I n t e r n a t i o n a l   T e l e c o m m u n i c a t i o n   U n i o n

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R M.1653
(06/2003)

Operational and deployment requirements for wireless access systems including radio local area networks in the mobile service to facilitate sharing between these systems and systems in the Earth exploration-satellite service (active) and the space research service (active) in the band 5 470-5 570 MHz within the 5 460-5 725 MHz range

M Series

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R M.1653*,**,***

Operational and deployment requirements for wireless access systems including radio local area networks in the mobile service to facilitate sharing between these systems and systems in the Earth exploration-satellite service (active) and the space research service (active) in the band 5 470-5 570 MHz within the 5 460-5 725 MHz range

(Questions ITU-R 218/7 and ITU-R 212/8)

(2003)

Scope

This Recommendation recommends operational and deployment requirements for wireless access systems including RLANs in the mobile service to facilitate sharing between these systems and systems in the Earth exploration-satellite service (active) and the space research service (active) in the band 5 470-5 570 MHz within the 5 460-5 725 MHz range. This Recommendation also includes methodology and parameters used in sharing studies.

The ITU Radiocommunication Assembly,

recognizing

a) that additional spectrum for the Earth exploration-satellite service (EESS) (active) and space research service (SRS) (active) in the 5 GHz frequency range would support new applications (e.g. wideband sensors);

b) that harmonized frequencies in the 5 GHz frequency range for the mobile service would facilitate the introduction of wireless access systems (WASs) including radio local area networks (RLANs);

c) that WAS including RLANs operating in the 5 GHz bands can provide effective solutions to broadband delivery to commercial and residential users;

d) that Recommendation ITU-R M.1450 provides a description of WAS including RLANs that are intended to operate in the 5 GHz frequency range;

e) that administrations can approve relevant transmission characteristics of WAS including RLANs required to facilitate sharing with EESS (active) through national equipment approval processes;

f) that spreading the loading of WAS across the 5 470-5 725 MHz band would reduce the aggregate emission levels from WAS into EESS (wideband synthetic aperture radars (SARs)) in the band 5 470-5 570 MHz,

considering

a) that many administrations permit WAS including RLAN devices to operate in the band 5 470-5 725 MHz on a licence-exempt basis as well as in other bands such as 5 150-5 350 MHz and 5 725-5 850 MHz;

b) that broadband RLANs could be deployed as licence-exempt devices, consequently making control of their deployment density more difficult;

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* This Recommendation was jointly developed by Radiocommunication Study Groups 8 and 9, and future revisions should be undertaken jointly.

** This Recommendation should be brought to the attention of Radiocommunication Study Group 7.

*** Radiocommunication Study Group 5 made editorial amendments to this Recommendation in 2008 in accordance with Resolution ITU-R 44.

c) that the deployment density of WAS including RLANs will depend on a number of factors including intrasystem interference and by the availability of other competing wireless and wireline access technologies and services;

d) that there is a need to specify an appropriate e.i.r.p. limit and operational restrictions for WAS including RLANs in the mobile service in this band in order to share with systems in the EESS (active) and the SRS (active);

e) that studies conducted by the ITU-R concluded that radar altimeter operation with a 320 MHz bandwidth centred at 5.41 GHz is compatible with WAS including RLAN characteristics (indoor/outdoor) with an e.i.r.p. of 1 W or less;

f) that user terminals will normally be operated while in a stationary position;

g) that WAS including RLANs are capable of operating both indoors and outdoors;

h) that interference mitigation techniques such as antenna masks, transmitter power control (TPC), dynamic frequency selection (DFS) and indoor operation are beneficial to sharing between EESS (active) and SRS (active) and WAS including RLANs;

j) that aggregate interference from WAS including RLANs to the EESS (active) and SRS (active) receivers with 320 MHz bandwidth, which could overlap with the 5 470-5 570 MHz band, should be taken into account;

k) that the performance and interference criteria of spaceborne active sensors in the EESS (active) are given in Recommendation ITU-R SA.1166,

noting

a) that the characteristics of EESS (active) encompass those of SRS (active),

recommends

1 that to facilitate sharing with EESS (active) and SRS (active) in the band 5 470-5 570 MHz, as described in Annex 1, either the operational and technical restrictions given in *recommends* 2, where WAS is limited to a maximum e.i.r.p. of 1 W, or those given in *recommends* 3, where WAS is limited to a maximum transmitter power of 250 mW and other WAS configurations with spectral masks versus elevations angle, should be applied to WAS including RLANs;

2 that WAS including RLANs, operating either indoors or outdoors, in the band 5 470-5 570 MHz as described in Annexes 2 and 3, should:

a) be limited to 1 W maximum mean e.i.r.p. and 17 dBm/MHz maximum mean e.i.r.p. spectral density per transmitter (Note 1);

b) employ TPC to give an aggregate power reduction of at least 3 dB. If transmitter power control is not implemented, then the power limitation given above should be reduced by 3 dB;

c) employ DFS operating across the 5 470-5 725 MHz band designed to provide near uniform loading of the available channels;

NOTE 1 – The interference criteria of spaceborne active sensors in the EESS (active) are provided by Recommendation ITU-R SA.1166. Further studies are required to confirm the suitability of these limitations in *recommends* 2 to comply with the requirements of Recommendation ITU-R SA.1166.

3 that WAS including RLANs operating either indoors or outdoors in the band 5 470-5 570 MHz, as described in Annexes 2 and 4, should be subject to the following conditions:

a) a maximum transmitter power of 250 mW (24 dBm) or $11 + 10 \log B$ (dBm) per transmitter, whichever power is less (B is the 99% power bandwidth (MHz));

b) a maximum e.i.r.p. should not exceed 1 W (0 dBW) or $-13 + 10 \log B$ (dBW) per transmitter, whichever power is less;

c) the e.i.r.p. spectral density of the emission of a WAS including RLANs base station transmitter operating outdoor in the band 5 470-5 570 MHz should not exceed the following values for the elevation angle θ above the local horizontal plane (of the Earth):

-13 dB(W/MHz) for $0° \le \theta < 8°$

$-13 - 0.716(\theta - 8)$ dB(W/MHz) for $8° \le \theta < 40°$

$-35.9 - 1.22(\theta - 40)$ dB(W/MHz) for $40° \le \theta \le 45°$

-42 dB(W/MHz) for $\theta > 45°$

Annex 1

Methodology and parameters used in sharing studies

1 Technical characteristics of wideband spaceborne active sensors

Technical characteristics of wideband spaceborne active sensors in the 5 250-5 570 MHz band are given in Tables 1 and 2.

TABLE 1

5.3 GHz typical wideband spaceborne SAR characteristics

Parameter	Value	
	SAR2	SAR3
Orbital altitude (km)	600 (circular)	400 (circular)
Orbital inclination (degrees)	57	
RF centre frequency (MHz)	5 405	
Peak radiated power (W)	4 800	1 700
Polarization	Horizontal and vertical (HH, HV, VH, VV)	
Pulse modulation	Linear FM chirp	
Pulse bandwidth (MHz)	310	

TABLE 1 (*end*)

Parameter	Value	
	SAR2	**SAR3**
Receiver bandwidth (MHz)	320	
Pulse duration (μs)	31	33
Pulse repetition rate (pps)	4 492	1 395
Duty cycle (%)	13.9	5.9
Range compression ratio	9 610	10 230
Antenna type (m)	Planar phased array 1.8 × 3.8	Planar phased array 0.7 × 12.0
Antenna peak gain (dBi)	42.9	42.7/38 (full focus/beamspoiling)
Antenna median side-lobe gain (dBi)	–5	
Antenna orientation (degrees from nadir)	20-38	20-55
Antenna beamwidth (degrees)	1.7 (El), 0.78 (Az)	4.9/18 (El), 0.25 (Az)
Antenna polarization	Linear horizontal/vertical	
System noise temperature (K)	550	
Receiver front end 1 dB compression point ref to receiver input (dBW)	–62 input	
Analogue-digital converter (ADC) saturation ref to receiver input	–114/–54 dBW input @ 71/11 dB receiver gain	
Receiver input maximum power handling (dBW)	+7	
Operating time (%)	30 the orbit	
Minimum time for imaging (s)	15	
Service area	Land masses and coastal areas	
Image swath width (km)	20	16/320

TABLE 2

5.3 GHz typical wideband spaceborne altimeter characteristics

Jason mission characteristics	
Lifetime	5 years
Altitude (km)	1 347 ± 15
Inclination (degrees)	66
Poseidon 2 altimeter characteristics	
Signal type	Pulsed chirp linear FM
Pulse repetition frequency (PRF) (Hz)	300
Pulse duration (μs)	105.6
Carrier frequency (GHz)	5.410
Bandwidth (MHz)	320
Emission RF peak power (W)	17
Emission RF mean power (W)	0.54
Antenna gain (dBi)	32.2
3 dB aperture (degrees)	3.4
Side-lobe level/maximum (dB)	–20
Back side-lobe level/maximum (dB)	–40
Beam footprint at –3 dB (km)	77
Interference threshold	–118 dBW in 320 MHz
Service area	Oceanic and coastal areas

Annex 2

Sharing constraints between wideband radar altimeters and broadband RLANs in the 5 470-5 570 MHz band

Introduction

This Annex presents the results of the sharing analyses for the band 5 470-5 570 MHz between the wideband spaceborne radar altimeter and the broadband RLANs.

Section 1 contains the results of sharing studies between typical RLAN systems and radio altimeters. The sharing analysis gives positive conclusions about the sharing feasibility in the 5 470-5 570 MHz band.

1 Sharing between RLANs and radar altimeters

1.1 Introduction

This section presents the results of a sharing analysis for the band 5 470-5 570 MHz between spaceborne radar altimeter sensors and broadband RLANs.

1.2 Technical characteristics of the two systems

The technical characteristics of the RLANs used for the sharing analysis are those of the HIPERLAN type 2, for which Europe has published the relevant specifications.

It provides broadband RLAN communications that are compatible with wired local area networks (LANs) based on ATM and IP standards.

HIPERLAN/2 parameters:

e.i.r.p.:	0.2 W (in the 5 250-5 350 MHz band) and 1 W (in the 5 470-5 570 MHz band)
Channel bandwidth:	16 MHz
Channel spacing:	20 MHz
Antenna directivity:	Omni
Minimum useful receiver sensitivity:	–68 dBm (at 54 Mbit/s) to –85 dBm (at 6 Mbit/s)
Receiver noise power (16 MHz):	–93 dBm
C/I:	8-15 dB
Effective range:	30-80 m

In addition, it is assumed that the following features are implemented:

– TPC to ensure a mitigation factor of at least 3 dB;

– DFS associated with the channel selection mechanism required to provide a uniform spread of the loading of the RLAN devices across a minimum of 330 MHz.

It is to be noted that the numbers given in the deployment scenarios are based on the assumption of the availability of a total of 330 MHz band for RLANs. Assuming that this bandwidth will be available in two sub-bands (5 150-5 350 MHz and 130 MHz above 5 470 MHz) and given the channel spacing and the need to create a guardband at the boundaries of the two sub-bands, the assumed number of channels used in the study is 8 in the lower band and 11 in the upper band.

For the purpose of the sharing study, the following assumptions related to the RLAN usage also apply:

– average building attenuation towards EESS instruments: 17 dB;

– active/passive ratio: 5%;

– percentage of outdoor usage: 15%.

For the spaceborne radar altimeter the characteristics in Annex 1 of this Recommendation are taken.

1.3 Interference from a single RLAN into altimeters

For this analysis, we consider one RLAN in the altimeter main lobe.

The altimeter has an extended bandwidth of 320 MHz, while the HIPERLANs have a channel bandwidth of 16 MHz included within the altimeter bandwidth.

The maximum RLAN transmitted e.i.r.p. ($P_h G_h$) is 30 dBm. The altimeter antenna gain, G_0, is 32.2 dB, G_a is the off-axis antenna gain towards the RLAN, with additional 1 dB input loss, L. The altimeter is nadir pointing, antenna size is 1.2 m. R is the range of the altimeter from the RLAN.

The power received by the altimeter from one RLAN in the boresight of the SAR (i.e. $G_a = G_0$) is:

$$P_r = \frac{P_h \, G_h \, G_a \, \lambda^2}{(4\pi)^2 \, R^2 L} \tag{1}$$

Considering the most critical RLAN parameters amongst those given in § 1.2 (e.i.r.p. of 1 W, outdoor attenuation which implies no building attenuation and no additional mitigation factor), we obtain a value for $P_r = -108.3$ dBm.

The altimeter interference threshold is –88 dBm; we can thus deduce that the altimeter can withstand the operation of a number of RLANs simultaneously, since we have a 20.3 dB margin**.**

Furthermore, the altimeter is built to provide measurements mainly over oceans and is not able to provide accurate data when a significant amount of land is in view of its antenna beam.

For completeness, the number of HIPERLANs in the –3 dB footprint that can be tolerated by the altimeter operating over land is calculated in the section below.

1.4 Estimation of the number of RLANs in the –3 dB footprint of an altimeter

The approach described below enables to estimate the number of tolerable RLANs in the visibility of an altimeter using the altimeter interference threshold of –88 dBm.

A simplistic approach is chosen, which assumes that all RLAN devices are seen from the altimeter in its main beam, i.e. $G_a = G_0$, and that the distance between the altimeter and the RLAN is constant and equal to the minimum distance, which is the altitude of the altimeter.

This consists of dividing the margin obtained in the calculation below to derive the allowed number of RLANs applying some factors related to the aggregation factors.

Aggregate building attenuation

Since the altimeters are nadir pointing an additional path loss of 20 dB (due to roof and ceiling attenuation) is included when calculating the interference from indoor RLANs.

It is assumed that the operation of outdoor RLANs is allowed. As stated in § 1.2, it is assumed that 15% of devices are outdoors at a given time, which leads to an aggregate additional attenuation factor of 8 dB.

Activity factor

An activity factor of 5% is considered for the RLANs, which means that 5% of RLANs will be transmitting at once.

Transmitter power control

The e.i.r.p. of the RLAN devices is taken at the maximum level: 1 W with an additional aggregate mitigation factor of 3 dB provided by the TPC over the satellite footprint as described in § 1.2.

TABLE 3

Calculation of number of terminals in the –3 dB footprint

Altimeter interference threshold (in 320 MHz)	–88 dBm
RLAN e.i.r.p.	30 dBm
Power received from one RLAN at the altimeter	–108.3 dBm
Percentage of RLANs operating outdoors	15%
Aggregate building attenuation	8 dB
Aggregate TPC effect	3 dB
Number of active RLANs	1 377
Percentage of active terminals	5%
Number of RLAN terminals in the visibility of the altimeter	27 540

We then obtain a number of 27 540 RLANs installed in the altimeter footprint as a limit not to interfere into the altimeter. Considering the size of the altimeter footprint (77 km diameter), it corresponds to about 6 RLAN devices/km^2.

Extra margins remain in the fact that:

– No polarization loss or additional propagation losses have been taken into account (about 3 dB).

– The gain of the altimeter in the direction of RLAN devices was overestimated in the calculation.

– The distance between the altimeter and the RLAN was underestimated.

Furthermore, the altimeter is built to provide measurements mainly over oceans and is not able to provide accurate data when a significant amount of land is in view of its antenna beam.

We can thus conclude that the altimeter will not suffer from interference from HIPERLANs when used over oceans and coastal areas.

1.5 Interference from altimeters into RLANs

In this case we consider a bandwidth reduction factor B_h/B_a, since the altimeter bandwidth B_a is much larger than the HIPERLANs bandwidth B_h. B_a = 320 MHz and B_h = 18 MHz, hence a reduction factor of 12.5 dB is obtained. The RLAN antenna gain G_h towards the vertical direction is 0 dB.

