International Telecommunication Union

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Radiocommunication Sector of ITU

Report ITU-R M.2481-0
(09/2019)

In-band and adjacent band coexistence and compatibility studies between IMT systems in 3 300-3 400 MHz and radiolocation systems in 3 100-3 400 MHz

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

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Note*: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R M.2481-0

In-band and adjacent band coexistence and compatibility studies between IMT systems in 3 300-3 400 MHz and radiolocation systems in 3 100-3 400 MHz

(2019)

Summary

This Report contains studies on operational measures to enable coexistence of International Mobile Telecommunication (IMT) and radiolocation service in the frequency band 3 300-3 400 MHz, and compatibility studies in adjacent bands between IMT systems operating in the frequency band 3 300-3 400 MHz and radiolocation systems operating below 3 300 MHz. It also provides guidance for operational measures to enable the coexistence of IMT and radiolocation service in these frequency bands. Studies performed in this Report analyse urban and suburban IMT deployments.

Keywords

IMT-Advanced, Radiolocation, Compatibility

Abbreviations/Glossary

AAS	Active antenna system
BS	Base-station
CDF	Cumulative distribution function
FDR	Frequency-dependent rejection
MCL	Minimum coupling loss
TRP	Total radiated power

TABLE OF CONTENTS

Page

Page

Page

Page

1 Introduction

The frequency band 3 100-3 300 MHz is allocated, in all three Regions, to the radiolocation service on a primary basis, and earth exploration and space research on a secondary basis.

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.

The frequency band 3 300-3 400 MHz is used for radar systems in a number of countries across the three Regions while a significant number of countries in Region 1 have no deployments in the band. At WRC-15, the band was allocated, on a primary basis, to the mobile service in a number of countries of the three Regions in accordance with Radio Regulations (RR) footnotes Nos. **5.429**, **5.429A**, **5.429C** and **5.429E** and also identified for IMT, in accordance with RR footnotes **5.429B**, **5.429D** and **5.429F**, by many other countries.

A significant amount of work has already been carried out at the ITU-R to study the coexistence of IMT systems with Radar systems in the 3 GHz frequency range.

– Report ITU-R M.2111 contains studies of sharing between IMT and Radar systems in the 3 400-3 700 MHz range.
– The Joint Task Group 4-5-6-7 studied the coexistence of indoor IMT systems operating in 3 300-3 400 MHz with radar systems. The studies are contained in Annex 32 to Document 4-5-6-7/715.

World Radiocommunication Conference 2015 (WRC-15) invited the ITU-R to perform further work to enable the co-existence of IMT and radiolocation in this band. Resolution **223 (Rev.WRC-15)** invites ITU-R to, among other things, study adjacent band compatibility between IMT in the frequency band 3 300-3 400 MHz and radiolocation service below 3 300 MHz.

This Report contains ITU-R studies on coexistence between IMT systems operating in 3 300-3 400 MHz and radar systems operating in 3 100-3 300 MHz and in 3 300-3 400 MHz.

2 Usage of the 3 300-3 400 MHz band

2.1 Region 1

The band 3 300-3 400 MHz is identified for IMT in 45 countries globally, of which 33 are from the African region. This band is important for administrations covered under the IMT identification footnotes as it is envisaged to provide increased capacity and performance for IMT systems operating in the C-Band.

2.1.1 Summary of the 3 300-3 400 MHz band usage survey in Africa

In 2016, the African Telecommunications Union (ATU), commissioned a usage survey for the band 3 300-3 400 MHz for purposes of establishing sharing studies relevant to the African Region, in respect of the envisaged deployment of IMT systems in the majority of Administrations on the African continent.

The purpose of the survey was to facilitate the studies towards the implementation of IMT in the 3 300-3 400 MHz band as called for by Resolution **223 (Rev.WRC-15)**.

The survey was specifically aimed at establishing the incumbent services that would require protection from IMT systems, as well as the extent of their deployments.

2.1.2 In-band co-existence (3 300-3 400 MHz)

Figure 1 shows countries of Africa included in RR footnote No. **5.429B** while Fig. 2 indicates planned use of 3 300-3 400 MHz band within the region.

FIGURE 1

African Countries included in RR footnote 5.429B

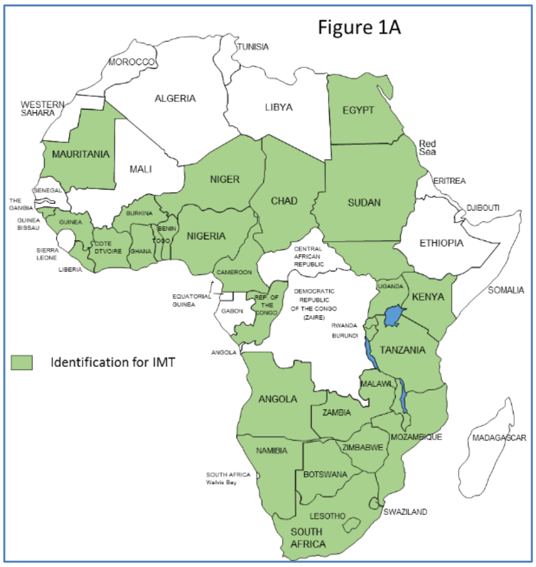
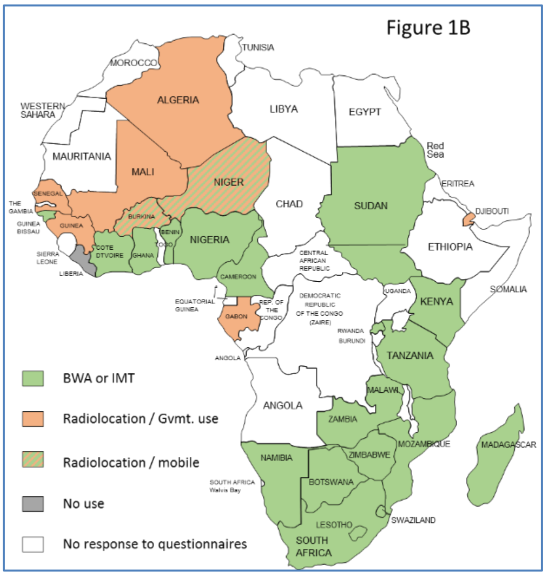


FIGURE 2

Planned use of the band 3 300-3 400 MHz in Africa



In a snapshot, the results of the survey were as follows:

– 28 responses were received.

– Currently, use of the 3 300-3 400 MHz band for radiolocation is confined to countries in the west coast and in the Sahara sub-region.

– The majority of countries on the continent are planning to implement IMT in the 3 300-3 400 MHz band.

– A majority of responses stated that a revised Recommendation ITU-R M.1036, which would include a channelling plan for the 3 300-3 400 MHz band, would be desirable for the implementation of IMT.

Based on the evidence above, the in-band coexistence studies called for by Resolution **223 (Rev.WRC-15)** would be of practical interest for Administrations sharing borders with countries deploying Radiolocation Services, and for Administrations sharing borders with international sea waters and airspace.

2.1.3 Adjacent band compatibility (3 100-3 300 MHz)

As the use of 3 100-3 400 MHz for radiolocation services is widespread in Region 1, the adjacent band compatibility studies called for by Resolution **223 (Rev.WRC-15)** would be of practical interest for all administrations.

2.2 Region 2

In Region 2, six (6) countries identified the band 3 300-3 400 MHz for IMT, at WRC-15. In countries where the 3 300-3 400 MHz band is identified for IMT by RR footnote No. **5.429D**, the in-band coexistence studies called for by Resolution **223 (Rev.WRC-15)** would be of practical interest for Administrations sharing borders with countries deploying Radiolocation Services, and for Administrations sharing borders with international sea waters and airspace.

As the use of 3 100-3 400 MHz band for radiolocation services is widespread in Region 2, the adjacent band compatibility studies in the 3 100-3 300 MHz as called for by Resolution **223 (Rev.WRC-15)** would be of practical interest for all Administrations.

2.3 Region 3

In-band co-existence (3 300-3 400 MHz)

In countries where the 3 300-3 400 MHz band is identified for IMT by RR footnote No. **5.429F**, the in-band coexistence studies called for by Resolution **223 (Rev.WRC-15)** would be of practical interest, in particular, for Administrations sharing borders with countries deploying Radiolocation services, and for Administrations sharing borders with international sea waters and airspace.

Adjacent band compatibility (3 100-3 300 MHz)

As the use of 3 100-3 400 MHz band for radiolocation services is widespread in Region 3, the adjacent band compatibility studies in the 3100-3300 MHz as called for by Resolution **223 (Rev.WRC-15)** would be of practical interest for all Administrations.

3 System characteristics

This Report presents interference analysis based on operational parameters of IMT-Advanced systems and Radiolocation systems.

3.1 Characteristics for IMT systems

The characteristics of the terrestrial IMT-Advanced systems for frequency sharing/interferences analyses are contained in Report ITU-R M.2292. Additional characteristics of the terrestrial IMT-2020 and Advanced Antenna Systems are provided in Tables 2 and 3.

3.1.1 Main characteristics of IMT BSs

Table 1 summarises the relevant base station characteristics.

TABLE 1

Base station characteristics/Cell structure

	Macro suburban	**Macro urban**	**Small cell outdoor/ Micro urban**	**Small cell indoor/ Indoor urban**
Cell radius/Deployment density	0.3-2 km (typical figure to be used in sharing studies 0.6 km)	0.15-0.6 km (typical figure to be used in sharing studies 0.3 km)	1-3 per urban macro cell <1 per sub-urban macro site	Depending on indoor coverage/ capacity demand
Antenna height	25 m	20 m	6 m	3 m
Sectorization	3 sectors	3 sectors	Single sector	Single sector
Downtilt (Note 1)	6 degrees	10 degrees	n.a.	n.a.
Frequency reuse	1	1	1	1

TABLE 1 (*end*)

	Macro suburban	**Macro urban**	**Small cell outdoor/ Micro urban**	**Small cell indoor/ Indoor urban**
Non-AAS BS Antenna pattern (Note 2)	Recommendation ITU-R F.1336 (*recommends* 3.1) ka = 0.7 kp = 0.7 kh = 0.7 kv = 0.3 Horizontal 3 dB beamwidth: 65 degrees Vertical 3 dB beamwidth: determined from the horizontal beamwidth by equations in Recommendation ITU-R F.1336. Vertical beamwidths of actual antennas may also be used when available		Recommendation ITU-R F.1336 omni	
Antenna polarization	Linear/±45 degrees	Linear/±45 degrees	Linear	Linear
Indoor base station deployment	n.a.	n.a.	n.a.	100%
Indoor base station penetration loss	n.a.	n.a.	n.a.	20 dB (3-5 GHz) 25 dB (5-6 GHz) (horizontal direction) Rec. ITU-R P.1238, Table 3 (vertical direction)
Below rooftop base station antenna deployment	0%	50%	100%	n.a.
Feeder loss (Note 2)	3 dB	3 dB	n.a	n.a
Maximum base station output power (5/10/20 MHz) (Note 2)	43/46/46 dBm	43/46/46 dBm	24 dBm	24 dBm
Maximum base station non-AAS antenna gain (Note 2)	18 dBi	18 dBi	5 dBi	0 dBi
Maximum base station output power/sector (e.i.r.p.) (Non-AAS BS) (Note 2)	58/61/61 dBm	58/61/61 dBm	29 dBm	24 dBm
Average base station activity	50%	50%	50%	50%
Average base station power/ sector (e.i.r.p.) (non-AAS BS) taking into account activity factor (Note 2)	55/58/58 dBm	55/58/58 dBm	26 dBm	21 dBm

NOTE 1 – For AAS Base Stations, the value relates to mechanical downtilt only.

NOTE 2 – The parameter is only applicable to non-AAS Base Stations. Antenna characteristics for AAS Base Stations are in Table 1-ter.

The studies take into account 3 to 9 micro base-stations per urban macro site, without assumption of clustering micro cells.

3.1.2 Antenna pattern of the non-AAS IMT BSs

According to Recommendation ITU-R F.1336, taking into account the parameters given in Table 1, the IMT-Advanced base stations' antenna pattern for non-AAS are:

– for urban micro BS, omnidirectional in azimuth and directive in elevation, leading to 5 dBi antenna gain in any horizontal direction toward radar stations.

– for macro BS base station, given in Figs 3, 4 and 5, which plot the vertical antenna pattern (gain is function of elevation angle θ) with downtilts respectively of 0°, 6° and 10°.

Because the separation distance between radar and IMT terrestrial systems are assumed to be far larger than their antenna heights (more than few km compared to less than few tens of metres), the line of sight between radars and base stations is assumed to be in the horizontal plane (elevation angle 0°) then the gain of urban macro BS antennas' mainlobe with 10° downtilt is estimated of 6.0 dBi, and the gain of sub-urban macro BS antennas' mainlobe with 6° downtilt is estimated of 10.0 dBi.

FIGURE 3

F.1336 directional antenna's elevation pattern of macro BS without downtilt angle

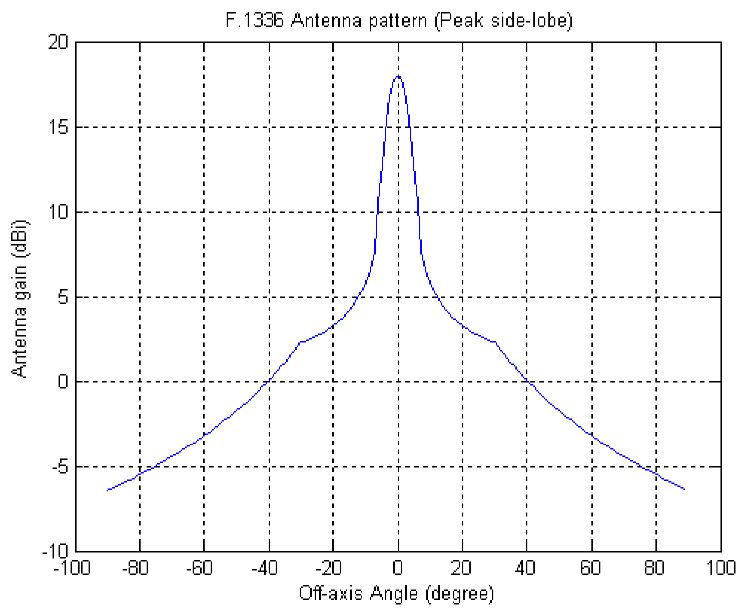


FIGURE 4

F.1336 directional antenna's elevation pattern of macro BS with downtilt angle of 6 degrees

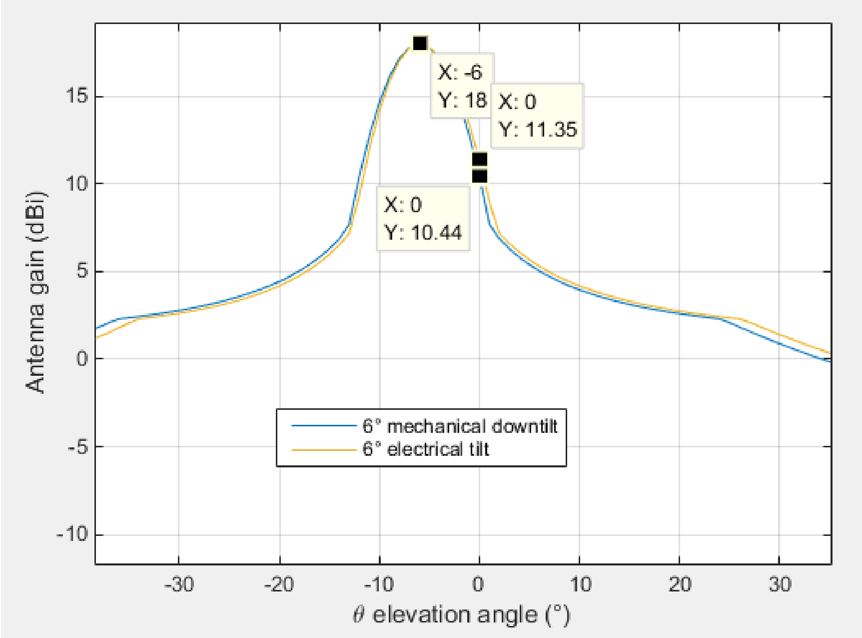
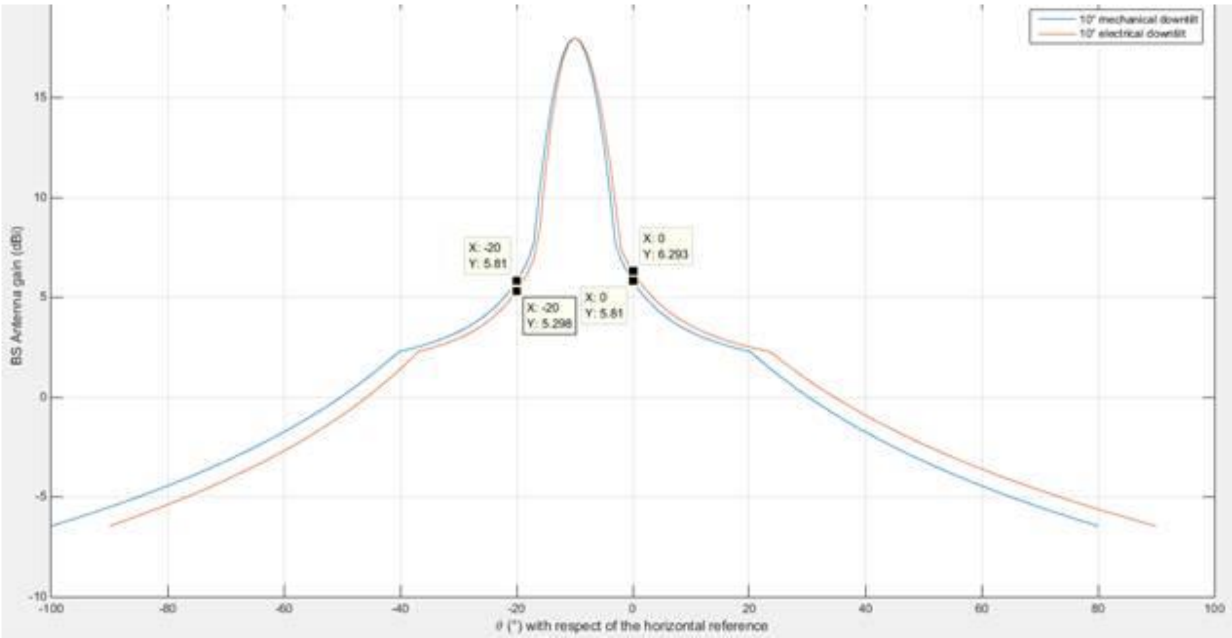


FIGURE 5

F.1336 directional antenna's elevation pattern of macro BS with downtilt angle of 10 degrees



The characteristics of IMT antenna pattern for AAS are given in Tables 2 and 3.

TABLE 2

IMT-2020 AAS base station antenna element and array parameters

Parameters	**Assumed Value**
Antenna element directional pattern $a_{E\text{ dB}}(\theta,\varphi)$	According to **3GPP TR 37.840 (section** 5.4.4.2**)**: $$a_{E\text{ dB}}(\theta,\varphi) = -\min\{-[A_{E,V\text{ dB}}(\theta) + A_{E,H\text{ dB}}(\varphi)],\ A_{m\text{ dB}}\},$$ $$A_{E,H\text{ dB}}(\varphi) = -\min\left\{12\left(\frac{\varphi}{\varphi_{3\text{ dB}}}\right)^2, A_{m\text{ dB}}\right\},$$ $$A_{E,V\text{ dB}}(\theta) = -\min\left\{12\left(\frac{\theta-90°}{\theta_{3\text{ dB}}}\right)^2, SLA_{V\text{ dB}}\right\},$$ where: 3 dB elevation beamwidth θ_{3dB} = 65°, 3 dB azimuth beamwidth $\varphi_{3\text{ dB}}$ = 80°, Front-to-back ratio A_m = 30 dB, Side-lobe ratio SLA_V = 30 dB. NOTE 1 – $a_E(\theta,\varphi) \leq 1$. NOTE 2 – Each antenna element is larger in size in the vertical direction, and so $\theta_{3dB} < \varphi_{3dB}$. See 3GPP TR 37.840.
Antenna element gain $G_{E\text{ dB}}$	8 dB
Number of base station beamforming elements (N_V, N_H)	8.8
Element spacing	0.9λ vertical separation. 0.6λ horizontal separation. NOTE – Larger vertical spacing provides narrower array beamwidth in elevation. See 3GPP TR 37.840 (Table 5.4.4.2.1-1).
Mechanical downtilt	Macro-cell: 10° NOTE – For macro-cell, see Rec. ITU-R M.2292 for 20 metres height and 300 m sector radius.
Array beamforming directional pattern $a_{\text{A}}(\theta,\varphi)$	According to 3GPP TR 37.840 (section 5.4.4.2): $$a_{\text{A}}(\theta,\varphi) = 1 + \rho\left[\left\lvert\sum_{m=1}^{N_{\text{H}}}\sum_{n=1}^{N_{\text{V}}} w_{m,n}v_{m,n}\right\rvert^2 - 1\right]$$ where: $$v_{m,n} = \exp\left[j\frac{2\pi}{\lambda}\{(m-1)d_{\text{H}}\sin(\varphi)\sin(\theta) + (n-1)d_{\text{V}}\cos(\theta)\}\right],$$ $$w_{m,n} = \frac{1}{\sqrt{N_{\text{H}}N_{\text{V}}}}\exp\left[-j\frac{2\pi}{\lambda}\{(m-1)d_{\text{H}}\sin(\varphi_{\text{SCAN}})\cos(\theta_{TILT}) - (n-1)d_{\text{V}}\sin(\theta_{TILT})\}\right],$$ and: ρ is the signal correlation across the antenna elements, $N_{\text{V}}, N_{\text{H}}$ are the number of vertical and horizontal antenna elements, $d_{\text{V}}, d_{\text{H}}$ are the vertical and horizontal antenna element spacings, $-\pi/2 \leq \theta_{TILT} \leq \pi/2$ is the downward beam steering tilt angle relative to boresight, and $-\pi \leq \varphi_{SCAN} \leq \pi$ is the anti-clockwise horizontal beam steering scan angle relative to boresight. NOTE – $0 \leq a_{\text{A}}(\theta,\varphi) \leq N$.

TABLE 3

Antenna characteristics for IMT-Advanced and IMT-2020 AAS base stations for bands between 3 and 6 GHz

		Outdoor Suburban hotspot	Outdoor Urban hotspot	Indoor
1	**Base station antenna characteristics**			
1.1	Antenna pattern	Refer to Rec. ITU-R M.2101		
1.2	Element gain (dBi)	8	8	8
1.3	Horizontal/vertical 3 dB beamwidth of single element (degree)	80° for H 65 for V	80° for H 65 for V	80° for H 65 for V
1.4	Horizontal/vertical front-to-back ratio (dB)	30 for both H/V	30 for both H/V	25 for both H/V
1.5	Antenna polarization	Linear ±45°	Linear ±45°	Linear ±45°
1.6	Antenna array configuration (Row × Column) (Note 1)	8 × 8 elements	8 × 8 elements	8 × 8 elements
1.7	Horizontal/Vertical radiating element spacing	0.6 of wavelength for H, 0.9 of wavelength for V	0.6 of wavelength for H, 0.9 of wavelength for V	0.6 of wavelength for H, 0.9 of wavelength for V
1.8	Array Ohmic loss (dB)	2	2	2
1.9	Conducted power (before Ohmic loss) per antenna element (dBm/200 MHz) (Note 2)	25/28/31	25/28/31	6/9/12
1.10	Base station maximum coverage angle in the horizontal plane (degrees)	120	120	120

Note 1 – The parameter is only applicable to non-AAS Base Stations.

Note 2 – Different AAS studies have assumed different bandwidth and power combinations.

3.1.3 Main characteristics of IMT user terminals

TABLE 4

User terminal characteristics

	Macro suburban	Macro urban	Small cell outdoor/ Micro urban	Small cell indoor/ Indoor urban
Indoor user terminal usage	70%	70%	70%	100%
Building wall penetration loss	20 dB	20 dB	20 dB	20 dB Rec. ITU-R P.1238, Table 3 (vertical direction)
User terminal density in active mode to be used in sharing studies	2.16/5 MHz/km^2	3/5 MHz/km^2	3/5 MHz/km^2	Depending on indoor coverage/capacity demand
Maximum user terminal output power	23 dBm	23 dBm	23 dBm	23 dBm
Average user terminal output power	−9 dBm	−9 dBm	−9 dBm	−9 dBm
Typical antenna gain for user terminals	−4 dBi	−4 dBi	−4 dBi	−4 dBi
Body loss	4 dB	4 dB	4 dB	4 dB

3.1.4 Out of block emissions of IMT BSs

Tables 5 and 6 provide the IMT transmission power suppression at the first adjacent frequency based on the Report ITU-R M.2292 noting 3GPP 36.104 v.11.2.0, § 6.6.2 specifications.

Furthermore, ACLR shall be no less than 45 dB.

For Wide Area (macro) BS, either the ACLR limits or the absolute limit of −15 dBm/MHz apply, whichever is more stringent since the BS has to meet both requirements.

For Local Area (micro) BS, either the ACLR limits or the absolute limit of −27 dBm/MHz shall apply, whichever is more stringent, since the BS has to meet both requirements.

The unwanted emissions limits at frequencies beyond the ACLR region (i.e. the frequency separation with the base station assigned channel is larger than two times the channel bandwidth), the operating band unwanted emission limits will refer to the following two tables.

TABLE 5

IMT macro base station unwanted emission limits for 5, 10, 15 and 20 MHz channel bandwidths

Frequency offset of measurement filter –3 dB point, Δ*f*	Frequency offset of measurement filter centre frequency, f_offset	Minimum requirement	Measurement bandwidth
0 MHz ≤ Δ*f* < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-7dBm-\frac{7}{5}\cdot\left(\frac{f\_offset}{MHz}-0.05\right)dB$	100 kHz
5 MHz ≤ Δ*f* < min(10 MHz, Δf_{max})	5.05 MHz ≤ f_offset < min(10.05 MHz, f_offset_{max})	–14 dBm	100 kHz
10 MHz ≤ Δ*f* ≤ Δf_{max}	10.5 MHz ≤ f_offset < f_offset_{max}	–15 dBm (Note 5)	1 MHz

TABLE 6

IMT micro base station unwanted emission limits for 5, 10, 15 and 20 MHz channel bandwidths

Frequency offset of measurement filter –3 dB point, Δ*f*	Frequency offset of measurement filter centre frequency, offset	Minimum requirement	Measurement bandwidth
0 MHz ≤ Δ*f* < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-30dBm-\frac{7}{5}\left(\frac{f\_offset}{MHz}-0.05\right)dB$	100 kHz
5 MHz ≤ Δ*f* < min(10 MHz, Δf_{max})	5.05 MHz ≤ f_offset < min (10.05 MHz, f_offset_{max})	–37 dBm	100 kHz
10 MHz ≤ Δ*f* ≤ Δf_{max}	10.05 MHz ≤ f_offset < f_offset_{max}	–37 dBm (Note 5)	100 kHz

Spurious emissions requirement is –30 dBm/MHz as refered to the Report ITU-R M.2292 noting 3GPP 36.104 v.11.2.0, Table 6.6.4.1.2.1-1 for non-AAS BS.

3.2 Characteristics of the Radiolocation systems

Recommendation ITU-R M.1465 gives characteristics of radiolocation radars operating in the frequency range 3 100-3 700 MHz. See Table 7. Shipborne radar C antenna height is 20 metres.

The parameters of new land based radars C, D, E, in the range 2.8-3.4 GHz, are given in Table 8.

Recommendation ITU-R M.1464 also gives characteristics of radiolocation radars operating in the frequency range 2 700-3 400 MHz. See Table 9.

Recommendation ITU-R M.1461 provides a radar receiver IF selectivity fall-off of −80 dB per decade.

For radar systems, no additional feeder loss parameter is described in these ITU-R Recommendations on radar characteristics, because in reception mode, radar feeder losses are already included in the noise figure values (see Note 2 of Table 9), and in transmitting mode, the transmitted power is defined at the input of the radar antenna.

TABLE 7

Table of characteristics of radiolocation systems in the frequency range 3 100-3 700 MHz

Parameter	**Units**	**Land-based systems**		**Ship systems**				**Airborne system**
		A	**B**	**A**	**B**	**C**	**D**	**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	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 (Peak)	kW	640	1 000	1 000	4 000-6 400	60-200	4-90	1 000
Pulse width	µs	160-1 000	1.0-15	0.25, 0.6	6.4-51.2	0.1-1000	0.1-100	1.25(1)
Repetition rate	kHz	0.020-2	0.536	1.125	0.152-6.0	0.3-10	0.5-10	2
Compression ratio		48 000	Not applicable	Not applicable	64-512	Up to 20 000	Up to 400	250
Type of compression		Not available	Not applicable	Not applicable	CPFSK	Not available	Not available	Not available
Duty cycle	%	2-32	0.005-0.8	0.28, 0.67	0.8-2.0	Max 20	Max 20	5
Tx bandwidth (–3 dB)	MHz	25/300	2	4, 16.6	4	25	3,15	> 30
Antenna gain	dBi	39	40	32	42	Up to 40	Up to 40	40
Antenna type		Parabolic		Parabolic	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	1.5-6, 4-20	1.2, 6.0
Vertical scan type		Not available	Not applicable	Not applicable	Random	Not applicable	Not applicable	Not available
Maximum vertical scan	degrees	93.5	Not applicable	Not applicable	90	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	Continuous 360 + Sector	Rotating
Maximum horizontal scan	degrees	360		360			360	360
Horizontal scan rate	degrees/s	15	25.7	24	Not applicable	30-360	50-180	36
Polarization		RHCP	V	H	V	Not available	V	Not available

TABLE 7 (*end*)

Parameter	Units	Land-based systems		Ship systems				Airborne system
		A	B	A	B	C	D	A
Rx sensitivity	dBm	Not available	–112	–112	Not available	Not available	Not available	Not available
S/*N* criteria	dB	Not applicable	0	14	Not available	Not available	Not available	Not available
Rx noise figure	dB	3.1	4.0	4.8	5.0	1.5	1.5	3
Rx RF bandwidth (−3 dB)	MHz	Not available	2.0	Not available		400		Not available
Rx IF bandwidth (−3 dB)	MHz	380	0.67	8	10	10-30	2-20	1
Deployment area		Worldwide	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide	Worldwide

(1) 100 ns compressed.

CPFSK: Continuous-phase FSK.

PA: Phased array.

SWA: Slotted waveguide array.

