Radiocommunication Study Groups

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Annex 32 to Joint Task Group 4-5-6-7 Chairman's Report

PRELIMINARY DRAFT NEW REPORT ITU-R M.[RADAR3300]

Sharing between indoor IMT systems and radar systems in the frequency band 3 300-3 400 MHz

1 Introduction

1.1 Scope and objective

The frequency band 3 300-3 400 MHz is allocated in all three Regions to the radiolocation service on a primary basis, and in Region 2 and Region 3 is also allocated to the fixed, mobile and amateur service on a secondary basis. By RR No. **5.429** and **5.430** the frequency band 3 300-3 400 MHz is also allocated to in some countries to the fixed, mobile and radionavigation services on a primary basis. The predominant use of this band is for radar systems. This document provides detailed study of compatibility between IMT indoor systems and radar systems in the frequency band 3 300-3 400 MHz.

1.2 Glossary of terms

ITU	International Telecommunication Union
IMT	International Mobile Telecommunications
3GPP	3rd generation partnership project
I/*N*	Interference-to-noise power ratio
e.i.r.p.	equivalent isotropic radiated power
UE	User equipment

2 Background

WRC-15 agenda item 1.1 considers additional spectrum allocations to the mobile service on a primary basis and identification of additional frequency bands for International Mobile Telecommunications (IMT) and related regulatory provisions, to facilitate the development of terrestrial mobile broadband applications, in accordance with Resolution **233 (WRC-12)**.

Resolution **233 (WRC-12)** invites the ITU-R to conduct sharing and compatibility studies with services already having allocations in the potential candidate bands and in adjacent bands, as appropriate, taking into account the current and planned use of these bands by the existing services, as well as the applicable studies already performed in ITU-R.

The sharing scenario between macro-cell and micro-cell IMT systems and radars operating in the frequency band 3.1-3.7 GHz is considered in Report ITU-R M.2111. This report considers sharing between the radiolocation service and indoor IMT systems.

3 Technical characteristic

3.1 IMT parameters

IMT base-station parameters are shown in the following table.

TABLE 1

Deployment-related parameters for 3 300-3 400 MHz

	Small cell indoor
Base-station characteristics / Cell structure	
Cell radius / Deployment density	Depending on indoor coverage/capacity demand
Antenna height	3 m
Sectorization	Single sector
Downtilt	n.a.
Frequency reuse[1]	1
Antenna pattern	Recommendation ITU-R F.1336 Omni
Antenna polarization	Linear
Indoor base-station deployment	100 %
Building penetration loss	11 dB (see Note 1)12 dB (See note[2]) 20 dB (Horizontal direction) P.1238, Table 3 (vertical direction)
Below rooftop base-station antenna deployment	n.a.
Feeder loss	n.a
	Small cell indoor
Base-station characteristics / Cell structure	
Maximum base-station output power (5/10/20 MHz)	24 dBm
Maximum base-station antenna gain	0 dBi
Maximum base-station output power (e.i.r.p.)	24 dBm
Bandwidth	5 / 10 / 20 MHz

[1] If the IMT network consists of three cell layers – macro cells, small outdoor cells and small indoor cells – they will not all use the same carrier. Two layers may use the same carrier, although separate carriers in the same or different bands are also possible.

[2] Corresponds to an average value whose distribution is featured by a 17 dB median and 7 dB standard deviation [proposed by the US input for RLANs in higher frequencies (5 GHz band)].

Note 1: Recommendation ITU-R P.1812, Table 7, and accompanying text provides appropriate values of building entry loss. Recommendation ITU-R P.1238 provides, in Table 3, values of loss within a building from one floor to another, but cautions that there is a limit on the loss due to multiple floors.

User Equipment (UE) characteristics	
Indoor UE usage	100%
Building penetration loss	11 dB (see Note 1) 20 dB (horizontal direction) Rec. ITU-R P.1238, Table 3 (vertical direction)
UE density in active mode to be used in sharing studies	depending on indoor coverage/capacity demand
Maximum UE output power	23 dBm
Typical antenna gain for UEs	-4 dBi
Bandwidth	5 / 10 / 20 MHz

Note 1: Recommendation ITU-R P.1812, Table 7, and accompanying text provides appropriate values of building entry loss. Recommendation ITU-R P.1238 provides, in Table 3, values of loss within a building from one floor to another, but cautions that there is a limit on the loss due to multiple floors.

3.2 Radar parameters

The table below provides the key radar parameters to be used for these studies[3].

[3] From Recommendation ITU-R M.1465-1: Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 3 100-3 700 MHz.

TABLE 2

Radiolocation service radar characteristics for use in compatibility studies in the frequency band 3 100-3 700 MHz

Parameter	Land-based systems		Ship systems			Airborne system
	A	**B**	**A**	**B**	**C**	**A**
Use	Surface and air search	Surface search	Surface and air search			Surface and air search
Modulation	P0N/Q3N	P0N	P0N	Q7N	P0N/Q7N	Q7N
Tuning range (GHz)	3.1-3.7		3.5-3.7	3.1-3.5	3.1-3.5	3.1-3.7
Tx power into antenna (kW) (Peak)	640	1 000	1 000	4 000-6 400	60-200	1 000
Pulse width (μs)	160-1 000	1.0-15	0.25, 0.6	6.4-51.2	0.1-200	1.25(1)
Repetition rate (kHz)	0.020-2	0.536	1.125	0.152-6.0	0.3-10	2
Compression ratio	48 000	Not applicable	Not applicable	64-512	Up to 300	250
Type of compression	Not available	Not applicable	Not applicable	CPFSK	Not available	Not available
Duty cycle (%)	2-32	0.005-0.8	0.28, 0.67	0.8-2.0	Max 20	5
Tx bandwidth (MHz) (–3 dB)	25/300	2	4, 16.6	4	25	> 30
Antenna gain (dBi)	39	40	32	42	Up to 40	40
Antenna type	Parabolic		Parabolic	PA	PA	SWA
Beamwidth (H,V) (degrees)	1.72	1.05, 2.2	1.75, 4.4, csc^2 to 30	1.7, 1.7	1.1-5,1.1-5	1.2, 6.0
Vertical scan type	Not available	Not applicable	Not applicable	Random	Not applicable	Not available
Maximum vertical scan (degrees)	93.5	Not applicable	Not applicable	90	90	± 60
Vertical scan rate (degrees/s)	15	Not applicable	Not applicable		instantaneous	Not available
Horizontal scan type	Not applicable	Rotating	Rotating	Random	Continuous 360 + Sector	Rotating
Maximum horizontal scan (degrees)	360		360			360
Horizontal scan rate (degrees/s)	15	25.7	24	Not applicable	30-360	36
Polarization	RHCP	V	H	V	Not available	Not available
Rx sensitivity (dBm)	Not available	–112	–112	Not available	Not available	Not available
S/N criteria (dB)	Not applicable	0	14	Not available	Not available	Not available
Rx noise figure (dB)	3.1	4.0	4.8	5.0	1.5	3
Rx RF bandwidth (MHz) (–3 dB)	Not available	2.0	Not available		400	Not available
Rx IF bandwidth (MHz) (–3 dB)	380	0.67	8	10	10-30	1
Deployment area	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide

(1) 100 ns compressed.
CPFSK: Continuous-phase FSK
PA: Phased array
SWA: Slotted waveguide array

3.3 Scenarios

Each of the studies below seeks to determine the minimum required separation distances necessary to avoid interference between an indoor IMT system deployment in the band 3 300-3 400 MHz and the radar systems described in Table 2 above.

The scenarios examined in each study are described in more detail below.

4 Analysis

4.1 Study A1

4.1.1 Assumptions

This study covers compatibility of IMT in-door system with land based system "A" and airborne system "A".

4.1.1.1 IMT parameters

Indoor base-station penetration loss	20 dB (3-5 GHz) (horizontal direction) Rec. ITU-R P.1238, Table 3 (vertical direction)

4.1.2 Methodology

4.1.2.1 Radiolocation service radar interference criteria

1. Interference criteria for radar:

The following methodology is adopted in Recommendation ITU-R M.1465.

The maximum allowable interference power for the radar analysed is:

$$I/N \leq -6 \text{ dB}$$

Where:

I: The maximum allowable interference power for radar, dBm;

N: Receiver noise, dBm.

4.1.2.2 Interference criteria for IMT

According to ECC Report 174， the interference threshold from Radar K to LTE base station is –112 dBm/MHz, the interference threshold from Radar K to LTE terminal is –110 dBm/MHz.

4.1.2.3 Methodologies

Assuming one base-station small cell or UE deployment interfere radiolocation service radar, the received interference power level at the radiolocation service radar is calculated according to the equation:

$$I_{IMT} = P_{IMT} + G_{IMT} + G_{Radar} - L(f,d) - S$$

I_{IMT} [4]: the received interference power level in 1MHz bandwidth at the radiolocation service radar (dBm);

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[4] Consider the interference aggregation from multiple IMT small cell deployments in the same building.

P_{IMT}: transmission power per MHz bandwidth of IMT system (dBm);

G_{IMT}: antenna gain of IMT system (dB);

G_{Radar}: reception antenna gain of radiolocation service radar (dB);

$L(f,d)$: the path loss (dB);

S: shadowing loss (dB) with standard deviation of 10 dB in log-normally distribution. In determined study, it is set to 0 dB.

Assuming radar interfere IMT, the received interference power level at the IMT is calculated according to the equation:

$$I_{Radar} = P_{Radar} + G_{Radar} + G_{IMT} - L(f,d) - S$$

where:

I_{Radar}: the received interference power level in 1 MHz bandwidth at the IMT (dBm);

P_{Radar}: transmission power per MHz bandwidth of radar system (dBm);

G_{Radar}: antenna gain of Radar system (dB);

G_{IMT}: reception antenna gain of IMT (dB);

$L(f,d)$: the path loss (dB);

S: shadowing loss (dB) with standard deviation of 10 dB in log-normally distribution. In determined study, it is set to 0 dB.

4.1.2.4 IMT network topology

Each building contains an IMT small cell indoor system comprising multiple IMT small cells.

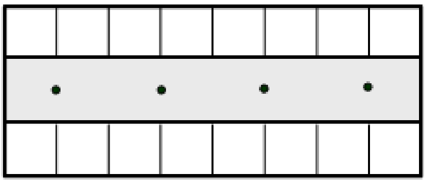
The IMT small cell indoor system topology is distributed in buildings of 6 floors, the topology of each floor is based on the below figure from the 3GPP specification 3GPP TR 36.814. As shown below:

– IMT small cell indoor system buildings size: 120 m x 50 m, including rooms and corridor;
– Number of rooms in the building (per floor): 16;
– Room size: 15 m x 15 m;
– Corridor size: 120 m x 20 m;
– 4 indoor IMT small cell BSs in each floor5;
– All UEs are deployed in the rooms;
– 6 floors in each building, the IMT indoor base-station are deployed in 4 floors randomly selected among the 6 available floors in the building (i.e. 16 IMT small cell base stations are always considered in each building):
– Height of each floor: 3 m;
– External wall loss: 20 dB [(in line with latest ITU-R WP 5D IMT parameter update)];
– Floor penetration loss: 18 dB for each floor (in line with [latest WP 5D and] Recommendation ITU P.1238-7, Table 3).

[5] Four small cell base stations are considered in each floor instead of the two base stations per floor considered in 3GPP TR 36.814.

FIGURE 1

IMT small cell indoor system building: floor topology



IMT small cell and radiolocation service radar deployment is shown as following. IMT UEs are also deployed indoor.

FIGURE 2

Interference scenario between land-based-A radar system and IMT system for small cell indoor deployment

FIGURE 3

Interference scenario between land-based-B radar system and IMT system for small cell indoor deployment

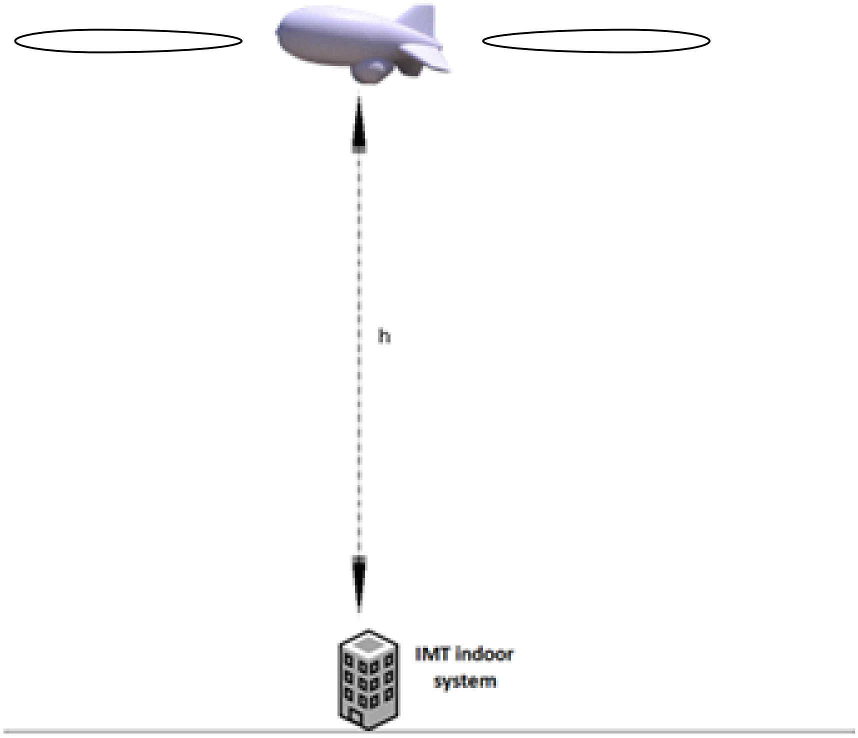
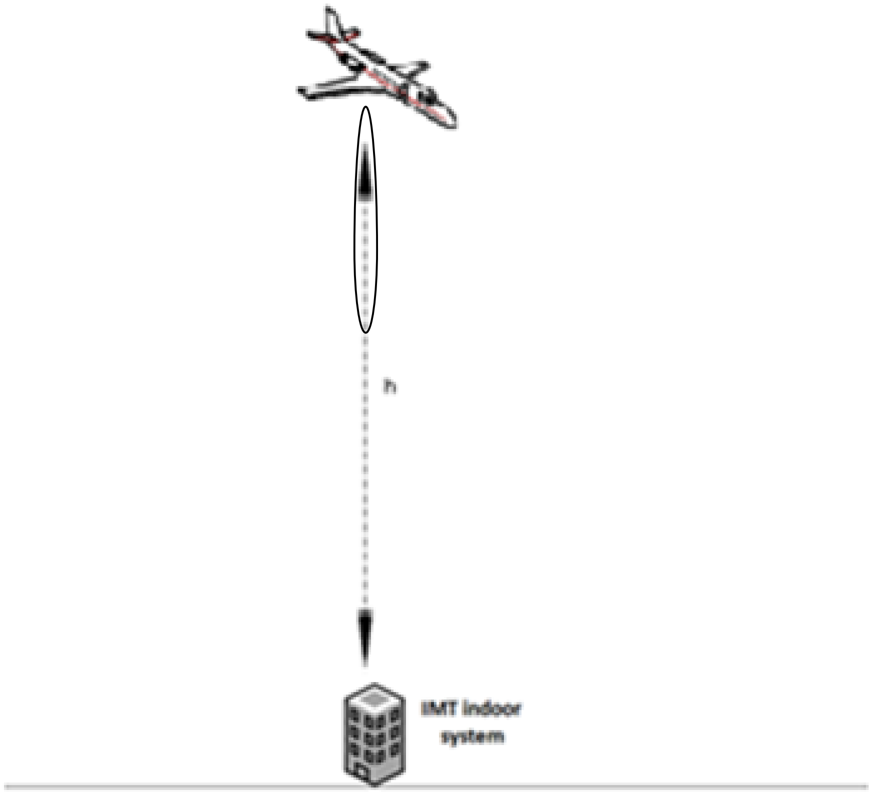


FIGURE 4

Interference scenario between airborne Radar A system and IMT system for small cell indoor deployment



Where:

$d_{protection}$: separation distance: the distance between the radiolocation service radar and IMT small cell base station;

h: Radiolocation service radar height relative to the ground. It is 5 metres for land-based Radar A, 4 600 metres for land-based Radar B and 9 000 metres for airborne Radar A.