The power received by one RLAN from the altimeter is:

$$P_r = \frac{P_a \, G_a \, G_h \, \lambda^2 \, B_h}{(4\pi)^2 \, R^2 L B_a} \tag{2}$$

The power transmitted by the altimeter into the RLAN will then be, at the worst case (e.g. main beam of the altimeter, closest distance 1 347 km, outdoor RLAN), –108.58 dBm, which includes a 1 dB additional input loss *L*.

This case (altimeter main beam into RLAN side lobes at the vertical) has to be considered as a worst case, since altimeter lobes decrease very quickly with boresight angle (they are at a –20 dB level 4° from nadir, and –40 dB level 15° from nadir).

Considering the RLAN receiver parameters given in § 1.2, the calculation above produces a very significant margin in every case; it is therefore concluded that the altimeter will not interfere into RLANs. Furthermore, the altimeter is a pulsed radar; the low duty cycle, polarization and additional propagation losses, which provide additional margins, have not been taken into account.

1.6 Summary of results

It is concluded that radar altimeter operation with a 320 MHz bandwidth centred at 5.41 GHz is compatible with WAS including RLAN characteristics (indoor/outdoor) with an e.i.r.p. of 1 W or less.

Annex 3

Study of interference from 5 GHz RLANs into wideband SAR satellites (EESS) (in support of *recommends* 2)

Summary

This Annex describes a study to evaluate the interference effects of a future deployment of RLANs in the 5 GHz band on wideband SAR used on board certain satellites in the EESS (active).

It is shown that, if the realistic projected densities of RLAN devices were to be deployed fully over a large urban area (e.g. London), then the interference that would be caused into the wideband SAR satellite receivers is marginally greater than the maximum limit specified. However, this is considered as representing very much the worst case and for the vast majority of the time the RLAN interference into the SAR spot beams will be well below the acceptable limits. Hence it is concluded that the sharing situation is acceptable for outdoor RLANs with a maximum e.i.r.p. of 1 W in the upper mobile band for which WRC-03 Agenda item 1.5 addresses a primary allocation.

Following concerns about more sensitive SAR systems, we have included simulations of the interference into these satellite receivers.

This study only addresses sharing with the EESS and not the SRS.

1 Introduction

The purpose of this Annex is to address one of the potentially difficult sharing issues which the ITU-R has identified in sharing studies between certain EESS satellites and RLANs in the upper band proposed to be allocated to the mobile service. This is the case of RLANs transmitting to EESS SAR satellites. In this Recommendation, we have modelled the interference into a SAR satellite receiver using a mixture of indoor and outdoor RLAN devices, which meet the HIPERLAN/2 specification based on projections of the number of RLAN devices operating within the SAR spot beam.

The interference in the reverse direction (i.e. EESS into RLAN) in the upper RLAN band has still to be addressed fully, but this is expected to be less problematical than the uplink interference case because of the short-term interference from the SAR satellites.

2 Details of sharing issue

The type of EESS satellite which is used in the studies here is that with the wideband SAR facility, in particular types SAR2[1] and SAR3, which both have a very large bandwidth straddling the upper and lower mobile bands. The large bandwidth (356.5 MHz) is because of the need to record high resolution (1 m) data over both land and sea from an altitude of 400-600 km depending on spacecraft type. For the wideband SAR2 and SAR3 types, over the full bandwidth, the thermal noise floor is –113.8 dBW, which leads to a long-term interference threshold of –119.84 dBW, assuming the interference allowance is 25% of the thermal noise. We have also checked the interference into the narrow-band more sensitive SAR systems, which only overlaps the lower RLAN band. This follows concern from the EESS community about interference into this more sensitive type of system for which the interference threshold is –128.73 dB(W/46 MHz). It should be noted that no short-term interference threshold is provided by the space science community, which implies that they cannot tolerate interference higher than these stated values.

However, we can highlight the fact that Recommendation ITU-R SA.1166 states firstly that the interference-to-noise ratio threshold of –6 dB for SARs using this band "may be exceeded upon consideration of the interference mitigation technique of SAR processing discrimination" and secondly that the threshold "should not be exceeded for more than 1% of the images in the sensor service area for systematic occurrences of interference".

Moreover, to fully model the short-term interference, the whole land surface of the Earth would have to be populated with RLAN devices, which is obviously not possible to do, especially if the number of devices is to be accurately modelled at each location. Hence, we address the static worst-case situation here, where the beam is momentarily covering an area with the highest population of RLAN devices. This is expected to be the very worst case since, for most of the time as the beam scans the Earth, the density of RLAN devices on the ground will be far less than this, because of the lower population density in smaller urban areas (e.g. towns) or in rural areas. So, the aggregate number of RLAN devices in the area of the spot beam (around 160 km^2) will be far less.

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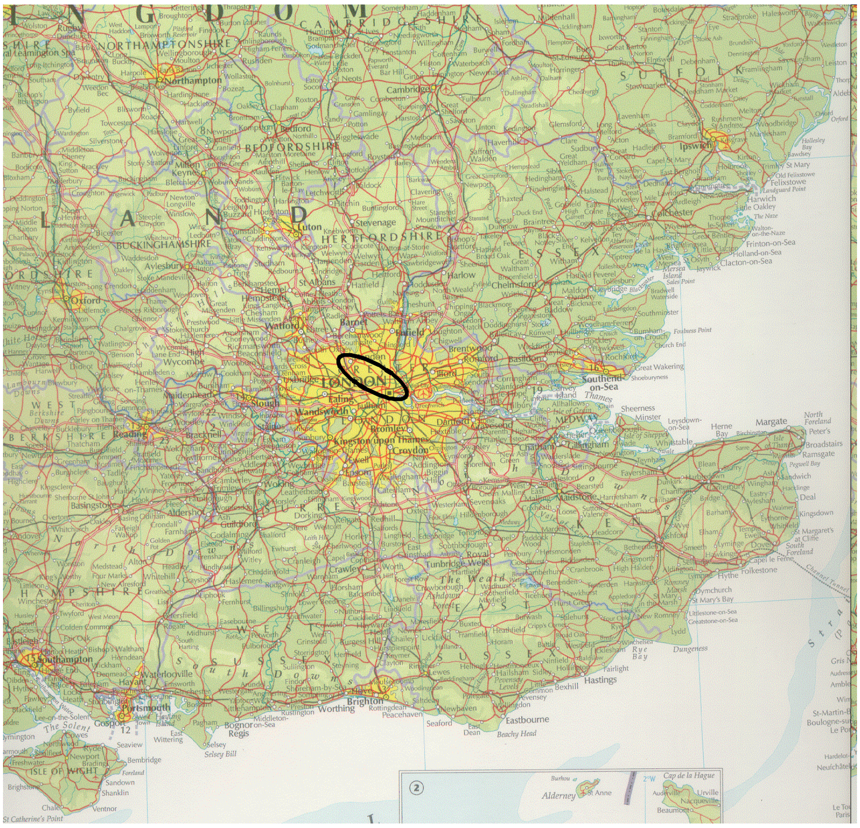
1 The SAR numbering is that used in Annex 1.

As an example, Fig. 1 indicates the size of the projected beam from a SAR2 spacecraft antenna on the surface of the Earth. Here the beam is momentarily passing over London and this is considered to be a typical worst-case situation because the beam could be filled with the maximum density of RLAN devices in such a highly populated area. As shown below, it is possible, given the European projections for the number of RLAN devices in future years, to estimate the aggregate interference from a representative complement of such devices over this heavily populated area with the agreed mix of RLAN types.

The RLAN devices are modelled as HIPERLAN/2 systems. The indoor RLANs have an excess path loss[2] due to building attenuation of 17 dB, which has been agreed in the ITU-R.

FIGURE 1

Size of SAR2 spot beam over greater London (164 km^2)
(the black ellipse denotes the half-power beamwidth)



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3 Simulations

3.1 Parameters used in the simulations

In order to realize a simulation of the interference between RLANs and EESS for the 5 GHz frequency band, we have firstly defined the number of RLAN devices concerned.

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[2] That is, in addition to free-space loss and gaseous attenuation.

Both ETSI BRAN and the HIPERLAN/2 Global Forum have produced projections for the density of penetration of RLAN devices in years 2005 and 2010, and this information is provided (for corporate, public and home use) in Appendix 1 to this Annex. These projections are expected to be the numbers for the greatest densities of corporate, public and home use and hence it is unrealistic to apply them over the full 164 km^2 spot size of the SAR2 spacecraft.

Instead, we have adopted an approach which uses the data and estimates in Appendix 1 of the densities of devices in areas such as the City of London (where the corporate use might be expected to be at its highest density) and the rest of the spot beam area as being similar to the inner London area of Camden, i.e. a more typical urban area with a mix of corporate, public and home use. Table 4 shows the population densities used. The penetration rates are those suggested in the HIPERLAN/2 Global Forum report referred to above.

The various steps to derive the aggregate e.i.r.p. are described below and the derivation of the total number of actively transmitting RLAN devices in the spot beam are shown in Tables 8 and 9.

TABLE 4

Population densities

Environment	Population density (Potential users/km^2)	Area per user (m^2)	Penetration (%)	
			2005	2010
City of London (worst-case scenario)				
Corporate	80 000	14	5	30
Public	100 000	10	2	20
Home	5 000	100	4	30
Rest of London (more typical case scenario: Camden densities)				
Corporate	4 200	14	5	30
Public	4 200	10	2	20
Home	10 000	100	4	30

From Table 1, it has been possible to estimate the number of devices contained in the footprint of 164 km^2 for SAR2, and 158 km^2 for SAR3, initially assuming the spot beam to be filled with the specified density of RLAN devices for the City of London over an area of 4 km^2 and the RLAN density for the urban area of Camden in the rest of the beam. The number of devices obtained has then been shared between outdoor and indoor devices, using a 15% outdoor usage ratio.

Then, using the active/passive ratio of 5% given in ITU-R documentation, we have restricted the number of devices that are going to be used within the simulation to the number of active devices, which we have then summed for the whole beam area.

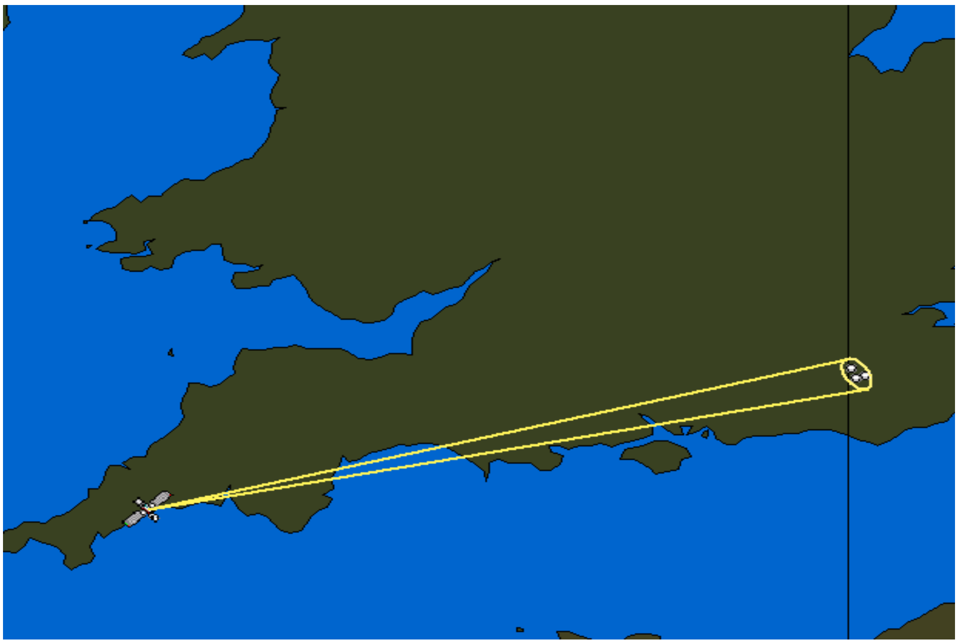
Furthermore, as the HIPERLAN/2 systems use time-division multiple access (TDMA), we have then calculated the total number of simultaneously transmitting devices by assuming that each corporate and public cell only has 1 in 10 devices (including the access point and all mobile terminals) transmitting at a time. For home use we have assumed a ratio of 1 in 4.

Rather than model every device separately in the beam, we have grouped the number of simultaneously transmitting devices into three categories: RLAN indoor lower band, RLAN indoor upper band, and RLAN outdoor upper band, for which we have estimated the total e.i.r.p. from all devices in both lower and upper bands. Effectively, all the corporate, public and home RLAN devices shown in Appendix 2 to this Annex are contained within the three groups, in proportion to the number of channels available in the upper and lower bands. Figure 2 shows the three groups lying within the SAR2 spot beam.

DFS is simulated by assuming all channels across the upper and lower bands are uniformly loaded.

FIGURE 2

SAR2 spot beam with three "groups" of RLAN present



A reduction in level due to the use of TPC of –3 dB is assumed[3]. This means the indoor RLAN devices will each have an average e.i.r.p. of –10 dBW whilst the outdoor RLAN devices will each have an average e.i.r.p. of –3 dBW. This is felt to be a realistic assumption. Omnidirectional coverage is assumed.

Since only part of each RLAN band overlaps the EESS satellite spectrum, due account has been taken of the proportion of the uplink e.i.r.p. which falls within the overlapping parts of the band. Note that we have not modelled the individual HIPERLAN channels (8 and 11, respectively, in the

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[3] For HIPERLAN/2 the maximum e.i.r.p. for indoor and outdoor RLAN devices is 200 mW and 1 W, respectively.

proposed upper and lower RLAN band). This is not expected to greatly affect the results obtained here, but may need to be done in a more accurate simulation. In this study, we have not included the effects of RLAN devices outside the half-power beamwidth. A fuller study could take this into account, however it is anticipated that the overall effect on the results would not be significant.

No benefit has been assumed from polarization coupling loss, although other simulations have assumed a 3 dB improvement factor. This is felt to be optimistic.

3.2 Simulation results and comments

The results from running the simulations are shown in Table 5.

Note that although the aggregate e.i.r.p. from the indoor devices is of the same order as that from the outdoor devices, the emissions from the indoor devices are further attenuated in the simulation by 17 dB because of the agreed factor to account for building penetration loss. This means that the outdoor devices are by far the dominant component of the total e.i.r.p. emanating from the RLANs within the spot beam area.

As an example of how the aggregate RLAN e.i.r.p. has been derived, the 177 outdoor devices estimated to be simultaneously transmitting within the SAR2 beam (see last row of Table 8) are each emitting –3 dBW. Hence the total e.i.r.p. in the SAR2 beam is –3 + 10 log(177) = 19.5 dBW. However, it is only the contribution of approximately half the upper band channels overlapping the EESS bandwidth which contribute to interference and this is accounted for in the simulation.

