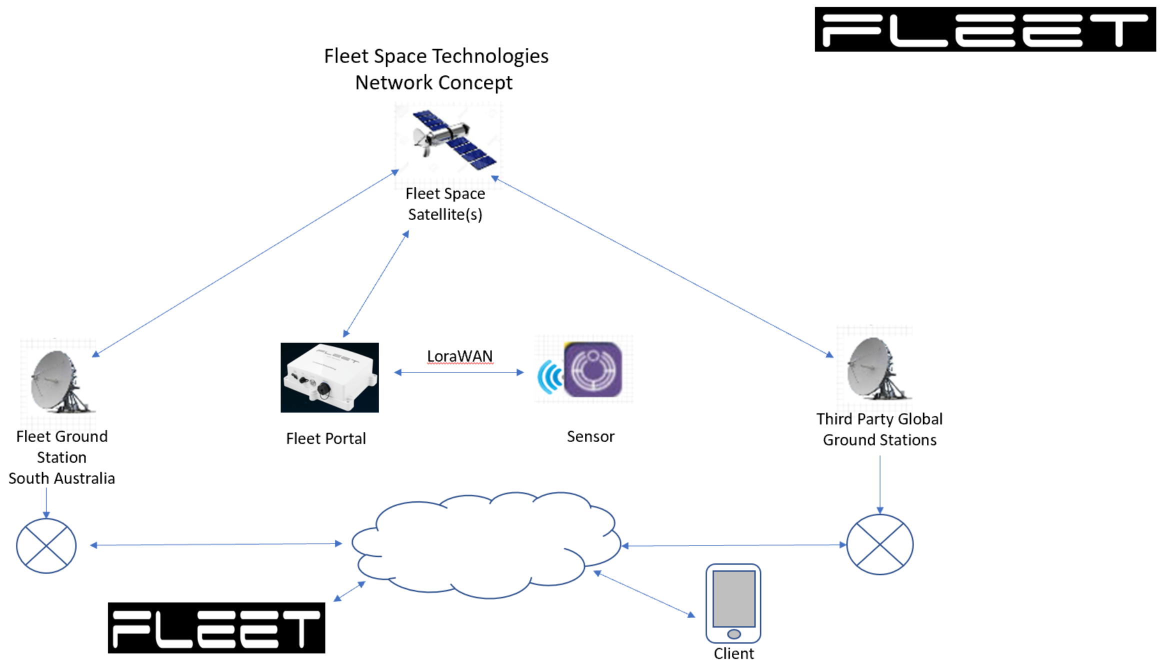


Figure 54: FLEET SPACE key components and system architecture Technical characteristics

A1.6.2 MES

IoT sensors in the FLEET SPACE network do not communicate directly with the FLEET SPACE satellites. FLEET SPACE IoT sensor devices communicate through a LoraWAN network to FLEET SPACE Portal terminals. The Portal terminals utilise an edge platform to process and compress the sensor data. FLEET SPACE's proprietary algorithm thus ensures that there is between a 90% and 95% data-saving, in terms of the sensor data collected, that is actually transmitted to the FLEET SPACE satellites.

In terms of the MES interference environment:

- The MES density is considerably lower, since each IoT sensor is not an independent MES. Each Portal MES will service up to 1000 IoT sensors within its catchment area. The maximum MES density is expected to be in the range 5-10 MES terminals per 100 km^2 and more typically would be in the range of 2 MES terminals per 100 km^2;
- Because of the consolidation of the sensor traffic within the Portal terminals, the data uplinked to the satellites will be only around 5% to 10% of the data actually generated by the IoT sensors;
- Within the 399.9-400.05 MHz band, FLEET SPACE will operate its Portal terminals only in the 399.9 - 400.02 MHz range, and will operate a limited number of telecommand uplinks in the 400.02-400.05 MHz band in accordance with RR No. 5.260B (WRC-19). It should be noted that FLEET SPACE is not seeking to introduce its telecommand uplink stations into the ERC Decision (99)06 process. The operation of those telecommand uplink stations will be subject to ITU frequency coordination and national licencing of specific earth stations in the usual manner;
- Each FLEET SPACE Portal terminal will transmit with a low duty cycle of 0.05%. The maximum signal burst duration from each terminal will not exceed 3 seconds when the full constellation is deployed, with a burst repeat-period of 6000 seconds (so a 'quiescent period' of 5997 seconds between bursts). The typical burst duration will be close to this maximum. Each Portal terminal will transmit only when a FLEET SPACE satellite is passing overhead.

The maximum e.i.r.p. level in the 312-315 MHz and 399.9-400.02 MHz bands will be in the range -5 dBW to +3.5 dBW, depending on the operational environment.

The RF Characteristics of a FLEET SPACE MES in the 312-315 MHz and 399.9-400.02 MHz bands are as shown in the following table.

Table 60: RF Characteristics of FLEET SPACE MES in the 312-315 MHz and 399.9-400.02 MHz frequency band

RF Characteristics	FLEET SPACE MES
Maximum output power (W)	1
Maximum e.i.r.p (dBW)	3.5
Modulation	Chirp Spread spectrum
Data rate (bps)	5600
Bandwidth (kHz)	120
Symbol rate (sps)	1 000

A1.6.3 SPACE SEGMENT

The FLEET SPACE system will be based on constellation of 145 nanosatellites with orbital parameters as shown in the following table:

Table 61: FLEET SPACE NGSO Satellites Orbital Parameters

Orbital Plane No.	No. of satellites in this plane	Orbital altitude (km)	Incli-nation (degree)	Mean anomaly (degree)	Arg. Of perigee (degree)	Right ascension of the ascending node (degree)	Eccentricity (degree)
1	5	587 x 577	45	Uniform distribution	0	0	0
2	5	587 x 577	45	Uniform distribution	7.2	18	0
3	5	587 x 577	45	Uniform distribution	14.4	36	0
4	5	587 x 577	45	Uniform distribution	21.6	54	0
5	5	587 x 577	45	Uniform distribution	28.8	72	0
6	5	587 x 577	45	Uniform distribution	36	90	0
7	5	587 x 577	45	Uniform distribution	43.2	108	0
8	5	587 x 577	45	Uniform distribution	50.4	126	0
9	5	587 x 577	45	Uniform distribution	57.6	144	0

Orbital Plane No.	No. of satellites in this plane	Orbital altitude (km)	Incli-nation (degree)	Mean anomaly (degree)	Arg. Of perigee (degree)	Right ascension of the ascending node (degree)	Eccentricity (degree)
10	5	587 x 577	45	Uniform distribution	64.8	162	0
11	5	587 x 577	45	Uniform distribution	72	180	0
12	5	587 x 577	45	Uniform distribution	79.2	198	0
13	5	587 x 577	45	Uniform distribution	86.4	216	0
14	5	587 x 577	45	Uniform distribution	93.6	234	0
15	5	587 x 577	45	Uniform distribution	100.8	252	0
16	5	587 x 577	45	Uniform distribution	108	270	0
17	5	587 x 577	45	Uniform distribution	115.2	288	0
18	5	587 x 577	45	Uniform distribution	122.4	306	0
19	5	587 x 577	45	Uniform distribution	129.6	324	0
20	5	587 x 577	45	Uniform distribution	136.8	342	0
22	1	505	97.3	-	0	310 (SSO)	0
23	1	525	97.6	-	0	317.6 (SSO)	0
25	4	582	53	Uniform distribution	0	0	0
26	4	582	53	Uniform distribution	0	36	0
27	4	582	53	Uniform distribution	0	72	0
28	4	582	53	Uniform distribution	0	108	0
29	4	582	53	Uniform distribution	0	144	0
30	4	582	53	Uniform distribution	0	180	0

Orbital Plane No.	No. of satellites in this plane	Orbital altitude (km)	Incli-nation (degree)	Mean anomaly (degree)	Arg. Of perigee (degree)	Right ascension of the ascending node (degree)	Eccentricity (degree)
31	4	582	53	Uniform distribution	0	216	0
32	4	582	53	Uniform distribution	0	252	0
33	4	582	53	Uniform distribution	0	288	0
34	4	582	53	Uniform distribution	0	324	0
35	1	450	97.2	-	0	0 (SSO	0
36	1	520	97.5	-	0	0 (SSO)	0
37	1	540	97.6	-	0	0 (SSO)	0

The main operating configuration is based on the 100-satellite configuration at 45° inclination in orbit planes 1–20 and the 40-satellite configuration at 53° inclination in orbit planes 25 - 34. Orbit planes 22, 23, 35, 36 and 37 are being used for initial implementation and technology validation and will continue to be operated after deployment of the full constellation, in order to provide better service availability to very high and very low latitudes. FLEET SPACE does not currently plan to use planes 21 and 24 as included in the published ITU filing and does not propose to include them in the compatibility studies. Therefore, these orbit planes are not included in the above table.

The satellite transmitting and receiving antennas in the <1 GHz frequencies have a 1.5 dBi gain pattern, symmetrical around the nadir axis.

Table 62: Satellite antenna gain pattern for the 312-315 MHz, 387-390 MHz, 399.9-400.02 MHz and 400.15-401 MHz bands

Off-axis angle (°)	0	10	20	30	40	50	60	70	80
Elevation (°)	90	79.4	68.7	57.9	46.9	35.4	22.9	1.3	-
Gain (dBi)	1.5	1.5	1.2	1	0.5	0.1	-1	-1.2	-1.3

Note that the above table is provided for the lowest altitude orbit, i.e. 407 km, since this case represents the configuration that results in the highest PFD on the Earth's surface.

Satellite emission characteristics:

- Maximum power at antenna flange: 6 dBW;
- Maximum e.i.r.p.: 7.5 dBW;
- Emission bandwidth: less than 125 kHz.

The FLEET SPACE satellite downlinks in the bands 387-390 MHz and 400.15-401 MHz will be used primarily for network control, firmware updates and confirmations of data packets received. The downlink channel may also be used to issue commands to user equipment linked to the Portal terminal (e.g. valve actuation), however, such use will represent only a very small use of the downlink channel (less than 1% of the downlinked data).

The duty cycle of the FLEET SPACE downlinks will not exceed 8% per satellite. The maximum signal burst duration from each satellite will not exceed 400 seconds, with a burst repeat-period of 5000 seconds (so a ‘quiescent period’ of 4600 seconds between bursts). The typical burst duration will be closer to 200 seconds, but for such a case the duty cycle would be less than 8%.

ANNEX 2: INTRA-SERVICES STUDIES

A2.1 INTRA-SERVICES STUDIES - ARGOS KINEIS – HIBER

A2.1.1 Studies for the band 399.9-400.05 MHz band

Ever since the relevant regulatory framework – namely ERC Decision (99)06 [10], ERC Decision (99)05 [11], ECTRA Decision (99)02 [12], was adopted, only the SAFIR-1 MSS system used the 399.9–400.05 MHz band, but ceased operations in the mid-2000s. By the time this report was drafted, no other NVNG MSS system other than HIBER's, is authorised or is planning to operate under the umbrella of the relevant ECC in the bands 399.9–400.05 MHz and 400.15-401 MHz. Moreover, even assuming this was not the case, HIBER's system is capable of sharing with current and future NGSO systems operating in the same frequency bands, and thus there is no mutual exclusivity. Spectrum sharing is possible because HIBER's satellites transmit only during short periods of time when the satellite is visible from the transmitting earth station. As a result, harmful interference is unlikely to occur and, in any event, could be avoided through coordination with the other NVNG MSS operators in order to avoid simultaneous satellite and HIBER earth station transmissions.

The 399.9-400.05 MHz band is allocated to the MSS (Earth-to-space) on an exclusive basis, and MSS systems are required to coordinate under RR9.11A.

The purpose of the compatibility studies presented in this section is to identify the main drivers leading to compatibility of both systems, based on their basic assumed characteristics. Both systems being in their development and early deployment phase, such parameters may be subject to refinement.

The following methodology is applied:

- Estimate the maximum number of co-frequency simultaneous MES emissions, or burst collisions, leading to an acceptable interference level;
- Estimate the maximum number of bursts in a satellite pass that will keep collision number at an acceptable level;
- Impact of satellite visibility on service.

A2.1.1.1 Number of possible simultaneous bursts

In this section, the number of possible simultaneous transmissions in the band 399.9-400.05 MHz is estimated.

Table 63: ARGOS KINEIS typical MES emissions characteristics:

Name	SSP	LBR
Modulation	Spread Spectrum – CDMA	PSK – FDMA
e.i.r.p.	0 dBW	0 dBW
Occupied bandwidth	120 kHz	2.4 kHz
C/N required	-17 dB	1 dB

ARGOS KINEIS satellite antenna gain: 3.6 dBi (15° elevation), -3.8 dBi (nadir).

ARGOS KINEIS satellite antenna temperature: 600°K

Table 64: Assumed HIBER typical MES emissions characteristics (these values may be reviewed by HIBER):

Name	CDMA
Modulation	Spread Spectrum
e.i.r.p.	0 dBW
Occupied bandwidth	120 kHz
C/N required	-17 dB

Assumed HIBER satellite antenna gain: 3 dBi (15° elevation), -2.6 dBi (nadir). (from ITU filing)

Assumed HIBER satellite antenna temperature: 600°K

The following table provides a link budget for both system, in favourable (nadir) and adverse conditions (15° elevation). From these link budgets, the amount of interference that would lead to link disruption is determined.

Table 65. Link budget for the two systems

	Argos				Hiber	
	SSP (15°)	LBR (15°)	SSP (90°)	LBR (90°)	CDMA (15°)	CDMA (90°)
EIRP (dBW)	0	0	0	0	0	0
Band (kHz)	120	2.4	120	2.4	120	120
C/N req (dB)	-17	1	-17	1	-17	-17
Elevation (°)	15	15	90	90	15	90
Range (km)	1731	1731	650	650	1626	600
Sat Rx Gain (dB)	3.6	3.6	-3.8	-3.8	3	-2.6
Rx Temp (°K)	600	600	600	600	600	600
C (dBW)	-145.7	-145.7	-144.5	-144.5	-145.7	-142.7
N (dBW)	-150.0	-167.0	-150.0	-167.0	-150.0	-150.0
C/N (dB)	4.4	21.4	5.5	22.5	4.3	7.4
C/N margin (dB)	21.4	20.4	22.5	21.5	21.3	24.4
I break-up (dBW)	-128.7	-146.7	-127.6	-145.6	-128.7	-125.7

The I break-up is the level of interference that drives the signal to noise (including interference) ratio to the limit acceptable for the satellite demodulation, i.e. the C/N required level.

This is expressed by the following equation (linear values):

$$\frac{C}{N + I_{break-up}} = (C/N)_{required} \tag{4}$$

Hence:

$$I_{break-up} = \frac{C}{(C/N)_{required}} - N \tag{5}$$

From "I break-up" value, it is possible to determine with a simplified model the number of co-frequency simultaneous emissions of each system MES that would lead to such limit interference level, as follows:

$$NB_{interfering\ MESs} = 10^{(I_{break-up} - I_{MES})/10} \tag{6}$$

Where:

- $I_{MES} = MES_{EIRP} - Free\ Space\ Loss\ (dist.interf.MES\ to\ Victim\ Sat.) + Gain_{victim\ sat.towards\ interfering\ MES}$

It should be noted that each system experiences emissions from its own MESs or the other system's MESs similarly as interference.

The following table provides the number of interfering MESs in specific geometrical configurations that lead to the interference limit. For the victim links, the number in parenthesis is the elevation at which the wanted MES is located with respect to the wanted satellite. For the interfering links, the number in parenthesis is the elevation at which the interfering MESs are located with respect to the wanted satellite.

Table 66:Number of interfering MESs leading to the interference limit

			Victim link					
			Argos				Hiber	
			SSP (15°)	LBR (15°)	SSP (90°)	LBR (90°)	CDMA (15°)	CDMA (90°)
Interfering MESs	Argos	SSP (15°)	49	39	64	50	49	101
		LBR (15°)	49	0	64	1	49	101
		SSP (90°)	38	30	49	39	24	49
		LBR (90°)	38	0	49	0	24	49
	Hiber	CDMA (15°)	49	39	64	50	49	101
		CDMA (90°)	38	30	49	39	24	49

The following comments can be drawn from the above results.

- Multiple simultaneous spread-spectrum signal reception at satellite is possible, in the order of a few tenths;
- Spread spectrum signals of both systems can accept multiple source interference. The geometrical configuration of the interfering MESs, compared to the wanted MES matters;
- The most favourable configuration corresponds to the wanted MES at satellite nadir, while the interfering MESs are at low elevation;
- 101 interfering transmissions coming from either ARGOS KINEIS or HIBER MESs would lead to HIBER link break-up;
- 64 interfering transmissions coming from either ARGOS KINEIS or HIBER MESs would lead to ARGOS KINEIS link break-up;
- The adverse situation occurs when the wanted MES is at located at low elevation from the satellite, while the interfering MESs are at the victim satellite Nadir;
- 24 interfering transmissions coming from either ARGOS KINEIS or HIBER MESs would lead to HIBER link break-up;
- 38 interfering transmissions coming from either ARGOS KINEIS or HIBER MESs would lead to ARGOS KINEIS link break-up.