TABLE 8

Table of characteristics of radiolocation systems in the frequency range 3 100-3 700 MHz

Parameter	Units	Land-based systems		
		C	D	E
Use		Multi-function Surface and air search	Multi-function surface and air search	Multi-function surface and air search
Modulation		P0N/Q7N	P0N/Q7N	
Tuning range	GHz	2.8-3.4	2.9-3.5	3.3-3.4
Tx power into antenna (Peak)	kW	200	60-70	0.33
Pulse width	µs	50-500	3-150	0.65
Repetition rate	kHz	>0.2 Variable in Doppler mode	0.8-50	160
Compression ratio		Up to 1 000	Up to 2 000	26
Type of compression		Not available	LFM & NLFM	Not applicable
Duty cycle	%	0.2-20	Max 12	Max 11
Tx bandwidth (–3 dB)	MHz	2	7-40	1-20
Antenna gain	dBi	31	40	22
Antenna type				PA
Beamwidth (H,V)	degrees	1.5	1-4.5	15,15
Vertical scan type		Not available	Random	Random
Maximum vertical scan	degrees	50	–5 – +90	75

TABLE 8 (*end*)

Parameter	Units	Land-based systems		
		C	**D**	**E**
Vertical scan rate	degrees/s	Not applicable	Variable	35
Horizontal scan type		Rotating + sector	Rotating	Random
Maximum horizontal scan	degrees	360	360	360
Horizontal scan rate	degrees/s	36	180	Not available
Polarization		Linear	V	V
Rx sensitivity	dBm	–110	–115	–141
S/*N* criteria	dB	Not available	Not available	Not available
Rx noise figure	dB	1.5	4	3
Rx RF bandwidth (–3 dB)	MHz	Not available	Not available	Not available
Rx IF bandwidth (–3 dB)	MHz	2	30	5,10
Deployment area		Worlwide	Worldwide	Worldwide

TABLE 9

Characteristics of radiolocation radars in the frequency band 2 700-3 400 MHz

Characteristics	Units	Radar I	Radar J	Radar K	Radar L	Radar M
Platform type (airborne, shipborne, ground)		Ground, ATC gap-filler coastal	2D/3D naval surveillance ground air defence	Ground air defence	Multifunction various types	Shipborne, ground
Tuning range	MHz	2 700-3 400	2 700-3 100	2 700 to 3 100 2 900 to 3 400	Whole frequency band up to 25% BW	2 700-3 400
Operational frequencies minimum/ maximum		Minimum: 2 spaced at > 10 MHz Maximum: fully agile	Minimum: 2 spaced at > 10 MHz Maximum: fully agile	Minimum: fixed Maximum: fully agile	Minimum: 2 spaced at > 10 MHz Maximum: fully agile	Minimum: 2 spaced at > 10 MHz Maximum: fully agile
Modulation		Non-linear FM P0N, Q3N	Non-linear FM P0N, Q3N	Non-linear FM Q3N	Mixed	P0N, Q3N
Transmitter power into antenna	kW	60 typical	60 to 200	1 000 typical	30 to 100	60 to 1 000
Pulse width	µs	0.4(1) to 40	0.1(1) to 200	> 100	Up to 2	0.1 to 1 000
Pulse rise/fall time	µs	10 to 30 typical	10 to 30 typical	Not given	Not given	> 50 0.05-1.00(6)
Pulse repetition rate	pps	550 to 1 100 Hz	300 Hz to 10 kHz	< 300 Hz	Up to 20 kHz	300 Hz to 10 kHz
Duty cycle	%	2.5 maximum	10 maximum	Up to 3	30 maximum	20 maximum
Chirp bandwidth	MHz	2.5	Up to 10	> 100	Depends on modulation	Up to 20
Compression ratio		Up to 100	Up to 300	Not applicable	Not given	Up to 20 000

TABLE 9 (*continued*)

Characteristics	Units	Radar I	Radar J	Radar K	Radar L	Radar M
RF emission bandwidth: −20 dB −3 dB	MHz	3.5 2.5	15 10	> 100	Not given	25
Output device		TWT	TWT or solid state	Klystron CFA	Active elements	Solid state
Antenna pattern type (pencil, fan, cosecant-squared, etc.)		Cosecant-squared	Pencil beam 3D or cosecant-squared 2D	Swept pencil beam	Pencil beam	Pencil beam 3D or cosecant-squared 2D
Antenna type (reflector, phased array, slotted array, etc.)		Shaped reflector	Planar array or shaped reflector	Frequency scanned planar array or reflector	Active array	Active array
Antenna azimuth beamwidth	degrees	1.5	1.1 to 2	Typically 1.2	Depends on number of elements	Depends on number of elements Typically 1.1 to 5
Antenna polarization		Linear or circular or switched	Linear or circular or switched	Fixed linear or circular	Fixed linear	Mixed
Antenna main beam gain	dBi	33.5 typical	Up to 40	> 40	Up to 43	Up to 40
Antenna elevation beamwidth	degrees	4.8	1.5 to 30	Typical 1	Depends on number of elements	Depends on number of elements Typically 1 to 30
Antenna horizontal scan rate	degrees/s	45 to 90	30 to 180	Typical 36	Sector scan instantaneous rotation scan up to 360	30 to 360
Antenna horizontal scan type (continuous, random, 360°, sector, etc.)	degrees	Continuous 360	Continuous 360 + sector scan	Continuous 360 + sector scan on	Random sector scan sector scan + rotation	Continuous 360+ Sector scan+ Random sector scan
Antenna vertical scan rate	degrees/s	Not applicable	Instantaneous	Instantaneous	Instantaneous	Instantaneous
Antenna vertical scan type (continuous, random, 360°, sector, etc.)	degrees	Not applicable	0 to 45	0 to 30	0 to 90	0 to 90
Antenna side lobe (SL) levels (1st SLs and remote SLs)	dB dBi	26 35	> 32 typical < –10	> 26 typical < 0	Not given	> 32 typical < –10
Antenna height above ground	m	4 to 30	4 to 20	5	4 to 20	4 to 50
Receiver IF 3 dB bandwidth	MHz	1.5 long 3.5 short	10	Not given	Not given	10-30
Receiver noise figure(2)	dB	2.0 maximum	1.5 maximum	Not given	Not given	1.5 maximum
Minimum discernible signal	dBm	–123 long pulse –104 short pulse	Not given	Not given	Not given	Not given

TABLE 9 (*end*)

Characteristics	Units	Radar I	Radar J	Radar K	Radar L	Radar M
Receiver front-end 1 dB gain compression point. Power density at antenna	W/m^2	1.5×10^{-5}	5×10^{-5}	1×10^{-6}	1×10^{-3}	5×10^{-5}
Receiver on-tune saturation level power density at antenna	W/m^2	4.0×10^{-10}	1×10^{-10}	Not given	Not given	1×10^{-10}
RF receiver 3 dB bandwidth	MHz	400	400	150 to 500	Up to whole frequency band	400
Receiver RF and IF saturation levels and recovery times		Not given	Not given	Not given	Not given	Not given
Doppler filtering bandwidth		Not given	Not given	Not given	Not given	Not given
Interference-rejection features(3)		(4)	(4) and (5)	(4) and (5)	Adaptive beamforming (4) and (5)	Not given
Geographical distribution		Worldwide fixed site transportable	Worldwide fixed site naval transportable	Worldwide fixed site transportable	Worldwide fixed site naval transportable	Littoral and offshore areas Worldwide fixed site Transportable
Fraction of time in use	%	100	Depends on mission	Depends on mission	Depends on mission	100

(1) Uncompressed pulse.

(2) Includes feeder losses.

(3) The following represent features that are present in most radar systems as part of their normal function: STC, CFAR, asynchronous pulse rejection, saturating pulse removal.

(4) The following represent features that are available in some radar systems: selectable PRFs, moving target filtering, frequency agility.

(5) Side lobe cancellation, side lobe blanking.

(6) This rise/fall time corresponds to short pulses with pulse width of 0.1 μs to 100 μs.

4 Propagation models

The propagation model between IMT system and ship based radar is from Recommendation ITU-R P.452-16. All the propagation factors in Recommendation ITU-R P.452 are considered. Parameters “dcr” and “dct”, are considered for sea and coastal scenarios. The values of parameter p = 20% and p = 10% are used (time percentage for which the calculated basic transmission loss is not exceeded). Lower values (p = 1%) are used for sensitivity analysis because some missions of radar systems could be more demanding.

The studies distinguish scenarios in different climatic regions (tropical, equatorial), because propagation losses are significantly different.

Clutter model

The clutter loss model used in this report combines for each IMT deployment, a percentage of above rooftop base stations without clutter loss and a percentage of below rooftop base stations with clutter loss values defined in § 3.2 of the Recommendation ITU-R P.2108 by a statistical model for end correction of terrestrial to terrestrial long-path propagation.

Figure 6 plots median clutter loss as function of distance.

Figure 7 plots the clutter distribution function for frequency 3.3 GHz and propagation paths longer than 1 km. This clutter model indicates that 5% of base station locations not exceed 18 dB loss, 50% of locations with loss below 28 dB, and 95% of locations with loss below 38 dB.

FIGURE 6

Median clutter loss for terrestrial paths

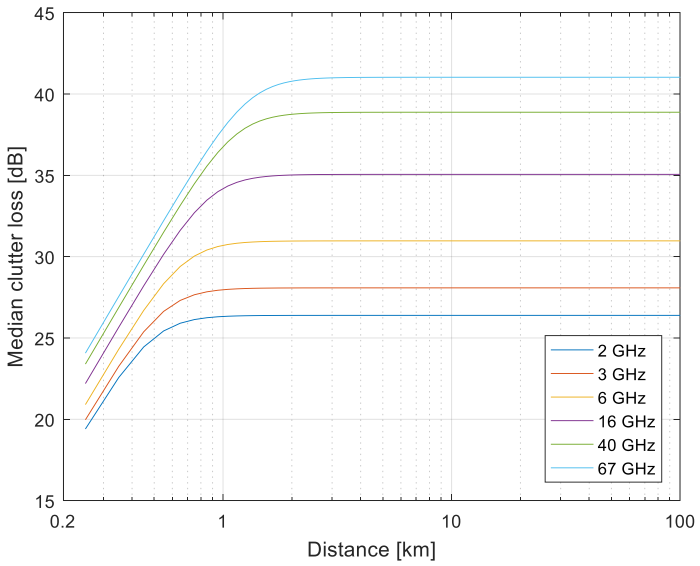
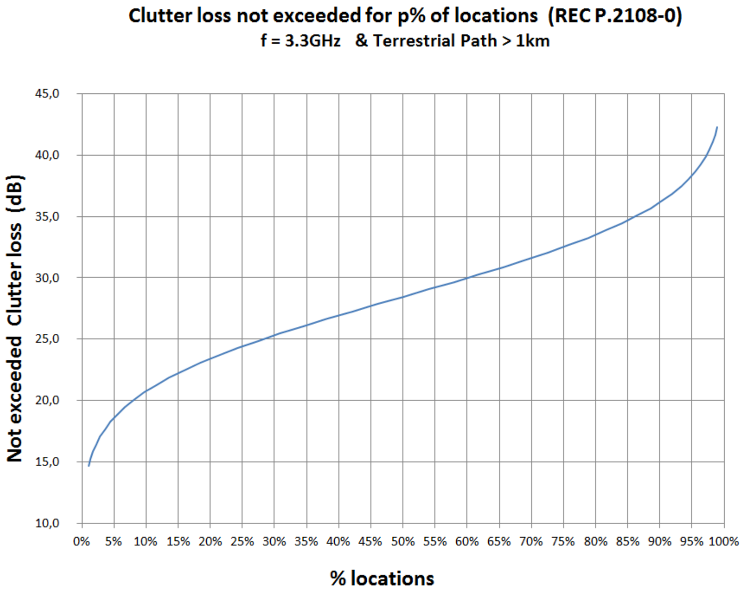


FIGURE 7

Clutter loss distribution for terrestrial paths



Due to truncation of the clutter curve at 1% and 99% of location, simulations randomize the clutter losses with a minimum clutter of 15 dB for 1% of locations and a maximum of 42 dB for 99% of locations.

5 Interference criteria

5.1 Interference criteria for radar systems

Signals received by radars from other systems could generate different types of degradation of performances. Desensitisation is generally due to low level of interfering signals, and saturation or blocking of receivers could be observed for larger interfering signals.

5.1.1 Blocking of radar receivers

The blocking phenomenon is observed when in-band or out-band interfering signals are at the input of the radar receiver with sufficiently high levels for saturating the RF chain and annealing the detection of weak radar returns. This effect on radar performance needs to be analysed for scenarios with small separation distances between IMT transmitters and radar receivers.

5.1.2 Radar interference criterion

The radar interference criteria in the radiolocation service are given in Recommendation ITU-R M.1465.

The interference criterion is:

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

where:

I: interference power for radar, dBm

N: receiver noise, dBm.

No percentage of time is associated with the radar protection criteria.

5.2 Interference criteria for IMT systems

The interference protection criteria of −6 dB is given in Report ITU-R M.2292. Protection mechanisms could be found in Recommendation ITU-R M.2012 – Detailed specification of the terrestrial radio interfaces of IMT Advanced.

5.3 Methodology for interference calculation from IMT to Radar

The methodology used for studies in this Report takes into account:

– Recommandation ITU-R M.1461 – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services.

– Recommandation ITU-R M.2101 – Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies, including section 8, noting that not every aspect is applicable to a single entry study.

– Recommandation ITU-R SM.337 – Frequency and distance separations.

5.3.1 Methodology for single entry studies in co-channel

Assuming one IMT base-station or terminal interfere a radiolocation service radar in co-channel, the received interference power level at the radiolocation service radar is calculated according to the equation:

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

where:

- I_{IMT}: received interference power level in the bandwidth of the radiolocation service radar (dBm)
- P_{IMT}: transmission power of IMT system (dBm)
- G_{IMT}: antenna gain of IMT system (dB) minus feeder loss
- G_{Radar}: reception antenna gain of radiolocation service radar (dB)
- $L(f,d)$: propagation loss (dB)
- OTR: On tune rejection as defined in Recommendation ITU-R SM.337.

5.3.1.1 Minimum Coupling Loss approach

The Minimum Coupling Loss (MCL) methodology aims to estimate the level of harmful interference in single entry worst case scenarios with maximum static peak antenna gain for both transmitter and receiver (i.e. considering the maximum static gain of IMT antenna in the horizontal plane taking into account the IMT antenna mechanical downtilt and the feeder loss).

5.3.1.2 Statistical approach

The statistical methodology aims to estimate the levels of interferences depending of variation of some parameters in the scenario, delivering interim results as described in Recommendation ITU-R M.2101.

5.3.2 Methodology for single entry studies in adjacent channel

Assuming one IMT base-station or terminal interfere radiolocation service radar with a frequency offset between the two systems, the received interference power level at the radiolocation service radar is calculated according to the equation:

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

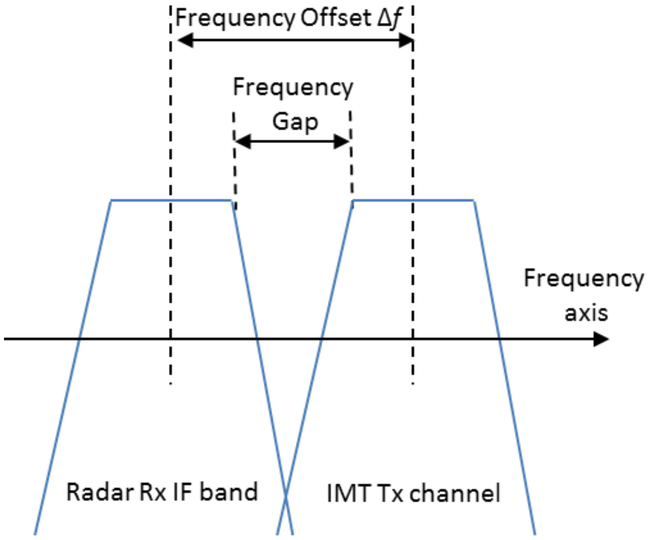
where:

- I_{IMT}: received interference power level in the bandwidth of the radiolocation service radar (dBm)
- P_{IMT}: transmission power of IMT system (dBm)
- G_{IMT}: antenna gain of IMT system (dB) minus feeder loss
- G_{Radar}: reception antenna gain of radiolocation service radar (dB)
- $L(f,d)$: propagation loss (dB)
- FDR: frequency-dependent rejection (dB)
- Δf: frequency offset (Hz) as defined in Recommendation ITU-R SM.337.

Figure 8 shows the relationship between definitions of frequency offset and frequency gap.

FIGURE 8

Frequency Offset and Gap between a radar receiver band and one IMT base station transmitter channel



The frequency-dependent rejection (FDR) value is determined from Recommendation ITU-R SM.337. The FDR is the rejection provided by a receiver to a transmitted signal as a result of the limited bandwidth of the receiver with respect to the transmitted signal and the detuning between the receiver and the transmitter.

The FDR can be divided into two terms, the on-tune rejection (OTR) and the off-frequency rejection (OFR). The OTR is the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of a transmitted signal exceeding the receiver bandwidth. The OFR is an additional rejection that results from off-tuning between interferer and receiver. FDR, OTR and OFR are considered as losses and defined below in a manner to ensure positive values:

$$FDR(\Delta f) = OTR + OFR(\Delta f)$$

5.3.2.1 MCL approach

The MCL methodology aims to estimate level of harmful interference in single entry worst case scenarios with maximum static peak antenna gain for both transmitter and receiver (i.e. considering the maximum static gain of IMT antenna in the horizontal plane taking into account the IMT antenna mechanical downtilt minus feeder loss).

5.3.2.2 Statistical approach

The statistical methodology aims to estimate the levels of interferences depending of variation of some parameters in the scenario, delivering interim results as described in Recommendation ITU-R M.2101.

5.3.3 Methodology to calculate aggregated interference

In a first approach, the aggregation studies are based on a deterministic calculations. In a second approach, Monte-Carlo simulations are performed over the IMT mobile network and the radar within the area of simulation to calculate the aggregated interference caused by the BSs in order to derive a reliable statistic taking into account many parameters variations (i.e. deployment characteristics, clutter variation, etc.).

In this Report, values between 90 and 99% are used for the percentile value of the I_{agg}/N CDF curve to compare with the radar protection criteria.

6 Summary of results from the technical studies

6.1 In-band coexistence and compatibility studies

6.1.1 Introduction

Studies on the coexistence of IMT and radiolocation service in the frequency band 3 300-3 400 MHz focussed on the following two high level scenarios:

– co-channel operations – firstly by single entry interference scenario, and secondly by aggregation scenario (details of these studies are provided in Annex 1).

– operations with a frequency offset between the two systems operating in the same allocated band. This scenario is similar in practice to adjacent band coexistence. The studies are provided in Annex 2.

More complex study cases, including those for IMT base stations operating on multiple channels in the 3 300-3 400 MHz band, are not analysed.

Larger IMT channel bandwidth of up to 200 MHz above 3 300 MHz also need to be considered.

6.1.2 Results of co-channel studies

6.1.2.1 Single entry studies between non-AAS IMT base stations and radars

TABLE 10

Summary of protection distances obtained from co-channel MCL single entry studies for time percentage, *p* = 20% of time

		Protection distance (km)					
Study cases		**Study A**	**Study A**	**Study B**	**Study B**	**Study C**	**Study D**
	Scenario	Tropical	Equatorial	Tropical	Equatorial	Equatorial	
BS type		Ship based radar	Ship based radar	Ship based radar	Ship based radar	Land based radar	Ship based radar
Micro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)						120-138
Micro BS (20 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	114-126	187-206	122 km	194 km	N/A	
	Radar at sea / BS at shoreline (with 18 dB clutter losses)	58-68	108-124				
	Radar at sea / BS at shoreline (with 28 dB clutter losses)	43-57	78-89				
	Radar at sea / BS at shoreline (with 38 dB clutter losses)	28-38	41-52				
	Radar standing 22 km at sea / BS in coastal zone (with 18 dB clutter losses)	N/A	N/A	39 km	68 km	N/A	
	Radar inland / BS inland (with 18 dB clutter losses)	N/A	N/A	N/A	N/A	65 km	

TABLE 10 (*end*)

		Protection distance (km)					
Study cases		**Study A**	**Study A**	**Study B**	**Study B**	**Study C**	**Study D**
Urban Macro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	N/A	N/A	268 km	364 km	N/A	247-257
	Radar standing 22 km at sea / BS in coastal zone (without clutter loss)	N/A	N/A	134 km	226 km	N/A	
	Radar inland / BS inland (without clutter loss)	N/A	N/A	N/A	N/A	230 km	
Urban Macro BS (20 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	237-250	336-353				
	Radar at sea / BS at shoreline (with 18 dB clutter losses)	136-147	218-234				
	Radar at sea / BS at shoreline (with 28 dB clutter losses)	96-106	165-181				
	Radar at sea / BS at shoreline (with 38 dB clutter losses)	67-77	130-137				
Suburban Macro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)			296-308	408-418		266-294

TABLE 11

Summary of protection distances obtained from co-channel MCL single entry studies for time percentage, *p* = 10% of time

		Protection distance (km)					
Study cases		**Study A**	**Study A**	**Study B**	**Study B**	**Study C**	**Study D**
	Scenario	Tropical	Equatorial	Tropical	Equatorial	Equatorial	
BS type		Ship based radar	Ship based radar	Ship based radar	Ship based radar	Land based radar	Ship based radar
Micro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)						225-240 km
Micro BS (20 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	213-226 km	302-318 km	224 km	310 km	N/A	
	Radar at sea / BS at shoreline (with 18 dB clutter losses)	114-124 km	181-195 km				

TABLE 11 (*end*)

		Protection distance (km)					
Study cases		Study A	Study A	Study B	Study B	Study C	Study D
	Radar at sea / BS at shoreline (with 28 dB clutter losses)	74-82 km	118-133 km				
	Radar at sea / BS at shoreline (with 38 dB clutter losses)	42-55 km	45-56 km				
	Radar standing 22 km at sea / BS in coastal zone (with 18 dB clutter losses)	N/A	N/A	52 km	106 km	N/A	
	Radar inland / BS inland (with 18 dB clutter losses)	N/A	N/A	N/A	N/A		
Urban Macro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	N/A	N/A	268 km	364 km	N/A	390-403 km
	Radar standing 22 km at sea / BS in coastal zone (without clutter loss)	N/A	N/A			N/A	
	Radar inland / BS inland (without clutter loss)	N/A	N/A	N/A	N/A		
Urban Macro BS (20 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	378-393 km	482-500 km				
	Radar at sea / BS at shoreline (with 18 dB clutter losses)	239-254 km	335-350 km				
	Radar at sea / BS at shoreline (with 28 dB clutter losses)	177-189 km	263-275 km				
	Radar at sea / BS at shoreline (with 38 dB clutter losses)	125-134 km	197-208 km				
Suburban Macro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)						409-446

Study A

Study A assumes that the mainbeam of the radar always points towards the IMT deployment. For a Micro BS located by the sea but inside the city and below rooftops, the protection distance would be in the 28-195 km range depending on the radar type and other variables. For macro urban BS located by the sea and with a 50% probability of being below rooftops, the protection distance would be 43-500 km range depending on radar type and other variables.

If clutter is not considered (i.e. the path to the radar is not obstructed by buildings), the protection distances will be considerably larger.

Study B

Study B assumes that the mainbeam of the radar always points towards the IMT deployment.

Micro cells case:

In summary it can be estimated that for ship-based Radar B/C/D/M, the co-channel protection distance between one IMT outdoor micro base-station located at the shoreline and a ship-based Radar is 122-194 km depending tropical or equatorial propagation conditions, using the propagation model with p = 20% and respectively 224-310 km for p = 10%.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, the emissions of one IMT outdoor micro base-station standing at the shoreline are received 42.0-45.5 dB over the co-channel protection threshold of the radar, depending tropical or equatorial propagation conditions over the sea using the propagation model with p = 20% and respectively 44.7-46.7 dB for p = 10%.

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, considering pathloss over sea, coastal and land zones, and considering a minimal clutter losses or mask effect of buildings of 18 dB, the protection distance from one micro BS which could interfere is 39-68 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20% and respectively 52 km-106 km for p = 10%. For a median clutter loss of 28 dB, the protection distance of a radar from one micro base station is found to be 32-49 km depending tropical or equatorial propagation conditions using the propagation model with p = 20% and respectively 38 km-76 km for p = 10%.

Without any other mitigation technique, this study shows that the installation of micro base stations operating co-frequency in coastal zones is not compatible with shipborne radars standing at 22 km from shoreline.

Macro cells case:

In summary it can be calculated that for ship-based Radar B/C, the co-channel protection distance between one IMT Urban macro BS located at the shoreline and a ship-based Radar is 246 / 268 (IMT BW 20/10 MHz) and 342 / 364 km (IMT BW 20/10 MHz) depending tropical or equatorial propagation conditions over the sea, using the propagation model with p = 20%.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, the emissions of one IMT macro base-station standing at the shoreline are received 65.5-68.5 dB over the co-channel protection margin of the radar, depending IMT channel bandwidths of 20 MHz or 10 MHz. At such low distance, this does not depend of tropical or equatorial propagation conditions.

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, and considering pathloss over sea, coastal and land zones, and no clutter losses or mask effect of buildings, the protection distance from any macro BS which could potentially interfered is 134-226 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%. In this MCL study, considering low clutter losses or mask effect of buildings of 18 dB, the co-frequency protection distance of a radar from one IMT 10 MHz macro BS is found as 66-145 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%. For a median clutter loss of 28 dB, the protection distance of a radar from one IMT 10 MHz macro base station is found to be 57-109 km depending tropical or equatorial propagation conditions using the propagation model with p = 20%.

Without any other mitigation technique, this study shows that the co-frequency operation of macro base stations in coastal zones is not compatible with shipborne radars.

Study C

Study C assumes that the mainbeam of the radar always points towards the IMT deployment.

Micro cell case:

In summary, it can be observed that the co-channel protection distance between one IMT 20 MHz outdoor micro base-station and a land based Radar, without clutter loss, is 118 km depending equatorial propagation conditions over the land using the propagation model with p = 20%.

In this MCL study, taking into account low clutter losses or mask effect of buildings of 18dB, the protection distance of a radar from one micro BS which could interfere is 65 km.

With a median clutter loss of 28 dB, the protection distance of a radar from one micro base station is found to be 45 km.

Macro cells case

In summary, it can be observed that the co-channel protection distance between one IMT 10 MHz urban macro base-station and a land based Radar, without clutter loss, is 230 km depending equatorial propagation conditions.

In this MCL study, taking into account low clutter losses or mask effect of buildings of 18 dB, the protection distance of a radar from one urban macro base station which could interfere is 150 km.

With a median clutter loss of 28 dB, the protection distance of a radar from one urban macro base station is found to be 113 km.

Study D

Coastal area scenarios are considered. Ship-based radiolocation radars B and C defined in Recommendation ITU-R M.1465 receive interference from single entry IMT-Advanced BS operating in co-channel or adjacent channel. IMT-Advanced BS is assumed to locate at shoreline in Incheon, Korea. The worst case is studied where the peak antenna gain of radar are taken, and peak gain with a loss due to antenna tilting is considered for computing the antenna gain of BS.

Interference powers at victim radars exceed the protection criteria for all cases, and they need to be further reduced by at least 98/94/74 dB for macro suburban/macro urban /micro urban without clutter loss.

For protection of radars B and C at 22 km far from shoreline, the interference power from macro suburban BS, without clutter loss, needs to be reduced by 72-77 dB. The interference power from macro urban BS, without clutter loss, needs to be reduced by 66-71 dB. The interference power from micro urban BS, without clutter loss, needs to be reduced by 48-52 dB.

6.1.2.2 Aggregation studies between non-AAS IMT base stations and radars

Study A

Study A assumes that the mainbeam of the radar always points towards the IMT deployment. For a scenario where macro cells are deployed in a coastal town overlapping the radar receiver main beam, the protection distances are between 227 and 240 km for the tropical climate region and 347-352 km for the equatorial climate region depending on the radar type considered.

A sensitivity analysis has been implemented for a representative radar (which is assumed to be radar B) deployed in the tropical region to examine the impact of varying key baseline scenario assumptions.

The sensitivity analysis results indicate that:

– The protection distance is 365 km when the IMT cell radius is 0.3 km and 227 km when the IMT cell radius is 2 km.

– The protection distance is 388 km when the percentage time is 10% and 227 km when the percentage time is 20%.

– The protection distance is 204 km when IMT BS activity factor is 20% and 245 km when IMT BS activity factor is 80%.

– The protection distance is 190 km when IMT BS transmit power is 5W (37 dBm) and 227 km when IMT BS transmit power is 20W (43 dBm).

– The protection distance is 255 km when IMT BS bandwidth is 10 MHz and 227 km when IMT BS bandwidth is 20 MHz.

– The protection distance is 347 km when the propagation is sea path in the equatorial region and 293 km when the propagation is mixed path in the equatorial region.

Study B

Study B assumes that the mainbeam of the radar always points towards the IMT deployment.

Micro cells case:

The interference study with aggregation of micro BS shows that a large number of base stations needs to be considered simultaneously. In the closest scenario of a shipborne radar standing 22 km from the shoreline, between 10 to 80 active micro BS are to be considered. The calculation of aggregated level of interference from these micro BS is complex to estimate because 100% of micro BS are considered below roof top of buildings. Considering urban deployment characteristics with density of 3 micro BS per macro cell, the results of a static analysis with Monte Carlo simulations show that the aggregated interference ratio I/N received by the radar is up to 40 dB or 44 dB depending tropical or equatorial scenario using the propagation model with $p = 20\%$, far above the radar protection criteria of −6 dB.

Macro cells case:

In a first aggregation study scenario, taking into account the aggregated power of all macro base stations simultaneously in visibility of the antenna beam of a shipborne radar at sea, and considering parameters of rooftop ratio, activity factor, and no clutter losses, either for urban or sub-urban 10 MHz deployments, the co-channel aggregated protection distances are calculated between 324 km and 422 km in tropical zone and between 446-540 km in equatorial zone, using the propagation model with $p = 20\%$.

In a second aggregation study scenario, taking into account the aggregated power of all urban macro base stations simultaneously in visibility of the antenna beam of a shipborne radar standing at 22 km from shoreline, the results of a static analysis with Monte Carlo simulation show that the aggregated interference ratio *I*/*N* received by radars is up to 79 dB or 82 dB depending on whether tropical or equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of −6 dB.

Study C

Study C assumes that the mainbeam of the radar always points towards the IMT deployment.

Microcells case:

Considering urban deployment characteristics with density of 3 micro BS per macro cell, the results of a static analysis with Monte Carlo simulation show that the aggregated interference ratio *I*/*N* received by the radars standing 20 km from a co-channel IMT deployment is up to 31 dB in land equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of −6 dB.

Macro cells case:

The results of a static analysis with Monte Carlo simulation show that the aggregated interference ratio *I*/*N* received by a land based radar standing 20 km from a co-channel IMT deployment is up to 74 dB in land equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of −6 dB.

6.1.2.3 Studies between IMT terminals and radars

According to Report ITU-R M.2292, the IMT terminal's maximum transmit power is 23 dBm. However, IMTs terminals have power control functionality and as a result the average transmit power is −9 dBm. In addition, the actual antenna gain is −4 dBi. Therefore, the IMT terminal e.i.r.p. is much lower than that of an IMT base station and as a result the separation distance required to protect radars would be much shorter than the distance required to protect from IMT base stations.

6.1.2.4 Single entry studies between AAS IMT base stations and radars

Study E

This study considers scenarios of micro urban, macro urban, indoor small cell IMT BS interfering with shipborne radar type D at four different world locations. In this Monte Carlo study, the radar antenna points to a random azimuth direction that is uniformly distributed between 0 and 360 degrees.

At 20 km separation distance, the probability of harmful interference is lower than 8% for the outdoor small cell case, and lower than 42% for the urban macro cell case. This does not change across location as the influence of the propagation model is small at such short distance.

At 50 km separation distance, the probability of harmful interference is lower than 20% or 7%, depending on the location, for urban macro cells. At 100 km separation distance, the probability of interference is below 14% in all locations for urban macro cells.

For indoor small cells, the probability of harmful interference is lower than 5% at 20 km separation distance in all locations.

6.1.2.5 Aggregation studies between AAS IMT base stations and radars

Study F

This study shows first a scenario with a coastal urban macro IMT deployment with 25 AAS BSs and ship-based Radars A-D standing 22 km from the shoreline at the edge of the territorial waters. It is assumed the radar antenna is always pointing towards the IMT deployment. Interference from IMT (with a 20 MHz bandwidth) is assessed to be 82.25-93.48 dB above the radar protection criteria of $I/N = -6$ dB, for an assumption of 99.999% CDF and depending on the radar type. The study uses temperate propagation conditions using the ITU-R P.452 propagation model with $p = 10\%$.

In addition, the second part of this study looks at the separation distances required to achieve the ITU-R M.1461 recommended radar protection criteria of $I/N = -6$ dB, using the same IMT deployment as above. Under the assumption of 99.999% of the CDF, these distances vary between 477-544 km, 354-421 km and 240-352 km depending on the radar type for ITU-R P.452 propagation model with $p = 1\%$, 10% and 20% respectively.

It has to be noted that variations between interference for 100% and 99.999% are insignificant.

6.1.3 Results of the frequency offset in-band study

The results of the frequency offset study done in Annex 2 are applicable to an IMT system and a radar system which operate in the same allocated band with a frequency offset between the transmitting and receiving bands. The summary of the technical study presented in § 6.2 is applicable to the frequency offset in-band case.

6.1.4 Radar interference to IMT system

The MCL study shows that shipborne radars transmitting in co-channel with 22 km separation distance to shoreline, their RF pulses are strongly blocking IMT receivers, with values estimated up to +57 dB over the saturation level of IMT receivers. Considering the high rate impulse feature of radar signals, the HARQ technique to mitigate the degradation of the performance of IMT system should be further evaluated.

6.2 Adjacent-band compatibility studies

6.2.1 Introduction

The study of adjacent band compatibility between IMT systems operating in the frequency band 3 300-3 400 MHz and radars systems operating in the radiolocation service below 3 300 MHz, is provided in Annex 2 of this Report with a technical analysis of systems operating with a frequency offset.

The methodology is to study firstly single entry interference scenario, and secondly aggregation scenarios.

More complex study cases are not analysed such as IMT base stations operating few or fully multichannels over 3 300-3 400 MHz band. In that case, an additional frequency channels power aggregation combined to a lower Off-tune Frequency Rejection (FDR/OFR) will lead to greater separation distances.