TABLE 5

Satellite parameters used and results of the simulations

Presentation and results		
Satellites	SAR2	SAR3
Orbital altitude (km)	600 (circular)	400 (circular)
Orbital inclination (degrees)	57	
RF centre frequency (MHz)	5 405	
Antenna orientation (degrees from nadir)	20-38	20-55
Antenna orientation used within the simulations (degrees)	30	40
Antenna beamwidth (degrees)	1.7 (El), 0.78 (Az)	4.9/18 (El), 0.25 (Az)
Antenna beamwidth within the simulations (degrees)	1.7 (El), 0.78 (Az)	4.9 (El), 0.25 (Az)
Receiver bandwidth (MHz)	356.5	
Path loss (dB)	164.43	162.1
Antenna peak gain (dBi)	42.9	42.7

TABLE 5 (*end*)

Presentation and results		
Satellites	SAR2	SAR3
RLANs total e.i.r.p. for 2005 (dBW)		
RLANs indoor lower band	16.21	16.06
RLANs indoor upper band	17.59	17.44
RLANs outdoor upper band	19.48	19.30
SAR interference threshold (I/N = –6 dB) (dBW)	–119.84	
Total interference obtained during the simulations (dBW)	–106.3	–103.6
Interference exceedance (dBW)	13.54	16.24
RLANs total e.i.r.p. for 2010 (dBW)		
RLANs indoor lower band	24.90	24.75
RLANs indoor upper band	26.28	26.14
RLANs outdoor upper band	28.13	27.98
SAR interference threshold (I/N = –6 dB) (dBW)	–119.84	

Table 6 provides a separate summary to highlight the exceeded levels for the two types of SAR studied for this worst-case situation.

TABLE 6

Summary of interference exceeded levels

	2005 (dB)	**2010 (dB)**
SAR2	13.5	22.1
SAR3	16.2	25

Taking the results for 2005 first. Clearly, for the SAR2 and SAR3 cases, the outdoor RLAN devices have a particularly strong influence on the level of interference generated in the satellite receiver, which is partially due to the higher e.i.r.p. (1 W), but predominantly due to the absence of building penetration loss which strongly aids the sharing situation for the indoor RLAN case (in fact removing the indoor devices from the simulation makes virtually no change to the result).

For completeness, simulations were also run to look at the case of having no outdoor devices in the upper band and the interference into all types of SAR device was found to be within the tolerable limits for the scenarios in both years 2005 and 2010.

However, in spite of the fact that the interference thresholds are exceeded in each case (but for a very short period of time), all of the calculated levels for the year 2005 can probably be accommodated since Recommendation ITU-R SA.1166 states firstly that the interference-to-noise ratio threshold of –6 dB for SARs using this band “may be exceeded upon consideration of the interference mitigation technique of SAR processing discrimination", and secondly that the threshold "should not be exceeded for more than 1% of the images in the sensor service area for systematic occurrences of interference".

The results for the year 2010 indicate that more severe interference would be caused to all types of SAR receiver. However, as the HIPERLAN/2 Global Forum have recognized (see Appendix 3), extra channels will be required by that time to cater for the additional RLAN traffic predicted. Therefore, concentrating all the traffic forecast for that time into the 19 channels identified in the 455 MHz bandwidth under study here is not a realistic sharing scenario to simulate.

4 Summary of results

– Using what is believed to be a realistic projection of the most dense deployment of 5 GHz RLAN devices in a very large urban area fully filling the SAR spot beams (> 159 km^2), it is clear that, although the use of outdoor RLAN devices will strongly influence the interference levels into wideband EESS SAR spacecraft receivers, the levels are only likely to be excessive (worst-case 16 dB above the threshold in the year 2005) in urban areas, for which it is understood that the measurement data is not used.

– In general, the interference level will be below the threshold as there will be very few areas like that modelled here where the whole spot beam is exposed to the worst-case RLAN deployment densities. It is thus expected that the 99% coverage requirement with interference below the threshold as required in Recommendation ITU-R SA.1166 will be respected.

– Furthermore, we have not taken into account building blockage which is difficult to model but may be significant for outdoor devices deployed in urban areas and this is likely to be an additional ameliorating factor.

– It can be appreciated why the EESS community are concerned about a proliferation of outdoor RLAN devices, but from this study it would seem that interference levels around the level of the threshold limit are likely to be rare and probably acceptable to the EESS community given the relaxation allowed in Recommendation ITU-R SA.1166 under certain conditions.

– No obvious mitigation techniques are available here. Outdoor RLAN devices are assumed to be "omnidirectional" in coverage to cope with highly elevated base stations. The inclusion of a 3 dB polarization coupling loss factor is difficult to justify from a consideration of the RLAN radiation characteristics.

– It is likely that more spectrum will be required by year 2010 to accommodate the forecasts referred to in § 3.1.

– This analysis indicates that sharing may be feasible between WAS including RLANs and EESS, in accordance with *recommends* 2.

– Further studies are required to confirm the suitability of those conditions in *recommends* 2 to comply with the requirements of Recommendation ITU-R SA.1166.

Appendix 1
to Annex 3

Source information for the environments analysed

The environments analysed are:

TABLE 7

a) Corporate office building

Attribute	Corporate
End-user equipment	PC or work station, personal digital agenda (PDA)
Environment examples	Corporate office, office landscape
Range	Up to 50 m for indoor systems desirable
Quality of service (QoS) expectation	Same as desktop
Applications	Same as desktop
Mobility	Stationary while in use
Coverage	Continuous within workspace
Cell geometry	Assume 30 m radius (in practice access point layout adapted to building)
Cell area	2 830 m^2

b) Public wireless access

Attribute	Public wireless access
End-user equipment	Portable computer, e.g. notebook or palmtop/PDA
Environment examples	Offices, schools, hospitals, airports, railway stations, shopping centres, etc.
Range	Up to 50 m for indoor systems; Up to 100 m for outdoor systems
QoS expectation	Slightly lower than desktop
Applications	Similar to desktop
Mobility	Limited or stationary during use
Coverage	Continuous within a defined area, e.g. airport hall
Cell geometry	Circular, radius 40 m
Cell area	5 030 m^2

TABLE 7 (*end*)

c) Home area network

Attribute	Home area network
End-user equipment	Personal computer, television, entertainment cluster, security systems, controls, PDA
Environment examples	Domestic premises, i.e. small rooms two or several floors with high attenuation between floors
Range	Up to 15 m
QoS expectation	Consistent with real-time multimedia services
Applications	Real-time multimedia
Mobility	Walking speed
Coverage	Continuous within specific rooms
Cell geometry	Circular, radius 15 m
Cell area	707 m^2

d) Market and traffic

Environment	Population density (Potential users/km^2)	Area per user (m^2)	Penetration (%)	
			2005	2010
Corporate	70 000	14	5	30
Public	100 000	10	2	20
Home	10 000	100	4	30

Appendix 2 to Annex 3

Calculation of the total number of RLAN devices in the spot beam of each SAR receiver type

The following parameters are used in Tables 8 and 9.

Population densities and penetration rates are from Table 4.

– Outdoor usage ratio: 15%
– Active/passive ratio: 5%
– No. of channels in upper RLAN band: 11
– No. of channels in lower RLAN band: 8
– Simultaneously active devices (corporate/public): 1 in 10
– Simultaneously active devices (home): 1 in 4

TABLE 8

Data for SAR2 (spot beam size on Earth's surface: 164 km²)[4]

Environment	**2005**		**2010**	
City of London				
Number of devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	13 600	2 400	81 600	14 400
Public	6 800	1 200	68 000	12 000
Home	680	120	5 100	900
Number of active devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	680	120	4 080	720
Public	340	60	3 400	600
Home	34	6	255	45
Total active devices	1 054	186	7 735	1 365
Rest of London (within the beam area)				
Number of devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	28 560	5 040	171 360	30 240
Public	11 424	2 016	114 240	20 160
Home	54 400	9 600	408 000	72 000
Number of active devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	1 428	252	8 568	1 512
Public	571	101	5 712	1 008
Home	2 720	480	20 400	3 600
Total active devices	4 719	833	34 680	6 120
Total beam				
Total number of active devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	2 108	372	12 648	2 232
Public	911	161	9 112	1 608
Home	2 754	486	20 655	3 645
Total active devices	5 773	1 019	42 415	7 485
Total number of simultaneously transmitting devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	211	38	1 265	224
Public	92	17	912	161
Home	689	122	5 164	912
Total RLAN devices per spot beam	992	177	7 341	1 297

[4] The area of the City of London is 4 km². The area covered by the rest of the spot beam is 160 km².

TABLE 9

Data to use for SAR3 (spot beam size on Earth's surface: 158 km^2)[5]

Environment	2005		2010	
City of London				
Number of devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	13 600	2 400	81 600	14 400
Public	6 800	1 200	68 000	12 000
Home	680	120	5 100	900
Number of active devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	680	120	4 080	720
Public	340	60	3 400	600
Home	34	6	255	45
Total active devices	1 054	186	7 735	1 365
Rest of London (within the beam area)				
Number of devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	27 489	4 851	164 934	29 106
Public	10 996	1 940	109 956	19 404
Home	52 360	9 240	392 700	69 300
Number of active devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	1 374	243	8 247	1 455
Public	550	97	5 498	970
Home	2 618	462	19 635	3 465
Total active devices	4 542	802	33 380	5 891
Total beam				
Total number of active devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	2 054	363	12 327	2 175
Public	890	157	8 898	1 570
Home	2 652	468	19 890	3 510
Total active devices	5 596	988	41 115	7 256
Total number of simultaneously transmitting devices	**Indoor**	**Outdoor**	**Indoor**	**Outdoor**
Corporate	206	37	1 233	218
Public	89	16	890	158
Home	663	117	4 973	878
Total RLAN devices per spot beam	958	170	7 096	1 254

5 The area of the City of London is 4 km^2. The area covered by the rest of the spot beam is 154 km^2.

Appendix 3
to Annex 3

Summary of spectrum requirements

TABLE 10

Environment	Corporate		Home		Public	
	2005	**2010**	**2005**	**2010**	**2005**	**2010**
Number of 20 MHz channels	13	27	2	20	2	23
Total spectrum for all services in environment (MHz)	260	540	40	400	40	460

Annex 4

Interference analysis between WAS and wideband SAR systems in the EESS (active) in the 5 470-5 570 MHz frequency range (in support of *recommends* 3)

1 Introduction

This Annex examines the potential interference between the EESS (active) and indoor and outdoor WAS including RLANs (WAS/RLANs) both operating in the 5 GHz range. In particular, this analysis examines the potential interference from WAS including RLANs to wideband SAR receivers with 320 MHz bandwidth, which could overlap with the 5 470-5 570 MHz band.

It is noted that although this study examined interference into wideband SARs, which operate in the band 5 250-5 570 MHz, the results of this study are only applicable to the band 5 470-5 570 MHz and are not transferable to the band 5 250-5 350 MHz.

In addition to the studies contained in this Annex, further studies were also performed using a different method. This study is contained in Appendix 1 to this Annex.

In order to examine the practical technologies for the implementation of radiation (e.i.r.p.) mask recommended in this Annex, studies were performed. These studies are included as Appendix 2 to this Annex.

2 Technical characteristics of EESS[6]

A number of different EESS applications operate or plan to operate in the 5 GHz band including SAR2, SAR3, scatterometers and altimeters.

[6] For the purpose of interference analysis, it is assumed that the characteristics of active sensors for space research and Earth exploration-satellite are the same for this frequency range.

In this analysis, the aggregate interference from indoor and outdoor WAS/RLANs into SAR2 and SAR3 is examined.

Table 11 shows the technical characteristics of spaceborne active sensors in the 5 GHz band used in this analysis.

TABLE 11

Spaceborne active sensors – Technical characteristics (summary)

Parameter	SAR2	SAR3
Orbital altitude (km)	600 (circular)	400 (circular)
Orbital inclination (degrees)	57	
Frequency (MHz)	5 405	
Peak radiated power (W)	4 800	1 700
Pulse bandwidth (MHz)	310	
Antenna gain pattern	See Table 12	See Table 13
Antenna orientation (degrees from nadir)	20-38	20-55
Receiver noise figure (dB)	4.62	
Footprint (km^2)	164.3	225.30
Receiver bandwidth (MHz)	356.5	
Noise power (dBW)	–113.84	
SAR interference threshold ($I/N = -6$ dB) (dBW)	–119.84	

TABLE 12

SAR2 antenna pattern

SAR2 antenna gain pattern SAR2	
Vertical	
$G_v(\theta_v) = 42.7 - 0.478\ (\theta_v^2)$ dBi	$0° \leq \theta_v < 3.6°$
$G_v(\theta_v) = 40.1 - 1.0\ (\theta_v)$ dBi	$3.6° \leq \theta_v < 45°$
$G_v(\theta_v) = -5$ dBi	$45° \leq \theta_v$
Horizontal	
$G_h(\theta_h) = 0.0 - 212\ (\theta_h^2)$ dBi	$0° \leq \theta_h < 0.24°$
$G_h(\theta_h) = -11.7 - 2.2\ (\theta_h)$ dBi	$0.24° \leq \theta_h < 2.7°$
$G_h(\theta_h) = -17.6$ dBi	$2.7° \leq \theta_h$
Gain pattern	
$G(\theta) = \text{Max}\ \{G_v(\theta_v) + G_h(\theta_h), -5\}$ dBi	

TABLE 13

SAR3 antenna pattern

SAR3 antenna gain pattern	
Vertical	
$G_v(\theta_v) = 42.9 - 3.21\ (\theta_v^2)$ dBi	$0° \leq \theta_v < 1.4°$
$G_v(\theta_v) = 38 - 1.0\ (\theta_v)$ dBi	$1.4° \leq \theta_v < 43°$
$G_v(\theta_v) = -5$ dBi	$43° \leq \theta_v$
Horizontal	
$G_h(\theta_h) = 0.0 - 21.5\ (\theta_h^2)$ dBi	$0° \leq \theta_h < 0.75°$
$G_h(\theta_h) = -10.4 - 2.2\ (\theta_h)$ dBi	$0.75° \leq \theta_h < 8.4°$
$G_h(\theta_h) = -28.9$ dBi	$8.4° \leq \theta_h$
Gain pattern	
$G(\theta) = \text{Max}\ \{G_v(\theta_v) + G_h(\theta_h), -5\}$ dBi	

3 Technical characteristics of outdoor WAS/RLANs

Table 14 summarizes the technical characteristics of outdoor WAS/RLANs used in this analysis.

TABLE 14

Technical characteristics of outdoor WAS/RLANS in the 5 GHz range

Parameter	Value
Bandwidth	20 MHz
Antenna gain pattern – azimuth plane	Omnidirectional
Antenna gain pattern – elevation plane (above the horizon)	Implicit within e.i.r.p. mask as shown in Fig. 3
Antenna tilt	0°
Cell radius	1.5 km
Transmitter power	250 mW = –6 dBW
Scattering coefficient	17 dB
Active ratio	100%

For the purpose of this analysis, the antenna is assumed to be omnidirectional in the azimuth plane and generates e.i.r.p. as shown in Fig. 3 in the elevation plane. In reality, these transmitters would operate with directional antennas both in the base (hub) stations and in the terminal stations. By specifying a single e.i.r.p. mask for all transmitters there is no need to prescribe different masks for base stations and terminal stations and associated active ratio and the analysis would further represent absolute worst-case results.

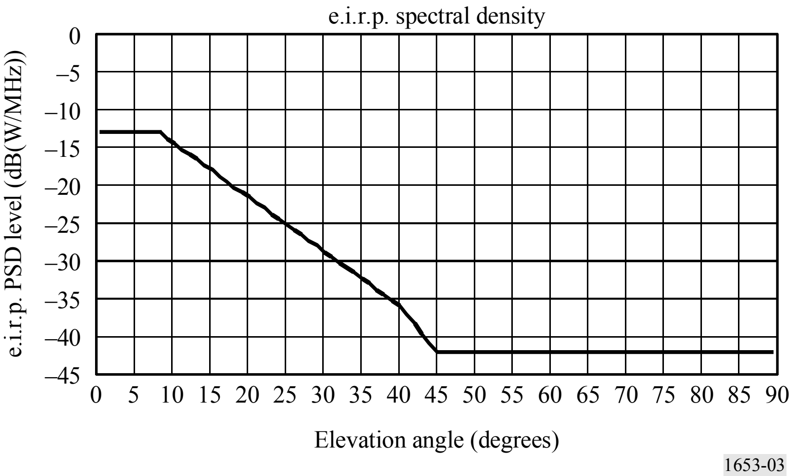
Furthermore, it is assumed that there will be one such antenna per cell operating at the same frequency channel at the same time as the EESS. The distribution of WAS/RLAN cells will be discussed in § 4.