Narrow-band ARGOS KINEIS signals can accept multiple Spread Spectrum signals, but are not compatible with any other simultaneously incoming co-frequency narrow band signal. Hence narrow band signals should preferably be spread across the band.

The above estimates assume that same e.i.r.p. level for all MESs. In reality, some dispersion in MES e.i.r.p. is expected (different terminal types, variable operational conditions), and this will augment the received signal level dispersion at the satellite receiver, and therefore degrade the system overall performances and capacity, since stronger MES signals consume the interference allowance and low power MESs links have a higher sensitivity to interference. Both systems use satellite receive antenna with an isoflux shape (higher gain at low elevation compared to higher elevation) to compensate for slant range and propagation loss variations throughout the satellite footprint. This helps to limit the dispersion to the received signal levels, when collecting data at lower elevations. .

The above results show that both HIBER and ARGOS KINEIS systems operate in an interference-limited environment. With the above assumptions, up to 20 to 30 simultaneous transmissions could occur, without noticeable impact on either system. When this above limit is reached, both systems could co-exist without any difficulty. Should higher simultaneous transmissions be envisaged, multiple parameters should be considered since the above analysis is a worst case analysis. Therefore, both systems could probably support a higher number of transmissions taking into account refined analysis.

A2.1.1.2 Burst collision statistics

In this section, an estimate is made of the number of bursts to be transmitted during a satellite pass of 10 minutes. It is assumed that both systems operate in asynchronous mode, i.e. MES transmit their bursts randomly in time, only when their associated satellite is in visibility.

For this calculation, ARGOS KINEIS and HIBER MESs are assumed to transmit 5000 bursts for each system in a period of 10 minutes. ARGOS KINEIS and HIBER MES bursts last respectively 1 second and 0.4 second. Any time overlap between two bursts is counted as a collision. The diagram below provides an illustration of the simultaneous transmissions (or collisions) count method.

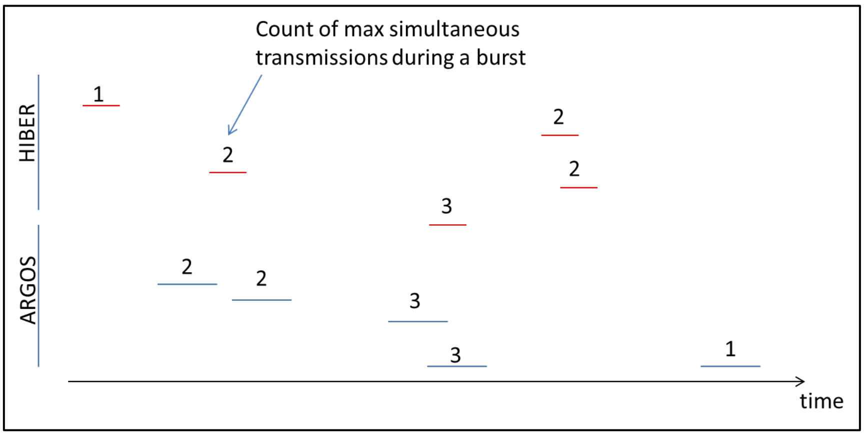


Figure 55: Illustration of the simultaneous transmissions (or collisions) count method

The following figure shows a cumulative distribution of the number of simultaneous transmissions (collisions) experienced by the MESs of each system.

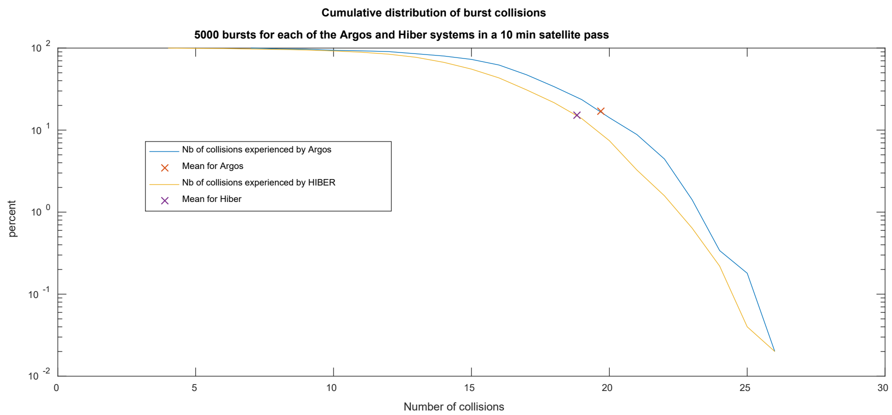


Figure 56: Cumulative distribution of burst collisions

This figure shows that both systems would experience up to about 25 collisions, for a limited number of bursts. As shown in the previous section, 25 simultaneous bursts may be close to the tolerable interference limit, leading to a total number of bursts of about 10000 per satellite pass, to be apportioned among the two systems.

Increasing the total number bursts significantly above 10000 per 10 minutes window may increase the interference level in the band. However, a refined analysis of the parameters could probably improve the capability of detection of each system.

Depending on the markets and associated geographical areas targeted by either system, the apportionment of the active number of MESs per system may vary geographically. Such apportionment should be part of the coordination discussions.

A2.1.1.3 Satellite visibility aspects

The HIBER and ARGOS KINEISs systems are designed to allow MES transmissions in the 399.9-400.05 MHz band only when satellites are visible above a certain elevation, to ensure better reception and avoid unnecessary transmissions.

The ARGOS KINEIS system constellation once fully deployed will provide a worldwide coverage, but not continuous in time. In effect, at latitudes applicable in CEPT, an ARGOS KINEIS MES will have a satellite in visibility for about 50% of the time when the constellation will be fully deployed. Consequently, in terms of compatibility with the HIBER system, ARGOS KINEIS MESs should not generate interference into HIBER satellites for about 50% of the time.

Similarly, the HIBER system is expected to deploy progressively up to 100 satellites for providing a continuous coverage. A lower number of satellites in the early stages of deployment of the HIBER system, should enable interference-free periods for the ARGOS KINEIS system.

A2.1.2 Studies for the 400.15-401 MHz band

The 400.15-401 MHz band is allocated to the MSS (space-to-Earth) on an primary basis, and MSS systems are required to coordinate under RR9.11A.

The satellites of the ARGOS-KINÉIS constellation will transmit continuously a narrow band carrier of 4 kHz bandwidth maximum.

The information provided for the HIBER system indicates that the power flux density produced on ground would amount to -129.14 dBW/m²/4 kHz in a 60 kHz band.

The ARGOS KINEIS system is expected produce a pfd level between -126.7 dBW/m²/4 kHz and about -130 dBW/m²/4 kHz depending on the operating elevation. As the MES have an omnidirectional gain pattern, the resulting C/I is close to 0 dB. As regards the ARGOS-KINÉIS system, co-frequency operations could in these conditions lead to harmful interference.

Taking into account the relatively large 850 kHz bandwidth of the concerned MSS allocation compared to the bandwidth requirement of both systems, it will be possible to ensure that co-frequency co-coverage operation is avoided. The necessary arrangements are to be discussed during frequency coordination.

Concerning the compatibility with terrestrial services in the 399.9-400.05 MHz band, no specific measures are necessary, since this band is allocated to the MSS (Earth-to-space) on an exclusive primary basis.

With respect to the compatibility with the terrestrial services in the 400.15-401 MHz band, the ARGOS KINEIS system meets the indicated pfd coordination threshold value in Annex 1 of Appendix 5 of the Radio Regulations. This ensured that the relevant Terrestrial Services are protected.

The Radio astronomy service in the 406.1-410 MHz band will also be protected by the ARGOS-KINÉIS system, due to a large frequency separation to RAS band edge and narrow band low power satellite transmissions.

Concerning the intra-service compatibility, the only concerned systems to date are HIBER and ARGOS. The study shows that while the ARGOS KINEIS and HIBER systems are deploying over the next years, the number of simultaneous MES transmissions will remain sufficiently low so that no detrimental impact on either system is expected. The waveforms employed in both systems permit co-frequency operations and are resilient to a number of burst collisions. However, when the interference level will increase due to a higher number of active satellites and MESs, both systems may have to share the overall theoretical capacity available in the band. This may result ultimately in a limitation of the number of bursts that a satellite may receive in a pass, such number would be lower than the number the same satellite would have been capable to receive without the other system’s interference. In conclusion, the ARGOS-KINÉIS and HIBER systems are compatible, provided that the coordination arrangements ensure that a detrimental interference cap is not exceeded within the band. The measures to be applied on each system is for discussion during coordination, as well as potential mitigation measures.

A2.1.3 Conclusions

Concerning the compatibility with terrestrial services in the 399.9-400.05 MHz band, no specific measures are necessary, since this band is allocated to the MSS (Earth-to-space) on an exclusive primary basis.

With respect to the compatibility with the terrestrial services in the 400.15-401 MHz band, the ARGOS KINEIS system meets the indicated pfd coordination threshold value in Annex 1 of Appendix 5 of the Radio Regulations. This ensured that the relevant Terrestrial Services are protected.

The Radio astronomy service in the 406.1-410 MHz band will also be protected by the ARGOS-KINÉIS system, due to a large frequency separation to RAS band edge and narrow band low power satellite transmissions.

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A2.2 INTRA-SERVICES STUDIES – SWARM – LEOTELCOM-1

A2.2.1 Interference level study

Considering the seniority of the systems recorded in ERC Decision (99)06, annex 1 [10], SWARM was responsible to provide intra-service compatibility studies in the frequency bands 137-138 MHz and 148-150.05 MHz with ORBCOMM. Both ORBCOMM and SWARM have filed their satellite systems LEOTELCOM-1 (ORBCOMM) and USASAT-NGSO-7 (SWARM) through and are licensed by the U.S. Federal Communications Commission (FCC).

A2.2.1.1 Frequency segmentation between SWARM and LEOTELCOM-1

The FCC authorisation of these systems in the USA involves a frequency band segmentation. The FCC ruled that SWARM and ORBCOMM will not be operating in the same portions of the VHF MSS spectrum and that ORBCOMM must vacate frequencies that it was not assigned to on a primary basis. See: Application of SWARM Technologies, Inc., IBFS File No. SAT-LOA-20181221-00094, Memorandum Opinion, Order and Authorization, DA 19-1044 (Int'l Bur. Oct. 17, 2019). The applicability of this ruling outside the U.S. territories has been approved by the FCC letter dated 10 March 2021 defining the frequency separation scheme for the operation of both systems.

Consequently, potential interference between the two systems using the abovementioned filings is excluded by the frequency separation.

A2.2.1.2 Co-frequency sharing studies

For additionally demonstrating the compatibility of operations in case of full frequency overlap in the VHF frequency bands the intra-service study between SWARM and ORBCOMM involves compatibility in the uplink direction in the 148-150.05 MHz band. This study considers:

- the one-to-one case, i.e., worst-case channel-by-channel influence from SWARM towards ORBCOMM and vice versa for a permanent signal transmission (i.e., for quantifying the potential level of interference and identifying the RF power-based compatibility);

- an aggregate case, which includes the aggregation of all interference contributions per elevation-defined coverage rings with an MES distribution over the full service area while implementing the typical duty cycles in both systems to further reduce the interference.

These analyses purely consider the power-based interference impact and – for the aggregation scenario – the duty cycle per MES, but not all the other interference mitigation techniques, which could significantly reduce the interference load compared to the results given in the tables below. The interference mitigation mechanisms implemented in the SWARM terminals include a low duty cycle, a listen-before-talk protocol, short individual transmission duration, flexible carrier frequencies, low power, and limited bandwidth signals. These interference mitigation techniques create a very low probability of collision not only with terrestrial services but also with emissions from MES of other S-PCS systems such as ORBCOMM, even if those transmissions occur on the same frequency band in an unsynchronised ALOHA mode.

A proof of the feasibility of operating in the same frequency band was also given by the satellite monitoring measurements carried out at the Leeheim station in Germany confirming that the ORBCOMM satellites continue to operate in the portions of the VHF downlink band that do not overlap with the SWARM authorised frequency bands.

A2.2.1.3 One-to-one Interference Scenario during Co-Frequency Uplink Operations

For the one-to-one interference worst-case scenario the interference potential from one SWARM MES to an ORBCOMM satellite and vice versa is estimated considering a full frequency overlap of both signals, a worst-case permanent transmission (i.e., without any duty cycle consideration) and an interfering MES location close to the wanted MES.

The technical system parameters used in these calculations were provided via bilateral communications between the operators and are summarised in Table 67. The interference power density at the victim's satellite is calculated for various elevation angles towards the ORBCOMM and SWARM satellites and adapted to the different orbit altitudes considering identical locations for terminals of both satellite systems. For each satellite elevation the corresponding free space loss (FSL) for the applicable slant path and desired signal power levels are obtained. Further atmospheric losses are not relevant in this frequency band. The worst-case wanted and interference power density reaching the victim's satellite from a transmitting interfering MES is obtained for the output of the satellite antenna as follows:

P_{Rx}, wanted = e.i.r.p. – SD_{MES}(wanted) + G_s(wanted per look angle) – FSL(per elevation) (dBW/Hz),

I_{Rx} = e.i.r.p. – SD_{MES}(Interferer) + G_s(Victim) – FSL_{ave} (dBW/Hz),

where G_s(Victim) is the victim's satellite gain at a given satellite look angle corresponding to the chosen elevation and SD_{MES} is the spectral density of the MES.

Based on identical locations of the interfering MES and the victim's MES with respect to the victim's satellite, the FSL used for calculating the interference power density is identical to the wanted one for the link budget defining cases. Hence, as long as the maximum antenna gain of the interfering MES is applied for worst-case considerations, the identical propagation conditions yield to identical C/(N + I) ratios at the satellite.

The impact of the interference power on the protection criterion of each satellite is assessed as follows:

C/(N+I) = PSD_{MES}(wanted) + G_{MES}(wanted) + G_s(wanted) – FSL(per elevation) – (N_s(ORBCOMM) + I_{Rx}) (dB).

This approach does not consider any polarisation discrimination between the two systems, which would further reduce mutual interference levels.

The calculation results are listed in Table 68. These pure interference level calculations did not consider the duty cycle of the SWARM or ORBCOMM MES but rather estimated the noise excess in the satellite of the other system in the event of receiving worst-case permanent interfering emissions from another MES. In other words, this is a worst-case analysis that will never be observed in reality.

This study concludes that – even during worst-case co-frequency operations – the interference impact is still acceptable and the C/(N + I) requirements can be met by both systems.

Table 67: Respective parameters for ORBCOMM and SWARM used for the study

Study parameters	ORBCOMM	SWARM	Remarks
MES transmitting power	3 W	0.7 W	
MES transmitting bandwidth	2.5 kHz	41.7 kHz	SWARM B/W can be adapted to different bandwidths if needed
MES antenna gain (Gx, Gr)	2 dBi	2.1 dBi	Max. gain of interfering MES as the worst case
MES E.I.R.P	7 dBW	0.55 dBW	
Satellite altitude	800 km	500 km	Notional
Satellite transmitting bandwidth	20 kHz	41.7 kHz	
Satellite Rx antenna gain	See Table 68, interpolated from ORBCOMM information	0 dBi See Table 69	
Victim MES noise temperature	400 K	≈ 750 K	Dependent on the waveform
Victim Satellite noise temperature	410 K	≈ 750 K	
Polarisation discrimination	0 dB	0 dB	RHCP assumed in both systems
Protection criterion C/(N+I)	+13.3 dB	-10 dB	

Table 68: Assessment of compliance of the emissions from a SWARM MES with the ORBCOMM protection criterion

Compatibility of SWARM uplink emissions with ORBCOMM protection criteria						
Elevation	Satellite look angle	ORBCOMM satellite antenna gain (interpolated)	Slant path	FSL (dB)	Interference PSD (dBW/Hz)	C/(N+I) required: 13.3 dB
5º	62º	1.5 dBi	2784 km	144.7	-188.9 dBW/Hz	18.3 dB
15º	59º	0.0 dBi	2033 km	142.0	-187.7 dBW/Hz	18.3 dB
20º	57º	-1.0 dBi	1769 km	140.8	-187.5 dBW/Hz	18.3 dB
30º	50º	-2.0 dBi	1395 km	138.7	-186.4 dBW/Hz	18.3 dB
45º	39º	-4.0 dBi	1074 km	136.5	-186.1 dBW/Hz	18.3 dB
60º	26º	-6.0 dBi	907 km	135.0	-186.7 dBW/Hz	18.3 dB
90º	0º	-8.5 dBi	800 km	133.9	-188.1 dBW/Hz	18.3 dB

The protection requirement of the ORBCOMM satellite can be met for all considered elevations ≥ 5 degrees.