4.1.2.5 Propagation models

4.1.2.5.1 Propagation model between IMT indoor system and Land-Based-A radar

The propagation model between IMT indoor system and Land-Based-A radar is from Recommendation ITU-R P.452-15.

Basic transmission loss is from Recommendation ITU-R P.452-15 as follows:

$$L = 92.5 + 20 \log f + 20 \log d + A_g + L_{d50} + A_{ht} + A_{hr} \quad \text{dB}$$

where:

L: transmission loss due to free-space propagation and attenuation by diffraction loss (dB);

f : frequency (GHz);

d : path length (km);

A_g : total gaseous absorption (dB);

L_{d50}: the median diffraction loss (dB):

$$L_{d50} = L_{m50} + \left(1 - e^{-\frac{L_{m50}}{6}}\right)\left(L_{t50} + L_{r50} + 10 + 0.04d\right) \quad \text{for } \nu_{m50} > -0.78$$

$$= 0 \quad \text{otherwise}$$

where:

L_{m50}: the median knife-edge diffraction loss for the main edge (dB);

Lt50: the median knife-edge diffraction loss for the transmitter-side secondary edge (dB);

Lr50: the median knife-edge diffraction loss for the receiver-side secondary edge (dB);

νm50: the diffraction parameter of the main edge (dB);

Aht,hr : additional losses to account for clutter shielding the transmitter and receiver.

Recommendation ITU-R P.452-15 requires the terrain information as input for diffraction loss. The proposal below uses the typical terrain information contained in the table 4 of Recommendation ITU-R P.452-14 and the method of applying height-gain correction in the Figure 3 of Recommendation ITU-R P.452-15.

TABLE 3

Nominal clutter heights and distances

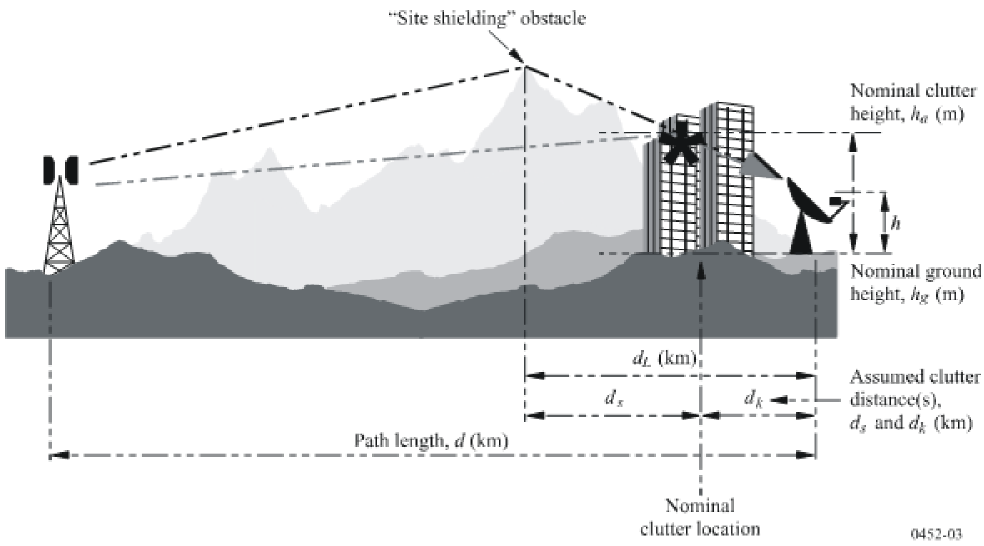
Clutter (ground-cover) category	**Nominal height ha (m)**	**Nominal distance dk (km)**
Suburban	9	0.025
Urban	20	0.02

h_a: Nominal clutter height (m) above local ground level;

d_k: Distance (km) from nominal clutter point to the antenna.

FIGURE 5

Method of applying height-gain correction



For transmitter and receiver side, the terrain info is according to the above table. The concrete value is based on which scenario the node is located.

4.1.2.5.2 Propagation model between IMT indoor system and airborne Radar A

The propagation model between IMT indoor system and Land-Based-B radar/airborne Radar A is from free space model.

$$L = 92.5 + 20 \log f + 20 \log d \qquad \text{dB}$$

where:

L: transmission loss due to free-space propagation (dB);

f: frequency (GHz);

d: path length (km).

4.1.3 Calculations

4.1.3.1 IMT system interference to radar system

Land-based-A radar system and IMT system

Protection distance between Land-based -A radar system and IMT system for small cell indoor deployment based on determined study is shown in the following table.

For the aggregated interference from IMT, 12 dB additional interference (16 IMT base-station per building) is considered compared with single entry interference. Considering the narrow bandwidth of radar, the interference range from the same building is reasonable.

TABLE 4

Protection distance between Land-based-A radar system and IMT system for small cell indoor deployment

Interference type: From IMT base-station to Land-based-A radar station								
IMT system deployment place	Located at radar antenna main lobe				Located at radar antenna side lobe			
IMT signal bandwidth (MHz)	20				20			
Maximum output power (dBm)	24				24			
Antenna gain of IMT indoor base-station (dBi)	0				0			
Insertion loss of IMT indoor base-station (dB)	2				2			
Operating height of IMT indoor base-station (m)	3 m above each floor				3 m above each floor			
Insertion loss of land-based Radar A (dB)	2				2			
Antenna gain of land-based Radar A (dBi)	39				0			
Operating height of land-based Radar A (m)	3				3			
Penetration loss of outdoor to indoor (dB)	20				20			
Required Outdoor Propagation loss (dB)	142.34				103.34			
Deployment scenario	Urban		Suburban		Urban		Suburban	
Min. separation distance (m)	< 200		1100		< 200		< 200	
Interference type: From IMT indoor UE to Land-based-A radar station								
IMT system deployment place	Located at radar antenna main lobe				Located at radar antenna side lobe			
IMT signal bandwidth (MHz)	20				20			
Maximum output power (dBm)	23				23			
Average output power (dBm)	-9				-9			
Antenna gain of IMT indoor UE (dBi)	-4				-4			
Operating height of IMT indoor UE (m)	1.5 m above each floor				1.5 m above each floor			
Insertion loss of land-based Radar A (dB)	2				2			
Antenna gain of land-based Radar A (dBi)	39				0			
Penetration loss of outdoor to indoor (dB)	20				20			
UE Output power (dBm)	23(max)		-9(average)		23(max)		-9(average)	
Deployment scenario	Urban	Suburban	Urban	Suburban	Urban	Suburban	Urban	Suburban
Required outdoor Propagation loss (dB)	127+12	127+12	95+12	95+12	88+12	88+12	56+12	56+12
Min. separation distance (m)	< 200	800	< 200	< 200	< 200	< 200	< 200	< 200

Airborne-A radar system and IMT system

Maximum tolerable outdoor power (e.i.r.p.) from IMT indoor system in sharing scenario between airborne Radar A system and IMT indoor system based on determined study is shown as following table.

For the aggregated interference from IMT, 6 dB additional interference (4 IMT base-station per floor) is considered compared with single entry interference. Considering the narrow bandwidth of radar, the interference range from the same floor (the highest floor) is reasonable.

TABLE 5

Maximum tolerable outdoor power (e.i.r.p.) between airborne Radar A system and IMT system for small cell indoor deployment

Interference type: From IMT small cell indoor base-station to airborne Radar A station		
Airborne Radar A receiver IF bandwidth = 1 MHz		
IMT system deployment place	Located at radar antenna main lobe	Located at radar antenna side lobe
IMT signal bandwidth (MHz)	20	20
Maximum output power (dBm)	24	24
Antenna gain of IMT indoor base-station (dBi)	0	0
Insertion loss of IMT indoor base-station (dB)	2	2
Operating height of IMT indoor base-station (m)	3	3
Penetration loss of outdoor to indoor (dB)	20	20
Insertion loss of airborne Radar A (dB)	2	2
Antenna gain of airborne Radar A (dBi)	40	-10
Operating height of airborne Radar A (m)	9000	9000
Required Total Propagation loss (dB)	170	120
Maximum tolerable outdoor power(e.i.r.p.) (dBm)	-17.5	32.5
Required additional isolation (dB)	28	-22
Interference type: From IMT small cell indoor UE to airborne Radar A station		
Airborne Radar A receiver IF bandwidth = 1 MHz		
IMT system deployment place	Located at radar antenna main lobe	Located at radar antenna side lobe
IMT signal bandwidth (MHz)	20	20

Maximum output power (dBm)	23		23	
Average output power (dBm)	-9		-9	
Antenna gain of IMT indoor UE (dBi)	-4		-4	
Operating height of IMT indoor UE (m)	1.5		1.5	
Penetration loss of outdoor to indoor (dB)	20		20	
Insertion loss of airborne Radar A (dB)	2		2	
Antenna gain of airborne d Radar A (dBi)	40		-10	
Operating height of airborne Radar A (m)	9000		9000	
UE Output power (dBm)	23(max)	-9(average)	23(max)	-9(average)
Required total Propagation loss (dB)	163	131	113	83
Maximum tolerable outdoor power(e.i.r.p.) (dBm)	-11.5		38.5	
Required additional isolation (dB)	20.5	-11,5	-29.6	-61.5

In case of interference from IMT small cell indoor base-station or indoor UE, additional isolation is required.

When IMT indoor system located at radar antenna main lobe:

– Required additional isolation between IMT indoor base-station deployed at first floor from the roof and airborne radar "A" is equal to 28 dB.

– Additional isolation can be achieved by adjacent frequency deployment of IMT or greater geographic separation.

– For IMT small cell indoor base-station deployed at second floor from the rooftop, there is additional penetration loss 20 dB from one external wall or the ceiling. Considering that IMT small cell indoor base-station antenna is deployed at the top of the room and it transmits downwards, 8 dB additional isolation is required to be provided by IMT base-station antenna discrimination.

– For IMT indoor UE interference to radar system, UE works normally under power control so additional penetration loss 20 dB from one external wall or one roof is enough for compatibility requirement. Even if UE outputs maximum power, the more additional isolation can be got from adjacent frequency deployment or more distance isolation.

When IMT system located at radar antenna side lobe:

– For interference from both IMT small cell indoor base-station and indoor UE, no additional isolation is needed.

4.1.3.2 Radar system interference to IMT system

Land-based-A radar system and IMT system

Received interference from Land-based -A radar system for small cell indoor deployment based on determined study is shown in the following table.

TABLE 6

Land-based-A radar system and IMT system for small cell indoor deployment

Interference type: From Land-based-A radar station to IMT base-station								
IMT system deployment place	Located at radar antenna main lobe				Located at radar antenna side lobe			
IMT signal bandwidth (MHz)	20				20			
Radar maximum output power (kW)	640 (88 dBm)				640 (88 dBm)			
Antenna gain of IMT indoor base-station (dBi)	0				0			
Insertion loss of IMT indoor base-station (dB)	2				2			
Operating height of IMT indoor base-station (m)	3 m above each floor				3 m above each floor			
Insertion loss of land-based Radar A (dB)	2				2			
Antenna gain of land-based Radar A (dBi)	39				0			
Operating height of land-based Radar A (m)	3				3			
Penetration loss of outdoor to indoor (dB)	20				20			
Radar bandwidth(MHz)	25		300		25		300	
Deployment scenario	Urban	Suburban	Urban	Suburban	Urban	Suburban	Urban	Suburban
Received interference level for 5km protect distance (dBm)	-88.91	-53.91	-99.70	-64.70	-127.91	-92.91	-138.7	-103.7
Interference type: From Land-based-A radar station to IMT indoor UE								
IMT system deployment place	Located at radar antenna main lobe				Located at radar antenna side lobe			

IMT signal bandwidth (MHz)	20				20			
Radar maximum output power (kW)	640 (88 dBm)				640 (88 dBm)			
Antenna gain of IMT indoor UE (dBi)	-4				-4			
Operating height of IMT indoor UE (m)	1.5 m above each floor				1.5 m above each floor			
Insertion loss of land-based Radar A (dB)	2				2			
Antenna gain of land-based Radar A (dBi)	39				0			
Penetration loss of outdoor to indoor (dB)	20				20			
Radar bandwidth(MHz)	25		300		25		300	
Deployment scenario	Urban	Suburban	Urban	Suburban	Urban	Suburban	Urban	Suburban
Received interference level for 5km separation distance (dBm)	-90.91	-55.91	-101.7	-66.7	-129.91	-94.91	-140.7	-105.7

On one hand, it should be emphasised that land based Radar A beamwidth is very narrow (1.72 degree), thus it is low probability that IMT system is located at radar antenna main lobe. On the other hand, it will not scan in the same area constantly so that the interference to a building with IMT indoor system only maintains very short time in total.

With a 5 kilometre geographic separation between radar transmitter and IMT system receivers the protection criteria for IMT would be exceeded in half of the scenarios considered, therefore additional mitigation for IMT is required. This may be achieved through implementations of techniques such as scheduling, error correction, frequency separation and/or increased geographic separation, however the issue of possible mitigation techniques, nor the possible acceptable degradation of IMT performance has not been covered by this study.

Airborne-A radar system and IMT system

Received interference from airborne Radar A system for small cell indoor deployment based on determined study is shown in the following table.

TABLE 7

Maximum tolerable outdoor power (e.i.r.p.) between airborne Radar A system and IMT system for small cell indoor deployment

Interference type: From airborne Radar A station to IMT small cell indoor base-station		
IMT system deployment place	Located at radar antenna main lobe	Located at radar antenna side lobe
IMT signal bandwidth (MHz)	20	20
Maximum Radar output power (KW)	1000	1000
Antenna gain of IMT indoor base-station (dBi)	0	0
Insertion loss of IMT indoor base-station (dB)	2	2
Operating height of IMT indoor base-station (m)	3m above each floor	3m above each floor
Insertion loss of airborne Radar A (dB)	2	2
Antenna gain of airborne Radar A (dBi)	40	-10
Operating height of airborne Radar A (m)	9000	9000
Penetration loss of outdoor to indoor (dB)	20	20
Radar bandwidth(MHz)	30	30
Received interference level (dBm)	-17.8	-67.8
Interference type: From airborne Radar A station to IMT small cell indoor UE		
IMT system deployment place	Located at radar antenna main lobe	Located at radar antenna side lobe
IMT signal bandwidth (MHz)	20	20
Maximum Radar output power (KW)	1000	1000
Antenna gain of IMT indoor UE (dBi)	-4	-4
Operating height of IMT indoor UE (m)	1.5m above each floor	1.5m above each floor
Insertion loss of airborne Radar A (dB)	2	2
Antenna gain of airborne d Radar A (dBi)	40	-10
Operating height of airborne Radar A (m)	9000	9000
Penetration loss of outdoor to indoor (dB)	20	20
Radar bandwidth(MHz)	30	30
Received interference level (dBm)	-19.8	-69.8

On one hand, it should be emphasised that airborne Radar A beamwidth is very narrow ((H,V)=(1.2,6.0) degree), thus it is low probability that an IMT system is located in the radar antenna main lobe. On the other hand, airborne radar carried by aircraft with speed of around 800 km/h will not scan in the same area constantly so that the interference to a building with IMT indoor system only maintains a limited time in total.

However the protection criteria for IMT would be exceeded in both of the scenarios considered, therefore additional mitigation for IMT is required. This may be achieved through implementations of techniques such as scheduling, error correction, frequency separation and/or increased geographic separation, however the issue of possible mitigation techniques, nor the possible acceptable degradation of IMT performance has not been covered by this study.

4.2 Study B1

The study covers compatibility with land based system “A” and “B”, ship systems “A”, “B” and “C” and airborne system “A”.

4.2.1 Assumptions

4.2.1.1 Radiolocation service radar interference criteria

The following methodology is adopted in Recommendation ITU-R M.2111.

The maximum allowable interference power for the radar analysed is:

$$I/N \leq -6 \text{ dB}$$

Where:

I: The maximum allowable interference power for radar, dBm;

N: Receiver noise, dBm.

4.2.1.2 Radiolocation service radar height relative to the ground

5 m for land-based Radar A, 4 600 metres for land-based radar B, 9 000 metres for airborne Radar A, 46 metres for ship-based Radar A, and 20 metres for ship-based radars B and C.

4.2.1.3 IMT network topology

A deployment of an IMT small cell indoor system in a single 6-floor building is considered. The IMT small cell indoor system comprises multiple IMT small cells.