It should be noted that by assuming omnidirectional antenna in the azimuth plane, it implies that at any given instant in time, there will be one transmitter from each cell transmitting at its highest possible e.i.r.p. towards the EESS.

Antenna tilt of the transmitters is set as 0°. In reality, transmit antennas could operate with tilt. However, as long as its e.i.r.p. meets the mask as shown in Fig. 3, the result of this analysis remains valid.

FIGURE 3

WAS/RLANS e.i.r.p. mask above local horizon as a function of elevation angle



The corresponding equations of the e.i.r.p. mask as shown in Fig. 3 are as follows:

$$-14 \quad \text{dB(W/MHz)} \qquad \text{for} \quad 0^\circ \leq \theta < 8^\circ$$

$$-14 - 0.718(\theta - 8) \quad \text{dB(W/MHz)} \qquad \text{for} \quad 8^\circ \leq \theta < 40^\circ$$

$$-38.9 - 1.22(\theta - 40) \quad \text{dB(W/MHz)} \qquad \text{for} \quad 40^\circ \leq \theta \leq 45^\circ$$

$$-45 \quad \text{dB(W/MHz)} \qquad \text{for} \quad \theta > 45^\circ$$

where θ is the elevation angle above local horizon in degrees.

Below the local horizon, an e.i.r.p. of 1 W or –13 dB(W/MHz) is used.

4 Technical characteristics of indoor WAS/RLANs

For the purposes of this simulation, the technical characteristics of indoor WAS/RLANs systems are as shown in Table 15.

TABLE 15

Technical characteristics of indoor WAS/RLANs in the 5 GHz range

Parameter	Value
Bandwidth	20 MHz
Antenna	Isotropic (for simulation purposes)
Antenna gain	0 dBi
Transmitter power	250 mW
Building loss	18 dB
Active ratio	100%

5 Distribution of outdoor WAS/RLANs systems

The method used to estimate the global deployment of WAS/RLANs is based on urban population centres that exceed 750 000 people as contained in the United Nations population database for the year 2015.

The following equation is used to estimate the radius of an urban area:

$$R_p = \alpha P^{\beta}$$

where R_p is the radius of the urban area (km), the value of α is set at 0.035 for urban centres in the United States of America and 0.0155 elsewhere. The value of β is fixed at 0.44 everywhere. The maximum number of possible hubs, N, within the radius of the urban area is calculated using the following equation:

$$N = Round\left(\eta_d\left(\frac{R_p}{R_h}\right)^2\right)$$

where η_d is the practical deployment factor used to account for the difference between the maximum number of hub stations and the most likely number of hub stations taking into account economic, demographic and geographic factors. A η_d = 0.3 is used in this study. The variable R_h represents the radius of a typical WAS/RLAN cell (km), in this study a value of 1.5 km is used.

In this study, a number of cities were modelled. City A represents one of the most densely populated large urban areas in the world, hence providing the worst-case aggregate interference into the EESS. Based on the above method, with a population 17.6 million, the radius of this city was determined to be approximately 54 km. In order to take into account effects of stations operating in suburban areas surrounding the city as well as to simulate effects of aggregate interference from stations operating in near-by cities, the radius was extended to approximately 81 km. Within this area, using a deployment factor of 0.3 as discussed above, approximately 870 cells of 1.5 km radius were modelled in a square area with a diagonal length of 162 km. Other cities of moderate sizes were also simulated. A summary of the assumptions made is shown in Table 16.

TABLE 16

Summary of parameters used to model cities

	City A	**City B**	**City C**	**City D**	**City E**	**City F**
City of similar size	City of New York	Chicago	Tokyo	Sao Paulo	Shanghai	Paris
Population (million)	17.6	7.5	28.9	20.3	17.9	9.7
Radius of urban city (km)	54	37	30	26	24	18
Radius of city simulated (km)	81	56	45	38	36	27
Number of active transmitters	870	418	270	193	173	97
Deployment area (km^2)	13 122	6 272	4 050	2 888	2 592	1 458
Density (number of transmitters/km^2)	0.066	0.066	0.066	0.066	0.066	0.066

Within each cell, it is assumed that there is one transmitter operating at all times on the same frequency as the EESS, with characteristics as described in § 3 of this Annex.

It was also assumed that one third of the overall active stations would each contribute 17 dB to the overall scattering effect.

6 Distribution of indoor WAS/RLAN systems

The distribution of indoor WAS is described in Table 17. These simultaneously active systems are distributed within the respective areas in a uniform manner. These systems are assumed to be located in the centre of the city.

It should be noted that it is generally difficult for indoor and outdoor WAS/RLAN systems to operate in the same geographical area on the same frequency at the same time (a self-limiting effect). Therefore, by placing these indoor WAS/RLAN systems in the centre of the city, the overall interference into the EESS has been over-estimated.

TABLE 17

Distribution of indoor systems under the SAR2 and SAR3 footprints

EESS	SAR2	SAR3
Number of active indoor WAS/RLAN systems	945	1 296
ployment area (km^2)	164.3	225.3
Density (number of active systems/km^2)	5.75	5.75

7 Interference into SAR2

In addition to the assumptions in § 1 to 6, polarization losses of 3 dB for outdoor systems and 0 dB for indoor systems, and no atmospheric attenuation are also assumed. The wideband SAR2 satellite was simulated to run for a period of 30 days, the period of the time in which the EESS would receive maximum interference was then revisited with time steps of 200 ms. The results shown in Figs. 4 and 5 represent a period of time in which the EESS would be visible by the WAS/RLAN systems in a single orbit in which EESS would experience the maximum possible interference from the aggregate interference of WAS/RLANs.

Interference analyses into SAR2 operating at 38° from nadir for four different cases were performed. The result, which represents the aggregate interference of indoor and outdoor WAS/RLANs with the addition of surface scattering effect is shown in Fig. 4. The first case examines the aggregate signal into the EESS given that all outdoor systems operate with 1 W e.i.r.p. with no e.i.r.p. mask, i.e. with omnidirectional antenna. The second case examines the effect of outdoor systems operating in accordance with the e.i.r.p. mask described in § 3. The third case examines the effect of all outdoor systems pointing upward, violating the e.i.r.p. mask, randomly from 0° to 10° above the local horizon. Finally, the last case examines the effect of all outdoor systems pointing upward, violating the e.i.r.p. mask, randomly from 0° to 20° above the local horizon. A summary of the results is provided in Table 18.

FIGURE 4

Aggregate interference from indoor and outdoor WAS/RLANs (including the effect of scattering) into SAR2 operating at 38° from nadir in the frequency bands 5 250-5 570 MHz with comparison on inadvertently upward pointing systems and omnidirectional WAS/RLAN systems

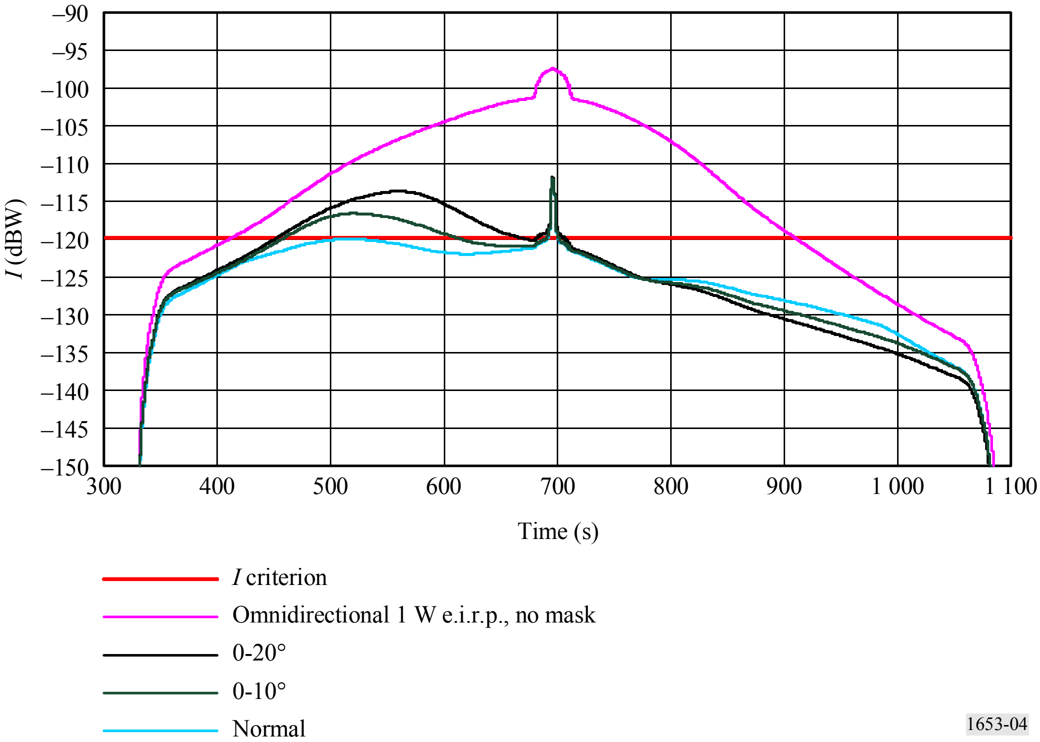


TABLE 18

Summary of results (as shown in Fig. 4) on aggregate interference into SAR2 operating at 38° from nadir

City A (New York)						
	Normal (with e.i.r.p. mask at 0° tilt)	**1 W e.i.r.p., no mask**	**With mask pointed 0° to 10° above local horizon**		**With mask pointed 0° to 20° above local horizon**	
I criterion (dBW)	–119.84					
Maximum *I* (dBW)	–111.9	–97.5	–117.5	–111.9	–113	–111.8
Duration of time when SAR2 is within view of the city (s)	758					
Duration of time when *I* exceeds criterion (s)	8.6	496.2	151.2	9.4	214.2	21.6
Time (%)	1.1	65.5	19.9	1.2	28.2	2.8

Given that the WAS/RLAN systems employ the e.i.r.p. mask as described in § 3 of this Recommendation, the interference criterion for SAR2 is met for the majority of time except for approximately 1.1% of the time the satellite is within view of the city, when the interference criterion is exceeded. The interference is mostly the result of emissions from indoor systems.

When no e.i.r.p. mask is used, that is, if WAS/RLAN systems are operating with omnidirectional antennas at an e.i.r.p. of 1 W in 20 MHz, the interference criterion for SAR2 is exceeded for approximately 65% of the time the satellite is within view of the city.

If all the WAS/RLAN transmitters use the e.i.r.p. mask as described in § 3, but are inadvertently pointed upwards anywhere between 0° to 10° randomly, the interference criterion for SAR2 may be exceeded for approximately 19.9% of the time in which the satellite is within view of the city by a maximum of approximately 2 dB and 1.2 % of the time by approximately 8 dB.

If all the WAS/RLAN transmitters use the e.i.r.p. mask as described in § 3, but are inadvertently pointed upwards anywhere between 0° to 20° randomly, the interference criterion for SAR2 may be exceeded for approximately 28% of the time in which the satellite is within view of the city by a maximum of approximately 6 dB and 2.8% of the time by approximately 8 dB.

It should be noted that in the results noted in the two preceding paragraphs it was assumed that all systems are pointed upwards, that is, they are all in violation of the mask. If only a percentage of these systems were violating the mask, interference into the satellite would be substantially less.

Interference analyses into SAR2 (operating at 38° from nadir) from different sizes of cities were also examined. The results, shown in Fig. 5, represent the aggregate interference of indoor and outdoor WAS/RLANs, with the addition of surface scattering effects. A summary of the results is also presented in Table 19.

FIGURE 5

Aggregate interference from indoor and outdoor WAS/RLANs (including the effect of scattering) into SAR2 operating at 38° from nadir in the frequency bands 5 250-5 570 MHz with comparison on aggregate interference from different sizes of cities

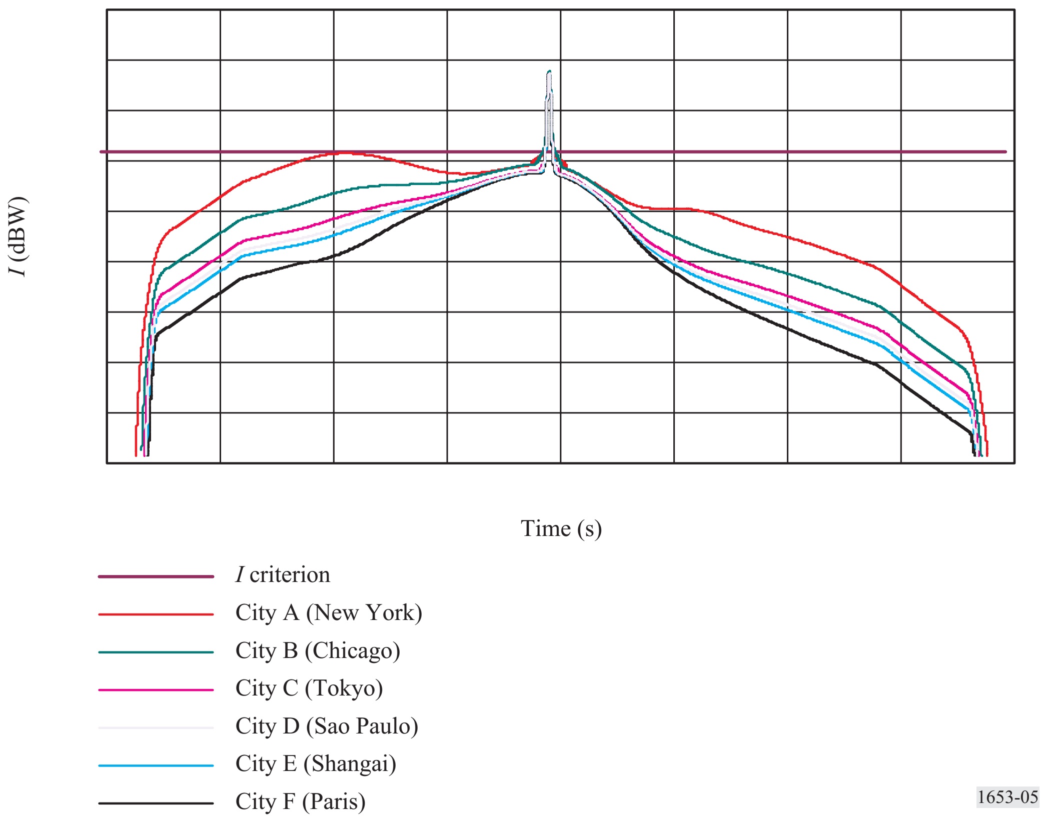


TABLE 19

Summary of results (as shown in Fig. 5) on aggregate interference into SAR2 operating at 38° from nadir

	City A	City B	City C	City D	City E	City F
	City of New York	**Chicago**	**Tokyo**	**Sao Paulo**	**Shanghai**	**Paris**
I criterion (dBW)	–119.84					
Maximum *I* (dBW)	–111.9		–112.1			
Duration of time when SAR2 is within view of the city (s)	758	747.4	742.8	739.8	739	735.4
Duration of time when *I* exceeds criterion (s)	8.6	8.4	6.6	6.4	6.8	5.8
Time (%)	1.1		0.9			0.8

As shown in Fig. 5, the interference criterion is exceeded for approximately 1% of the time in the cities simulated with a maximum interference of –112 dBW. However, by examining Fig. 5 and noting that the "peak" of the interference is mostly the result of emissions from indoor isotropic WAS/RLAN systems, it can be seen that for outdoor WAS/RLAN systems operating in cities of typical sizes, an average margin of 5 to 15 dB exists before the aggregate interference may exceed the interference criterion. Based on these results, sharing will be difficult between SAR2 and WAS/RLANs operating with 1 W e.i.r.p. in 20 MHz with omnidirectional antennas and no emission mask.

