CEPT ECC
Electronic Communications Committee

ECC Report 376

Technical report on small IoT transmit-only satellite terminals for land and maritime applications transmitting in the 5850-5875 MHz and 14.0-14.5 GHz band

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0 EXECUTIVE SUMMARY

Technological innovations in the areas of small antennas, signal processing and interference cancellation have opened up alternative solutions for Internet of Things (IoT) systems using existing C-band and Ku-band satellite capabilities.

The nature of many IoT applications is 'transmit-only', i.e. the IoT terminals might be implemented without simultaneously available bi-directional satellite connectivity. The IoT terminals under discussion have typical maximum duty cycles below 1% or in many cases even below 0.1% and are pre-designed to transmit in such a way as to limit the number of simultaneously transmitting devices. This reduces the opportunity for interference. The network operator must take specific measures to prevent accidental or synchronous events (e.g. at network start up, malfunctioning of IoT terminals) that would violate the statistical nature of this simultaneous interference. The combination of small antenna, low power, low duty cycle devices allows an opportunity for satellite-based IoT.

These satellite IoT systems are characterised by:

- Asynchronous access, i.e. no specific radio resource mechanisms are foreseen and terminals transmit asynchronously within an agreed aggregate statistically bounded envelope. This implies increased complexity at the gateway to decode overlapping transmissions;
- Receive capabilities (not necessarily via satellite) can be added for control purposes. This control feature would be used to set the configuration of the device and would be required as part of a reset condition to prevent devices operating beyond a limited period of activity (i.e. each device will only be authorised to operate for a limited period of time, instead of having a real-time bi-directional link for network control);
- IoT terminals with small transmitters with small antennas as a result of the terminal integration. Those terminals have little directionality and low gain values;
- Physical installation of the IoT terminal by users without any precise antenna alignment;
- Limited configuration of the terminal by the user, for example, pre-programmed user profiles;
- Limited provisioning procedures, for example, pre-programmed authentication credentials;
- Use of IoT terminals on platforms in motion, within Fixed Satellite Service (FSS) assignments.

These characteristics have required a new approach to accessing coexistence compared to conventional systems. Despite the low Equivalent Isotropically Radiated Power (*e.i.r.p.*) and low duty cycles, these IoT devices may pose an interference risk to other receivers (both terrestrial and satellite) when acting as a population of devices. This Report seeks to identify methods to assess both the opportunity for causing interference and methods that can be used to constrain and control interference to remain within acceptable limits. In particular, the statistical nature of the random transmissions needs to be accounted for and maintained below limits to satisfy both off axis *e.i.r.p.* limits and Active Device Density (ADD) to limit interference to victim receivers.

Based on Monte Carlo simulation methods, the probability of exceeding the interference threshold not more than 20% of time for different ADD, *e.i.r.p.* values and services have been performed for the frequency ranges subject to this Report:

- 5850-5875 MHz: The ADD required to not exceed the interference threshold more than 20% of the time for different *e.i.r.p.* values, and different applications are shown in Table 1;
- 14.0-14.25 GHz (lower Ku-band): Existing ECC Decisions support deployment with no restriction on movement or need for individual licensing of terminals in the band 14.0-14.25 GHz. This frequency range is not allocated to terrestrial service and coexistence is therefore not an issue;
- 14.25-14.5 GHz (upper Ku-band): The ADD required to not exceed the interference threshold more than 20% of the time for different *e.i.r.p.* values, and different applications are shown in Table 2.

Table 1: ADD (per km²) required depending on the *e.i.r.p.* of the device and the considered victim system

e.i.r.p. of the device	23 dBm	26 dBm	29 dBm	32 dBm	35 dBm	38 dBm
Broadband Fixed Wireless Access (BFWA)	0.02	0.01	0.005	0.003	0.002	0.0009
Intelligent Transport System (Road Side Unit) - (ITS (RSU))	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	0.09
Intelligent Transport System (On Board Unit) - (ITS (OBU))	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1
Mobile Broadband Radio (terrestrial IoT) - (MBR (T))	> 0.1	> 0.1	0.07	0.04	0.02	0.006
MBR (Maritime IoT) - (MBR(M))	0.002	0.001	0.0007	0.0005	0.0003	0.0002
MBR (M) with 2 km isolation	0.003	0.002	0.002	0.0006	0.0004	0.0003

Table 2: ADD (per km²) required depending on the *e.i.r.p.* of the device and the considered victim system

e.i.r.p. of the device	23 dBm	26 dBm	29 dBm	32 dBm	35 dBm	38 dBm
FS_37	0.003	0.002	0.001	0.0009	0.0007	0.0005
FS_49	0.005	0.004	0.003	0.002	0.001	0.0008

Based on the statistical evaluation method developed in this Report the sharing and compatibility assessment can be summarised as:

- C-band in the range 5850-5875 MHz: IoT devices with Active Device Densities of 0.001 and with powers of up to 35 dBm could conservatively be deployed with no restrictions on their movement in the vicinity of any potential terrestrial victims. Terrestrial deployments with higher ADD could be permitted with lower *e.i.r.p.* values. Higher *e.i.r.p.* values (up to 38 dBm) would not cause interference if their ADD in the vicinity of a victim receiver is less than 0.001. Maritime terminals in the vicinity of MBR victims can operate with *e.i.r.p.* values of less than 32 (resp. 38) dBm, ADD of less than 0.0005 (resp. 0.0002) respectively, with no minimum separation distance. Constraining deployment by a new metric (Active Device Density) could be difficult to enforce. ADD limitations required to protect potential victim systems are less restricting on device deployment than considering limitations on the aggregate number of devices in order to conform to an off-axis *e.i.r.p.* density mask for small IoT terminals associated to a unique satellite network. Since satellite operators should ensure compliance with this off-axis *e.i.r.p.* density mask, enforcement of ADD limits in order to protect terrestrial victims can (and would, in effect) be performed at the system level required to limit interference to GSO networks. With respect to road tolling systems mentioned in Annex 2, the scenario of interference would be related to small IoT devices transmitting in C-band mounted on vehicles. It was discussed that interruption of barrier operation of road tolling of more than 7 s was considered unacceptable to road users, the issue could be solved by ensuring that the unwanted power emission of a small IoT device with a transmission duration of more than 7 s in C-band remains below -65 dBm/MHz in 5795-5815 MHz;
- Ku-band in the range 14.0-14.25 GHz (lower Ku-band): Existing ECC Decisions support deployment with no restriction on movement or need for individual licensing of terminals in the band 14.0-14.25 GHz. This frequency range is not allocated to terrestrial service and coexistence is therefore not an issue. Maritime operation of these devices will not cause any interference to the terrestrial applications used in CEPT countries and the constraints of ITU-R Resolution 902 (Rev.WRC-23) (to protect terrestrial systems) do not apply. Some non-CEPT in the vicinity of non-CEPT countries may require coordination for use of small IoT terminals. Aeronautical use of these small IoT terminals within CEPT countries would not pose any interference risk, though coordination may be required where interference could be a risk to non-CEPT countries deploying FS services. Off-axis limits contained in Recommendation ITU-R S.524-9 [3] still apply;
- Ku-band in the range 14.25-14.5 GHz: There is the possibility to allow low ADD, low *e.i.r.p.* IoT terminals in the upper Ku-band. Neglecting any additional losses due to the nature of the terrain within a 750 km radius, IoT deployments with ADD values of 0.0001 are unlikely to exceed the interference threshold at FS

receivers. However, such interference could impact RAS or some FS systems. It is worth noting that the active duration of an IoT device (with the necessarily low data rate) is longer than the typical frame length of a FS link and that the FS links typically support carrier grade communication links. For these carrier grade links prolonged interference is problematic even if the probability of such an event is low. It is worth noting that no configuration characteristics were provided for this band.

A list of device characteristics proposed for use by device manufacturers in both C-band and Ku-band (in the range 14.0-14.25 GHz) is provided. It is proposed that any initial deployment is restricted to these device types. The permitted configurations can be reviewed if there is sufficient demand.

TABLE OF CONTENTS

0 Executive summary 2

1 Introduction 7

2 System characteristics and parameters 9
2.1 Reference systems 9
2.1.1 General characteristics 9
2.1.2 System A 9
2.1.3 System B 10
2.1.4 System C 10
2.1.5 System D 10
2.2 Transmit characteristics 10
2.2.1 Transmit-only nature of the IoT terminal 10
2.2.2 Transmit *e.i.r.p.* and bandwidth 10
2.2.3 Low duty cycle 11

3 Services and applications in the bands under study 12
3.1 5850-5875 MHz 12
3.1.1 Broadband Fixed Wireless Applications (BFWA) 13
3.1.2 Fixed Satellite Service (FSS) (Earth-to-space) 13
3.1.3 Industrial, Scientific and Medical (ISM) 14
3.1.4 Intelligent Transport Systems (ITS) 14
3.1.5 Mobile Broadband Radio (MBR) 14
3.1.6 Non-specific Short Range Devices (SRDs) 14
3.1.7 Radiodetermination applications - Tank Level Probing Radar (TLPR) 14
3.1.8 Wireless Industrial Applications (WIA) 15
3.2 14.0-14.5 GHz 15
3.2.1 Fixed Satellite Service (FSS) (Earth-to-space) 17

4 Small terminal interference assessment in the band 5850-5875 MHz 18
4.1 Minimum Coupling Loss calculations to protect services 18
4.2 Monte Carlo Interference assessment Methodology 19
4.3 Monte Carlo Interference assessment Results 20
4.4 Interference impact and consequences for IoT deployment 25

5 Small terminal interference assessment in the band 14.0-14.5 GHz 26
5.1 Minimum Coupling Loss calculations to protect services 26
5.2 Application of the MC Interference methodology to FS in the 14.25-14.5 GHz band 26
5.3 Interference impact and consequences for IoT deployment 28

6 Configurations Intended for use 29

7 Conclusion 31

ANNEX 1: Off-Axis limits for system D 34

ANNEX 2: COnsiderations on Road Tolling - Transport and Traffic Telematics (TTT) 35

ANNEX 3: List of References 36

LIST OF ABBREVIATIONS

Abbreviation	Explanation
ADD	Active Device Density per square kilometre
BFWA	Broadband Fixed Wireless Access
CEPT	European Conference of Postal and Telecommunications Administrations
DFS	Dynamic Frequency Selection
ECC	Electronic Communications Committee
e.i.r.p.	Equivalent Isotropically Radiated Power
ESIM	Earth Stations in Motion
E-SSA	Enhanced-Spread Spectrum Aloha
FSPL	Free Space Path Loss
FS	Fixed Service
FSS	Fixed Satellite Service
FWA	Fixed Wireless Access
GNSS	Global Navigation Satellite System
IoT	Internet of Things
iRSS	Interference Received Signal Strength
ISM	Industrial, Scientific and Medical
ITS	Intelligent Transport System
M2M	Machine to Machine
MBR	Mobile Broadband Radio
MCL	Minimum Coupling Loss
NCF	Network Control Function
OBU	On Board Unit
PER	Packet Error Rate
QAM	Quadrature Amplitude Modulation
RAS	Radio Astronomy Service
RSU	Road Side Unit
SIMI	Satellite Interrogation Multiple Access
SRD	Short Range Device
TLPR	Tank Level Probing Radar
TS-UNB	Telegram Splitting Ultra Narrow Band
TTT	Transport and Traffic Telematics
WIA	Wireless Industrial Applications

1 INTRODUCTION

Technological innovations in the areas of small antennas, signal processing and interference cancellation have opened up alternative solutions for IoT systems using existing C-band and Ku-band satellite capabilities.

The main applications of M2M/IoT operation via satellite are described in ECC Report 305 [1]. The various companies seeking to implement M2M/IoT systems have not always succeeded in obtaining access to spectrum or have chosen not to invest in new space infrastructure: they prefer to use existing space segment resources combined with new technological developments which allow to offer similar services.

The nature of many IoT applications is "transmit-only", i.e. the IoT terminals might be implemented without simultaneously available bi-directional satellite connectivity. This Report focuses on such transmit-only IoT applications. The overall system is depicted in Figure 1, and could consist of a population of hundreds of thousands of IoT terminals, existing in-orbit satellites, and a receiving gateway station.

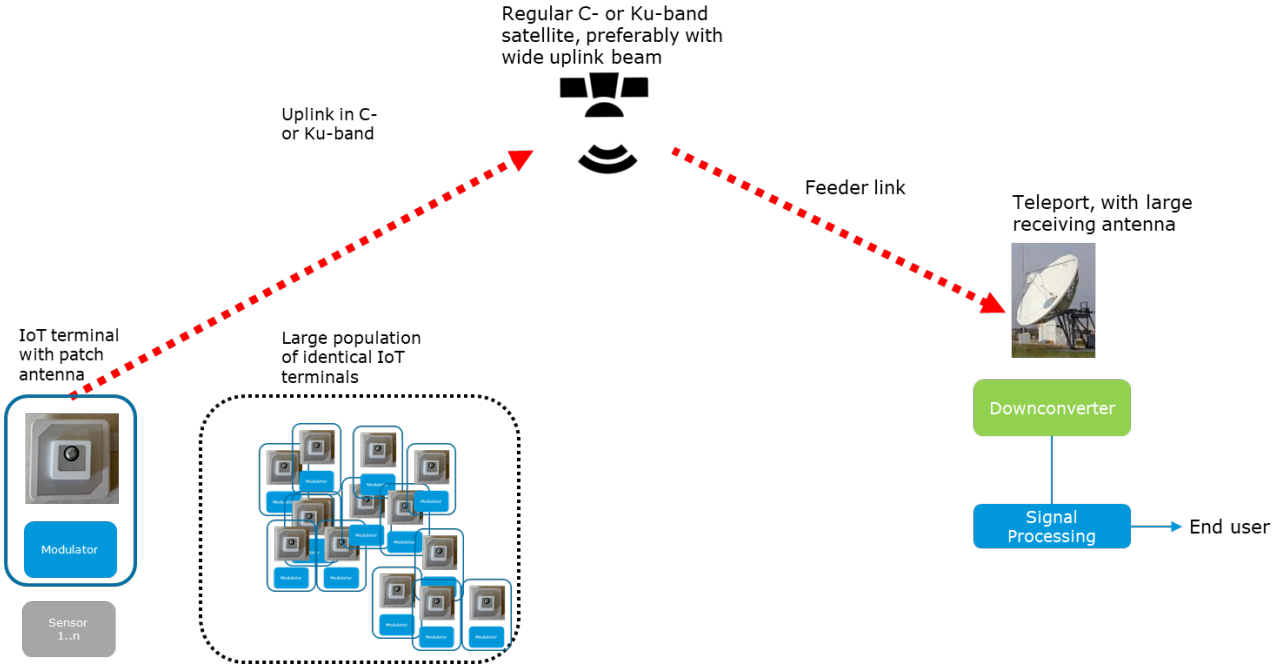


Figure 1: Architecture of proposed system

The low *e.i.r.p.* of uplink terminals, typically approximately 30 dBm, leads to limited SNR values in the reception, i.e. lower than -20 dB. Nevertheless, these low SNR values are sufficient to demodulate and decode the received messages, thanks to optimised signal processing algorithms in the receiver.