6.2.2 Results of adjacent channel studies

TABLE 12

Summary of protection distances obtained from adjacent channel single entry studies with a frequency gap of 10 MHz between non-AAS IMT and radar systems

		Protection distance (km) for *p* = 20% of time from adjacent channel MCL single entry studies with a frequency gap of 10 MHz					
Study cases		**Study G**	**Study G**	**Study H**	**Study H**	**Study I**	**Study J**
	Scenario	Tropical	Equatorial	Tropical	Equatorial	Equatorial	
BS type		Ship based radar	Ship based radar	Ship based radar	Ship based radar	Land based radar	Ship based radar
Micro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)						28-61
Micro BS (20 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	27-58	39-93	44	86	N/A	
	Radar at sea / BS at shoreline (with 18 dB clutter losses)	5-24	5-24				
	Radar at sea / BS at shoreline (with 28 dB clutter losses)	1-7	1-7				
	Radar at sea / BS at shoreline (with 38 dB clutter losses)	1-2	1-2				
	Radar standing 22 km at sea / BS in coastal zone (with 18 dB clutter losses)	N/A	N/A	20	24	N/A	
	Radar inland / BS inland (with 18 dB clutter losses)	N/A	N/A	N/A	N/A	27	

TABLE 12 (*end*)

		Protection distance (km) for *p* = 20% of time from adjacent channel MCL single entry studies with a frequency gap of 10 MHz					
Study cases		**Study G**	**Study G**	**Study H**	**Study H**	**Study I**	**Study J**
Urban Macro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	N/A	N/A	114	188	N/A	58-107
	Radar standing 22 km at sea / BS in coastal zone (without clutter loss)	N/A	N/A	62	110	N/A	
	Radar inland / BS inland (without clutter loss)	N/A	N/A	N/A	N/A	139	
Urban Macro BS (20 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	62-110	113-187				
	Radar at sea / BS at shoreline (with 18 dB clutter losses)	32-70	39-111				
	Radar at sea / BS at shoreline (with 28 dB clutter losses)	12-51	12-71				
	Radar at sea / BS at shoreline (with 38 dB clutter losses)	4-24	4-24				
Suburban Macro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)						71-129

TABLE 13

Summary of protection distances obtained from adjacent channel single entry studies with a frequency gap of 10 MHz between non-AAS IMT and radar systems

		Protection distance (km) for *p* = 10% of time from adjacent channel MCL single entry studies with a frequency gap of 10 MHz					
Study cases		**Study G**	**Study G**	**Study H**	**Study H**	**Study I**	**Study J**
	Scenario	Tropical	Equatorial	Tropical	Equatorial	Equatorial	
BS type		Ship based radar	Ship based radar	Ship based radar	Ship based radar	Land based radar	Ship based radar
Micro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)						41-94
Micro BS (20 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	41-87	41-141	84	138	N/A	
	Radar at sea / BS at shoreline (with 18 dB clutter losses)	5-26	5-26				
	Radar at sea / BS at shoreline (with 28 dB clutter losses)	1-8	1-8				
	Radar at sea / BS at shoreline (with 38 dB clutter losses)	1-2	1-2				
	Radar standing 22 km at sea / BS in coastal zone (with 18 dB clutter losses)	N/A	N/A	20	24	N/A	
	Radar inland / BS inland (with 18 dB clutter losses)	N/A	N/A	N/A	N/A	27	
Urban Macro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	N/A	N/A	114	188	N/A	110-198
	Radar standing 22 km at sea / BS in coastal zone (without clutter loss)	N/A	N/A	62	110	N/A	
	Radar inland / BS inland (without clutter loss)	N/A	N/A	N/A	N/A	139	

TABLE 13 (*end*)

		Protection distance (km) for *p* = 10% of time from adjacent channel MCL single entry studies with a frequency gap of 10 MHz					
Study cases		**Study G**	**Study G**	**Study H**	**Study H**	**Study I**	**Study J**
Urban Macro BS (20 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)	113-196	179-296				
	Radar at sea / BS at shoreline (with 18 dB clutter losses)	43-103	43-164				
	Radar at sea / BS at shoreline (with 28 dB clutter losses)	12-70	12-79				
	Radar at sea / BS at shoreline (with 38 dB clutter losses)	4-26	4-26				
Suburban Macro BS (10 MHz channel)	Radar at Sea / BS at shoreline (without clutter loss)						124-231

TABLE 14

Necessary unwanted emissions for BS, obtained from adjacent band aggregated study between AAS IMT and radar systems at 3 300 MHz

Necessary AAS TRP unwanted emissions below 3 300 MHz (dBm/MHz) respecting 99% likelihood that *I*/*N* < –6 dB (Assumption of AAS beamsteering toward 70% indoor UE without building penetration loss)							
Study case			**Study L**		**Study M**		**Study N**
Separation distance			3 km	10 km	1 km	3 km	3 km
IMT deployment with 5 rings of urban macro AAS BS	Land radars B and D	AAS correlated	−50.6	−47.2			
		AAS non-correlated	−44.2	−36.8			
	Land radar I	AAS correlated	−44.2	−42.9			
		AAS non-correlated	−37.8	−31.1			
IMT deployment with a sub-urban area (radius = 12 km) and urban area (radius = 5 km)	Land radar I	AAS correlated			–51.1	-49.3	
	Land radar L-D (ITU-R M.1465-3)	AAS correlated			–57.8	–55.8	
	Shipborne radar S-D (ITU-R M.1465-3)	AAS correlated			–57.4	–55.7	

TABLE 14 (*end*)

Study case			**Study L**		**Study M**		**Study N**
IMT deployment with 20 rings of urban macro AAS BS	Land radar B	AAS correlated					–58.6
		AAS non-correlated					–52.3
Necessary AAS TRP unwanted emissions below 3 300 MHz (dBm/MHz) respecting 95% likelihood that *I*/*N* < –6 dB (Assumption of AAS beam steering toward 70% indoor UE with / without building penetration loss)							
Study case			**Study L**		**Study M**		**Study N**
Separation distance			3 km	10 km	1 km	3 km	3 km
IMT deployment with 5 rings of urban macro AAS BS	Land radars B and D	AAS correlated	–35.3 / –43.8	–31.7 / –43.6			
		AAS non-correlated	–38.5 / –41.6	–33.6 / –36.2			
	Land radar I	AAS correlated	–35.6 / –37.9	–26.0 / –38.2			
		AAS non-correlated	–33.8 / –37.5	–28.3 / –30.5			

6.2.2.1 Single entry studies between non-AAS IMT base stations and radars

Study G

This study assumes that the mainbeam of the radar always points towards the IMT deployment. For a Micro BS located by the sea but inside the city and below rooftops, the protection distance would be 1-26 km depending on the radar type and other variables. For macro urban BS located by the sea and with a 50% probability of being below rooftops, the protection distance would be in the 4-296 km range depending on radar type and other variables.

If clutter is not considered (i.e. the path to the radar is not obstructed by buildings), the protection distances will be considerably higher.

Study H

This study assumes that the mainbeam of the radar always points towards the IMT deployment.

Micro cells case

In summary, between one IMT 20 MHz urban micro base-station standing at shoreline and a ship-based Radar B/C/D/M, their bandwidths separated by a frequency gap of 10 MHz, the protection distance is 44 km or 86 km depending tropical or equatorial conditions using the propagation model with p = 20% and 84-138 km for p = 10% respectively.

With a statistical approach, the cumulative distribution using the propagation model with p = 20%, and obtained with a simulation taking into account the statistical law of clutter loss, the results show that the maximum single entry interference I/N is +6 dB received on radars standing 22 km from seashore.

Considering low clutter losses or mask effect of buildings of 18 dB, considering their bandwidths separated by a frequency gap of 10 MHz, the radar protection distance from one micro base station is evaluated to 20-24 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%, and 26 km for p = 10% respectively.

Macro cells case

In summary, it can be observed that, for ship-based Radar B/C/D/M, considering no clutter loss, the protection distance between one IMT 10 MHz macro base-station located at the shoreline and a shipborne Radar is 114 km or 188 km, with 10 MHz frequency gap between −3 dB based on edges of the IMT emission mask and radar IF bandwidth, and depending of tropical or equatorial propagation conditions using the propagation model with p = 20%.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, one IMT 10 MHz macro base-station standing at the shoreline, and their bandwidths separated by a frequency gap of 10 MHz, the IMT emissions of are received 41 dB over the protection level of the radar. At such low distance, considering 20 m heights for antennas of both systems, the propagation loss does not depend significantly of tropical or equatorial propagation conditions.

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, a pathloss over sea, coastal and land zones, and their bandwidths separated by a frequency gap of 10 MHz, the protection distance of a radar from one IMT 10 MHz macro base station is 62 or 110 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20% and not taking into account any clutter loss or mask effect of buildings.

Considering low clutter losses or mask effect of buildings of 18 dB and a frequency gap of 10 MHz, the protection distance of a radar from one macro BS is found 46-68 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%. For a median clutter loss of 28 dB, the protection distance of a radar from one IMT 10 MHz macro base station, is found to be 28-48 km depending tropical or equatorial propagation conditions using the propagation model with p = 20%.

Without any other mitigation technique, this MCL study shows that the installation of macro base stations in coastal zones with a frequency gap of 10 MHz is not compatible with shipborne radars.

Considering a frequency gap of 30 MHz, leading up to 50 MHz frequency offset between central frequencies of IMT interfering channel and victim radar receiver tuned band, an additional rejection of interfering signals about 20 dB could be expected. Nevertheless, for a shipborne radar standing 22 km from the shoreline, the IMT emissions would be received with 23 dB over the protection level of the radar using the propagation model with p = 20%. Considering 18 dB low clutter losses for some BS located at shoreline, the IMT emissions would be received about 5 dB over the protection level of the radar standing 22 km at sea. The protection distance from macro BS associated to low clutter losses, is found of 32 km using the propagation model with p = 20%.

Considering the case of an IMT 10 MHz macro urban base station standing below rooftop masked with median clutter losses of 28 dB, operating with a frequency gap of 30 MHz, the IMT emissions would be received below the protection level of the radar standing at 22 km from the shoreline using the propagation model with p = 20%.

Study I

This study assumes that the mainbeam of the radar always points towards the IMT deployment.

Micro cell case

In summary, it can be observed that the protection distance between one IMT 20 MHz outdoor micro base-station and a land based Radar, operating with their bandwidths separated by a frequency gap of 10 MHz, without clutter loss, is 63 km depending equatorial propagation conditions over the land using the propagation model with p = 20%.

In this MCL study, taking into account low clutter losses or mask effect of buildings of 18 dB, the protection distance of a radar from one micro BS, operating with 10 MHz frequency gap, is 27 km. With a median clutter loss of 28 dB, the protection distance of a radar from one IMT 20 MHz micro base station, operating with 10 MHz frequency gap, is found to be lower 16 km using the propagation model with p = 20%.

Macro cell case

In summary, it can be observed that the protection distance between one IMT 10 MHz urban macro base-station and a land based Radar, their bandwidths separated by a frequency gap of 10 MHz, and without clutter loss, is 139 km depending equatorial propagation conditions over the land using the propagation model with p = 20%.

In this MCL study, taking into account low clutter losses or mask effect of buildings of 18 dB, the protection distance of a radar from one urban macro base station is 80 km. With a median clutter loss of 28 dB, the protection distance of a radar from one macro base station is found to be 56 km.

Study J (Land-based radars B/C/I)

This study assumes that the mainbeam of the radar always points towards the IMT deployment. Considering the spurious emission requirement of −30 dBm/MHz as mentioned in Report ITU-R M.2292 noting 3GPP 36.104 v.11.2.0, Table 6.6.4.1.2.1-1 the required separation distance of 31 km between one IMT-Advanced base station and a radar is not compatible to short separation distance scenarios.

As result for a single entry scenario, with a realistic separation distance of 1 km,

– the spurious level of IMT-Advanced macro base stations should be below −60 dBm/MHz to be compatible of urban, and suburban deployments;

– the spurious level of IMT-Advanced micro base stations should be below −58 dBm/MHz to be compatible of a worse case installation without clutter loss in an urban deployment.

This study shows that level of IMT spurious emission requirement of about −60 dBm/MHz could be necessary to mitigate harmful interference on land radar with a separation distance of 1 km.

More stringent requirements on spurious levels of BS should be necessary to take into account the aggregated effect of many IMT base stations.

Study K

Interference powers at victim radars locating 1 km far from shoreline exceed the protection criteria for all cases. They need to be further reduced by at least 55 dB for suburban macro and 51 dB for urban macro and 34 dB for urban micro, on the assumption of zero clutter loss.

It is required to protect radars 22 km far from shoreline for the following environment.

– Between radar B and macro urban BS with 28 dB clutter loss.

– Between radar B and micro urban BS with 18 or 28 dB clutter loss.

– Between radar C (10 MHz bandwidth) and macro urban BS with 28 dB clutter loss.

– Between radar C (10 MHz bandwidth) and micro urban BS with 18 or 28 dB clutter loss.

– Between radar C (30 MHz bandwidth) and micro urban BS with 28 dB clutter loss.

6.2.2.2 Aggregation studies between non-AAS IMT base stations and radars

Study G

This study assumes that the mainbeam of the radar always points towards the IMT deployment. For a scenario where macro cells are deployed in an area of a coastal town overlapping the radar receiver main beam, the protection distances are between ***43*** and ***61 km*** for the tropical climate region and ***94-137 km*** for the equatorial climate region depending on the radar type considered.

The sensitivity analysis has been implemented for a representative radar (which is assumed to be radar B) deployed in the tropical region to examine the impact of varying key baseline scenario assumptions.

The sensitivity analysis results indicate that:

– The protection distance is ***89 km*** when the IMT cell radius is 0.3 km and ***44 km*** when the IMT cell radius is 2 km.

– The protection distance is ***92 km*** when the percentage time is 10% and ***44 km*** when the percentage time is 20%.

– The protection distance is ***38 km*** when IMT BS activity factor is 20% and ***46 km*** when IMT BS activity factor is 80%.

– The protection distance is ***33 km*** when IMT BS transmit power is 5W (37 dBm) and ***44 km*** when IMT BS transmit power is 20W (43 dBm).

– The protection distance is ***46 km*** when IMT BS bandwidth is 10 MHz and ***44 km*** when IMT BS bandwidth is 20 MHz.

– The protection distance is ***94 km*** when the propagation is sea path in the equatorial region and ***69 km*** when the propagation is mixed path in the equatorial region.

– The protection distance is ***162 km*** when there is no guard band and ***10 km*** when there is 40 MHz guard band.

Study H

This study assumes that the mainbeam of the radar always points towards the IMT deployment.

Micro cell case

The interference study with aggregation of micro BS shows that a large number of base station needs to be considered. In the closest scenario of a shipborne radar standing 22 km from the shoreline, between 10 to 80 active micro BS are still to be considered.

Considering urban deployment characteristics with density of 3 micro BS per macro cell, the results of a static analysis with Monte Carlo simulation show that the aggregated interference ratio I/N received by the radar operating at 22 km in adjacent band with a frequency gap of 10 MHz, is up to +12 dB and +17 dB depending tropical and equatorial propagation conditions using the propagation model with p = 20% respectively, which is above the radar protection criteria of −6 dB.

Macro cells case

A forth scenario, considering urban deployment characteristics with density of 3 micro BS per macro cell, the results of a static analysis with Monte Carlo simulations show that the aggregated interference ratio I/N received by radars operating in adjacent band with a frequency gap of 10 MHz, is between +19 dB / +50 dB and between +22 dB/+52 dB depending tropical or equatorial propagation conditions using the propagation model with p = 20% respectively, which is above the radar protection criteria of –6 dB

Study I

This study assumes that the mainbeam of the radar always points towards the IMT deployment.

Micro cell case:

Considering urban deployment characteristics with density of 3 micro BS per macro cell, the results of a static analysis with Monte Carlo simulation show that the aggregated interference ratio *I*/*N* received by radars operating at 22 km in adjacent band with a frequency gap of 10 MHz, is in range of –20 dB to +2 dB in equatorial propagation conditions using the propagation model with p = 20%, which is for some radar cases above the radar protection criteria of −6 dB. With a separation distance of about 55 km, and similar other simulation parameters, it is found that all the simulated radar types are not victims of harmful interference.

Study L

This study examines the impact of an IMT network of macro urban BS with and without Advanced Antenna System into land based radars type B, D and I operating in an adjacent channel. The study shows the out of block emissions levels required at the BSs in order to achieve a probability of not exceeding the *I*/*N* threshold at the radar receiver for separation distances between the IMT network and the radar of 3 km and 10 km. In this study the radar antenna points to a random azimuth direction at each Monte Carlo trial. The direction is uniformly distributed between 0 and 360 degrees. The radar is located at the centre of five rings of IMT cells. The smallest ring has a radius of 3 km or more depending the scenario.

For AAS systems at a separation distance of 3 km, the required OOB limits to ensure a 90% probability that the interference is below the protection threshold vary between −31.7 and −39.5 dBm/MHz TRP depending on the scenario.

For AAS systems at a separation distance of 10 km, the required OOB limits to ensure a 90% probability that the interference is below the protection threshold vary between −26.1 and −38.3 dBm/MHz TRP depending on the scenario.

For non AAS systems at a separation distance of 3 km, the required OOB limits to ensure a 90% probability that the interference is below the protection threshold vary between −30.3 and −42.0 dBm/MHz TRP depending on the scenario.

For non AAS systems at a separation distance of 10 km, the required OOB limits, to ensure a 90% probability that the interference is below the protection threshold, vary between −26.8 and −37.4 dBm/MHz TRP, depending on the scenario.

Study M

This study assumes that the mainbeam of the radar always points towards the IMT deployment. Considering an IMT system deployment in a town (urban radius 5 km and suburban radius 12 km), with AAS antennas, in the frequency band 3 300-3 400 MHz, and (land & shipborne) radar systems operating below 3 300 MHz in the vicinity of this town, the study shows that AAS base stations unwanted emissions at and below 3 300 MHz should be lower than:

−51 to −58 dBm/MHz for a separation distance of 1 km,

−49 to −56 dBm/MHz for a distance separation of 3 km,

depending on radar systems and different assumptions (AAS antenna characteristics, propagation, clutter, radar protection criteria *I*/*N* = −6 dB…, etc…).

Study N

This study shows that permitted unwanted emissions are in range TRP −58.6 / −52.3 dBm/MHz for an IMT deployment of 20 rings of urban AAS macro based stations, respectively correlated (ρ = 1) or uncorrelated (ρ = 0), at 3 km from a radar B. In this study the radar antenna points to a random azimuth direction at each Monte Carlo trial. The direction is uniformly distributed between 0 and 360 degrees. The radar is located at the centre of several rings of IMT cells. The smallest ring has a radius of 3 km or more depending the scenario.

6.2.2.3 Studies between IMT terminals and radars

For TDD systems operating in the frequency band 3 300-3 400 MHz, IMT terminals would have the same frequency offset as base stations regarding radar systems.

According to Report ITU-R M.2292, the IMT terminal’s maximum transmit power is 23 dBm. However IMTs terminals have power control functionality and as a result the average transmit power is −9 dBm. In addition, the actual antenna gain is −4 dBi because of the body loss. Therefore, the IMT terminal e.i.r.p. is much lower than IMT base station and as a result the separation distance required to protect radars would be much shorter than the distance required to protect from IMT base stations.

6.2.3 Radar interference to IMT system

The results of the MCL study, with shipborne radars standing 22 km to shoreline and transmitting in adjacent bands with a large frequency gap, their RF pulses strongly interfere (up to −46 dBm), without blocking the IMT receivers. Considering the impulse feature of radar signals, the HARQ technique to mitigate the degradation of the performance of IMT system should be further evaluated.

7 Analysis of the results

As requested by Resolution **223 (Rev.WRC-15)**, this Report contains technical studies and operational measures to enable coexistence of International Mobile Telecommunication (IMT) and radiolocation service in the frequency band 3 300-3 400 MHz, and compatibility studies in adjacent band between IMT systems operating in the frequency band 3 300-3 400 MHz and radiolocation systems operating below 3 300 MHz. Both non-AAS and AAS IMT BSs are considered.

7.1 Analysis of the results of studies for non-AAS IMT Systems

This Report provides compatibility studies between IMT-Advanced systems and shipborne or land based radar systems on recommended parameters.

Single entry studies using the MCL methodology have shown estimations of protection distances between the two systems. Moreover, a static aggregation study was also performed on generic deployments of IMT-Advanced base stations. Both were provided with macro BS and outdoor micro BS, on urban or suburban scenarios. This study shows the large variability of propagation losses depending the IMT deployment considered in tropical or equatorial zones.

– for aggregation studies, further statistical analysis needs be done with more realistic parameters of future IMT-Advanced deployment in the 3 300-3 400 band;
– the distribution of the BS antenna pointing direction, i.e. tilt is assumed to be uniform; however it is recognized that further analysis on the statistical orientation of the BS beam has to be performed;

– the regular distribution of the macro cells in the generic deployments considered, however it is recognized that further analysis on the statistical distribution of base stations fitting future deployments.

Taking into account the results obtained, this report shows that the adjacent band coexistence between shipborne or land-based radars systems and IMT-Advanced non-AAS micro BS deployment would be possible with separation distances of few or tens of kilometres, in coastal or land border zones, by operating micro base stations with sufficiently clutter losses below rooftop, with a frequency offset ensuring a frequency gap of 10 MHz, and with other suitable mitigation techniques such as specifying a spurious level of IMT-Advanced non-AAS base stations below −60 dBm/MHz and transmitted power reduction in these areas. The studies done with deployments of macro base stations have demonstrated that coexistence in adjacent band with a frequency gap of 10MHz requires protection distances of 4 to 296 of kilometres depending on the scenarios and in the absence of mitigation techniques.

Interference to radar systems operating in adjacent channel can be maintained below the agreed *I*/*N* threshold if BS out of band emissions are below certain levels. These levels are in the range of −26.8 to −45.3 dBm/MHz TRP depending on the required likelihood of not exceeding the threshold, on the separation distance (3 km or 10 km) and on other parameters. With these conditions coexistence is possible. There is a trade of between the level of filtering of unwanted emissions at the BS and the size of the exclusion area around the radar system.

In the co-channel scenario, one study shows that additional reduction of 46 to 100 dB in interference power is necessary for macro base station to satisfy the interference protection criterion. Considering the e.i.r.p. of IMT-Advanced micro base station, 29 dBm/10 MHz, and median clutter loss of 28 dB, it is difficult to achieve the coexistence by the limitation of the e.i.r.p. Therefore, additional mitigation techniques are required for in band coexistence.

During transmitting mode of a shipborne radar standing 22 km from an IMT-Advanced deployment, with sufficient frequency offset for IMT Rx operating in radar’s spurious domain, the RF pulses may interfere IMT base stations.

7.2 Analysis of the results of studies for AAS IMT Systems

Co-channel scenarios

One study considers scenarios of micro urban, macro urban, indoor small cell IMT BS interfering with shipborne radar type D at four different world locations. This is a single entry Monte Carlo study where the radar antenna points to a random azimuth direction that is uniformaly distributed between 0 and 360 degrees. At 20 km separation distance and for the outdoor small cell deployment, the probability of exceeding the interference criteria is lower than 8%., and the probability of exceeding the interference criteria is lower than 42% for the urban macro cell case.

At 50 km separation distance, the probability of harmful interference is lower than 1%-5% for the outdoor small cell case, and the probability of harmful interference is lower than 7%-20%, depending on the location, for urban macro cells.

At 100 km separation distance, the probability of harmful interference is lower than 3% for the outdoor small cell case the probability of interference is below 2%-14% in all locations for urban macro cells. For indoor small cells, the probability of harmful interference is lower than 5% at 20 km separation distance in all locations.

Another study analyses co-channel aggregation-based interference into the radar. In this study, the first scenario is a coastal urban macro IMT deployment with 25 AAS BSs and ship-based Radars A-D standing 22 km from the shoreline at the edge of the territorial waters. Interference from IMT (with a 20 MHz bandwidth) is assessed to be 82.25-93.48 dB above the radar protection criteria of *I*/*N* = −6 dB, for an assumption of 99.999% CDF and depending on the radar type.

In addition, the second part of this study looks at the separation distances using the same IMT deployment as above. Under the assumption of 99.999% of the CDF, these distances vary between 477-544 km, 354-421 km and 240-352 km depending on the radar type for ITU-R P.452 propagation model with p = 1%, 10% and 20% respectively.

Adjacent scenarios

Studies in this Report show that coexistence between IMT systems and radar systems in adjacent bands is possible provided that IMT BS comply with certain Out of Block emissions levels.

One study shows that depending on the scenarios and assumptions considered, the OOB requirements would vary within the −23 to −50 dBm/MHz TRP range. For example, for a separation distance between radar and IMT of 3 km, 95% probability of below threshold interference, non-correlated OOB emissions and radar type I, the OOB requirement is −33.8 dBm/MHz TRP for AAS IMT systems. If the separation distance is extended to 10 km (same probability of interference and radar type), then the OOB requirement is −28.3 dBm/MHz TRP for AAS BSs.

A second study demonstrated that an unwanted emission limit has to be established for IMT systems using AAS in order to ensure the protection of radars operating below 3 300 MHz. A value of −57 dBm/MHz TRP unwanted emission level at 3 300 MHz appears to be appropriate when radars operates in the vicinity of the IMT deployment distance down to 1 km.

A third study shows that permitted unwanted emissions are in range TRP −58.6 /−52.3 dBm/MHz for an IMT deployment of 20 rings of urban AAS macro based stations, respectively correlated (ρ = 1) or uncorrelated (ρ = 0), at 3 km from a radar B.

It has to be noted that AAS systems cannot be fitted with additional external filters, unlike non-AAS BSs. The implementation of internal filters for AAS BSs would depend on the operator's spectrum specific assignment, the filter (and the AAS base stations) would become operator-specific which would not be sustainable in terms of effort. Assuming it would be economically feasible to implement the required additional filters, in addition, a frequency separation is likely to be required and studies should be conducted to confirm the need for such separation and to determine the width of such a frequency separation.

8 Technical and operational measures to ensure coexistence

The results of the in-band and adjacent band compatibility studies, presented in § 6, give generic values of separation distances obtained with models from ITU-R recommendations for coexistence of future IMT deployment in the band 3 300-3 400 MHz. The studies presented in this Report show clearly that mitigation techniques and measures are necessary for the coexistence of future deployment of IMT systems with incumbent radar systems in these bands.

Administrations preparing future deployment of IMT systems in the band 3 300-3 400 MHz would have to consider mitigation techniques and measures.

8.1 Technical measures

Some technical measures, or combination of them, that could be considered to ensure coexistence and compatibility between the two systems in coastal and in land borders areas, are for example:

– consider power reduction for IMT base stations;
– adjustment of radiating patterns of base stations’ transmitting antennas to reduce the e.i.r.p. in the direction of all possible radar sites;
– consider possible frequency separation between IMT and radar systems,

– defining specific masks of out-band and spurious emissions of base stations, which could be achieved by using specific RF filters in BS transmitters (additional filters can be external for non-AAS and are internal for AAS)[1]. In order to reach the required unwanted emission limits below 3 300 MHz, a frequency separation may be needed in order to implement the necessary filter at IMT BS transmitter side;
– defining specific characteristics of IMT deployment in this band (i.e. BS density, cell radius);
– performing specific compatibility study for each IMT deployment project, taking into account its propagation characteristics i.e. clutter losses, antenna heights, terrain relief and masking from buildings for specifying the most appropriate network topology of base stations.

It has to be noted that AAS systems cannot be fitted with additional external filters, unlike non-AAS BSs. The implementation of internal filters for AAS BSs would depend on the operator's spectrum specific assignment, the filter (and the AAS base stations) would become operator-specific which would not be sustainable in terms of effort. Assuming it would be economically feasible to implement the required additional filters, in addition, a frequency separation is likely to be required and studies should be conducted to confirm the need for such separation and to determine the width of such a frequency separation.

8.2 Operational measures

Some operational measures for IMT deployment in 3 300-3 400 MHz band, or combination of them that could be studied to ensure coexistence and compatibility with radar systems are for example:
– Restriction zones: the administration may define a zone around a specific radar location where a restriction to IMT deployment applies. The restriction could take the form of exclusion zone, where no IMT BS can be deployed. However, a more efficient alternative could be to impose operational restrictions in IMT deployment that ensure that the IMT does not cause harmful interference. Examples of such restrictions could be some of the technical measures mentioned above, such as power reduction or an adjustment in the radiation pattern of the BS. Other examples of restrictions are indoor deployment only or reduced antenna height.
– Power flux density limits: For instance cross border protection, a limitation expressed as a power flux density limit at the boundary between countries would in practice result in an exclusion or restriction zone along the boundary.
– If the radar operates near the IMT system only for a limited period of time, it may be possible to put in place a coexistence regime where IMT is required to turn off, or to operate with restrictions such as lower power, when radar is active nearby, e.g. to use a network of sensors to detect the presence of the radars and to relay this information to the IMT networks.

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[1] CEPT has studied the adjacent band co-existence between IMT systems with non-AAS and AAS and land radiolocation systems, the proposed interference mitigation solution for ensuring the adjacent band co-existence between IMT and radiolocation radars is the unwanted emission limit in the radiolocation radar band. The study results for IMT system with non-AAS can be found in ECC Report 203 and CEPT Report 49, and for IMT system with AAS they can be found in ECC Report 281 and CEPT Report 67. It has to be noted that types of radar operating below 3 300 MHz can be different from those operating up to 3 400 MHz and this could lead to different results.

8.3 Analysis of the technical and operational measures

Each of the regulatory measures above suits certain coexistence scenarios better than others. The Table below presents a high level assessment of this.

Approach	Best suited to a scenario wherein	Disadvantages
Frequency separation	Radiolocation and IMT operate (and are tuned) in adjacent channels, locations of radars are not known (or mobile), significant number of radar deployments	• Ineffective for co-channel operation, • in the case where a guard band is defined, spectrum in such a guard band may remain unused
Out of band Emission limits	Suited to the same scenarios as above, in addition an emissions mask gives licensees flexibility to trade between filters, frequency separation from the band edge and lower power	• Ineffective for the co-channel case, • Filters can be expensive, • Necessity to define a harmonised limit for OOBE to support a sustainable economic development of AAS BSs
Exclusion or restriction zones	Radars are at known locations and not too numerous	Not applicable if the locations of the victims are not known. If the locations are known but with great uncertainty (for instance a cross border case), then the zones are likely to be large
Indoor restrictions	Radar locations are not known, and low power + penetration losses are helpful to avoid interference	Considerably reduces the performance and coverage of the IMT network
Exchange of information between radar and IMT operators	Radars operate on temporary basis, and the radar operator is capable of (and willing to) inform IMT operators of radar activation and where it is located	• Not applicable for radars with continuous operation (to be addressed via exclusion zones) • The radar operator may not want or be allowed to communicate sensitive information to the mobile operator
Sensor networks	Coordination between the radar operator and the IMT operators cannot be achieved	• Deploying and running a sensor network will be onerous if the area to cover is large • Some mechanisms have not demonstrated effectiveness for all types of radars
Site measures (such as antenna height, azimuth, radiation pattern restrictions)	Useful mitigation at most outdoor cases	May not to be sufficient on their own in many scenarios

Annex 1

Analysis of co-channel interference between IMT-Advanced systems operating in the 3 300-3 400 MHz band and radar systems operating in the same band

This Annex provides compatibility studies between IMT-Advanced systems and radar systems in the frequency band 3 300-3 400 MHz operating in co-frequency. This document presents separation distance results for the following scenarios:

– Interference from urban outdoor IMT micro base stations to ship-based or land-based radar;
– Interference from urban outdoor IMT macro base stations to ship-based or land-based radar;
– Interference from suburban outdoor IMT macro base stations to ship-based or land-based radar;
– Interference from urban outdoor IMT micro base stations to land-based radar;
– Interference from urban outdoor IMT macro base stations to land-based radar;

considering many cases:

– 10 MHz and 20 MHz IMT base stations;
– Single entry studies of interference from one IMT base station to one ship-based radar;
– Aggregation studies of interference from IMT base stations deployment to a ship-based radar;
– Propagation path fully over sea for scenario between a shipborne radar at sea distance from base stations standing at the shoreline;
– Mixed Propagation path over sea, coastal and inland zones depending of scenarios with ship standing at the limit of territorial sea (22 km) and base stations inside coastal or inland zones;
– Propagation path fully inland for scenario between a land-based radar and base stations;
– Propagations losses in tropical regions and those in equatorial regions.

The scenario of interference from IMT base stations operating multichannels over 3 300-3 400 MHz band (i.e. TDD mode with a bandwidth of 100 MHz) has not been considered. An additional frequency channels aggregation factor would need to be taken into account in this case, leading to greater separation distances, but the methodological approach would be the same.

In addition, the Annex presents an assessment of the likelihood of interference from IMT terminals into radar systems, and from radar systems into IMT systems.

Study A

This section provides a study of compatibility between IMT and radar systems in the frequency band 3 300-3 400 MHz. The following scenarios have been considered:

– Micro urban IMT BS interfering with shipborne radars;

– Macro urban IMT BS interfering with shipborne radars.

The impact of single entry and aggregate interference has been examined. In the analysis of single entry interference, under each scenario, the implications of path loss percentage time and clutter loss have been also investigated. In the case of aggregate interference analysis, a baseline analysis has been implemented for a set of assumptions. The implications of variations in assumed parameter values have been investigated as part of the sensitivity analysis.

1 Technical characteristics of IMT and radar systems

1.1 IMT system parameters

Section 3.1 in the main body contains the list of parameters for IMT deployment. Main IMT BS modelling parameters are shown below for completeness.

TABLE A1.1

IMT BS Main Modelling Parameters

Parameters	Assumed Value
Max Transmit Power	46 dBm / 20 MHz (Macro Urban) 24 dBm / 20 MHz (Micro Urban)
Max Antenna Gain	18 dBi (Macro Urban) 5 dBi (Micro Urban)
Antenna Height (a.g.l.)	20 m (Macro Urban) 6 m (Micro Urban)

1.2 Shipborne radar parameters

Recommendation ITU-R M.1465 provides the characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 3 100-3 700 MHz.

Section 3.2 in the main body provides the key radar parameters to be used for these studies.

The key shipborne radar modelling parameters are summarised below for completeness.