Based on these results, sharing is possible between the EESS (active) and WAS/RLANs, operating either indoors or outdoors with characteristics as shown in § 3 and 4. Furthermore, with reference to the preceding paragraph, it may be concluded that the e.i.r.p. mask for outdoor WAS/RLANs as shown in Fig. 3 could be increased (relaxed) by at least 3 dB and the interference criterion for SAR2 will still be met for the vast majority of cities in the world. Hence, the e.i.r.p. mask may be modified as follows:

$$-11 \quad \text{dB(W/MHz)} \qquad \text{for} \quad 0° \leq \theta < 8°$$

$$-11 - 0.716(\theta - 8) \quad \text{dB(W/MHz)} \qquad \text{for} \quad 8° \leq \theta < 40°$$

$$-35.9 - 1.22(\theta - 40) \quad \text{dB(W/MHz)} \qquad \text{for} \quad 40° \leq \theta < 45°$$

$$-42 \quad \text{dB(W/MHz)} \qquad \text{for} \quad \theta \geq 45°$$

where θ is the elevation angle above local horizon (degrees).

However, given that the e.i.r.p. is assumed to be limited to 1 W e.i.r.p. or –13 dB(W/MHz), the e.i.r.p. mask is modified as follows:

$$-13 \quad \text{dB(W/MHz)} \qquad \text{for} \quad 0° \leq \theta < 8°$$

$$-13 - 0.716(\theta - 8) \quad \text{dB(W/MHz)} \qquad \text{for} \quad 8° \leq \theta < 40°$$

$$-35.9 - 1.22(\theta - 40) \quad \text{dB(W/MHz)} \qquad \text{for} \quad 40° \leq \theta < 45°$$

$$-42 \quad \text{dB(W/MHz)} \qquad \text{for} \quad \theta \geq 45°$$

where θ is the elevation angle above local horizon (degrees).

8 Interference into SAR3

In addition to the assumptions presented in § 1 to 6, polarization losses of 3 dB for outdoor systems and 0 dB for indoor systems, and no atmospheric attenuation are also assumed. The wideband SAR3 satellite was simulated to run for a period of 30 days, the period of the time in which the EESS would receive maximum interference was then revisited with time steps of 200 ms. The results shown in Figs. 6 and 7 represent a period of time in which the EESS would be visible by the WAS/RLAN systems in a single orbit in which EESS would experience the maximum possible interference from the aggregate interference of WAS/RLANs.

Interference analyses into SAR3 operating at 55° from nadir for four different cases were performed. The result, which represents the aggregate interference of indoor and outdoor WAS/RLANs with the addition of surface scattering effect is shown in Fig. 6. The first case examines the aggregate signal into the EESS given that all outdoor systems operate with 1 W e.i.r.p. with no e.i.r.p. mask, i.e. with omnidirectional antennas. The second case examines the effect of outdoor systems operating in accordance with the e.i.r.p. mask described in § 3. The third case examines the effect of all outdoor systems pointing upward, violating the e.i.r.p. mask, randomly from 0° to 10° above the local horizon. Finally, the last case examines the effect of all outdoor systems pointing upward, violating the e.i.r.p. mask, randomly from 0° to 20° above the local horizon. A summary of results is provided in Table 20.

FIGURE 6

Aggregate interference from indoor and outdoor WAS/RLANs (including the effect of scattering) into SAR3 operating at 55° from nadir in the frequency bands 5 250-5 570 MHz with comparison on inadvertently upward-pointing systems and omnidirectional WAS/RLAN systems

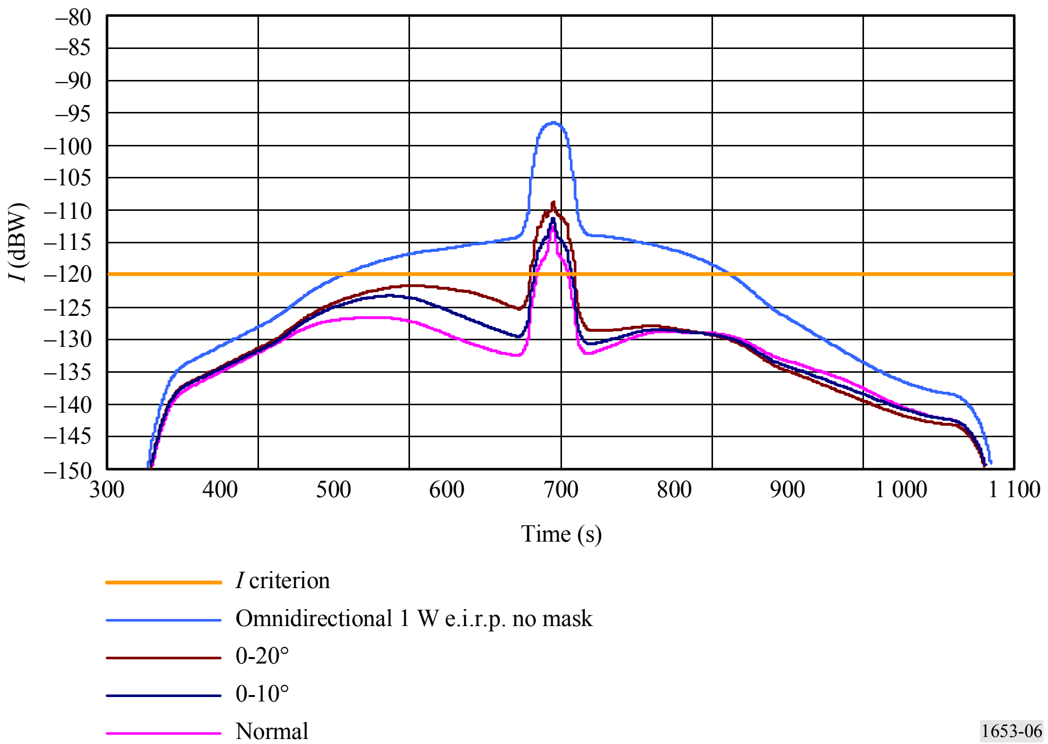


TABLE 20

Summary of results (as shown in Fig. 6) on aggregate interference into SAR3 operating at 55° from nadir

City A (New York)				
	Normal with e.i.r.p. mask	**1 W e.i.r.p., no mask**	**With mask pointed 0° to 10° above local horizon**	**With mask pointed 0° to 20° above local horizon**
I criterion (dBW)	–119.84			
Maximum *I* (dBW)	–112.4	–96.4	–111.1	–109.7
Duration of time when SAR3 is within view of the city (s)	568			
Duration of time when *I* exceeds *I* criterion (s)	20	254.2	24.8	29.2
Time (%)	3.5	45	4.4	5.1

Given that the WAS/RLAN systems employ the e.i.r.p. mask as described in § 3 of this Annex, the interference criterion for SAR3 is met for the majority of time except for approximately 3.5% of the time the satellite is within view of the city when the interference criterion is exceeded. This interference is mostly the result of emissions from indoor systems.

When no e.i.r.p. mask is used, that is, if WAS/RLAN systems are operating with omnidirectional antenna with an e.i.r.p. of 1 W in 20 MHz, the interference criterion for SAR3 is exceeded for approximately 45% of the time the satellite is within view of the city.

If all the WAS/RLAN transmitters use the e.i.r.p. mask as described in § 3, but are inadvertently pointed upwards anywhere between 0° to 10° randomly, the interference criterion for SAR3 may be exceeded for approximately 4.4% of the time in which the satellite is within view of the city by a maximum of approximately 8 dB.

If all the WAS/RLAN transmitters use the e.i.r.p. mask as described in § 3, but are inadvertently pointed upwards anywhere between 0° to 20° randomly, the interference criterion for SAR3 may be exceeded for approximately 5.1% of the time in which the satellite is within view of the city by a maximum of approximately 8 dB.

It should be noted that in the results noted in the two preceding paragraphs it was assumed that all systems are pointed upwards, that is, they are all in violation of the mask. If only a percentage of these systems were violating the mask, interference into the satellite would be substantially less.

Interference analyses into SAR3 (operating at 55° from nadir) from different sizes of cities were also examined. The results, shown in Fig. 8, represent the aggregate interference of indoor and outdoor WAS/RLANs, with the addition of surface scattering effects. A summary of the results is also presented in Table 21.

As shown in Fig. 6, the interference criterion is exceeded for approximately 3.5% of the time in City A (extremely dense populated area). In other cities of more moderate size, the interference criterion is exceeded for very short durations of time (around 1%). For cities of typical size, an average margin of at least 10 dB exists before the aggregate interference may exceed the interference criterion.

FIGURE 7

Aggregate interference from indoor and outdoor WAS/RLANs (including the effect of scattering) into SAR3 operating at 55° from nadir in the frequency bands 5 250-5 570 MHz with comparison on aggregate interference from different sizes of cities

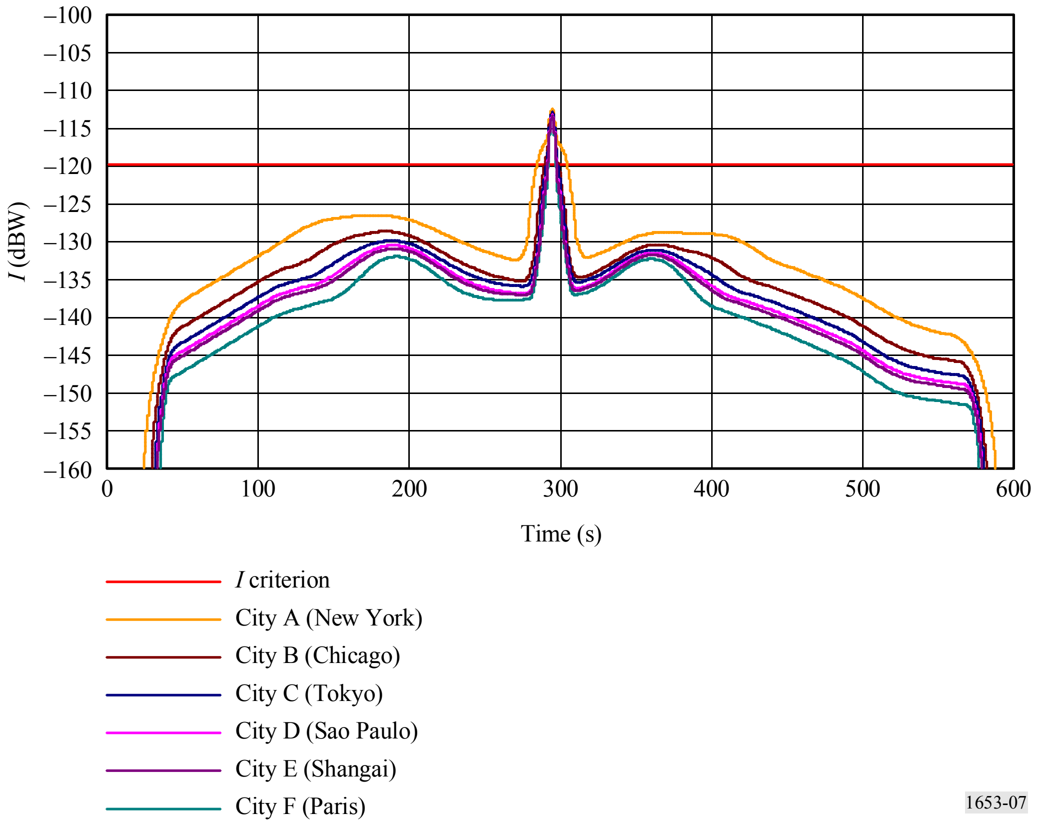


TABLE 21

Summary of results (as shown in Fig. 7) on aggregate interference into SAR3 operating at 55° from nadir

	City A	**City B**	**City C**	**City D**	**City E**	**City F**
	City of New York	**Chicago**	**Tokyo**	**Sao Paulo**	**Shanghai**	**Paris**
I criterion (dBW)	–119.84					
Maximum *I* (dBW)	–112.4	–112.9		–113.3	–113.4	–113.5
Duration of time when SAR3 is within view of the city (s)	568	556.6	553.2	550.4	549.6	546
Duration of time when *I* exceeds *I* criterion (s)	20	9	7	6		
Time (%)	3.5	1.6	1.3	1.1		

Based on these results, sharing will be difficult between SAR3 and WAS/RLANs operating with omnidirectional antennas at 1 W e.i.r.p. in 20 MHz and no emission mask.

However, sharing is possible between SAR3 and WAS/RLANs, operating either indoors or outdoors with characteristics as shown in the previous sections. Furthermore, with reference to § 8.8, it may also be concluded that the e.i.r.p. mask for outdoor WAS/RLANs as shown in Fig. 3 may be increased (relaxed) by at least 3 dB and the interference criterion for the SAR3 will still be met for the vast majority of cities in the world. Hence, the e.i.r.p. mask may be modified as follows:

-11 dB(W/MHz)	for $0° \le \theta < 8°$
$-11 - 0.716(\theta - 8)$ dB(W/MHz)	for $8° \le \theta < 40°$
$-35.9 - 1.22(\theta - 40)$ dB(W/MHz)	for $40° \le \theta < 45°$
-42 dB(W/MHz)	for $\theta \ge 45°$

where θ is the elevation angle above local horizon (degrees).

However, given that the e.i.r.p. is assumed to be limited to 1 W e.i.r.p. or –13 dB(W/MHz), the e.i.r.p. mask is modified as follows:

-13 dB(W/MHz)	for $0° \le \theta < 8°$
$-13 - 0.716(\theta - 8)$ dB(W/MHz)	for $8° \le \theta < 40°$
$-35.9 - 1.22(\theta - 40)$ dB(W/MHz)	for $40° \le \theta < 45°$
-42 dB(W/MHz)	for $\theta \ge 45°$

where θ is the elevation angle above local horizon (degrees).

9 Summary of results

The actual deployment of indoor and outdoor WAS/RLANs is expected to be less than what is assumed in this analysis. Furthermore, the result represents worst-case interference for the EESS; interference is expected to be less at any other time.

In the band 5 470-5 570 MHz, sharing between the EESS (active) and WAS/RLANs may be difficult unless outdoor WAS/RLAN systems employ an radiation mask.

Sharing is feasible given that the e.i.r.p. spectral density of each transmitter operating outdoors is limited as follows:

-13 dB(W/MHz)	for $0° \le \theta < 8°$
$-13 - 0.716(\theta - 8)$ dB(W/MHz)	for $8° \le \theta < 40°$
$-35.9 - 1.22(\theta - 40)$ dB(W/MHz)	for $40° \le \theta \le 45°$
-42 dB(W/MHz)	for $\theta > 45°$

where θ is the elevation angle above local horizon (degrees).