Table 69: Assessment of compliance of the emissions from a ORBCOMM MES with the SWARM protection criterion

Compatibility of ORBCOMM uplink emissions with SWARM protection criteria						
Elevation	**Satellite look angle**	**SWARM satellite antenna gain**	**Slant path**	**FSL (dB)**	**Interference Power (dBW)**	**C/(N+I) required: -10 dB**
5º	68°	0.0 dBi	2078 km	142.2 dB	-135.4 dBW	-6.3 dB
15º	64°	0.0 dBi	1408 km	138.8 dB	-132.1 dBW	-6.3 dB
20º	60°	0.0 dBi	1193 km	137.4 dB	-130.6 dBW	-6.2 dB
30º	54°	0.0 dBi	910 km	135.0 dB	-128.3 dBW	-6.2 dB
45º	41°	0.0 dBi	683 km	132.5 dB	-125.8 dBW	-6.2 dB
60º	28°	0.0 dBi	571 km	131.0 dB	-124.2 dBW	-6.2 dB
90º	0°	0.0 dBi	500 km	129.8 dB	-123.1 dBW	-6.2 dB

The protection requirement of the SWARM satellite can be met for all elevations > 5 degrees.

With the results of this analysis, as displayed in Table 68 and Table 69, it can be concluded that the interference in both directions provides C/(N+I) ratios sufficient for a working co-frequency concept of operations.

A2.2.1.4 Aggregate interference

In order to estimate the worst-case aggregate interference caused by a distribution of respective MESs, a reasonable number of transmitters had to be estimated over a given area visible to each system's satellites. As the satellite rises from the horizon its beam coverage evolves with increasing altitude, hence the change in the visible number of transmitting MES.

The aggregated interference analysis took the following approach:

1. Divide the visibility area of the victim satellite into several coverage rings according to Figure 57 for adapting the propagation to different slant paths;
2. Define a deployment density of potentially interfering terminals per km² per one frequency channel;
3. Determine the aggregate interference power I per coverage ring (see Figure 57) applying the MES e.i.r.p. and Duty Cycle, the satellite Rx gain and the elevation specific FSL and finally aggregate all interference powers from all coverage rings towards one aggregated interference power I;
4. Calculate link budgets, (i.e., achieved $C/N_{thermal}$ for the wanted signals of the victim system per coverage ring to adapt to different FSLs);
5. Calculate C/(N + I) based on the final result from 3 and 4.

Figure 57: Illustration of the elevation-based division of the visibility area for an ORBCOMM satellite in transit at 800 km

It is important to note that this is a worst-case consideration of this sharing case without taking into account any frequency separation, or further interference mitigation measures (such as listen-before-talk) implemented in the systems.

The results of this analysis are summarised in Table 71 and Table 72. By calculating the visibility area between each two consecutive satellite elevations the number of transmitting MES per channel can be obtained for each coverage ring (see Table 70). Taking the respective typical uplink duty cycles and the number of transmitting MES, the interference power density per geographical ring (see Figure 57) can be calculated, which similar to the single interferer case is used to assess the compliance with the protection criterion C/(N+I) for each system. For determining the aggregated interference level, all individual interference contributions from each coverage ring will be linearly added, covering the worst case of simultaneous transmission by all interfering MESs assuming a simultaneous operation of all MESs.

To obtain the worst-case $C/(N+I_{total})$ values in Table 71, the total interfering power density at the victim's satellite caused by all MESs inside the full satellite coverage was used.

Table 70: Applied DCs and MES deployment densities used in the studies

	ORBCOMM	SWARM	Comments
Typical Duty Cycle used for the interference aggregation	0.01%	0.1%	
Deployment density threshold for meeting the $C/(N+I)_{required}$ under interference aggregation over the full coverage	0.042/km2	0.0063/km2	Based on the interference aggregation analyses

Table 71: Results of SWARM aggregate interference calculations caused to ORBCOMM

Min. Elevation applicable to a geographical ring	ORBCOMM's visibility area between two consecutive elevations (km^2)	Number of SWARM terminals per one frequency slot	Interference PSD_{MES}(SWARM @ ORBCOMM satellite per elevation ring [dBW/Hz]	C/(N+I) (worst case aggregated per elevation ring	Interference PSDMES(SWARM) @ ORBCOMM satellite aggregated over its full coverage [dBW/Hz]	C/($N+I_{total}$) @ ORBCOMM satellite aggregated over its full coverage
5º	10200000	1307	-187.7 dBW/Hz	17.1 dB	-183.3	13.3 dB
15º	2900000	372	-192.0 dBW/Hz	22.4 dB	-183.3	14.5 dB
20º	3300000	423	-191.2 dBW/Hz	21.9 dB	-183.3	14.7 dB
30º	2200000	282	-191.9 dBW/Hz	23.6 dB	-183.3	15.8 dB
45º	890000	114	-195.6 dBW/Hz	27.1 dB	-183.3	16.1 dB
60º	510000	65	-198.5 dBW/Hz	28.8 dB	-183.3	15.5 dB
90º	0	0	-220.0 dBW/Hz	32.8 dB	-183.3	14.1 dB

Table 72: Results of ORBCOMM aggregate interference calculations caused to SWARM

Min. Elevation applicable to a geographical ring	SWARM's visibility area between two consecutive elevations (km^2)	Number of ORBCOMM terminals per one frequency slot	Interference $Power_{MES}$(ORBCOMM @ SWARM satellite per elevation ring [dBW]	C/(N+I) (worst case aggregated per elevation ring	Interference $Power_{MES}$(ORBCOMM) @ SWARM satellite aggregated over its full coverage [dBW]	C/(N+I_{total}) @ SWARM satellite aggregated over its full coverage
5º	6932904	5881	-137.7 dBW	-4.0 dB	-137.7	-10.0 dB
15º	1628086	1381	-140.7 dBW	2.2 dB	-137.7	-6.6 dB
20º	1735698	1472	-138.9 dBW	2.0 dB	-137.7	-5.2 dB
30º	1048924	890	-138.8 dBW	4.1 dB	-137.7	-2.8 dB
45º	412830	350	-140.3 dBW	8.1 dB	-137.7	-0.3 dB
60º	220290	187	-141.5 dBW	10.8 dB	-137.7	1.2 dB
90º	0 km^2	0	-220.0 dBW	24.4 dB	-137.7	2.4 dB

A2.2.1.5 Conclusion of interference-level study

In both single emitter (one-to-one) and aggregate worst-case interference scenarios, it can be concluded that

- the SWARM MESs transmitting in any co-frequency uplink channel across 148-150.05 MHz, and not only in 149.9-149.95 MHz, with the given duty cycle will comply with the required protection criterion set by ORBCOMM;
- the ORBCOMM MESs transmitting in any co-frequency uplink channel with the given duty cycle will comply with the required protection criterion set by SWARM.

A2.2.2 Time domain study for the frequency range 149.9-149.95 MHz

A2.2.2.1 Technical analysis in the Time Domain: Impact from SWARM to ORBCOMM

A technical analysis for MSS intra-service studies in the time domain has been considered for the impact from SWARM to ORBCOMM for the frequency range 149.9-149.95 MHz and is based on the following constraints and assumptions:

- the 1% duty cycle limit in a 15 min period for SWARM earth station terminals. To meet this criterion, the active transmission time is limited to a total of 9 seconds per this 15 minutes period;
- the typical duty cycle of SWARM MESs is 0.1% occupying far less than 9 seconds in any 15 minutes period;
- the spectrum at 149.9-149.95 MHz is in most European countries not used by terrestrial applications such as land mobile applications;
- the spectrum at 149.9-149.95 MHz has no regulatory limit on a maximum burst duration;
- co-frequency sharing between MSS systems in 149.9-149.95 MHz is expected.

A study has been performed and the following table shows that ORBCOMM's DCAAS access method could be more disturbed by repetitive short 500 ms bursts than by a lower number or less repetitive emissions of SWARM's 1700 ms bursts. This is due to the significantly higher OFF-ON-switching rate compared to the 5 sec duration scan interval of ORBCOMM satellite's DCAAS. This could provide wrong results when the OFF-ON switching of a SWARM burst starts during the scanning period, especially between the time when this particular channel was already scanned until the time when the scanning is finished and the result is transmitted towards the ground for the uplink channel choice.

Table 73: Time domain study

	Limited Burst Length	External inputs (Protection criteria and ORBCOMM parameter)	SWARM Necessary Burst Length
	Burst length = 500 ms	1% per 15 min	Burst length = 1700 ms
Average No. of bursts and ON-time per burst	18 @ 500ms / burst	Total: 9 sec / 15 min	5.3 @ 1700ms / burst
OFF-time (average, intermediate)	≈ 50 sec between bursts	Total: 891 sec / 15 min	≈ 3 min between bursts

Potential No. of false-positive scan failures[4] (average)	≤ 18 per 15 min period	ORBCOMM's DCAAS with uplink scanning interval of 5 sec.	≤ 5 to 6 per 15 min period
Potential No. of false-negative scan failures[5] (average)	≤ 18 per 15 min period		≤ 5 to 6 per 15 min period
Failed ORBCOMM burst allocations per total No. of ideally unaffected bursts	≤ 1.34%		≤ 0.44%
Averaged No. of unaffected ORBCOMM bursts	Total: ≤ 2673 unaffected bursts[6] per 15 min period	Assumption for ORBCOMM's uplink burst length: 300 ms	Total: ≤ 2673 unaffected bursts[3] per 15 min period
	≈ 150 consecutive burst periods unaffected between SWARM bursts		≈ 540 consecutive burst periods unaffected between SWARM bursts
Averaged No. of affected ORBCOMM bursts	Total: 27 affected bursts[3] per 15 min period		Total: 27 affected bursts[3] per 15 min period
	≈ 1.7 consecutive burst periods affected		≈ 5 consecutive burst periods affected

The table shows in qualitative and quantitative terms that there is no net negative aggregate interference difference between a 500 ms burst transmit time and a 1700 ms burst transmit time as long as SWARM meets the criteria of 1% within 15 min period.

The comparison of the potential interference impact of different burst length of one MSS system (SWARM) towards another MSS system (ORBCOMM) demonstrates:

4 The total interference impact per period of time will remain unchanged (see blue arrows):
- The dominant criterion is the duty cycle of 1% per 15 min period of time.
- The total period of time of all affected and unaffected bursts in system A is identical.

5 The chance of having a higher number of unaffected and better usable consecutive burst periods in system A (ORBCOMM) is better with larger burst length in system B (SWARM) yielding to significantly larger OFF-times between two bursts in system B (SWARM; green arrow).

6 The number of false channel allocations due to the scan period of system A (ORBCOMM) is significantly lower (only 1/3) with the larger burst length in system B (SWARM; green arrows) compared to the short burst length in system B (SWARM).

Consequently, there is no net aggregate interference difference between a 500 ms burst transmit time and a 1700 ms burst transmit time as long as SWARM meets the criteria of 1% within 15 min period.

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[4] The DCAAS identifies a clean channel which becomes occupied after the specific frequency scan but still within the scanning period.

[5] The DCAAS identifies an occupied channel which will become free during the scanning period

[6] In ideal case, that means without DCAAS failures as per the lines above.

According to Recommendation ITU-R M.1039, annex 2, section 5 [25], this probability of simultaneous transmitters depends on the average transmissions per time (< 1% per 15 min) and the number of transmit terminals, but not from the burst length.

The consideration is limited to the frequency range 149.9-149.95 MHz and to considerations in the time domain.

Table 74: Initial Operational constraints for SWARM from intra-service considerations SWARM – ORBCOMM in 149.9-149.95 MHz

Operational constraints for SWARM	
Uplink designated band	149.90-149.95 MHz
Downlink designated bands	Operational subbands: 137.0250-137.1750 MHz, 137.3275-137.3750 MHz, 137.4725-137.5350 MHz, 137.5850-137.6500 MHz; 137.8125-138.0000 MHz Not more than 4 SWARM satellites visible over CEPT at any given time Only one satellite per sub band over CEPT
Multiple Access Method	CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance)
Modulation Method	Narrow band Frequency or Phase Modulation
Maximum CMESs e.i.r.p. spectral density (uplink)	0 dBW/4 kHz
Technique to avoid causing interference from CMESs	Low duty cycle (<1%), low-power, and carrier sense multiple access (CSMA) media access control (MAC) protocol with Collision Avoidance (CSMA/CA) “listen before talk” (LBT); energy detection threshold near noise floor in 148-150.05 MHz
Maximum burst duration for CMESs transmission	1700 msec (in 149.9000-149.9500 MHz band)
Maximum duty cycle for CMESs and system control	Not greater than 1% in any 15 minute period for any single channel
Maximum duty cycle for system control bursts	N/A

A2.3 INTRA-SERVICES STUDIES ON MYRIOTA – LEOTELCOM-1

MYRIOTA modules and micro-gateways share radio frequencies with other satellite communication systems. This section analyses the extent that MYRIOTA IoT modules and micro-gateways cause interference to LEOTELCOM systems, and the extent to which those MSS systems cause interference to the reception of signals from MYRIOTA IoT modules and micro-gateways. The communications systems of interest here are packetised, so the analysis takes the form of a maximum rate at which a given system can transmit packets before causing intolerable interference to another system

A2.3.1 DOWNLINK (MYRIOTA to/from LEOTELCOM-1)

MYRIOTA’s downlink is expected to produce an average power flux density below -125 dB(W/m²/4 kHz) in a 4 kHz band and 20 kHz band. MYRIOTA will coordinate with the LEOTELCOM-1 system operator to identify whether band segmentation is necessary

A2.3.2 UPLINK (MYRIOTA to/from LEOTELCOM-1)

This study considers two satellite communication systems that share a segment of radio frequencies of bandwidth W. With the aim of understanding the constraints under which these two systems can operate in a largely uncoordinated fashion, for example, without need for dividing the radio frequencies into two segments of bandwidth W/2. To this end the interference caused by one satellite communications system upon another is analysed. The proposed methods will arrive at acceptable rates at which one system can transmit so as not to cause intolerable interference on another. These methods are used to compare the interoperability between MYRIOTA's system (with IoT modules and micro-gateways) and the MSS system of LEOTELCOM (ORBCOMM):

- The analysis performed makes use of the following parameters that describe each system:
- Transmit power P, measured in Watts (W);
- Burst length B, measured in seconds (s);
- Normalised signal-to-noise ratio (SNR) T, measured in KHz.

The power P is the effective isotropic radiated power (e.i.r.p.). This incorporates the effect of amplifiers and antennas in the transmission of signals. In the case that a system may transmit at multiple distinct power levels, then P is taken to be the average power.

All systems featured in this comparison are packetised, so data is transmitted in bursts of finite length B. For example, the duration of bursts transmitted by the MYRIOTA IoT module are all 260 ms. In the case that a system makes use of multiple distinct burst lengths, then B is taken to be the average burst length.

The normalised signal-to-noise measures the ability of the system to tolerate interference or noise signals and is defined as follows.

$$\mathrm{T} = C_0 W_0$$

where C0 is the minimum carrier-to-noise ratio that allows for successful reception of the signal (unitless), and W0 is the burst occupied bandwidth (kHz). Both C0 and W0 are parameters commonly provided by operators for the purpose of compatibility analysis. The normalised SNR given by the product T = C0W0 is considered to be more useful than carrier-to-noise ratio alone due to the need to compare systems operating at various bandwidths. The normalised SNR T has the following physical interpretation. Let x(t) be a burst transmitted, in time domain with power P in Watts (W), and let n(t) be white noise of power spectral density, in time domain, N Watts per kilohertz (W kHz−1). Suppose the signal plus noise is given as:

$$x(t) + n(t)$$

is observed at a receiver. The normalised SNR T is such that information contained in the burst x can be extracted if

$$\mathrm{T} < \frac{P}{N}$$

That is, decoding of the burst succeeds if the ratio of the signal power to noise power spectral density exceeds the normalised SNR T.

The Table 75outlines the power P, burst length B, and normalised SNR T for the MYRIOTA IoT module, MYRIOTA micro-gateway, and the LEOTELCOM MSS system. The remainder of this document describes how these parameters can be used to analyse the interference caused by one system upon another to evaluate the ability of two satellite communication systems to share a segment of radio frequencies of bandwidth W. To this end this study supposes one system to be the victim and another to be the interferer, and analyses the extent to which transmissions from the interferer impact the victim. In particular, a number of bursts Si per second that the interferer may transmit without causing intolerable interference to the victim is determined. The bursts per second S_i can be computed for any combination of interfering and victim systems, and provides a metric of compatibility with two possible outcomes:

A system can profitably transmit Si bursts per second and not cause intolerable interference to others, and the interferer is compatible with the victim.

Alternatively, S_i is too small for the interferer to be profitable and the interferer is not compatible with the victim.