TABLE A1.2

Shipborne Radar Modelling Parameters

Parameters	Assumed Value
Maximum antenna gain	42 dBi (Radar B) 40 dBi (Radar C, D and M)
Antenna height (a.g.l.)	20 m (Radar B, C and D), 50 m (Radar M)
IF bandwidth	10 MHz (Radar B) 10-30 MHz (Radar C and M) 2-20 MHz (Radar D)
Noise figure	5 dB (Radar B) 1.5 dB (C, D and M))
Interference criterion	$I/N = -6$ dB

2 Propagation model and related parameters

The propagation model used to calculate the co-channel and adjacent band co-existence requirements is Recommendation ITU-R P.452-16.

The simple model described in § 3.2 of Recommendation ITU-R P.2108 has been incorporated into the modelling to consider the impact of clutter losses.

The implications of Equatorial and Tropical climatic zones have been taken into consideration.

3 Analysis approach

This section provides description of single entry and aggregate interference analysis methods adopted in this study.

3.1 Single Entry Interference Analysis Approach

The minimum required path loss to satisfy the interference criterion at the radar receiver is calculated for each scenario. The calculated path loss is then translated into separation distance using interference path propagation mechanisms described in Recommendation ITU-R.452-16.

Interference scenarios consider the implications of following deployment scenarios.

– Macro IMT BSs deployed in urban environment and micro IMT BSs deployed in urban environment;
– Four shipborne radar types assumed to be using various channel bandwidths;
– No clutter scenario, and scenarios with clutter losses based on Recommendation ITU-R P.2108-0 model; and
– Tropical and equatorial climate zones.

3.2 Aggregate Interference Analysis Approach

The following approach has been adopted to model the impact of interference aggregation from a population of IMT BSs deployed in a hypothetical town and assumed to be operating within the shipborne radar antenna main beam. The study considers that:

– From the radar receiver point of view, interference from a population of IMT BSs located at a distance in a hypothetical town within the main beam of the radar is assumed to be a point interference source.
– Antenna gain and path loss variations from individual IMT BSs that are modelled as an effective point interference source are assumed to be insignificant for the radar receiver located at the sea away from a hypothetical town where IMT BSs are deployed. Interference from sectors pointing towards the sea will dominate the aggregate interference.
– For an assumed distance between the radar and effective interference source, e.g. a territorial sea limit of 22 km, aggregate interference is calculated by taking account of clutter loss and aggregate IMT BS power towards the radar receiver.
– In order to obtain generic results without land effects, path losses are assumed to be associated with sea path propagation defined in Recommendation ITU-R P.452.
– The aggregate power towards the radar receiver is determined using the assumed density and activity factor of IMT BS transmitters.
– Aggregate interference is compared against the radar interference criterion and the analysis is repeated by varying the distance until the criterion is satisfied.

4 Co-channel single entry interference analysis results

4.1 Micro urban

4.1.1 Baseline analysis

Single entry interference analysis results for the micro urban IMT BS transmitter are shown in Table A1.3.

TABLE A1.3

Single entry interference from micro urban IMT BS

Parameter	Radar B	Radar C	Radar D	Radar M
Carrier frequency (MHz)	3 300			
IMT BS transmitter bandwidth (MHz)	20			
IMT BS transmitter power (dBm)	24			
IMT BS transmitter max antenna gain (dBi)	5			
Radar receiver antenna gain (dBi)	42	40	40	40
Radar receiver bandwidth (MHz)	10	10-30	2-20	10-30
Radar receiver noise figure (dB)	5	1.5	1.5	1.5
Radar receiver interference criterion (dBm) (1)	–105	(–108.5) – (–103.7)	(–115.5) – (–105.5)	(–108.5) – (–103.7)
OTR (dB)	3	3-0	10-0	3-0
Required Path Loss (dB) (2)	173	174.5-172.7	174.5	174.5-172.7
Protection distance (km) (no clutter loss) (Path loss not exceeded for 10% of time)	304 (Equatorial) 216 (Tropical)	315-302 (Eq.) 226-214 (Tr.)	315 (Equatorial) 226 (Tropical)	318-304 (Eq.) 225-213 (Tr.)

TABLE A1.3 (*end*)

Parameter	Radar B	Radar C	Radar D	Radar M
Protection distance (km) (no clutter loss) (Path loss not exceeded for 20% of time)	189 (Equatorial) 116 (Tropical)	197-187 (Eq.) 122-114 (Tr.)	197 (Equatorial) 122 (Tropical)	206-196 (Eq.) 126-119 (Tr.)

(1) kTBNF – 6 dB.

(2) Required Path Loss (dB) = IMT BS EIRP (dBm) + Radar Antenna Gain (dBi) – OTR (dB) – Radar Interference Criterion (dBm).

4.1.2 Analysis with clutter loss

Initially, the impact of clutter losses has been analysed by using 18, 28 and 38 dB loss values corresponding to clutter losses not exceeded for 5, 50 and 95% of IMT BS locations according to Recommendation ITU-R P.2108. Note that the propagation loss is still assumed to be sea path.

TABLE A1.4

Implications of clutter losses (micro urban)

Parameter	Radar B	Radar C	Radar D	Radar M
Required path loss from Baseline Analysis (dB)	173	174.5-172.7	174.5	174.5-172.7
	Path loss not exceeded for 10% of time			
Protection distance (km) (no clutter loss)	304 (Equatorial) 216 (Tropical)	315-302 (Eq.) 226-214 (Tr.)	315 (Equatorial) 226 (Tropical)	318-304 (Eq.) 225-213 (Tr.)
Protection distance (km) (18 dB clutter loss)	183 (Equatorial) 115 (Tropical)	192-181 (Eq.) 122-114 (Tr.)	192 (Equatorial) 122 (Tropical)	195-184 (Eq.) 124-115 (Tr.)
Protection distance (km) (28 dB clutter loss)	121 (Equatorial) 75 (Tropical)	131-118 (Eq.) 81-74 (Tr.)	131 (Equatorial) 81 (Tropical)	133-120 (Eq.) 82-76 (Tr.)
Protection distance (km) (38 dB clutter loss)	45 (Equatorial) 43 (Tropical)	55-54 (Eq.) 47-42 (Tr.)	55 (Equatorial) 47 (Tropical)	56-46 (Eq.) 55-46 (Tr.)
	Path loss not exceeded for 20% of time			
Protection distance (km) (no clutter loss)	189 (Equatorial) 116 (Tropical)	197-187 (Eq.) 122-114 (Tr.)	197 (Equatorial) 122 (Tropical)	206-196 (Eq.) 126-119 (Tr.)
Protection distance (km) (18 dB clutter loss)	109 (Equatorial) 59 (Tropical)	115-108 (Eq.) 62-58 (Tr.)	115 (Equatorial) 62 (Tropical)	124-117 (Eq.) 68-64 (Tr.)
Protection distance (km) (28 dB clutter loss)	78 (Equatorial) 43 (Tropical)	82-87 (Eq.) 45-43 (Tr.)	82 (Equatorial) 45 (Tropical)	89-84 (Eq.) 57-55 (Tr.)
Protection distance (km) (38 dB clutter loss)	42 (Equatorial) 29 (Tropical)	48-41 (Eq.) 32-28 (Tr.)	48 (Equatorial) 32 (Tropical)	52-42 (Eq.) 38-34 (Tr.)

As a next step, a scenario where a radar receiver is at 22 km[2] from the shore has been investigated. Table A1.5 shows path loss and interference values (with no clutter loss) for each radar.

2 Territorial sea limit.

TABLE A1.5

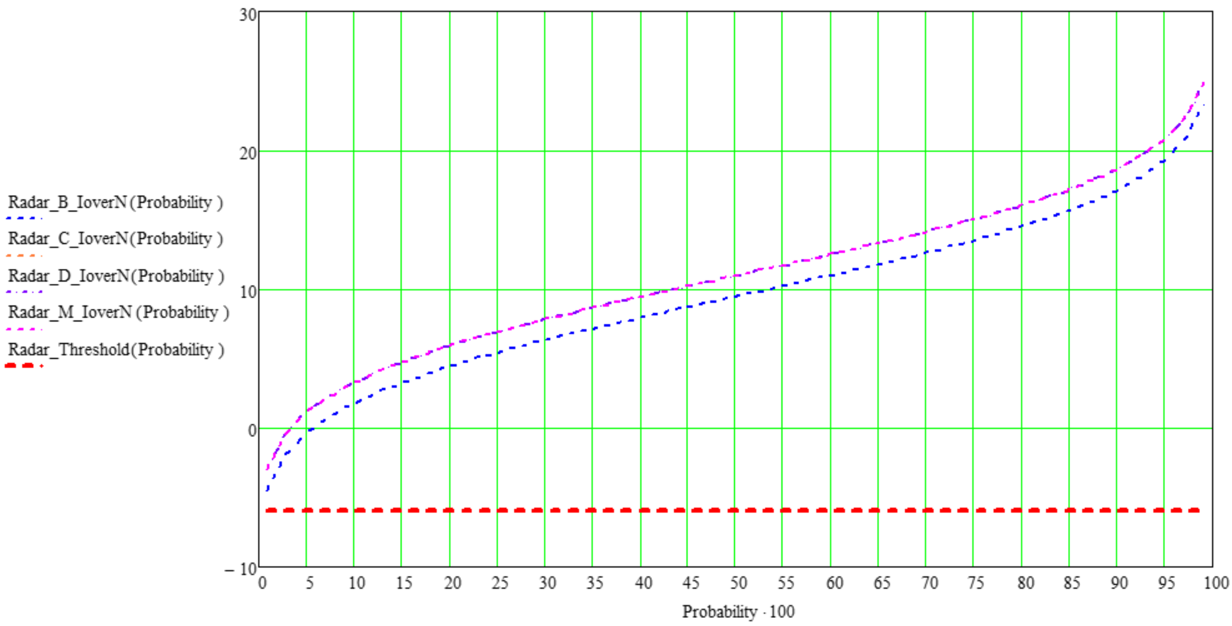
Radar receiver at 22 km from the shore (micro urban)

Parameter	Radar B	Radar C	Radar D	Radar M
Path Loss (dB)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 131 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 131 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 131 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)
Representative interference (dBm in radar bandwidth) (no clutter loss)	−61 (20%, Eq., 10 MHz radar bandwidth)	−63 (20%, Eq., 10 MHz radar bandwidth)	−60 (20%, Eq., 20 MHz radar bandwidth)	−63 (20%, Eq., 10 MHz radar bandwidth)
Radar receiver interference criterion (dBm)	−105	−108.5	−105.5	−108.5

The impact of clutter losses has been examined using Recommendation ITU-R P.2108. Figure A1-1 shows the probability of *I*/*N* being a less than a y-axis value. For example, for radar B, the probability of *I*/*N* being less than 23 dB is 99% while the probability of *I*/*N* being less than −5 dB is 1%. It should be noted that where the probability is high (i.e. the right end of the curves) the clutter loss is small and where the probability is low (i.e. the left end of the curves) the clutter loss is high. The results are also compared against the radar threshold of −6 dB.

FIGURE A1-1

***I*/*N* probability at 22 km from the Shore (with clutter losses, micro urban, 20%, Eq.)**



Note that probabilities corresponding to Radar C, D and M are at the same level for a given *I*/*N* hence appear to be a single line.

4.2 Macro urban

4.2.1 Baseline analysis

Single entry interference analysis results for the macro urban IMT BS transmitter are presented in Table A1.6.

TABLE A1.6

Single Entry Interference from Macro Urban IMT BS

Parameter	Radar B	Radar C	Radar D	Radar M
Carrier frequency (MHz)	3 300			
IMT BS transmitter bandwidth (MHz)	20			
IMT BS transmitter power (dBm) (including feeder losses)	43			
IMT BS transmitter antenna gain (dBi) (10 degrees downtilted Rec. 1336 antenna)	6			
Radar receiver antenna gain (dBi)	42	40	40	40
Radar receiver bandwidth (MHz)	10	10-30	2-20	10-30
Radar receiver noise figure (dB)	5	1.5	1.5	1.5
Radar receiver interference criterion (dBm)	–105	(–108.5) – (–103.7)	(–115.5) – (–105.5)	(–108.5) – (–103.7)
OTR (dB)	3	3-0	10-0	3-0
Required path loss (dB)	193	194.5-192.7	194.5	194.5-192.7
Protection distance (km) (no clutter loss) (Path loss not exceeded for 10% of time)	483 (Equatorial) 380 (Tropical)	500-484 (Eq.) 393-378 (Tr.)	500 (Eq.) 393 (Tr.)	498-482 (Eq.) 387-372 (Tr.)
Protection distance (km) (no clutter loss) (Path loss not exceeded for 20% of time)	338 (Equatorial) 240 (Tropical)	349-336 (Eq.) 250-238 (Tr.)	349 (Eq.) 250 (Tr.)	353-340 (Eq.) 248-237 (Tr.)

4.2.2 Analysis with Clutter Loss

The impact of clutter losses is analysed in Table A1.7.

TABLE A1.7

Implications of Clutter Losses (Macro Urban)

Parameter	Radar B	Radar C	Radar D	Radar M
Required path loss from baseline analysis (dB)	193	194.5-192.7	194.5	194.5-192.7
	Path loss not exceeded for 10% of time			
Protection distance (km) (no clutter loss)	483 (Equatorial) 380 (Tropical)	500-484 (Eq.) 393-378 (Tr.)	500 (Equatorial) 393 (Tropical)	498-482 (Eq.) 387-372 (Tr.)
Protection distance (km) (18 dB clutter loss)	338 (Equatorial) 243 (Tropical)	350-336 (Eq.) 254-241 (Tr.)	350 (Equatorial) 254 (Tropical)	349-335 (Eq.) 251-239 (Tr.)
Protection distance (km) (28 dB clutter loss)	265 (Equatorial) 180 (Tropical)	275-263 (Eq.) 189-178 (Tr.)	275 (Equatorial) 189 (Tropical)	275-263 (Eq.) 187-177 (Tr.)
Protection distance (km) (38 dB clutter loss)	199 (Equatorial) 127 (Tropical)	208-197 (Eq.) 134-125 (Tr.)	208 (Equatorial) 134 (Tropical)	208-197 (Eq.) 134-125 (Tr.)
	Path loss not exceeded for 20% of time			
Protection distance (km) (no clutter loss)	338 (Equatorial) 240 (Tropical)	349-336 (Eq.) 250-238 (Tr.)	349 (Equatorial) 250 (Tropical)	353-340 (Eq.) 248-237 (Tr.)
Protection distance (km) (18 dB clutter loss)	219 (Equatorial) 138 (Tropical)	228-218 (Eq.) 145-136 (Tr.)	228 (Equatorial) 145 (Tropical)	234-224 (Eq.) 147-139 (Tr.)
Protection distance (km) (28 dB clutter loss)	167 (Equatorial) 97 (Tropical)	174-165 (Eq.) 103-96 (Tr.)	174 (Equatorial) 103 (Tropical)	181-172 (Eq.) 106-100 (Tr.)
Protection distance (km) (38 dB clutter loss)	124 (Equatorial) 68 (Tropical)	137-130 (Eq.) 72-67 (Tr.)	130 (Equatorial) 72 (Tropical)	137-130 (Eq.) 77-74 (Tr.)

For a radar receiver at 22 km from the shore, it can be shown that the path loss and interference values (with no clutter loss) for each radar are as follows.

TABLE A1.8

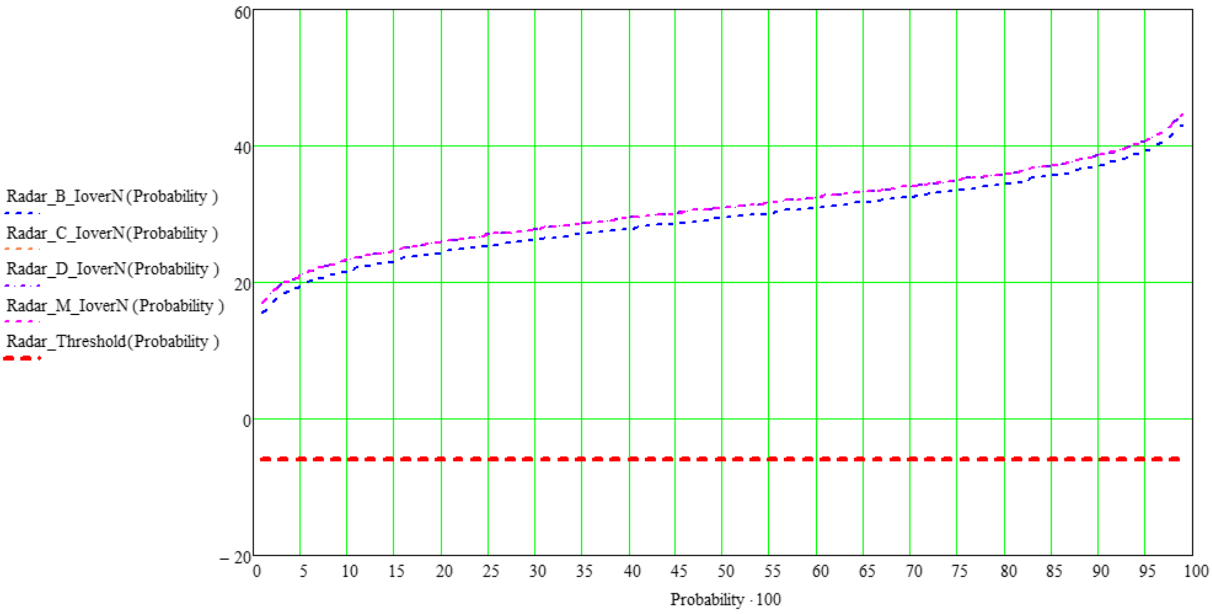
Radar Receiver at 22 km from the Shore (Macro Urban)

Parameter	Radar B	Radar C	Radar D	Radar M
Path loss (dB)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)
Representative interference (dBm in radar bandwidth) (no clutter loss)	−41 (20%, Eq., 10 MHz radar bandwidth)	−43 (20%, Eq., 10 MHz radar bandwidth)	−40 (20%, Eq., 20 MHz radar bandwidth)	−43 (20%, Eq., 10 MHz radar bandwidth)
Radar receiver interference criterion (dBm)	−105	−108.5	−105.5	−108.5

Figure A1-2 shows the *I*/*N* probability when clutter losses are considered. The results are also compared against the radar *I*/*N* threshold.

FIGURE A1-2

***I*/*N* probability at 22 km from the Shore (with clutter losses, macro urban, 20%, Eq.)**



Note that probabilities corresponding to Radar C, D and M are at the same level for a given *I*/*N* hence appear to be a single line.

5 Co-channel aggregate interference analysis results

Baseline analysis has been implemented for a set of assumptions. The implications of variations in assumed parameter values have been investigated as part of the sensitivity analysis.

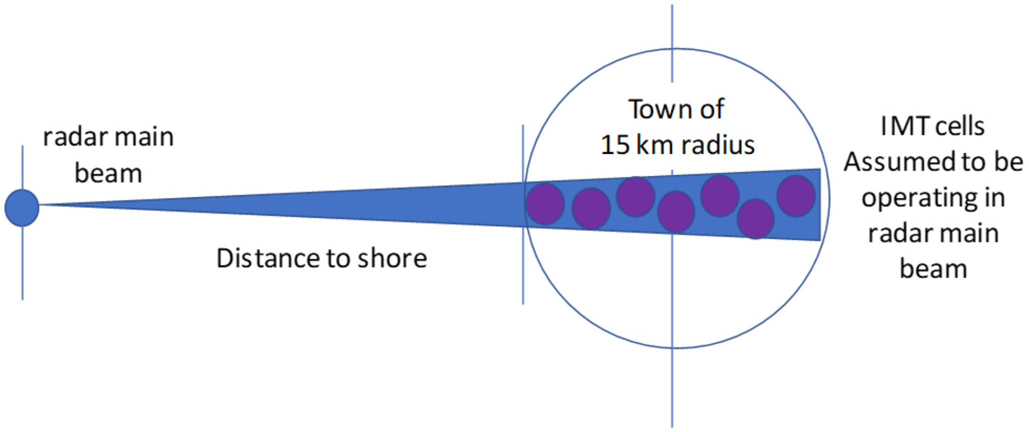
5.1 Baseline analysis

5.1.1 Assumptions

The key principle of the baseline analysis is aggregation of interference from IMT BS transmitters providing coverage within an area of a coastal town overlapping the radar receiver main beam. The coastal town is assumed to be 15 km radius based on the approximate size of Lagos and Cape Town. For an assumed radar distance to the shore and radar beamwidth, the town area overlapped by the main radar beam is calculated. The number of IMT BS transmitters covering the overlapped area is determined by assuming that the IMT cell radius is 2 km (see Table 1). Interference power towards the radar receiver is then calculated by aggregating IMT BS transmit powers.

FIGURE A1-3

Interference Aggregation



The aggregate power is modified to take account of an assumed 50% BS transmitter activity (i.e. 3 dB reduction in aggregate power). The path loss is assumed to be sea path and approximated by the path loss between the radar and the centre of the town. It is assumed that the IMT BS sectors are pointing towards the radar receiver.

The impact of clutter losses is considered by deriving the probability of aggregate interference being a less than a given value based on Recommendation ITU-R P.2108. For each IMT BS contributing to the aggregate interference power, it is assumed that the Recommendation ITU-R P.2108 clutter loss distribution applies, i.e. the probability of clutter loss being more than a given value is the same for each interfering IMT BS.

Table A1.9 shows the baseline analysis assumptions.

TABLE A1.9

Baseline Analysis Assumptions

Parameter	Radar B	Radar C	Radar D	Radar M
Carrier frequency (MHz)	3 300			
IMT BS transmitter bandwidth (MHz)	20			
IMT BS transmitter power (dBm) (including feeder losses)	43			
IMT BS transmitter antenna gain (dBi) (6 degrees downtilted Rec. 1336 Antenna)	10.5			
IMT BS transmitter activity factor (%)	50			
IMT cell radius (km)	2			
Percentage time for path loss (%)	20			
Clutter loss	Recommendation ITU-R P.2108			
Radar receiver antenna gain (dBi)	42	40	40	40
Radar antenna beamwidth (degree)	1.7	1.1	1.5	1
Radar receiver bandwidth (MHz)	10	10	20	10
Radar receiver noise figure (dB)	5	1.5	1.5	1.5
Radar receiver interference criterion (dBm)	−105	−108.5	−105.5	−108.5
OTR (dB)	3	3	0	3

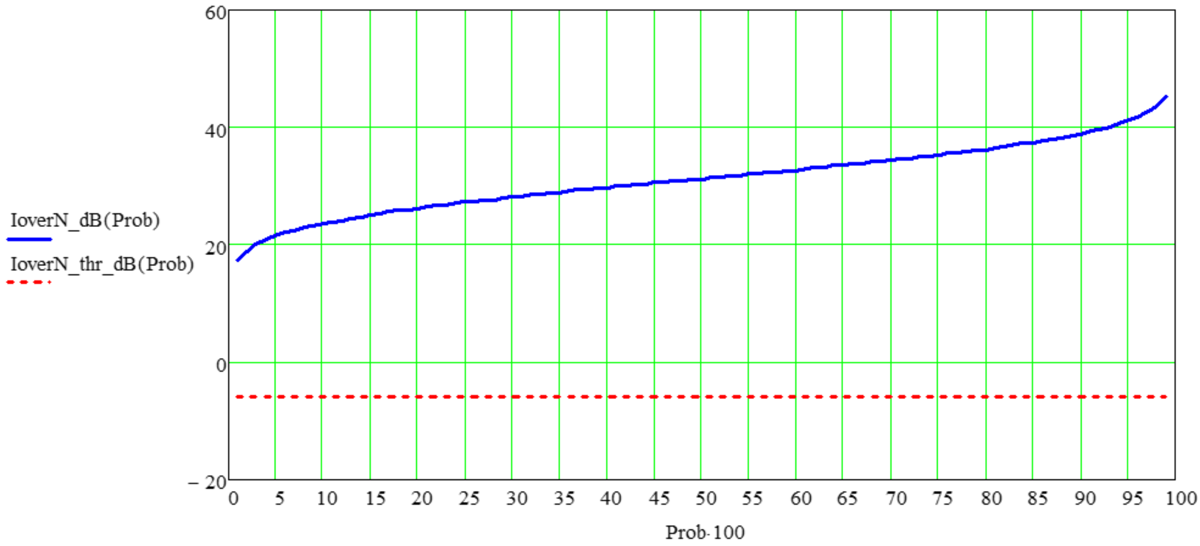
5.1.2 22 km scenario

Using the assumptions outlined above, a scenario where it is assumed that the radar receiver is at 22 km from the shore has been analysed. For example, for Radar B, it can be shown that there are three IMT BSs covering the town area overlapped by the radar beam leading to an aggregation factor of 4.8 dB.

The total interference at the radar receiver is −39 dBm/10 MHz in equatorial region with no clutter loss. This is approximately 66 dB above the interference criterion. For this scenario, the following plot can be derived using Recommendation ITU-R P.2108 clutter loss model to show the probability of *I*/*N* being less than y-axis value. The plot also shows the *I*/*N* threshold −6 dB.

FIGURE A1-4

***I*/*N* probability at 22 km from the shore for aggregate interference into radar B**



As can be seen, the aggregate interference causes *I*/*N* to remain well above the −6 dB criterion.

The analysis repeated for all radars and results are summarised below for the tropical and equatorial regions.

TABLE A1.10

22-km scenario analysis results

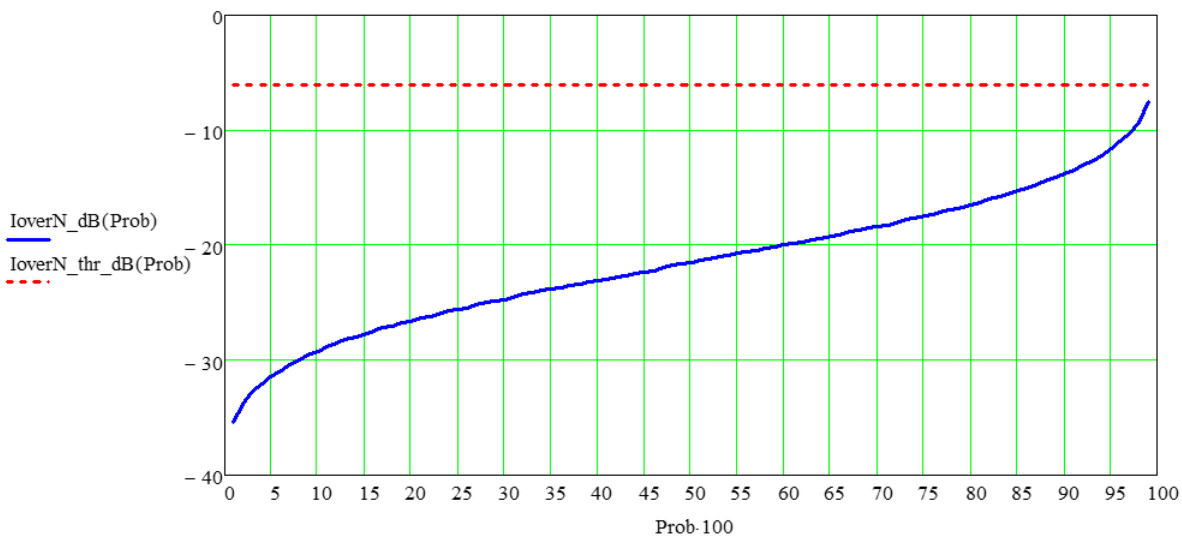
Parameter	Radar B	Radar C	Radar D	Radar M
No of IMT BSs within Radar Beamwidth	3	2	3	2
Aggregate interference at radar receiver with no clutter loss (dBm in radar bandwidth)	–39 (equatorial) –42 (tropical)	–43 (eq.) –45.5 (tr.)	–38 (eq.) –41 (tr.)	–43 (eq.) –43 (tr.)
Radar receiver interference criterion (dBm in radar bandwidth)	–105	–108.5	–105.5	–108.5
Excess compared to criterion (dB)	66 (equatorial) 63 (tropical)	65.5 (eq.) 63 (tr.)	67.5 (eq.) 64.5 (tr.)	65.5 (eq.) 65.5 (tr.)
Probability of *I*/*N* exceeding −6 dB with clutter losses (%)	100	100	100	100

5.1.3 Protection distances

Interference scenarios examined above have been used to calculate required protection distances from aggregate interference by moving the radar further away from the shore and re-calculating the overlap area and number of IMT BS interferers. For example, for radar B, when the distance from the shore is 347 km in the equatorial region the number of IMT BS transmitters within the radar beam is 25 and the *I*/*N* plot remains below the −6 dB criterion as shown below.

FIGURE A1-5

***I*/*N* probability at 347 km from the shore for aggregate interference into radar B**



The analysis has been repeated for all radars and the required protection distances are summarised in Table A1.11.

TABLE A1.11

Protection distance analysis results

Parameter	Radar B	Radar C	Radar D	Radar M
Protection distance from the shore (km)	347 (equatorial) 227 (tropical)	347 (eq.) 227 (tr.)	352 (eq.) 240 (tr.)	347 (eq.) 227 (tr.)
No of IMT BSs within radar beamwidth	25 (equatorial) 17 (tropical)	17 (eq.) 12 (tr.)	23 (eq.) 16 (tr.)	15 (eq.) 11 (tr.)

5.2 Sensitivity analysis

In this section, the impact of varying key modelling parameters has been investigated. Given that baseline analysis results do not differ significantly the sensitivity analysis has been implemented for a representative radar which is assumed to be radar B.

5.2.1 IMT cell radius

The baseline modelling assumes that 2-km radius IMT cells provide coverage for the town from which interference is aggregated. The required separation distances in the tropical region have been calculated for a range of assumed cell radius. Results are summarised in Table A1.12.

TABLE A1.12

Protection distances (radar B, tropical region, IMT cell radius sensitivity)

Parameter	0.3 km	0.6 km	1 km	2 km
Protection distance from the shore (km)	365	310	282	227
No of IMT BSs within radar beamwidth	1155	250	83	17

5.2.2 Percentage time

The baseline assumption regarding the path loss percentage time is 20%. The calculation has been repeated for 10%.

TABLE A1.13

Protection Distances (Radar B, Tropical Region, Percentage Time Sensitivity)

Parameter	10%	20%
Protection Distance from the Shore (km)	388	227

5.2.3 IMT BS activity factor

In the baseline analysis, it is assumed that the IMT BS activity factor is 50%. Protection distances have been re-calculated for 20% and 80% activity factors.

TABLE A1.14

Protection Distances (Radar B, Tropical Region, IMT BS Activity Factor Sensitivity)

Parameter	20%	50%	80%
Protection distance from the shore (km)	204	227	245

5.2.4 IMT BS power

The baseline model assumes that IMT BS transmit power is 43 dBm (including feeder losses), which is approximately 20 W. The impact of reduced transmit power has been examined for assumed 10 W and 5 W transmit power levels.

TABLE A1.15

Protection distances (radar B, tropical region, IMT BS transmit power sensitivity)

Parameter	5 W (37 dBm)	10 W (40 dBm)	20 W (43 dBm)
Protection Distance from the Shore (km)	190	209	227

5.2.5 IMT BS bandwidth

Table A1.16 compares protection distances obtained for 10 & 20 MHz IMT BS bandwidths.

TABLE A1.16

Protection distances (Radar B, tropical region, bandwidth sensitivity)

Parameter	10 MHz	20 MHz
Protection Distance from the Shore (km)	255	227

5.2.6 Propagation loss

The baseline model assumption is based on the sea path propagation to obtain generic results that do not include land path effects. The impact of propagation over land has been investigated for an assumed mixed land and sea path towards the radar receiver located at sea. It is assumed that the land portion of the interference path is spherical Earth in the equatorial region to reflect the Lagos deployment case.

TABLE A1.17

Protection distances (radar B, tropical region, propagation path sensitivity)

Parameter	Sea path	Mixed path
Protection distance from the shore (km)	347	293

Study B

1 Technical characteristics of IMT and Radar systems

1.1 IMT system parameters

Section 2 in main body contains the list of parameters for IMT deployment, which are taken from Report ITU-R M.2292.

1.2 Radar parameters

Section 2 in main body provides the key radar parameters to be used for these studies.

Ship-based Radar A cannot be considered in this study because this system operate above 3.5 GHz

For radar systems, no feeder loss parameter is described by ITU-R characteristics because in reception mode, radar feeder losses are already included in the noise figure values, and in transmitting mode, the transmitter power is defined at the radar antenna input.

Table A1.18 gives the selection of shipborne radar and parameters for the coexistence study in the same band.

TABLE A1.18

Shipborne Radar considered parameters for the coexistence study

Characteristics	Units	Radar B	Radar C	Radar D	Radar M
Antenna height above ground	m	20	20	20	50
Antenna Gain	dBi	42	40	40	40
Feeder insertion loss	dB	0	0	0	0
Receiver IF 3 dB bandwidth	MHz	10	10-30	2-20	10-30
Receiver noise figure	dB	5	1.5	1.5	1.5
Receiver IF selectivity Fall-off	dB/decade	−80	−80	−80	−80
Horizontal Beamwitdth	degree	1.7	1.1-5.0	1.5-6.0	1.0-5.0

In the study B, indexes m and n of radars' names $R_{m,n}$ which are shown in some tables or figures indicate that the calculation used either minimum (m=1) or maximum (m=2) values for their receivers bandwidth, and either minimum (n=1) or maximum (n=2) values for their antenna beamwidth.