The size of the terminal antennas is typically not larger than 5*5 cm (C-band) or 4*4 cm (Ku-band). The small size of the terminal antennas leads to gain values typically lower than 5 dBi. The terminals are in the majority of the cases transmit-only. The receiving end is implemented using regular teleport infrastructure, i.e. benefiting from large receiving antennas, and therefore higher gain values. Example antennas demonstrating the small IoT device sizes are shown in Figure 2.

The IoT terminals under discussion have duty cycles below 1% and are pre-designed to transmit in such a way as to limit the number of simultaneously transmitting devices. This reduces the opportunity for interference. The network operator must take specific measures to prevent accidental or synchronous events (e.g. at network start up, malfunctioning of IoT terminals) that would violate the statistical nature of this simultaneous interference. The combination of small antenna, low power, low duty cycle devices allows an opportunity for satellite-based IoT.



Figure 2: Example of C-band and Ku-band antennas

2 SYSTEM CHARACTERISTICS AND PARAMETERS

2.1 REFERENCE SYSTEMS

This section describes four IoT satellite systems which are under development, and which intend to use very small C-band or Ku-band terminals.

2.1.1 General characteristics

The satellite IoT systems proposed are characterised by:

- Asynchronous access, i.e. no specific radio resource mechanisms are foreseen and terminals transmit asynchronously within an agreed aggregate statistically bounded envelope. This implies increased complexity at the gateway to decode overlapping transmissions;
- Receive capabilities (not necessarily via satellite) can be added for control purposes. This control feature would be used to set the configuration of the device and would be required as part of a reset condition to prevent devices operating beyond a limited period of activity (i.e. each device will only be authorised to operate for a limited period of time, instead of having a real-time bi-directional link for network control);
- IoT terminals with small transmitters with small antennas as a result of the terminal integration. Those terminals have little directionality and low gain values;
- a physical installation of the IoT terminal by users without any precise antenna alignment;
- Limited configuration of the terminal by the user, for example, pre-programmed user profiles;
- Limited provisioning procedures, for example, pre-programmed authentication credentials;
- Use of IoT terminals on platforms in motion, within Fixed Satellite Service (FSS) assignments.

A driving constraint for all these IoT systems is that the number of simultaneously transmitting terminals should be sufficiently small that the off-axis *e.i.r.p.* density mask of Recommendation ITU-R S.524-9 [3] is observed. The number of IoT devices transmitting simultaneously at any instant will be random (with a Poisson distribution). The overall population of devices and their configurations should be managed by the network operators to ensure that the aggregate transmission level does not exceed the off-axis limits beyond an unacceptable degree. The number of devices permitted to operate depends upon their *e.i.r.p.*, transmission bandwidth (including spreading factor, or frequency hopping mechanism), deployment density, duty cycle and satellite G/T. This results in a wide range of different system configurations that can be deployed. Some examples are described below to indicate the main differences and initial configurations intended for use by device manufacturers are listed in section 6.

2.1.2 System A

This system intends to use evolutions of the E-SSA/SIMI [2] air interfaces, which exploits spreading of the signal and uses successive interference cancellation. Such waveforms – that might use spreading factors from 256 up to 512 – can be decoded up to a C/N of -26 to -23 dB, while still delivering 26 to 52 bps.

IoT terminal characteristics are assumed to be 25 dBm Tx power and a 5 dBi circular polarised antenna, leading to an *e.i.r.p.* of 30 dBm. Assuming a regular GSO C-band satellite G/T of -5 dB/K and using only 100 kHz of bandwidth would lead to a C/N of -25 dB.

Considering the above constraints, and permitting aggregated exceedance of the off-axis mask less than 0.01% of time, if one assumes an application where each IoT terminal transmits every hour some identification and a global navigation satellite system (GNSS) position coded in a total of 8 bytes, one could serve approximately 13000 terminals.

If one assumes another application in which these IoT terminals transmit-only once per day their position, one could serve a population of 300000 terminals/100 kHz. Above systems performance numbers suggest that the number of IoT terminals that can be supported for an application sending 8 bytes every hour is about 13000 in 100 kHz, or 300000 terminals per MHz.

2.1.3 System B

System B uses as assumption the use of regular C-band satellites with global, regional or spotbeams having a G/T of -4.7, 2.1 or 5.6 dB/K respectively.

For the IoT terminal, a simple patch antenna or a simplified 18 or 25 element patch antenna is assumed, leading to an overall *e.i.r.p.* of 23, 34 or 37 dBm respectively.

Simulations – in which the standardised TS-UNB protocol ETSI TS 103 357 [4] is used and a global C-band beam – lead to an overall system capacity of 102 messages/Hz/day, where an IoT terminal transmits on average 10 messages per day.

Such a system could then accommodate about 10 million terminals in 1 MHz.

2.1.4 System C

System C uses the methods described in ETSI EN 301 443 [5] and ETSI TS 102 721 [6], in which an IoT terminal is assumed with an *e.i.r.p.* of 23 dBm, assuming a regular GSO C-band satellite with a G/T of -5 dB/K. This method allows to distinguish between hundreds of simultaneous transmissions while using a C-band patch antenna with an *e.i.r.p.* of 23 dBm.

The principle of this system has also been demonstrated over Ku-band, in which IoT terminals send their GNSS position coded in 40 bits every hour at 10 bit/s, with an *e.i.r.p.* of 23 dBm. In 20 kHz of bandwidth, 2700 IoT terminals could be accommodated with this traffic profile. In 1 MHz one could then accommodate 140000 terminals.

2.1.5 System D

System D uses regular Ku-band satellites having a typical G/T of 4.0 dB/K and exploits Golden Modulation technology, which has been introduced in [7]. It operates over a single 125 kHz channel or a set of elementary 125 kHz channels.

Simple low dimension 3D antenna (3 cm diameter) is assumed at the terminal side.

System D can support more than 30 million messages per day in a 1 MHz bandwidth, which would be equivalent to 1.25 million terminals per MHz if these terminals transmitted hourly. Precision dimensioning (in terms of devices per MHz) depends upon the configuration of the set of deployed terminals, and the protection required to protect both terrestrial receivers and to operate within the off-axis emission mask to protect other satellite systems. Further details on System D sharing within the spectrum environment can be found in Annex 1.

2.2 TRANSMIT CHARACTERISTICS

2.2.1 Transmit-only nature of the IoT terminal

The nature of many IoT applications is 'transmit-only', i.e. the IoT terminals are intended to be implemented without simultaneously available bi-directional satellite connectivity.

Specific measures should be designed such that no accidental or synchronous events (e.g. at network start up, malfunctioning of IoT terminals) occur that would violate the statistical nature of the IoT transmissions.

2.2.2 Transmit *e.i.r.p.* and bandwidth

It is noted that the transmit *e.i.r.p.* is constrained to ensure that aggregate off-axis *e.i.r.p.* does not exceed the limits to protect FSS. The power and bandwidth of the four systems identified in section 2.1 to be considered in sharing and compatibility studies are shown in Table 3.

Table 3: Technical characteristics for very small IoT terminals in 5850-5875 MHz and 14.00-14.25 GHz bands

	System A	System B	System C	System D
f1_Tx (MHz)	5850-5875	5850-5875	5850-5875	
f2_Tx (GHz)	14.00-14.25	14.00-14.25	14.00-14.25	14.00-14.25
f2_Rx (GHz)				10.95-12.75
Indicative bandwidth (kHz) (Note 1)	50	50	20	125
Antenna gain (dBi)	5	9	5	8
Tx (dBm)	25	14, 25 or 28	23	30
e.i.r.p. (dBm)	30	23, 34 or 37	28	38
Note 1: This bandwidth is indicative only, as provided by the system proponents, and could change in the future. Nevertheless, this would have no impact on the results of the compatibility studies because full frequency overlap was assumed.				

2.2.3 Low duty cycle

Typically, these very small IoT terminals will be actively transmitting for short durations and for a limited number of times per day - resulting in a low duty cycle. For example, with an *e.i.r.p.* of 28 dBm, a Ku-band device transmitting 30 bytes, 12 times per day has a duty cycle of 0.0001 (or 0.01%). Neglecting the off-axis *e.i.r.p.* density constraint, up to 2.3 million devices could be supported in the channel bandwidth of 2MHz (Type_9_KL, from Table 14). However, the off-axis *e.i.r.p.* density constraint limits the number of simultaneously active terminals to less than 80, meaning that less than 0.8 million devices could be supported in 2 MHz. The density of these active devices (the Active Device Density), if spread across the 46 CEPT countries would be less than 0.00001, or less than 0.00022 if the population were concentrated in Germany[1]. The relevance and utility of these active device densities will become clearer when the interference impact is assessed.

[1] In these examples and in this Report, the land areas of 46 CEPT member states, EU27 and Germany are approximated to be 6.5M, 4.0M and 350.0K km^2 respectively.

3 SERVICES AND APPLICATIONS IN THE BANDS UNDER STUDY

3.1 5850-5875 MHZ

Table 4: Allocations in the frequency range 5850-5925 MHz (ITU Radio Regulations, Article 5, Edition 2024)

Region 1	Region 2	Region 3
5 850-5 925 FIXED FIXED-SATELLITE (Earth-to-space) MOBILE 5.150	**5 850-5 925** FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Amateur Radiolocation 5.150	**5 850-5 925** FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Radiolocation 5.150

5.150 The following bands:

13 553-13 567 kHz	(centre frequency 13 560 kHz),
26 957-27 283 kHz	(centre frequency 27 120 kHz),
40.66-40.70 MHz	(centre frequency 40.68 MHz),
902-928 MHz	in Region 2 (centre frequency 915 MHz),
2 400-2 500 MHz	(centre frequency 2 450 MHz),
5 725-5 875 MHz	(centre frequency 5 800 MHz), and
24-24.25 GHz	(centre frequency 24.125 GHz)

are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. 15.13.

It is worth noting Article 15.13: "Administrations shall take all practicable and necessary steps to ensure that radiation from equipment used for industrial, scientific and medical applications is minimal and that, outside the bands designated for use by this equipment, radiation from such equipment is at a level that does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations."

In addition, ERC Report 25 [9], identifies the harmonisation measure applying to Non-specific SRDs, Radiodetermination applications and Wireless Industrial Applications (WIA) as ERC Recommendation 70-03 [8] which "sets out the CEPT position on common spectrum which can be designated for Short Range Devices (SRD) applications and is a reference document to assist in preparing national spectrum regulations." In the introduction to ERC Recommendation 70-03, it is noted that "The term “Short Range Device” (SRD) is intended to cover radio equipment which has a low capability to cause interference. The use of SRD is usually covered by general / non-exclusive authorisations on a non-protected, non-interference basis. SRD applications are not a “radiocommunication service” as defined by the ITU Radio Regulations in Article 1" and in Considering b: "that in general SRD cannot claim protection from interference caused by radiocommunication services as defined by ITU".

Based on this, Industrial, Scientific and Medical (ISM) should not cause, and SRDs (including WIA) cannot claim protection from, interference from devices operating in this band used for a radiocommunication service.

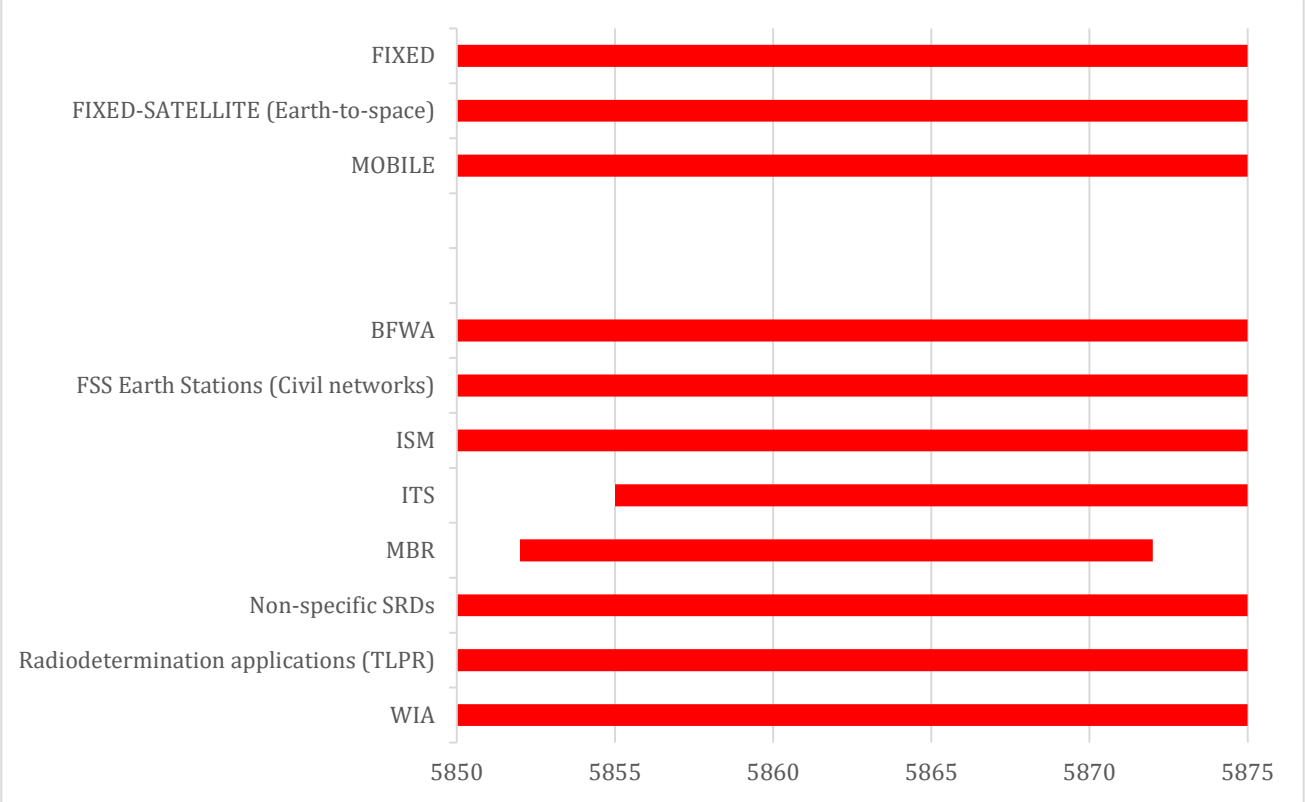


Figure 3: Allocations and Applications identified in ERC Report 25 in the frequency range 5850 - 5875 MHz

Figure 3 shows the allocations and applications in the range 5850-5875 MHz from ERC Report 25 [9]. In the following sections, the key findings of a range of ECC deliverables for the in-band applications identified above are summarised.