The method for determining the bursts per second S_i for an interfering system in terms of the power, burst length, and normalised SNR is now derived. Let P_i and B_i be the power and burst length of the interfering system and let P_v and T_v be the power and normalised SNR of the victim. The interfering system is supposed to utilise the entire bandwidth W such that the interference generated can be approximately modelled as white noise with power spectral density I_{PSD} described by:

$$I_{PSD} = \frac{S_i P_i B_i}{W}$$

per kHz. Intolerable interference will be caused to the victim if the ratio of the signal power Pv to this noise power is less than normalised SNR Tv. That is, if

$$T_v > \frac{P_v W}{S_i P_i B_i}$$

The maximum number of bursts per seconds S_i that the interferer can transmit is then:

$$S_i = \frac{P_v W}{T_v P_i B_i}$$

This expression above is simple and useful but ignores the variation of received signal strength that occurs as satellites orbit the earth. To account for this, denote the path loss of the victim by L_v and of the interferer by L_i. While the radiated power of the victim is P_v the received power is P_v/L_v. Similarly, the received power of the interfering signals is P_i/L_i. The maximum number of bursts per second accounting for path loss is then:

$$S_i = \frac{L_i P_v W}{T_v L_v P_i B_i}$$

Observe that this is simply the first equation for S_i scaled by the ratio of path losses Li/Lv. It remains to define the path losses L_v and L_i in relation to the receiving satellite of the victim.

A satellite orbiting at altitude A has range given by:

$$R(\theta) = R_E\left(\sqrt{\left(\frac{A + R_E}{R_E}\right)^2 - cos^2(\theta)} - sin(\theta)\right)$$

when viewed at elevation angle θ, where R_E = 6378 km is the radius of the earth. The path loss at elevation θ is given by:

$$L(\theta) = \frac{16\pi^2 R^2(\theta) f_c^2}{c^2}$$

Where:

- c = 299,792 km/s is the speed of light, (km/s)
- fc is the frequency (Hz) at which the signal is transmitted.

Satellite antennas often display elevation dependent gain that is denoted by G(θ). The gain G (dBi) is specified at a number of elevations for each system and varies from system to system. If bursts from the interfering system occur at elevation θ_i, and bursts from the victim occur at elevation θ_v, then the ratio of path losses takes the form:

$$\frac{L_i}{L_v} = \frac{R^2(\theta_i) G(\theta_v)}{R^2(\theta_v) G(\theta_i)}$$

The final expression of the maximum number of bursts per second that may be transmitted by an interference system is:

$$S_i = \frac{P_v W R^2(\theta_i) G(\theta_v)}{T_v P_i B_i R^2(\theta_v) G(\theta_i)}$$

Where:

- R(θ) is the range (km);
- G(θ) is the antenna gain (in linear scale) of the victim's satellite when viewed at elevation angle θ. (None of the values in the equation are in dB).

In what follows, the value of S_i is considered in three scenarios:

- Best-case scenario, where θ_i = 15° and θ_v = 90°
- Median scenario, where $\theta_i = \theta_v$ and L_v/L_i = 1
- Worst-case scenario, where θ_v = 15° and θ_i = 90°

The best-case scenario supposes that devices from the interfering system observe the victim satellite at 15° elevation, while the devices of the victim observe the victim satellite at 90°. In this case, the distance from satellite to interferer is larger than from satellite to victim. The interference is correspondingly smaller, and the number of bursts S_i that can be transmitted by the interfering system is larger. The best-case scenario might be realisable in a partially coordinated setting where systems actively choose to limit transmissions when satellites of a different MSS operator are visible.

The median scenario considers the path loss to be equal between systems. This is a likely outcome in a fully uncoordinated setting.

The worst-case scenario observes what happens when transmissions from an interfering system are concentrated when in close proximity to a satellite of a different MSS operator. While interesting for analytical purposes, the worst-case scenario is unlikely to occur in a sustained manner in practice.

The table below outlines the relevant properties of expected radiated power P, average burst length B, and normalised SNR T. The altitude and antenna gain of the MSS systems are also tabulated. The power and burst length have been specified by the operators of these systems. The normalised SNR for the MYRIOTA IoT module is T = 4. The MYRIOTA micro-gateway can operate with various noise tolerances. For this study a typical operating value T = 4 is assumed.

The normalised SNR is specified by the carrier to noise C_0, and occupied bandwidth W_0, as:

$$T = C_0 W_0$$

LEOTELCOM has not specified either a noise tolerance or carrier to noise ratio. For these systems, a normalised SNR of 12/5 is to be assumed, which is equivalent to the ARGOS KINEIS wideband service. The equivalent assumption was made, for example, by ARGOS KINEIS who assumed the HIBER 120 kHz CDMA service to have a carrier to noise ratio of −17 dB in their compatibility analysis.

Table 75: Typical system properties

MSS System	P Earth station e.i.r.p. (dBW)	B Burst length (s)	T Normalised SNR	A Satellite altitude (km)	G(15°) Satellite antenna gain at 15° (dBi)	G(90°) Satellite antenna gain at 90° (dBi)
MYRIOTA (IoT Module)	-3	0.26	4	600	0	0
MYRIOTA (micro-gateway)	0	0.5	4	600	0	0
LEOTELCOM	11	0.5	2.4	600	0	0

This intra-service analysis shows that uplink operations of MYRIOTA's system poses minimal interference risk to LEOTELCOM, and that sharing of the spectrum may be possible. The tables below summarise the results of the analysis, and outline the number of bursts per second a single MSS system can transmit when operating with 150 kHz bandwidth in the VHF MSS band. This analysis motivates further detailed coordination studies between MYRIOTA and LEOTELCOM to identify the best sharing methods, whilst also considering the effects of interference to MYRIOTA's system.

Table 76: Maximum bursts per second that may be transmitted by MYRIOTA before causing interference to other MSS systems, with W = 150 kHz, for median scenario $\theta_i = \theta_v$

VICTIM	INTERFERER	
	MYRIOTA (IoT module)	MYRIOTA (micro-gateway)
LEOTELCOM	6038.19	1573.66

Tabel 1: Maximum bursts per second that may be transmitted separately by each MSS system before causing interference to MYRIOTA , with W = 150 kHz, for median scenario $\theta_i = \theta_v$

INTERFERER	VICTIM	
	MYRIOTA (IoT module)	MYRIOTA (micro-gateway)
LEOTELCOM	2.99	5.96

A2.4 INTRA-SERVICES STUDIES – MYRIOTA – HIBER

A2.4.1 UPLINK (MYRIOTA to/from HIBER)

MYRIOTA modules and micro-gateways share radio frequencies with other satellite communication systems. This document analyses the extent that MYRIOTA IoT modules and micro-gateways cause interference to the HIBER, and the extent to which the HIBER system causes interference to the reception of signals from MYRIOTA IoT modules and micro-gateways. The communications systems of interest here are packetised, so the analysis takes the form of a maximum rate at which a given system can transmit packets before causing intolerable interference to another system.

The CEPT compatibility study applies to the operation of MYRIOTA 's and HIBER's satellite systems in Europe, showing the coexistence between these systems. Further compatibility studies are intended to be mutually ongoing between operators to determine precisely how coexistence is achieved for maximum capacity, with intent to optimise parameters between systems.

This study considers two satellite communication systems that share a segment of radio frequencies of bandwidth W. With the aim of understanding the constraints under which these two systems can operate in a largely uncoordinated fashion, for example, without need for dividing the radio frequencies into two segments of bandwidth W/2. To this end the interference caused by one satellite communications system upon another is analysed. The proposed methods will arrive at acceptable rates at which one system can transmit so as not to cause intolerable interference on another. These methods are used to compare the interoperability between MYRIOTA's system (with IoT modules and micro-gateways) and the MSS systems of HIBER.

The analysis performed makes use of the following parameters that describe each system:

- Transmit power P, measured in Watts (W);
- Burst length B, measured in seconds (s);
- Noise tolerance T, (unitless constant).

The power P is the effective isotropic radiated power (e.i.r.p.). This incorporates the effect of amplifiers and antennas in the transmission of signals. In the case that a system may transmit at multiple distinct power levels, then P is taken to be the average power.

All systems featured in this comparison are packetised, so data is transmitted in bursts of finite length B. For example, the duration of bursts transmitted by the MYRIOTA module are all 260 ms. In the case that a system makes use of multiple distinct burst lengths, then B is taken to be the average burst length.

The noise tolerance measures the ability of the system to tolerate interference or noise signals and is defined as follows. Given a burst x with unit power (1 W) and a white noise signal n of constant power spectral density 1 W kHz−1, then the tolerance T is a positive constant such that useful information can be gained from observation of the sum

$$x + \alpha n$$

when α2 ≤ T. For α2 > T, information may not be able to be extracted from observation of the sum. In practice this typically means that the information contained in x (the bits) is not correctly demodulated or decoded.

The noise tolerance T is typically measured by simulation or experiment as a part of the communication system design. For example, in MYRIOTA's case, the occupied bandwidth of a burst is 4 kHz, so a burst x is well represented by samples x_k = x(k / R), k ∈ ℤ taken at rate R > 8 kHz. The amplitude of the burst is scaled so that the total energy

$$\int_{-\infty}^{\infty} |x(t)|^2 dt = B$$

or equivalently, so that the average power of the burst is 1 W. Similarly, samples n_k, k ∈ ℤ of the noise process n taken at rate R, are independent and have variance R/1000 corresponding with n having power spectral density 1 W kHz−1. One then applies the demodulator and decoder to the samples

$$x_k + \alpha n_k$$

for various values of α to determine the tolerance T. Such experiments are commonplace in the communications system design process.

Table 77 outlines the power P, burst length B, and noise tolerance T for the MYRIOTA module, MYRIOTA micro-gateway, and the MSS systems of HIBER. The remainder of this document describes how these parameters can be used to analyse the interference caused by one system upon another to evaluate the ability of two satellite communication systems to share a segment of radio frequencies of bandwidth W. To this end this study supposes one system to be the victim and another to be the interferer and analyses the extent to which transmissions from the interferer impact the victim. In particular, a number of packets per second S_i that the interferer may transmit without causing intolerable interference to the victim is determined. The packets per second S_i can be computed for any combination of interfering and victim systems, and provides a metric of compatibility with two possible outcomes:

A system can profitably transmit S_i packets per second and not cause intolerable interference to others, and the interferer is compatible with the victim.

Alternatively, S_i is too small for the interferer to be profitable, and the interferer is not compatible with the victim.

The method for determining the packets per second S_i for an interfering system in terms of the power, burst length, and noise tolerance is now derived. Let P_i and B_i be the power and burst length of the interfering system and let P_v and T_v be the power and noise tolerance of the victim. The interfering system is supposed to utilise the entire bandwidth W such that the interference generated can be approximately modelled as white noise with power spectral density I_{PSD} described by:

$$I_{PSD} = \frac{S_i P_i B_i}{W}$$

per kHz. Intolerable interference will be caused to the victim if this noise power exceeds the tolerance Tv once normalised by the power of the victim P_v, that is, if

$$T_v < \frac{S_i P_i B_i}{P_v W}$$

The maximum number of packets per seconds S_i that the interferer can transmit is then:

$$S_i = \frac{T_v P_v W}{P_i B_i}$$

This expression is simple and useful but ignores the variation of received signal strength that occurs as satellites orbit the earth. To account for this, denote the path loss of the victim by L_v and of the interferer by L_i. While the radiated power of the victim is P_v the received power is P_v/L_v. Similarly, the received power of the interfering signals is P_i/L_i . The maximum number of packets per second accounting for path loss is then:

$$S_i = \frac{T_v L_i P_v W}{L_v P_i B_i}$$

Observe that this is simply the first equation for S_i scaled by the ratio of path losses L_i/L_v . It remains to define the path losses L_v and L_i in relation to the receiving satellite of the victim.

A satellite orbiting at altitude A has range given by:

$$R(\theta) = R_E\left(\sqrt{\left(\frac{A + R_E}{R_E}\right)^2 - cos^2(\theta)} - sin(\theta)\right)$$

when viewed at elevation angle θ, where R_E = 6378 km is the radius of the earth. The path loss at elevation θ is given by:

$$L(\theta) = \frac{16\pi^2 R^2(\theta) f_c^2}{c^2}$$

Where:

- c = 299.792 km/s is the speed of light;
- f_c is the frequency (Hz) at which the signal is transmitted.

Satellite antennas often display elevation dependent gain that is denoted by G(θ). The gain G (dBi) is specified at a number of elevations for each system and varies from system to system. If packets from the interfering system occur at elevation θ_i, and packets from the victim occur at elevation θ_v, then the ratio of path losses takes the form:

$$\frac{L_i}{L_v} = \frac{R^2(\theta_i)G(\theta_v)}{R^2(\theta_v)G(\theta_i)}$$

The final expression of the maximum number of packets per second that may be transmitted by an interference system is:

$$S_i = \frac{T_v P_v W R^2(\theta_i) G(\theta_v)}{P_i B_i R^2(\theta_v) G(\theta_i)}$$

Where:

- R(θ) is the range (km);
- G(θ) is the antenna gain (dBi) of the victim's satellite when viewed at elevation angle θ.

In what follows, the value of S_i in three scenarios is considered:

- Best-case scenario, where θ_i = 15° and θ_v = 90°;
- Realistic scenario, where $\theta_i = \theta_v$ and L_v/L_i = 1;
- Worst-case scenario, where θ_v = 15° and θ_i = 90°.

The best-case scenario supposes that devices from the interfering system observe the victim satellite at 15° elevation, while the devices of the victim observe the victim satellite at 90°. In this case, the distance from satellite to interferer is larger than from satellite to victim. The interference is correspondingly smaller, and the number of packets Si that can be transmitted by the interfering system is larger. The best-case scenario might be realisable in a partially coordinated setting where systems actively choose to limit transmissions when satellites of a different MSS operator are visible.

The realistic scenario considers the path loss to be equal between systems. This is a likely outcome in a fully uncoordinated setting.

The worst-case scenario observes what happens when transmissions from an interfering system are concentrated when in close proximity to a satellite of a different MSS operator. While interesting for analytical purposes, the worst-case scenario is unlikely to occur in a sustained manner in practice.

Table 77 outlines the relevant properties of expected radiated power P, average burst length B, and noise tolerated T. The altitude and antenna gain of the MSS systems are also tabulated. The power and burst length have been specified by the operators of these systems. The noise tolerance for the MYRIOTA IoT module is T = ¼. The MYRIOTA micro-gateway can operate with various noise tolerances. For this study, a typical operating value T = ¼ is assumed.

The noise tolerance for the HIBER services is specified by the carrier to noise ratio and occupied bandwidth of these systems. Given carrier to noise ratio C_0, and occupied bandwidth W_0, the corresponding noise tolerance is:

$$T = \frac{1}{C_0 W_0}$$

HIBER has not specified either a noise tolerance or carrier to noise ratio. For these systems we assume a noise tolerance of 5/12, which is equivalent to the ARGOS KINEIS wideband service. The equivalent assumption was made, for example, by ARGOS KINEIS who assumed the HIBER 120 kHz CDMA service to have a carrier to noise ratio of −17 dB in their compatibility analysis.

Table 77: Typical system properties

MSS System	P Earth station e.i.r.p. (dBW)	B burst length (s)	T noise tolerance (unitless)	A satellite altitude (km)	G(15°) satellite antenna gain at 15° (dBi)	G(90°) satellite antenna gain at 90° (dBi)
MYRIOTA (IoT Module)	-3	0.26	0.25	600	0	0
MYRIOTA (micro-gateway)	0	0.5	0.25	600	0	0
HIBER	0	0.4	0.417	600	3	-2.6

This intra-service analysis shows that uplink operations of MYRIOTA's system poses minimal interference risk HIBER's system, and that sharing of the spectrum may be possible. The two tables below summarises the results of the analysis, and outline the number of packets per second a single MSS system can transmit when operating with 150 kHz bandwidth. This analysis motivates further detailed coordination studies between MYRIOTA and HIBER to identify the best sharing methods, whilst also considering the effects of interference to MYRIOTA's system.

Table 78: Maximum packets per second that may be transmitted by MYRIOTA before causing interference to HIBER, with W = 150 kHz, for realistic scenario $\theta_i = \theta_v$

VICTIM	INTERFERER	
	MYRIOTA (IoT module)	MYRIOTA (micro-gateway)
HIBER	480.01	125.10

Table 79: Maximum packets per second that may be transmitted separately by HIBER before causing interference to MYRIOTA , with W = 150 kHz, for realistic scenario $\theta_i = \theta_v$

INTERFERER	VICTIM	
	MYRIOTA (IoT module)	MYRIOTA (micro-gateway)
HIBER	46.99	93.75

System compatibility calculations in the UHF band are provided for the following:

- The number of packets per second that HIBER can transmit without causing intolerable interference to the MYRIOTA system, for MYRIOTA's IoT modules and micro-gateways;
- The number of packets per second that MYRIOTA's IoT modules and micro-gateways can transmit without causing intolerable interference to themselves and to HIBER's system;
- The best-case, realistic, and worst-case scenarios are considered for each compatibility assessment. The results are between two systems; not the combined aggregate of all systems.