2 Coexistence and compatibility scenarios between IMT and Radar

Recommendation ITU-R M.1465 provides indication of the typical uses of the airborne, land-based and ship-based radars operating in the frequency band 3 100-3 700 MHz. Based on the guidance of this recommendation, the following scenario of potential interference have been analysed:

2.1 Interference from IMT to ship based radar

The study considers:

– a smooth earth between transmitter and receiver, with a path terrain profile at 0 metre above sea level at all points;

– in one case, a full sea path scenario, considering a radio climatic zone B at all points;

– in second case, a mixed path scenario, 22 km at sea + moving the BS inside the coastal city, considering radio climatic zones B+A1+A2.

Scenarios considering tropical and equatorial regions because propagations losses are significantly different. Radio climatic parameters of Cape Town and Lagos cities are used.

In this study interference many scenarios are considered:

– Interference from one micro IMT 20MHz base stations in urban small-cell deployment to ship-based radars.

– Interference from one IMT 20 MHz base station in urban macro-cell deployment to ship-based radars.

– Interference from one IMT 10 MHz base station in urban macro-cell deployment to ship-based radars.

– Interference from aggregated 20 MHz IMT base stations in sub-urban or urban macro-cell deployment to ship-based radars.

– Interference from aggregated 10 MHz IMT base stations in sub-urban or urban macro-cell deployment to ship-based radars.

The scenario of interference from a mix of urban and suburban macro BS in instantaneous visibility of the radar antenna beam is not considered in this study, neither a mix of 10 MHz and 20 MHz base stations.

The scenario of interference from one or many aggregated IMT base stations operating few or fully multichannels over 3 300-3 400 MHz band has not yet be considered. An additional frequency channels aggregation factor will need to be taken into account in this case, leading to greater separation distances.

3 Interference criteria

In accordance with § 5 of the main body of the Report.

4 Propagation models

The propagation model between IMT system and ship based radar is from Recommendation ITU-R P.452, and performed by an average year prediction with cases of parameter p = 10% and 20% (time percentage for which the calculated basic transmission loss is not exceeded). All the propagation factors in Recommendation ITU-R P.452, except clutter losses, are considered.

The calculation of path losses takes into account the Recommendation ITU-R P.452 radio climatic zones encountered along the path depending of the different scenarios considered:

– Propagation fully above sea waters, for scenarios between an IMT transmitter located at the shoreline and a shipborne radar receiver at various distances at sea.

– Propagation partially above sea waters, partially on coastal zone and partially on land zone for larger separation distance, for scenarios between a shipborne radar located at the limit of the territorial waters and an IMT transmitter at ground.

Table A1.19 gives parameters used to calculate propagation losses.

TABLE A1.19

Parameters used propagation losses calculated with Recommendation ITU-R P.452

	Geographic situation	**Equatorial**	**Tropical**	**Equatorial**	**Tropical**
	Base station type	Macro	Macro	Micro	Micro
φt	Latitude Transmitter (degree)	6.45306	–33.9528	6.45306	–33.9528
ψt	Longitude Transmitter (degree)	3.39583	18.42322	3.39583	18.42322
φr	Latitude Receiver (degree)	6.45306	–33.9528	6.45306	–33.9528
ψr	Longitude Receiver (degree)	3.39583	18.42322	3.39583	18.42322
htg	Transmitter Height (metres)	20	20	6	6
hrg	Receiver Height (metres)	20	20	20	20
Gt	Transmitter Antenna gain (dB)	6	6	5	5
Gr	Transmitter Antenna gain (dB)	40	40	40	40
N0	Sea-level surface refractivity (N-units)	379.2	333.4	379.2	333.4
deltaN	Average radio-refractive index lapse-rate (N-units/km)	51.9	49.1	51.9	49.1
dcr	Distance over land from Rx antenna to the coastline (km)	0	0	0	0
dct	Distance over land from Tx antenna to the coastline (km)	0-5	0-5	0-5	0-5

Figure A1-6 shows path losses calculated completely above sea waters, and during 20% of time for which the transmission loss is not exceeded. The curves indicate the minimum path losses using the propagation model with p = 20%.

Figure A1-7 shows path losses calculated completely above sea waters, and during 10% of time for which the transmission loss is not exceeded. The curves indicate the minimum path losses using the propagation model with p = 10%. It should be noticed the high sensitivity of the "percentage of time" parameter showing variation minimum around 20 dB on minimum path losses between the two considered cases (p = 20%, p = 10%) at large distances over horizon. Depending criticality of the radar mission, more stringent values of percentage of time (e.g. p = 5%, p = 1%) should be considered. For short distance below roughly 30 km, path losses appear not very sensitive to time percentage.

It should be noticed the importance of the latitude on value of propagation losses. Equatorial and tropical cases are considered, showing variation around 20 dB. Figure A1-8 shows path losses calculated between a shipborne radar located at 22 km of the shoreline and an IMT transmitter located at various distances perpendicular of the shoreline. As recommended in Recommendation ITU-R P.452, the coastal zone is limited to 50 km, said 72 km from the radar.

FIGURE A1-6

Scenario between a shipborne radar at sea and an IMT base station located on shoreline

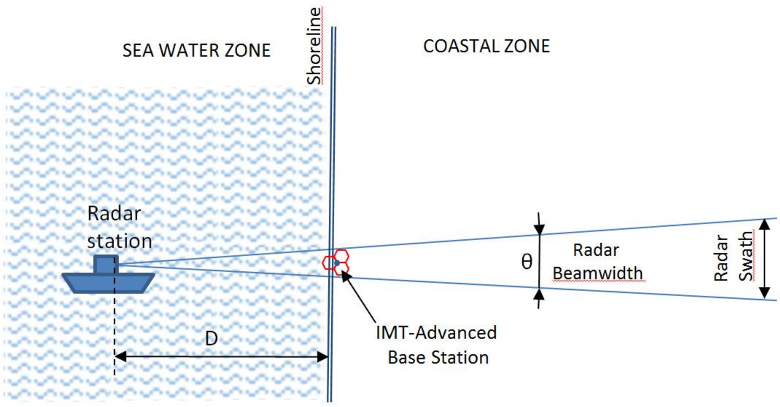


FIGURE A1-7

Path losses between an IMT base station located on shoreline and a shipborne radar at sea (ITU-R P.452-16 *p* = 20%)

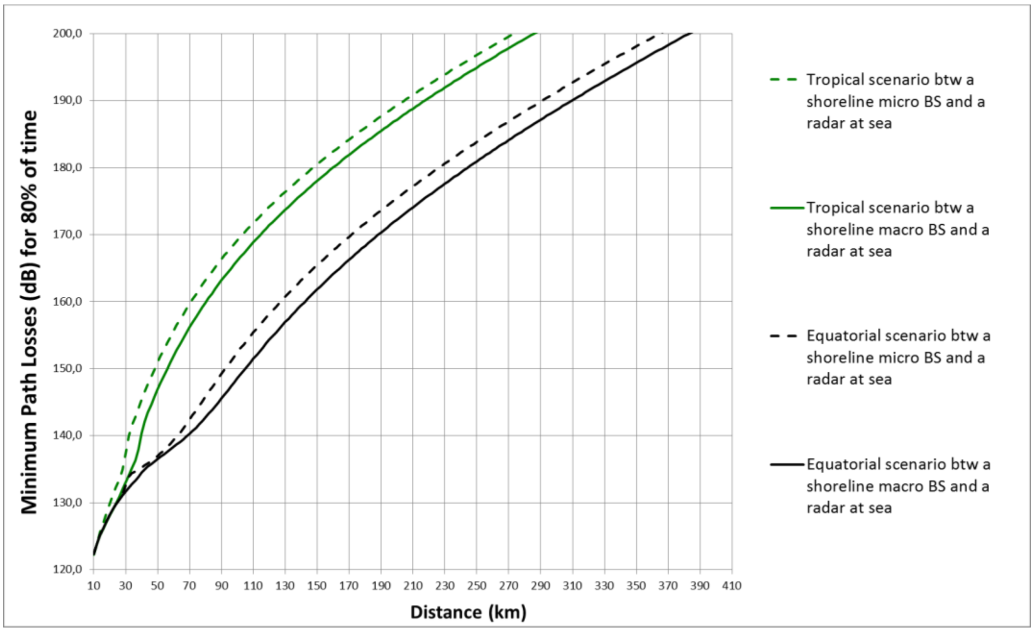


FIGURE A1-8

Path losses between an IMT base station located on shoreline and a shipborne radar at sea (ITU-R P.452-16 *p* = 10%)

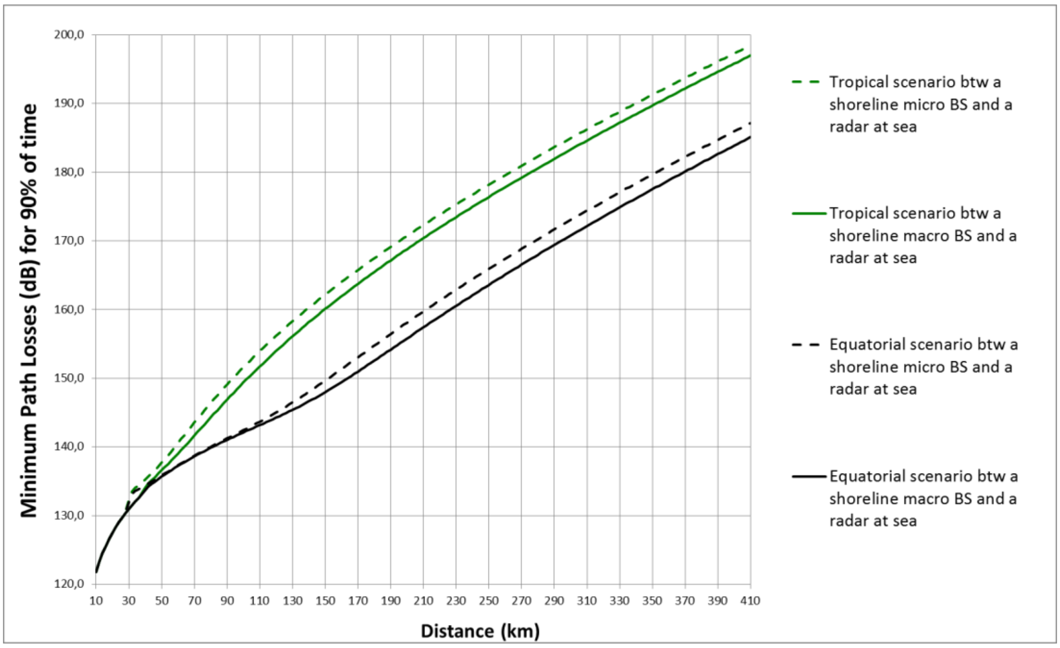


FIGURE A1-9

Scenario between a shipborne radar located 22 km from shoreline and one IMT base station located on ground

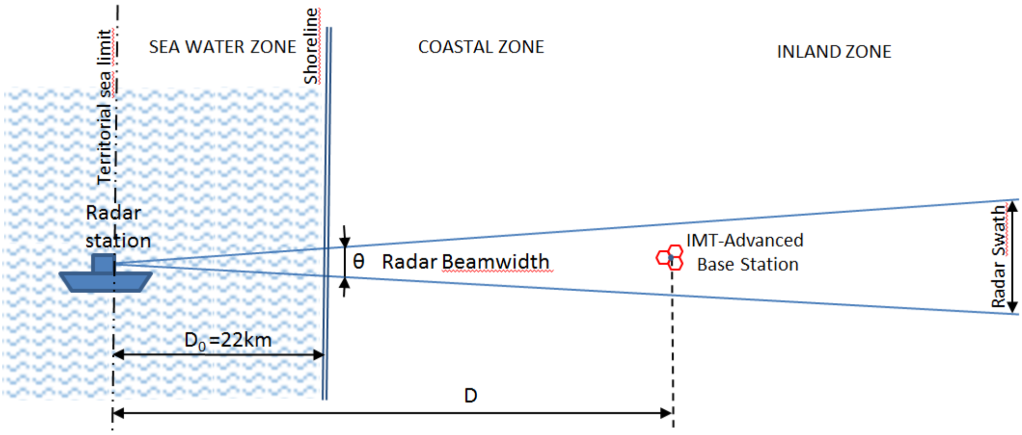
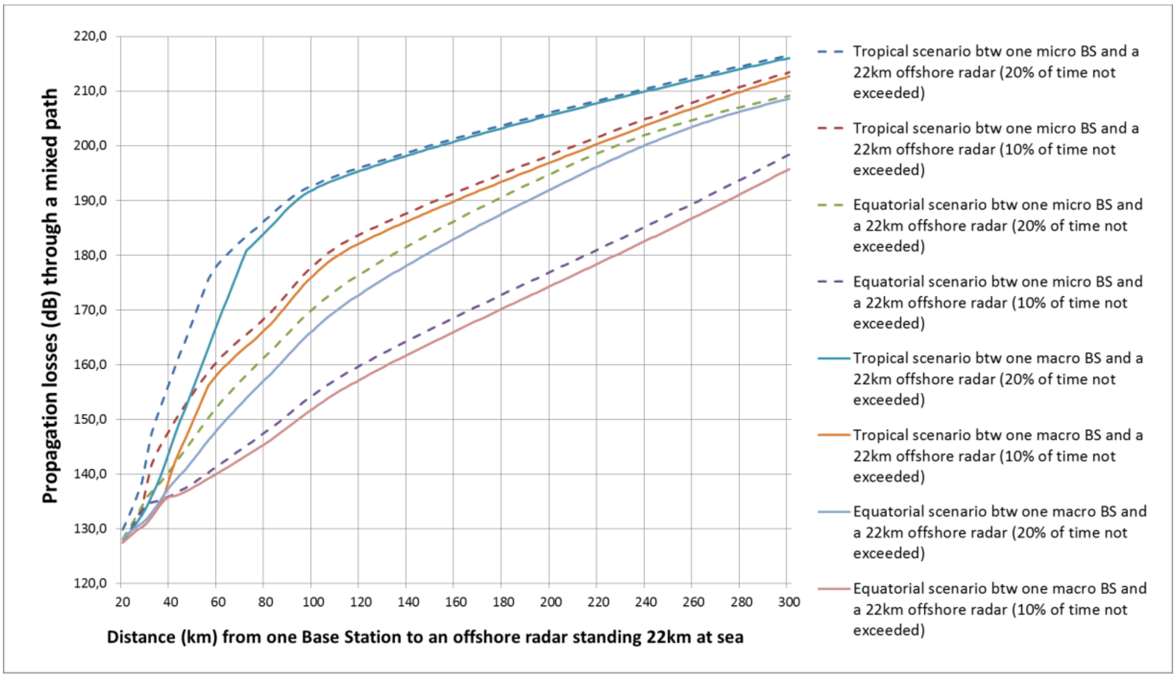


FIGURE A1-10

Path losses between a shipborne radar located 22km from shoreline and a distant IMT base station located on ground (ITU-R P.452-16)



Clutter models

In accordance to § 4 in main body, the clutter loss value is defined to zero for pathloss calculations of suburban macro BS, for single entry calculation of urban macro BS and for the shoreline worst case single entry calculation of urban micro BS. For aggregation studies, the impact of buildings on separation distance or margin will be approximated by using the statistical distribution defined in § 4 of the main body.

5 Study results

5.1 IMT micro base stations deployed in small cells outdoors

The protection distance to avoid interference in a co-channel scenario involving an IMT outdoor micro BS interfering into ship based radars of type B, C, D and M is evaluated in this section.

5.1.1 Single entry Interference from one IMT micro base-station

Table A1.20 gives the required propagation loss to prevent interference from one 20 MHz micro base station toward a radar.

TABLE A1.20

Interference from one IMT outdoor micro 20 MHz base-station to ship-based radar stations

Parameters		**Ship-based-B radar**	**Ship-based-C radar**	**Ship-based-D radar**	**Ship-based-M radar**
Carrier frequency (GHz)		3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)		20	20	20	20
Maximum output power (dBm)		24	24	24	24
Antenna gain of outdoor micro IMT base-station (dBi)		5	5	5	5
Insertion loss of radar (dB)		0	0	0	0
Antenna gain radar (dBi)		42	40	40	40
Frequency offset (MHz)		0	0	0	0
Number of IMT base-station in urban scenario		1	1	1	1
Average base station activity		100%	100%	100%	100%
Noise figure		5.0	1.5	1.5	1.5
Radar bandwidth (MHz)		10	10-30	2-20	10-30
On Tune Rejection (dB)[3]		3.0	3.0-0	10.0-0	3.0-0
Maximum Allowable interference power at radar receiver input (dBm)		–105	–108.5 / –103.7	–115.5	–108.5 / –103.7
Required propagation loss (dB)		**173.0**	**174.5-172.7**	**174.5-174.5**	**174.5-172.7**
Propagation model	**ITU-R P.452-16 (Case 1 : *p* = 20%)**				
Protection distance (km) with a tropical sea pathloss		116	122	122	122
Protection distance (km) with an equatorial sea pathloss		188	194	194	194
Loss for a 22 km tropical sea path (dB)		–131	–131	–131	–131

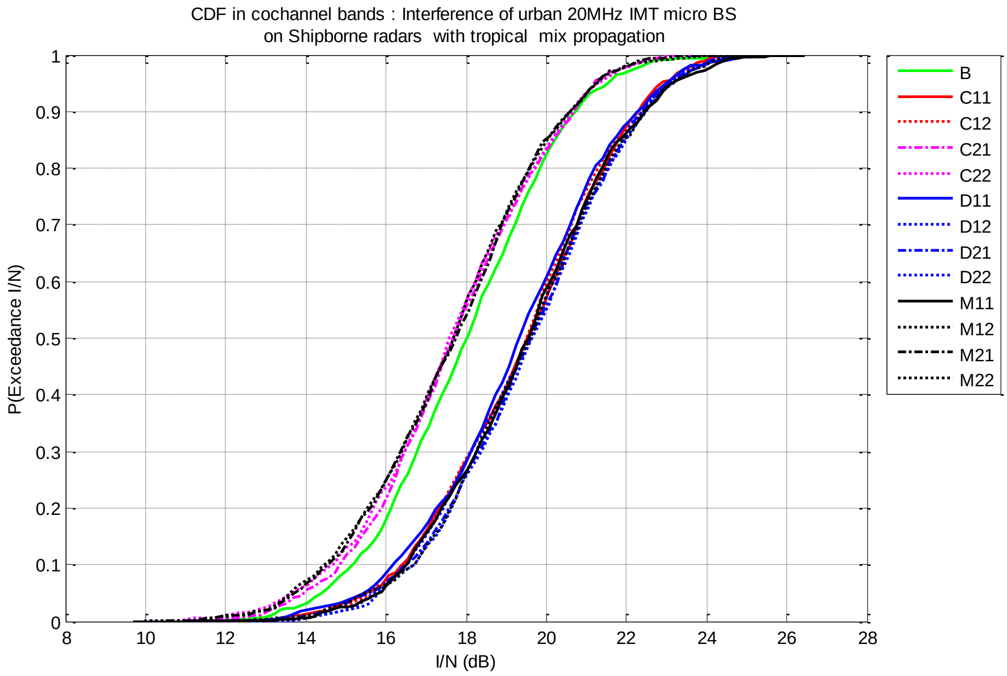
3 Recommendation ITU-R SM.337 defines the On Tune Rejection (OTR) as the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of a transmitted signal exceeding the receiver bandwidth.

TABLE A1.20 (*end*)

Parameters		**Ship-based-B radar**	**Ship-based-C radar**	**Ship-based-D radar**	**Ship-based-M radar**
Interference overcoupling at 22 km tropical sea (dB)		42.0	43.5-41.7	43.5	43.5-41.7
Loss for a 22 km equatorial sea path (dB)		–129	–129	–129	–129
Interference overcoupling at 22 km equatorial sea (dB)		44.0	45.5-43.7	45.5	45.5-43.7
Propagation model	**ITU-R P.452 (Case 2 : *p* = 10%)**				
Protection distance (km) with a tropical sea pathloss		214	224	224	224
Protection distance (km) with an equatorial sea pathloss		300	310	310	310
Loss for a 22 km tropical sea path (dB)		–128	–128	–128	–128
Interference overcoupling at 22 km tropical sea (dB)		45.0	46.5-44.7	46.5	46.5-44.7
Loss for a 22 km equatorial sea path (dB)		–128	–128	–128	–128
Interference overcoupling at 22km equatorial sea (dB)		45.0	46.5-44.7	46.5	46.5-44.7

With a statistical approach, Fig. A1.11 gives the cumulative distribution of the single entry interfering level received on radars standing 22 km from seashore with path loss using the propagation model with p = 20%, obtained with a simulation taking into account the statistical law of clutter loss. The statistical result obtained at P(I/N) = 100% is coherent to MCL single entry approach, because the statistical simulation does not take into account 2% of base station's locations with clutter loss below 16 dB, including worse case of 0 dB loss leading to I/N = 42 dB.

FIGURE A1-11



Summary

In summary it can be observed that for ship-based Radar B/C/D/M, the co-channel protection distance between one IMT 20 MHz outdoor micro base-station located at the shoreline and a ship based Radar is 122-194 km depending tropical or equatorial propagation conditions over the sea using the propagation model with p = 20%, and respectively 224-310 km for p = 10%.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, the emissions of one IMT 20MHz outdoor micro base-stations standing at the shoreline are received 42.0-45.5 dB over the co-channel protection level of the radar, depending tropical or equatorial propagation conditions using the propagation model with p = 20%, and respectively 44.7-46.7 dB using the propagation model with p = 10%.

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, and considering pathloss over sea, coastal and land zones, the protection distances are shown in Table A1.21. In this MCL study, considering low clutter losses or mask effect of buildings of 18 dB, the protection distance of a radar from one micro BS is 39 km-68 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%, and respectively 52 km-106 km using the propagation model with p = 10%. For a median clutter loss of 28 dB, the protection distance of a radar from one macro base station is found to be 32 km-49 km depending tropical or equatorial propagation conditions using the propagation model with p = 20%, and respectively 38 km-76 km using the propagation model with p = 10%.

Without any other mitigation technique, this study shows that the installation of micro base stations operating co-frequency in coastal zones is not compatible with shipborne radars standing at 22 km from shoreline.

TABLE A1.21

Interference from one IMT outdoor micro 20 MHz base-station to a ship-based radar station standing at 22 km from shoreline. Propagation with path losses over sea, coastal and land zones of Recommendation ITU-R P.452

Parameters	**Ship-based-B radar**	**Ship-based-C radar**	**Ship-based-D radar**	**Ship-based-M radar**
Single entry without clutter loss				
Required propagation loss (dB) without clutter	173.0	174.5-172.7	174.5	174.5-172.7
Single entry with low clutter loss				
Low clutter loss for micro BS (dB)	18	18	18	18
Required propagation loss (dB)	155	156.5-154.7	156.5	156.5-154.7
Protection distance (km) with a tropical pathloss (p = 20%) and low clutter loss	38	39-38	39	39-38
Protection distance (km) with an equatorial pathloss (p = 20%) and low clutter loss	66	68-64	68	68-64
Protection distance (km) with a tropical pathloss (p = 10%) and low clutter loss	42	52-49	52	52-49
Protection distance (km) with an equatorial pathloss (p = 20%) and low clutter loss	102	106-101	106	106-101

TABLE A1.21 (*end*)

Parameters	**Ship-based-B radar**	**Ship-based-C radar**	**Ship-based-D radar**	**Ship-based-M radar**
Single entry with median clutter loss				
Median clutter loss for micro BS (dB)	28	28	28	28
Required propagation loss with median clutter (dB)	145	146.5-144.7	146.5	146.5-144.7
Protection distance (km) with a tropical pathloss (p = 20%) and median clutter loss	31	32-30	32	32-30
Protection distance (km) with an equatorial pathloss (p = 20%) and median clutter loss	46	49-46	49	49-46
Protection distance (km) with a tropical pathloss (p = 10%) and median clutter loss	36	38-36	38	38-36
Protection distance (km) with an equatorial pathloss (p = 10%) and median clutter loss	72	76-72	76	76-72

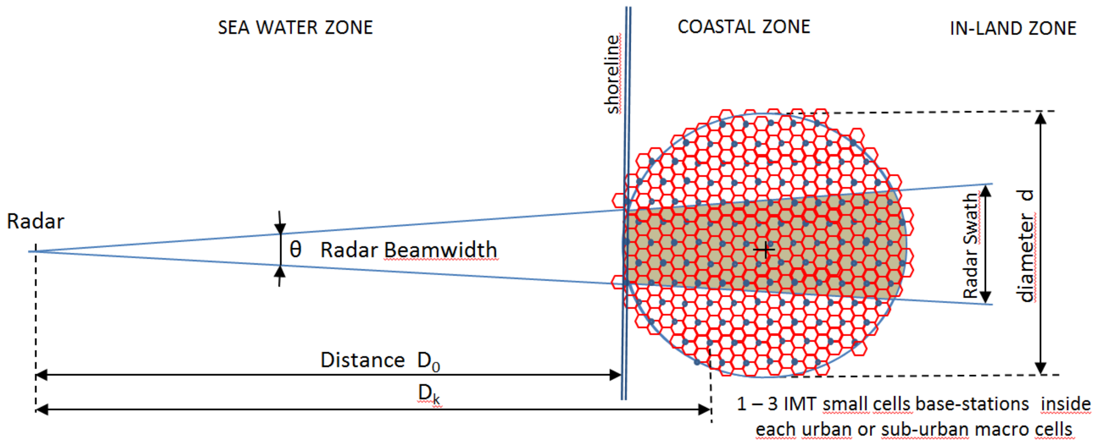
5.1.2 Aggregation study of micro BS

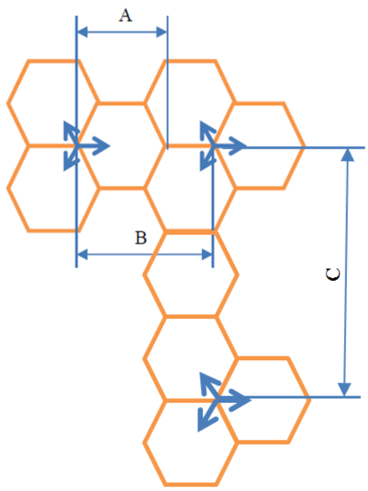
The Radar main lobe can cover simultaneously many micro BS.

Figure A1-12 shows that many IMT micro base stations from an urban or suburban coastal area are simultaneously received by the Radar through the antenna main lobe beamwidth, leading to consider the aggregation of all interfering signals to define the aggregated separation distance.

FIGURE A1-12

IMT micro base-stations simultaneously in visibility of a radar





Each cell (also referred to as a sector) is shown as a hexagon, and in this figure there are three cells/sectors per base station site, accordingly to Report ITU-R M.2292, where:

D_0 : distance to shoreline

D_k : distance in the radial direction from a base station k to radar

d : diameter of the coastal IMT deployment area (km)

S_k : radar swath at distance D_k (km)

A : macro cell radius

B : macro cells Base station inter site in radial direction from radar (km)

C : macro cells Base station inter site in transversal direction from radar (km)

with relations:

$$B = 3/2 \,.\, A \qquad \text{and} \quad C = 3/2 \,.\, \sqrt{3} \,.\, A$$

The typical value of parameters used in this study are given in Table A1.22, based on realistic metrics like seaside cities of Lagos (Nigeria) and Capetown (South Africa).

TABLE A1.22

Parameters used for micro BS aggregation study

Localisation	**Scenarios**	**Area diameter 'd'**	**Macro cell radius (km)**	**Micro BS per macro cells**	**Average BS activity**
Equatorial	Urban	8 km	0.3	3	50%
Tropical	Urban	5 km	0.3	3	50%

The typical number of urban micro base station per macro cells taken into account are 1 to 3 according to Table 1 from main body, extracted from Report ITU-R M.2292 on IMT Deployment-related parameters.

Tables A1.23 and A1.24 show that aggregation studies consider the case of number many tens up to more than a thousand of active micro base stations simultaneously in the radar antenna main beam.

Table A1.23 shows that a number of many tens or hundreds active urban micro base stations to consider in the aggregation studies for the scenario of a shipborne radar standing 22 km from the shoreline

TABLE A1.23

Aggregation of micro BS from an urban area in tropical zone (see parameters in Table A1-22)

Ship-based radar type	B	C	C	D	D	M	M
Horizontal radar beamwitdth (degree)	1.7	1.1	5	1.5	6	1	5
Distance D_0 from radar to urban area (km)	126	134	134	134	134	134	134
Radar beam cross-section on the urban area (km^2)	17.0	12.5	19.6	16.2	19.6	11.4	19.6
Macro cell hexagonal area (km^2)	0.058	0.058	0.058	0.058	0.058	0.058	0.058
Number of macro site in the radar beam	97	71	112	92	112	65	112
Number of active micro BS to consider in the radar beam (Assumption of 1 micro BS per macro sector)	145	107	168	139	168	98	168
Number of active micro BS to consider in the radar beam (Assumption of 3 micro BS per macro sector)	436	320	504	416	504	294	504

TABLE A1.24

Aggregation of micro BS from an urban area in equatorial zone (see parameters in Table A1-22)

Ship-based radar type	B	C	C	D	D	M	M
Horizontal Beamwitdth (deg.)	1.7	1.1	5	1.5	6	1	5
Distance D_0 from Radar to Urban area (km)	214	224	224	224	224	224	224
Radar beam cross-section on the urban area (km^2)	45.4	33.2	50.3	42.8	50.3	30.5	50.3
Macro cell hexagonal area (km^2)	0.058	0.058	0.058	0.058	0.058	0.058	0.058
Number of macro site in the radar beam	259	189	287	244	287	174	287
Number of active micro BS to consider in the radar beam (Assumption of 1 micro BS per macro sector)	388	284	430	367	430	261	430
Number of active micro BS to consider in the radar beam (Assumption of 3 micro BS per macro sector)	1164	851	1290	1100	1290	782	1290

TABLE A1.25

Aggregation of micro BS from a shipborne radar standing at 22 km (Equatorial urban scenario)

Ship-based radar type	B	C	C	D	D	M	M
Horizontal Beamwitdth (degree)	1.7	1.1	5	1.5	6	1	5
Distance D_0 from Radar to Urban area (km)	22	22	22	22	22	22	22
Radar beam cross-section on the urban area (km^2)	6.2	4.0	17.9	5.4	21.4	3.6	17.9
Macro cell hexagonal area (km^2)	0.058	0.058	0.058	0.058	0.058	0.058	0.058
Number of macro site in the radar beam	35	23	102	31	122	21	102
Number of active micro BS to consider in the radar beam (Assumption of 1 micro BS per macro sector)	53	34	153	47	183	31	153
Number of active micro BS to consider in the radar beam (Assumption of 3 micro BS per macro sector)	158	102	460	140	548	93	460

Aggregation study of the scenario with a shipborne radar standing 22 km from the shoreline

This analysis is considered as static by assuming that the position of the ship with respect of the IMT-Advanced BSs on the ground is fixed, and that the radar antenna is pointing toward the IMT deployment, The aggregation process is not done over the rotation of the radar antenna because the performance of shipborne radar is generally requested for each azimuthal direction of its main beam.

Monte-Carlo simulations are performed over the IMT mobile network and the radar within the area of simulation to calculate the aggregated interference with caused by the BSs in order to derive a reliable statistic, e.g. CDF of the experienced aggregated interference over noise level, i.e. I_{agg}/N.

The randomization process is done at each run of simulation on following parameters:

– Uniform repartition of position for each micro BS in its macro cell

– Activity or not of the base station

– Clutter value of the propagation path associated to each base-station

Let's denote j the index of the random samplings of each micro base-station in the deployment.

The aggregated interference is then achieved in the following way:

$$Iagg = 10\log_{10}\left(\sum_{\substack{1\le i\le \mathrm{NbBSs},\\ 1\le j\le \mathrm{NbEvents}}} 10^{\frac{P_{R,ij}}{10}}\right).$$

The simulation of the urban deployment considers density of three micro BS per macro-cell.

Figures A1-13 and A1-14 depict the cdf of I_{agg}/N (i.e. $P(X \le x_0)$ in ordinate while x-axis provides associated I/N values) for equatorial and tropical cases. Curves represent CDF for different radar types, with $R_{m,n}$ names' indexes indicating minimum and maximum values for their receivers bandwidths and antenna beamwidths.