3.1.1 Broadband Fixed Wireless Applications (BFWA)

In some countries BFWA operates as a radio service (e.g. Fixed Service), but in others as a de facto non-protected radio application as it is for other radio applications which are exempted from individual licences. Different approaches are used based on ECC Recommendation (06)04 [10]:

- a majority of countries have implemented BFWA using exemption from individual licensing;
- some countries use registration/ notification procedures (light licensing) where the user provides location details about the central station or even client location.

ECC Report 068 [11] describes the technical characteristics and architectures of a range of different Fixed Wireless Access (FWA) systems used in compatibility studies in the band 5725-5875 MHz. ECC Report 259 [12] post-dates ECC Report 068 and identified BFWA characteristics for co-existence with Maritime Broadband Radio (MBR) and provides parameters in Table 5 which are used in this Report for co-existence assessment. Based on these, an antenna height of 50 m will be considered, a main lobe gain of 17 dBi (sector antenna) and a maximum (in-band) interference level in the receiver of -95 dBm (based on 64 QAM, 3% Packet Error Rate (PER)).

3.1.2 Fixed Satellite Service (FSS) (Earth-to-space)

In Region 1, FSS is a primary service in the lower adjacent band. The band 5850-5925 MHz is allocated in Regions 1, 2 and 3, and according to ECC Report 206 [13] is part of the heavily used FSS global uplink band with major operators operating in the upper portion of the band.

As previously noted, the transmit IoT *e.i.r.p.* will be constrained to ensure that aggregate off-axis *e.i.r.p.* density does not exceed the limits to protect FSS, as defined in of Recommendation ITU-R S.524-9 [3]. It should be noted in this context that the mask defined in Recommendation ITU-R S.524-9 applies to individual earth stations equipment of which a considerable number is in use across Europe.

3.1.3 Industrial, Scientific and Medical (ISM)

As noted above, RR No. 5.150 applies, as do the provisions of RR No.15.13.

3.1.4 Intelligent Transport Systems (ITS)

ECC Decision (08)01 [14] identified compatibility conditions for safety-related ITS systems in the band 5875-5935 MHz[2]. ECC Report 101 [15] and ECC Report 228 [16] consider compatibility issues with ITS in the band 5855-5925 MHz with co-channel and adjacent channel services respectively.

ECC Decision (08)01 decided that 5875-5925 MHz be designated on a non-exclusive basis for safety related ITS for road and rail ITS. Road ITS has priority over urban rail ITS in 5875-5915 MHz, and urban rail ITS priority over road ITS in 5915-5925 MHz. In addition, 5925-5935 MHz is designated for Urban Rail ITS (on a non-exclusive basis).

ITS use in the band 5850-5875 MHz is not designated for safety-related communications. For the case of co-channel interference with ITS in the band 5855-5875 MHz, a maximum allowable interference at the ITS receiver of -88 dBm can be used, with a required C/I of 6 dB. Though the Road Side Unit (RSU) and the On-Board Units (OBU) use different antennas, the receiver characteristics are the same and the same value of maximum allowable interference will be used for both.

3.1.5 Mobile Broadband Radio (MBR)

MBR is a maritime mobile radio communication system providing broadband radio links between platforms and vessels as well as between vessels, engaged in coordinated off-shore activities. ECC Report 259 identifies the results of sharing and compatibility studies between MBR in the 5850-5900 MHz frequency band and other systems. This Report concludes that separation distances on the order of 100 km are needed for mutual protection with BFWA, GSO FSS, and land and maritime radar and fixed services with an MBR *e.i.r.p.* of 32 dBW. An antenna gain of 24 dBi, and the interference threshold at the receiver is -93 dBm, after allowing for a minimum C/I of 10 dB. ERC Recommendation (17)03 [18] provides guidance for the harmonised use and coordination for MBR systems on board ships and off-shore platforms.

3.1.6 Non-specific Short Range Devices (SRDs)

Under ERC Recommendation 70-03, annex 1 [8], CEPT countries allow use of generic non-specific short range devices up to 25mW in the band 5725-5875 MHz, without Dynamic Frequency Selection (DFS). In addition, there is no duty cycle restriction or bandwidth restriction for those SRDs. This means that there is already a considerable population of non-application specific devices based on 25 mW in this part of the C-band under consideration. SRDs cannot claim protection from other transmitters. The SRD regulation for this part of the C-band was defined decades ago and followed different consideration in which no ADD considerations were applied.

3.1.7 Radiodetermination applications - Tank Level Probing Radar (TLPR)

ERC Recommendation 70-03 identifies the maximum *e.i.r.p.* that can be used for TLPR radiodetermination applications to be less than -41.3 dBm/MHz *e.i.r.p.* outside of the enclosed test tank structure. In addition, TLPR have strict rules on the direction of their intended emissions (normally down, towards the ground). As an SRD, no receiver characteristics are provided and TLPR cannot claim protection from other transmitters.

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[2] ECC Decision (08)01 states that the operation of the non-safety frequency band for ITS is considered to be on a non-protected and non-interference basis.

3.1.8 Wireless Industrial Applications (WIA)

ECC Report 206 [13] examines the compatibility between Wireless Industrial Applications and other systems in the band 5725-5875 MHz. These WIA devices have a maximum *e.i.r.p.* of 400 mW and are limited to indoor use. This is intended to be similar to outdoor use of 25 mW with a wall penetration loss. WIA are used to support frequent, low latency, small packets with terminal densities ranging from 0.001 to 3 per m^2.

3.2 14.0-14.5 GHZ

Table 5: Allocations in the frequency range 14-14.5 GHz (ITU Radio Regulations, Article 5, Edition of 2024)

<table>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td colspan="3">14-14.25
FIXED-SATELLITE (Earth-to-space) 5.457A 5.457B 5.484A 5.484B 5.506 5.506B
RADIONAVIGATION 5.504
Mobile-satellite (Earth-to-space) 5.504B 5.504C 5.506A
Space research
5.504A 5.505</td></tr>
<tr><td colspan="3">14.25-14.3
FIXED-SATELLITE (Earth-to-space) 5.457A 5.457B 5.484A 5.484B 5.506 5.506B
RADIONAVIGATION 5.504
Mobile-satellite (Earth-to-space) 5.504B 5.506A 5.508A
Space research
5.504A 5.505 5.508</td></tr>
<tr><td>14.3-14.4
FIXED
FIXED-SATELLITE (Earth-to-space) 5.457A 5.457B 5.484A 5.484B 5.506 5.506B
MOBILE except aeronautical mobile
Mobile-satellite (Earth-to-space) 5.504B 5.506A 5.509A
Radionavigation-satellite
5.504A</td><td>14.3-14.4
FIXED-SATELLITE (Earth-to-space) 5.457A 5.484A 5.484B 5.506 5.506B
Mobile-satellite (Earth-to-space) 5.506A
Radionavigation-satellite
5.504A</td><td>14.3-14.4
FIXED
FIXED-SATELLITE (Earth-to-space) 5.457A 5.484A 5.484B 5.506 5.506B
MOBILE except aeronautical mobile
Mobile-satellite (Earth-to-space) 5.504B 5.506A 5.509A
Radionavigation-satellite
5.504A</td></tr>
<tr><td colspan="3">14.4-14.47
FIXED
FIXED-SATELLITE (Earth-to-space) 5.457A 5.457B 5.484A 5.484B 5.506 5.506B
MOBILE except aeronautical mobile
Mobile-satellite (Earth-to-space) 5.504B 5.506A 5.509A
Space research (space-to-Earth) 5.504A</td></tr>
<tr><td colspan="3">14.47-14.5
FIXED
FIXED-SATELLITE (Earth-to-space) 5.457A 5.457B 5.484A 5.506 5.506B
MOBILE except aeronautical mobile
Mobile-satellite (Earth-to-space) 5.504B 5.506A 5.509A
Radio astronomy 5.149 5.504A</td></tr>
</table>

Selected footnotes of RR Article 5, relevant to use of Ku-band for FSS IoT terminals in CEPT countries:

5.149 In making assignments to stations of other services to which the bands: … 14.47-14.5 GHz .. are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29). (WRC-07)

5.504A In the band 14-14.5 GHz, aircraft earth stations in the secondary aeronautical mobile-satellite service may also communicate with space stations in the fixed-satellite service. The provisions of Nos. 5.29, 5.30 and 5.31 apply. (WRC-03).

5.504B Aircraft earth stations operating in the aeronautical mobile-satellite service in the frequency band 14-14.5 GHz shall comply with the provisions of Annex 1, Part C of Recommendation ITU-R M.1643-0, with respect to any radio astronomy station performing observations in the 14.47-14.5 GHz frequency band located on the territory of Spain, France, India, Italy, the United Kingdom and South Africa. (WRC-15).

5.506A In the frequency band 14-14.5 GHz, ship earth stations with an equivalent isotropically radiated power (*e.i.r.p.*) greater than 21 dBW shall operate under the same conditions as earth stations located on board vessels, as provided in Resolution 902 (Rev.WRC-23). This footnote shall not apply to ship earth stations for which the complete Appendix 4 information has been received by the Bureau prior to 5 July 2003. (WRC-23)5.506B Earth stations located on board vessels communicating with space stations in the fixed-satellite service may operate in the frequency band 14-14.5 GHz without the need for prior agreement from Cyprus and Malta, within the minimum distance given in Resolution 902 (Rev.WRC-23) from these countries. (WRC-23).

5.508 Additional allocation: in Germany, France, Italy, Libya, North Macedonia and the United Kingdom, the frequency band 14.25-14.3 GHz is also allocated to the fixed service on a primary basis. (WRC-19).

Figure 4 shows the allocations and applications identified in ERC Report 25 [9] in the specific sub-bands of interest.

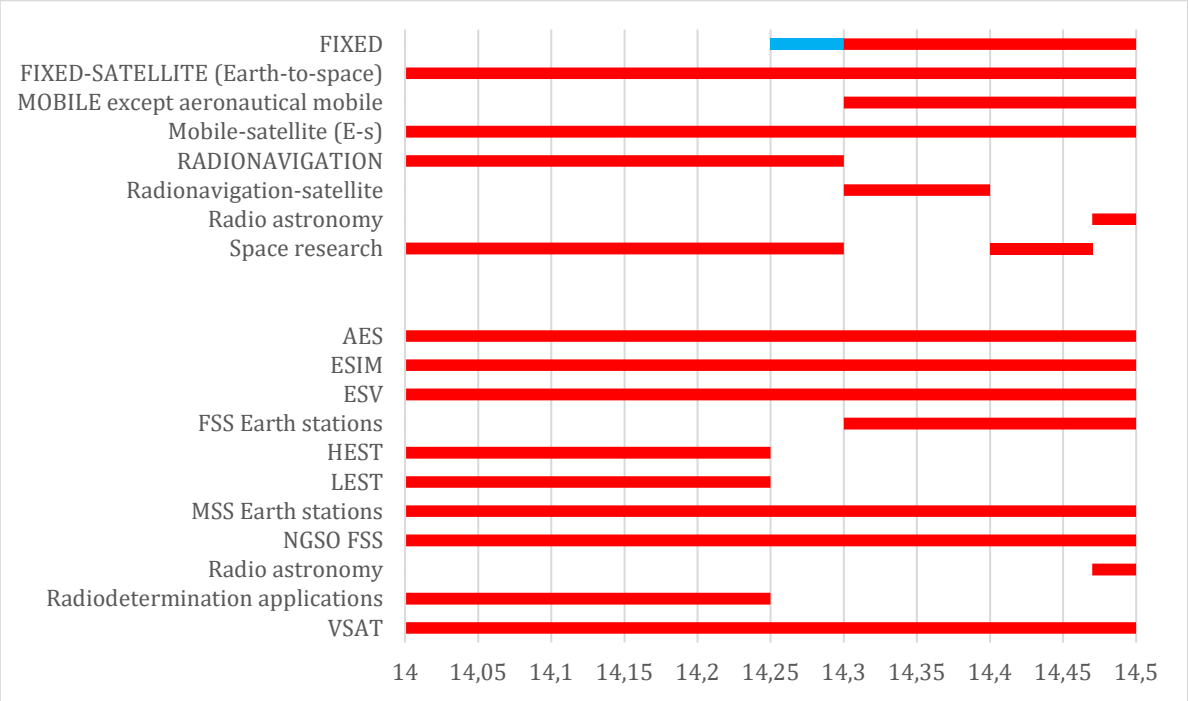


Figure 4: Allocations and Applications identified in ERC Report 25 in the frequency range 14.0 - 14.5 GHz (note inclusion of the footnote allocation for FS between 14.25 and 14.3 GHz)

3.2.1 Fixed Satellite Service (FSS) (Earth-to-space)

It is noted that in the range 14.0-14.25 GHz, Fixed Satellite Service is the only primary service used within CEPT countries. In the range 14.25-14.5 GHz, the Fixed Service is allocated on a primary basis, and Radio Astronomy Service (RAS) is allocated on a secondary basis in 14.47-14.5 GHz (for formaldehyde spectral line assessment).

ECC Report 271 [17] examines compatibility and sharing studies related to NGSO satellite systems in the bands 10.7-12.75 GHz (space-to-Earth) and 14-14.5 GHz (Earth-to-space). After a band-by-band assessment, this report reasons why further consideration of Space Research Service and Radionavigation Service can be neglected. This report then details relatively large protection areas to protect the limited number of RAS and FS locations that are operational. The methods provided in ECC Report 271 are a template for identifying conditions for coexistence with FS and RAS in the band 14.25-14.5 GHz.