The topology of each floor is based on the below figure from the 3GPP specification 3GPP TR 36.814. As shown in figure below:

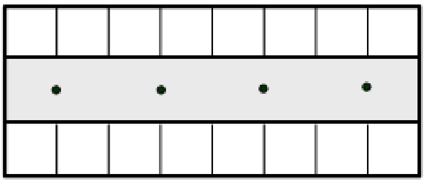
– IMT small cell indoor system buildings size: 120 m x 50 m, including rooms and corridor;
– Number of rooms on one floor: 16;
– Number of floors in building: 6;
– Room size: 15 m x 15 m;
– Corridor size: 120 m x 20 m;
– 4 indoor IMT small cell base stations on each floor[6];
– All UE are deployed in the rooms;

[6] Four small cell base stations are considered in each floor instead of the two base stations per floor considered in 3GPP TR 36.814.

– It is assumed that at least one UE per base station is transmitting at the maximum power. Only such UE (24 of them) are considered in the aggregate interference analysis;
– Height of each floor: 3 m;
– Average building penetration loss for calculating path loss: 11 dB
– Indoor user penetration loss: 20 dB ([in line with latest ITU-R WP 5D IMT parameter update]. Note that the indoor penetration losses here include not only the building entry/wall loss but also additional attenuation for the signal to penetrate deeper into the building. This penetration loss may be frequency dependent);
– Penetration loss: Calculations are conducted with penetration losses of 11 and 20 dB, representing the average building penetration loss and the value used for indoor IMT planning respectively;
– Radar antenna main lobe to IMT main lobe coupling is considered. This is the worst case scenario as usually the radar beam does not remain pointing with a static bearing and IMT stations will fall within the main beam at some point during the radar's rotation.

FIGURE 6

IMT small cell indoor system building: floor topology



4.2.2 Methodology

4.2.2.1 Methodology of analysis of interference to the radiolocation service

Assuming one base-station small cell or UE interfering with a radiolocation service radar, the received interference power level at the radiolocation service radar is calculated according to the equation:

$$I_{IMT} = P_{IMT} + G_{IMT} + G_{Radar} - L(f, d)$$

I_{IMT}: the received interference power level in 1 MHz bandwidth at the radiolocation service radar (dBm);

P_{IMT}: transmission power per MHz bandwidth of IMT system (dBm);

G_{IMT}: antenna gain of IMT system (dB);

G_{Radar}: reception antenna gain of radiolocation service radar (dB);

$L(f, d)$: the path loss (dB).

In the aggregate interference case, the analysis is identical to the above with the exception of an increase in the interference power by a factor on 24 representing the number of transmitting base-station or UE in the building.

Results are presented for both co-channel and non-co-channel scenarios. Note that in the non-co-channel analysis the frequency dependent rejection attenuation is determined according to

Figure A2-3 of Report ITU-R. M.2111 for the IMT masks corresponding to ACLR1= –50 dB and IMT bandwidth 25 MHz.

4.2.2.2 Interference to the IMT indoor system

The interference from the radiolocation service radar to the IMT indoor system was considered using the same methods as described above. The maximum allowable interference level is calculated for $I/N \leq -6$ dB.

4.2.2.3 Propagation models

The propagation model used to estimate the required separation distance between the IMT indoor system and land-based-A radar and ship-based radars A, B and C is from Recommendation ITU-R P.452-14, using a smooth earth model for the terrain profile.

In addition, this study uses the clutter loss as calculated from section 4.5 of Recommendation ITU-R P.452-14. The following table shows the clutter parameters used in calculations.

Path loss model ITU-R P.452 allows for clutter at either or both ends of the link. Note that radars are often installed at locations clear of clutter and therefore no clutter is defined near the radar in the calculations.

TABLE 8

Nominal clutter heights and distances

Clutter (ground-cover) category	Nominal height h_a (m)	Nominal distance d_k (km)
Urban	20	0.02

h_a: Nominal clutter height (m) above local ground level.

d_k: Distance (km) from nominal clutter point to the antenna.

The propagation model used for land-based-B and airborne Radar A is the model given in Recommendation ITU-R P.528-3. Path loss was first analysed using the free-space model governed by the equation:

$$L = 92.5 + 20 \log f + 20 \log d \qquad \text{dB}$$

where:

L: transmission loss due to free-space propagation (dB);

f: frequency (GHz);

d: path length (km).

When the minimum separation distance is greater than the height of the radar it is re-calculated using the path loss model specified in Recommendation ITU-R P.528-3. For interference analysis the 5% curves of the Recommendation ITU-R P.528-3 are used.

4.2.3 Calculations

4.2.3.1 Land based radars

Minimum separation distances between land-based A and land-based B radar systems and indoor IMT systems are shown in the following tables. Interference from IMT system base-station/UE into radar and from radar into IMT systems UE /base-station are considered.

TABLE 9

Interference from IMT indoor base-station to land-based radar station (co-channel)

Radar system deployed	Land-based-A radar station				Land-based-B radar station			
Carrier frequency (GHz)	3.3				3.3			
IMT Signal bandwidth (MHz)	20				20			
Maximum output power (dBm)	24				24			
Antenna gain of indoor IMT base-station (dBi)	0				0			
Insertion loss IMT indoor (dB)	2				2			
Insertion loss of radar (dB)	2				2			
Antenna gain radar (dBi)	39				40			
Penetration loss of outdoor to indoor (dB)	11		20		11		20	
Frequency difference (MHz)	0				0			
FDR (dB)	0				0			
Number of IMT base-station	1	24	1	24	1	24	1	24
Allowable interference level (dBm/MHz)	-117				-117			
Allowable interference power (dBm)	-104				-104			
Required propagation loss (dB)	152.0	165.8	143.0	156.8	153.0	166.8	144.0	157.8
Propagation model	ITU-R P.452-14				ITU-R P.528-3			
Min separation distance using propagation model (km)	15	25	10	18.5	161.5	294	140.5	188

TABLE 10

Interference from IMT indoor base-station to land-based radar station (non-co channel)

Radar System Deployed	Land- Based-A radar station				Land based-B radar station			
Carrier frequency (GHz)	3.3				3.3			
IMT Signal bandwidth	20				20			
Maximum output power	24				24			
Antenna gain of indoor IMT base-station	0				0			
Insertion loss IMT indoor	2				2			
Insertion loss of radar	2				2			
Antenna gain radar	39				40			
Penetration loss of outdoor to indoor	11		20		11		20	
Frequency difference (MHz)	20				20			
FDR (dB)	60				63.41			
Number of IMT base-station	1	24	1	24	1	24	1	24
Allowable interference level (dBm/MHz)	-117	-117	-117	-117	-117	-117	-117	-117
Allowable interference power (dBm)	-103.99	-103.99	-103.99	-103.99	-103.99	-103.99	-103.99	-103.99
Required propagation loss	92.0	105.8	83.0	96.8	89.6	103.4	80.6	94.4
Min separation distance (free-space) (km)	0.3	1.4	0.1	0.5	0.2	1.1	0.1	0.4

TABLE 11

Interference from IMT indoor UE to land-based radar stations (co-channel)

Radar system deployed	Land-based-A radar station				Land-based-B radar station			
Carrier frequency (GHz)	3.3				3.3			
IMT Signal bandwidth (MHz)	20				20			
Maximum output power (dBm)	23				23			
Antenna gain of indoor IMT UE (dBi)	-4				-4			
Insertion loss of radar (dB)	2				2			
Antenna gain radar (dB)	39				40			
Penetration loss of outdoor to indoor (dB)	11		20		11		20	
Frequency difference (MHz)	0				0			
FDR (dB)	0				0			
Number of indoor UE	1	24	1	24	1	24	1	24
Allowable interference level (dBm/MHz)	-117				-117			
Allowable interference power (dBm)	-104				-104			
Required propagation loss (dB)	149.0	162.8	140.0	153.8	150.0	163.8	141.0	154.8
Propagation model	ITU-R P.452-14				ITU-R P.528-3			
Min separation distance using propagation model (km)	13	23.5	8.5	15.5	154	261	119	167

TABLE 12

Interference from IMT indoor UE to land-based-A radar station (non-co channel)

Radar System Deployed	Land based-A radar station				Land based-B radar station			
Carrier frequency (GHz)	3.3				3.3			
IMT Signal bandwidth	20				20			
Maximum output power	23				23			
Average output power	23				23			
Antenna gain of IMT UE	-4				-4			
Insertion loss radar	2				2			
Antenna gain radar	39				40			
Penetration loss of outdoor to indoor	11		20		11		20	
Frequency difference (MHz)	20				20			
FDR (dB)	60				63.41			
Number of IMT base-station	1	24	1	24	1	24	1	24
Allowable interference level (dBm/MHz)	-117	-117	-117	-117	-117	-117	-117	-117
Allowable interference power (dBm)	-103.9	-103.9	-103.9	-103.9	-103.9	-103.9	-103.9	-103.9
Required propagation loss	89.0	102.8	80.0	93.8	86.6	100.4	77.6	91.4
Min separation distance (km)	0.2	0.99	0.72	0.35	0.2	0.8	0.1	0.3

TABLE 13

Interference from land-based-A radar station to IMT indoor base-station

Carrier frequency (GHz)	3.3			
Radar Signal bandwidth (MHz)	4			
Maximum output power (dBm)	88			
Antenna gain of indoor IMT base-station (dBi)	0			
Insertion loss IMT indoor (dB)	2			
Insertion loss of radar (dB)	2			
Antenna gain radar (dBi)	39			
Penetration loss of outdoor to indoor (dB)	11	20	11	20
Frequency difference (MHz)	0		20	
FDR (dB)	0		60	
Allowable interference level (dBm/MHz)	-115			
Allowable interference power (dBm)	-109			
Required propagation loss (dB)	221.0	212.0	161.0	152.0
Min separation distance P.452-14 (km)	520	402	55	44.5

TABLE 14

Interference from Land-based-B radar station to IMT indoor base-station

Carrier frequency (GHz)	3.3			
Radar Signal bandwidth (MHz)	4			
Maximum output power (dBm)	90			
Antenna gain of indoor IMT base-station (dBi)	0			
Insertion loss IMT indoor (dB)	2			
Insertion loss of radar (dB)	2			
Antenna gain radar (dBi)	42		0	
Penetration loss of outdoor to indoor (dB)	11	20	11	20
Allowable interference level (dBm/MHz)	-115			
Allowable interference power (dBm)	-109			
Required propagation loss (dB)	226	217	184	175
Min separation distance Rec. ITU-R P.528-3 (km)	1008	886	563.5	500

In the case of co-channel interference from IMT small cell indoor base-station and indoor UE to land-based Radar A, the worst case separation distances are 25 and 24 kilometres respectively assuming the penetration loss of 11dB for a building containing 24 base stations. However, in the case of co-channel interference from IMT small cell indoor base-station and indoor UE to land-based Radar B the separation distances required are 294 and 261 kilometres respectively. These observations are expected considering that land-based Radar B is at a height of 4 600 metres where there is no terrain/clutter protection within a long radio horizon.

It is assumed that the IMT indoor system is located within the radar antenna main lobe (modelling the worst case for a rotating radar):

- for an IMT small cell indoor base-station deployment a penetration of 11 dB representing propagation through an average building is used. The calculation is also done for 20 dB penetration loss representing propagation inside the building. The effect of multiple base-station deployed in a building (maximum 24 base-station per building) is also considered. The aggregate analysis shows considerable extra protection is necessary in the worst case aggregate scenario;
- for IMT indoor UE interference to a radar system, it is assumed that the worst case where the UE is transmitting at maximum power. The analysis shows that in the aggregate case the effects of UEs are as severe as aggregate base-station;
- The analysis shows that non-co channel sharing is possible for land Radar A with separation distance of 1.4 kilometres. Considering that land Radar B is 4.6 kilometres in the air it may be that non-co channel sharing is also possible between land Radar B and the IMT systems.

Even though Land-Based-B radar beamwidth is very narrow ((H,V)=(1.05, 2.2) degree), there is a high likelihood that at some percentage of the time it will be directed towards a building containing one or many base-station and UE. The severity of this problem is dependent on the percentage of buildings which have IMT small cell coverage. It is conceivable in the not too distant future that the majority of buildings in a city may have IMT small cell coverage, in this case it is almost certain that the land-based B radar main beam will be coupled with numerous base-station and UE at any point in time.

The co-channel and non-co channel interference from the land-based Radar A to the IMT systems is very severe. The analysis shows that the separation distance required is 520 and 55 kilometres for co-channel and non-co channel respectively.

The co-channel interference from the land-based Radar B to the IMT systems is more severe than that from land-based Radar A. The analysis shows that the separation distance required is 1 008 kilometres.

4.2.3.2 Airborne radars

The minimum separation distances between airborne Radar A system and IMT indoor system are shown in the following tables. Interference from IMT system base-station/UE into radar and from radar into IMT systems UE/ base-station are considered.

TABLE 15

Interference from IMT indoor base-station to airborne Radar A station (co-channel)

Carrier frequency (GHz)	3.3			
IMT Signal bandwidth (MHz)	20			
Maximum output power (dBm)	24			
Antenna gain of indoor IMT base-station (dBi)	0			
Insertion loss IMT indoor (dB)	2			
Insertion loss of radar (dB)	2			
Antenna gain radar (dBi)	40			
Penetration loss of outdoor to indoor (dB)	11		20	
Frequency difference (MHz)	0			
FDR (dB)	0			
Number of IMT base-station	1	24	1	24
Allowable interference level (dBm/MHz)	-117			
Allowable interference power (dBm)	-104			
Required propagation loss (dB)	153.0	166.8	144.0	157.8
Propagation model	ITU-R P.528-3			
Min separation distance using propagation model (km)	348.5	422.5	166	410

TABLE 16

Interference from IMT indoor base-station to airborne-A radar station (non-co channel)

IMT system deployment place	Located at radar antenna main lobe			
Carrier frequency (GHz)	3.3			
IMT Signal bandwidth (MHz)	20			
Maximum output power (dBm)	24			
Antenna gain of indoor IMT base-station (dBi)	0			
Insertion loss IMT indoor (dB)	2			
Insertion loss of radar (dB)	2			
Antenna gain radar (dBi)	40			
Penetration loss of outdoor to indoor (dB)	11		20	
Frequency difference (MHz)	20			
FDR (dB)	34.7			
Number of IMT base-station	1	24	1	24
Allowable interference level (dBm/MHz)	-117			
Allowable interference power (dBm)	-104			
Required propagation loss (dB)	118.3	132.1	109.3	123.1
Min separation distance (free space)(km)	N/A	N/A	2.1	N/A
Propagation model	ITU-R P.528-3			
Min separation distance using propagation model(km)	9	51.5	N/A	17.5

TABLE 17

Interference from IMT indoor UE to airborne-A radar station (co-channel)

IMT system deployment place	Located at radar antenna main lobe			
Carrier frequency (GHz)	3.3			
IMT Signal bandwidth (MHz)	20			
Maximum output power (dBm)	23			
Antenna gain of indoor IMT UE (dBi)	-4			
Insertion loss of radar (dB)	2			
Antenna gain radar (dB)	40			
Penetration loss of outdoor to indoor (dB)	11		20	
Frequency difference (MHz)	0			
FDR (dB)	0			
Number of IMT UE	1	24	1	24
Allowable interference level (dBm/MHz)	-117			
Allowable interference power (dBm)	-104			
Required propagation loss (dB)	150.0	163.8	141.0	154.8
Propagation model	ITU-R P.528-3			
Min separation distance using propagation model(km)	291	423	138	385

TABLE 18

Interference from IMT indoor UE to airborne-A radar station (non-co channel)

IMT system deployment place	Located at radar antenna main lobe			
Carrier frequency (GHz)	3.3			
IMT Signal bandwidth (MHz)	20			
Maximum output power (dBm)	23			
Antenna gain of indoor IMT UE (dBi)	-4			
Insertion loss of radar (dB)	2			
Antenna gain radar (dBi)	40			
Penetration loss of outdoor to indoor (dB)	11		20	
Frequency difference (MHz)	20			
FDR (dB)	34.7			
Number of IMT UE	1	24	1	24
Allowable interference level (dBm/MHz)	-117			
Allowable interference power (dBm)	-104			
Required propagation loss (dB)	115.3	129.1	106.3	120.1
Min separation distance (free space) (km)	4.2	N/A	1.5	7.3
Propagation model	ITU-R P.528-3			
Min separation distance using propagation model(km)	N/A	36	N/A	N/A

TABLE 19

Interference from airborne Radar A station to IMT indoor base-station

Carrier frequency (GHz)	3.3				
Radar Signal bandwidth	4				
Maximum output power	90				
Antenna gain of indoor IMT base-station	0				
Insertion loss IMT indoor	2				
Insertion loss of radar	2				
Antenna gain radar	40		40		0
Penetration loss of outdoor to indoor	11	20	11	20	20
Frequency difference (MHz)	0		20		60
FDR (dB)	0		32		60.0
Allowable interference level (dBm/MHz)	-115		-115		-115
Allowable interference power (dBm)	-109.0				
Required propagation Loss (dB)	224.0	215.0	191.9	182.9	115.0
Min protection Distance (free space) (km)	N/A	N/A	N/A	N/A	4
Propagation model	ITU-R P.528-3				
Min protection distance using propagation model(km)	1057	937	697	623	N/A

As expected the results for the airborne Radar A are similar to the land-based Radar B. This is because they both operate at high altitude. The separation distance required for the airborne Radar A are more exaggerated than those of the land-based B because of its larger height above the ground of 9 kilometres. For co-channel sharing the minimum separation distance required between the airborne radar and the IMT systems is in approximately 420 kilometres.