FIGURE A1-13

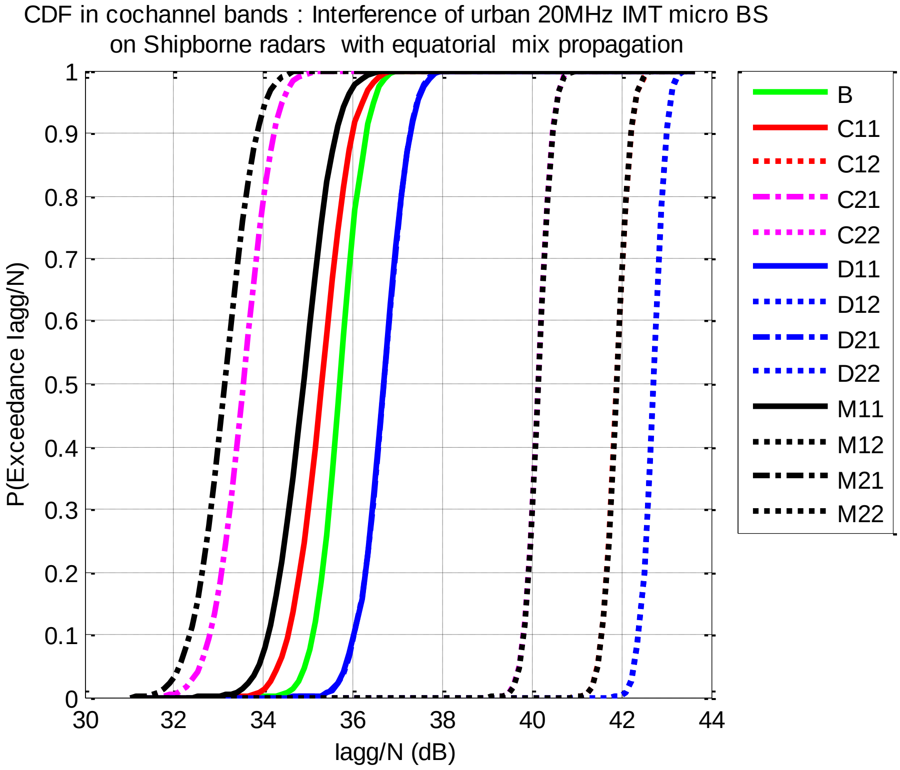
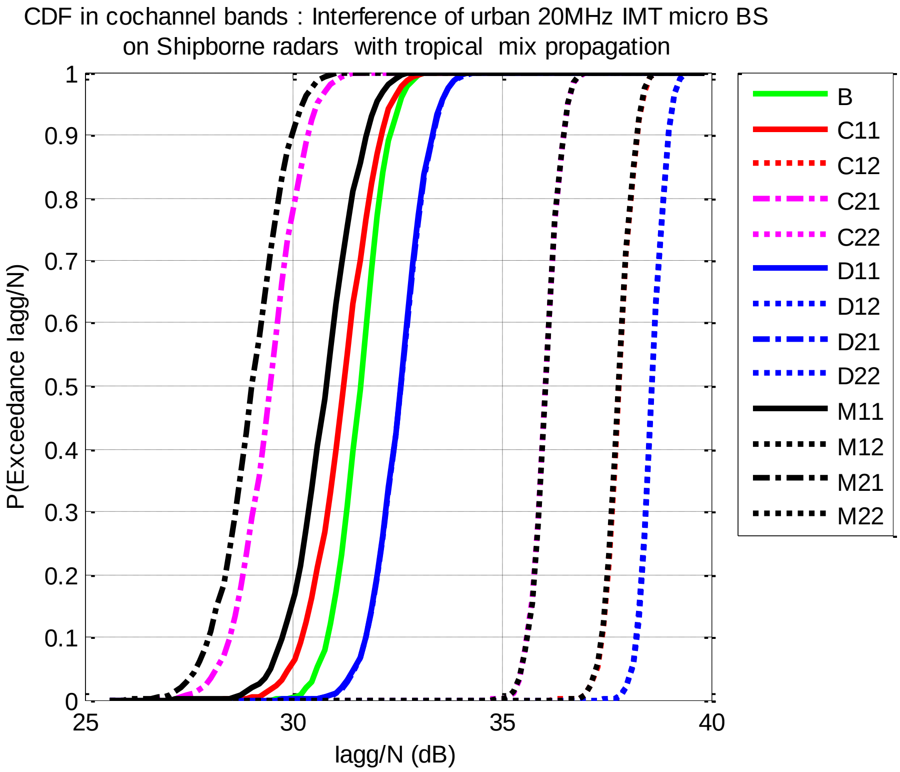


FIGURE A1-14



Simulation results show a value of the CDF at 100% which indicates that the aggregated interference ratio *I/N* received by the radar is up to 40 dB or 44 dB depending tropical or equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of −6 dB.

In conclusion, based on these results, it can be concluded that an urban micro BS IMT-Advanced deployment is not compatible with protection criteria of shipborne radar systems in co-channel operations within 3.3-3.4 GHz.

5.1.3 Summary of co-channel study of interference from Outdoor micro BS to shipborne radars

In summary it can be estimate that for ship-based Radar B/C/D/M, the co-channel protection distance between one IMT outdoor micro base-station located at the shoreline and a ship based Radar is –122-194 km depending tropical or equatorial propagation conditions over the sea, using the propagation model with p = 20%, and respectively 224-310 km using the propagation model with p = 10%.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, the emissions of one IMT outdoor micro base-station standing at the shoreline are received 42.0-45.5 dB over the co-channel protection level of the radar, depending tropical or equatorial propagation conditions over the sea using the propagation model with p = 20%, and respectively 44.7-46.7 dB for using the propagation model with p = 10%

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, considering pathloss over sea, coastal and land zones, and considering a low clutter losses or mask effect of buildings of 18 dB, the protection distance from one micro BS is 39-68 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%, and respectively 52 km-106 km using the propagation model with p = 10%. For a median clutter loss of 28 dB, the protection distance of a radar from one macro base station is found to be 32-49 km depending tropical or equatorial propagation conditions using the propagation model with p = 20%.

The interference aggregation study shows that a large number of micro base stations needs to be considered. In the scenario of a shipborne radar standing 22 km from the shoreline, between 30 to 240 locations of micro base stations are still to be considered. The calculation of aggregated level of interference from these micro base stations is complex to estimate because 100% of them are considered below roof top of buildings. In order to estimate a meaningful separation distance, further calculation will need to take into account the clutter or masking losses of each specific urban real deployment. Considering urban deployment characteristics with density of 3 micro BS per macro cell, static analysis with Monte Carlo simulations shows that the aggregated interference ratio I/N received by the radar is up to 40 dB or 44 dB depending tropical or equatorial propagation conditions using the propagation model with p = 20%, far above the radar protection criteria of −6 dB.

In conclusion on the MCL and aggregation static analyses, based on different assumptions and these results, it can be concluded that an urban micro BS IMT-Advanced deployment is not compatible with protection criteria of shipborne radar systems in co-channel operations within 3.3-3.4 GHz.

5.2 IMT base stations deployed in urban macro cells

This section studies the protection distance to avoid interference from an IMT system deployed in urban macro BS to ship based radars of type B, C, D and M.

5.2.1 Interference from only one IMT macro base-station interference

Tables A1.26 and A1.27 evaluate the separation distance for allowable interference from only one IMT macro base-station to one ship based radar.

TABLE A1.26

Interference from one IMT outdoor urban macro 20 MHz base-station to ship-based radar stations

		Ship-based-B radar	**Ship-based-C radar**	**Ship-based-D radar**	**Ship-based-M radar**
Carrier frequency (GHz)		3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)		20	20	20	20
BS Feeder loss (dB)		3	3	3	3
BS Maximum output power (dBm)		46	46	46	46
Antenna gain of Urban macro IMT base-station (dBi) (considering downtilt)		6	6	6	6
Insertion loss of radar (dB)		0	0	0	0
Antenna gain radar (dBi)		42	40	40	40
Frequency difference (MHz)		0	0	0	0
Number of IMT base-station		1	1	1	1
Average base station activity		100%	100%	100%	100%
Radar bandwidth (MHz)		10	10-30	2-20	10-30
On Tune Rejection (dB)4		3.0	3.0-0	10.0-0	3.0-0
Maximum Allowable interference power at radar receiver input (dBm)		–105.0	–108.5 / –103.7	–115.5 / –105.5	–108.5 / –103.7
Required propagation loss (dB)		193.0	194.5-192.7	194.5	194.5-192.7
Propagation model	Recommendation ITU-R P.452 (Case 1 : *p* = 20%)				
Protection distance (km) at tropical sea		238	246-234	246	246-234
Protection distance (km) at equatorial sea		330	342-328	342	342-328
Loss for a 22 km sea path (dB) (equatorial or tropical)		–129	–129	–129	–129
Interference overcoupling at 22 km on sea (dB)		64.0	65.5-63.7	65.5	65.5-63.7

4 Recommendation ITU-R SM.337 defines the On Tune Rejection (OTR) as the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of a transmitted signal exceeding the receiver bandwidth. The Radar receiver IF selectivity fall-off of −80 dB per decade (see Recommendation ITU-R M.1461) is taken into account in calculation of OTR.

TABLE A1.27

Interference from one IMT outdoor urban macro 10 MHz base-station to ship-based radar stations

	Ship-based-B radar	**Ship-based-C radar**	**Ship-based-D radar**	**Ship-based-M radar**
Carrier frequency (GHz)	3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)	10	10	10	10
BS Feeder loss (dB)	3	3	3	3
BS Maximum output power (dBm)	46	46	46	46
Antenna gain of Urban macro IMT base-station (dBi) (considering downtilt)	6	6	6	6
Insertion loss of radar (dB)	0	0	0	0
Antenna gain radar (dBi)	42	40	40	40
Frequency offset gap (MHz)	0	0	0	0
Number of IMT base-station	1	1	1	1
Average base station activity	100%	100%	100%	100%
Radar bandwidth (MHz)	10	10-30	2-20	10-30
On Tune Rejection (dB)[5]	0	0	7.0-0	0
Maximum Allowable interference power at radar receiver input (dBm)	–105.0	–108.5 / –103.7	–115.5 / –105.5	–108.5 / –103.7
Required propagation loss (dB)	196.0	197.5-192.7	197.5-194.5	197.5-192.7
Propagation model	Recommendation ITU-R P.452-16 (Case 1 : p = 20%)			
Protection distance (km) at tropical sea	258	268-234	268-246	268-234
Protection distance (km) at equatorial sea	352	364-328	364-342	364-328
Loss for a 22 km sea path for macroBS height (dB) (equatorial and tropical)	–129	–129	–129	–129
Interference overcoupling at 22 km on sea (dB)	67.0	68.5-63.7	68.5-65.5	68.5-63.7

In summary, it can be observed that for ship-based Radar B/C/D/M, the co-channel protection distance between one IMT macro base-station located at the shoreline and a ship based Radar, is 246-268 km (IMT BW 20/10 MHz) and 342-364 km (IMT BW 20/10 MHz) depending tropical or equatorial propagation conditions over the sea, using the propagation model with p = 20%,

[5] Recommendation ITU-R SM.337 defines the On Tune Rejection (OTR) as the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of a transmitted signal exceeding the receiver bandwidth. The Radar receiver IF selectivity fall-off of −80 dB per decade (see Recommendation ITU-R M.1461) is taken into account in calculation of OTR.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, the emissions from one IMT macro base-station standing at the shoreline are received 65.5-68.5 dB over the co-channel protection level of the radar, depending IMT channel bandwidths of 20 MHz or 10 MHz. At such low distance, considering 20 m heights for antennas of both systems, the propagation loss does not depend significantly of tropical or equatorial propagation conditions.

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, and considering pathloss over sea, coastal and land zone, the protection distances are shown in Table A1.28. In this MCL study, considering no clutter losses or mask effect of buildings (nominal case of all suburban macro BS, or worst case of urban macro BS), the co-frequency protection distance of a radar from one IMT 10 MHz macro base station which could interfere from inland zone is 134-226 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%.

In this MCL study, considering the case of low clutter losses or mask effect of buildings of 18 dB, the co-frequency protection distance of a radar from one IMT 10 MHz macro BS is found to 70-145 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%. For a median clutter loss of 28 dB, the protection distance of a radar from one IMT 10 MHz macro base station is found to be 62-109 km depending tropical or equatorial propagation conditions using the propagation model with p = 20%.

Without any other mitigation technique, this study shows that the co-frequency operation of macro base stations in coastal zones is not compatible with shipborne radars.

TABLE A1.28

Interference from one IMT outdoor macro 10 MHz base-station to a ship-based radar station standing at 22 km from shoreline – Propagation with path losses over sea, coastal and land zones of Recommendation ITU-R P.452

Parameters	Ship-based-B radar	Ship-based-C radar	Ship-based-D radar	Ship-based-M radar
Single entry without clutter loss for one macro BS				
Required propagation loss (dB) with a 10 MHz IMT macro BS without clutter	196.0	197.5-192.7	197.5-194.5	197.5-192.7
Protection distance (km) with a tropical pathloss	124	134-104	134-114	134-104
Protection distance (km) with an equatorial pathloss	218	226-202	226-212	226-202
Single entry without clutter loss for one macro BS				
Low clutter loss for a macro BS below rooftop (dB)	18	18	18	18
Required propagation loss with low clutter (dB)	178.0	179.5-174.7	179.5-176.5	179.5-174.7
Protection distance (km) with a tropical pathloss (p = 20%) and low clutter loss	69	70-66	70-68	70-66
Protection distance (km) with an equatorial pathloss (p = 20%) and low clutter loss	139	145-126	145-133	145-126

TABLE A1.28 (*end*)

Parameters	Ship-based-B radar	Ship-based-C radar	Ship-based-D radar	Ship-based-M radar
Single entry with median clutter loss for one macro BS below rooftop				
Median clutter loss for a macro BS below rooftop (dB)	28	28	28	28
Required propagation loss with median clutter (dB)	168.0	169.5-164.7	169.5-166.5	169.5-164.7
Protection distance (km) with a tropical pathloss (p = 20%) and median clutter loss	60	62-57	62-59	62-57
Protection distance (km) with an equatorial pathloss (p = 20%) and median clutter loss	104	109-96	109-100	109-96

5.2.2 Aggregation study

5.2.2.1 Principles

Figure A1-15 shows that many IMT base stations from an urban or suburban area are simultaneously received by the Radar through the antenna main lobe beamwidth. Then, an aggregation factor AF should be considered in the separation distance calculation, as:

$$AF = AF_1 + AF_2 + AF_3 \quad \text{(dB)}$$

with:

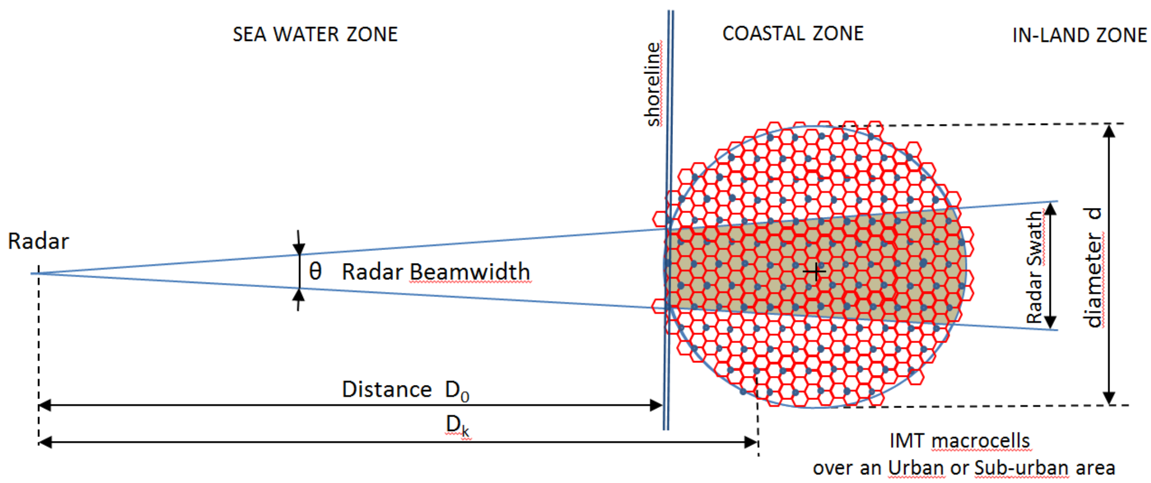
AF_1: factor due to the received power from all base stations simultaneously in visibility

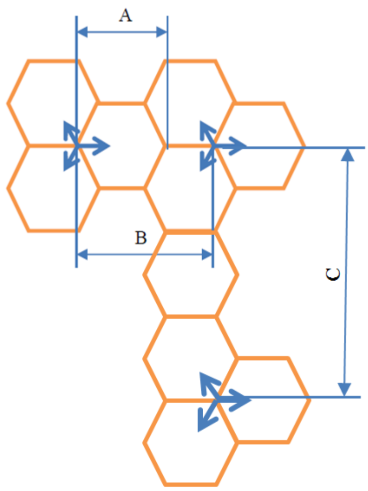
AF_2: it reflects clutter or masking losses

AF_3: it reflects activity of base stations.

FIGURE A1-15

IMT Macro Base stations simultaneously in visibility of a radar





Each cell (also referred to as a sector) is shown as a hexagon, and in this figure there are three cells/sectors per base station site, accordingly to Report ITU-R M.2292.

Taking into account the increasing propagation losses as function of the distance of IMT macro base-stations from the radar position, the aggregation factor AF_1 can be approximated as:

$$AF_1 = 10\,Log_{10}\left(\sum_{\substack{D_0 \\ in\ radial \\ steps\ k}}^{D_0+d} N.M_k.10^{\frac{Att_0 - Att_k}{10}}\right) \quad (1)$$

where:

- D_0: minimal protection distance from one interfering IMT base station to radar
- D_k: distance in the radial direction from a subgroup of base stations to radar
- k: index of calculation step of distance D_k in the radial direction from radar
- N: number of base stations in one step of radial distance
- M_k: number of base stations in the transversal swath at the distance D_k from radar
- Att_0: Propagation loss at distance D in the middle of the IMT area
- Att_k: Propagation loss at distance D_k
- d: area diameter (km)
- *step*: discretisation of distance by steps in the radial direction (value used is 2 km)
- S_k: radar swath at distance D_k (km)
- A: macro cell radius
- B: macro cells Base station inter site in radial direction from radar (km)
- C: macro cells Base station inter site in transversal direction from radar (km).

with relations:

- $N =$ step / B
- $M_k =$ S_k / C
- $B =$ $3/2 . A$
- $C =$ $3/2 . \sqrt{3} . A$

The typical value of deployment parameters used in this study are given in Table A1.29. The diameter of coastal IMT deployment area is based on realistic metrics like seaside cities of Lagos (Nigeria) and Capetown (South Africa).

TABLE A1.29

Parameters for macro BS aggregation study

Localisation	**Scenario**	**Deployment area diameter 'd'**	**Macro cell radius**
Tropical	Sub-urban	20 km	0.6 km
Equatorial	Sub-urban	30 km	0.6 km
Tropical	Urban	5 km	0.3 km
Equatorial	Urban	8 km	0.3 km

In order to estimate the protection distance, the calculation would need to take into account the clutter or masking losses of each specific urban real deployment. A preliminary generic calculation of aggregated level of interference from these macro BS is to consider the additional aggregation faction AF_2 from:

– all of them in sub-urban deployment because 0% are considered below roof top of buildings.

– Half of them in urban deployment because 50% are considered below roof top of buildings.

The third part AF_3 of aggregation factor reflects an average activity of 50% for each macro base-station

5.2.2.2 Scenario with a shipborne radar at large distance from shoreline

This scenario consider that distance D_0 (from radar to the edge of IMT area deployment) is the minimal protection distance over the sea calculated in the previous section about the interference level from only one IMT macro base station. The aggregation factors AF_1 are given in Tables A1.30 to A1.33.

TABLE A1.30

Aggregation of 10 MHz macro BS from a sub-urban area in tropical zone

Ship-based radar type	B	C_1	C_2	D_1	D_2	M_1	M_2
Horizontal Beamwitdth (deg.)	1.7	1.1	5	1.5	6	1	5
Distance D_0 from Radar to Urban area (km)	296	308	308	308	308	308	308
Aggregation factor AF_1 (dB)	**16.2**	**14.2**	**21.6**	**16.2**	**22.4**	**14.0**	**14.2**

TABLE A1.31

Aggregation of 10 MHz macro BS from a sub-urban area in equatorial zone

Ship-based radar type	B	C	C	D	D	M	M
Horizontal Beamwitdth (degree)	1.7	1.1	5	1.5	6	1	5
Distance D from Radar to Urban area (km)	408	418	418	418	418	418	418
Aggregation factor AF_1 (dB)	**19.0**	**17.3**	**24.0**	**18.8**	**24.8**	**16.4**	**24.0**

TABLE A1.32

Aggregation of 10 MHz macro BS from an urban area in tropical zone

Ship-based radar type	B	C	C	D	D	M	M
Horizontal Beamwitdth (degree)	1.7	1.1	5	1.5	6	1	5
Distance D from radar to urban area (km)	296	308	308	308	308	308	308
Aggregation factor AF_1 (dB)	**14.9**	**13.0**	**19.8**	**14.5**	**20.6**	**12.3**	**19.8**

TABLE A1.33

Aggregation of 10 MHz macro BS from an urban area in equatorial zone

Ship-based radar type	B	C	C	D	D	M	M
Horizontal Beamwitdth (degree)	1.7	1.1	5	1.5	6	1	5
Distance D from radar to urban area (km)	408	418	418	418	418	418	418
Aggregation factor AF_1 (dB)	**18.3**	**16.5**	**23.2**	**18.0**	**24.0**	**16.0**	**23.2**

Taking into account aggregation factors AF_1, AF_2, and AF_3, the minimal aggregated protection distance values, are shown in Table A1.34.

TABLE A1.34

Protection distance from 10 MHz macro BS aggregation study

	Ship-based-B radar	**Ship-based-C radar**	**Ship-based-D radar**	**Ship-based-M radar**
Point-to-point required maximum propagation loss (dB)	196.0	197.5	197.5	197.5
AF_1 for suburban area in tropical zone (dB)	16.2	21.6	22.4	14.2
AF_1 for suburban area in equatorial zone (dB)	19.0	24,0	24,9	24,0
AF_1 for urban area in tropical zone (dB)	14.9	19.8	20.6	19.8
AF_1 for urban area in equatorial zone (dB)	18.3	23.2	24.0	23.2

TABLE A1.34 (*end*)

	Ship-based-B radar	Ship-based-C radar	Ship-based-D radar	Ship-based-M radar
AF_2: suburban scenario (dB)	0	0	0	0
AF_2: urban scenario (dB)	–3	–3	–3	–3
AF_3: Activity factor (dB)	–3	–3	–3	–3
Required propagation loss with aggregation for suburban tropical scenario (dB)	209	216	217	209
Required propagation loss with aggregation for suburban equatorial scenario (dB)	212	218	219	218
Required propagation loss with aggregation for urban tropical scenario (dB)	205	211	212	211
Required propagation loss with aggregation for urban equatorial scenario (dB)	208	215	215	215
Propagation model	ITU-R P.452-16 (case 1: p = 20%)			
Protection distance (km) at tropical sea in front of a suburban deployment	Between 354-422 km			
Protection distance (km) at equatorial sea in front of a suburban deployment	Between 480-540 km			
Protection distance (km) at tropical sea in front of an urban deployment	Between 324-380 km			
Protection distance (km) at equatorial sea in front of an urban deployment	Between 446-506 km			

In conclusion, taking into account the aggregated power of all macro base stations simultaneously in visibility of the antenna beam of a shipborne radar at sea, and considering parameters of rooftop ratio, activity factor, and no clutter losses, for either urban or sub-urban 10 MHz deployments, the minimal co-channel aggregated protection distances are calculated between 324 km and 422 km in tropical zone and between 446-540 km in equatorial zone.

5.2.2.3 Scenario with shipborne radar at 22 km from seaside

This scenario considers 22 km for distance D_0 from the ship based radar to the edge of IMT area deployment. The calculation considers the aggregated power of all macro base stations simultaneously in visibility of the antenna beam of the shipborne radar, and rooftop ratio, activity factor, and clutter losses, for urban 10 MHz deployments.

This analysis is considered as static by assuming that the position of the ship with respect of the IMT-Advanced BSs on the ground is fixed, and the radar antenna is pointing toward the IMT deployment, The aggregation process is not done over the rotation of the radar antenna because the performance of shipborne radar is generally requested for each azimuthal direction of its main beam.

Monte-Carlo simulations are performed over the IMT mobile network and the radar within the area of simulation to calculate the aggregated interference with caused by the BSs in order to derive a reliable statistic, e.g. CDF of the experienced aggregated interference over noise level, i.e. I_{agg}/N.

The randomization process is done at each run of simulation on following parameters:

– Uniform jitter on the position of the grid of BS macro site in transversal direction of the radar beam

– Position below roof top macro BS (or not) in macro urban scenario

– Activity or not of the base station

– Clutter value of the propagation path associated to each base-station

Let's denote *j* the index of the random samplings of macro base-stations in the IMT deployment.

The aggregated interference is then achieved in the following way:

$$Iagg = 10\log_{10}\left(\sum_{\substack{1\le i\le NbBSs,\\ 1\le j\le NbEvents}} 10^{\frac{P_{R,ij}}{10}}\right).$$

Figures A1-16 and A1-17 depict the CDF of I_{agg}/N (i.e. $P(X \le x_0)$ in ordinate while x-axis provides associated I/N values) for equatorial and tropical cases. Curves represent CDF for different radar types, with $R_{m,n}$ names' indexes indicating minimum and maximum values for their receivers bandwidths and antenna beamwidths.

FIGURE A1-16

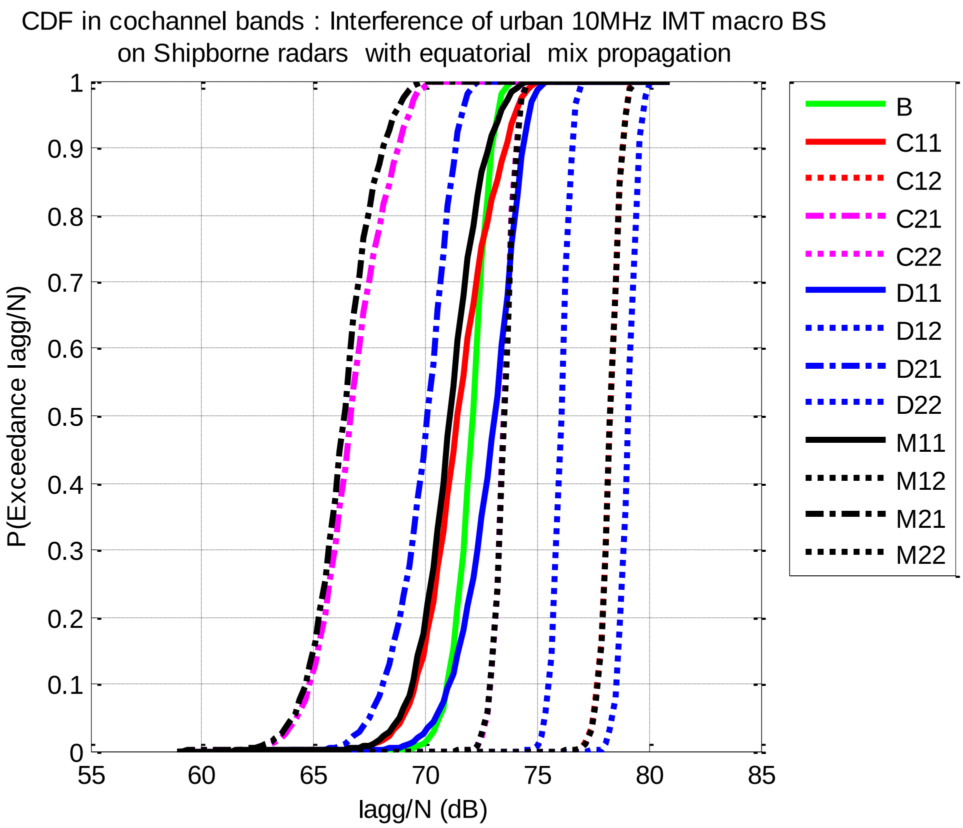
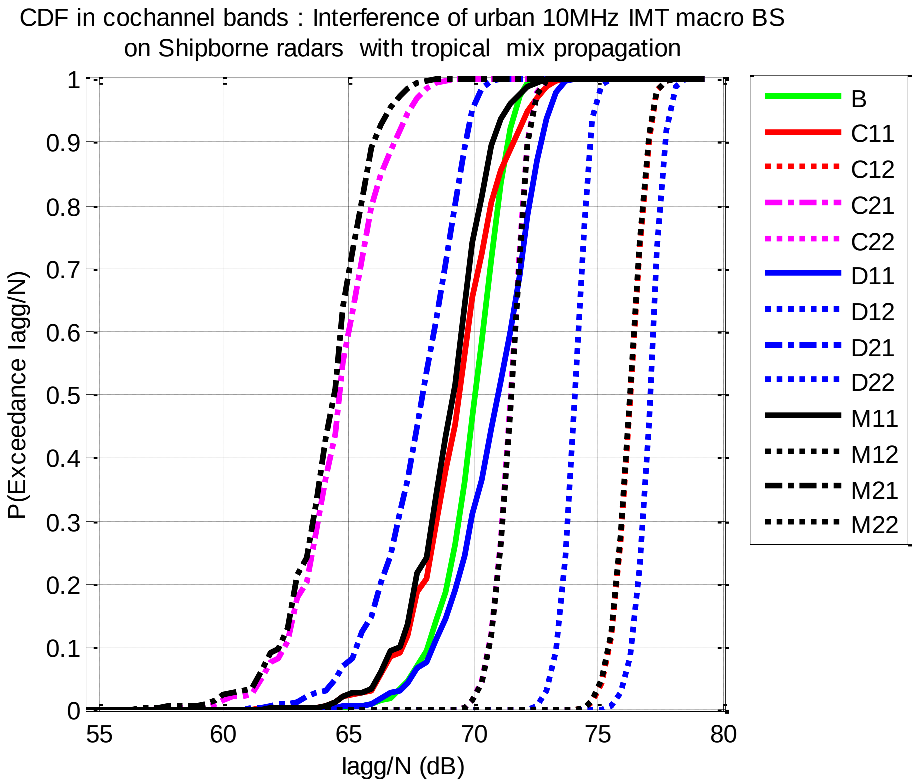


FIGURE A1-17



The Monte Carlo simulation results show a value of the CDF at 100% which indicates that the aggregated interference ratio *I*/*N* received by the radars standing 22 km from shoreline is up to 79 dB or 82 dB (at 100% in the CDF) depending tropical or equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of −6 dB.

In conclusion, based on these results, it can be concluded that a macro BS IMT-Advanced deployment is not compatible with protection criteria of shipborne radar systems in co-channel operations within 3.3-3.4 GHz.

5.2.3 Summary of co-channel interference from urban macro BS to shipborne radars

In summary it can be observed that for ship-based Radar B/C/D/M, the co-channel protection distance between one IMT macro base-station located at the shoreline and a ship based Radar, is 246 / 268 km (IMT BW 20/10 MHz) and 342 / 364 km (IMT BW 20/10 MHz) depending tropical or equatorial propagation conditions over the sea, using the propagation model with p = 20%.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, the emissions from one IMT macro base-station standing at the shoreline are received 65.5-68.5 dB over the co-channel protection margin of the radar, depending IMT channel bandwidths of 20 MHz or 10 MHz. At such low distance, this not depends of tropical or equatorial propagation conditions.

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, and considering path loss over sea, coastal and land zones, and no clutter losses or mask effect of buildings, the protection distance from any macro BS which could potentially interfered is 134-226 km, depending tropical or equatorial propagation conditions for 80% of time.

In this MCL study, considering low clutter losses or mask effect of buildings of 18 dB, the co-frequency protection distance of a radar from one IMT 10 MHz macro BS is found to 66-145 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%. For a median clutter loss of 28 dB, the protection distance of a radar from one IMT 10 MHz macro base station is found to 57-109 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%.

Without any other mitigation technique, this study shows that the co-frequency operation of macro base stations in coastal zones is not compatible with shipborne radars.

In a first aggregation study scenario, taking into account the aggregated power of all macro base stations simultaneously in visibility of the antenna beam of a shipborne radar at sea, and considering parameters of rooftop ratio, activity factor, and no clutter losses, either for urban or sub-urban 10 MHz deployments, the co-channel aggregated protection distances are calculated between 324 km and 422 km in tropical zone and between 446-540 km in equatorial zone with propagation conditions using the propagation model with p = 20%.

In a second aggregation study scenario, taking into account the aggregated power of all urban macro base stations simultaneously in visibility of the antenna beam of a shipborne radar standing at 22 km from shoreline, the Monte Carlo simulation results show that the aggregated interference ratio I/N received by radars is up to 79 dB or 82dB depending tropical or equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of −6 dB.

In conclusion, based on these results, it can be concluded that a macro BS IMT-Advanced deployment is not compatible with protection criteria of shipborne radar systems in co-channel operations within 3.3-3.4 GHz.

5.3 IMT terminal interference to Radar system

According to Report ITU-R M.2292, the IMT terminal’s maximum transmit power is 23 dBm. However, IMTs terminals have power control functionality and as a result the average transmit power is −9 dBm. In addition, the actual antenna gain is −4 dBi because of the body loss. Therefore, the IMT terminal e.i.r.p. is much lower than that of an IMT base station and as a result the separation distance required to protect radars will be much shorter than the distance required to protect from IMT base stations.

5.4 Radar interference to IMT system

The Report ITU-R M.2292 gives characteristics of IMT-Advanced (LTE) noting that:

– IMT-Advanced protection criteria I/N is –6 dB;

– specification in 3GPP TS 36.104 states that the base station receiver can saturate at − 43 dBm.

Table A1.35 shows interference levels into one IMT 10MHz macro base-station from one ship-based radar station standing at 22 km from shoreline.