ECC Report 271 identifies a range of different antenna gains that can be used (in range of 37-49 dBi), with a range of channel bandwidths. A S/N ratio of 30 dB has been used and an I/N of -10 dB has been used in the simulations with antenna gains covering the range provided. ECC Report 271 notes that the 49dBi gain has been used to assess coexistence criteria for short term interference impact.

ECC Decision 18(04) [26] has authorised harmonised use, exemption from individual licensing and free circulation of land based Earth Stations in Motion (ESIM) operating with GSO FSS satellite networks using 14.0-14.5 GHz band, based on inter alia compliance with operational requirements in its Annex 3 and, additionally, with implementation of protection zones for 14.25-14.50 GHz. ECC Decision (06)03 [27] provides for the exemption from individual licensing of high *e.i.r.p.* satellite terminals in the band 14.0-14.25 GHz subject, inter alia, with conformance to EN 301 428 [29]. Hence, existing Decisions support deployment with no restriction on movement or need for individual licensing of terminals in the band 14.0-14.25 GHz.

ITU Resolution 902 (Rev.WRC-23) [28], imposes restrictions on conventional FSS Earth Stations on Vessels in order to protect terrestrial systems and to avoid a high coordination burden of administrations. These restrictions include provisions for a minimum antenna size, a maximum *e.i.r.p.* spectral density of 12.5 dB (W/MHz) towards the horizon, and minimum off-shore distances for ESV operation without coordination.

ECC Decision (05)10 [31] authorises the free circulation and use of Earth Stations on board Vessels operating in fixed satellite service networks in the frequency bands 14-14.5 GHz, subject to the conditions of ITU-R Resolution 902 (Rev.WRC-23). It is noted that whilst geographical restrictions are noted for the band 14.25 - 14.5GHz, these are not applied to the band 14.0-14.25 GHz.

Aircraft earth stations operating in the aeronautical mobile-satellite service are not restricted in the range 14.0 - 14.25 GHz. ECC Decision (05)11 [32] authorises the free circulation and use of Aircraft Earth Stations (AES) in the frequency band 14.0-14.5 GHz bands, and some other bands, subject, inter alia, to reporting conditions and a maximum *e.i.r.p.* of 50 dBW.

From the above, it can be established that in the frequency range 14.0-14.25 GHz deployment of IoT devices should not be an issue on land, in maritime or in aeronautical environments.

4 SMALL TERMINAL INTERFERENCE ASSESSMENT IN THE BAND 5850-5875 MHZ

4.1 MINIMUM COUPLING LOSS CALCULATIONS TO PROTECT SERVICES

An initial assessment of the potential for co-channel interference with BFWA, MBR and ITS services can be performed using the following parameters (extracted from the previous ECC studies identified in section 3.1).

A single IoT transmitter is assumed to be used, with a co-channel *e.i.r.p.* of 30 dBm (Tx power of 25 dBm, with a 5 dBi quasi-omnidirectional antenna), a transmit bandwidth of 1 MHz[3], and a nominal antenna height of 1.5 m. The victim system receiver characteristics and the resulting path losses and Free Space Path Loss Distances (FSPL) are shown in Table 6.

Table 6: Basic system parameters used in MCL analysis

System name	Peak Antenna Gain (dBi)	Nominal Antenna Height (m)	Bandwidth (MHz)	Frequency (GHz)	Interference threshold at receiver (dBm)	Minimum Path Loss (dB)	FSPL distance (km)
BFWA (Note 1)	17	50	20	5.8625	-95.0	142.0	49.7
ITS (RSU)	10	6	10	5.8625	-88.0	128.0	10.1
ITS (OBU)	8	1.5	10	5.8625	-88.0	126.0	7.6
MBR	24	75	20	5.8625	-93.0	147.0	86.5
Note 1: This is for 64 QAM reception.							

ITS systems are more resilient than either BFWA or MBR. In all cases, this minimum coupling loss (MCL) calculation indicates that victim receiver threshold interference can be exceeded by one IoT terminal that is not particularly close to the victim receiver. However, this may be due to assumptions that are not realistic in practice. Aspects that would mitigate any interference are:

- FSPL is unlikely to be a realistic propagation model over such long distances. In addition, no account has been taken of any clutter or diffraction that may be expected;
- The IoT devices are expected to have a low duty cycle, and any interference would not be present at all times;
- In practice the worst-case antenna boresight alignment used in the simple MCL assessment would occur very rarely. A more realistic assessment would consider actual antenna gain responses;
- The interference thresholds are based upon minimum sensitivity and high values of C/I (64 QAM). In practice the desired signal would typically be more, and some rate adaption could be deployed.

Another aspect that would, on the other hand, increase interference is the consideration that multiple devices may transmit at the same time, increasing the interference compared to an individual interfering device. Since the devices are transmitting 'at random', there would be a Poisson distributed number of simultaneously transmitting devices.

These aspects are addressed in section 4.2.

[3] We note that only the power in the receiver bandwidth is relevant since the interferer bandwidth is less than the victim bandwidth. The BW reduction factor is used when referencing all systems to power spectral density values.

4.2 MONTE CARLO INTERFERENCE ASSESSMENT METHODOLOGY

SEAMCAT software tool [19], developed specifically to support Monte Carlo analysis for Spectrum Engineering and coexistence assessment. SEAMCAT has several features built-in which address some of the deficiencies identified with the MCL assessment:

- Support for a more realistic propagation model: ITU-P.452-17 [20]. This is the latest version of ITU-P.452 supported by SEAMCAT V.5.5.0;
- Support for flexible methods of distributing interfering transmitters across an area of interest;
- Support for defining antenna gain responses (azimuth and elevation).

SEAMCAT V.5.5.0 is also able to generate devices with a user-specified duty cycle, and density of deployment for a user-specified, fixed, number of interfering devices (the area where the devices are spread is adjusted so that the mean number of interfering devices is the same as the fixed number of interfering devices). This is not sufficient to model the Poisson distribution.

It is also required to assess the aggregate level of interference against a threshold value where the interference is deemed acceptable. It is noted that for individual interferers this has previously been done by establishing the propagation distance, using a probability of time metric of 20%, where the received interference signal strength is below the interference threshold. Here it is required to assess an acceptable probability of interference for possibly multiple overlapping interferers, transmitting from different locations. ECC Report 302 [21] sets a useful precedent for interference assessment in the band of interest, and the following conservative approach is proposed:

- Interference should not exceed the threshold I/N value for more than 20% of time (as advised by Recommendation ITU-R F.758 [22] for the long term protection criterion);
- Aggregated interference (based on the Poisson distributed number of active interferers) will be used;
- Adopt Recommendation ITU-R P.452 for the propagation algorithm for the interference paths. In ECC Report 302, time percentages corresponding to 0.01% to 100% of time were used - though it is noted that Recommendation ITU-R P.452 is only defined for the most pessimistic (i.e. least attenuated) 50% of time.

Based on this, the following method has been used to model the case of interest:

- For each victim technology of interest, use SEAMCAT to generate the interference Received Signal Strength (iRSS) to a fixed victim receiver location from a large number of randomly located aggressor IoT locations across a coverage area of interest. The propagation algorithm will use time percentage values uniformly selected in the range 0 to 50% for half of the sample population of randomly located interferers, and percentage time values of 50% for the other half of the population of devices. Use SEAMCAT to export these representative interference events for the random IoT positions (this uses SEAMCAT's features to distribute interferers, antenna characterisation and propagation modelling and iRSS calculation);
- Within Octave, for different IoT device densities and duty cycles within the coverage area aggregate the interference from N simultaneously active interfering transmitters that are characteristic of the expected mean number of the Poisson distributed number of transmitters;
- The active transmitters are assumed to transmit 'co-channel' with the victim receiver and span the range of *e.i.r.p.* values identified in Table 1. The accumulated contributions from all interfering transmitters are aggregated in the victim receiver. Since the bandwidth of all potential IoT devices is less than the victim receivers being considered, no account has been taken for some interference power being 'out of band'. This means that any interference is assumed to aggregate IoT devices operating in multiple narrowband channels, and any deployment should take that into account;
- Since Recommendation ITU-R P.452 is only defined for time percentages up to 50%, half of the random snapshots will use propagation %time values from the range 0-50%, and the other half will use values corresponding to the 50th percentile value (equivalent to the median value).
- Acceptable interference will be assessed on the conditions for which the aggregated interference (using the conservative estimation of all percentage time values) does not exceed the threshold for more than 20% of cases;
- The Recommendation ITU-R P.452-17 implementation in SEAMCAT V.5.5.0 has a range of parameters that can be configured - including suggested default values. These do not allow selection of the Radio Climatic Zones, or the proportion of the propagation path over water. For this reason, no differences have been applied to terrestrial or maritime propagation paths. The values shown in Table 7 have been used for all propagation paths.

Table 7: Parameters used in Recommendation ITU-R P.452-17 propagation model for all propagation paths

Attribute	Value	Unit
Terrain Profile Data	Not selected	N/A
Diffraction Only	Not selected	N/A
Water Concentration	3.0	g/m^3
Surface Pressure	1013.25	hPa
Refractivity Gradient	40.0	km^{-1}
Surface Temperature	15.0	°C
Latitude	45.0	°
Sea Level Surface refractivity	325.0	#
Time Percentage	0-50, and 50 (see text)	%
Local Clutter at Tx, Rx	See Table 7.	N/A

If there is a deployment of IoT devices (system 'i'), uniformly distributed spatially, with density ρ_i, and which randomly transmit short bursts, with a Duty Cycle DC_i, then the expected number of actively transmitting devices in the coverage area, A, is:

$$N_{tx_i} = A.\rho_i.\ DC_i$$

For this system, the random number of simultaneously active transmitters, X_i, will be Poisson Distributed, with mean N_{tx_i}, where:

$$X_i \sim Po(A \cdot \rho_i \cdot\ DC_i)$$

Since the sum of 2 Poisson-distributed random variables is also Poisson distributed with a mean value the sum of the individual means [23], then if there are multiple independent systems, with the same *e.i.r.p.* operating in the same area, the number of simultaneously active interferers, SA, will also be distributed as a Poisson random variable, where,

$$SA \sim Po\left(A \sum_{i=1}^{N} \rho_i \cdot DC_i\right)$$

Therefore, if there are different types of IoT systems, which have different duty cycles and densities, sharing co-channel spectrum in a given area, the impact of the combined population can be characterised[4] as the sum of the individual system's Active Device Density (where $ADD_i = \rho_i.\ DC_i$).

4.3 MONTE CARLO INTERFERENCE ASSESSMENT RESULTS

The additional details required to model the iRSS_th within SEAMCAT are shown in Table 8. Two million sample locations were generated for each of the simulation radii given (one million for p% in range 0-50%, and one million with p%=50%). For terrestrial victim receivers (i.e. BFWA, ITS (RSU), ITS (OBU)), the IoT locations were distributed uniformly around the victim receiver up to the range given. For these terrestrial receivers there is no exclusion distance (so the transmitters can be located adjacent to the receivers). For the MBR victim system it is assumed that victim transmitters could be land-based or on a vessel. To simulate land-based IoT systems a minimum separation of 10 km is assumed (approximating the MBR being 10 km from a coastline) and the coastline is assumed to run North-South, with the MBR located 10 km West, with the antenna pointing East (to the shore). For a maritime based transmitter, IoTs are simulated with no separation distance assumed,

[4] This applies if the different IoT systems have the same *e.i.r.p.* Clearly, the maximum *e.i.r.p.* of the systems deployed could be used to set an upper bound on the expected interference impact. Further analysis could consider the impact of different *e.i.r.p.* in more detail.

or with a minimum separation of 2 km (and for this maritime case, the transmitters are assumed to surround the MBR receiver (similar to the BFWA terrestrial case)).

Table 8: Additional system parameters used to extract iRSS values for random positions in coverage within SEAMCAT

System name	Antenna Horizontal Response	Antenna Vertical Response	SEAMCAT Propagation Model	Victim Receiver Clutter	IoT Transmitter Clutter	Azimuth Arc range	Maximum Distance (km)
BFWA	17 dBi, Class CS 3 ETSI EN 302 085, table 15a	Omni	Recommendation ITU-R P.452-17 [20]	Suburban	Suburban	±180° from boresight	200
ITS (RSU)	Omni	ECC Report 101, figure 5	Recommendation ITU-R P.452-17	Suburban	Suburban	±180° from boresight	40
ITS (OBU)	Omni	ECC Report 228, section 3.3.2, with additional 25° downtilt	Recommendation ITU-R P.452-17	Suburban	Suburban	±180° from boresight	40
MBR(T) (terrestrial IoT)	ECC Report 259, figure 4	Omni	Recommendation ITU-R P.452-17	No Clutter	Suburban	±90° from boresight	200 (not less than 10 km)
MBR(M) (maritime IoT)	ECC Report 259, figure 4	Omni	Recommendation ITU-R P.452-17	No Clutter	No Clutter	±180° from boresight	200
MBR(M) (maritime IoT)	ECC Report 259, figure 4	Omni	Recommendation ITU-R P.452-17	No Clutter	No Clutter	±180° from boresight	200 (not less than 2 km)

Within Octave, for each victim technology and maximum distance, 100000 snapshots were generated. For each snapshot the iRSS for a Poisson distributed number of locations were aggregated to calculate the total interference at the victim receiver. These snapshots use random samples from the population of 2M simulated positions. iRSS interference threshold values of -95 dBm, -88 dBm, -88 dBm, -93 dBm and -93 dBm were used for BFWA, ITS (RSU), ITS(OBU), MBR(T) and MBR(M) systems respectively. The Maritime case is also simulated assuming a 2 km isolation distance.

The probability that the aggregated iRSS exceeds the threshold interference is plotted versus ADD in the area considered are shown in Figure 5, Figure 6, Figure 7, Figure 8, Figure 9and Figure 10, using *e.i.r.p.* values in the range 23 to 38 dBm and distances from the victim receiver identified in Table 8.