– For IMT small cell indoor base-station deployments, a penetration loss of 11 dB representing propagation through an average building is used. The calculation is also made for 20 dB penetration loss representing propagation inside the building. The effect of multiple base-station deployed in a building (maximum 24 base-station per building) is also considered. The aggregate analysis shows considerable extra protection is necessary in the worst case aggregate scenario.

– For IMT indoor UE interference to radar system, the worst case is assumed where the UE is transmitting at maximum power. The analysis shows that in the aggregate case the effects of UE are as severe as aggregate BS.

– The analysis shows that non-co channel sharing may be possible for airborne Radar A where there is at least 20 dB of penetration loss. Where there is 11 dB penetration loss the minimum separation distance required is 52 kilometres for IMT base-station and 36 kilometres for UE.

Even though airborne Radar A beamwidth is very narrow ((H,V)=(1.2,6.0) degree), there is a high likelihood that at some percentage of the time it will be directed towards a building containing one or many base-station and UE. The severity of this problem is dependent on the percentage of buildings which have IMT small cell coverage. It is conceivable that the majority of buildings in a city may have IMT small cell coverage, in this case it is almost certain that the airborne Radar A main beam will be coupled with numerous base-station and UE at any point in time.

The co-channel and non-co channel interference from the airborne Radar A to the IMT systems is very severe. The analysis shows that the separation distance required is 1 057 and 697 kilometres for base-station and UE respectively.

4.2.3.3 Ship based radars

Minimum separation distances between ship-based radars A, B and C stations and indoor IMT system are given in the following tables. Interference from IMT system base-station and UE into radar and from radar into IMT systems UE and base-station are considered. Note that the frequency dependent rejection attenuation is determined according to Report ITU-R. M.2111 Figure A2-3 for an ACLR1= -50 dB. Report ITU-R M.2111 does not cover ship-based Radar System C, hence no non-co channel results are presented and IMT bandwidth 25 MHz.

TABLE 20

Interference from IMT indoor base-station to ship-based radar stations (co-channel)

Radar system deployed	Ship-based-A radar station				Ship-based-B radar station				Ship-based-C radar station			
Carrier frequency (GHz)	3.3				3.3				3.3			
IMT signal bandwidth (MHz)	20				20				20			
Maximum output power (dBm)	24				24				24			
Antenna gain of indoor IMT base-station (dBi)	0				0				0			
Insertion loss IMT indoor (dB)	2				2				2			
Insertion loss of radar (dB)	2				2				2			
Antenna gain radar (dBi)	32				42				40			
Penetration loss of outdoor to indoor (dB)	11		20		11		20		11		20	
Frequency difference (MHz)	0				0				0			
FDR (dB)	0				0				0			
Number of IMT base-station	1	24	1	24	1	24	1	24	1	24	1	24
Allowable interference level (dBm/MHz)	-117				-117				-117			
Allowable interference power (dBm)	-104				-104				-104			
Required propagation loss (dB)	145.0	158.8	136.0	149.8	155.0	168.8	146.0	159.8	153.0	166.8	144.0	157.8
Propagation model	ITU-R P.452-14											
Min protection distance using propagation model(km)	13	21	6	15.5	18.5	29	13	22	19	30	14	22.5

TABLE 21

Interference from IMT indoor base-station to Ship-based radar stations (non-co channel)

Radar system deployed	Ship-based-A radar station	Ship-based-B radar station	Ship-based-C radar station
Carrier frequency	3.3	3.3	3.3

(GHz)												
IMT Signal bandwidth (MHz)	20				20				20			
Maximum output power (dBm)	24				24				24			
Antenna gain of indoor IMT base-station (dBi)	0				0				0			
Insertion loss IMT indoor (dB)	2				2				2			
Insertion loss of radar (dB)	2				2				2			
Antenna gain radar (dBi)	32				42				40			
Penetration loss of outdoor to indoor (dB)	11		20		11		20		11		20	
Frequency difference (MHz)	20				20				40			
FDR (dB)	34.7				34.7				32.71			
Number of IMT base-station	1	24	1	24	1	24	1	24	1	24	1	24
Allowable interference level (dBm/MHz)	-117				-117				-117			
Allowable interference power (dBm)	-104				-104				-104			
Required propagation loss (dB)	110.3	124.1	101.3	115.1	120.3	134.1	111.3	125.1	120.3	134.1	111.3	125.1
Min separation distance (free space) (km)	2.4	11.5	0.8	4.1	7.5	36.5	2.6	13.0	7.4	36.4	2.6	12.9
Propagation model	ITU-R P.452-14											
Min protection distance using propagation model(km)	4	5	N/A	N/A	5	6	N/A	5	5	6.7	4.5	5.5

TABLE 22

Interference from IMT indoor UE to ship-based radar stations (co-channel)

Radar system deployed	Ship-based-A radar station	Ship-based-B radar station	Ship-based-C radar station
Carrier frequency (GHz)	3.3	3.3	3.3
IMT signal bandwidth (MHz)	20	20	20

Maximum output power (dBm)	23				23				23			
Antenna gain of indoor IMT UE (dBi)	-4				-4				-4			
Insertion loss of radar (dB)	2				2				2			
Antenna gain radar (dB)	32				42				40			
Penetration loss of outdoor to indoor (dB)	11		20		11		20		11		20	
Frequency difference (MHz)	0				0				0			
FDR (dB)	0				0				0			
Number of indoor UE	1	24	1	24	1	24	1	24	1	24	1	24
Allowable interference level (dBm/MHz)	-117				-117				-117			
Allowable interference power (dBm)	-104				-104				-104			
Required propagation loss (dB)	142.0	155.8	133.0	146.8	152.0	165.8	143.0	156.8	150.0	163.8	141.0	154.8
Propagation model	ITU-R P.452-14											
Min protection distance using propagation model (km)	10.5	19	6	14	16.5	26.5	11	19.5	17.5	27.5	12.5	20.5

TABLE 23

Interference from IMT indoor base-station to ship-based radar stations (non-co channel)

Radar system deployed	Ship-based-A radar station				Ship-based-B radar station				Ship-based-C radar station			
Carrier frequency (GHz)	3.3				3.3				3.3			
IMT Signal bandwidth (MHz)	20				20				20			
Maximum output power (dBm)	23				23				23			
Antenna gain of indoor IMT UE (dBi)	-4				-4				-4			
Insertion loss of radar (dB)	2				2				2			
Antenna gain radar (dBi)	32				42				40			
Penetration loss of outdoor to indoor (dB)	11		20		11		20		11		20	
Frequency difference (MHz)	20				20				40 (Note 1)			
FDR (dB)	34.7				34.7				32.71			
Number of IMT UE	1	24	1	24	1	24	1	24	1	24	1	24
Allowable interference level (dBm/MHz)	-117				-117				-117			
Allowable interference power (dBm)	-104				-104				-104			
Required propagation loss (dB)	107.3	121.1	98.3	111.1	117.3	131.1	108.3	122.1	117.3	131.1	108.3	122.1
Min separation distance (free space) (km)	1.7	8.2	0.59	2.9	5.3	25.8	1.9	9.2	5.3	25.7	1.9	9.1
Propagation model	ITU-R P.452-14											
Min protection distance using propagation model(km)	N/A	5	N/A	N/A	5	5.5	N/A	5	5.0	6.0	4.4	5.0

Note 1: Note the 40 MHz carrier separation compared to 20 MHz in other radars. Wide receive bandwidth radar requires additional separation to achieve sufficient FDR to achieve similar results as a narrow receive bandwidth radar.

TABLE 24

Interference from ship system-A radar station to IMT indoor base-station

Carrier frequency (GHz)	3.3				
Radar Signal bandwidth (MHz)	4				
Maximum output power (dBm)	90				
Antenna gain of indoor IMT base-station (dBi)	0				
Insertion loss IMT indoor (dB)	2				
Insertion loss of radar (dB)	2				
Antenna gain radar (dBi)	32		32		0
Penetration loss of outdoor to indoor (dB)	11	20	11	20	20
Frequency difference (MHz)	0		60		1000
FDR (dB)	0		31.1		80.0
Allowable interference level (dBm/MHz)	-115		-115		-115
Allowable interference power (dBm)	-109.0				
Required propagation loss (dB)	216.0	207.0	184.9	175.9	95.0
Min protection distance (km)	N/A	N/A	N/A	N/A	0.40
Propagation model	ITU-R P.452-14				
Min protection distance using propagation model (km)	433	320	105	75	N/A

TABLE 25

Interference from ship system-B radar station to IMT indoor base-station

Carrier frequency (GHz)	3.3				
Radar signal bandwidth (MHz)	4				
Maximum output power (dBm)	98.1				
Antenna gain of indoor IMT base-station (dBi)	0				
Insertion loss IMT indoor (dB)	2				
Insertion loss of radar (dB)	2				
Antenna gain radar (dBi)	42		42		0
Penetration loss of outdoor to indoor (dB)	11	20	11	20	20
Frequency difference (MHz)	0		20		100
FDR (dB)	0		32.0		60
Allowable interference level (dBm/MHz)	-115		-115		-115
Allowable interference power (dBm)	-109.0				
Required propagation Loss (dB)	234.0	225.0	202.0	193.0	123.0
Propagation model	ITU-R P.452-14				
Min protection distance using propagation model(km)	680	550	264	170	18

TABLE 26

Interference from ship system-C radar station to IMT indoor base-station (co-channel)

Carrier frequency (GHz)	3.3			
Radar Signal bandwidth (MHz)	25			
Maximum output power (dBm)	83.0			
Antenna gain of indoor IMT base-station (dBi)	0			
Insertion loss IMT indoor (dB)	2			
Insertion loss of radar (dB)	2			
Antenna gain radar (dBi)	40		0	
Penetration loss of outdoor to indoor (dB)	11	20	11	20
Allowable interference level (dBm/MHz)	-115		-115	
Required propagation loss (dB)	209.0	200.0	169.0	160.0
Propagation model	ITU-R P.452-14			
Min separation distance 452 (Urban) (km)	385.5	276	69	57

For co-channel sharing the minimum separation distance required between the ship-based radars and the IMT systems is in the range between 19 and 30 kilometres.

– for IMT small cell indoor base-station deployed penetration loss of 11 dB through average building and of 20 dB penetration loss for propagation inside the building is assumed. Additionally the effect of multiple base-station deployed in a building (maximum 24 base-station per building) is considered. The aggregate analysis shows considerable extra protection is necessary in the worst case aggregate scenario;

– for IMT indoor UE interference to radar system, the worst case where the UE is transmitting at maximum power is assumed. The analysis shows that in the aggregate case the effects of UEs are as severe as aggregate base-station;

– the analysis shows that non-co channel sharing may be practical for ship-based radars (A and B) where the minimum separation distance required is between 5 and 7 kilometres.

The co-channel and non-co channel interference from the ship-based Radar A to the IMT systems is very severe. The analysis shows that the separation distance required is 433 and 105 kilometres for co-channel and non-co channel respectively.

The co-channel and non-co channel interference from the ship-based Radar B to the IMT systems is very severe. The analysis shows that the separation distance is 680 and 264 kilometres co-channel and non-co channel respectively.

The co-channel interference from the ship-based radar C to the IMT systems is not as severe as the case with ship-based radars A and B. However the minimum separation distance required is 386 kilometres.

4.3 Study B2

The study presents compatibility with airborne system "A".

4.3.1 Assumptions

4.3.1.1 IMT systems parameters

IMT systems parameters

Base-station characteristics / Cell structure	Small cell indoor (100%)
Antenna height	3 m
Sectorization	single sector
Antenna pattern	Recommendation ITU-R F.1336 omni
Indoor base-station Penetration Loss PL	12dB[7]
Maximum base-station output power (5/10/20 MHz)	24 dBm
Maximum base-station antenna gain	0 dBi
Maximum base-station output power (e.i.r.p.)	24 dBm
Average base-station activity	50 %
Average base-station power/sector (to be used in sharing studies)	21 dBm

[7] Corresponds to an average value whose distribution is featured by a 17 dB median and 7 dB standard deviation [proposed by the US input for RLANs in higher frequencies (5 GHz band)].

Each building contains an IMT small cell indoor system comprising multiple IMT small cells.

The IMT small cell indoor system topology is distributed in buildings of 6 floors, the topology of each floor is based on the below figure from the 3GPP specification 3GPP TR 36.814. As shown below:

– IMT small cell indoor system buildings size: L × l=120 m x 50 m, including rooms and corridor;

– the number of indoor IMT small cell base-stations within each floor NS=28;

– the average number of floors per building NF=6,

– average penetration loss: 12 dB,

– street width: W=20m.

4.3.1.2 Radar systems

In this document, the considered radar for the sharing study is the airborne radar. Airborne radars purpose is for long range surveillance, target tracking and Air Traffic Control. The spectrum characteristics for typical airborne radar found in this band are depicted in Figure 2, extracted from Recommendation ITU-R M.1465-1. The antenna of this system is a large, slotted waveguide array assembly mounted atop of the airframe. If surveillance aircraft makes the radar (embedded on the aircraft operating at altitude *h*= 9 000 m) pointing to the horizon, the vertical scanning process of the radar antenna concerns as aircrafts surveillance for higher altitudes as air and sea surveillance mode for lower altitudes, resulting in ±60° elevation angle.

This airborne system can be operated for extended hours of up to 12 h depending upon aircrew availability. In some situations constant surveillance is maintained on a 24 h per day basis by replenishment aircraft.

Recommendation ITU-R M.1465-1 contains in particular the interference criterion, *I*/*N*, that is used to protect radar systems from other services with the *I*/*N* = –6 dB recommended value (see *recommends* 3 of Recommendation ITU-R M.1465-1).

TABLE 17

Radiolocation system

Parameter	**Airborne system**
	A
Use	Surface and air search
Tuning range (GHz)	3.1-3.7
Antenna gain (dBi)	40
Beamwidth (H,V) (degrees)	1.2, 6.0
Vertical scan type	Not available
Maximum vertical scan (degrees)	±60
Interference criterion (dB)	I/N=–6dB
Vertical scan rate (degrees/s)	Not available
Horizontal scan type	Rotating
Maximum horizontal scan (degrees)	360
Rx noise figure (dB)	3

[8] Four small cell base stations are considered in each floor instead of the two base stations per floor considered in 3GPP TR 36.814.

4.3.2 Methodology

A Minimum Coupling Loss approach is used, modelling multiple interferers-victim pair (as to be smallcells indoor within the surface covered by the main beam of the radar system-to-Radar). From this method, we derive the In-Band restricted emissions of IMT systems when they share the same band as radar systems in 3 300-3 400 MHz band.

According to the nature of the airborne radar, the propagation model separating the radar receiver from the smallcells indoor within the urban area is assumed free space loss (FSL) for distances lower than horizon distance d.

Aggregation factor calculation requires assessing the density of smallcells indoor per km^2 as well as the surface which is covered by the main lobe of the airborne radar.