Table 80: Maximum packets per second for HIBER interfering with the MYRIOTA module as the victim, with W = 150 kHz shared bandwidth between 399.9-400.05 MHz

System	Scenario	Best-case	Realistic	Worst-case
HIBER	Interferer	345.01	46.99	6.40

Table 81: Maximum packets per second that may be transmitted by MYRIOTA modules before causing interference to HIBER, with W = 150 kHz shared bandwidth between 399.9-400.05 MHz

System	Scenario	Best-case	Realistic	Worst-case
HIBER	Victim	970.76	480.01	237.35

Table 82: Maximum packets per second for HIBER interfering with the MYRIOTA micro-gateway as the victim, with W = 150 kHz shared bandwidth between 399.9-400.05 MHz

System	Scenario	Best-case	Realistic	Worst-case
HIBER	Interferer	688.38	93.75	12.77

Table 83: Maximum packets per second that may be transmitted by MYRIOTA micro-gateways before causing interference to HIBER systems, with W = 150 kHz shared bandwidth between 399.9 - 400.05 MHz

System	Scenario	Best-case	Realistic	Worst-case
HIBER	Victim	253.00	125.10	61.86

A2.4.2 DOWNLINK (MYRIOTA to/from HIBER)

The information provided for the HIBER system indicates that the power flux density produced on ground would amount to -129.14 dB(W/m²/4 kHz) in a 60 kHz band. MYRIOTA's downlink is expected to produce an average power flux density below -125 dB(W/m²/4 kHz) in a 4 kHz band and 20 kHz band. Considering the relatively large 850 kHz bandwidth of the concerned MSS allocation compared to the bandwidth requirements of both systems, it will be possible to ensure that co-frequency, co-coverage operation is avoided.

A2.5 INTRA-SERVICES STUDIES – MYRIOTA – ARGOS KINEIS

A2.5.1 CEPT compatibility study

MYRIOTA IoT modules and micro-gateways share radio frequencies with other satellite communication systems. This document analyses the extent that MYRIOTA IoT modules and micro-gateways cause interference to ARGOS KINEIS systems, and the extent to which those MSS systems cause interference to the reception of signals from MYRIOTA IoT modules and micro-gateways. The communications systems of interest here are packetised, so the analysis takes the form of a maximum rate at which a given system can transmit packets before causing intolerable interference to another system.

A2.5.2 Methodology

Two satellite communication systems are considered to share a segment of radio frequencies of bandwidth W. Of interest is understanding the constraints under which these two systems can operate in a largely uncoordinated fashion, for example, without need for dividing the radio frequencies into two segments of bandwidth W/2. From this, the interference caused by one satellite communications system upon another is analysed. The methods will arrive at acceptable rates at which one system can transmit so as not to cause intolerable interference on another. These methods are used to compare the interoperability between MYRIOTA's system (with IoT modules and micro-gateways) and the ARGOS KINEIS system.

The results presented here are pairwise between systems, that is, they analyse the extent to which two systems are compatible in the absence of any others. As such, the results provided here should be considered indicators of compatibility between two systems and no more. In particular, they are not finalised rules or requirements to be imposed on any operator. The rationale for the approach taken in this study is to:

1. Provide analysis methods that are simple to use;
2. Treat operators equitably with respect to the total energy radiated by their systems.

The first point corroborates the objective to indicate the level of compatibility between systems rather than provide finalised rules. Simple equations may be useful in this context since they can be applied in a spreadsheet, rather than more complicated studies that require more sophisticated software simulations.

The second point considers the alternate approach to take into account the variation in burst length and transmit power between these systems, i.e., the energy per burst. A system with low energy bursts produces less interference per burst and correspondingly could transmit relatively more bursts per unit time.

The analysis performed makes use of the following parameters that describe each system:

- Transmit power P, measured in Watts (W);

- Burst length B, measured in seconds (s);
- Normalised signal-to-noise ration Ƭ, measured in kilohertz (KHz).

The power P is the effective isotropic radiated power (e.i.r.p.). This incorporates the effect of amplifiers and antennas in the transmission of signals. In the case that a system may transmit at multiple distinct power levels, then P is taken to be the average power.

All systems featured in this comparison are packetised, so data is transmitted in bursts of finite length B. For example, the duration of bursts transmitted by the MYRIOTA IoT module are all 260 ms.

The normalised signal-to-noise ratio (SNR) Ƭ measures the ability of the system to tolerate noise or interference. The normalised SNR is given by

$$\mathrm{T} = C_0 W_0$$

where C0 is the minimum carrier-to-noise ratio that allows for successful reception of the signal (unitless), and W0 is the burst occupied bandwidth (kHz). Both C0 and W0 are parameters commonly provided by operators for the purpose of compatibility analysis. The normalised SNR given by the product Ƭ = C0W0 is considered to be more useful than carrier-to-noise ratio alone due to the need to compare systems operating at various bandwidths. The normalised SNR Ƭ has the following physical interpretation. Let x(t) be a burst transmitted, in time domain with power P in Watts (W), and let n(t) be white noise of power spectral density, in time domain, N Watts per kilohertz (W kHz−1). Suppose the signal plus noise

$$x(t) + n(t)$$

is observed at a receiver. The normalised SNR Ƭ is such that information contained in the burst x can be extracted if

$$\mathrm{T} < \frac{P}{N}$$

That is, decoding of the burst succeeds if the ratio of the signal power to noise power spectral density exceeds the normalised SNR Ƭ.

The power P, burst length B, and normalised SNR Ƭ for the MYRIOTA IoT module, MYRIOTA micro-gateway, and the ARGOS KINEIS system are listed in A1.3 and A1.5. Before doing so it is described how these parameters can be used to analyse the interference caused by one system upon another. Of interest in analysing the ability of two satellite communication systems to share a segment of radio frequencies of bandwidth W. To this end this study supposes one system to be the victim and another to be the interferer and analyses the extent to which transmissions from the interferer impact the victim. In particular, a number of bursts per second S_i is determined that the interferer may transmit without causing intolerable interference to the victim. The bursts per second S_i can be computed for any combination of interfering and victim systems, and provides a metric determining compatibility.

If a system can profitably transmit S_i bursts per second and not cause intolerable interference to others, then these systems can be considered compatible.

On the other hand, S_i is too small for the interferer to be profitable then the systems are not compatible.

The bursts per second S_i is determined for an interfering system in terms of the power, burst length, and normalised SNR. Let P_i and B_i be the power and burst length of the interfering system and let P_v and $Ƭ_v$ be the power and normalised SNR of the victim. The interfering system is supposed to utilise the entire bandwidth W such that the interference generated can be approximately modelled as white noise with power spectral density equal to the average power spectral density of the transmission of all bursts:

$$PSD_i = \frac{S_i P_i B_i}{W}$$

per kHz. Intolerable interference will be impacted on the victim if the ratio of the signal power P_v to this noise power is less than normalised SNR Tv that is, if

$$T_v > \frac{P_v}{PSD_i} = \frac{P_v W}{S_i P_i B_i}$$

The maximum number of bursts per seconds S_i that the interferer can transmit is then:

$$S_i = \frac{P_v W}{T_v P_i B_i}(1)$$

The above expression (1) sets the interferer burst rate Si value so that the victim link noise allowance is entirely allocated to the external interference created by the average contribution of the interfering system. No allowance is considered for multiple transmissions in the victim system and victim system receiver thermal noise.

Also, the implicit assumption in the calculation of S_i is that the interfering system bursts impact is averaged in time and frequencies. The interfering burst arrival at the victim system being a stochastic process, burst arrival events at a rate above S_i will trigger victim burst loss. This may be captured in a more complex statistical study, to be used, e.g., during the ITU coordination process. S_i can be considered as the maximum burst arrival rate in the interfering system to be tolerated by a single link in the victim system, corresponding to optimal bursts arrivals in time and frequencies.

Considering the above, the value of S_i is expected to be over-estimated compared to an operational situation.

The expression (1) is simple and useful but ignores the variation of received signal strength that occurs as satellites orbit the earth. To account for this, denote the path loss between the victim system transmitter and receiver by L_v and of the path loss between the interferer transmitter and victim receiver by. While the radiated power of the victim is P_v the received power is P_v/L_v. Similarly, the received power of the interfering signals is P_i/L_i. The maximum number of bursts per second accounting for path loss is then:

$$S_i = \frac{L_i P_v W}{T_v L_v P_i B_i}$$

Observe that this is simply (1) scaled by the ratio of path losses L_i/Lv. It remains to define the path losses L_v and L_i in relation to the receiving satellite of the victim.

A satellite orbiting at altitude A has range given by:

$$R(\theta) = R_E\left(\sqrt{\left(\frac{A + R_E}{R_E}\right)^2 - cos^2(\theta)} - sin(\theta)\right)$$

when viewed at elevation angle θ, where R_E = 6378 km is the radius of the earth. The path loss at elevation θ is given by:

$$L(\theta) = \frac{16\pi^2 R^2(\theta) f_c^2}{c^2}$$

where c = 299.792 is the speed of light (km/s) and fc is the frequency (Hz) at which the signal is transmitted.

Satellite antennas often display elevation dependent gain that is denoted by G(θ). The gain G (dBi) is specified at a number of elevations for each system and varies from system to system. If bursts from the interfering system occur at elevation θ_i, and bursts from the victim occur at elevation θ_v , then the ratio of path losses takes the form:

$$\frac{L_i}{L_v} = \frac{R^2(\theta_i)G(\theta_v)}{R^2(\theta_v)G(\theta_i)}$$

The final expression of the maximum number of packets per second that may be transmitted by an interference system is:

$$S_i = \frac{P_v W R^{\mathrm{r}}(\theta_i) G(\theta_v)}{T_v P_i B_i R^2(\theta_v) G(\theta_i)}$$

Where:

- R(θ) is the range (km) and
- G(θ) is the antenna gain (linear scale) of the victim's satellite when viewed at elevation angle θ.
- (None of the values in the equation are in dB).

In what follows, the values of S_i are considered in three scenarios:

- Best-case scenario, where θ_i = 15° and θ_v = 90°;
- Median scenario, where $\theta_i = \theta_v$ and L_v/L_i = 1;
- Worst-case scenario, where θ_v = 15° and θ_i = 90°.

The best-case scenario supposes that devices from the interfering system observe the satellite at 15° elevation, while the devices of the victim observe the satellite at 90°. In other words, the victim satellite is directly above the victim earth station transmitters, while the interfering earth stations are off axis to the satellite at an elevation of 15°. In this case, the distance from satellite to interferer is larger than from satellite to victim. The interference is correspondingly smaller, and the number of bursts S_i that can be transmitted by the interfering system is larger. The best-case scenario might be realisable in a partially coordinated setting where systems actively choose to limit transmissions when satellites of a different MSS operator are visible.

The median scenario considers the path loss to be equal between systems. This is a likely outcome in a fully uncoordinated setting.

The worst-case scenario observes what happens when transmissions from an interfering system are concentrated when in close proximity to a satellite of a different MSS operator.

The geometrical configurations in the three above scenarios are likely to happen during system operations. The median scenario provides an average indication of interference impact.

A2.5.3 System properties

Table 84 outlines the relevant properties of expected radiated power P, average burst length B, and normalised SNR T for the MYRIOTA and ARGOS KINEIS system. The altitude and antenna gain of the MSS systems are also tabulated. Some parameters used in Table 84 may not be exactly that intended to be used by the MSS operator. They can be assumed to be a good approximation for calculation purposes and to prove compatibility among systems. They should not be used to constrain any MSS operator, and any operator agreeing to these studies is not necessarily agreeing to the accuracy of the parameter assumptions.

The power and burst length have been specified by the operators of these systems. In the case that a system specifies multiple distinct powers or a range of powers then P is taken to be the average of these powers. It may be that these systems use either the upper or lower end of the stated power range more frequently. The average power P could be adjusted to accommodate such information when it becomes available. Similarly, when a system specifies multiple distinct burst lengths or a range of burst length then B is taken to be the average burst length. Again, it may be that these systems use either shorter or longer bursts within the stated range more frequently. The average burst length B could be adjusted to accommodate such information when it becomes available.

The normalised SNR for the MYRIOTA IoT module is *T =4*, and the normalised SNF for the MYRIOTA micro-gateway system is anticipated to be similar.

The normalised SNR for the ARGOS KINEIS wideband and narrowband services are specified by the minimum carrier-to-noise ratio C0, and occupied bandwidth W_0 of these systems.

In the case of the ARGOS KINEIS wideband code-division-multiple-access (CDMA) service this is:

$$\mathrm{T} = C_0 W_0 = -17\mathrm{dB} \times 120\ \mathrm{kHz} \approx \frac{12}{5}$$

In the case of the ARGOS KINEIS narrowband service this is:

$$\mathrm{T} = C_0 W_0 = -1\mathrm{dB} \times 2.4\ \mathrm{kHz} \approx 3$$

Table 84: Typical system properties

MSS System	P Earth station e.i.r.p. (dBW)	B burst length (s)	T Norma-lised SNR (kHz)	W shared bandwidth (kHz)	A satellite altitude (km)	G(15°) satellite antenna gain at 15° (dBi)	G(90°) satellite antenna gain at 90° (dBi)
MYRIOTA (IoT Module)	-3	0.26	4	150	600	0	0
MYRIOTA (micro-gateway)	0	0.5	4	150	600	0	0
ARGOS KINEIS (SSP) (-9 dBW)	-9	1	2.4	150	650	3.6	-3.8
ARGOS KINEIS (SSP) (-3 dBW)	-3	1	2.4	150	650	3.6	-3.8
ARGOS KINEIS (LBR)	0	1	3	150	650	3.6	-3.8

A2.5.4 Summary

This section provides system compatibility calculations in the UHF bands for the following:

- The number of bursts per second that each individual MSS system can transmit without causing intolerable interference to the MYRIOTA system, for MYRIOTA's IoT modules and micro-gateways. The number of bursts per second that MYRIOTA's IoT modules and micro-gateways can transmit without causing intolerable interference to themselves and to other MSS systems;
- The best-case, median, and worst-case scenarios are considered for each compatibility assessment. The results are between two systems; not the combined aggregate of all systems.

The studies consider MYRIOTA 's IoT modules and micro-gateways, which are separated in the results. The results are simplified to assume only one type of Earth station in MYRIOTA 's system at a time.

Table 85 shows the number of bursts per second that each UHF MSS system may transmit before interfering with the MYRIOTA IoT module single link.

Table 86 shows the number of bursts per second that the MYRIOTA IoT module may transmit before interfering with ARGOS KINEIS single link.

Table 87 shows the number of bursts per seconds that each UHF MSS system may transmit before interfering with the MYRIOTA micro-gateway single link.

Table 88 shows the number of bursts that the micro-gateway may transmit per second before interfering with ARGOS KINEIS single link.

Table 85: Maximum bursts per second for each system interfering with the MYRIOTA module as the victim, with W = 150 kHz shared bandwidth between 399.9-400.05 MHz

System	Scenario	Best-case	Median	Worst-case
ARGOS KINEIS (SSP) (-9 dBW)	Interferer	1096.71	149.29	20.32
ARGOS KINEIS (SSP) (-3 dBW)	Interferer	275.38	37.50	5.10
ARGOS KINEIS (LBR)	Interferer	138.07	18.79	2.56

This table shows that the MYRIOTA IoT transmissions received at low elevation are highly affected by a small number of ARGOS KINEIS transmissions received at or close to MYRIOTA satellite nadir (worst-case scenario). By contrast, MYRIOTA satellite reception is relatively resilient to ARGOS KINEIS transmissions when the MYRIOTA IoT module is seen at higher elevation (best-case scenario).

Table 86: Maximum bursts per second that may be transmitted by MYRIOTA modules before causing interference to ARGOS KINEIS systems, with W = 150 kHz shared bandwidth between 399.9 - 400.05 MHz

System	Scenario	Best-case	Median	Worst-case
ARGOS KINEIS (SSP) (-9 dBW)	Victim	78.02	60.38	39.87
ARGOS KINEIS (SSP) (-3 dBW)	Victim	310.61	240.38	186.33
ARGOS KINEIS (LBR)	Victim	494.61	383.70	296.89

This table shows the ARGOS KINEIS system is relatively resilient to the MYRIOTA modules transmission, irrespective of the elevation at which the MYRIOTA module is seen.