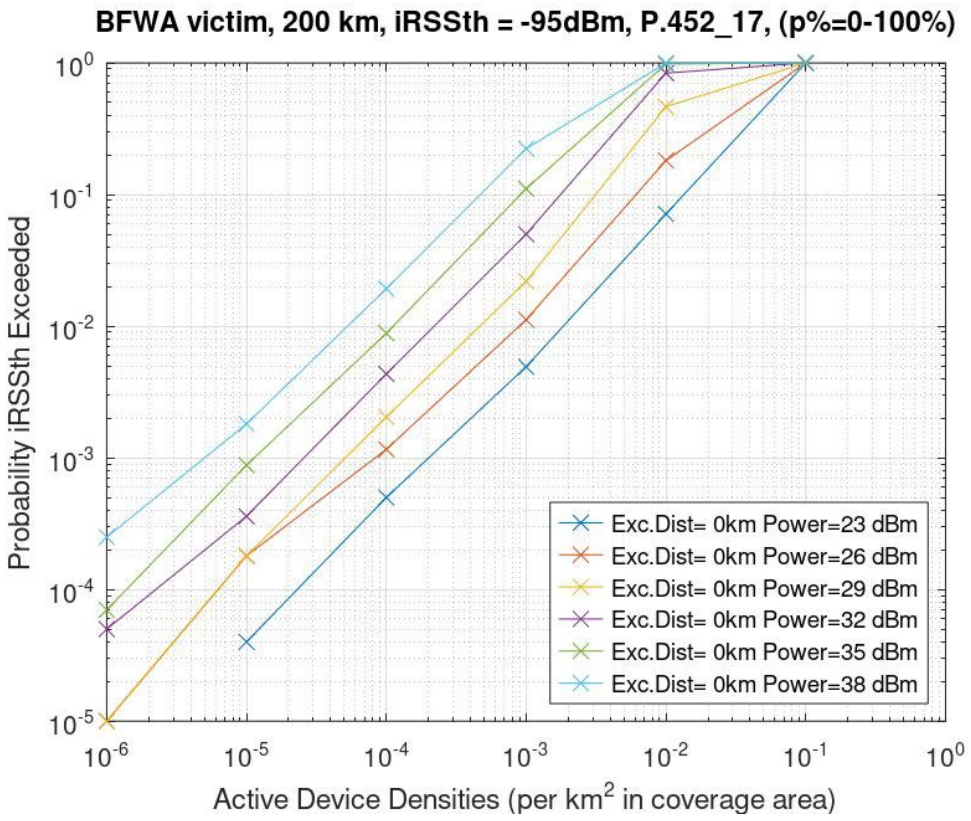


Figure 5: BFWA Victim Receiver. Probability that iRSS_th exceeded for different Active Device Densities and *e.i.r.p.* within 200 km of the victim receiver

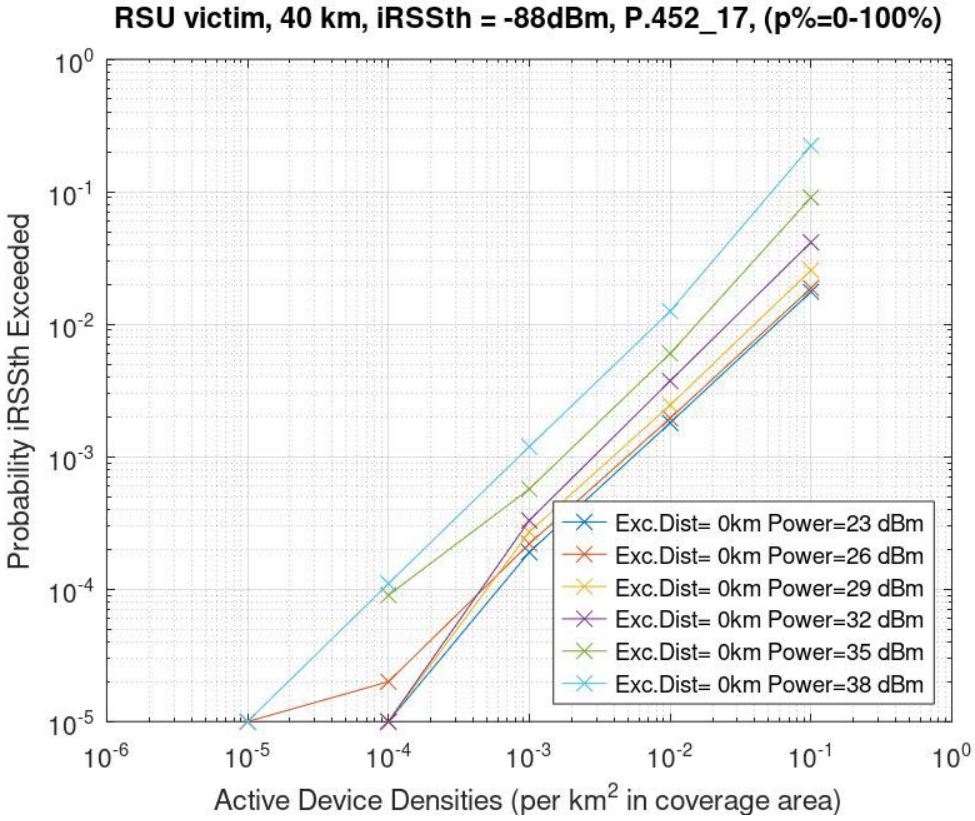


Figure 6: ITU RSU Victim Receiver. Probability that iRSS_th exceeded for different Active Devices Densities and *e.i.r.p.* within 40 km of the victim receiver

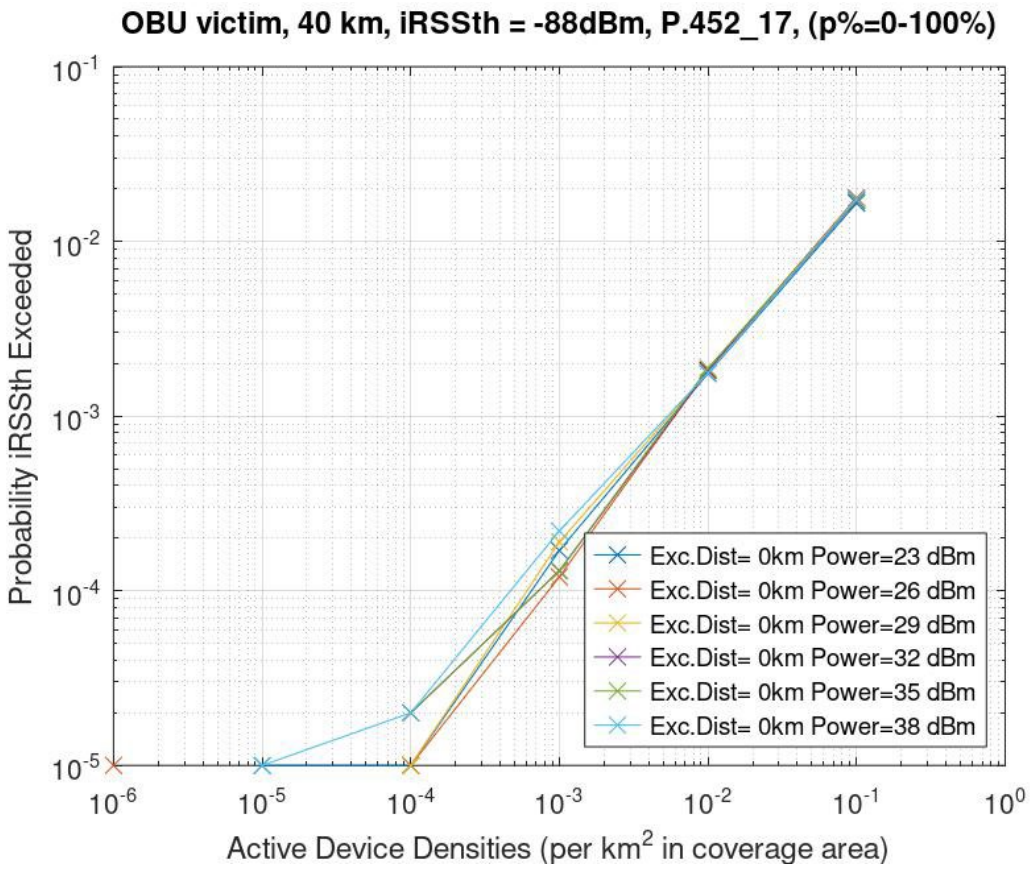


Figure 7: ITS OBU Victim Receiver. Probability that iRSS_th exceeded for different Active Devices Densities and *e.i.r.p.* within 40 km of the victim receiver

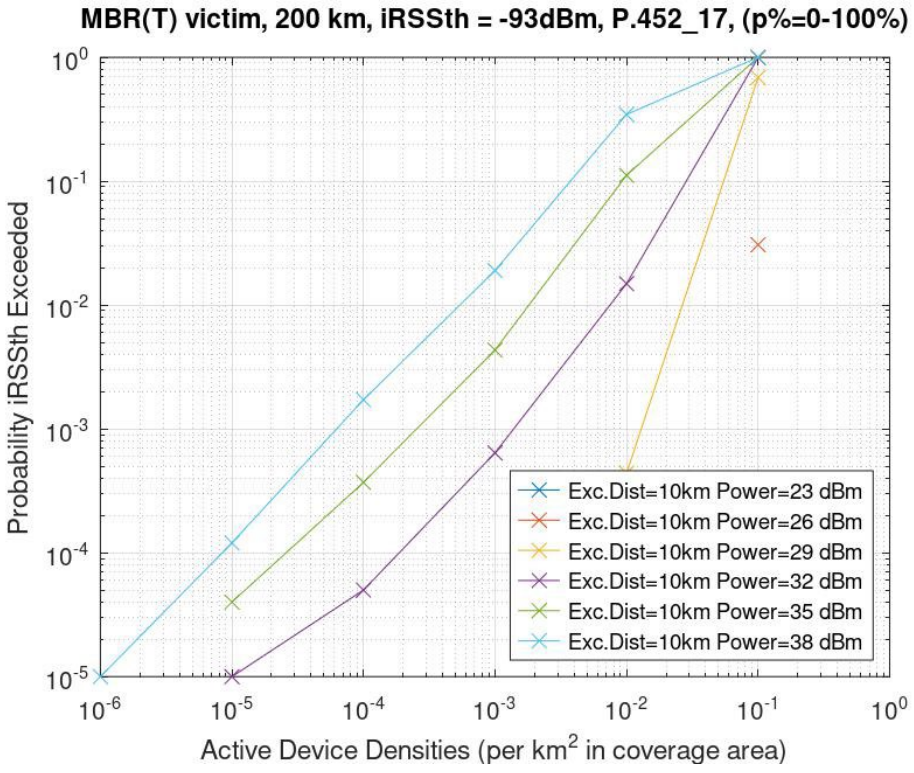


Figure 8: MBR(T) Victim Receiver Terrestrial IoT. Probability that iRSS_th exceeded for different Active Devices Densities and *e.i.r.p.* within 200 km of the victim receiver (10 km exclusion)

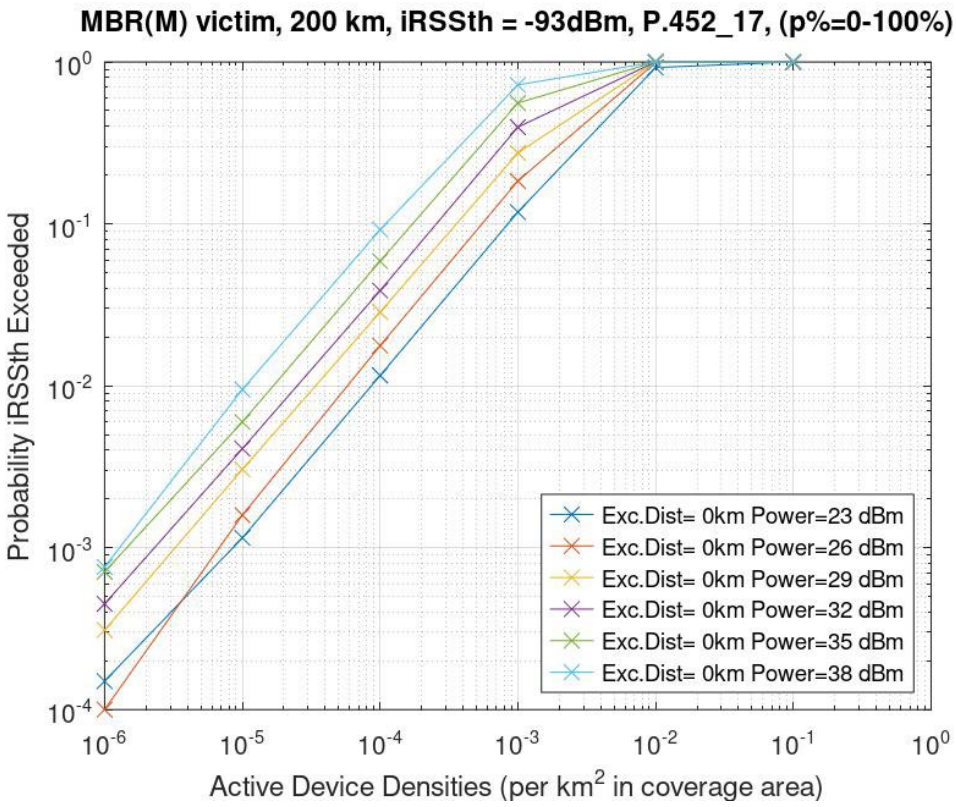


Figure 9: MBR(M) Victim Receiver Maritime IoT. Probability that iRSS_th exceeded for different Active Devices Densities and *e.i.r.p.* within 200 km of the victim receiver