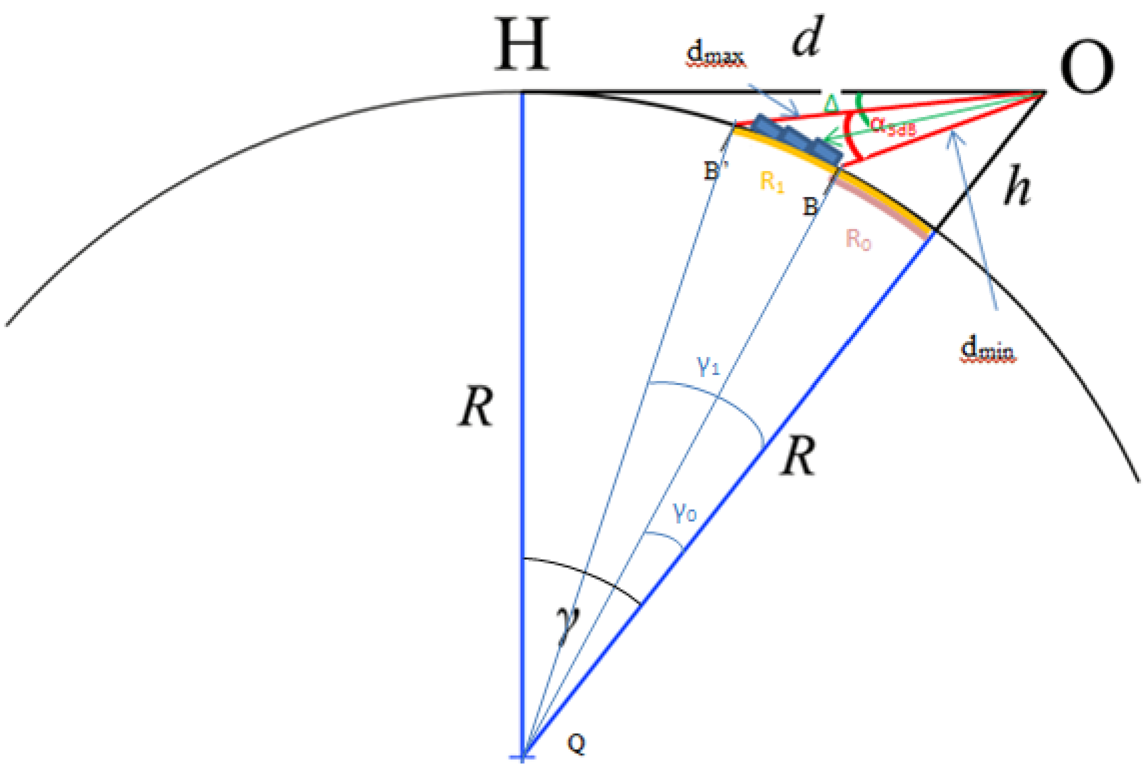
From the previous information, the density of smallcells indoor per area (km^2), denoted D, is equal to: D= $(\boldsymbol{W}(\boldsymbol{l}+\boldsymbol{L}+\boldsymbol{W})+\boldsymbol{L}\times\boldsymbol{l})\times\boldsymbol{NF}\times\boldsymbol{NS}$.

In the deployment scenario shown in Figure 1, IMT-Advanced smallcells indoor of the buildings that are covered by the main beam of the airborne radar are potential main[9] interferers.

As the aggregated interference, interferences from smallcells stations located (in buildings) **in the area delimited by ground distances R_0 and R_1 are** summed up, as indicated in 7.

FIGURE 7

Radar and IMT-Advanced deployment model for aggregate interference consideration



9 IMT smallcells in the sidelobes of the airborne radar are not considered in this study.

Parameters d_{max} and d_{min} may be derived as follows:

In the triangle (QBO):

$$QB^2 = QO^2 + OB^2 - 2QO.OB.cos\widehat{BOC}$$

which is equivalent to:

$$R^2 = (R+h)^2 + d_{min}^2 - 2(R+h)d_{min}.cos\left[\frac{\pi}{2} - \gamma - (\Delta + \frac{\alpha_{3dB}}{2})\right]$$

The identification of the polynomial of the d_{min} variable leads to the following (valid) root expression:

$$d_{min} = (R+h)cos\left[\frac{\pi}{2} - \gamma - \left(\Delta + \frac{\alpha_{3dB}}{2}\right)\right] - \sqrt{(R+h)^2 cos^2\left(\frac{\pi}{2} - \gamma - (\Delta + \frac{\alpha_{3dB}}{2})\right) - 2Rh + h^2}.$$

In the same manner, d_{max} value can be derived:

$$d_{max} = (R+h)cos\left[\frac{\pi}{2} - \gamma - \left(\Delta - \frac{\alpha_{3dB}}{2}\right)\right] - \sqrt{(R+h)^2 cos^2\left(\frac{\pi}{2} - \gamma - (\Delta - \frac{\alpha_{3dB}}{2})\right) - 2Rh + h^2}$$

Where:

$$\gamma = Acos\left(\frac{R}{R+h}\right).$$

In the same manner, we get:

$$\gamma_0 = Acos\left(\frac{{d_{min}}^2 - R^2 - (R+h)^2}{-2R(R+h)}\right) \text{ and } \gamma_1 = Acos\left(\frac{{d_{max}}^2 - R^2 - (R+h)^2}{-2R(R+h)}\right).$$

(considering respectively triangles (QBO) and (QB'O)).

which leads to:

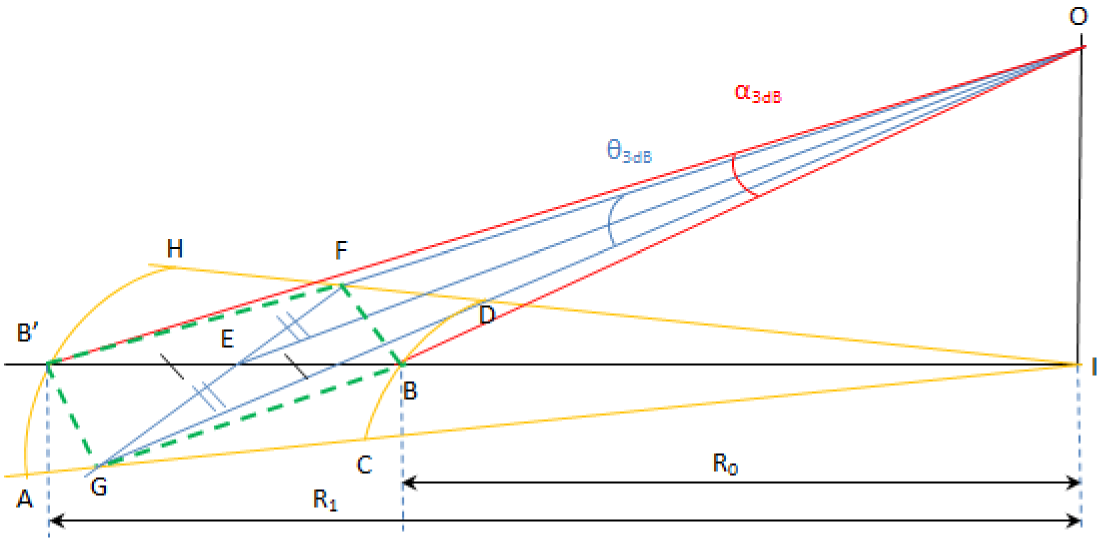
$$R_0 = R\gamma_0 = R\ Acos\left(\frac{{d_{min}}^2 - R^2 - (R+h)^2}{-2R(R+h)}\right) \text{ and } R_1 = R\gamma_1 = R\ Acos\left(\frac{{d_{max}}^2 - R^2 - (R+h)^2}{-2R(R+h)}\right).$$

R_0 and R_1 are similar (and small) when elevation angle Δ is close to the maximum (in absolute) value.

Number of smallcells indoor in sight of airborne radar antenna main beam

FIGURE 8

Surface covered by the airborne radar antenna main beam



The surface which is covered by the airborne radar antenna main beam is modelled as the surface of the angular sector portion (HDCA), denoted Σ, depicted in the Figure 8. **This surface is down bounded by the surface of the (B'FBG) kite shaped quadrilateral**, delimited with dashed green line. It is then proposed to calculate the (B'FBG) surface in this contribution.

Figure 8 shows that:

$$\widehat{\mathrm{EI}} = R_0 + \frac{R_1 - R_0}{2}.$$

In the triangle (EIQ[10]), $\gamma_{med} \triangleq \frac{\widehat{\mathrm{EI}}}{R} = \frac{R_0 + \frac{R_1 - R_0}{2}}{R}$ (1)

In the triangle (EOQ), EO=$\sqrt{R^2 + (R+h)^2 - 2R(R+h)cos(\gamma_{med})}$ (2)

$$Surface(B'FBG) = \frac{AD \times GF}{2} = (R_1 - R_0) \times EF = (R_1 - R_0) \times EO.\tan\left(\frac{\theta}{2}\right)$$

From (1) and (2), we thus obtain:

$$Surface(B'FBG) = (R_1 - R_0) \times \sqrt{R^2 + (R+h)^2 - 2R(R+h)cos\left(\frac{R_0 + \frac{R_1 - R_0}{2}}{R}\right)}.\tan\left(\frac{\theta}{2}\right).$$

[10] Q point being the center of the earth, as depicted in Figure 1.

The considered urban surface is that one from Ile-de-France region which includes Paris as well as its suburb[11].When the airborne radar antenna points at the horizon, the solid angle covers the largest terrestrial zone. According to The table X, the largest area is lower than the Ile-de-France region, which leads to conclude that previous assumptions on smallcells indoor deployment within the urban area may apply in the whole area.

We then derive the number of smallcells indoor (NSI) in sight of the main beam of the airborne radar: $\mathrm{NSI} = \Sigma \times D$.

Restricted in-band emission level for IMT smallcells indoor

This parameter refers to the aggregation factor in the following link budget:

Isolation= e.i.r.p.(dBm/MHz)+PenetrationLoss+PathLoss[12]+AggFactor+G_R-I/N+Noise(dBm/MHz)

= e.i.r.p.(dBm/MHz)+PL+FSL+10$\log_{10}$(NSI) +G_R -I/N+Noise(dBm/MHz).

Additional isolation is required when Isolation<0dB. In such a case, restricted in-band level could be required in order to ensure the protection of the airborne radar:

InBand Emission level (dBm/MHz)= e.i.r.p.(dBm/MHz)+ min(Isolation,0).

4.4 Study B3

The study presents compatibility with land systems “A” and “B” and with airborne system “A”.

4.4.1 Assumptions

Analysis of Recommendation ITU-R M.1465 showed that currently technical characteristics of three ground-based and air-borne radars were available. The radars are:

– Radar A deployed on the Earth surface and used for aerospace and ground surveillance;

– Radar B deployed on balloons and used for ground surveillance;

– Radar A deployed aboard aircraft.

Based on the above the following scenarios of potential interference were analysed.

Scenario 1: Estimation of interference from IMT to ground-based Radar A

Estimation of interference effect to the ground based radar assumed a scenario when interference from an IMT system was at a maximum level. The case analysed assumed a building with its flank wall perpendicular to direction of radar (see Fig. 1). When propagating through the flank wall emissions fade with a level depending on properties of the wall material and building structure. The fading was assumed to be 20 dB.

[11] Corresponding to 12 000km^2.

[12] Free Space Loss.

FIGURE 9

Scenario of interference between ground-based Radar A and IMT systems (indoor small cell)

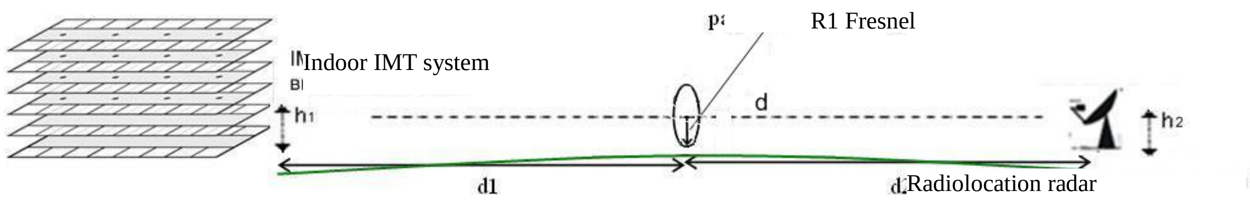


Fig. 9 legend:

$d=d_1+d_2$: separation distance is a distance between the building and the radiodetermination radar;

h_1: height of the IMT base station transmitting antenna;

h_2: height of the radar receiving antenna phase centre, (5 m);

d_1: distance between the building with IMT system and the point of maximum first Fresnel zone radius;

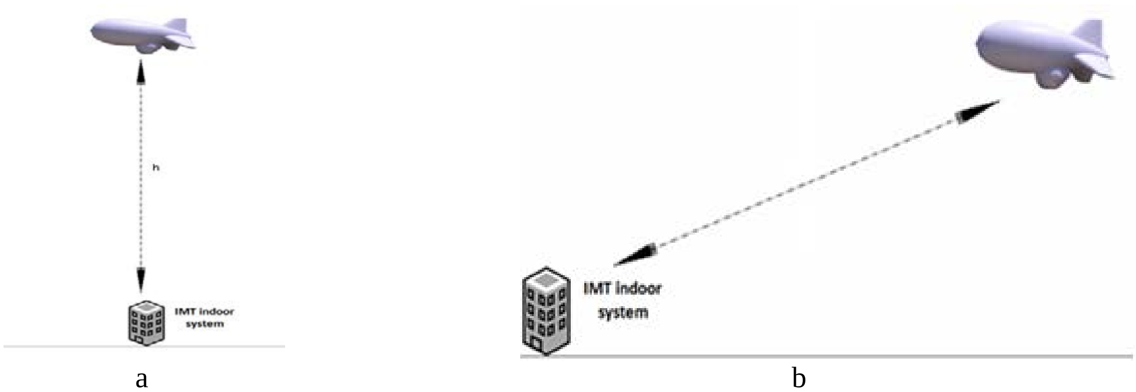
d_2: distance between the radar and the point of maximum first Fresnel zone radius.

Scenario 2: Estimation of interference from IMT to balloon radar

This scenario assumed a generic Radar B operating aboard balloon at an average altitude of 4 600 metres above the earth surface (see Fig. 10) in close proximity to a building with indoor IMT system. The scenario considered two potential balloon radar locations relative to the building, i.e. the radar is directly above the building (situation “a” of Fig. 10) and the radar is aside from the building (situation “b” of Fig. 10).

FIGURE 10

Scenario of interference between Radar B and IMT system (indoor small cell)



Note: *h* is radar altitude above the earth surface.

It is obvious that in the first case all interfering emissions from IMT transmitters would propagate only through ceiling plates having high propagation loss.

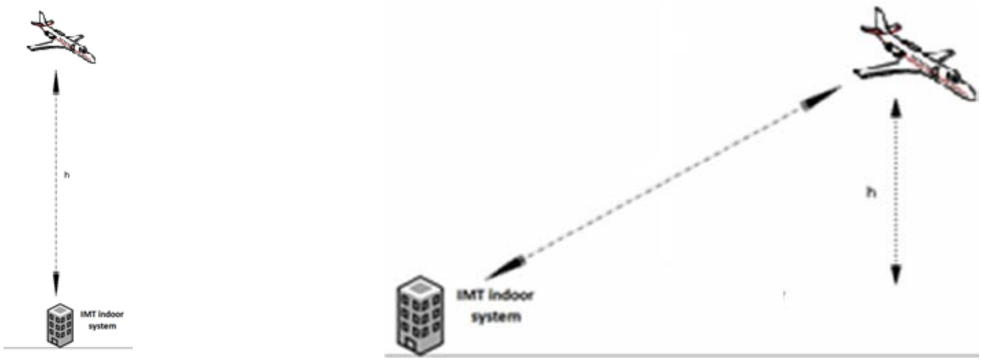
In the second case interfering emissions from IMT transmitters would propagate through the building side walls with significantly less propagation loss.

Scenario 3: Estimation of interference from IMT to Air-Borne Radar A

Estimation of maximum level of interference to air-borne radar of type A assumed an appropriately equipped aircraft flying over the building at 9 000 metres altitude (see Fig. 11). Two potential option aircraft route were considered, including the first one with the radar directly over the building (situation “a” of Fig. 11) and the second one with the radar off-side from the building (situation “b” of Fig. 11).