Table 87: Maximum bursts per second for each system interfering with the MYRIOTA micro-gateway as the victim, with W = 150 kHz shared bandwidth between 399.9-400.05 MHz

System	Scenario	Best-case	Median	Worst-case
ARGOS KINEIS (SSP) (-9 dBW)	Interferer	2188.22	297.87	40.55
ARGOS KINEIS (SSP) (-3 dBW)	Interferer	549.66	74.82	10.19
ARGOS KINEIS (LBR)	Interferer	275.48	37.50	5.10

This table shows that the MYRIOTA micro-gateways transmissions received at low elevation are highly affected by a small number of ARGOS KINEIS transmissions received at or close to MYRIOTA satellite nadir (worst-case scenario). By contrast, MYRIOTA micro-gateways reception is resilient to ARGOS KINEIS transmissions when the micro-gateway is seen at higher elevation (best-case scenario).

Table 88: Maximum bursts per second that may be transmitted by MYRIOTA micro-gateways before causing interference to ARGOS KINEIS systems, with W = 150 kHz shared bandwidth between 399.9 - 400.05 MHz

System	Scenario	Best-case	Median	Worst-case
ARGOS KINEIS (SSP) (-9 dBW)	Victim	20.33	15.74	12.20
ARGOS KINEIS (SSP) (-3 dBW)	Victim	80.95	62.65	48.56
ARGOS KINEIS (LBR)	Victim	128.98	100.00	77.38

This table shows that a small number of micro-gateway transmissions can significantly affect the low power ARGOS KINEIS SSP transmissions, irrespective of the elevation at which the interfering micro-gateways are seen. As the SSP transmissions are in spread-spectrum, frequency avoidance does not provide a mitigation. If the micro-gateways employ a relatively high duty cycle then a small number of these units in the ARGOS KINEIS satellite footprint (e.g. Europe) will affect ARGOS KINEIS SSP low power signal reception.

A2.6 INTRA-SERVICES STUDIES ON MYRIOTA – SWARM

A2.6.1 Compatibility study in the VHF frequency bands

MYRIOTA 's mobile satellite system shares radio frequencies with other satellite communication systems, including SWARM's. This sharing study is based on the methodologies of the HIBER- ARGOS KINEIS study, see section A2.1. This study demonstrates mutual intra-service compatibility in terms of interference power, with methodology generally applicable to both affected systems MYRIOTA and SWARM in the VHF frequency bands.

Based on the achieved link margins M (see Table 94 used onwards), this methodology considers the determination of the permissible interference into the other system's receiver.

The following table defines the permissible interference or interference break-up threshold as described in the HIBER-ARGOS study for both systems:

Table 89: Calculation of permissible interference

From C/N (see HIBER-ARGOS study, section 3.1)	From permissible noise increase (ΔT/T principle)
In linear domain: $$\frac{C}{N + I_{break-up}} = (C/N)_{required}$$ Hence: $$I_{break-up} = \frac{C}{(C/N)_{required}} - N$$ $$I_{break-up} = \left[\frac{\left(\frac{C}{N}\right)_{achieved}}{(C/N)_{required}} - 1\right] * N$$	$$(C/N)_{required} = (C/N)_{achieved} - M$$ In linear domain: $$(C/N)_{required} = \frac{(C/N)_{achieved}}{M}$$ $$\frac{(C/N)_{achieved}}{M} = \frac{C}{N + I_{aggr}}$$ $$\frac{M}{(C/N)_{achieved}} = \frac{N + I_{aggr}}{C}$$ $$\frac{M * C}{(C/N)_{achieved}} - N = I_{aggr.} = M * N - N$$
Check: $$I_{break-up}(M) = (M-1) * N$$ =	$$I_{break-up}(M) = (M-1) * N$$

Based on the aggregated interference level at the input of the receiver, the aggregated interfering e.i.r.p. from the interfering MESs towards the victim's satellite can be calculated with the simplified formula:

$$EIRP_{total} = \frac{(M-1) * N_V * L_I}{G_{Victim}(to\ I)}$$

with L_I = free space loss between the interferer and the victim receiver (corresponding to the slant path R_I). This can be assumed as the averaged loss over the full operational elevation range (e.g., 5°to 90°) or as the worst case for the 90° elevation.

The operators are able to examine this permissible level of interference in the time domain and translate this into the number of packets per second for certain packet lengths. This sharing study is focused on determining the compatibility of coexistence through permissible interference power, and assessment in the time domain is outside the scope of this study. Further coordination steps will be covered by subsequent operator-to-operator frequency coordination work, including analyses about Listen-Before-Talk mechanisms; the data throughput; and other parameters in the time-domain.

The following table outlines the permissible interference power at the victim's satellite receiver, for protecting SWARM's uplink operations.

Table 90: Permissible interference level at SWARM's VHF receiver

Parameters	[Units]	SWARM (VHF)	
		Uplink 1	Uplink 2
Tx power, P(Tx)	[W]	0.7	0.7
Tx antenna gain, G(Tx)	[dBi]	0	2
Rx antenna gain, G(Rx)	[dBi]	0	0
Signal bandwidth, W	[kHz]	41.7	41.7
Rx Noise power, N signal bandwidth (matched filter)	[dBm]	-119	-119
Polarisation discrimination, A	[dB]	0	0
C/N required, C/N	[dB]	-10	-10
Orbit altitude, H	[km]	500	500
Slant paths			
SWARM elevation = 5.0°, R(5°)	[km]	2078	2078
SWARM elevation = 90.0°, R(90°)	[km]	500	500
Path losses			
SWARM elevation = 5.0°, L (5°)	[dB]	142.2	142.2
SWARM elevation = 90.0°, L (90°)	[dB]	129.8	129.8
Total link margin M			
SWARM elevation = 5.0°, M	[dB]	15.2	17.25
SWARM elevation = 90.0°, M	[dB]	27.6	29.6
Permissible Interference at victims' receiver			
SWARM elevation = 5.0°, I	[dBW]	-133.9	-131.8
SWARM elevation = 90.0°, I	[dBW]	-121.4	-119.4

Based on the above permissible aggregated interference at the victim's receiver, the following table contains the derived aggregate interfering e.i.r.p.s for different combinations of elevations. It spans a range of the permissible interfering e.i.r.p. for different operational cases:

Table 91: Maximum aggregated e.i.r.p. [dBW] from MYRIOTA MESs for different elevations per channel bandwidth Aggregated e.i.r.p. [dBW] value to reach the permissible interference at victim's receiver, per channel bandwidth

Parameter		Protecting SWARM in the VHF frequency bands	
		Uplink 1	Uplink 2
SWARM elevation = 5.0°	MYRIOTA elevation = 5°	8.3	10.4
	MYRIOTA elevation = 90°	-4.1	-2
SWARM elevation = 90.0°	MYRIOTA elevation = 5°	20.8	22.8
	MYRIOTA elevation = 90°	8.4	10.4

Table 91 shows calculated results of the aggregated e.i.r.p. of MYRIOTA devices (per channel bandwidth) before the SWARM satellite receiver cannot receive signals from SWARM devices.

For example, when the SWARM satellite is directly overhead a SWARM device (90°), and a MYRIOTA device is at elevation angle 5° to SWARM satellite, then the aggregation of MYRIOTA devices is permitted to transmit at e.i.r.p. = 22.8 dBW.

This value is compared to the ones given in Table 92, where the e.i.r.p. of a single device is either -3 or + 5 dBW, showing that in the worst case, up to 61 MYRIOTA devices per channel could be emitting simultaneously before the SWARM system would be unable to maintain its link.

It is noted that some cases may be challenging but statistically there are enough opportunities for successful communication.

The following table outlines the permissible interference power at the victim's satellite receiver, for protecting MYRIOTA's uplink operations.

Table 92: Permissible interference level at MYRIOTA's VHF receiver

Parameters	[Units]	MYRIOTA (VHF)	
		Uplink 1	Uplink 2
Tx power, P(Tx)	[W]	0.50	1.00
Tx antenna gain, G(Tx)	[dBi]	0	5
Rx antenna gain, G(Rx)	[dBi]	0	0
Signal bandwidth, W	[kHz]	4	4
Rx Noise power, N signal bandwidth (matched filter)	[dBm]	-119	-119
Polarisation discrimination, A	[dB]	0	0
C/N required, C/N	[dB]	0	0
Orbit altitude, H	[km]	600	600
Slant path			

Parameters	[Units]	MYRIOTA (VHF)	
		Uplink 1	Uplink 2
MYRIOTA elevation = 5.0°, R(5°)	[km]	2329	2329
MYRIOTA elevation = 90.0°, R(90°)	[km]	600	600
Path losses			
MYRIOTA elevation = 5.0°, L (5°)	[dB]	143.2	143.2
MYRIOTA elevation = 90.0°, L (90°)	[dB]	131.4	131.4
Total link margin M			
MYRIOTA elevation = 5.0°, M	[dB]	2.8	10.9
MYRIOTA elevation = 90.0°, M	[dB]	14.6	22.6
Permissible Interference at victims' receiver			
MYRIOTA elevation = 5.0°, I	[dBW]	-149.5	-138.4
MYRIOTA elevation = 90.0°, I	[dBW]	-134.6	-126.4

Based on the above permissible aggregated interference at the victim's receiver, the following table contains the derived aggregate interfering e.i.r.p.s for different combinations of elevations. It spans a range of the permissible interfering e.i.r.p. for different operational cases:

Table 93: Maximum aggregated e.i.r.p. [dBW] from SWARM MESs for different elevations per channel bandwidth

Aggregated e.i.r.p. [dBWvalue to reach the permissible interference at victim's receiver, per channel bandwidth		Protecting MYRIOTA in the VHF frequency bands	
		Uplink 1	Uplink 2
MYRIOTA elevation = 5.0°	SWARM elevation = 5°	-6.3	4.9
	SWARM elevation = 90°	-18	-6.8
MYRIOTA elevation = 90.0°	SWARM elevation = 5°	8.6	16.8
	SWARM elevation = 90°	-3.2	5.0

Table 93 shows calculated results of the aggregated e.i.r.p. of SWARM devices (per channel bandwidth) before the MYRIOTA satellite receiver cannot receive signals from MYRIOTA devices.

For example, when the MYRIOTA satellite is directly overhead a MYRIOTA device (90°), and a SWARM device is at elevation angle 5° to MYRIOTA satellite, then the aggregation of SWARM devices is permitted to transmit at e.i.r.p. = 16.8 dBW.

This value is compared to the ones given in Table 90, where the e.i.r.p. of a single device is either -1.5 or + 0.5 dBW, showing that in the worst case, up to 43 SWARM devices per channel bandwidth could be emitting simultaneously before the MYRIOTA system would be unable to maintain its link.

It is noted that some cases may be challenging but statistically there are enough opportunities for successful communication.

A2.6.2 Conclusions (uplink)

Compatibility of MYRIOTA's MES with SWARM protection requirements in the VHF bands: The e.i.r.p. of the MYRIOTA MESs is well inside the permissible e.i.r.p. range given by the values in in Table 73. Compatibility of SWARM's MES with MYRIOTA protection requirements in the VHF bands: The e.i.r.p. of the SWARM MESs is well inside the permissible e.i.r.p. range given by the values in Table 75.

This study proves that compatible operation of both satellite systems under conditions of co-frequency sharing is possible in the VHF MSS frequency bands.

This study considers uplink for mobile earth stations (e.g. MYRIOTA IoT Module and SWARM Tile). The operators are able to apply the same principle of permissible level of interference for their VHF gateways (e.g. MYRIOTA micro-gateway, SWARM Fixed Earth Station) to enable coexistence.

Additional considerations for interoperability (such as listen-before-talk) are omitted from this study, but both operators agree that other techniques can be employed by their respective systems that may further enhance the ability to coexist.

Subsequent operator-to-operator frequency coordination will further develop the arrangements for VHF gateways; operating parameters in the time-domain; and other sharing mechanisms in general.

A2.6.3 DOWNLINK

Considering the relatively large 1000 kHz bandwidth of the concerned VHF MSS allocation 137-138 MHz compared to the bandwidth requirements of both systems, it should be possible that co-frequency, co-coverage operation of VHF downlink is avoided. The compatibility of the downlink operations of both systems will be studied in further detail between the operators, also covering further system aspects and sharing mechanisms in the time domain.

Table 94: Parameters and Abbreviations

A	Variable Margin ≤ M	**M**	Link Margin (with M-1 as the noise increase tolerance factor)
B	Burst length	**N**	Noise Power
C	Carrier power	N_0	Noise Power Density
C/N	Carrier-to-noise power ratio	P_I	Interfering Power
DC	Duty Cycle	**R**	Slant Path
e.i.r.p.	Equivalent Isotropic Radiated Power	S_I	Number of (interfering) packets / bursts per second
ED	Energy Detect (threshold for LBT)	**V**	Victim
G	Antenna Gain	**W**	Signal Bandwidth
I	Interference power	**Z**	Number of systems sharing the same frequency spectrum
L	Path Loss		
LBT	Listen-Before-Talk		

ANNEX 3: COMPATIBILITY WITH THE RADIO ASTRONOMY SERVICE

A3.1 INTRODUCTION

The Radio Astronomy Service use of the protected bands 150.05−153 MHz and 406−410 MHz is of high importance for many observatories not only in Europe but all around the world and its protection from terrestrial and space-borne sources must be guaranteed. Among the observatories in Europe (see Table 95), which make observations in these bands, are Jodrell Bank (UK), Effelsberg (Germany), several dozens of LOFAR stations (Netherlands and many CEPT countries), Nançay (France), and Pushchino (Russia). Due to the extreme sensitivity of radio telescopes it is a normal practice to locate them in isolated regions or to look for geographical protection to avoid (as much as possible) the ubiquitous radio frequency interference in populated areas. Being run under public funds, most radio telescopes enjoy the protection of their National Administration when granting licenses to new services that can generate interference in their operations.

The protection of these bands allowed for some famous results such as the 408 MHz all-sky map, which was done with Jodrell, Effelsberg and Parkes (Australia). Effelsberg also participated in measurements of the landing of the NASA Mars-rover mission “Insight” (at a frequency of 400 MHz). The Nançay observatory operates the radio astronomy bands 150−153 MHz and 406−410 MHz with the radio telescopes Radioheliograph and ORFEES for observations of the Sun and for space weather. The ORFEES instrument is a spectro-heliograph dedicated for the real-time monitoring of solar activity. The data is used for the study of solar flare as well as for space weather related to the French Air Force. The 150 MHz band is also used by the LOFAR station located at Nançay observatory.

The Nançay radioheliograph (NRH) produces interferometric images of the Sun's corona in the frequency range 150−450 MHz. It is one of the major telescopes in the world capable of imaging the sun in the VHF range. It plays an important role in the diagnosis of non-thermal emissions from corona, and provides a support service to several space missions, such as STEREO, Parker Solar Probe (PSP) and Solar Orbiter. NRH data can also play an important role in monitoring space weather.

The 150 MHz and 400 MHz frequencies are also extensively used for Pulsar research.

This Annex presents studies of the subscriber uplinks and downlinks of the proposed S-PCS <1 GHz to inform administrations within CEPT countries with RAS stations about the coordination distances needed (in the case of subscriber uplinks) or to verify the compliance to the requirements established by Recommendation ITU-R RA.769 [3] and ITU-R Resolution 739 [23] (in the case of downlink).