As well, the transmit power of each WAS/RLAN transmitter, operating indoors or outdoors, should be limited to 250 mW or $11 + 10 \log B$ (dBm) and the power spectral density should not exceed 11 dBm in any 1.0 MHz (B is the 99% power bandwidth in MHz). Furthermore, the maximum e.i.r.p. should not exceed 1 W (0 dBW) or $-13 + 10 \log B$ (dBW), whichever power is less.

Appendix 1
to Annex 4

Aggregate interference analysis of one proposed WAS presented in the *recommends* part: WAS including RLANs in the mobile service sharing with the EESS (active) in the band 5 470-5 570 MHz

1 Introduction

This Recommendation has three *recommends*. In r*ecommends* 2 WAS is limited to a maximum e.i.r.p. of 1 W, and *recommends* 3 consists of WAS limited to a maximum transmitter power of 250 mW and other WAS with spectral masks versus elevation angle. This Appendix studies the aggregate interference into wideband (310 MHz) SARs from WAS in the 5 470-5 570 MHz band with the characteristics as given in the *recommends* 3 as proposed for the 5 470-5 570 MHz band. These results are completely separate and not transferable to the lower band 5 250-5 350 MHz.

2 Technical characteristics of wideband spaceborne SARs

The technical characteristics for typical wideband SARs (SAR2-3) at 5.3 GHz are given in Annex 1. The characteristics used in this analysis as shown in Table 1 are those which would result in the worst-case interference to a typical wideband SAR receiver.

3 Technical characteristics of WAS/RLAN systems

A summary of the characteristics corresponding to *recommends* 2 and 3 of this Recommendation is shown in Table 22. This analysis uses the characteristics as in *recommends* 3, for which the WAS can operate either indoors or outdoors, with limitations on the maximum transmitter power, power spectral density, and maximum e.i.r.p. with a mask for the e.i.r.p. spectral density. *recommends* 2 b) and c) refer to mitigation techniques such as TPC and DFS to further reduce interference from those WAS with the characteristics as in *recommends* 2.

Consider the characteristics as given in *recommends* 3. The information on the configuration of the Dir-WAS1 system (maximum e.i.r.p. spectral density of –13 dB(W/MHz)) was taken from Annex 3. The e.i.r.p. spectral density mask is as follows (see Fig. 8):

The e.i.r.p. spectral density of the emission of a RLAN transmitter operating outdoor should not exceed the following values for the elevation angle θ above the local horizontal plane:

-13 dB(W/MHz)	for $0° \le \theta < 8°$
$-13 - 0.716(\theta - 8)$ dB(W/MHz)	for $8° \le \theta < 40°$
$-35.9 - 1.22(\theta - 40)$ dB(W/MHz)	for $40° \le \theta \le 45°$
-42 dB(W/MHz)	for $\theta > 45°$

Using the e.i.r.p. spectral density mask of Fig. 8, and assuming a bandwidth of 20 MHz, e.i.r.p.s of –15.3 dBW, –29 dBW and –29 dBW are obtained at offset angles of 29.5°, 47.7° and 68°, respectively, with a transmit power level of –6 dBW. These characteristics are summarized in Table 23. The subscriber mobile terminals are assumed to have a maximum transmitter power of 250 mW, and to have omnidirectional antennas, as summarized in Table 24.

4 Performance and interference criteria for the spaceborne SAR

The performance and interference criteria for the spaceborne SAR are given in Recommendation ITU-R SA.1166:

"that the performance and interference criteria for active sensing of the Earth's land, ocean and atmosphere by SAR near 400 MHz, near 1.25 GHz, 5.3 GHz, at 8.6 GHz and 9.6 GHz are as follows:

– that the degradation of the normalized standard deviation of power received from a pixel by less than 10% in the presence of interference would be consistent with mission objectives;

– that the criteria for harmful interference to SARs is that the aggregate interference power-to-noise power ratio (corresponding to a pixel signal-to-noise ratio (*S*/*N*) of 0 dB) should be less than –6 dB, which corresponds to an interference level of –138 dB(W/10 MHz) for a SAR operating near 400 MHz, for example. This level may be exceeded upon consideration of the interference mitigation effect of SAR processing discrimination and the modulation characteristics of the radiolocation/radionavigation systems operating in the band;

– that the maximum allowable interference level should not be exceeded for more than 1% of the images in the sensor service area...."

It should be noted that a 10% degradation of the normalized standard deviation of power received from a pixel yields an *I*/*N* of 0 dB for *S*/*N* of 10 dB and yields an *I*/*N* of –6 dB for *S*/*N* of 0 dB. *S*/*N* of 10 dB is representative of most land surfaces on the Earth at low look angles and *S*/*N* of 0 dB is representative of ocean/water surfaces at high look angles. However, a 10% degradation of the interferometric measurement accuracy independent of *S*/*N* yields an *I*/*N* of –6 dB. Since typically the same SAR in orbit can be used for interferometric purposes as well as imaging, the most sensitive *I*/*N* value of –6 dB for interferometric measurements will be used. The SAR interference criteria is that the maximum allowable interference level of 6 dB lower than the system noise should not be exceeded for more that 1% of the images in the sensor service area.

The maximum allowable interference threshold of *I*/*N* = –6 dB corresponds to a spectral density level of –120.3 dB(W/320 MHz) for SAR2-3. The receiver bandwidth is 320 MHz or 3.2% wider than the transmitter bandwidth of 310 MHz.

5 Aggregate interference from broadband RLANs into SARs

The first step in analysing the aggregate interference potential from broadband RLANs into spaceborne wideband SAR receivers is to determine the interference for WAS, including RLAN, deployment in the 5 470-5 570 MHz band. For the 5 470-5 570 MHz band, one can determine the signal power from a single broadband RLAN cell at the spaceborne SAR2-3. Then, the single interferer margin can be calculated by comparing the interference level with the SAR interference threshold. For a certain cell size, the number of WAS systems which completely cover the SAR footprint can be determined. Knowing the SAR footprint, the number of active broadband RLANs transmitter cells can then be calculated, using a conservative activity ratio for the fraction of hub/subscriber transmitters operating at any one time.

5.1 Interference from outdoor deployment of WAS transmitters in the 5 470-5 570 MHz band

5.1.1 Interference from a single WAS transmitter located outdoors in the 5 470-5 570 MHz band

Table 25 first shows the interference from a single cell of Dir-WAS1/Omni-RLAN1 devices in a broadband RLAN in the 5 470-5 570 MHz band into SAR2-3. A directional antenna is assumed for the outdoor base station Dir-WAS1 using an elevation mask. An omnidirectional antenna is assumed for the outdoor subscriber mobile terminals Omni-RLAN1. For SAR2-3 over the range of incidence angles, Table 25 shows positive margins for the transmitter cells of 14.8 dB to 19.8 dB. This implies that even with no frequency reuse, there could be 30 to 96 directional outdoor transmitter base station cells in the footprint and still not be over the maximum allowable interference level.

Table 26 shows the interference event from a single misdirected Dir-WAS1 transmitter into SAR2-3 with main lobe-to-main lobe coupling, yielding a margin of –0.4 dB to +7.8 dB. This shows that if there was a misdirected directional antenna at 1 W e.i.r.p. into the SAR2-3 antenna main beam, there would be a positive margin for the misdirected WAS transmitters except for the case of interference at 20° from nadir into the SAR3. This implies that there could be 1-6 misdirected directional outdoor transmitters in the footprint and still not be over the maximum allowable interference level, except for the unlikely case of interference at 20° from nadir into the SAR3 (69° elevation angle of the WAS).

5.1.2 Interference from outdoor deployment of WAS transmitters in the 5 470-5 570 MHz band

Table 25 shows the margin from an outdoor deployment of directional wireless access systems for the base station and omnidirectional RLANs for the subscriber terminals for SAR2-3 in the 5 470-5 570 MHz band. The directional transmitter cell interference is below the interference threshold level for the wideband SAR2-3 by 14.8 to 19.8 dB, for 1.5 km cell radii.

Eleven channels, each 16 MHz wide with 20 MHz spacing, are anticipated over the 5 470-5 570 MHz band. It is assumed that the DFS mechanism will provide a uniform spread of the load across the 11 channels.

5.2 Aggregate interference from a deployment of RLAN/WAS transmitters in the 5 GHz range

To calculate the deployment of broadband RLANs for SAR2-3 in the 5 470-5 570 MHz band, we can assume that each lower and upper band uses a portion of the budget of interference level. To account for interference from other sources within the SAR bandwidth of 320 MHz, the interference budget could be apportioned according to the ratio of the 100 MHz bandwidth in 5 470-5 570 MHz and the entire SAR receiver bandwidth of 320 MHz, giving a factor of 0.31. In Table 25, the SAR interference threshold would then be decreased by 5 dB, and thus the number of active transmitters in the SAR footprint will be reduced by the factor of 0.31.

For the directional WASs/omnidirectional RLANs, the first step in analysing the interference potential from a WAS into spaceborne SARs receivers is to first determine the signal power from a single directional transmitter cell at the spaceborne SAR2-3. Then, the single interferer margin can be calculated by comparing the interference level with the SAR interference threshold. Knowing the SAR footprint, the number of active WAS transmitter cells can then be calculated, if there is a positive margin. Table 27 shows the average number of cells within the SAR2-3 footprints for the low and high incidence angles, obtained by dividing the footprint area by the individual cell area.

The surface scattering contribution or eventual scattering from nearby buildings will be a possible source of interference. This is dependent on the area where these systems are deployed and on which altitude these will be placed (on top of buildings, sideways, etc.). It can be envisaged that these systems are present in high density urban areas where by definition scattering from a wide range of objects will occur, so these effects will also have to be taken into account. One could especially think of modern office buildings which are constructed out of metal, where the possibility of a high reflectivity into the direction of the sensor cannot be excluded. With the use of multiple sector antennas in azimuth at the same location, several transmitters can overlap in the worst case, increasing the surface scattering contribution above that for one omnidirectional transmitter (in azimuth).

For the Dir-WAS1 single directional transmitter cell with the e.i.r.p. spectral mask from Fig. 8, deployed outdoors, the directional WAS transmitter cell interference is below the interference level for the wideband SAR2-3 by about 14.8 dB to 19.8 dB, corresponding to 30 to 96 transmitters, over the range of incidence angles as shown in Table 25. Assuming a frequency reuse factor of 4, this corresponds to 119 to 384 cells, and from Table 27, 7 to 28 cells of radii 1.5 km would be needed to completely cover the SAR2-3 footprint. Thus, for cells of radii 1.5 km, the interference level into the SAR2-3 is below the maximum allowable interference level by a margin of 8.7 to 14.5 dB.

For the aggregate effect, to account for interference from other sources within the SAR receiver bandwidth of 320 MHz, the interference budget could be apportioned according to the ratio of the 100 MHz bandwidth in 5 470-5 570 MHz and the entire SAR receiver bandwidth of 320 MHz, giving a factor of 0.31. In Table 25, the SAR interference threshold would then be decreased by 5 dB, and thus the maximum number of active transmitters in the SAR footprint will be reduced by a factor of 0.31. Thus, for cells of radii 1.5 km, the aggregate interference level into the SAR2-3 is below the maximum allowable interference level by a margin of 3.7 to 9.5 dB.

6 Interference from SARs into broadband RLANs

ITU-R documentation contains the analysis of the interference potential from spaceborne SARs into broadband RLANs. Table 28 gives the equations for the antenna relative gain patterns in azimuth. For SAR2-3, the peak antenna gains are 43-48 dB higher than the average side-lobe levels of –5 dBi. Therefore for the duration of the flyover, which in the main beam of the SAR would be about 0.5-1 s, the SAR interference levels at the surface would still be below a −91 dBW interference threshold. The typical repeat period for the SAR is 8-10 days, although the SAR is not necessarily active for every repeat pass. Therefore, a given area on the Earth would be illuminated by the SAR beam no more often than 0.5-1 s every 8-10 days.

7 Summary of results

The potential aggregate interference from WAS including RLANs in the proposed WAS configuration in the 5 470-5 570 MHz band into spaceborne wideband SARs was analysed in this Annex for an outdoor deployment of WAS in the 5 470-5 570 MHz band, for which these outdoor directional base station WASs and outdoor omnidirectional mobile terminals appear to be compatible with EESS (active). For the single cell of Dir-WAS1/omnidirectional transmitters deployed outdoors in the 5 470-5 570 MHz band, the WAS transmitter cell interference was below the maximum threshold level for SAR2-3. Calculating the aggregate interference and to account for interference from other sources within the SAR receiver bandwidth of 320 MHz, the interference budget could be apportioned according to the ratio of the 100 MHz bandwidth in 5 470-5 570 MHz and the entire SAR receiver bandwidth of 320 MHz, giving a factor of 0.31.

For a single Dir-WAS1 directional transmitter with the e.i.r.p. spectral mask from Fig. 8 deployed outdoors, the directional WAS/omnidirectional RLAN transmitter cell interference is below the permissible interference level for the wideband SAR2-3 by about 14.8 dB to 19.8 dB, corresponding to 30 to 96 transmitters, over the range of incidence angles. Assuming a frequency reuse factor of 4, this corresponds to 119 to 384 WAS cells. It has been shown that 7 to 28 cells of radii 1.5 km would be needed to completely cover the SAR2-3 footprint. For cells of radii 1.5 km, the interference level into SAR2-3 is below the maximum permissible interference level by a margin of 8.7 to 14.5 dB.

For the interference from a single misdirected Dir-WAS1 transmitter into SAR2-3 with main lobe-to-main lobe coupling, this yields a margin of –0.4 dB to +7.8 dB. This shows that if there were a misdirected directional antenna at 1 W e.i.r.p. into the SAR2-3 antenna main beam, there would be a positive margin for the misdirected WAS transmitters, except for the case of interference at 20° from nadir into the SAR3. This implies that there could be 1-6 misdirected directional outdoor transmitters in the footprint and still not be over the maximum allowable interference level, except for the unlikely case of interference at 20° from nadir into the SAR3 (69° elevation angle of the WAS).

Interference from the spaceborne SARs into WAS including RLANs in the 5 470-5 570 MHz band was also examined. For the SARs examined in this study, the peak interference experienced by the WAS over the duration of the flyover in the main beam of the SAR would be about 0.5-1 s. Since the repeat period for the SAR is 8-10 days, and the SAR is not necessarily active for every repeat pass, a given area on the Earth would be illuminated by the SAR main beam no more often than 0.5-1.0 s every 8-10 days.

The analysis indicates that sharing is feasible between the WAS/RLAN configuration of *recommends* 3 of this Recommendation and EESS (active). These results are completely separate and not transferable to the lower band 5 250-5 350 MHz.