TABLE A1.35

Interference into one IMT 10MHz macro base-station from one ship-based radar station standing at 22 km from shoreline

	Ship-based B radar	**Ship-based C radar**	**Ship-based D radar**	**Ship-based M radar**
Carrier frequency (GHz)	3.3	3.3	3.3	3.3
Radar Transmitter bandwidth (–3 dB) (MHz)	4	25	15	25
Radar Transmitter output power (dBm)	98	83	79	90
Radar antenna gain (dBi)	42	40	40	40
Separation distance (km)	22	22	22	22
Propagation loss (dB) P.452-16, Equatorial, sea path, *p* = 20%)	129	129	129	129
IMT Urban Macro BS antenna gain (considering downtilt) (dBi)	6.0	6.0	6.0	6.0
IMT BS feeder loss (dB)	3	3	3	3
Frequency offset (MHz)	0	0	0	0
IMT BS Receiver bandwidth (MHz)	10	10	10	10
IMT BS Rx Noise Factor	5.0	5.0	5.0	5.0
Maximum allowable interference power at IMT BS receiver input (dBm)	–105	–105	–105	–105
IMT BS Receiver in band saturation (dBm)	–43	–43	–43	–43
Interference power at BS receiver input (dBm)	+14.0	–3.0	–7.0	+4.0
Blocking (dB) over saturation level	**+57**	**+40**	**+36**	**+47**
Pulse width (µs)	6.4-51.2	0.1-1000	0.1-100	0.1-1000
Repetition rate (kHz)	0.152-6.0	0.3-10	0.5-10	0.3-10

It can be concluded that during shipborne radars transmitting mode in co-frequency, the RF pulses are strongly blocking the IMT receivers, even considering additional clutter losses for BS below rooftops. Taking into account that receivers' radio interface characteristics of micro base stations and user equipments are in the same order of magnitude than macro BS ones, radar pulses should block cofrequency reception of micro BS and UE.

The interference is too strong for even a short period of time, then the forward Error Correction (FEC) may not be effective. However, LTE also uses Hybrid-Automatic Repeat reQuest (HARQ) with Chase combining. In this technique, if portions of one LTE frame are detected with errors that cannot be corrected by FEC, the frame is retransmitted and the received signals are weighted by their signal-to-noise ratio and soft combined until the frame is error free. This type of error correction is one of the most powerful mechanisms for retaining an acceptable throughput rate on a LTE network that is experiencing strong interference. Although a strong interferer could cause a high weighting for the packet in error that could cause further retransmission of the packets and lower the throughput, the IMT system can still work. The mechanism of HARQ can be found in Recommendation ITU-R M.2012, 3GPP TS 36211, 36213 and other related recommendations.

The long-period degradation of the IMT system and the HARQ mitigation technique performance, considering the short-period impulse feature of radar blocking signals, should be further evaluate.

Study C

1 Technical characteristics of IMT and land-based radar systems

1.1 IMT system parameters

Section 2 in main body contains the list of parameters for IMT deployment, which are taken from Report ITU-R M.2292.

1.2 Radar parameters

Section 2 in main body provides the key radar parameters, and Table A1.36 gives parameters of land based radars to be used for these studies. For reducing the number of cases to study, the based radars to consider are types A to E, and a type M with IF bandwith of 10 MHz.

The radar receiver IF selectivity fall-off is –80 dB/decade. The radar antenna height is 20 metres.

TABLE A1.36

Land based Radar considered parameters for the coexistence study

Characteristics	Units	Radar								
		A	**B**	**C**	**D**	**E**	**I**	**K**	**L**	**M**
Antenna height above ground	m	20	20	20	20	20	20	20	20	20
Antenna Gain	dBi	39	40	31	40	22	33.5	40	43	40
Receiver IF 3 dB bandwidth	MHz	380	0.67	2	30	5-10	1.5, 3.5	NA	NA	10 -30
Receiver noise figure	dB	3.1	4.0	1.5	4	3	2	NA	NA	1.5
Receiver IF selectivity Fall-off	dB/decade	−80	−80	−80	−80	−80	−80	−80	−80	−80

2 Coexistence and compatibility scenarios between IMT and Radar

Recommendation ITU-R M.1465 provides indication of the typical uses of the airborne, land-based and ship-based radars operating in the frequency band 3 100-3 700 MHz. Based on the guidance of this recommendation, the following scenario of potential interference have been analysed:

2.1 Interference from IMT to land based radar

The study considers:

– a smooth earth between transmitter and receiver, with a path terrain profile at 0 metre above sea level at all points;

– a full inland propagation path;

– Scenarios considering equatorial regions because propagations losses are significantly less than tropical region.

As described in Figs A1.19 and A1.20, the following scenarios are considered:

– Single entry study of interference from one IMT 20 MHz micro base station in an urban deployment to land-based radars standing in a foreign country.

– Single entry study of interference from one IMT 10 MHz macro base station in an urban deployment to land-based radars standing in a foreign country.

– Interference from aggregated 10 MHz IMT base stations in sub-urban or urban macro-cell deployment to land-based radars.

FIGURE A1-18

Single entry scenario between an IMT base-stations and a Radar station located in a foreign country

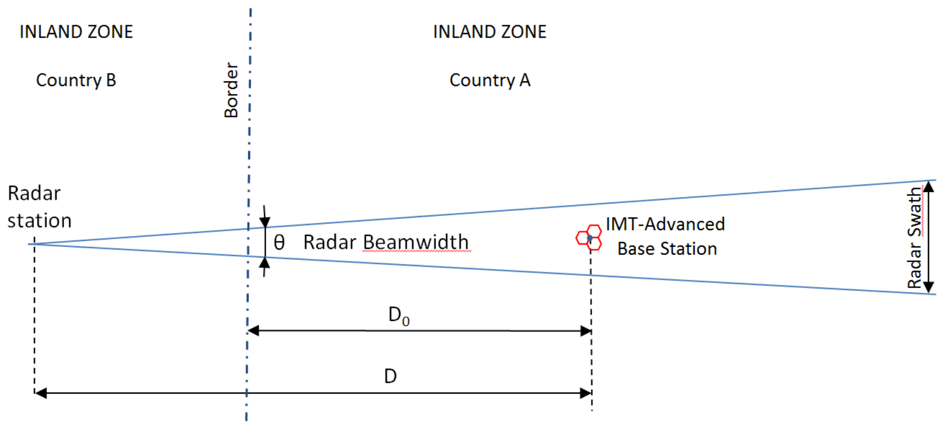
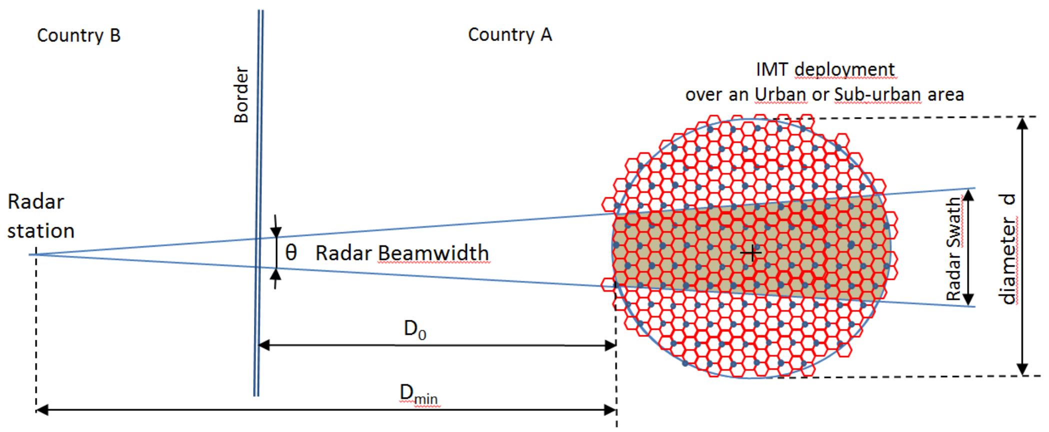
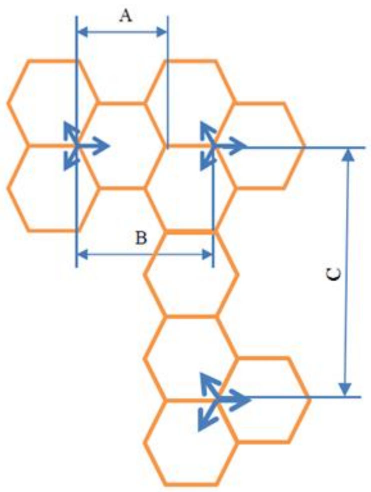


FIGURE A1-19

Aggregation scenario between IMT base-stations from a country A deployment, and a Radar station located in a country B





Each cell (also referred to as a sector) is shown as a hexagon, and in this Figure there are three cells/sectors per base station site, accordingly to Report ITU-R M.2292,

where:

D_0: distance to border from edge of IMT deployment

D: distance in the radial direction from a base station to radar

D_{min}: distance in the radial direction to radar from edge of IMT deployment

d: diameter of the IMT deployment area (km)

θ: radar beamwidth (°) at –3 dB points in azimuth

A: macro cell radius

B: macro cells Base station inter site in radial direction from radar (km)

C: macro cells Base station inter site in transversal direction from radar (km)

with relations:

$$B = 3/2 \, . \, A \qquad \text{and} \quad C = 3/2 \, . \, \sqrt{3} \, . \, A$$

The value of parameters used in this study, for the IMT deployment, are given in Table A1.37.

TABLE A1.37

Parameters used for micro BS aggregation study

Localisation	Scenarios	Area diameter 'd'	Macro cell radius (km)	Micro BS per macro cells	Average BS Activity
Equatorial	Urban	8 km	0.3	3	50%
Tropical	Urban	5 km	0.3	3	50%

The typical number of urban micro base station per macro cells taken into account are 1 to 3 accordingly to Table 1 from main body, extracted from Report ITU-R M.2292 on IMT Deployment-related parameters.

The scenario of interference from a mix of urban and suburban macro BS in instantaneous visibility of the radar antenna beam is not considered in this study, neither a mix of 10 MHz and 20 MHz base stations.

The scenario of interference from one or many aggregated IMT base stations operating few or fully multichannels over 3 300-3 400 MHz band has not yet be considered. An additional frequency channels aggregation factor will need to be taken into account in this case, leading to greater separation distances.

3 Interference criteria

In accordance to § 5 of the main body of the Report.

4 Propagation models

The propagation model between IMT system and land based radar is from Recommendation ITU-R P.452, and performed by an average year prediction with cases of parameter p =10% and 20% (time percentage for which the calculated basic transmission loss is not exceeded). All the propagation factors in Recommendation ITU-R P.452, except clutter losses, are considered.

The calculation of pathlosses, fully in land, takes into account the Recommendation ITU-R P.452 radio climatic zone A2. As recommended in ITU-R P.452, the in-land zone is 50 km away from coastal salt waters.

Table A1.38 gives parameters used to calculate propagation losses, based on an hypothetic case of an IMT deployment in city of Yaounde (Cameroun) and an hypothetic radar system operating in north of Gabon.

TABLE A1.38

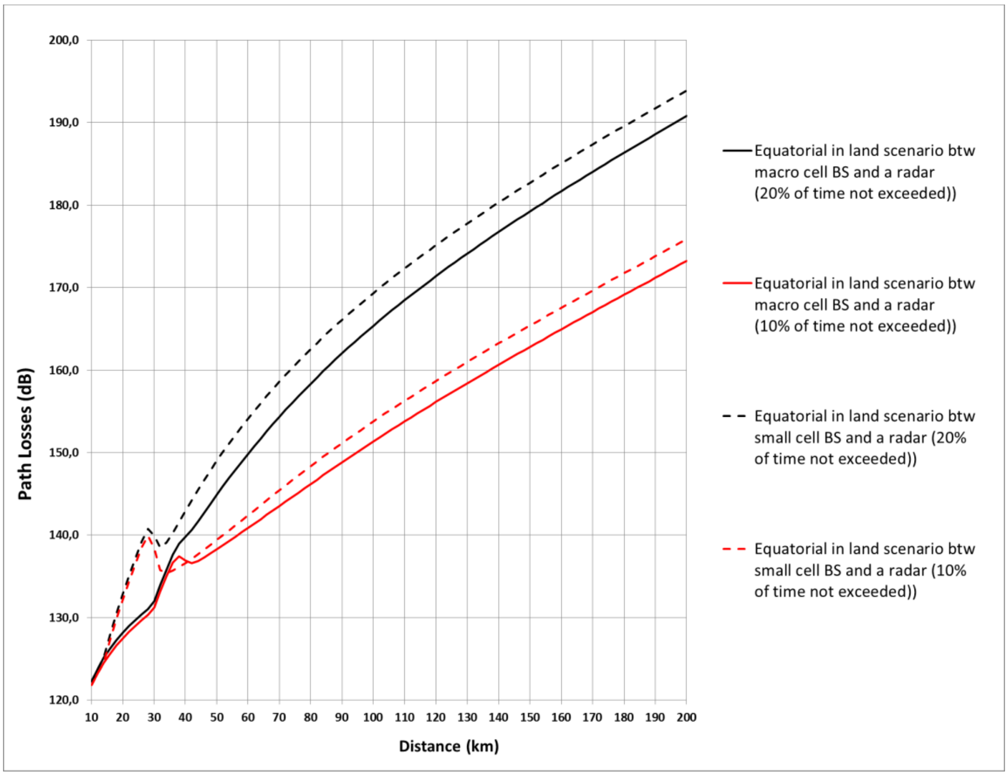
Parameters used propagation losses calculated with Rec. ITU-R P.452

	Geographic situation	**Equatorial**	**Equatorial**
	Base station type	Macro	Micro
φt	Latitude transmitter (degree)	3° 52’	3° 52’
ψt	Longitude transmitter (degree)	11° 31’	11° 31’
φr	Latitude receiver (degree)	2° 05’	2° 05’
ψr	Longitude receiver (degree)	11° 29’	11° 29’
htg	Transmitter height (metres)	20	6
hrg	Receiver height (metres)	20	20
Gt	Transmitter antenna gain (dB)	6-10	5
Gr	Transmitter antenna gain (dB)	22-40	22-40
N0	Sea-level surface refractivity (N-units)	375	375
deltaN	Average radio-refractive index lapse-rate (N-units/km),	50	50

Figure A1-20 shows annual average pathlosses calculated completely in land, and during p = 10% and p = 20% of time for which the transmission loss is not exceeded. The curves indicate the minimum path losses respectively using the propagation model with p = 10% and 20%. It should be noticed the sensitivity of this parameter showing variation around 20 dB between the two cases of percentage of time.

FIGURE A1-20

Path losses between an IMT base station and a land-based radar (ITU-R P.452-16 with $p = 10\%$ and $p = 20\%$)



Clutter models

In accordance to § 4 in main body, the clutter loss value is defined to zero for MCL single entry calculation. Informative analysis with clutter losses of 18 and 28 dB is also done. For aggregation studies, the impact of buildings on separation distance or margin will be approximated by using the statistical distribution defined in § 4 of main body.

5 Study results

5.1 IMT micro base stations deployed in outdoor micro BS

The protection distance to avoid interference in a co-channel scenario from an IMT system deployed in outdoor micro BS to land based radars is evaluated in this section.

5.1.1 Single entry Interference from one IMT micro base-station

Table A1.39 gives the required propagation loss and protection distance of a radar from one 20 MHz micro base station.

TABLE A1.39

Interference from one IMT outdoor 20 MHz micro base-station to land based radar stations

Parameters	Radar A	Radar B	Radar C	Radar D	Radar E	Radar M
Carrier frequency (GHz)	3.3	3.3	3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)	20	20	20	20	20	20
Maximum output power (dBm)	24	24	24	24	24	24
Antenna gain of outdoor micro IMT base-station (dBi)	5	5	5	5	5	5
Antenna gain radar (dBi)	39	40	31	40	22	40
Radar Rx Noise figure	3.1	4.0	1.5	4.0	3.0	1,5
Radar IF bandwidth (MHz)	380	0.67	2	30	5-10	10
Frequency offset (MHz)	0	0	0	0	0	0
On Tune Rejection (dB)[6]	0	14.7	10.0	0	6.0-3.0	3.0
Maximum allowable interference power at radar receiver input (dBm)	–91.1	–117.7	–115.5	–101.2	–110.0 / –107.0	–108.5
Propagation model	ITU-R P.452-16 (Case 1: *p* = 20%)					
Single entry without clutter loss for one micro BS						
Required propagation loss (dB) without clutter	159.1	172.0	165.5	170.2	155.5	174.5
Protection distance (km) with equatorial land pathlosses (*p* = 20%)	71	109	88	102	62	118
Single entry with low clutter loss for one micro BS						
Low clutter loss for micro BS (dB)	18	18	18	18	18	18
Required propagation loss (dB)	141.1	154.0	147.5	152.2	137.5	156.5
Protection distance (km) with an equatorial pathloss (*p* = 20%) and low clutter loss	37	60	47	56	24	65
Single entry with median clutter loss for one micro BS						
Median clutter loss for micro BS (dB)	28	28	28	28	28	28
Required propagation loss with median clutter (dB)	131.1	144.0	137.5	142.2	127.5	146.5
Protection distance (km) with an equatorial pathloss (*p* = 20%) and median clutter loss	19	42	24	39	16	45

6 Recommendation ITU-R SM.337 defines the On Tune Rejection (OTR) as the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of a transmitted signal exceeding the receiver bandwidth.

In summary, it can be observed that the co-channel protection distance between one IMT 20 MHz outdoor micro base-station and a land based Radar, without clutter loss, is 118 km depending equatorial propagation conditions over the land using the propagation model with p = 20%.

In this MCL study, taking into account low clutter losses or mask effect of buildings of 18 dB, the protection distance of a radar from one micro base station is 65 km.

With a median clutter loss of 28 dB, the protection distance of a radar from one micro base station is found to be 45 km.

5.1.2 Aggregation study of micro base-stations

This analysis is considered as static by assuming that the position of the land based radar with respect of the IMT-Advanced BS is fixed, (arbitrary separation distance of 20km) and that the radar antenna is pointing toward the IMT deployment, The aggregation process is not done over the rotation of the radar antenna because the performance of a radar is generally requested for each azimuthal direction of its main beam.

Monte-Carlo simulations are performed over the IMT mobile network and the radar within the area of simulation to calculate the aggregated interference with caused by the BSs in order to derive a reliable statistic, e.g. CDF of the experienced aggregated interference over noise level, i.e. I_{agg}/N.

The randomization process is done at each run of simulation on following parameters:

– Uniform repartition of position for each micro BS in its macro cell

– Activity or not of the base station

– Clutter value of the propagation path associated to each base-station

Let's denote j the index of the random samplings of each micro base-station in the deployment.

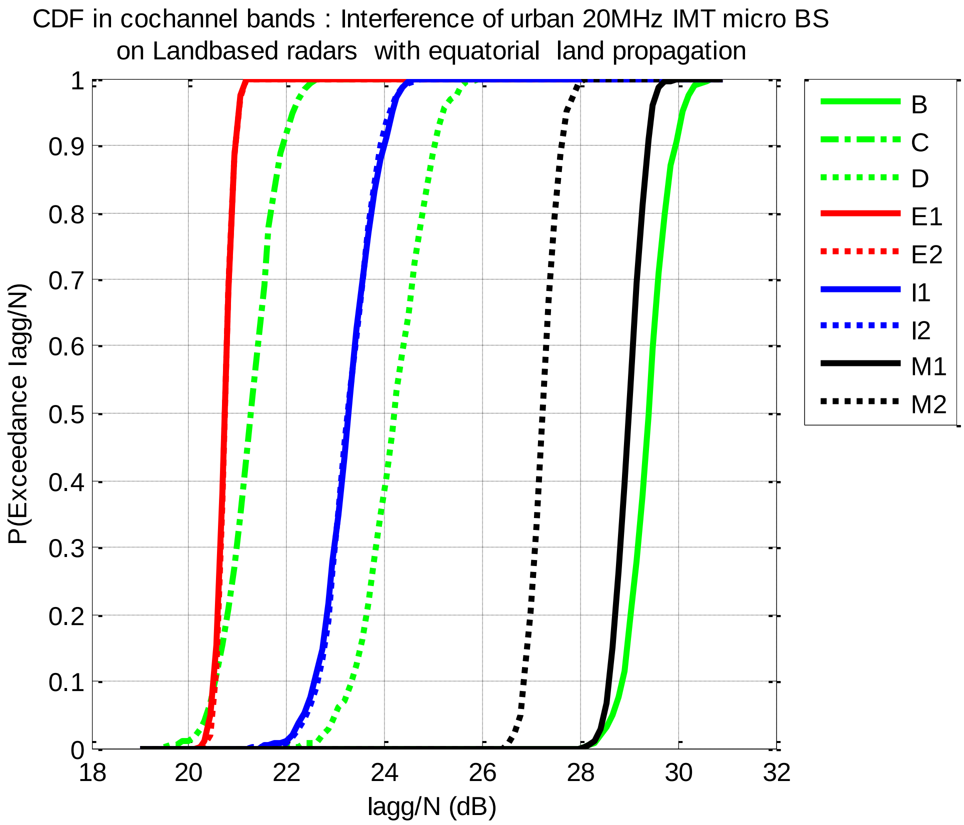
The aggregated interference is then achieved in the following way:

$$Iagg = 10\log_{10}\left(\sum_{\substack{1\leq i\leq \text{NbBSs},\\ 1\leq j\leq \text{NbEvents}}} 10^{\frac{P_{R,ij}}{10}}\right).$$

The simulation of the urban deployment considers and density of three micro BS per macro-cell.

Figure A1-21 depicts the CDF of I_{agg}/N (i.e. $P(X \leq x_0)$ in ordinate while x-axis provides associated I/N values) for equatorial case. Curves represent CDF for different radar types, with Rm names' indexes indicating minimum and maximum values for the receivers bandwidths. Only one case of antenna beamwidth per radar type is considered in this study.

FIGURE A1-21



Considering urban deployment characteristics with density of 3 micro BS per macro cell, the results of a static analysis with Monte Carlo simulation show that the aggregated interference ratio *I*/*N* received by the radars standing 20 km from a co-channel IMT deployment is up to 31 dB in land equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of –6dB.

In conclusion, based on these results, it can be concluded that a micro BS IMT-Advanced deployment is not compatible with protection criteria of land-based radar systems in co-channel operations within 3.3-3.4 GHz.

5.2 IMT base stations deployed in urban macro cells

This section studies the protection distance to avoid interference to land-based radars from IMT macro base stations in an urban deployment.

5.2.1 Interference from only one IMT urban macro base-station

Table A1.40 evaluates the separation distance for allowable interference from only one IMT 10 MHz urban macro base-station to a land based radar.

TABLE A1.40

Interference from one IMT 10 MHz urban macro base-station to land based radar stations

Parameters	Radar A	Radar B	Radar C	Radar D	Radar E	Radar M
Carrier frequency (GHz)	3.3	3.3	3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)	10	10	10	10	10	10
Maximum output power (dBm)	46	46	46	46	46	46
Antenna gain of IMT urban macro BS with 10°downtilt (dBi)	6	6	6	6	6	6
Antenna gain radar (dBi)	39	40	31	40	22	40
Frequency offset (MHz)	0	0	0	0	0	0
Noise figure	3.1	4.0	1.5	4.0	3.0	1.5
Radar IF bandwidth (MHz)	380	0.67	2	30	5-10	10
On Tune Rejection (dB)[7]	0	11.7	7.0	0	3.0-0.0	0.0
Maximum Allowable interference power at radar receiver input (dBm)	–91.1	–117.7	–115.5	–101.2	–110.0 / –107.0	–108.5
Propagation model	ITU-R P.452-16 (Case 1 : *p* = 20%)					
Single entry without clutter loss for one micro BS						
Required propagation loss (dB) without clutter	179.1	195.0	188.5	190.2	178.0	197.5
Protection distance (km) with equatorial land pathlosses for *p* = 20%	149	219	189	196	145	230
Single entry with low clutter loss for one micro BS						
Low clutter loss for micro BS (dB)	18	18	18	18	18	18
Required propagation loss (dB)	161.1	177.0	170.5	172.2	160.0	179.5
Protection distance (km) with an equatorial pathloss (*p* = 20%) and low clutter loss	88	141	116	123	84	150
Single entry with median clutter loss for one urban micro BS						
Median clutter loss for micro BS (dB)	28	28	28	28	28	28
Required propagation loss with median clutter (dB)	151.1	167.0	160.5	162.2	150.0	169.5
Protection distance (km) with an equatorial pathloss (*p* = 20%) and median clutter loss	62	105	84	90	60	113

In summary, it can be observed that the co-channel protection distance between one IMT 10 MHz urban macro base-station and a land based Radar, without clutter loss, is 230 km depending equatorial propagation conditions over the land using the propagation model with *p* = 20%.

[7] Recommendation ITU-R SM.337 defines the On Tune Rejection (OTR) as the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of a transmitted signal exceeding the receiver bandwidth.

In this MCL study, taking into account low clutter losses or mask effect of buildings of 18 dB, the protection distance of a radar from one urban macro base station is 150 km.

With a median clutter loss of 28 dB, the protection distance of a radar from one urban macro base station is found to be 113 km.

5.2.2 Aggregation study of macro BS

This analysis is considered as static by assuming that the position of the land based radar with respect of the IMT-Advanced BS is fixed, (arbitrary separation distance of 20 km), and the radar antenna is pointing toward the IMT deployment, The aggregation process is not done over the rotation of the radar antenna because the performance of a radar is generally requested for each azimuthal direction of its main beam.

Monte-Carlo simulations are performed over the IMT mobile network and the radar within the area of simulation to calculate the aggregated interference with caused by the BSs in order to derive a reliable statistic, e.g. cdf of the experienced aggregated interference over noise level, i.e. I_{agg}/N.

The randomization process is done at each run of simulation on following parameters:

– Uniform jitter on the position of the grid of BS macro site in transversal direction of the radar beam

– Position below roof top macro BS (or not) in macro urban scenario

– Activity or not of the base station

– Clutter value of the propagation path associated to each base-station.

Let us denote *j* the index of the random samplings of macro base-stations in the IMT deployment.

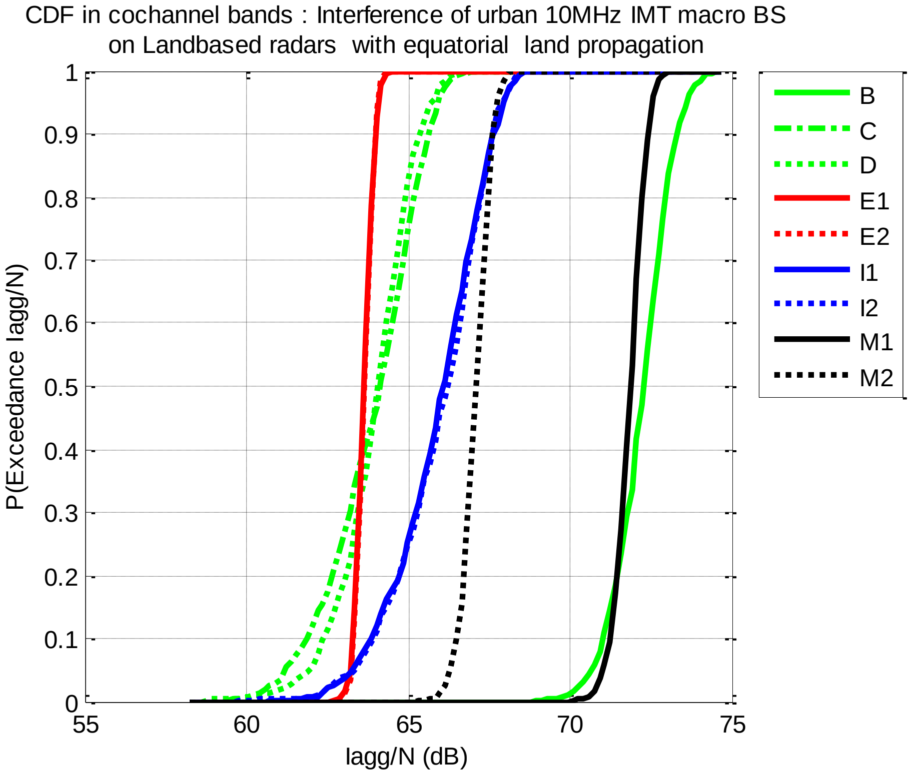
The aggregated interference is then achieved in the following way:

$$Iagg = 10\log_{10}\left(\sum_{\substack{1\le i\le NbBSs,\\ 1\le j\le NbEvents}} 10^{\frac{P_{R,ij}}{10}}\right).$$

The simulation of the urban deployment considers random uniform repartition and density of three micro BS per macro-cell.

Figure A1-22 depicts the cdf of I_{agg}/N (i.e. $P(X \le x_0)$ in ordinate while x-axis provides associated I/N values) for equatorial case. Curves represent cdf for different radar types, with Rm names' indexes indicating minimum and maximum values for the receivers bandwidths. Only one case of antenna beamwidth per radar type is considered in this study.

FIGURE A1-22



The results of a static analysis with Monte Carlo simulation show that the aggregated interference ratio *I*/*N* received by a landbased radar standing 20 km from a co-channel IMT deployment is up to 74 dB (at 100% in the CDF) in land equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of −6 dB.

In conclusion, based on these results, it can be concluded that a macro BS IMT-Advanced deployment is not compatible with protection criteria of land-based radar systems in co-channel operations within 3.3-3.4 GHz.

Study D

1 Scenarios for coexistence study

Coastal area scenarios are considered. Ship-based radiolocation radars B and C defined in Recommendation ITU-R M.1465 receive interference from single entry IMT-Advanced BS operating in co-channel or adjacent channel. IMT-Advanced BS is assumed to locate at shoreline in Incheon, Korea. The worst case is studied where the peak antenna gain of radar are taken, and peak gain with a loss due to antenna tilting is considered for computing the antenna gain of BS.

2 System characteristics

2.1 Characteristics for IMT BS with Adaptive Antenna System

Table A1.41 summarises the relevant base station characteristics from Report ITU-R M.2292.

TABLE A1.41

Characteristics of IMT-Advanced System in 3 300-3 400 MHz frequency band (Table 1 of Att. 4.13 to Doc. 5D/875)

Parameter	**Macro suburban**	**Macro urban**	**Micro urban**
Carrier frequency (GHz)	3.3	3.3	3.3
Signal bandwidth (MHz)	10	10	10
Maximum output power (dBm/10 MHz)	46	46	24
BS antenna height (m)	25	20	6
Downtilting (degrees)	6	10	0
Antenna gain with downtilting (dBi)	10.4	5.8	5
Feeder loss (dB)	3	3	0
EIRP/10MHz (dBm)	53.4	48.8	29
Below rooftop base station antenna deployment (%)	0	50	100

2.2 Characteristics of the Radiolocation systems

Recommendation ITU-R M.1465 provides characteristics of radiolocation radars operating in the frequency range 3 100-3 700 MHz. Part of parameters for sharing study are summarized in Table A1.42. The antenna height is 20 metres. Rx IF bandwidth of 10 or 30 MHz for Radar C are applied because the 10 MHz operation causes the worst case of co-channel study while the 30 MHz does that of adjacent channel study.

TABLE A1.42

Characteristics of Radar in 3 300-3 400 MHz frequency band (Rec. ITU-R M.1465-2)

Parameter	**Ship-based Radar B**	**Ship-Based Radar C**	
Antenna gain (dBi)	42	Up to 40	
Antenna height (m)	20	20	
Rx noise figure (dB)	5.0	1.5	
Rx IF bandwidth (–3 dB) (MHz)	10	10	30
Allowable interference power (dBm/10MHz)	−105	−108.5	−103.7

3 Propagation models

The propagation model between IMT system and ship based radar is from Recommendation ITU-R P.452-16. All the propagation factors in Recommendation ITU-R P.452 are considered. The 20%, 10%, and 1% time percentages are used, but cannot be considered as a worst case because some missions of radar systems could be more demanding.

The clutter loss model used in this Report combines for each IMT deployment, a percentage of above rooftop base stations without clutter loss and a percentage of below rooftop base stations with clutter loss values defined in § 3.2 of the Recommendation ITU-R P.2108 by a statistical model for end correction of terrestrial to terrestrial long-path propagation.

TABLE A1.43

Parameters used propagation losses calculated with Rec. ITU-R P.452

Symbol	Parameter	Value
φt	Latitude transmitter (degree)	37.45
ψt	Longitude transmitter (degree)	37.45
φr	Latitude receiver (degree)	126.59
ψr	Longitude receiver (degree)	126.59
htg	Transmitter height (metres)	25 (suburban macro), 20 (urban macro), 6 (urban micro)
hrg	Receiver height (metres)	20
hgt	Transmitting ground height above mean sea level (metres)	0, 50
hgr	Receiving ground height above mean sea level (metres)	0
Gt	Transmitter antenna gain (dB)	18 (suburban macro), 18 (urban macro), 5 (urban micro)
Gr	Transmitter antenna gain (dB)	40 (radar B), 42 (radar C)
N0	Sea-level surface refractivity (N-units)	330
ΔN	Average radio-refractive index lapse-rate (N-units/km)	45

4 Interference criteria

Signals received by radars from other systems could generate different types of degradation of performances. Desensitisation is generally due to low level of interfering signals, and saturation or blocking of receivers could be observed for larger interfering signals.