Table 95: List of RAS stations in Europe operating in the 150 MHz and/or the 408 MHz bands

Observatory	Country	Geographical latitude	Geographical longitude
Pushchino	Russia	54°49’20” N	37°37’53” E
Jodrell Bank	United Kingdom	53°14’10” N	-02°18’26” E
Westerbork	Netherlands	52°55’01” N	06°36’15” E
LOFAR (core)	Netherlands	52°55’ N	06°52’ E
Effelsberg	Germany	50°31’32” N	06°53’00” E
Nançay	France	47°22’24” N	02°11’50” E
Medicina	Italy	44°31’14” N	11°38’49” E
Sardinia	Italy	39°29’34” N	09°14’42” E
LOFAR (remote stations)	Poland, Germany, UK, Ireland, Sweden, France, Latvia		

A3.2 CASES CONSIDERED

The RAS frequency bands considered are 150.05−153 MHz and 406−410 MHz. A number of S-PCS use frequencies adjacent or very close to these two bands. The following cases are relevant:

- Subscriber uplinks in 150 MHz:
  - LEOTELCOM-1
  - SWARM
  - MYRIOTA IoT
  - MYRIOTA Gateway
- Subscriber downlinks in 150 MHz:
  - SWARM
  - MYRIOTA IoT
  - MYRIOTA Gateway
- Subscriber uplinks in 400 MHz:
  - HIBER
  - ARGOS KINEIS
  - Fleet
  - MYRIOTA
- Subscriber downlinks in 400 MHz:
  - HIBER
  - ARGOS KINEIS
  - Fleet
  - MYRIOTA

A3.3 S-PCS SYSTEMS PARAMETERS

Based on the information available, the technical parameters of the satellite systems are collected in the following table. The power spectral density radiated in the RAS band can be calculated as:

$$Psd_{tx} = P_{tx} + OOB + G_o + 10 * \log\left(\frac{d}{100}\right) - 10 * \log(B) \left[\frac{dBW}{Hz}\right]$$

Table 96: System parameters of the S-PCS<1 GHz under study for up- and downlink

System	Fo (MHz)	Transmitted power	Gain in the horizontal plane	Duty cycle	Bandwidth	Number of emitters	OOB attenuation in the RAS band	PSD in RAS band
LEOTELCOM-1 Uplinks	149	10.96 dBW	0 dBi	0.01 %	5 kHz	1	-60 dBc	-126.1 dBW/Hz
SWARM Uplink	149	7 dBW	0 dBi	0.1%	20.8 kHz	1	-70 dBc	-136.2 dBW/Hz
MYRIOTA IoT Uplink	149 MHz	-3 dBW	0 dBi	0.02%	4 kHz	1	-65 dBc	-141 dBW/Hz
MYRIOTA Gateway Uplink	149 MHz	-3 dBW	0 dBi	0.5%	25 kHz	1	-65 dBc	-135 dBW/Hz

System	Fo (MHz)	Transmitted power	Gain in the horizontal plane	Duty cycle	Bandwidth	Number of emitters	OOB attenuation in the RAS band	PSD in RAS band
HIBER Uplink	400	0 dBW	-4 dBi	0.4 %	120 kHz	1	-65 dBc	-143 dBW/Hz
ARGOS KINEIS Uplink	400	0 dBW	0 dBi	0.01 %	120 kHz	1	-65 dBc	-155.8 dBW/Hz
MYRIOTA IoT Uplink	400 MHz	-3 dBW	0 dBi	0.02%	4 kHz	1	-65 dBc	-141 dBW/Hz
MYRIOTA Gateway Uplink	400 MHz	-3 dBW	0 dBi	0.5%	25 kHz	1	-65 dBc	-135 dBW/Hz
Fleet Uplink	400 MHz	0 dBW	0 dBi	0.05%	120 kHz	1	-85 dBc	-168.8 dBW/Hz
SWARM Downlink	137.5	1.76 dBW	0 dBi	10%	20.8 kHz	150	-100 dBc	-151.4 dBW/Hz
HIBER Downlink	400	10 dBW	.0.2 dBi	1.8%	150 kHz	72	n/a	-140.6 dBW/Hz
ARGOS KINEIS Downlink	400 MHz	7.2 dBW	-3.96dBi	100%*	4 kHz	25	n/a	-140 dBW/Hz
MYRIOTA Downlink	137 MHz	1.5 dBW	0 dBi	10%	4 kHz	52	-110 dBc	-154.5 dBW/Hz
MYRIOTA Downlink	400 MHz	10 dBW	0 dBi	10 %	4 kHz	52	-110 dBc	-146 dBW/Hz
Fleet Downlink	400 MHz	6 dBW	1.5 dBi	8%	125 kHz	140	-87.6 dBc	-143.5 dBW/Hz

A3.4 UPLINKS COMPATIBILITY STUDY

To study the compatibility between a radio telescope and a terrestrial transmitter the propagation model ITU-R P.452-16 [2] is used, this model is recommended for use in compatibility studies from above 0.1 GHz and considers line of sight, diffraction and scatter among other propagation mechanisms. The real strength of Recommendation ITU-R P.452 [2] lies in its ability to include propagation loss due to terrain irregularities around specific sites, because radio telescope sites within CEPT countries can be very diverse in their surrounding topology, a generic study (with a flat terrain) is considered for this annex. This generic study is useful to present the largest coordination distance needed for the protection of RAS stations.

To calculate these coordination distances, the minimum attenuation (or Minimum Coupling Loss, MCL) method is used. The MCL is obtained as the difference between the average transmitted power in the RAS band (radiated in horizontal direction) and the protection limit defined in Recommendation ITU-R 769-2 [3] for each frequency range. Likewise, the minimum distance that produces a propagation loss equal to the MCL is obtained from the Recommendation ITU-R P.452-16 [2] model.

Recommendation ITU-R P.452-16 is a quite sophisticated propagation model that requires several parameters. The next table shows the parameters that are common to both frequency ranges, the last column of the table provides a rationale on the selection of each parameter.

Table 97: Path propagation parameters for terrestrial sight lines.

Parameter	Symbol	Value	Comments
Transmitter height	Htx	2 m	Considers that a device can be on the roof of a house
Receiver height	Hrx	2 m	Some of the RAS stations conducting observations in these frequencies use small low frequency antennas
Percentage of time	p	2%	This is the percentage of time that the propagation loss can be lower than the result obtained with P.452-16 [2]. The 2% data loss is in line with Recommendation ITU-R RA.1531
Temperature	T	K	Assumed 290 K
Pressure	Press	hPa	Assumed 1013 hPa
Path profile (*)	Flat Earth		To make the studies generic, a flat path is considered. This means that the P452 [2] model will consider effects like: Line of Sight, Diffraction on the spherical Earth surface, Tropo-scatter and Ducting
Clutter, Tx	Sparse (note 1)*	N/A	Low clutter considered in the vicinity of RAS stations. Nominal clutter height = 4 m, Nominal distance to clutter = 0.1 km
Clutter, Rx	None	N/A	No clutter considered at the receiving RAS station
Mean Longitude	Lon	7 deg	
Mean Latitude	Lat	50 deg	Approximate centre of CEPT region

Note 1: * “Sparse” is a name used by pycraf that represents the first row in Recommendation ITU-R P.452-16, table 4 [2]

A3.4.1 Single transmitter case

The study of compatibility between terrestrial transmitters (uplinks) and a RAS station observing in 150.05-153 MHz or 406-410 MHz is described here. The study is conducted considering a single transmitter’s PSD in the RAS bands as calculated in Table 97.

The protection limits defined in Recommendation ITU-R RA.769-2 [3] are:

$$Psd_{limit_{150MHz}} = -264 \left[\frac{dBW}{Hz}\right] \tag{7}$$

$$Psd_{limit_{408MHz}} = -269 \left[\frac{dBW}{Hz}\right] \tag{8}$$

The minimum coupling loss required is:

$$MCL = Psd_{tx} - Psd_{limit} \tag{9}$$

The obtain the minimum distance necessary between the considered transmitter and a RAS station conducting observations in these frequency bands the propagation model from Recommendation ITU-R P.452-16 [2] is used with the parameters from Table 97.

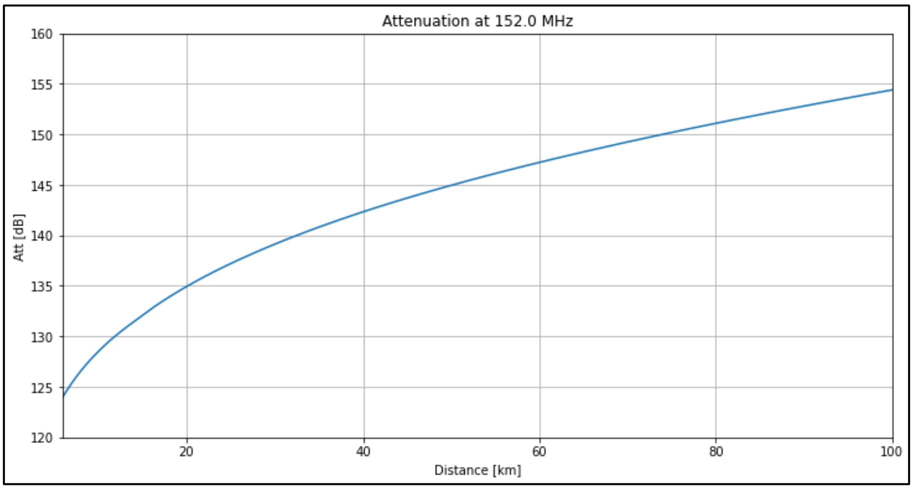

Figure 58: Total attenuation at 150 MHz

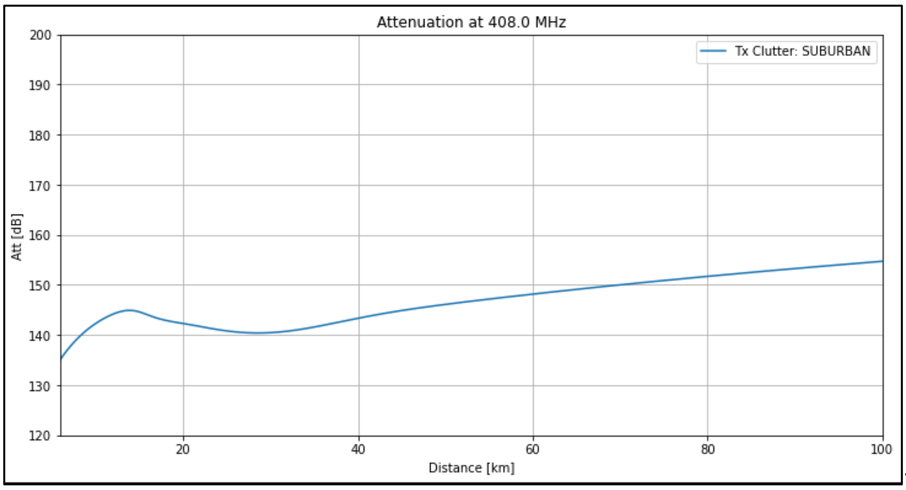

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Figure 59: Total attenuation at 408 MHz

Note that the “dip” in the attenuation in Figure 59 (at about 30 km) is caused by anomalous propagation effects.

Considering the PSD limit in each band as defined in Recommendation ITU-R RA.769 [3], the MCL is calculated, and the minimum separation distance is obtained from the two above figures.

Table 98: Results of the terrestrial single-interferer studies

System	MCL	Coordination distance
LEOTEL-1`Uplinks	138.1 dB	27.5 km
SWARM Uplink	128 dB	9.5 km
MYRIOTA IoT Uplink, VHF	123.2	5.5 km
MYRIOTA uGateway Uplink, VHF	129.2	10.9 km
HIBER Uplink	125 dB	3.2 km
ARGOS Uplink	113 dB	1.6 km
MYRIOTA IoT Uplink, UHF	127.8	3.8 km

System	MCL	Coordination distance
MYRIOTA Gateway Uplink, UHF	133.8	5.5 km
Fleet Uplink	100	0.7 km

For a generic study, Table 98 reflects the minimum distance that different system's uplinks need to comply to the RA.769 [3] requirements considering a single transmitter using a time-percentage parameter of 2% within the propagation model P.452 [2].

As most RAS stations are located in remote rural areas, the sparse clutter type was assumed in the studies. If a different clutter type would apply the resulting separation distance may be different. The single-interferer scenario is usually conducted as a worst-case scenario. For particular telescope sites the local terrain, the distribution of duty cycles, and also the deployment densities of the subscribers should be taken into account.

Furthermore, it has to be mentioned that the frequency band 401-403 MHz is dedicated to Data Collection systems (DCS) for space and meteorological agencies. The corresponding DCS platforms transmit data from locations anywhere all over the world in the Earth to space direction. This situation is similar as the situation in the MSS band 399.9-400.05 MHz. Two types of system are currently in operation in the 401-403 MHz band: GSO and non-GSO. In total, GSO satellites relay hundreds of thousands of messages every day, with values of e.i.r.p. much higher than those envisaged for the 399.9-400.05 MHz band. For non-GSO satellites, millions of messages every day are conveyed through the 401-403 MHz band.

In addition, it is noted that compatibility studies have been made in the past for all existing systems and appropriate regulation has been formulated. Furthermore, the majority of the RAS stations are located in remote areas with a quite rural radio background and low activity of MSS.

Therefore, administrations wishing to protect RAS from out-of-band emission by radio services operating in adjacent bands may consider establishing local coordination zones around the RAS stations. In particular, it should be noted that the establishment of these coordination distances should be justified by appropriate compatibility studies taking into account site-specific information, such as terrain and clutter types.

A3.5 DOWNLINKS COMPATIBILITY STUDY

For satellite constellations of nGSO systems, the equivalent-power flux density (EPFD) method as outlined in Recommendation ITU-R S.1586 [6] and Recommendation ITU-R M.1583 [7] is used. For this, each satellite constellation is fully simulated for a given time period, here 2000 seconds, and the aggregated power flux density (pfd) is determined. As it is possible that certain sky areas have a higher likelihood of being disturbed, M.1583 proposes to split the visible sky (elevations above 0 degree) into cells of approximately equal solid angle and analyse the (cumulative) distribution function of the received aggregated pfds. Recommendation ITU-R RA.1513 [8] permits other services to interfere with the RAS for 2% of the time. Unfortunately, it is not well laid out, how this criterion is to be understood. One interpretation could be to calculate the 98% percentile level of the received aggregated pfds over the full sky and compare that number to the threshold value given in Recommendation ITU-R RA.769 [3] (hereafter call total data loss). However, other studies in ECC SE40, e.g. of the Iridium constellation, seem to count the number of sky cells in which the average pfd is larger than the RAS threshold and relate that to the total number of cells, i.e., no more than 2% of the sky area must be affected. These analyses were classically performed in the topocentric frame (azimuth and elevation). But radio astronomy almost always observes sources in the equatorial frame, in which stars and other astronomical objects are more or less fixed (in contrast to the topocentric frame, where stars appear to move with time, owing to Earth's rotation). Therefore, one could also demand that any object in the sky, i.e., a given sky cell in the equatorial frame, must not be affected by RFI for more than 2% of the observing time. This would actually be the approach that fits best to the nature of astronomical observations, where scientists need to propose which astronomical objects are worth to be observed for a given time (these proposal are then reviewed and owing to the limited number of RAS facilities, observing time is often heavily overbooked, such that only a small fraction of proposals is granted time). It would be very ineffective if after such a work-intensive process, the source of interest could only be observed properly for a fraction much smaller than 98% of the time. In the following, the figures of merit for all three approaches are computed.

For the EPFD simulations, the first step is to calculate the satellite positions for a range of time steps. Here, 2000 s were simulated, with a time resolution of 1 s. For a statistical meaningful result, the simulation must be repeated a number of times, such that one can work with the averages over many orbit realisations. With 200 iterations, the performed simulations provided stable results (in the statistical sense). To calculate the aggregate pfd for each iteration, an observer (RAS station) location needs to be defined. One hypothetical site was chosen, having a geographic location of 50°N, 0°E, which is representative for a RAS station in the CEPT region. It is also necessary to determine the position of the observer in the moving satellite frame in order to calculate the effective satellite antenna gain towards the observer. Likewise, in the topocentric frame, for a given boresight angle of the radio telescope the angular separation to the apparent position of each satellite must be computed in order to determine the effective RAS antenna gain. This needs to be repeated for each satellite and naturally depends on the observing time.

The next step is to create a grid of sky cells. Annex 1 of Recommendation ITU-R M.1583 [7] describes a possible scheme, which is followed here. The size of the cells was chosen to have a solid angle of 1 square degree each. For each iteration and for each sky cell a random RAS pointing position is chosen (which must be located within the sky cell). It is important that these random pointings are uniformly distributed on the sphere, which can be done by sampling the azimuth angle uniformly between the lower and upper boundary of the cell, while the elevation must be sampled according to the following formula:

$$Az_i \sim U\left(Az_{i,low}, Az_{i,high}\right) \quad (10)$$

$$El_i \sim 90° - \cos^{-1} U\left(z_{i,low}, z_{i,high}\right)$$

$$with\ z_{i,\{low,high\}} = \cos\left(90° - El_{i,\{low,high\}}\right)$$

In Table 99, the results for the satellite systems are summarised for each of the simulated observer latitudes. The column “total data loss” specifies what fraction of the overall epfd values exceeds the RAS threshold. The next column “Margin @ 2% data loss” (for single constellations) and “Margin @ 5% data loss” (all constellations aggregated, which operate in the same band) contain the difference between the epfd value at the 2%/5% data loss level (98%/95% percentile of the epfd distribution) and the RAS threshold. In all three of these columns, statistical errors are specified that are based on the 15.865% and 84.135% percentiles, which would be a measure of the 1σ errors, if the distributions were Normal. Then, in “Fraction of bad cells (horizontal)” the percentage of sky grid cells is given, in which the average (over all iterations) received epfd value exceeds the RAS threshold. This is usually a small number, if not zero, as it is rare that the same horizontal-frame grid cells are affected in every single iteration. Usually, this only happens if the total data loss is very high, as well. The next two columns, “Number of cells with more than 2% / 5% loss (equatorial)” indicate how many equatorial grid cells have more than 2% (individual constellation) or 5% (aggregate) data loss. Furthermore, in Figure 60 to Figure 64 (for the example of the HIBER system) the results for each sky cell is visualised, showing the aggregated pfd (i.e., summed over all satellites and averaged with respect to the 2000 s integration time) received in each cell (displayed is the average of all iterations) and the data loss per cell for both the topocentric and equatorial frames.