TABLE 22

***Recommends* 2 and 3 of this Recommendation**

recommends	Sub-part 1	Sub-part 2	Notes
2	WAS including RLANs operating either indoors or outdoors limited to maximum mean e.i.r.p. of 1 W or 17 dB(mW/MHz) spectral density	Not applicable	Mitigation techniques to further reduce interference from WAS including RLANs (*Notes*: TPC or 3 dB power reduction and DFS)
3	WAS including RLANs operating either indoors or outdoors limited to maximum transmitter power of 250 mW (24 dBm) or 11 + 10 log B dBm, whichever is less. Power spectral density should not exceed 11 dB(mW/MHz) per transmitter. Maximum e.i.r.p. not to exceed 1.0 W (0 dBW) or –13 + 10 log B dBW, whichever is less	e.i.r.p. spectral density of outdoor RLAN should not exceed following for elevation angle θ above local horizontal plane: –13 dB(W/MHz) for $0° \leq \theta < 8°$ $-13 - 0.716(\theta - 8)$ dB(W/MHz) for $8° \leq \theta < 40°$ $-35.9 - 1.22(\theta - 40)$ dB(W/MHz) for $40° \leq \theta \leq 45°$ –42 dB(W/MHz) for $\theta > 45°$	Further consideration to limiting application of e.i.r.p. spectral density emission mask to outdoor base stations only, and maximum transmitter power of 250 mW to subscriber stations only

TABLE 23

Technical characteristics of Dir-WAS1 system near 5.3 GHz

Parameters	Dir-WAS1
Frequency band (GHz)	5.47-5.57
Operation mode	Point-to-multipoint
Max. e.i.r.p. density (dB(W/MHz))	–13 (e.i.r.p. mask in Fig. 1)
WAS transmitter peak density (dB(mW/MHz))	11
WAS antenna peak gain (dBi)	Implicit within e.i.r.p. mask as shown in Fig. 8
Average antenna elevation gain (dBi)	–9.8 to –23
Transmitter bandwidth (MHz)	20.0
Polarization	Vertical or horizontal
Antenna tilt (degrees)	–5 to 0
Cell radius (km)	1-3.5
Active ratio	90% outdoor base station 10% subscriber unit

TABLE 24

Technical/operational characteristics of omnidirectional RLAN1 near 5.3 GHz

Parameter	Value
	Omni-RLAN1
Antenna directivity	Omni
Peak radiated power (W)	0.250
Deployment	Indoors/outdoors
Mean building attenuation (dB)	0 outdoors/ 17 indoors
Polarization	Random
Bandwidth (MHz)	20/channel (4 channels/100)
Interference duty cycle into SAR (%)	100
Operational activity (active/passive ratio (%))	Not available
Number of transmitters per area	Not available

FIGURE 8

Dir-WAS1 e.i.r.p. spectral density mask

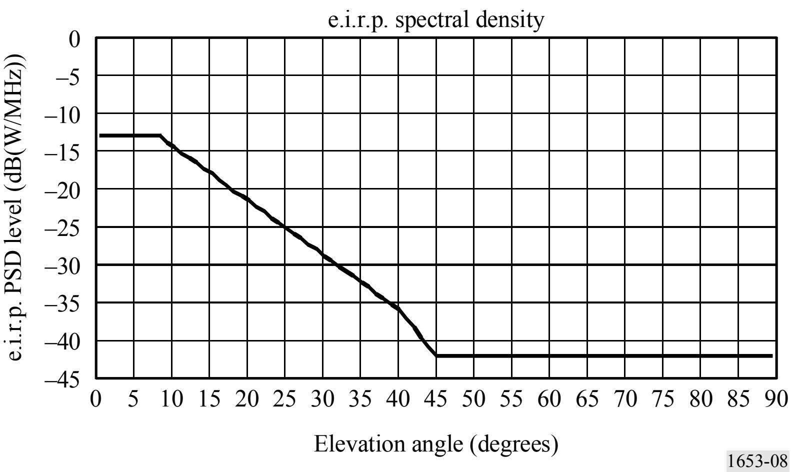


TABLE 25

Interference from Dir-WAS1/Omni-RLAN1 system to SAR2-3

Dir-WAS1/Omni-RLAN1 to SAR2

		Parameter	**20° from nadir Value**	**20° from nadir dB**	**38° from nadir Value**	**38° from nadir dB**
Interfering e.i.r.p. due to WAS antenna side lobe	From access point	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
		Antenna gain, transmit (dBi)		–23.00		–23.00
		Active ratio (%)	90.00	–0.46	90.00	–0.46
		e.i.r.p. (dBW)		–29.46		–29.46
	From mobile terminal	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
		Antenna gain, transmit (dBi)		0.00		0.00
		Active ratio (%)	10.00	–10.00	10.00	–10.00
		e.i.r.p. (dBW)		–16.00		–16.00
	Total e.i.r.p. due to side lobe (dBW)			–15.81		–15.81

Dir-WAS1/Omni-RLAN1 to SAR3

		Parameter	**20° from nadir Value**	**20° from nadir dB**	**55° from nadir Value**	**55° from nadir dB**
Interfering e.i.r.p. due to WAS antenna side lobe	From access point	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
		Antenna gain, transmit (dBi)		–23.00		–9.80
		Active ratio (%)	90.00	–0.46	90.00	–0.46
		e.i.r.p. (dBW)		–29.46		–16.26
	From mobile terminal	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
		Antenna gain, transmit (dBi)		0.00		0.00
		Active ratio (%)	10.00	–10.00	10.00	–10.00
		e.i.r.p. (dBW)		–16.00		–16.00
	Total e.i.r.p. due to side lobe (dBW)			–15.81		–13.12

TABLE 25 (*continued*)

Dir-WAS1/Omni-RLAN1 to SAR2						
			20° from nadir		**38° from nadir**	
		Parameter	**Value**	**dB**	**Value**	**dB**
Interfering power due to scattering at the surface	From access point	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
		Active ratio (%)	90.00	–0.46	90.00	–0.46
		Transmitted power (dBW)		–6.46		–6.46
	From mobile terminal	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
		Active ratio (%)	10.00	–10.00	10.00	–10.00
		Transmitted power (dBW)		–16.00		–16.00
	Number of overlapping beams		1.00	0.00	1.00	0.00
	Total transmitted power (dBW)			–6.00		–6.00
	Scattering coefficient (dB)			–18.00		–18.00
	Total scattered e.i.r.p. (dBW)			–24.00		–24.00
Total interfering e.i.r.p. from a cell (dBW)			0.0302	–15.20	0.0302	–15.20

Dir-WAS1/Omni-RLAN1 to SAR3						
			20° from nadir		**55° from nadir**	
		Parameter	**Value**	**dB**	**Value**	**dB**
Interfering power due to scattering at the surface	From access point	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
		Active ratio (%)	90.00	–0.46	90.00	–0.46
		Transmitted power (dBW)		–6.46		–6.46
	From mobile terminal	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
		Active ratio (%)	10.00	–10.00	10.00	–10.00
		Transmitted power (dBW)		–16.00		–16.00
	Number of overlapping beams		1.00	0.00	1.00	0.00
	Total transmitted power (dBW)			–6.00		–6.00
	Scattering coefficient (dB)			–18.00		–18.00
	Total scattered e.i.r.p. (dBW)			–24.00		–24.00
Total interfering e.i.r.p. from a cell (dBW)			0.0302	–15.20	0.0528	–12.78

TABLE 25 (*continued*)

Dir-WAS1/Omni-RLAN1 to SAR2					
		20° from nadir		38° from nadir	
	Parameter	**Value**	**dB**	**Value**	**dB**
Interference power received at SAR	Antenna gain, receiver (dBi)		42.90		42.90
	Polarization loss (dB)		–3.00		–3.00
	Wavelength (m)	0.0565	–24.97	0.0565	–24.97
	$1/(4\pi)^2$	0.006	–21.98	0.006	–21.98
	Distance (km)	642.54	–116.16	784.66	–117.89
	Power received (dBW)		–138.40		–140.14
SAR receiver sensitivity	Noise figure (dB)		4.62		4.62
	$k\ T$	1×4^{-21}	–203.98	1×4^{-21}	–203.98
	Receiver bandwidth (MHz)	320.00	85.05	320.00	85.05
	Noise power (dBW)		–114.31		–114.31
	SAR Interference threshold (I/N = –6 dB)		–120.31		–120.31

Dir-WAS1/Omni-RLAN1 to SAR3					
		20° from nadir		55° from nadir	
	Parameter	**Value**	**dB**	**Value**	**dB**
Interference power received at SAR	Antenna gain, receiver (dBi)		42.70		42.70
	Polarization loss (dB)		–3.00		–3.00
	Wavelength (m)	0.0565	–24.97	0.0565	–24.97
	$1/(4\pi)^2$	0.006	–21.98	0.006	–21.98
	Distance (km)	427.45	–112.62	748.94	–117.49
	Power received (dBW)		–135.06		–137.51
SAR receiver sensitivity	Noise figure (dB)		4.62		4.62
	$k\ T$	1×4^{-21}	–203.98	1×4^{-21}	–203.98
	Receiver bandwidth (MHz)	320.00	85.05	320.00	85.05
	Noise power (dBW)		–114.31		–114.31
	SAR Interference threshold (I/N = –6 dB)		–120.31		–120.31

TABLE 25 (*continued*)

Dir-WAS1/Omni-RLAN1 to SAR2						Dir-WAS1/Omni-RLAN1 to SAR3					
		20° from nadir		**38° from nadir**				**20° from nadir**		**55° from nadir**	
Parameter		**Value**	**dB**	**Value**	**dB**	**Parameter**		**Value**	**dB**	**Value**	**dB**
Number of WAS cells	Margin (dB)		18.10		19.83	Number of WAS cells	Margin (dB)		14.76		17.21
	Maximum number of WAS cells using same RF channel within SAR2 footprint	64.51		96.20			Maximum number of WAS cells using same RF channel within SAR3 footprint	29.89		52.57	
	Maximum number of WAS cells assuming frequency reuse factor of 4	258.02		384.78			Maximum number of WAS cells assuming frequency reuse factor of 4	119.57		210.29	
	Maximum number of WAS cells with 1.5 km radius in SAR2-3 footprint	9.08		14.47			Maximum number of WAS cells with 1.5 km radius in SAR2-3 footprint	7.40		28.28	
Margin (dB)			14.53		14.25	Margin (dB)			12.09		8.71
Number of WASs for 5 dB margin		79.99		119.28		Number of WASs for 5 dB margin		37.07		65.19	

TABLE 25 (*end*)

Dir-WAS1/Omni-RLAN1 to SAR2						**Dir-WAS1/Omni-RLAN1 to SAR3**					
		20° from nadir		**38° from nadir**				**20° from nadir**		**55° from nadir**	
Parameter		**Value**	**dB**	**Value**	**dB**	**Parameter**		**Value**	**dB**	**Value**	**dB**
Total e.i.r.p. for 5 dB margin (W)		0.6167		0.9197		Total e.i.r.p. for 5 dB margin (W)		0.2858		0.8773	
Total interference power received at SAR with 5 dB margin (dBW)			–125.31		–125.31	Total interference power received at SAR with 5 dB margin (dBW)			–125.31		–125.31

TABLE 26

Interference from single misdirected WAS transmitter to SAR2-3

Dir-WAS1 with directional antenna to SAR2					
Parameter		**20° from nadir**		**38° from nadir**	
		Value	**dB**	**Value**	**dB**
Interfering e.i.r.p. due to WAS antenna	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
	Transmit power control	1.00	0.00	0.50	–3.01
	Transmit path loss (dB)		0.00		0.00
	Antenna gain, transmit (dB)		6.00		6.00
Total interfering e.i.r.p. from an RLAN (dBW)		1.0000	0.00	0.5000	–3.01
Interference power received at SAR	Antenna gain, receive (dB)		42.90		42.70
	Polarization loss (dB)		–3.00		–3.00
	Wavelength (m)	1×5.65^{-2}	–24.96	1×5.65^{-2}	–24.96
	$1/(4\pi)^2$	1×6.33^{-3}	–21.98	1×6.33^{-3}	–21.98
	Distance (km)	642.54	–116.16	784.66	–117.89
	Power received (dBW)		–123.20		–128.15

Dir-WAS1 with directional antenna to SAR3					
Parameter		**20° from nadir**		**55° from nadir**	
		Value	**dB**	**Value**	**dB**
Interfering e.i.r.p. due to WAS antenna	Transmitted peak power (W)	0.251	–6.00	0.251	–6.00
	Transmit power control	1.00	0.00	0.50	–3.01
	Transmit path loss (dB)		0.00		0.00
	Antenna gain, transmit (dB)		6.00		6.00
Total interfering e.i.r.p. from an RLAN (dBW)		1.0000	0.00	0.5000	–3.01
Interference power received at SAR	Antenna gain, receive (dB)		42.70		42.70
	Polarization loss (dB)		–3.00		–3.00
	Wavelength (m)	1×5.65^{-2}	–24.96	1×5.65^{-2}	–24.96
	$1/(4\pi)^2$	1×6.33^{-3}	–21.98	1×6.33^{-3}	–21.98
	Distance (km)	427.45	–112.62	748.94	–117.49
	Power received (dBW)		–119.86		–127.74

TABLE 26 (*end*)

Dir-WAS1 with directional antenna to SAR2					
		20° from nadir		**38° from nadir**	
Parameter		**Value**	**dB**	**Value**	**dB**
SAR receiver sensitivity	Noise figure (dB)		4.62		4.62
	k T	1×4^{-21}	–203.98	1×4^{-21}	–203.98
	Receiver bandwidth (MHz)	320.00	85.05	320.00	85.05
	Noise power (dBW)		–114.31		–114.31
	SAR interference threshold (I/N = –6 dB)		–120.31		–120.31
Margin (dB)			2.89		7.84

Dir-WAS1 with directional antenna to SAR3					
		20° from nadir		**55° from nadir**	
Parameter		**Value**	**dB**	**Value**	**dB**
SAR receiver sensitivity	Noise figure (dB)		4.62		4.62
	k T	1×4^{-21}	–203.98	1×4^{-21}	–203.98
	Receiver bandwidth (MHz)	320.00	85.05	320.00	85.05
	Noise power (dBW)		–114.31		–114.31
	SAR Interference threshold (I/N = –6 dB)		–120.31		–120.31
Margin (dB)			–0.45		7.44

TABLE 27

Average number of cells within the SAR2-3 footprint

Parameters	SAR2		SAR3	
	20°	**38°**	**20°**	**55°**
Incidence angle (degrees)	21.97	42.34	21.31	60.52
Slant range (km)	642.54	784.66	427.45	748.94
Elevation beamwidth (degrees)	1.9		4.9	
Footprint dimension (El) (km)	14.42	18.25	37.32	75.16
Azimuth beamwidth (degrees)	0.75		0.24	
Footprint dimension (Az) (km)	5.67	7.14	1.78	3.39
Footprint area (km^2)	64.21	102.28	52.28	199.90
Number of cells				
0.25 km	327.0	520.9	266.3	1 018.1
0.5 km	81.8	130.2	66.6	254.5
1.0 km	20.4	32.6	16.6	63.6
1.5 km	9.1	14.5	7.4	28.3
2.0 km	5.1	8.1	4.2	15.9
2.5 km	3.3	5.2	2.7	10.2
3.0 km	2.3	3.6	1.8	7.1
3.5 km	1.7	2.7	1.4	5.2

TABLE 28

SAR2-3 antenna relative gain patterns in azimuth

SAR2 azimuth or horizontal relative gain equation	
$G_h(\theta_h) = 0.0 - 20.8\ (\theta_h^2)$ dB	$0° < \theta_h < 0.76°$
$G_h(\theta_h) = -12.0 - 0.44\ (\theta_h)$ dB	$0.76° < \theta_h < 82°$
$G_h(\theta_h) = -47.9$ dB	$82° < \theta_h$
SAR3 azimuth or horizontal relative gain equation	
$G_h(\theta_h) = 0.0 - 212\ (\theta_h^2)$ dB	$0° < \theta_h < 0.24°$
$G_h(\theta_h) = -11.7 - 2.03\ (\theta_h)$ dB	$0.24° < \theta_h < 17.7°$
$G_h(\theta_h) = -477$ dB	$17.7° < \theta_h$

Appendix 2
to Annex 4

Example technologies for the implementation of radiation masks allowing coexistence between WASs including RLANs and EESS systems in the 5 GHz range

1 Introduction

Previous studies (see Annexes 3 and 4) have demonstrated that sharing between WASs including RLANs (WAS/RLANs) in the 5 GHz range is feasible provided that WAS/RLANs operate under certain technical constraints.