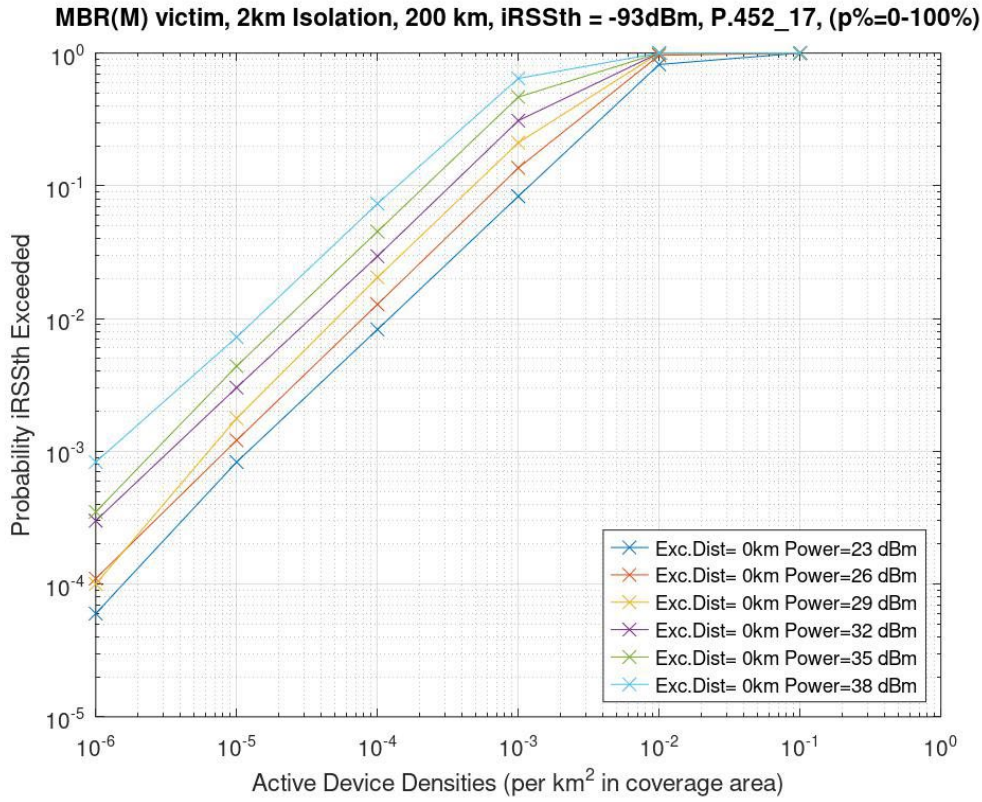


Figure 10: MBR(M) Victim Receiver Maritime IoT with 2 km Isolation. Probability that iRSS_th exceeded for different Active Devices Densities and *e.i.r.p.* within 200 km of the victim receiver

4.4 INTERFERENCE IMPACT AND CONSEQUENCES FOR IOT DEPLOYMENT

As expected from other studies, BFWA is the most constraining co-existence case considered. It is noteworthy, that for BFWA, ITS RSU and MBR(M) cases, a similar probability of interference is achieved with half the device density and 3 dB more *e.i.r.p.* from each device in the area of interest (i.e. where the probability of interference is between 0.001 and 0.1). This same behaviour is not evident with MBR(T) (where a relatively large exclusion area is used) or for ITS RSU (where the antenna downtilt would mitigate against the effect of aggregation of more distant interferers, and there is less averaging of significant interferers).

Using the 20% interference threshold, Table 9 identifies the maximum ADD values that could be tolerated with each of the IoT *e.i.r.p.* transmit powers considered.

Table 9: Maximum ADD values (per km^2) for different victim systems and IoT transmit powers

	23 dBm	26 dBm	29 dBm	32 dBm	35 dBm	38 dBm
BFWA	0.025	0.01	0.005	0.003	0.002	0.0009
ITS (RSU)	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	0.09
ITS (OBU)	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1
MBR(T) (terrestrial IoT) with 10 km exclusion	> 0.1	> 0.1	0.07	0.04	0.02	0.006
MBR(M) (maritime IoT)	0.002	0.001	0.0007	0.0005	0.0003	0.0002
MBR(M) (maritime IoT) with 2 km exclusion	0.003	0.002	0.002	0.0006	0.0004	0.0003

These results support that deployment of IoT devices with densities of 0.001 active devices per km^2 and with powers of up to 35 dBm could be deployed with no restrictions on their movement in the vicinity of any potential terrestrial victims, without causing an unacceptable level of interference. The highest *e.i.r.p.* considered of 38 dBm would cause interference above the threshold with an ADD less than 0.0009.

MBR base stations are more susceptible than other systems (high receive antennas with no clutter losses assumed). However, the results support that an ADD of 0.001 and 30 dBm or less *e.i.r.p.* could be used for the maritime case with a minimum 2 km separation distance, or an ADD of less than 0.0005 using an *e.i.r.p.* of less than 32 dBm and no isolation distance. An *e.i.r.p.* of 38 dBm would restrict the maximum ADD to less than 0.0002.

The off-axis limit is calculated across the utilised bandwidth of the satellite network - the interference to potential victims is the aggregate interference from IoT devices within proximity of any victim and transmitting within the receiver bandwidth of the victim. In this, and in all cases considered, the off-axis limit constrains the number of IoT devices than can be deployed across the GSO satellite network service area, prior to the limit required to protect potential victims from interference.

To put these values into context, at C-band, the off-axis mask restricts the number of simultaneously active devices in a 500 kHz channel with 32 dBm *e.i.r.p.* to be less than 15 across the satellite network. This would be less than 600 devices in a bandwidth of 20 MHz (the worst-case victim receiver bandwidth), corresponding to an ADD within the CEPT (resp. EU 27) land area of less than 0.0001 (resp. 0.00015).

In all cases considered, the off-axis limit constrains the number of devices rather than the ADD limit required to protect victim receivers.

5 SMALL TERMINAL INTERFERENCE ASSESSMENT IN THE BAND 14.0-14.5 GHZ

5.1 MINIMUM COUPLING LOSS CALCULATIONS TO PROTECT SERVICES

This section examines the feasibility of coexistence with FS and RAS in the 14.25-14.5 GHz band using the same Monte Carlo methodology identified in section 4.2. The victim FS parameters are taken from ECC Report 271, table 3 [17] (with two different antenna gains (discrimination) using a long term I/N protection ratio of -10 dB.

Protection criteria used for radio astronomical measurements are provided in Recommendation ITU-R RA.769-2 [24]. Recommendation ITU-R RA.769-2, table 2 identifies the 14.488 GHz spectral line bandwidth of 150 kHz, and a threshold interference power of -214 dBW (equivalent to -236 dBm/Hz). For primary[5] RAS allocations, Recommendation ITU-R RA.1513 [25] notes that the threshold value should not be exceeded for more than 2% of samples. Recommendation ITU-R RA.769-2 notes that (terrestrial) interference 'is almost always received through the antenna side lobes, so the main beam response to interference need not be considered'. These parameters have been used in the interference assessment.

Based on the above, the parameters needed to protect RAS and FS from IoT terminals using a simple minimum coupling loss MCL analysis can be summarised, as shown in Table 10.

Table 10: Basic system parameters used in MCL analysis

System name	Antenna Gain (dBi)	Nominal Antenna Height (m)	Bandwidth (MHz)	Frequency (GHz)	Interference threshold at receiver (dBm) (bandwidth and antenna gain dependent)	Minimum Path Loss (dB) with 49 dBi Rx antenna	FSPL distance (km)
FS	49 (37 also identified)	30	2.5, 3.5, 7, 14, 28	14.25	-116 - -101.5	155.5-170	99.3-524
RAS	0	30	0.150	14.488	-184.5	189.5	5.163

The protection distances needed to protect co-channel FS or RAS receivers would be typically in the order of tens of kilometres, but note that the FSPL is a conservative propagation model. Also note that the distance given to protect RAS receivers is based on an antenna gain of 0 dBi.

Both FS and RAS operate above 14.25 GHz. The simple MCL analysis suggests that coexistence with FS and RAS are likely to be difficult with IoT devices operating above 14.25 GHz. No such concern exists for IoT operation in the 14.0-14.25 GHz band. Hence Monte Carlo interference assessment need only concern the 14.25-14.5 GHz band.

5.2 APPLICATION OF THE MC INTERFERENCE METHODOLOGY TO FS IN THE 14.25-14.5 GHZ BAND

As above, additional parameters needed to perform the Monte Carlo analysis can be identified.

[5] The 14.47-14.5 GHz allocation is secondary.

Table 11: Additional system parameters used to extract iRSS values for random positions in coverage within SEAMCAT

System name	Antenna Horizontal Response	Antenna Vertical Response	SEAMCAT Propagation Model	Victim Receiver Clutter	IoT Transmitter Clutter	Azimuth Arc range	Maximum Distance (km)
FS_37	Recommendation ITU-R F.699-8 [30] (37 dBi)	Omni	Recommendation ITU-R P.452-17 [20]	None	None	±180° from boresight	750
FS_49	Recommendation ITU-R F.699-8 (49 dBi)	Omni	Recommendation ITU-R P.452-17	None	None	±180° from boresight	750

Similar to the above, results of the probability of interference for the different FS victim antennas are plotted for the different IoT *e.i.r.p.* values in Figure 11 and Figure 12.

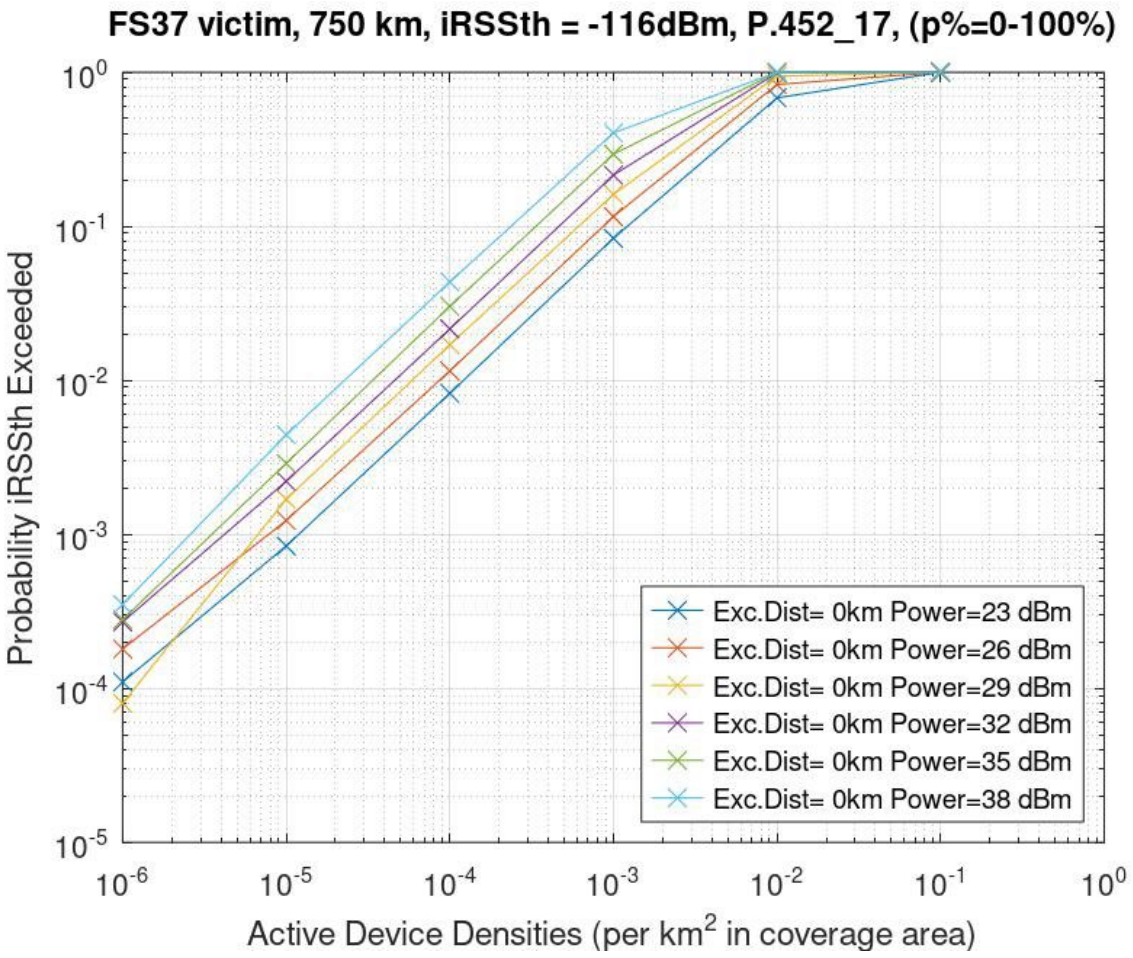


Figure 11: FS Victim Receiver (37 dBi main lobe gain). Probability that iRSS_th exceeded for different Active Device Densities and *e.i.r.p.* within 750 km of the victim receiver

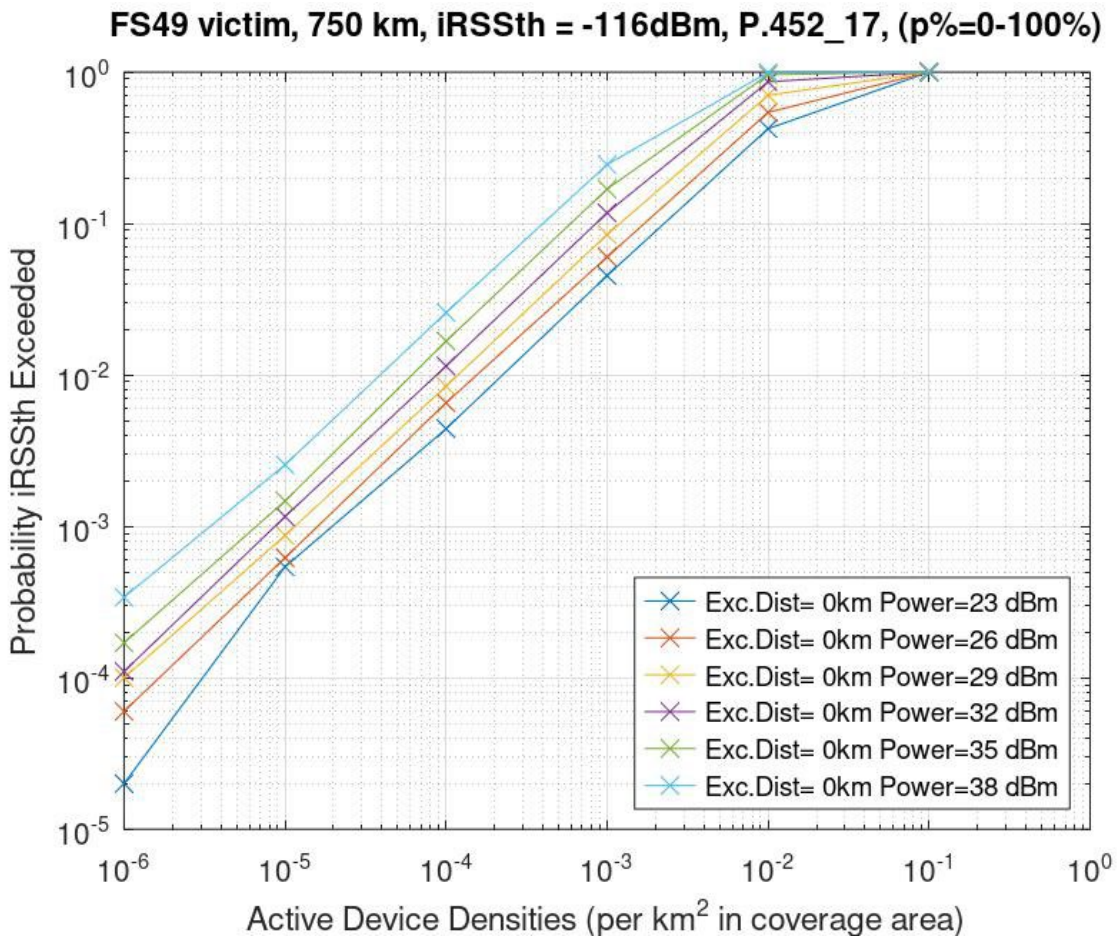


Figure 12: FS Victim Receiver (49 dBi main lobe gain). Probability that iRSS_th exceeded for different Active Device Densities and *e.i.r.p.* within 750 km of the victim receiver

5.3 INTERFERENCE IMPACT AND CONSEQUENCES FOR IOT DEPLOYMENT

As expected, it is more difficult to avoid interference to FS. Table 12 identifies the Active Device Densities that could be tolerated with each of the IoT *e.i.r.p.* transmit powers considered by the two different FS systems (assuming a 20% probability of exceeding the interference threshold, and with no isolation zone).