The topocentric frame (also known as horizontal frame) uses the observer’s local horizon to define a celestial coordinate system. Angles in the topocentric frame are expressed as azimuth (angle of the object around the horizon, from true north and increasing eastward) and elevation (or altitude, angle between object and horizon). As the Earth rotates, celestial (deep sky) objects seem to move across the sky. For astronomical applications this apparent motion needs to be treated, e.g. by having telescopes track the objects. Furthermore, the equatorial frame is defined, in which Earth’s equator defines the reference plane and the zero meridian is dependent on time. Effects such as nutation and precession, or even motion of the solar system have to be considered, too. Deep celestial objects are almost fixed in the equatorial system.

Based on the former it is possible to count the ratio of cells, where the average pfd is higher than the permitted threshold. Furthermore, for all systems under study one finds a number of grid cells in the equatorial frame where the data loss is larger than 2%, which would significantly affect the observing possibilities for astronomical objects in such sky areas.

This is in particular the case for some of the systems, for which, despite compliance to the data loss value of 2%, a large number of grid cells (representing important portions of the accessible sky) show a data loss above 2%.

Table 99: Results for RAS station latitude of 50°

System	Total data loss[%]	Margin @ 2% data loss [dB]	Margin @ 5% data loss [dB]	Fraction of bad cells (horizontal) [%]	Number of cells with more than 2% loss (equatorial)	Number of cells with more than 5% loss (equatorial)
LEOTELCOM-1 Downlinks			n/a			n/a
SWARM Downlinks	$0.47^{+0.50}_{-0.47}$	$4.0^{+4.3}_{-2.1}$	n/a	0	481	n/a
HIBER Downlinks	$0.90^{+0.14}_{-0.16}$	$6.3^{+3.0}_{-1.7}$	n/a	0.0	1127	n/a
Kinéis ARGOS Downlinks	$1.48^{+0.35}_{-0.36}$	$4.5^{+6.6}_{-2.5}$	n/a	0	5534	n/a
MYRIOTA Downlinks (137 MHz)	$0.00^{+0.00}_{-0.00}$	$9.6^{+0.6}_{-0.5}$	n/a	0	0	n/a
MYRIOTA Downlinks (400 MHz)	$0.65^{+0.09}_{-0.09}$	$9.1^{+1.6}_{-1.2}$	n/a	0	358	n/a
Fleet	$1.83^{+0.14}_{-0.13}$	$0.6^{+0.5}_{-0.5}$	n/a	0.1	5336	n/a
Aggregate 137 MHz (SWARM+MYRIOTA)	$0.48^{+0.50}_{-0.48}$	n/a	$6.8^{+3.1}_{-1.8}$	0	n/a	38
Aggregate 400 MHz (HIBER + ARGOS KINEIS + Fleet + MYRIOTA)	$4.93^{+0.47}_{-0.47}$	n/a	$0.1^{+0.8}_{-0.7}$	0.3	n/a	5282

(Total number of simulated equatorial-grid sky cells: 30938)

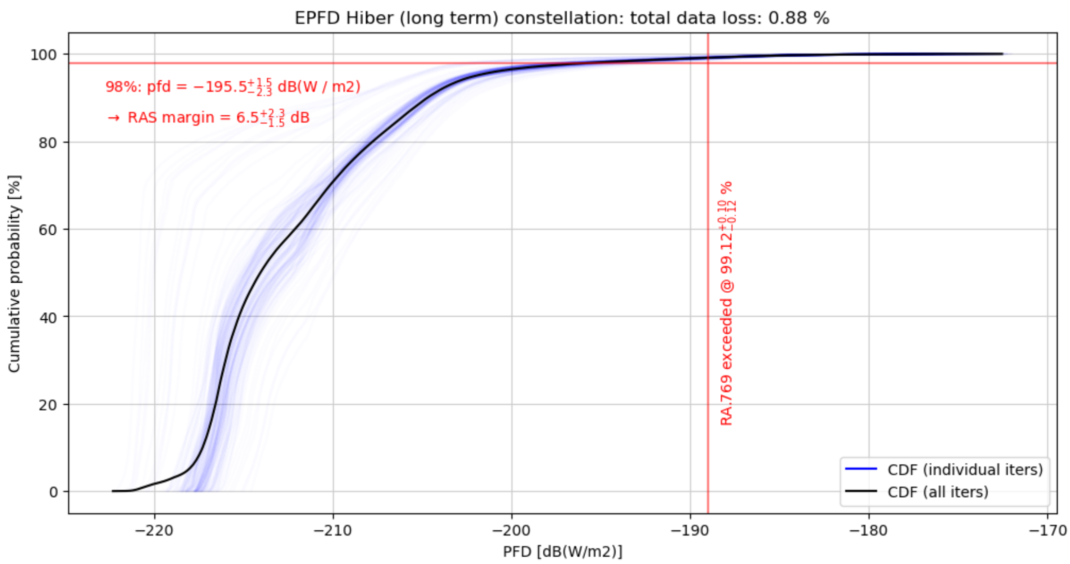

Figure 60: Cumulative distribution function for epfd values (example: HIBER system)

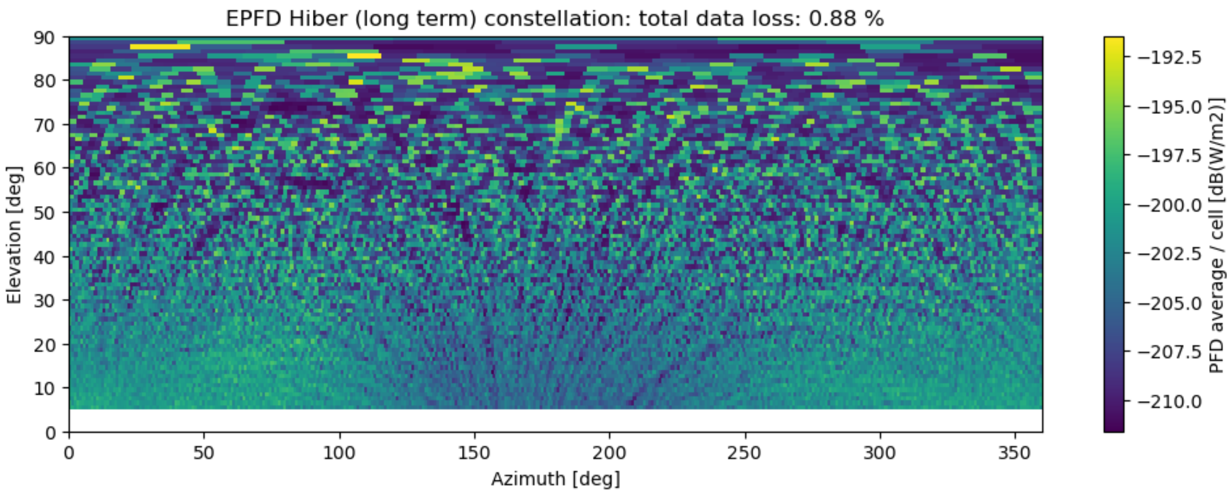

Figure 61: Average epfd for each simulated sky cell in the horizontal frame (example: HIBER system)

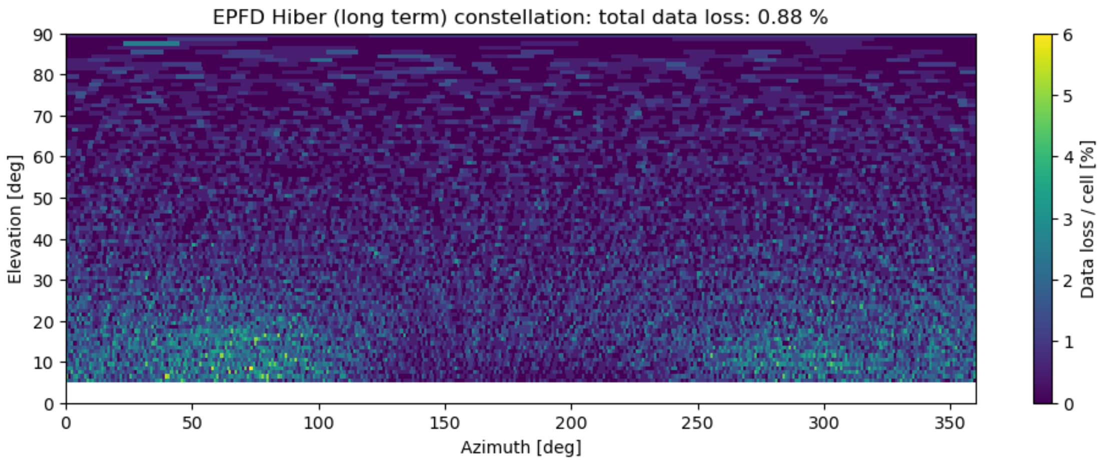

Figure 62: Data loss rate for each simulated sky cell in the horizontal frame (example: HIBER system)

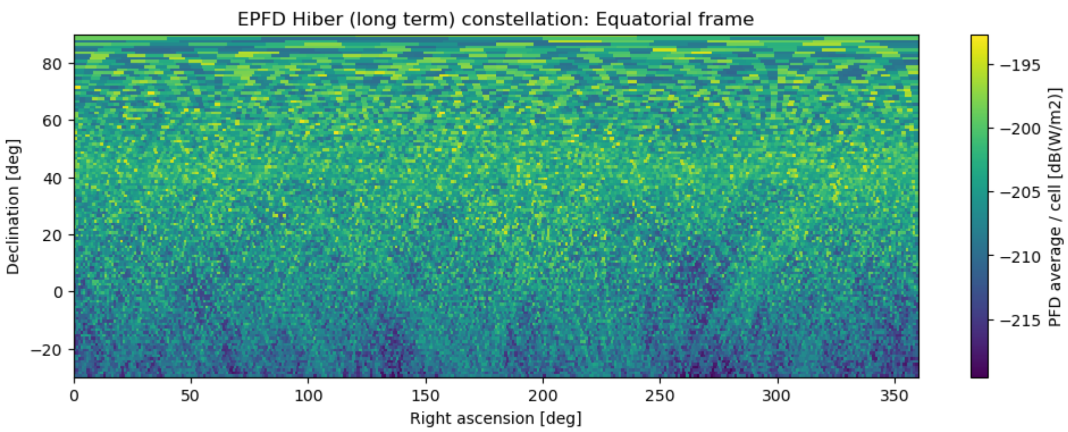

Figure 63: Average epfd for each simulated sky cell in the equatorial frame (example: HIBER system)

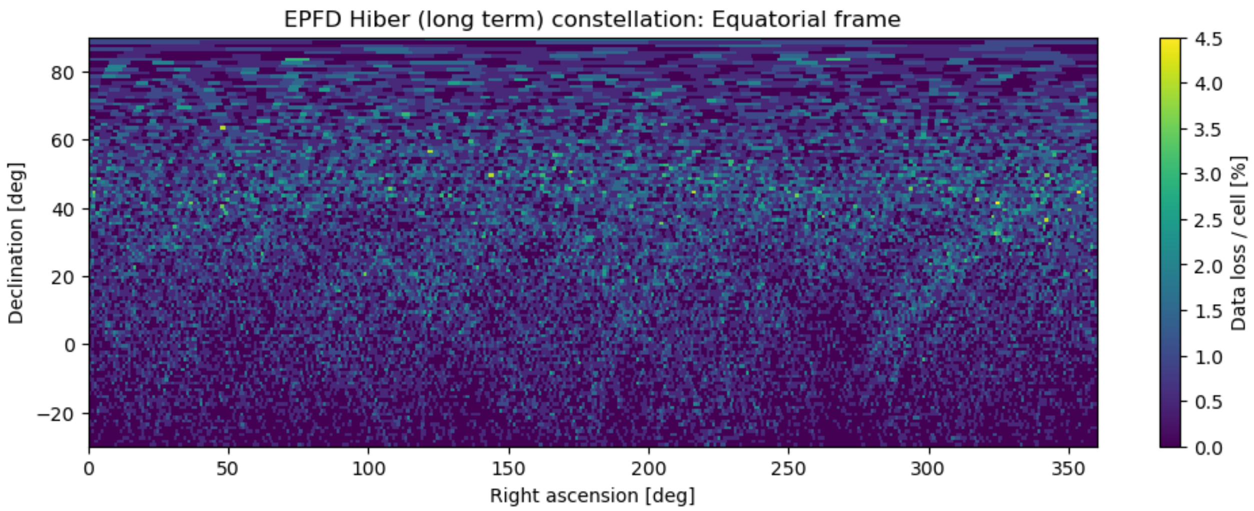

Figure 64: Data loss rate for each simulated sky cell in the equatorial frame (example: HIBER system)

It should be noted that the sky plots depend a lot on how the duty cycle is implemented in the EPFD simulation. Naively one may be inclined to simply work with lower transmitted powers, such that the average over longer periods of time would be the same as for a pulsed transmission with short pulses but higher output power. However, it turns out that the overall aggregated power can change significantly depending on the chosen duty cycle scheme. For the example of the HIBER system, the resulting data loss is almost a factor of two larger if the “averaging” method is applied.

A3.5.1 Aggregate effect of multiple constellations

Recommendation ITU-R RA.1513 [8] allows all services together to impair up to 5% of the data. As there could potentially be several constellations operating in each of the 137 MHz and 400 MHz bands, the overall received power must be considered. Therefore, the joint effect of HIBER, ARGOS KINEIS, MYRIOTA and Fleet at 400 MHz, as well as of SWARM and MYRIOTA , and ORBCOMM at 137 MHz was studied. This was done in the exact same way as for the individual constellations alone. The results are also included in Table 99. It should be noted that for the 400-MHz systems the median aggregated data loss is already close to 5% and that a relatively large fraction of the simulated runs violated the 5% threshold.

ANNEX 4: LIST OF REFERENCE

[1] Recommendation ITU-R M.1808: "Technical and operational characteristics of conventional and trunked land mobile systems operating in the mobile service allocations below 869 MHz to be used in sharing studies in bands below 960 MHz"

[2] Recommendation ITU-R P.452: "Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz"

[3] Recommendation ITU-R RA.769: "Protection criteria used for radio astronomical measurements"

[4] Recommendation ITU-R 1026-5: "Aggregate interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit"

[5] Recommendation ITU-R SA.1027-4: "Sharing criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit"

[6] Recommendation ITU-R S.1586: "Calculation of unwanted emission levels produced by a non-geostationary fixed-satellite service system at radio astronomy sites"

[7] Recommendation ITU-R M.1583: "Interference calculations between non-geostationary mobile-satellite service or radionavigation-satellite service systems and radio astronomy telescope sites"

[8] Recommendation ITU-R RA.1513: "Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis"

[9] ITU Radio Regulations, Edition of 2020

[10] ERC Decision (99)06: "The harmonised introduction of satellite personal communication systems operating in the bands below 1 GHz (S-PCS<1GHz), approved March 1999, Annex 1 and 2 amended on 20 November 2020. Annex 1 and 2 amended on 5 March 2021. Annex 2 amended on 2 July 2021.

[11] ERC Decision (99)05: "Free Circulation, Use and Exemption from Individual Licensing of Mobile Earth Stations.(S-PCS < 1 GHz)", approved March 1999

[12] ECTRA Decision (99)02: "Harmonisation of authorisation conditions in the field of Satellite Personal Communications Services (S-PCS) in Europe, operating in the bands below 1 GHz (S-PCS<1 GHz)", approved March 1999

[13] Report ITU-R SM.2091: "Studies related to the impact of active space services allocated in adjacent or nearby bands on radio astronomy service"

[14] Recommendation ITU-R RA.1631: "Reference radio astronomy antenna pattern to be used for compatibility analyses between non-GSO systems and radio astronomy service stations based on the epfd concept"

[15] Recommendation ITU-R SA.1165-1: "Technical characteristics and performance criteria for radiosonde systems in the meteorological aids service"

[16] Recommendation ITU-R RS.1263: "Interference criteria for meteorological aids operated in the 400.15-406 MHz and 1 668.4-1 700 MHz bands"

[17] ERC Report 87: "Sharing studies between MES and existing terrestrial services in the bands already allocated to the MSS below 1 GHz", approved June 2000

[18] Report ITU-R M.2359-0: "Protection of the 406-406.1 MHz band"

[19] ECC Decision (08)05: "The harmonisation of frequency bands for the implementation of digital Public Protection and Disaster Relief (PPDR) narrow band and wide band radio applications in bands within the 380-470 MHz range", approved June 2008 and latest amended March 2019

[20] ETSI EN 301 721: "Harmonised Standard for Mobile Earth Stations (MES) providing Low Bit Rate Data Communications (LBRDC) using Low Earth Orbiting (LEO) satellites operating below 1 GHz frequency band covering the essential requirements of article 3.2 of the Directive 2014/53/EU" requirements of article 3.2 of the Directive 2014/53/EU

[21] ECC Report 181: "Improving spectrum efficiency in SRD bands", approved September 2012

[22] ERC Report 25: "The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz."

[23] ITU-R Resolution 739: "Compatibility between the radio astronomy service and the active space services in certain adjacent and nearby frequency bands"

[24] Recommendation ITU-R M.1039: "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)"