In particular, an e.i.r.p. radiation mask (see § 2) on outdoor WAS/RLANs was proposed. This mask, if implemented, would significantly reduce interference from WAS/RLANs into EESS into wideband (SAR2 and SAR3) systems identified by the EESS community.

Since the introduction of the mask, concerns were raised on the practicality of such a mask. In particular, concerns were raised that practical antennas could not be developed. Concern was also raised regarding measures to ensure proper orientation of the antenna, since the installation and use of the devices would be undertaken by the general public.

This Recommendation addresses these issues and proposes a number of technologies and techniques that can be used to ensure preservation of the e.i.r.p. radiation mask of WAS terminals under all installation and deployment conditions.

2 Practical antennas conforming to the proposed e.i.r.p. mask

It is proposed, through studies mentioned in § 1, that an e.i.r.p. mask in which the e.i.r.p. spectral density of a WAS terminal operating outdoors should not exceed the following values for the elevation angle θ above the local horizontal plane:

-13 dB(W/MHz) for $0° \leq \theta < 8°$

$-13 - 0.716(\theta - 8)$ dB(W/MHz) for $8° \leq \theta < 40°$

$-35.9 - 1.22(\theta - 40)$ dB(W/MHz) for $40° \leq \theta \leq 45°$

-42 dB (W/MHz) for $\theta > 45°$

The antennas conforming to this elevation pattern will vary considerably in design and appearance. Antennas used for base station applications are typically installed on fixed structures, towers or buildings and will in general illuminate azimuth sectors (typically from 20° to 120° wide). With such antennas, size and aesthetic appearance are not generally design issues and maintaining the e.i.r.p. profile given above is relatively easy to achieve providing there is a mechanism to ensure that the elevation orientation is maintained at installation and afterward.

Size and aesthetic appearance are of paramount importance with antennas used in nomadic applications such as portable computers. These antennas need to receive and transmit signals omnidirectionally in azimuth. Maintaining the e.i.r.p. profile as a function of elevation above local horizon as required by the mask becomes considerably more complicated with such antennas, especially since they are expected to be often moved and adjusted. Special consideration has to be given to the design of such antennas to counter their ad hoc movement, deployment and use, but as with the base station antennas, there must be a mechanism to ensure that the e.i.r.p. profile is preserved under all circumstances.

2.1 Base station or access point antennas for 5 GHz WAS/RLANs applications

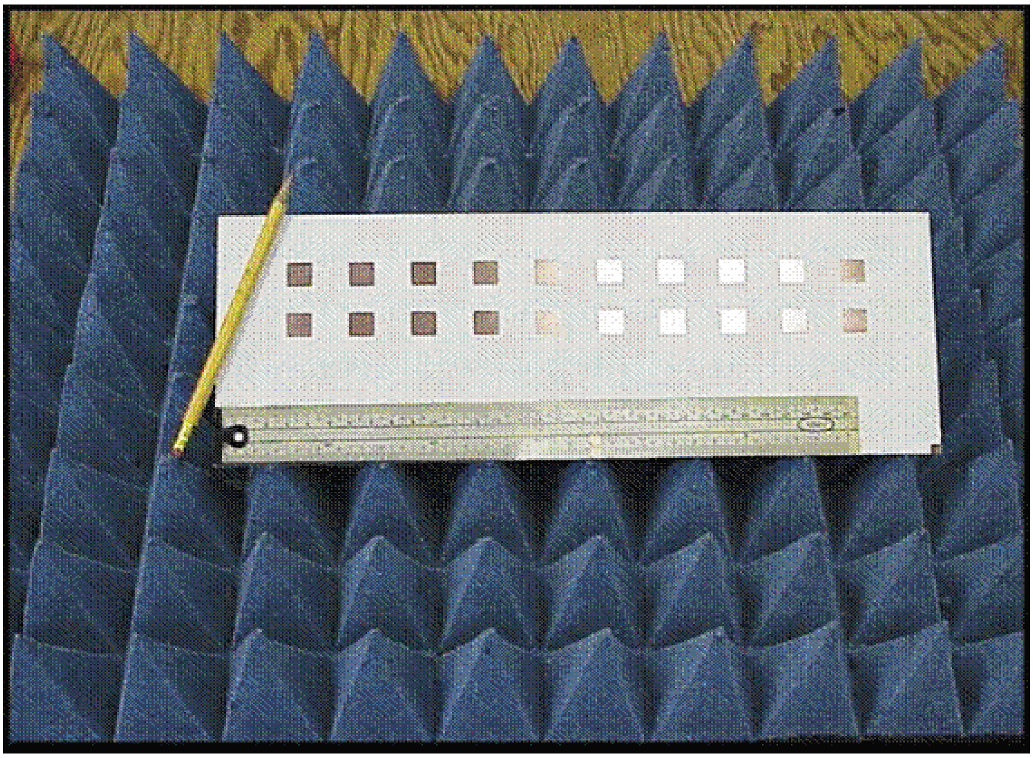
Making a 5 GHz base station antenna conforming to the above e.i.r.p. requirements is generally a straightforward design and production task. Because of the relatively narrow bandwidths being contemplated for WAS/RLANs systems (for example, in the 5 250-5 350 MHz range there is a total of 100 MHz at a centre frequency of 5.3 GHz available for WAS/RLANs), and the directive nature of base station antennas, there is a large class of antenna technologies can be used to implement effective designs. Microstrip, small optical reflector, resonant wire, helical, dipole and dielectric antennas are a few of the many technologies that can be used. Regardless of the technology that is used, radiation physics dictates that a compliant antenna will have an aperture of at least 4-5 wavelengths width in the vertical plane, or about 23-30 cm (at 5 GHz) to generate a radiation pattern capable of meeting the proposed e.i.r.p. mask. Smaller apertures would be difficult to use because side-lobe levels would become high and would also likely require the antenna pattern to be down-tilted below the horizon in order to conform to the proposed e.i.r.p. profile.

Through judicious antenna design it is possible to guarantee compliance; however, there is always the possibility that the antenna will be incorrectly installed and violate the e.i.r.p. mask when deployed. To address this possibility there must always be a mechanism which is physically coupled to the antenna and which will monitor the installation angle of the antenna in two axes. Such a device is discussed below.

Figure 9 shows a typical base station antenna that conforms to the e.i.r.p. mask. As shown in Fig. 10, the antenna forms a 45° wide sector in azimuth. This antenna conforms to the proposed e.i.r.p. mask when it is installed with its maximum gain oriented toward the horizon. This antenna is one of many designs being currently produced and marketed today to meet the demands of a growing 5 GHz RLAN market. Many of these antennas comply with the proposed e.i.r.p. mask.

FIGURE 9

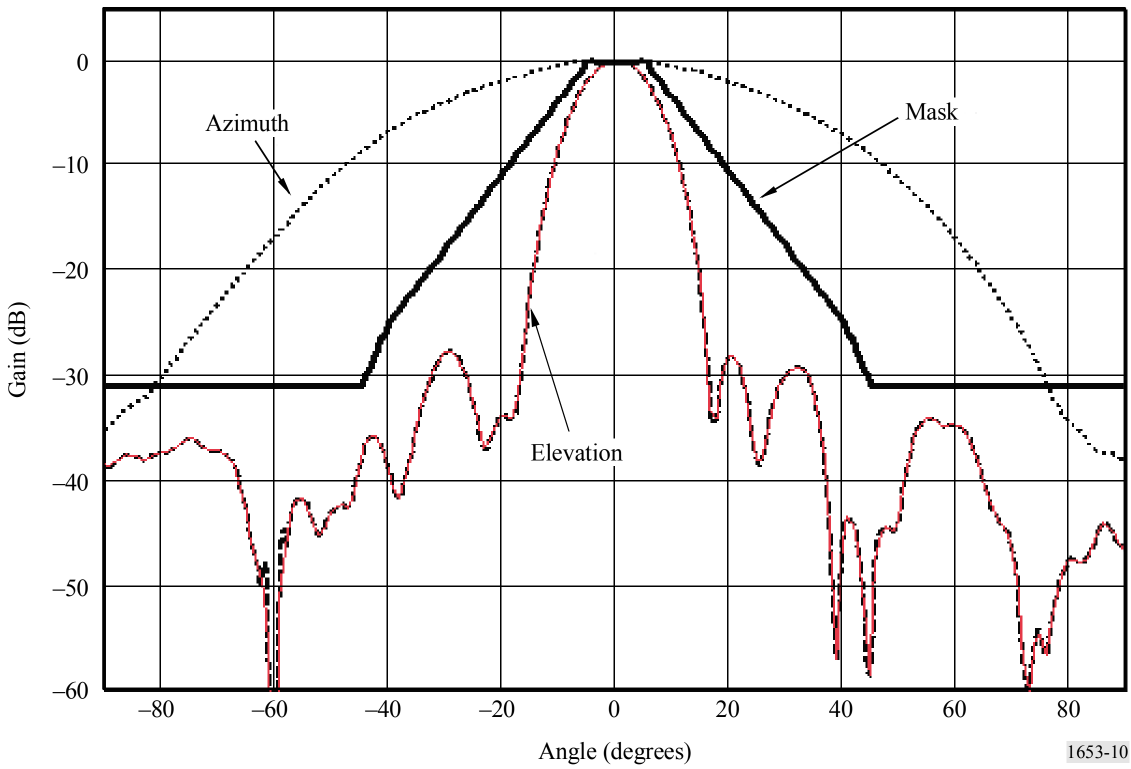
Typical microstrip antenna for base station/access points in the 5 250-5 350 MHz band that conforms to the e.i.r.p. mask



1653-09

FIGURE 10

Radiation pattern for antenna shown in Fig. 9



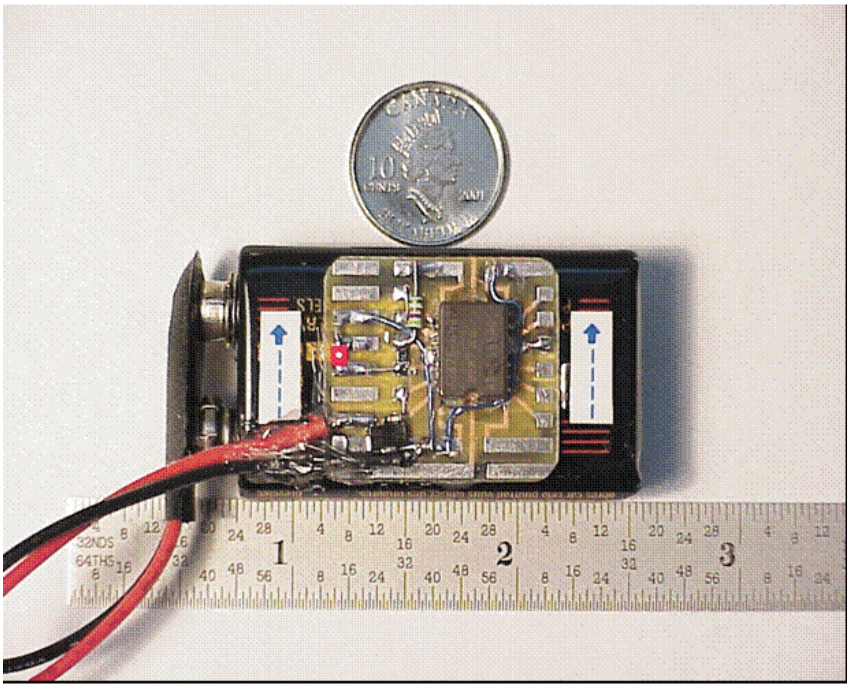
1653-10

3 Tilt sensors and their application to 5 GHz WAS/RLAN antennas

Current state-of-the-art tilt sensors are made from micro-machined silicon components (MEMS). These devices have seen significant development and commercialization over the last decade and are now being mass-produced and used for a diversity of applications. The devices typically function over a –55° to +125° C temperature range; they can detect angular changes of less than 1° in two axes. They are low cost, with a single two-axis device being quoted at 5 US dollars per 100 000. The devices are small, usually less than a square centimetre in area and can be easily installed inside an antenna. Figure 11 shows the size and simplicity of the circuitry for a tilt sensor that can be used in e.i.r.p. control applications.

FIGURE 11

A functioning tilt sensor based on MEMS technology mounted on a 9 V battery



1653-11

Tilt sensors provide an effective way to ensure that the operation of the WAS/RLANs is compliant to the e.i.r.p. mask in the 5 GHz range. Devices equipped with such tilt sensors will detect conditions where a 5 GHz WAS/RLAN antenna, normally compliant to the e.i.r.p. mask, is tilted in such manner that non-compliance occurs. Under such circumstances it will be possible to automatically exercise a number of options, which limit the radiation from the WAS/RLAN, thereby mitigating potential interference into the EESS.

One option is to have the directional sensor or tilt sensor linked to either the power amplifier feeding the antenna or to a switch within the antenna. The directional sensor is set in such a manner that full WAS/RLAN terminal RF power is directed to the antenna only when it is correctly oriented. The radiation characteristics of the antenna thereby constrain the emissions to angles defined by the e.i.r.p. mask. If the antenna is not correctly oriented, causing the sensor's tilt threshold limits to be exceeded (indicating emissions now being in non-compliance with the radiation mask), the tilt sensor would terminate the transmission. This option is probably the simplest to implement, but it may limit the operation of the WAS/RLAN terminal, especially in cases where the angle to the base station may be high as in the case where the access point is on a high tower while the WAS/RLAN is in close proximity, but considerably below it.

A second option would be to use the tilt sensor to adjust the radiated power of the terminal. A WAS/RLAN terminal meeting the radiation mask while normally deployed would see its radiated power reduced commensurately as its antenna was tilted. The reduction in peak radiated power would be adjusted in such a way that the terminal would always stay within the constraints of the e.i.r.p. mask. Such control is easily achieved since radiated power control is a feature common to all current and proposed RLAN and WAS networks, and given the sensitivity and fast reaction time of the MEMS tilt sensors (~2 ms), it is felt that an accurate, orientation-sensitive radiated power control system could easily be implemented. The advantage of this system is that it allows the antenna to be tilted whilst the WAS/RLAN is in close proximity to a much higher access point, and it also provides a more user-friendly WAS/RLAN terminal, minimizing the adjustment of the antenna.

Another option is the use of antennas that can automatically adjust their radiation pattern based on their orientation. Such antennas are currently used for mobile-satellite applications, hence the technology has shown feasibility. The antennas anticipated for 5 GHz WAS applications could be electronically steered and would automatically use compliant antenna patterns that would be selected based on the immediate orientation of the antenna. Such a solution would be ideal as it would make the terminal user-friendly while meeting the requirement to mitigate interference to the EESS.

4 Summary of results

It is quite feasible to develop antennas for base station applications that would meet the characteristics of the e.i.r.p. mask proposed as shown in § 2. There are numerous examples of antennas that can meet these requirements. Preservation of the radiation mask in an active terminal as it changes orientation is a problem that can be solved by using MEMS tilt sensors, which must be physically attached to the antennas. A number of options can be implemented which will limit emissions to the EESS by either turning off the power or modifying the radiation pattern or emission power of the 5 GHz WAS/RLAN as a function of its orientation.

The use of these techniques will ensure that the problem of the single “rogue” terminal, which is inadvertently or purposefully mis-oriented, thereby causing harmful interference into an EESS, does not occur. Furthermore, the use of such techniques and the highly directive antennas they call for will improve the sensitivity, battery life and overall performance of the 5 GHz WAS/RLAN terminals. The cost of achieving this is relatively low and, it is felt, of minor consequence to the form factor and aesthetic appearance of the 5 GHz WAS/RLAN terminal.