Table 12: Maximum ADD values for different IoT transmit powers and FS antenna gains

	23 dBm	26 dBm	29 dBm	32 dBm	35 dBm	38 dBm
FS_37	0.003	0.002	0.001	0.0009	0.0007	0.0005
FS_49	0.005	0.004	0.003	0.002	0.001	0.0008

The less directional (37 dBi) antenna FS system is more susceptible than the higher gain 49 dBi antenna base station. In both cases lower ADD deployments would be needed to protect FS in the upper part of Ku band - than the terrestrial victims in C-band. Even lower density deployments would be required to protect RAS than FS. However, based on the interference assessment, without considering the topological losses within a 750 km radius, ADD values of 0.0001 would rarely exceed the interference threshold at FS receivers.

Despite this, it is worth noting that the active duration of an IoT device (with their necessarily low data rate) is longer than the typical frame length of a FS link, and that the FS links typically support carrier grade communication links. For these carrier grade links, prolonged interference is problematic even if the probability of such an event is low.

6 CONFIGURATIONS INTENDED FOR USE

There are a large number of possible configurations of small IoT terminals that could be deployed. Many aspects of these systems differ from traditional FSS satellite terminals. The preferred characteristics and indicative dimensioning for a range of systems in C-band and Ku-band have been provided by the system proponents and are shown in Table 13 and Table 14 respectively.

The duty cycle may be observed over a period of at least one hour. In the event of low target duty cycles, the observation period will consist of multiple periods of one hour so that a representative average duty cycle can be estimated.

Table 13: C-band configurations and number of devices

Type ID	EIRP (dBm)	Transmitter or Channel Bandwidth (kHz)	System Bandwidth (MHz)	Message size (bytes)	Message /day	Device Duty Cycle per day	Number of Devices Deployable	Transmit duration (seconds)
Type_1_C	15	4500	4.5	15	12	0.0033	300000	23.76
Type_2_C	25	50	1	20	12	0.0015	18032	11.07
Type_3_C	26	4500	4.5	250	24	0.0111	100000	39.96
Type_4_C	27	100	1	20	12	0.0010	22626	6.99
Type_5_C	30	50	1	20	12	0.0005	3558	3.50
Type_6_C	30	100	1	20	12	0.0005	9145	3.50
Type_7_C	30	137	1.524	180	12	0.0008	185547	5.90
Type_8_C	30	137	1.524	180	24	0.0008	92773	2.95
Type_9_C	30	137	1.524	220	12	0.0010	151811	7.21
Type_10_C	30	137	1.524	220	24	0.0010	75906	3.60
Type_11_C	30	200	0.2	10	24	0.0001	260000	0.37
Type_12_C	30	200	0.2	10	96	0.0004	65000	0.36
Type_13_C	30	1524	1.524	180	12	0.0008	185547	5.90
Type_14_C	30	1524	1.524	180	24	0.0008	92773	2.95
Type_15_C	32	240	1	8	24	0.0003	25781	1.01
Type_16_C	33	0.5	0.5	8	24	0.0002	46183	0.70
Type_17_C	34	0.5	0.5	8	24	0.0002	58141	0.56
Type_18_C	37	4500	4.5	250	120	0.0111	100000	7.99
Type_19_C	38	137	1.524	220	12	0.0010	23970	7.21
Type_20_C	38	137	1.524	220	24	0.0010	11985	3.60
Type_21_C	38	200	0.2	220	12	0.0001	260000	0.75
Type_22_C	38	200	0.2	220	24	0.0004	65000	1.44

Table 14: Lower Ku-band configurations and number of devices

Type ID	EIRP (dBm)	Transmitter or Channel Bandwidth (kHz)	System Bandwidth (MHz)	Message size (bytes)	Message/ day	Device Duty Cycle per day	Number of Devices Deployable	Transmit duration (seconds)
Type_1_KL	20	125	2	30	12	0.00046	2250000	3.28
Type_2_KL	20	250	2	30	12	0.00023	2250000	1.64
Type_3_KL	20	250	2	50	48	0.00131	390625	2.36
Type_4_KL	24	125	2	30	12	0.00013	2511161	0.92
Type_5_KL	24	250	2	30	12	0.00006	4017857	0.46
Type_6_KL	24	250	2	50	48	0.00037	685976	0.67
Type_7_KL	27	0.5	0.5	8	24	0.00039	23147	1.40
Type_8_KL	27	100	1	20	12	0.00049	9145	3.50
Type_9_KL	28	125	2	30	12	0.00007	2343750	0.49
Type_10_KL	28	250	2	30	12	0.00003	4687500	0.25
Type_11_KL	28	250	2	50	48	0.00020	878906	0.36
Type_12_KL	30	0.5	0.5	20	12	0.00024	36947	1.75
Type_13_KL	31	0.5	0.5	8	24	0.00015	58141	0.56
Type_14_KL	32	100	1	20	12	0.00015	927	1.11
Type_15_KL	32	125	2	30	12	0.00004	2197266	0.26
Type_16_KL	32	240	1	8	24	0.00014	12949	0.50
Type_17_KL	32	250	2	30	12	0.00002	3955078	0.13
Type_18_KL	32	250	2	50	48	0.00011	1171875	0.20
Type_19_KL	32	250	3	50	24	0.00015	1208	0.55
Type_20_KL	35	125	2	30	12	0.00002	1607143	0.14
Type_21_KL	35	250	2	30	12	0.00001	3214286	0.07
Type_22_KL	35	250	2	50	48	0.00006	1487380	0.11
Type_23_KL	38	250	3	50	24	0.00052	4	1.87
Type_24_KL	38	500	3	50	24	0.00052	148	1.87

7 CONCLUSION

Technological innovations in the areas of small antennas, signal processing and interference cancellation have opened up alternative solutions for Internet of Things (IoT) systems using existing C-band and Ku-band satellite capabilities.

The nature of many IoT applications is 'transmit-only', i.e. the IoT terminals might be implemented without simultaneously available bi-directional satellite connectivity. The IoT terminals under discussion have typical maximum duty cycles below 1% or in many cases even below 0.1% and are pre-designed to transmit in such a way as to limit the number of simultaneously transmitting devices. This reduces the opportunity for interference. The network operator must take specific measures to prevent accidental or synchronous events (e.g. at network start up, malfunctioning of IoT terminals) that would violate the statistical nature of this simultaneous interference. The combination of small antenna, low power, low duty cycle devices allows an opportunity for satellite-based IoT.

These satellite IoT systems are characterised by:

- Asynchronous access, i.e. no specific radio resource mechanisms are foreseen and terminals transmit asynchronously within an agreed aggregate statistically bounded envelope. This implies increased complexity at the gateway to decode overlapping transmissions;
- Receive capabilities (not necessarily via satellite) can be added for control purposes. This control feature would be used to set the configuration of the device and would be required as part of a reset condition to prevent devices operating beyond a limited period of activity (i.e. each device will only be authorised to operate for a limited period of time, instead of having a real-time bi-directional link for network control);
- IoT terminals with small transmitters with small antennas as a result of the terminal integration. Those terminals have little directionality and low gain values;
- a physical installation of the IoT terminal by users without any precise antenna alignment;
- Limited configuration of the terminal by the user, for example, pre-programmed user profiles;
- Limited provisioning procedures, for example, pre-programmed authentication credentials;
- Use of IoT terminals on platforms in motion, within Fixed Satellite Service (FSS) assignments.

These characteristics have required a new approach to accessing coexistence compared to conventional systems. Despite the low Equivalent Isotropically Radiated Power (*e.i.r.p.*) and low duty cycles, these IoT devices may pose an interference risk to other receivers (both terrestrial and satellite) when acting as a population of devices. This Report seeks to identify methods to assess both the opportunity for causing interference and methods that can be used to constrain and control interference to remain within acceptable limits. In particular, the statistical nature of the random transmissions needs to be accounted for and maintained below limits to satisfy both off axis *e.i.r.p.* limits and Active Device Density (ADD) to limit interference to victim receivers.

Based on Monte Carlo simulation methods, the probability of exceeding the interference threshold not more than 20% of time for different ADD, *e.i.r.p.* values and services have been performed for the frequency ranges subject to this Report:

- 5850-5875 MHz: The ADD required to not exceed the interference threshold more than 20% of the time for different *e.i.r.p.* values, and different applications are shown in Table 15;
- 14.0-14.25 GHz (lower Ku-band): Existing ECC Decisions support deployment with no restriction on movement or need for individual licensing of terminals in the band 14.0-14.25 GHz. This frequency range is not allocated to terrestrial service and coexistence is therefore not an issue;
- 14.25-14.5 GHz (upper Ku-band): The ADD required to not exceed the interference threshold more than 20% of the time for different *e.i.r.p.* values, and different applications are shown in Table 16.

Table 15: ADD (per km^2) required depending on the *e.i.r.p.* of the device and the considered victim system

e.i.r.p. of the device	23 dBm	26 dBm	29 dBm	32 dBm	35 dBm	38 dBm
Broadband Fixed Wireless Access (BFWA)	0.02	0.01	0.005	0.003	0.002	0.0009
Intelligent Transport System (Road Side Unit) - (ITS (RSU))	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	0.09
Intelligent Transport System (On Board Unit) - (ITS (OBU))	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1	> 0.1
Mobile Broadband Radio (terrestrial IoT) - (MBR (T))	> 0.1	> 0.1	0.07	0.04	0.02	0.006
MBR (Maritime IoT) - (MBR(M))	0.002	0.001	0.0007	0.0005	0.0003	0.0002
MBR (M) with 2 km isolation	0.003	0.002	0.002	0.0006	0.0004	0.0003

Table 16: ADD (per km^2) required depending on the *e.i.r.p.* of the device and the considered victim system

e.i.r.p. of the device	23 dBm	26 dBm	29 dBm	32 dBm	35 dBm	38 dBm
FS_37	0.003	0.002	0.001	0.0009	0.0007	0.0005
FS_49	0.005	0.004	0.003	0.002	0.001	0.0008

Based on the statistical evaluation method developed in this Report the sharing and compatibility assessment can be summarised as:

- C-band in the range 5850-5875 MHz: IoT devices with Active Device Densities of 0.001 and with powers of up to 35 dBm could conservatively be deployed with no restrictions on their movement in the vicinity of any potential terrestrial victims. Terrestrial deployments with higher ADD could be permitted with lower *e.i.r.p.* values. Higher *e.i.r.p.* values (up to 38 dBm) would not cause interference if their ADD in the vicinity of a victim receiver is less than 0.001. Maritime terminals in the vicinity of MBR victims can operate with *e.i.r.p.* values of less than 32 (resp. 38) dBm, ADD of less than 0.0005 (resp. 0.0002) respectively, with no minimum separation distance. Constraining deployment by a new metric (Active Device Density) could be difficult to enforce. ADD limitations required to protect potential victim systems are less restricting on device deployment than considering limitations on the aggregate number of devices in order to conform to an off-axis *e.i.r.p.* density mask for small IoT terminals associated to a unique satellite network. Since satellite operators should ensure compliance with this off-axis *e.i.r.p.* density mask, enforcement of ADD limits in order to protect terrestrial victims can (and would, in effect) be performed at the system level required to limit interference to GSO networks. With respect to road tolling systems mentioned in Annex 2, the scenario of interference would be related to small IoT devices transmitting in C-band mounted on vehicles. It was discussed that interruption of barrier operation of road tolling of more than 7 s was considered unacceptable to road users, the issue could be solved by ensuring that the unwanted power emission of a small IoT device with a transmission duration of more than 7 s in C-band remains below -65 dBm/MHz in 5795-5815 MHz;
- Ku-band in the range 14.0-14.25 GHz (lower Ku-band): Existing ECC Decisions support deployment with no restriction on movement or need for individual licensing of terminals in the band 14.0-14.25 GHz. This frequency range is not allocated to terrestrial service and coexistence is therefore not an issue. Maritime operation of these devices will not cause any interference to the terrestrial applications used in CEPT countries and the constraints of ITU-R Resolution 902 (Rev.WRC-23) (to protect terrestrial systems) do not apply. Some non-CEPT in the vicinity of non-CEPT countries may require coordination for use of small IoT terminals. Aeronautical use of these small IoT terminals within CEPT countries would not pose any interference risk, though coordination may be required where interference could be a risk to non-CEPT countries deploying FS services. Off-axis limits contained in Recommendation ITU-R S.524-9 still apply;
- Ku-band in the range 14.25-14.5 GHz: There is the possibility to allow low ADD, low *e.i.r.p.* IoT terminals in the upper Ku-band. Neglecting any additional losses due to the nature of the terrain within a 750 km

radius, IoT deployments with ADD values of 0.0001 are unlikely to exceed the interference threshold at FS receivers. However, such interference could impact RAS or some FS systems. It is worth noting that the active duration of an IoT device (with the necessarily low data rate) is longer than the typical frame length of a FS link and that the FS links typically support carrier grade communication links. For these carrier grade links prolonged interference is problematic even if the probability of such an event is low. It is worth noting that no configuration characteristics were provided for this band.