FIGURE 11

Scenario of interference between air-borne Radar A and IMT system (indoor small cell)



a b

Note: *h* is radar altitude above the earth surface.

In the first assumed case all interfering emissions from IMT transmitters would propagate only through ceiling plates having high propagation loss.

In the second case interfering emissions from IMT transmitters would propagate through the building side walls with significantly less propagation loss.

4.4.2 Methodology

4.4.2.1 Methodology of studies for ground-based Radar A (Scenario 1)

4.4.2.1.1 Methodology of estimating the interference from IMT base-station transmitters to ground-based Radar A

Estimation of interference to ground-based Radar A included a detailed analysis of two issues:

– propagation model used in the compatibility studies;

– probability of multi-source interference to Radar A.

The studies proposed to employ a propagation model described in Recommendation ITU-R P.452. Using the proposed propagation model a required separation distance was estimated. The separation distance would not exceed 200 metres. Analysis of the emission propagation model as described in Recommendation ITU-R P.452 resulted in conclusions that the proposed propagation model would not be feasible for such small distances between a transmitter and a receiver, specifically in the case when the airborne radar was equipped with a high gain antenna having its pattern width not exceeding 2 degrees.

Analysis of Recommendation ITU-R P.526-10 also showed that if the first Fresnel zone in the propagation radio path had no obstacles then the methodology of estimating the free space interference would apply to calculations of interference propagation conditions (see Recommendation ITU-R P.525-2). On that basis a maximum distance between the radar and the building to be feasible for using the model of free space propagation was determined. To do that the first Fresnel zone radius was estimated as a function of a distance between the radar and the building wall and the distance between the radar and the building was determined where the first Fresnel zone intersected with the Earth's surface.

The first Fresnel zone radius was calculated using the following expression (see Recommendation ITU-R P.526-10):

$$R_n = 550 \left[\frac{n\, d_1\, d_2}{(d_1 + d_2)\, f} \right]^{1/2} \quad \text{m,} \qquad (1)$$

where:

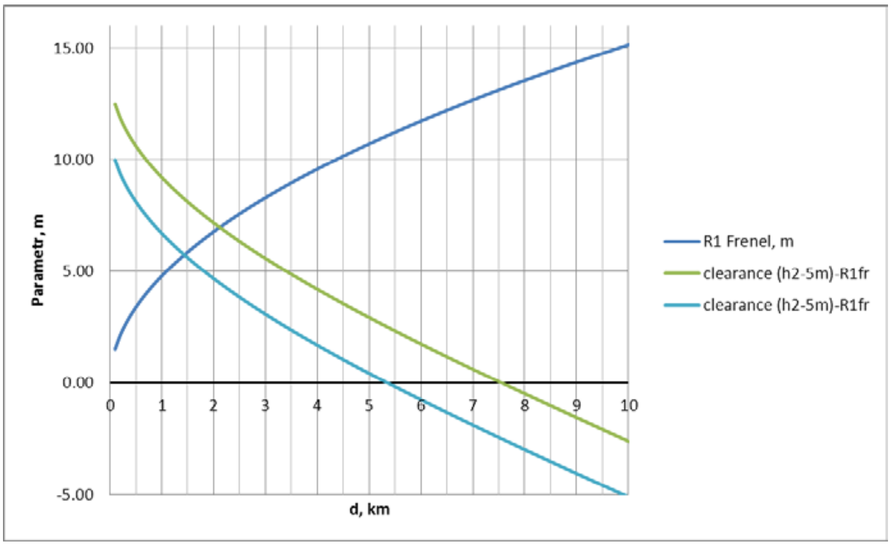
- n – number of Fresnel zone (the *1-st* assumed herein);
- f – frequency (*MHz*);
- d_1 – distance (*km*) between the transmitter and the point in which the *n-th* Fresnel zone radius was calculated;
- d_2 – distance (*km*) between the receiver and the point in which the *n-th* Fresnel zone radius was calculated.

Analysis of the first Fresnel zone radius as a function of distance between the receiver and the transmitter showed that the first Fresnel zone radius would be maximum in the middle of the path considered. Therefore the Fresnel zone radius as a function of the distance from the first Fresnel zone edge to the earth surface was estimated for different heights of the radar receiving antenna. The estimation results are shown in Fig. 12. There Curve 1 refers to maximum first Fresnel area radius as a function of distance between the IMT transmitter and the radar receiver; Curve 2 denotes dependence of distance between the first Fresnel zone edge and the earth surface for the IMT transmitter at the height of 18 metres and for the radar receiver at 10 metres height; Curve 3 shows dependence of distance between the first Fresnel zone edge and the earth surface for the IMT transmitter at the height of 18 metres and for the radar receiver at 5 metre height.

Analysis of the above curves shows that for the IMT transmitter at 18 metre height (the ceiling of the building upper story) and for the radar receiver at 5 m altitude the first Fresnel zone would touch the earth surface when the distance between the IMT base station and the radar is 5.3 metres. If the radar receiver height is 10 metre then the first Fresnel zone would touch the earth surface at a distance of 7.5 km between the IMT base-station and the radar. Thus it is obvious that for distances significantly exceeding the separation distance the free space propagation model would apply and this model was used in further compatibility studies.

FIGURE 12

The first Fresnel zone radius, its clearance over the earth surface and difference between the clearance and the first Fresnel zone as functions of the distance between the radar and IMT base-station



Estimation of probability for multi-source interference to Radar A considered that a number of interferers affecting the Radar A antenna main lobe would be a function of the lobe width in the vertical plane defined by the distance from the radar to the building (see Fig. 13). The vertical lobe size (in meters) would be a function of distance such as:

$$h_{lobe} = 2d\ tg(\varphi/2),\ (m) \qquad (2)$$

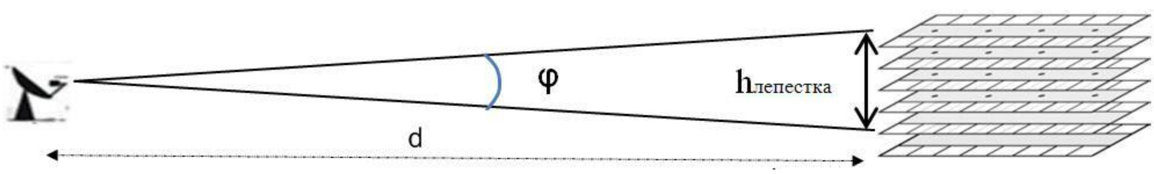
where:

φ = 1.72 degrees. – angle size, degrees;

d: distance from the radar receiver antenna to the building wall, m.

FIGURE 13

Coverage of the building floors by the antenna beam



The main lobe of the radar covers a different number of 3-meter high floors depending on the distance between the radar and the building (see Table 28).

TABLE 28

Number of building floors affected by the radar antenna main lobe as a function of distance

Number of floors	Antenna lobe vertical size, (m)	Distance between radar and building (m)
2	3.3	110
3	6.3	210
4	9.3	310

Analysis of Table 28 shows that with distances between the radar and the building below 110 metres the radar antenna main lobe could be affected by all interferers located in one floor; if the distance between the radar and the building is from 110 m and 210 m then the radar antenna main lobe could be affected by all interferers located in two floors; if the distance between the radar and the building is from 210 metres and 310 metres then the radar antenna main lobe could be affected by all interferers located in three floors. If the distance between the radar and the building exceeds 310 metres then the radar antenna main lobe could be affected by all interferers located in four floors of the building considered.

Aggregate interference field strength is estimated as:

$$E_{sum} = 10 \lg \left(\sum_{i=1}^{n} 10^{\frac{E_i}{10}}\right), \quad (3)$$

where: E_i – field strength of interference from *i-th* IMT base-station, dB(μV/m).

Field strength of interference from the *i-th* transmitter is:

$$E_i = P_t - 20 \log d + 74{,}8 - \sigma, \text{ dB(μV/m)}, \quad (4)$$

where:

P_t – transmitter e.i.r.p. in the radar frequency band, dBW;

d – distance, km;

σ - attenuation in the building walls, dB.

Then interference power at the receiver front end would be:

$$I = E_{sum} - 20 \log f + G - 167.2, \text{ dBW}, \quad (5)$$

where:

G – radar receiving antenna gain, dBW;

f – frequency, GHz.

4.4.2.1.2 Methodology of estimating the interference from ground-based Radar A to IMT receiver

Estimation of interference from the radars to the IMT receivers used emissions propagation model from Recommendation ITU-R P.452. Method of minimum coupling loss (MCL) was used to estimate the loss levels providing for interference-free operation of the IMT receivers taking building wall losses into account. It was such as:

$$L = P_{RLS} + G_{RLS} + G_{IMT} - I_{accIMT} - \sigma,$$

where:

L – minimum required propagation loss;

P_{RLS} – radar transmitter power;

G_{RLS} – radar antenna gain;

G_{IMT} – IMT receiver antenna gain;

$I_{acc\ IMT}$ – acceptable level of interference at the IMT receiver front end;

σ - building wall propagation loss.

The loss values obtained thereby were used for estimating the separation distances required.

4.4.3 Methodology of studies for balloon Radar B (Scenario 2) and airborne Radar A (Scenario 3)

4.4.3.1 Methodology of estimating interference from IMT transmitters to balloon Radar B receiver (Scenario 2) and to air-borne Radar A receiver (Scenario 3)

The studies in the considered cases assumed that the radar antenna main lobe was affected by emissions from all IMT base-station transmitters. Field strength of interference from *i-th* IMT base-station was estimated using the following equation:

$$E_i = P_t - 20 \log d + 74{,}8 - \sigma_i, \text{ dB}(\mu\text{V/m}), \qquad (6)$$

where:

σ_i – attenuation in the path from the *i-th* transmitter to the radar receiver accounting for amount of building ceilings.

Aggregate interference field strength was estimated using equation (3) and interference power was estimated using equation (5). The estimated interference power was used for calculating interference-to-noise (I/N) ratio that was further compared with the protection criterion.

4.4.3.2 Methodology of estimating interference from transmitters of balloon Radar B and air-borne Radar A

Estimation of interference from the radars to the IMT systems used a model of free space propagation. Effect of emission attenuation in the walls was accounted by appropriate reducing the radar e.i.r.p. Therefore the level of interference at the IMT receiver front end was estimated using the following equation:

$$I_{IMT} = e.i.r.p._{RLS} - \sigma + G_{IMT} + 20 * \lg(\lambda / 4\pi R), \qquad (7)$$

where:

I_{IMT} – power of interference at the IMT receiver front end, dBW;

$e.i.r.p._{RLS}$- radar e.i.r.p., dBW;

λ – operational wavelength, m;

R – distance between the radar and the IMT receiver, m;

σ - loss of propagation in the building.

Based on the maximum acceptable value of interference power at the IMT receiver front end the maximum separation distance was estimated as:

$$R_{\min} = 10^{\frac{EIRP_{RLS} - \sigma + G_{IMT} + 20\lg(\lambda / 4\pi) - I_{IMTacc}}{20}} \qquad (8)$$

4.4.4 Calculations

4.4.4.1 Calculations results for compatibility study related to ground-based Radar A (Scenario 1)

4.4.4.1.1 Effect of IMT transmitters on ground-based Radar A (Scenario 1)

An acceptable interference level was estimated to define interference effect on Radar A operation. The Radar A thermal noise power was estimated using the following equation:

$$N = kT\Delta F, \text{ W} \quad (9)$$

where:

k – Boltzmann constant, $1.38 \cdot 10^{-23}$ J/K;

T – receiver noise temperature, K;

ΔF – receiver passband, 380 000 000 Hz.

The receiver noise temperature was determined using the following equation:

$$T = T_0 \cdot (10^{Nf/10} - 1), \text{ K,} \quad (10)$$

where:

T_0 – nominal noise temperature T_0 = 290 K;

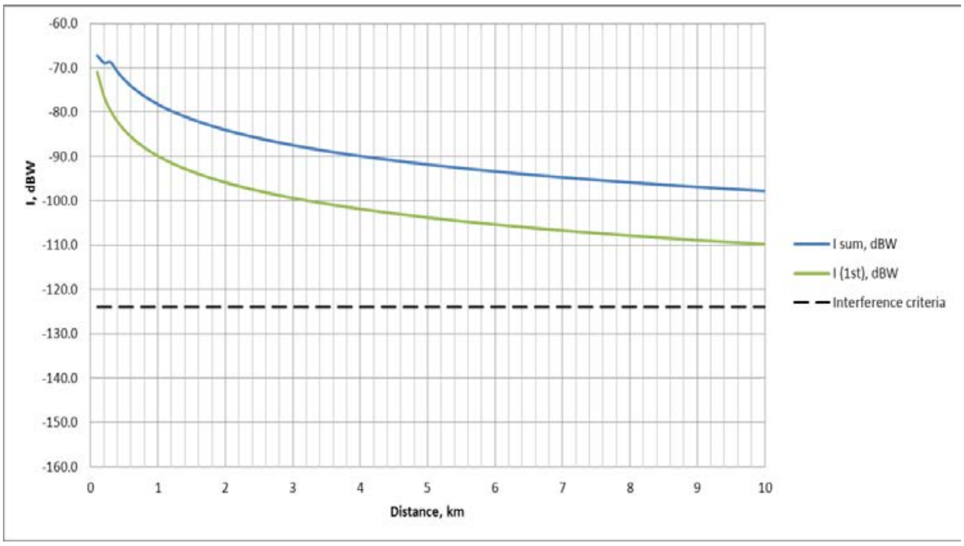
Nf – radar receiver noise figure, 3.1 dB.

Analysis of Recommendation ITU-R M.1465 showed that Radar A receiver noise figure was 3.1 dB. It corresponded to noise power of -118.0 dBW. Thus, based on the Radar A protection criterion (I/N = -6 dB) the maximum acceptable noise power at the Radar A receiver front end would be minus 124 dBW.

Fig. 14 below shows dependence of the interference levels at the Radar A receiver front end from emissions by a single IMT base-station (green curve) and by all IMT base-stations affecting the Radar A antenna main lobe (blue curve).

FIGURE 14

Interference from IMT base-station as a function of distance between the radar and the building



Analysis of the estimates shows that for Radar A antenna height of 5 m and for the distance between the radar and the building wall of 5.3 km the threshold I/N ratio would be exceeded:

– by 18.5 dB for a single IMT base-station;

– by 30.5 dB for aggregate interference from all IMT base-station deployed in the building.

For Radar A antenna height of 10 m and for the distance between the radar and the building wall of 7.5 km the threshold I/N ratio would be exceeded:

– by 16.7 dB for a single IMT base-station;

– by 28.7 dB for aggregate interference from all IMT base-station deployed in the building.

The above results were obtained for an IMT base-station operating in the frequency band of 5 MHz in width and for losses in building walls of 20 dB. The above protection criterion exceeding values would be the same for IMT base-stations operating in the 20 MHz frequency band because Radar A operating bandwidth significantly exceeds that of an IMT base-station transmitter.

It should be noted that path losses through the walls are averaged and could be significantly lower. Reducing those losses would result in increasing interference at the ground-based Radar A front end and to additional excess of I/N ratio at the Radar A front end.

Because at line-of-sight distances indoor IMT base-stations cause unacceptable interference to radar operation for which the propagation model in Recommendation ITU-R P.452 was used for assessing the required separation distance. The estimation took into account that the ground-based Radar A operational bandwidth was 380 MHz at the intermediate frequency. In combination with the radar noise figure of 3.1 dB that would result in the radar thermal noise power of –118 dBW and in a maximum acceptable interference power of –124 dBW with a consequent required minimum coupling losses of 164 dB. Estimation using the Recommendation ITU-R P.452 propagation model shows that to provide those additional losses requires separation distances of 45 kilometres.

4.4.4.1.2 Effect of ground-based Radar A on IMT receivers

An estimation of radars effect on IMT receiver operation assumed the following parameters:

– IMT receiver noise figure was 10 dB[13];

– maximum acceptable I/N ratio at the IMT receiver front end was –6 dB.

The above assumptions were used for estimating the receiver thermal noise and maximum acceptable interference power for receiving channels of 5 MHz, 10 MHz and 20 MHz pass-bands. The results of estimation are shown in Table 29.

TABLE 29

Acceptable interference power at IMT receiver front end

Channel width, MHz	5	10	20
Noise figure, dB	10	10	10
Noise temperature, K	2610	2610	2610
Receiver thermal noise, dBW	-127	-124	-121
Max acceptable interference power, dBW	-133	-130	-127

[13] A noise figure of 10 dB is the figure quoted for an IMT base station (micro) in Report ITU-R M.2292.