A list of device characteristics proposed for use by device manufacturers in both C-band and Ku-band (in the range 14.0-14.25 GHz) is provided. It is proposed that any initial deployment is restricted to these device types. The permitted configurations can be reviewed if there is sufficient demand.

ANNEX 1: OFF-AXIS LIMITS FOR SYSTEM D

For operation in the 14-14.25 GHz frequency range, which is allocated to FSS on a primary basis, direct device to satellite service has to comply with Recommendation ITU-R S.524-9 [3] regulation and should consider supplementary harmonisation rules defined by the FSS operators.

Recommendation ITU-R S.524-9 regulation [3]

$39 - 25.\log_{10}\varphi$	dBW / 40 kHz for	$2.5° \leq \varphi \leq 7°$
18	dBW / 40 kHz for	$7° < \varphi \leq 9.2°$
$42 - 25.\log_{10}\varphi$	dBW / 40 kHz for	$9.2° < \varphi \leq 48°$
0	dBW / 40 kHz for	$48° < \varphi$

As a representative mask used by FSS operators to ensure protection of adjacent systems, the following can be considered [7]:

$F - 25.\log_{10}\theta$	dBW / 40 kHz for	$1° \leq \theta \leq 7°$
$F - 21$	dBW / 40 kHz for	$7° < \theta \leq 9.2°$
$F + 3 - 25.\log_{10}\theta$	dBW / 40 kHz for	$9.2° < \theta \leq 48°$
$F - 39$	dBW / 40 kHz for	$48° < \theta$

With F = 31 dBW / 40 kHz, when considered in the Golden Modulation configurations for System D.

- Ultra low RF sensitivity;
- In-axis *e.i.r.p.*: -4.8 to +5.2 dBW / 40 kHz.

As a consequence of the very low *e.i.r.p.* densities where System D can operate, the ITU-R recommendation and additional requirements from FSS operators are fulfilled even with low directivity antenna as those described above.

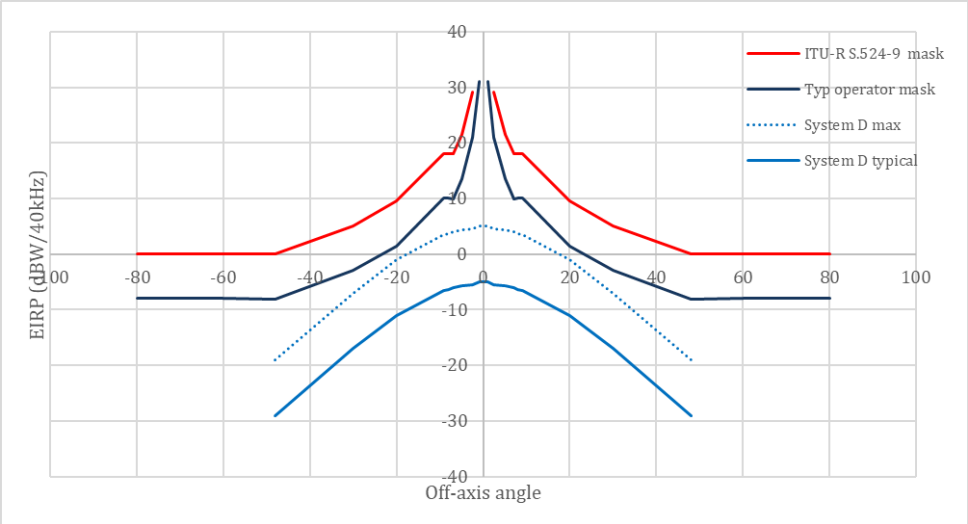


Figure 13: Off-axis emission by system D versus Recommendation ITU-R S.524-9 [3] regulation spectrum mask and versus more stringent operator representative mask

ANNEX 2: CONSIDERATIONS ON ROAD TOLLING - TRANSPORT AND TRAFFIC TELEMATICS (TTT)

Road tolling operates in 5795-5815 MHz. As of ECC Report 250, road tolling transaction durations are typically 50 ms. ECC Report 101 [15] studied the out of band emissions from ITS (which go in-band into the road tolling system) considering the receiver sensitivity of the road side equipment for road tolling. Interferer out-of-band emission limits are considered in ECC Report 101 relevant for systems operating in close vicinity of road tolling locations. Since these issues are local in nature and relevant in the geographic vicinity, ECC's work has led to the creation of a geolocation database. Road tolling locations can be found in this geolocation database, which is being maintained by the European toll road operators.

Considering the frequency separation of 35 MHz between 5815 MHz and 5850 MHz, as well as the maximum bandwidth indicated for C-Band small Iot terminals, it is to be noted that the bandwidth of operation of TTT corresponds to the spurious domain of small IoT terminals.

Road tolling systems are designed to cope with short duration interference (in the order of ms), and several IoT configurations imply longer transmit durations (up to 40 seconds). Road tolling transactions extend to 100 ms when using retries. This implies that longer transmission durations of interferers, even if used sporadically, may not be compensated by the built-in robustness mechanisms of road tolling systems.

A Monte Carlo analysis of a large deployment area does not cover the local issue of long IoT transmission durations in the vicinity of the victim receiver. IoT transmitters use transmission durations between 360 ms and 40 seconds in the C-Band (Table 12). Road tolling systems expect message exchanges to be completed within 100 ms (see ECC Report 250, figure 5 [31]).

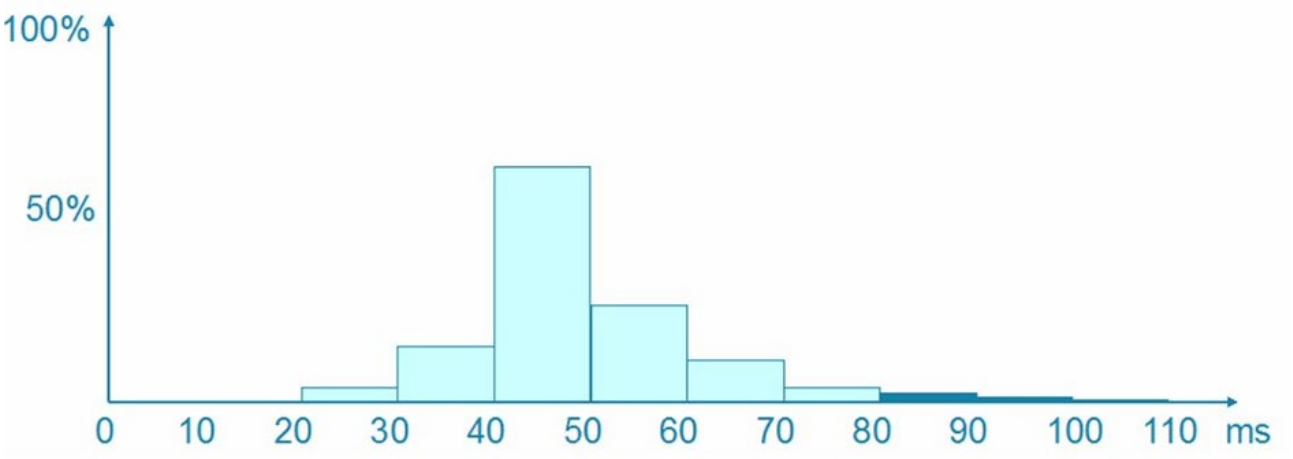


Figure 14: Histogram of a typical tolling transaction duration (ECC Report 250, figure 5)

However, road tolling is only affected within the close vicinity of the road side equipment, expressed by so-called protected zones, which are quite small (55 m default radius). The scenario of interference would be related to small IoT devices transmitting in C-band mounted on vehicles. It was discussed that interruption of barrier operation of road tolling of more than 7 s was considered unacceptable to road users.

The issue could be solved by:

- ensuring that the unwanted power emission of a small IoT device with a transmission duration of more than 7 s in C-band remains below -65 dBm/MHz in 5795-5815 MHz and interference depends to the antenna beam alignment and is limited to the RTTT communication zone (ECC Report 101 [15]), or;
- avoiding C-band transmissions within the protected zones contained in the already existing geolocation database for road tolling in Europe.

ANNEX 3: LIST OF REFERENCES

[1] ECC Report 305:"M2M/IoT Operation via Satellite", approved February 2020

[2] Hofmann C. A and Knopp A.: "Ultra-narrowband Waveform for IoT Direct Random Multiple Access to GEO Satellites", IEEE Internet of Things Journal, vol. 6, pp. 10134-10149, December 2019

[3] Recommendation ITU-R S.524-9: "Maximum permissible levels of off-axis e.i.r.p. density from earth stations in geostationary-satellite orbit networks operating in the fixed-satellite service transmitting in the 6 GHz, 13 GHz, 14 GHz and 30 GHz frequency bands"

[4] ETSI TS 103 357: "Short Range Devices; Low Throughput Networks (LTN); Protocols for radio interface A"

[5] ETSI EN 301 443: "Satellite Earth Stations and Systems (SES); Harmonised Standard for Very Small Aperture Terminal (VSAT); Transmit-only, transmit-and-receive, receive-only satellite earth stations operating in the 4 GHz and 6 GHz frequency bands covering the essential requirements of article 3.2 of the Directive 2014/53/EU"

[6] ETSI TS 102 721: "Satellite Earth Stations and Systems; Air Interface for S-band Mobile Interactive Multimedia (S-MIM); Part 3: Physical Layer Specification, Return Link Asynchronous Access"

[7] Vangelista L., Jechoux B., Canonici J.X. and Zorzi X: "Golden Modulation: a New and Effective Waveform for Massive IoT, IEEE Transactions on Communications", vol. 72, pp. 1938-1948, April 2024

[8] ERC Recommendation 70-03: "Relating to the use of Short Range Devices (SRD)", approved October 1997, latest amended October 2025

[9] ERC Report 25: "The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz", approved January 2025

[10] ECC Recommendation (06)04: "Use of the band 5725-5875 MHz for Broadband Fixed Wireless Access BFWA (BFWA)", approved December 2006

[11] ECC Report 068: "Compatibility studies in the band 5725-5875 MHz between Fixed Wireless Access (FWA) systems and other systems", approved June 2005

[12] ECC Report 259: "Sharing and compatibility studies between MBR in the 5850-5900 MHz frequency band and other systems", approved January 2017

[13] ERC Report 206: "Compatibility studies in the band 5725-5875 MHz between SRD equipment for wireless industrial applications and other systems", approved February 2014

[14] ECC Decision (08)01: "The harmonised use of Safety-Related Intelligent Transport Systems (ITS) in the 5875-5935 MHz frequency band", approved March 2008, latest amendment March 2025

[15] ECC Report 101: "Compatibility studies in the band 5855-5925 MHz between Intelligent Transport Systems (ITS) and other systems", approved February 2007

[16] ECC Report 228: "Compatibility studies between Intelligent Transport Systems (ITS) in the band 5855-5925 MHz and other systems in adjacent bands", approved February 2007

[17] ECC Report 271: "Compatibility and sharing studies related to NGSO satellite systems operating in the FSS bands 10.7-12.75 GHz (space-to-Earth) and 14-14.5 GHz (Earth-to-space)", approved January 2018, latest amendment April 2021

[18] ERC Recommendation (17)03: "Guidance for the harmonised use and coordination of Maritime Broadband Radio (MBR) systems on board ships and off-shore platforms operating within the frequency bands 5852-5872 MHz and 5880-5900 MHz", approved May 2017

[19] SEAMCAT home page: https://www.cept.org/eco/eco-tools-and-services/seamcat-spectrum-engineering-advanced-monte-carlo-analysis-tool, accessed 29 September 2023

[20] Recommendation ITU-R P.452-17: "Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz"

[21] ECC Report 302: "Sharing and compatibility studies related to Wireless Access Systems including Radio Local Area Networks (WAS/RLAN) in the frequency band 5925-6425 MHz", approved May 2019

[22] Recommendation ITU-R F.758-8: "Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz, September 2021

[23] Papoulis A. and Pillai S.U: "Probability, Random Variables and Stochastic Processes", McGraw Hill. 4th Edition, 2002. See (6-86)

[24] Recommendation ITU-R RA.769-2: "Protection Criteria used for radio astronomical measurements"

[25] Recommendation ITU-R RA.1513-2 (03/2015): "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" (version incorporated by reference into the Radio Regulations)

[26] ECC Decision (18)04: "The harmonised use, exemption from individual licensing and free circulation and use of land based Earth Stations In-Motion (ESIM) operating with GSO FSS satellite systems in the frequency bands 10.7-12.75 GHz and 14.0-14.5 GHz", approved July 2018, latest amendment November 2024

[27] ECC Decision (06)03: "Exemption from individual licensing of high EIRP satellite terminals (HEST) operating with geostationary satellites and in the frequency bands 10.70-12.75 GHz or 19.70-20.20 GHz space-to-earth and 14.00-14.25 GHz or 29.50-30 GHz Earth-to-space", approved March 2006, latest amendment November 2022

[28] ITU Resolution 902 (Rev.WRC-23): "Provisions relating to earth stations located on board vessels which operate in fixed-satellite service networks in the uplink frequency bands 5 925-6 425 MHz and 14-14.5 GHz". WRC Dubai 2023

[29] ETSI EN 301 428: "Satellite Earth Stations and Systems (SES); Harmonised Standard for Very Small Aperture Terminal (VSAT); Transmit-only, transmit/receive or receive-only satellite earth stations operating in the 11/12/14 GHz frequency bands covering the essential requirements of article 3.2 of Directive 2014/53EU"

[30] Recommendation ITU-R F.699-8: "Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz"

[31] ECC Decision (05)10: "The free circulation and use of Earth Stations on board Vessels operating in fixed satellite service networks in the frequency bands 14-14.5 GHz", approved June 2005, amended March 2019

[32] ECC Decision (05)11: "The free circulation and use of Aircraft Earth Stations (AES) in the frequency bands 14.0-14.5 GHz (Earth-to-space), 10.7-11.7 GHz (space-to-Earth) and 12.5-12.75 GHz (space-to-Earth)", approved June 2005, updated November 2024

[33] ECC Report 250: "Compatibility studies between TTT/DSRC in the band 5805-5815 MHz and other systems", approved April 2016