The results reflected in Table 29 were used in estimating the minimum coupling losses with the estimation results shown in Table 30.

TABLE 30

Minimum coupling losses

Channel width, MHz	5	10	20
Additional propagation losses, σ, dB	20		
Minimum coupling losses, dB	198	198	198
Minimum separation distance, km	124.5	124.5	124.5
Additional propagation losses, σ, dB	5		
Minimum coupling losses, дБ	213	213	213
Minimum separation distance, km	271	271	271

At first estimation was conducted for interference from Radar A to IMT receivers operating inside the building having wall attenuation of 20 dB. Assessment of interference caused by Radar A showed that an additional propagation loss of 198 dB would be required for interference-free operation of IMT systems independent of the width of the IMT channel used. It would correspond to a minimum separation distance of 124.5 kilometres.

The above wall attenuation is untypical for modern office buildings with glass walls. Attenuation in such walls would be about 5 dB to result in minimum coupling losses of 213 dB. That value would correspond to a required separation distance of 271 kilometres.

4.4.4.2 Calculation results for a study related to balloon Radar B (Scenario 2)

4.4.4.2.1 Effect of interference from the IMT transmitters to Radar B

The first estimation of interference caused by IMT transmitters to Radar B operation was conducted for the scenario shown in Fig. 10a. Interference at the radar receiver front end was estimated for a single IMT transmitter deployed in the upper story and for all IMT transmitters in the building. The estimation referred to transmitter channel widths of 5 MHz, 10 MHz and 20 MHz.

For the first case the additional losses in the building were minimal and were defined by losses in ceiling overhead only. The interference power at the Radar B receiver front end was defined by the following equation:

$$I_{RLS} = e.i.r.p._{IMT} + G_{RLS} + 20\lg(\lambda/4\pi) - \sigma .$$

The interference power at the Radar B receiver front end for different width of IMT channel are shown in Table 4.

The Radar B noise figure in Recommendation ITU-R M.1465 is 4 dB. For Radar B operational bandwidth of 0.67 MHz the radar inherent thermal noise level was –143.9 dBW. That provided for estimating the maximum acceptable power at the radar receiver front end to be –149.9 dBW for the protection criterion of I/N = –6 dB.

TABLE 31

Excess of Radar B protection criterion for a single-source interference

Channel width, MHz	5	10	20
Radar B receiver interference power, dBW	-110.7	-113.7	-116.7
Radar receiver thermal noise power, dBW	-143.9		
Radar protection criterion, I/N, dB	-6		
Acceptable level of interference at radar front end, dBW	-149.9		
Protection criterion excess, dB	39.2	36.2	33.2

The above values for maximum acceptable interference power were used for estimating the excess of the protection criterion. The results are presented in Table 32. It is obvious that for a 5 MHz channel the excess of the protection criterion would be of 39.2 dB whereas for a 20 MHz channel it would reduce to 33.2 dB.

For the second case the interference field strength produced by each of the IMT transmitters at the radar front end was estimated using equation (4). The aggregate interference field strength was estimated using equation (3). This field strength was used for estimating the aggregate interference power at the radar receiver front end as defined in equation (5). The results are shown in Table 32.

TABLE 32

Excess of Radar B protection criterion for a multi-source interference

Channel width, MHz	5	10	20
Radar B receiver interference power, dBW	-104.7	-107.7	-110.7
Radar receiver thermal noise power, dBW	-143.9		
Radar protection criterion, I/N, dB	-6		
Acceptable level of interference at radar front end, dBW	-149.9		
Protection criterion excess, dB	45.2	42.2	39.2

The above values for maximum acceptable interference power were used for estimating excess of the protection criterion. The results are presented in Table 33. It is obvious that for a 5 MHz channel the excess of the protection criterion would be of 45.2 dB whereas for a 20 MHz channel it would reduce to 39.2 dB.

The above values of protection criterion excess were used for estimating a minimum separation distance which would ensure acceptable interference radar operation. The separation distance was estimated using the following equation:

$$R_{\min} = \lambda \cdot 10^{(L_{ex}+L_{add})/20} / 4\pi \,,$$

where:

L_{ex} – existing radio path losses due to radar antenna altitude above the building (4 600 m), dB;

L_{add} – required additional losses due to protection criterion excess, dB;

λ – operational wave length.

Existing propagation losses were defined by the distance from IMT transmitters to radar antenna and were estimated using the following equation:

$$L_{ex} = -20\lg(\lambda / 4\pi R)$$

The results of this estimation are shown in Table 33.

TABLE 33

Minimum separation distances for Radar B

Single-source interference			
Channel width, MHz	5	10	20
Existing losses, dB	116		
Required additional losses, dB	39.2	36.2	33.2
Required total losses, dB	155.2	153.2	149.2
Minimum separation distance, km	402	327	207
Aggregate interference			
Existing losses, dB	116		
Required additional losses, dB	45.2	42.2	39.2
Required total losses, dB	161.2	158.2	155.2
Minimum separation distance, km	822	582	402

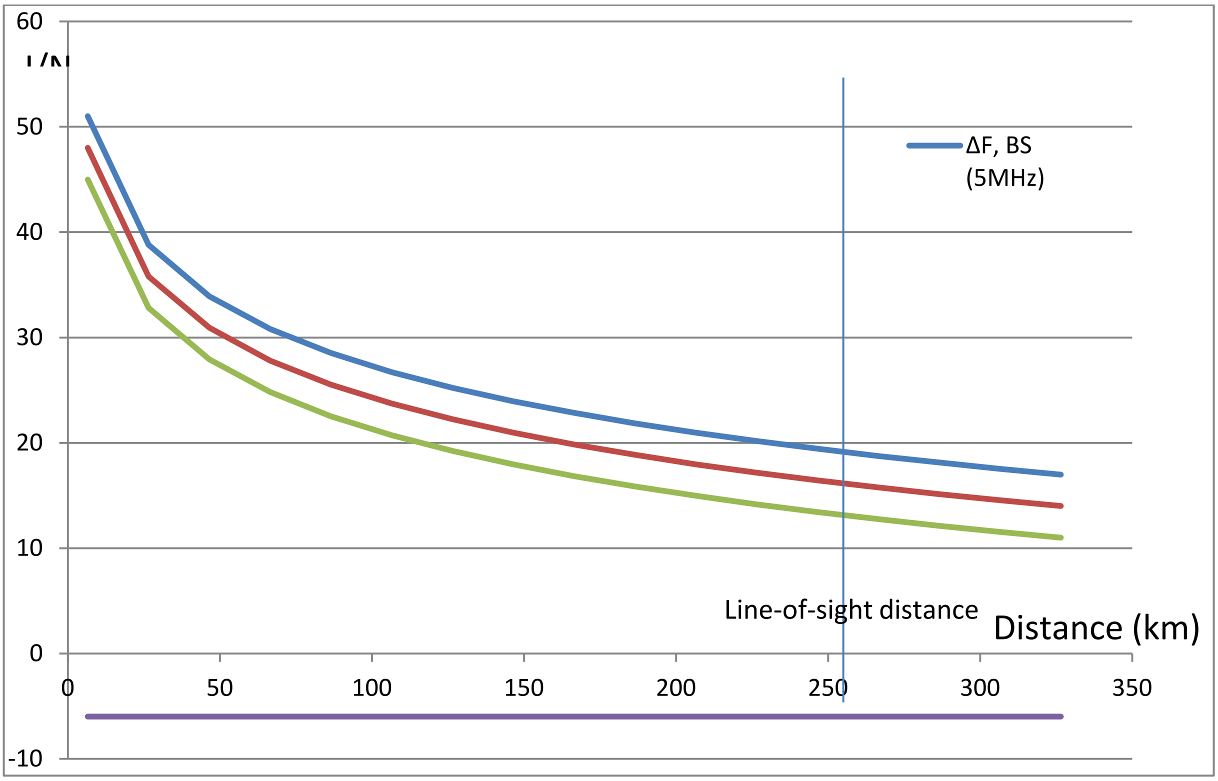
It is obvious that the separation distance required for the scenario concerned would exceed a maximum altitude of balloon operation. It implies that sharing between the proposed IMT transmitters and a balloon Radar B would be unfeasible.

The value of losses in the ceiling/roof corresponds to those for reinforced concrete structures. With radio-transparent ceiling and floor structures the propagation losses would significantly decrease and result in increasing the excess of Radar B receiver protection criteria.

The above is confirmed with the results of that shown in situation "b" of Figure 10 interference scenario. It was assumed that the side wall propagation losses would be 5 dB with emissions from four IMT base-station transmitters that propagate through the side wall. The results of estimating the excess of the Radar B receiver protection criteria as a function of balloon-building distance are shown in Fig. 15.

FIGURE 15

I/N ratio at the radar receiver front end as a function of the building-balloon distance



In Fig. 15 the blue curve reflects interference from IMT transmitters with 5 MHz channel width; the red curve refers to those of 10 MHz channel width and the green curve corresponds to those of 20 MHz channel width. The violet curve shows the radar protection criterion equal to I/N = -6 dB. The obtained data analysis showed that protection of Radars B from interference caused by indoor IMT transmitters would require separation distances exceeding those of line-of-sight.

4.4.4.2.2 Effect of interference from Radar B on IMT receivers

Interference caused by Balloon Radar B was estimated using the same assumptions referred to IMT receiver protection criteria as presented in section 4.4.4.1.2 above. Interference power from Radar B at the IMT receiver front end was estimated using equation (7). Estimates of required separation distances were provided with equation (8) for receiving channel widths of 5 MHz, 10 MHz and 20 MHz and for two values of additional penetration losses. The results are shown in Table 34.

TABLE 34

IMT receiver minimum separation distances

Channel width, MHz	5	10	20
Noise figure, dB	10	10	10
Noise temperature, K	2610	2610	2610
Receiver thermal noise, dBW	- 127	- 124	- 121
Max acceptable interference power, dBW	- 133	- 130	- 127
Additional propagation losses σ, dB	5		
Min separation distance, km	>R	>R	>R
Additional propagation losses σ, dB	20		
Min separation distance, km	>R	>R	>R

The obtained results showed that even with wall propagation losses of 20 dB the required separation distances would exceed that of line-of-sight (R) which would be 261 kilometres for the above mentioned balloon flight altitude without accounting for tropospheric refraction.

4.4.4.3 Calculation results for study related to airborne Radar A (Scenario 3)

4.4.4.3.1 Effect of interference from IMT base-station on airborne Radar A

The first estimation of interference caused by IMT transmitters to air-borne Radar A operation was conducted for the scenario shown in Fig. 11a. Interference at the radar receiver front end was estimated for a single IMT transmitter deployed on the upper floor and for all IMT transmitters in the building. The estimation referred to an IMT transmitter operating with channel widths of 5 MHz, 10 MHz and 20 MHz.

For the first case the additional losses in the building were minimal and were defined by losses in ceiling overhead only. The interference power at the airborne Radar A receiver front end was described by the following equation:

$$I_{RLS} = e.i.r.p._{IMT} + G_{RLS} + 20\lg(\lambda/4\pi) - \sigma .$$

The values of interference power at the Radar A receiver front end for different IMT channel widths are shown in Table 35.

The airborne Radar A noise figure in Recommendation ITU-R M.1465 is 3 dB. For Radar A operational bandwidth of 1.0 MHz the radar inherent thermal noise level was -144.0 dBW. That provided for estimating the maximum acceptable power at the radar receiver front end to be -150.0 dBW for the protection criterion of I/N = –6 dB.

TABLE 35

Excess of airborne Radar A protection criterion for a single-source interference

Channel width, MHz	5	10	20
Radar A receiver interference power, dBW	-114.8	-117.8	-120.8
Radar receiver thermal noise power, dBW	-144		
Radar protection criterion, I/N, dB	-6		
Acceptable level of interference at radar front end, dBW	-150,0		
Protection criterion excess, dB	35.2	32.2	29.2

The above values for maximum acceptable interference power were used for estimating the excess of the protection criterion. The results are presented in Table 35. It is obvious that for a 5 MHz channel width the excess of the protection criterion would be of 35.2 dB whereas for a 20 MHz channel width it would reduce to 29.2 dB.

For the second case the interference field strength produced by each of the IMT transmitters at the radar antenna front end was estimated in line with equation (4). The aggregate interference field strength was estimated using equation (3). This field strength was used for estimating the aggregate interference power at the radar receiver front end as defined by equation (5). The results are shown in Table 36.

TABLE 36

Excess of Radar A protection criterion for a multi-source interference

Channel width, MHz	5	10	20
Radar A receiver interference power, dBW	-108.8	-111.8	-114.8
Radar receiver thermal noise power, dBW	-144.0		
Radar protection criterion, I/N, dB	-6		
Acceptable level of interference at radar front end, dBW	-150.0		
Protection criterion excess, dB	41.2	38.2	35.2

The above values for maximum acceptable interference power were used for estimating the excess of the protection criterion. The results are presented in Table 36. It is obvious that for 5 MHz channel the excess of the protection criterion would be of 41.2 dB whereas for 20 MHz channel it would reduce to 35.2 dB.

The above values of protection criteria excess were used for estimating a minimum distance providing for acceptable interference radar operation. The separation distance was estimated using the following equation:

$$R_{\min} = \lambda \cdot 10^{\left(L_{ex}+L_{add}\right)/20} / 4\pi ,$$

where:

L_{ex} – existing radio path losses due to radar antenna altitude above the building (9 000 m), dB;

L_{add} – required additional losses due to protection criterion excess, dB;

λ – operational wave length.

Existing propagation losses were defined by the distance from IMT transmitters to radar antenna and were estimated using the following equation:

$$L_{ex} = -20\lg(\lambda / 4\pi R)$$

The results of estimation are shown in Table 37.

TABLE 37

Minimum separation distances for Radar A

Single-source interference			
Channel width, MHz	5	10	20
Existing losses, dB	122		
Required additional losses, dB	39.2	36.2	33.2
Required total losses, dB	161.2	158.2	155.2
Min separation distance, km	828	582	412
Aggregate interference			
Existing losses, dB	122		
Required additional losses, dB	45.2	42.2	39.2
Required total losses, dB	167.2	164.2	161.2
Min separation distance, km	1641	1162	828

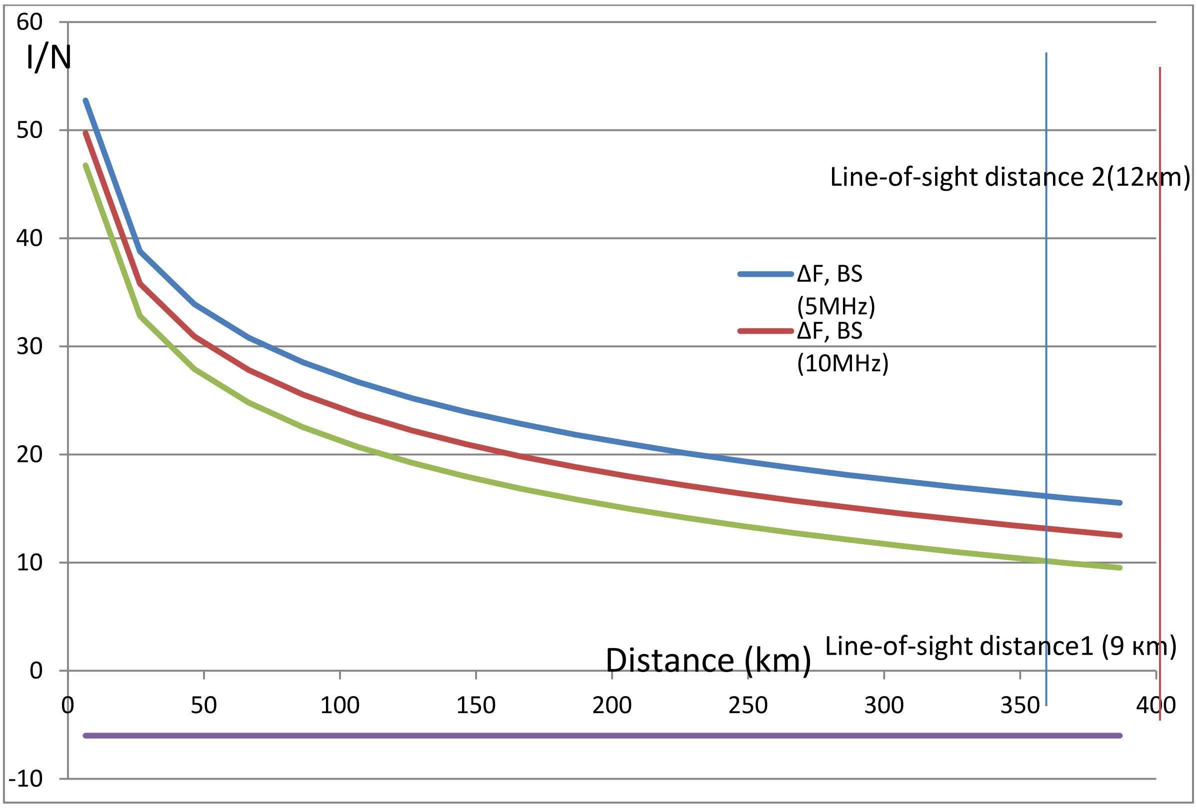
It is obvious that the separation distance required for the scenario concerned would exceed the maximum altitude of aircraft operation. It implies that sharing between the proposed IMT transmitters and the airborne Radar A would be unfeasible for the considered scenario.

The value of losses in ceilings/roofs corresponds to those for reinforced concrete structures. With radio translucent ceiling and floor structures the propagation losses would significantly increase to result in increasing the excess of Radar A receiver protection criteria.

The above is confirmed with the results of that shown in situation “b” of Figure 10 interference scenario. It was assumed that the side wall propagation losses would be 5 dB with emissions by four IMT base-station transmitters propagating through the side wall. The results of estimating the excess of Radar A receiver protection criteria as a function of aircraft-building distance are shown in Fig. 16.

FIGURE 16

I/N ratio at the Radar A receiver front end as a function of the building-aircraft distance



In Fig. 16 the blue curve reflects interference from IMT transmitters with a 5 MHz channel width; the red curve refers to those of a 10 MHz channel width and the green curve corresponds to those of a 20 MHz channel width. The violet curve shows the radar protection criterion equal to I/N = –6 dB. The obtained data analysis showed that the protection of Radars A from interference caused by indoor IMT transmitters would require separation distances exceeding those of line-of-sight.

It is to be noted that the airborne Radar A receiving antenna main lobe could cover several buildings simultaneously to result in extra excess of the airborne Radar A receiver protection criterion.

4.4.4.3.2 Effect of interference from air-borne Radar A on IMT receivers

Interference caused by airborne Radar A was estimated using the same assumptions referred to IMT receiver protection criteria as presented in section 4.4.4.1.2 above. Interference power from Radar A at the IMT receiver front end was estimated using equation (7). Estimates of required separation distances were correlated with equation (8) for receiving channel widths of 5 MHz, 10 MHz and 20 MHz and for two values of additional propagation losses. The results are shown in Table 38.

TABLE 38

IMT receiver minimum separation distances

Channel width, MHz	5	10	20
Noise figure, dB	10	10	10
Noise temperature, К	2610	2610	2610
Receiver thermal noise, dBW	-127	- 124	- 121
Max acceptable interference power, dBW	-133	- 130	- 127
Additional propagation losses σ, dB	5		
Min separation distance, km	>R	>R	>R
Additional propagation losses σ, dB	20		
Min separation distance, km	>R	>R	>R

The obtained results showed that even with wall propagation losses of 20 dB the required separation distances would exceed those of line-of-sight (R) which would be 360 kilometres for an aircraft flight altitude of 9 000 metres without accounting for tropospheric refraction. For an aircraft flight altitude of 12 000 metres the distance between the aircraft and building would be 412 kilometres without accounting for tropospheric refraction.

5 Results

5.1.1 Summary of results: Compatibility between in-door IMT base-station and radars described in Recommendation ITU-R M.1465 – IMT interfering with radar. Separation distances in km.

Study	Case	Land radar “A”	Land radar “B”	Ship radar “A”	Ship radar “B”	Ship radar “C”	Airborne radar “A”
A1	Co-channel	0,2 – 1,1	-	-	-	-	See note 1
	Non co-channel	-	-	-	-	-	-
B1	Co-channel	25	294	21	29	30	422
	Non co-channel	1,4	1,1	5	6	6,7	52
B2	Co-channel	-	-	-	-	-	> 338,4
	Non co-channel	-	-	-	-	-	-
B3	Co-channel	45	402-822	-	-	-	828-1641
	Non co-channel	-	-	-	-	-	-

Note 1. Study A1 did not provide the required separation distance between indoor IMT base-station and type “A” airborne radar, however it describes the required additional isolation up to 28 dB.

5.1.2 Summary of results: compatibility between radars described in Recommendation ITU-R M.1465 and in-door IMT base-station. Radar interfering with IMT. Separation distances in km

Study	Case	Land radar "A"	Land radar "B"	Ship radar "A"	Ship radar "B"	Ship radar "C"	Airborne radar "A"
A1	Co-channel	See note 2	-	-	-	-	See note 3
	Non co-channel	-	-	-	-	-	-
B1	Co-channel	520	1008	433	680	386	1057
	Non co-channel	55	N/A	105	264	N/A	697
B2	Co-channel	-	-	-	-	-	-
	Non co-channel	-	-	-	-	-	-
B3	Co-channel	124,5 -271	>LOS (261)	-	-	-	>LOS (360 – 412)
	Non co-channel	-	-	-	-	-	-

Note 2: Study A1 does not provide the calculation of the separation distance, however it has assessed that with 5 km geographic separation between radar transmitter and IMT system receiver the protection criteria for IMT would be exceeded in half of the scenarios considered in the study.

Note 3: Study A1 does not provide the calculation of the separation distance, however it has assessed that protection criteria for IMT in-door base-station which is -112 dBm/MHz for IMT in-door base-station will be in this case exceeded by 81 dB at a distance of 9 000 metres between IMT and radar.

Detailed results of the studies A1, B1, B2, B3 are indicated below.

5.2 Results of study A1

5.2.1 IMT system interferences to Radar system

Land-based-A radar system and IMT system

Interference type: From IMT base-station to Land-based-A radar station								
IMT system deployment place	Located at radar antenna main lobe				Located at radar antenna side lobe			
Deployment scenario	Urban		Suburban		Urban		Suburban	
Min. separation distance (m)	< 200		1100		< 200		< 200	
Interference type: From IMT indoor UE to Land-based-A radar station								
IMT system deployment place	Located at radar antenna main lobe				Located at radar antenna side lobe			
UE Output power (dBm)	23(max)		-9(average)		23(max)		-9(average)	
Deployment scenario	Urban	Suburban	Urban	Suburban	Urban	Suburban	Urban	Suburban
Min. separation distance (m)	< 200	800	< 200	< 200	< 200	< 200	< 200	< 200

Airborne-A radar system and IMT system

Interference type: From IMT small cell indoor base-station to airborne Radar A station				
Airborne Radar A receiver IF bandwidth = 1 MHz				
IMT system deployment place	Located at radar antenna main lobe		Located at radar antenna side lobe	
Maximum tolerable outdoor power(e.i.r.p.) (dBm)	-17.5		32.5	
Required additional isolation (dB)	28		-22	
Interference type: From IMT small cell indoor UE to airborne Radar A station				
Airborne Radar A receiver IF bandwidth = 1 MHz				
IMT system deployment place	Located at radar antenna main lobe		Located at radar antenna side lobe	
UE Output power (dBm)	23(max)	-9(average)	23(max)	-9(average)
Maximum tolerable outdoor power(e.i.r.p.) (dBm)	-11.5		38.5	
Required additional isolation (dB)	20.5	- 11,5	-29.6	-61.5

5.2.2 Radar system interferences to IMT system

Land-based-A radar system and IMT system

Interference type: From Land-based-A radar station to IMT base-station								
IMT system deployment place	Located at radar antenna main lobe				Located at radar antenna side lobe			
Radar bandwidth(MHz)	25		300		25		300	
Deployment scenario	Urban	Suburban	Urban	Suburban	Urban	Suburban	Urban	Suburban
Received interference level for 5km protect distance (dBm)	-88.91	-53.91	-99.70	-64.70	-127.91	-92.91	-138.7	-103.7
Interference type: From Land-based-A radar station to IMT indoor UE								
IMT system deployment place	Located at radar antenna main lobe				Located at radar antenna side lobe			
Radar bandwidth(MHz)	25		300		25		300	
Deployment scenario	Urban	Suburban	Urban	Suburban	Urban	Suburban	Urban	Suburban
Received interference level for 5km protect distance (dBm)	-90.91	-55.91	-101.7	-66.7	-129.91	-94.91	-140.7	-105.7

Airborne-A radar system and IMT system

Interference type: From airborne Radar A station to IMT small cell indoor base-station		
IMT system deployment place	Located at radar antenna main lobe	Located at radar antenna side lobe
Received interference level (dBm)	-17.8	-67.8
Interference type: From airborne Radar A station to IMT small cell indoor UE		
IMT system deployment place	Located at radar antenna main lobe	Located at radar antenna side lobe
Received interference level (dBm)	-19.8	-69.8

5.3 Results of study B1

The following table summarises the worst case minimum separation distances.

The worst case interference scenarios are defined by:

– Aggregate interference from multiple transmitters

– Average building penetration loss of 11 dB

– Main beam to main beam coupling

TABLE 39

Interference Scenario	Co-channel	Non-co Channel
Base-station into Land-based A	25 km	1.4 km
Base-station into Land-Based B	294 km	1.1 km
UE into Land-based A	24 km	0.99 km
UE into Land-based B	261 km	0.8 km
Base-station into Airborne A	422 km	52 km
UE into Airborne A	423 km	36 km
Base-station into Ship-based A	21 km	5 km
Base-station into Ship-based B	29 km	6 km
Base-station into Ship-based C	30 km	6.7 km
UE into Ship-Based A	19 km	5 km
UE into Ship-Based B	26 km	6 km
UE into Ship-Based C	28 km	6 km
Land-based A into BS	520 km	55 km
Land-based B into BS	1008 km	Not Available
Airborne A into BS	1057 km	697 km
Ship-based A into BS	433 km	105 km
Ship-based B into BS	680 km	264 km
Ship-based C into BS	386 km	Not Available

With regard to the results in this report, they were directed to protect radar systems from IMT indoor systems in the frequency band 3 300-3 400 MHz. The following observations may be reached:

- It may be possible to deploy IMT system for small cell indoor deployment in the area with a separation distance of less than 200 metres for a land-based-A radar station in the non-co-channel interference case in the same geographical area. However the worst case analysis (including aggregation) suggests that co-channel sharing requires in the order of one kilometre of separation.
- It would be difficult to co-locate indoor IMT systems and land-based-B radar station in a co-channel interference case in the same geographical area because:
  - Separation distances in the range 261–294 kilometres are required in the worst case.
  - It is not possible to ensure additional isolation of IMT base-station and UEs under all circumstances all of the time.
  - In spite of the very narrow land-based-B radar beamwidth ((H,V)=(1.05, 2.2) degree), there is a high likelihood that at some percentage of the time it will be directed towards a building containing one or many base-stations and UE. The severity of this problem is dependent on the percentage of buildings which have IMT small cell coverage. It is conceivable that the majority of buildings in a city may have IMT small cell coverage, in this case it is almost certain that the land-based B radar main beam will be coupled with numerous base-stations and UE at any point in time.
- Based on the results of interference from IMT indoor systems to radar, non-co-channel sharing between ship-based radars and land-based Radar A may be possible with separation distances of 5-7 kilometres.
- The co-channel and non-co-channel interference from all the radars to the IMT systems are very severe and suggests that neither form of sharing is possible unless the IMT receivers are designed in such a way to mitigate high power pulsed interference.
  The analysis shows that the separation distance required in both cases is in the hundreds of kilometres.

5.4 Results of study B2

For different elevation angles the required in-band emission level which would ensure the protection of the airborne radar embedded in aircraft has been calculated. Some observations can be made, emphasizing this studied case as not a worst case:

- the lower absolute value of elevation angle, the most stringent the inband emission level. The best case corresponds to the maximum elevation angle (-60°); where
- –40.9 dBm/MHz is required. For the lower absolute value of elevation angle, the requirement of in-band emission level for smallcells is expected to be more stringent;
- aggregation of interference was derived on surface[14] lower than the Σ surface covered by the airborne radar antenna main beam;
- aggregation of interference only addressed the impact of the smallcells indoor pointing in the main beam of the airborne radar and thus did not take account of the impact of the smallcells indoor pointing to the sidelobes of the airborne radar;
- free space pathloss is derived for d_{max} distance (which overestimates by some dBs the propagation loss as it would depend on the location of the smallcells in d_{min},d_{max} range).

[14] (B'FBG) kite quadrilateral.

Elevation angle of the airborne radar (°)	-3	-5	-10	-20	-30	-40	-50	-60
Surface covered by the airborne radar (km^2)	583	56.2	9.2	1.6	0.6	0.3	0.2	0.1
No smallcells indoor in sight of the main lobe of the airborne radar within (B'FBG) surface	713850	68791	11216	1903	685	346	214	109
No smallcells indoor in sight of the main lobe of the airborne radar	>713850	>68791	>11216	>1903	>685	>346	>214	>109
R_1 (km)	338.4	113.4	52	24.8	15.6	10.7	7.5	0.5
Required in-Band emission level (dBm/MHz) (IMT e.i.r.p)	<-47.5	<-46.8	<-45.6	<-44	<-42.8	<-42.1	<-41.5	<-40.9

In addition, this table shows that:

– not only are the in-band restricted emission levels[15] required for R_1 short distances less than 10 kilometres which could reflect "cross-border" situations where the aircraft performs sea and/or earth surveillance, these restricted emissions levels are also required for very long distances (more than 100 kilometres) when an airborne radar operates at low elevation angles (less than 5°);

– the most stringent in-band emission level (-47.5 dBm/MHz) is required for low elevation angle case corresponding to the common scenario where the aircraft operates far from the cross-border.

5.5 Results of study B3

The results of studies conducted show that interference caused by emissions from IMT base-stations deployed inside the building under consideration would considerably exceed the protection criteria for all analysed types of radars. With regards to potential long-term interference effect the excess could result in degradation of radar operational performances including temporal disability for the radars.

The above presented results assumed accounting for interference caused only by IMT base-station transmitters. However analysis of technical characteristics associated with IMT user equipment envisioned for operation in the frequency band under consideration showed that the difference between the e.i.r.p. of IMT base-stations and that of IMT user equipment was 1 dB. It implies that IMT user equipment would cause unacceptable interference to radars operating in the frequency band 3 300-3 400 MHz.

The separation distances required to protect the radiolocation service from IMT varies from 45 kilometres for land based Radar-A, 822-402 kilometres for land based Radar-B and 1 641-828 kilometres for airborne Radar A, depending on the scenario concerned.

15 For IMT smallcells indoor.

6 Conclusions

This report presents result of studies between IMT base-station and UE and all relevant types of radar systems described in the Recommendation ITU-R M.1465-1, as well as sharing between those radar systems and IMT base-station and UE.

Taking into account the results presented in section 5 of this report, this results show that sharing between IMT and land based radar “B” is not feasible in the same geographical area. As to other radar systems taken into account, the results vary depending on the study. However 3 of 4 studies included in this report conclude that sharing between IMT and airborne radar type “A” is not feasible in the same geographical area. The study that shows that sharing between IMT and airborne Radar A may be feasible relies on a level of additional isolation that may be very difficult to achieve and will not be guaranteed in all deployment scenarios.

For one study sharing between IMT indoor and land based Radar “A” was shown to be possible, however other studies did not confirm this.

The possible impact of radar systems on IMT has been also presented in the report. The overall conclusion is that in-door IMT systems shall be separated from all the radar types specified in Recommendation ITU-R M.1465 by hundreds of kilometres. All of the studies on the protection of in-door IMT from airborne radar “A” indicate that the required separation distance exceeds hundreds of kilometres. Some of the included studies indicate that the required separation distance between radar systems and IMT may even exceed 1 000 kilometres.

Bearing in mind the worldwide deployment of the radar systems presented in Recommendation ITU-R M.1465-1 it can be concluded, that sharing between IMT and the radiolocation service in the frequency band 3 300-3 400 MHz is not feasible.