Recommendation ITU-R M.1465 provides the radar interference criteria in the radiolocation service given as $I/N \leq -6$ dB, where I is the interference power for radar and N is the receiver noise power.

5 Methodology for interference calculation from IMT to Radar

5.1 Methodology for single entry studies in co-channel

Assuming one IMT BS or user equipment interferes a radiolocation service radar in co-channel or adjacent channel, the received interference power level at the radiolocation service radar is given by:

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

where:

I_{IMT} : the received interference power level in the bandwidth of the radiolocation service radar (dBm)

P_{IMT} : transmission power 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 propagation loss (dB)

OTR : On tune rejection as defined in Recommendation ITU-R SM.337.

5.2 Methodology for single entry studies in adjacent-channel

Assuming one IMT BS or user equipment interferes a radiolocation service radar in co-channel or adjacent channel, the received interference power level at the radiolocation service radar is given by

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

where:

I_{IMT} : received interference power level in the bandwidth of the radiolocation service radar (dBm)

P_{IMT} : transmission power of IMT system (dBm)

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

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

$L(f,d)$: propagation loss (dB)

FDR : Frequency dependent rejection (dB) as defined in Recommendation ITU-R SM.337

Δf : Frequency offset (Hz) as defined in Recommendation ITU-R SM.337.

6 Results of coexistence studies

6.1 Co-channel studies between single IMT base station and radar

The Minimum Coupling Loss method is applied to estimate potential interference power from in single entry worst case scenarios. Average base station activity factor is ignored. The minimum propagation loss required to protect the ship-based radar B and C is computed first since it is independent of propagation model and could be the base line of coexistence studies with diverse propagation assumption. Presented below are the minimum separation distances for main propagation parameters: BS ground height, percentage of time, and clutter loss.

TABLE A1.44

Minimum propagation loss and corresponding separation distance (minimum protection distance) required to protect ship-based radars B and C from IMT BS interference, No clutter loss

Minimum propagation loss (dB)		BS ground height above sea level (m)	Percentage of time (%)	Minimum protection distance (km)	
Radar B 10 MHz	Radar C 10 MHz			Radar B 10 MHz	Radar C 10 MHz
Macro Suburban					
200.4	201.9	0	1	757	772
			10	432	446
			20	283	294
		50	1	714	729
			10	409	421
			20	266	277
Macro Urban					
195.8	197.3	0	1	708	723
			10	390	403
			20	247	257
		50	1	667	682
			10	370	382
			20	235	245
Micro Urban					
176	177.5	0	1	501	515
			10	225	235
			20	120	127
		50	1	479	494
			10	230	240
			20	132	138

Presented below are the amount of additional reduction in interference power required to protect the ship-based radars B and C locating 1 or 22 km away from shoreline. The additional reduction could be achieved with higher clutter loss, lower EIRP of IMT BS, and/or building entry loss due to indoor deployment of IMT BS.

Percentage of time has little effect on the amount of additional reduction since propagation losses at distances below 25 km are almost same as shown in Fig. A1.23. BS ground height also hardly affect the amount of additional reduction.

TABLE A1.45

The amount of additional reduction in interference power required to protect ship-based radars B and C from IMT BS interference

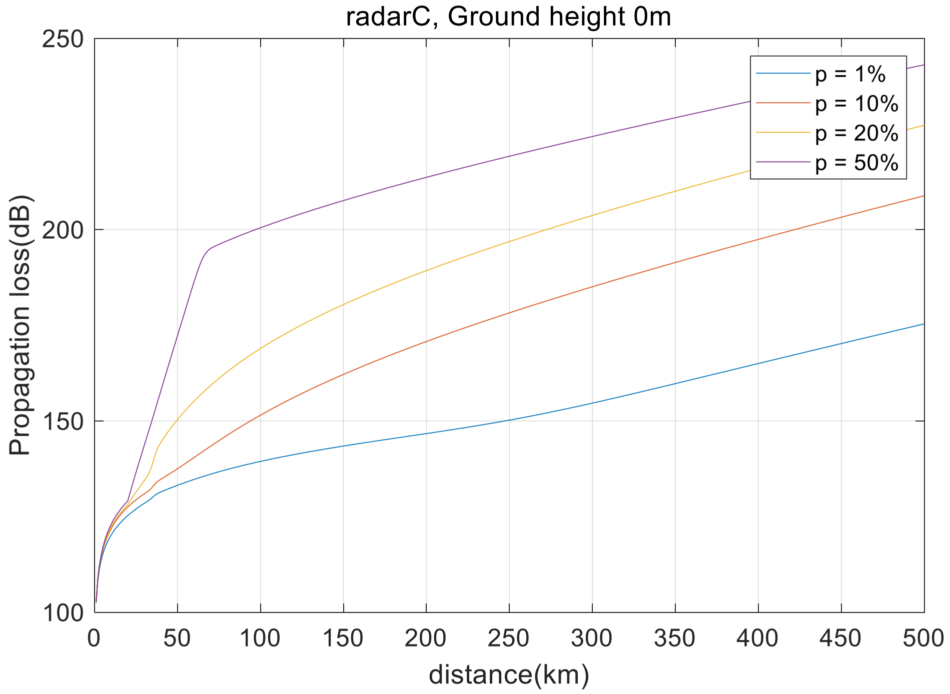
Clutter loss (dB)	BS ground height above sea level (m)	Percentage of time (%)	Additional reduction in interference power (dB)			
			Radar B 10 MHz		Radar C 10 MHz	
			1 km far from shoreline	22 km far from shoreline	1 km far from shoreline	22 km far from shoreline
Macro Suburban						
0	0	1	98	75	100	77
		10		73		75
		20		72		74
	50	1		75		77
		10		73		75
		20		72		74
Macro Urban						
0	0	1	94	69	96	71
		10		67		69
		20		66		68
	50	1		69		71
		10		67		69
		20		66		68
18	0	1	76	51	78	53
		10		49		51
		20		48		50
	50	1		51		53
		10		49		51
		20		48		50
28	0	1	66	41	68	43
		10		39		41
		20		38		40
	50	1		41		43
		10		39		41
		20		38		40

TABLE A1.45 (*end*)

Clutter loss (dB)	BS ground height above sea level (m)	Percentage of time (%)	Additional reduction in interference power (dB)			
			Radar B 10 MHz		Radar C 10 MHz	
			1 km far from shoreline	22 km far from shoreline	1 km far from shoreline	22 km far from shoreline
Micro Urban						
0	0	1	74	50	76	52
		10		48		50
		20		45		47
	50	1		50		52
		10		48		50
		20		48		49
18	0	1	56	32	58	34
		10		30		32
		20		27		29
	50	1		32		34
		10		30		32
		20		30		31
28	0	1	46	22	48	24
		10		20		24
		20		17		19
	50	1		22		24
		10		20		22
		20		20		21

FIGURE A1-23

Propagation loss for various percentages of time for ship-based radar C, zero ground height of BS (Rec. ITU-R P.452)



6.2 Studies between IMT terminals and radars

According to Attachment 4.13 to Document 5D/875, the separation distance required to protect radars would be much shorter than the distance required to protect from IMT base stations.

7 Summary and concluding remarks

All numerical results are analysed for BS locating at shoreline and ship-based radars in co-channel channel.

The results presented in this report show clearly that mitigation techniques and measures are necessary for the coexistence of future deployment of IMT-Advanced systems with incumbent radar systems in these bands.

7.1 Co-channel studies

Interference powers at victim radars exceed the protection criteria for all cases, and they need to be further reduced by at least 98/94/74 dB for macro suburban/macro urban /micro urban without clutter loss.

For protection of radars B and C at 22 km far from shoreline, the interference power from macro suburban BS, without clutter loss, needs to be reduced by 72-77 dB. The interference power from macro urban BS, without clutter loss, needs to be reduced by 66-71 dB. The interference power from micro urban BS, without clutter loss, needs to be reduced by 48-52 dB.

These variations of power reduction are dependent on BS ground height and percentage of time input to Recommendation ITU-R P.452 model. For the short distance of 1 km from shoreline, the required power reduction does not depend on ground height and percentage time since the two parameters nearly affect propagation loss at such low distance.

TABLE A1.46

The amount of additional reduction in interference power required to protect ship-based radars B and C from IMT BS (10 MHz) interference

Clutter loss (dB)	BS ground height above sea level (m)	Percentage of time (%)	Additional reduction in interference power (dB)			
			Radar B 10 MHz		Radar C 10 MHz	
			1 km from shoreline	22 km from shoreline	1 km from shoreline	22 km from shoreline
Macro Suburban						
0	0-50	1-20	98	72-75	100	74-77
Macro Urban						
0	0-50	1-20	94	66-69	96	68-71
18	0-50	1-20	76	48-51	78	50-53
28	0-50	1-20	66	38-41	68	40-43
Micro Urban						
0	0-50	1-20	74	48-50	76	49-52
18	0-50	1-20	56	30-32	58	29-34
28	0-50	1-20	46	17-22	48	19-24

Study E

This section provides a study of compatibility between IMT and radar systems in the frequency band 3 300-3 400 MHz. The following scenarios have been considered:

– Micro urban IMT BS interfering with shipborne radar type D

– Macro urban IMT BS interfering with shipborne radars type D

– Indoor small cell IMT BS interfering with shipborne radars type D

The impact of single entry interference from an IMT BS with Advanced Antenna System has been examined for macro and micro urban BSs operating co-channel with the radar and located at two locations: a tropical and an equatorial location.

1 Technical characteristics of IMT and radar systems

TABLE A1.47

IMT base station deployment parameters

Parameters	Assumed value
Base station coordinates (x_{BS}, y_{BS})	**Hexagonal deployment of macro-cells** Macro-cell ISD: Urban: 1.5 × 300 = 450 metres. See **ITU-R M.2292**. For small cell: consider 150m cell radius
Base station antenna height (above ground) z_{BS}	Macro-cells: Urban: 20 m. Outdoor small cell: 6m See **ITU-R M.2292**
Tx power (dBm)	56 dBm for Macro cell (Noted that the 3GPP LS defines outdoor hotspot which the Tx power is 10 dB less than this value, this assumption try to evaluate the worst case which for Macro cell deployment), 34 dBm for outdoor small cell(Same to IMT-Advanced Tx power density which may overestimate the AAS interfernce) 30 dBm indoor small cell. See **ITU-R M.2292**
Sectorization	Each macro base station would have three independent sectors (120° each). See **3GPP TR 37.840**. The orientation of the sectors need not change from one Monte Carlo trial to the next
TDD factor	DL ratio 0.8 is assumed. Use of a *single* value is based on the assumption of synchronised UL/DL phases in a network. This value is based on the proposed value in **ITU-R TG5/1 document 36**. For single entry, assume 1 as the worst case
Network loading	A network loading factor of 0.5 is assumed. See **ITU-R M.2292**. For single entry case, assume 1 as the worst case
Bandwidth	200 MHz

TABLE A1.48

IMT base station antenna element and array parameters

Parameters	**Assumed Value**
Antenna element directional pattern $a_{E\,\text{dB}}\,(\theta,\varphi)$	According to **3GPP TR 37.840 (section** 5.4.4.2**)**: $$a_{E\,\text{dB}}\,(\theta,\varphi) = -\min\{-[A_{E,V\,\text{dB}}(\theta) + A_{E,H\,\text{dB}}(\varphi)],\ A_{m\,\text{dB}}\},$$ $$A_{E,H\,\text{dB}}(\varphi) = -\min\left\{12\left(\frac{\varphi}{\varphi_{3\,\text{dB}}}\right)^2, A_{m\,\text{dB}}\right\},$$ $$A_{E,V\,\text{dB}}(\theta) = -\min\left\{12\left(\frac{\theta-90°}{\theta_{3\,\text{dB}}}\right)^2, SLA_{V\,\text{dB}}\right\},$$ where: 3 dB elevation beamwidth θ_{3dB} = 65°, 3 dB azimuth beamwidth φ_{3dB} = 80°, Front-to-back ratio A_m = 30 dB, Side-lobe ratio SLA_V = 30 dB. NOTE 1 – $a_E(\theta,\varphi) \leq 1$. NOTE 2 – Each antenna element is larger in size in the vertical direction, and so $\theta_{3dB} < \varphi_{3dB}$. See **3GPP TR 37.840**.
Antenna element gain $G_{E\,\text{dB}}$	8 dB
Number of base station beamforming elements (N_V, N_H)	8.8
Element spacing	0.9λ vertical separation. 0.6λ horizontal separation. NOTE – Larger vertical spacing provides narrower array beamwidth in elevation. See **3GPP TR 37.840** (Table 5.4.4.2.1-1).
Mechanical downtilt	Urban macro-cell: 10° Suburban macro-cell: 6° See **ITU-R M.2292**. Outdoor small cell: 10° **ITU-R TG5/1 document 36**. NOTE – For macro-cell, see **ITU-R M.2292** for 20 metres height and 300 m sector radius.

TABLE A1.49

IMT base station antenna element and array parameters (2)

Parameters	Assumed Value
Array beamforming directional pattern $a_A(\theta, \varphi)$	According to **3GPP TR 37.840 (section** 5.4.4.2): $$a_A(\theta,\varphi) = 1 + \rho\left[\left\|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{m,n} v_{m,n}\right\|^2 - 1\right]$$ where: $$v_{m,n} = \exp\left[j\frac{2\pi}{\lambda}\{(m-1)d_H\sin(\varphi)\sin(\theta) + (n-1)d_V\cos(\theta)\}\right],$$ $$w_{m,n} = \frac{1}{\sqrt{N_H N_V}}\exp\left[-j\frac{2\pi}{\lambda}\{(m-1)d_H\sin(\varphi_{SCAN})\cos(\theta_{TILT}) - (n-1)d_V\sin(\theta_{TILT})\}\right],$$ and: ρ is the signal correlation across the antenna elements, N_V, N_H are the number of vertical and horizontal antenna elements, d_V, d_H are the vertical and horizontal antenna element spacings, $-\pi/2 \leq \theta_{TILT} \leq \pi/2$ is the downward beam steering tilt angle relative to boresight, and $-\pi \leq \varphi_{SCAN} \leq \pi$ is the anti-clockwise horizontal beam steering scan angle relative to boresight. NOTE – $0 \leq a_A(\theta,\varphi) \leq N$.
Correlation	ρ = 1.
Beamforming	At each Monte Carlo trial, in each sector a single beam is steered in azimuth and elevation toward a UE which is dropped randomly within the sector. 70% of UEs will be considered indoor (see **ITU-R M.2292**), with a height above ground that is uniformly distributed with values of 1.5 + {0, 3, 6, 9, 12, 15} metres. Outdoor UEs in all cases are assumed to be at a height of 1.5 m above the ground.

TABLE A1.50

Radar receiver parameters (Ship based Radar D is evaluated)

Parameters	**Assumed Value**
Radar receiver antenna height above ground z_{BS}	20 metres
Radar receiver directional gain	Ship based radar D: Up to 40 dBi
Beamwidth (H,V) degrees	Radar D: 1.5-6, 4-20 Radar Antenna pattern: Recommendation ITU-R M.1465 does not provide the ship-based Radar antenna pattern. Due to the lack of the information, a conservative Radar pattern is considered as following. It is considered the maximum antenna gain 40 dBi with max (H,V) beam size (6, 20), Antenna side lobe (SL) levels is assumed to be 0 dBi.
Mechanical up-tilt	0° NOTE – No up-tilt is used in the absence of other information.
Mechanical azimuth scan	In order to capture the rotate feature of Radar system, at every Monte Carlo trial, the radar antenna points to a random azimuth direction that is uniformly distributed between 0 and 360°.
Noise figure	Radar D: 1.5 dB
Target experienced interference *I/N*	–6 dB

2 Propagation model

Interference to the radar receiver is calculated as the single entry in band interference from one IMT base station, using the ITU-R P.452-16 propagation model. All the propagation factors in Recommendation ITU-R P.452 are considered. Parameters “dcr” and “dct”, are considered for sea and coastal scenarios. The 10% and 20% time percentages is used. Full sea path is considered for ship-based Radar, radio climatic zone B at all points. Four locations are considered:

- City 1 (latitude: 6.45306 degree, longitude: 3.39583 degree, delta N: 51.9, N0: 379.2).
- City 2 (latitude: −33.9528 degree, longitude: 18.42322 degree, delta N: 49.1, N0: 333.4).
- City 3 (latitude: 43.291302 degree, longitude: XXX, delta N: 50, N0: 330).
- City 4 (latitude: 25.140273 degree, longitude: 56.302984 degree, delta N: 70, N0: 370).

TABLE A1.51

Parameters used propagation losses calculated with Recommendation ITU-R P.452

	Geographic situation	City 1 Equatorial	City 2 Tropical	City 1 Equatorial	City 2 Tropical	City 3	City 4
	Base station type	Macro urban	Macro Urban	Micro	Micro	Macro Urban/Micro	Macro Urban/Micro
φt	Latitude transmitter (degree)	6.45306	−33.9528	6.45306	−33.9528	43.291302	25.140273
ψt	Longitude transmitter (degree)	3.39583	18.42322	3.39583	18.42322	XXX	56.302984
φr	Latitude receiver (degree)	6.45306	−33.9528	6.45306	-33.9528	43.291302	25.140273
ψr	Longitude receiver (degree)	3.39583	18.42322	3.39583	18.42322	XXX	56.302984
htg	Transmitter height (metres)	20	20	6	6	20/6	20/6
hrg	Receiver Height (metres)	20	20	20	20	20/6	20/6
N0	Sea-level surface refractivity (N-units)	379.2	333.4	379.2	333.4	330	370
deltaN	Average radio-refractive index lapse-rate (N-units/km),	51.9	49.1	51.9	49.1	50	70
dcr	Distance over land from Rx antenna to the coastline (km)	0	0	0	0	0	0
dct	Distance over land from Tx antenna to the coastline (km)	0	0	0	0	0	0

Figures A1-24 to A1-27 show pathloss calculated completely above sea waters, and during 20% of time for which the transmission loss is not exceeded. The curves indicate the minimum path losses using the propagation model with p = 20%.

FIGURE A1-24

Path losses between an IMT base station located on shoreline and a shipborne radar at sea (ITU-R P.452-16 City 1 case)

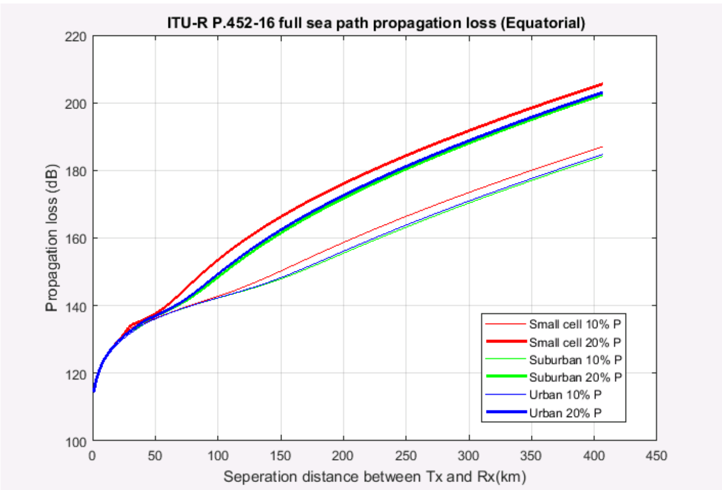


FIGURE A1-25

Path losses between an IMT base station located on shoreline and a shipborne radar at sea (ITU-R P.452-16 City 2 case)

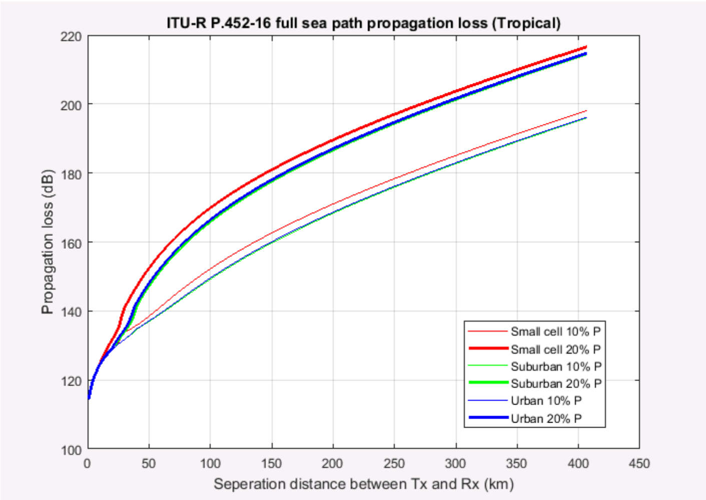


FIGURE A1-26

Path losses between an IMT base station located on shoreline and a shipborne radar at sea (ITU-R P.452-16 City 3 case)

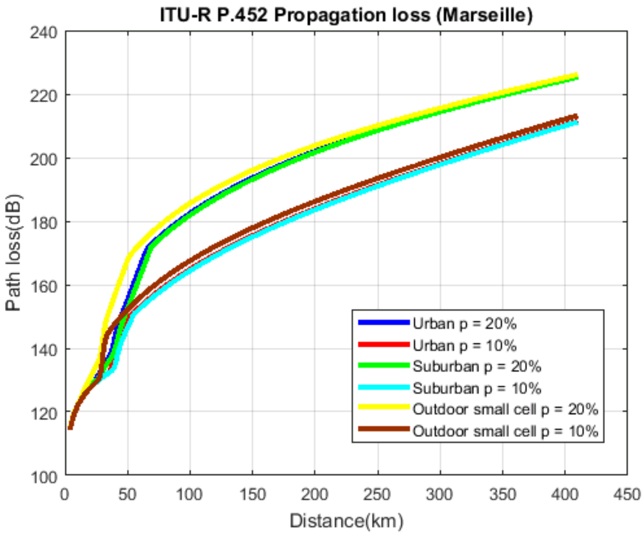
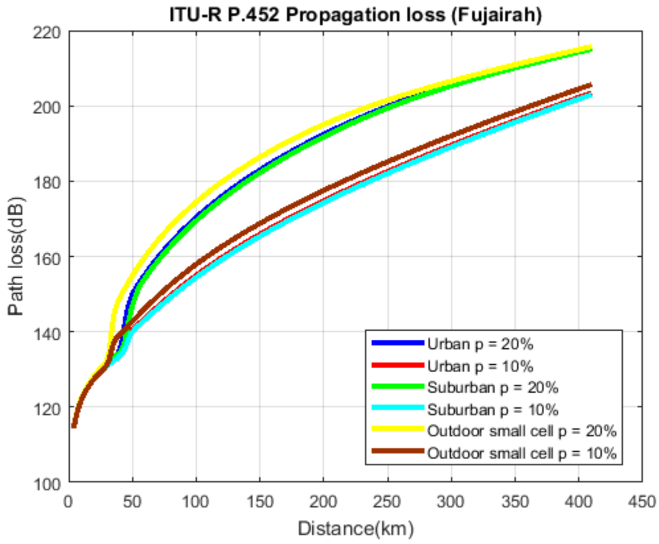


FIGURE A1-27

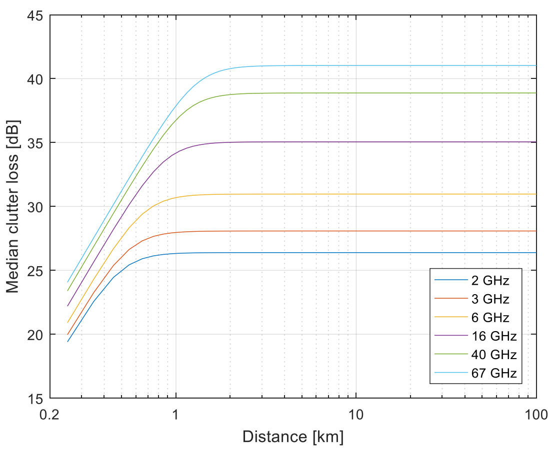
Path losses between an IMT base station located on shoreline and a shipborne radar at sea (ITU-R P.452-16 City 4 case)



Recommendation ITU-R P.2108 clutter loss model is considered with random location variability *P*%.

FIGURE A1-28

Median clutter loss for terrestrial paths

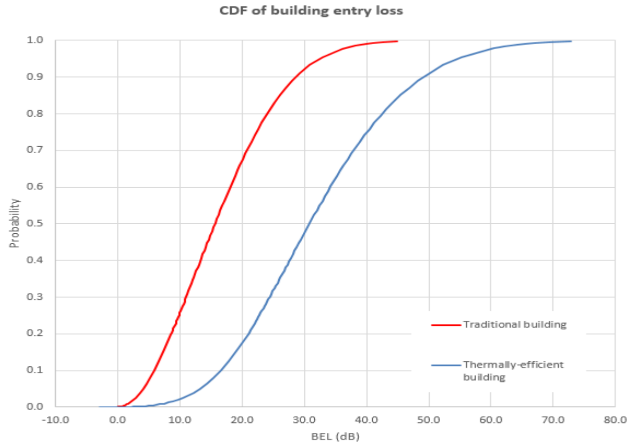


For IMT indoor BS, building entry loss refers to Recommendation ITU-R P.2109. The values of 2 dB and 7.5 dB are used respectively for traditional and thermally efficient building entry loss. 1% location variability is considered in order to evaluate the worst case.

For IMT outdoor BS scenarios in this study, building entry loss is not considered.

FIGURE A1-29

Building entry loss

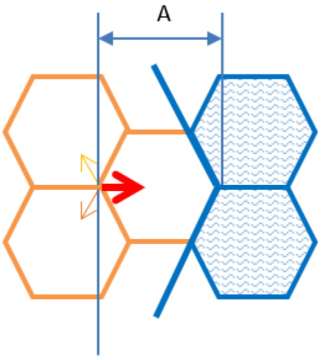


3 Analysis approach

One IMT base station is positioned several kms away Radar, with 1 sector pointing towards the coast as shown in Fig. A1-30.

FIGURE A1-30

IMT BS with 1 sector pointing towards the coast



The antenna element radiation pattern is based on ITU-R M.2101, with vertical and horizontal 3 dB beamwidths of 65° and 80°, respectively, a front-to-back ratio of 30 dB, and a gain of 8 dBi.

The radar receiver antenna is modeled as located 20 metres above the ground with a mechanical downtilt of 0°. Ship based Radar D is evaluated in this study because MCL study has shown that this is the worst case Radar type.

FIGURE A1-31

Angular discrimination between IMT BS and radar receiver

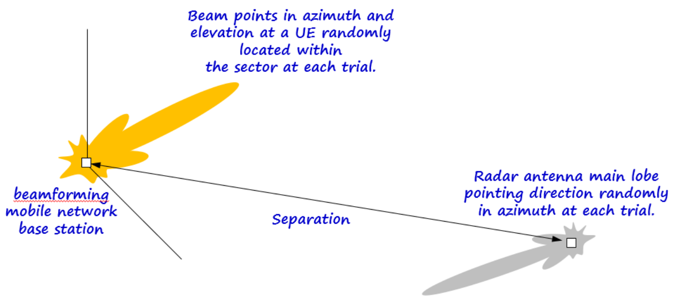


Figure A1-31 illustrates the way in which angular discrimination is modelled at the IMT base stations and radar receiver:

- At each Monte Carlo trial, the radar rotation is considered such that radar receiver is assumed to point its beam towards a random direction in azimuth (uniformly distributed between 0° and 360°).
- At each Monte Carlo trial, each IMT base station sector is assumed to radiate towards a user equipment (UE) which is located within the area of the sector. UEs are assumed to be indoors with a probability of 70% (equally likely to be 1.5, 4.5, 7.5, 10.5, 13.5 or 16.5 metres above ground). Outdoors UEs are assumed to be 1.5 metres above ground.

The intention in the above modelling approach is to adequately capture the benefits of angular discrimination at the transmitters and receiver.

4 Co-channel single entry interference analysis results

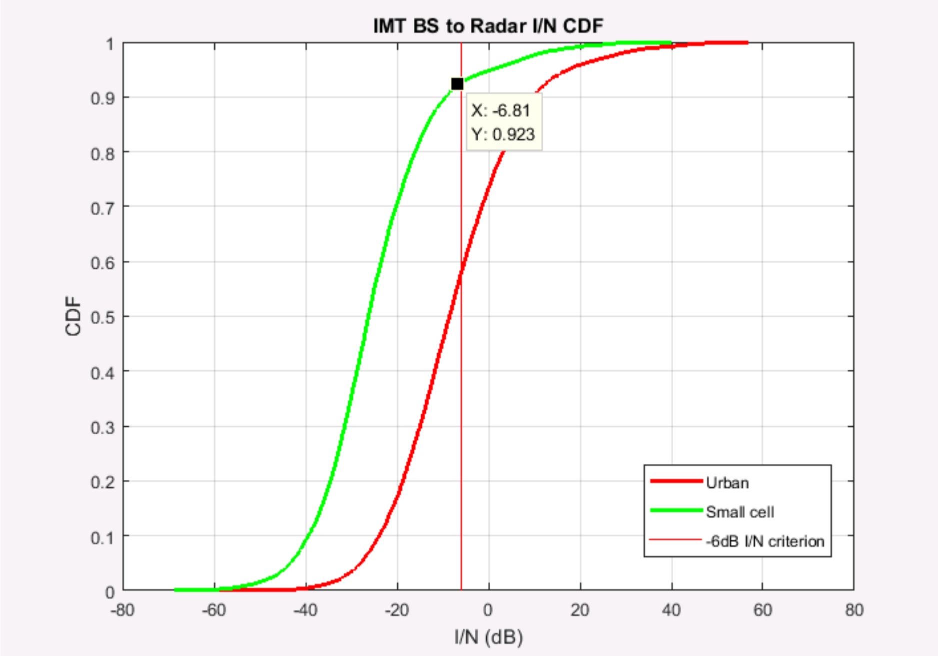
The simple MCL evaluation provided in this report suggest that compatibility between IMT with AAS and ship based radars is possible.

20 km separation distance

For such distance, the Longitude and latitude location and time percentage influence the propagation loss very negligible. For outdoor small cell, more than 92% that the interference is lower than −6 dB *I*/*N* criterion. For urban macro cell, more than 58% that the interference is lower than −6 dB *I*/*N* criterion.

FIGURE A1-32

***I*/*N* at the radar receiver**



Separation distances larger than 20 km

The longitude and latitude information and time percentage influence the propagation very much if the separation distance, below Table provide the probability of IMT interference lower than −6 dB *I*/*N* criterion for difference cases.

TABLE A1.52

Probability that the interference from BS into radar is below the −6 dB *I*/*N* criterion (equatorial and tropical locations)

BS type	Separation distance (km)	City 1 *P* = 10%	City 1 *P* = 20%	City 2 *P* = 10%	City 2 *P* = 20%
Urban Macro	20	58%	58%	58%	58%
	50	80%	80%	80%	93%
	100	86%	93%	93%	98%
Urban Micro	20	92%	92%	92%	92%
	50	95%	95%	95%	99%
	100	97%	99%	99%	>99%
Indoor small cell (Traditional 1% *P* Building entry loss)	10	92%	92%	92%	92%
	20	95%	95%	95%	95%
Indoor small cell (Thermally efficient 1% *P* Building entry loss)	10	95%	95%	95%	95%
	20	98%	98%	98%	98%

TABLE A1.53

Probability that the interference from BS into radar is below the −6 dB *I*/*N* criterion (City 3 and City 4 locations)

BS type	Separation distance (km)	City 3 *P* = 10%	City 3 *P* = 20%	City 4 *P* = 10%	City 4 *P* = 20%
Urban Macro	20	58%	58%	58%	58%
	50	93%	96%	80%	93%
	100	98%	> 99%	96%	> 99%
Urban Micro	20	92%	92%	92%	92%
	50	99%	> 99%	97%	> 99%
	100	> 99%	> 99%	> 99%	> 99%
Indoor small cell (Traditional 1% *P* Building entry loss)	10	92%	92%	92%	92%
	20	95%	95%	95%	95%
Indoor small cell (Thermally efficient 1% *P* Building entry loss)	10	95%	95%	95%	95%
	20	98%	98%	98%	98%

Study F

This study analyses the co-channel interference and compatibility between International Mobile Telecommunications (IMT) deployments that use Advanced Antenna System (AAS)s and ship borne radars in the frequency band 3 300-3 400 MHz. The impact of macro urban IMT Base Station (BS)s operating in a temperate coastal urban environment on the ship based radars is evaluated through theoretical analysis and Monte Carlo based simulations. The scope of the study is limited to analysing the interference from IMT BS downlinks (links from IMT BSs to IMT user terminals); it does not consider possible interference from IMT uplinks (links from IMT user terminals to IMT BSs) in to the radar systems.

The methodology used for this study takes into account the current versions of following Recommendations and Reports:

Recommendation ITU-R SM.337 – Frequency and distance separations

Recommendation ITU-R F.1336 – Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile services for use in sharing studies in the frequency range from 400 MHz to about 70 GHz

Recommendation ITU-R M.1461 – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services

Recommendation ITU-R M.1465 – Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency range 3 100-3 700 MHz

Recommendation ITU-R M.2101 – Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies

Report ITU-R M.2292 – Characteristics of terrestrial IMT-Advanced systems for frequency sharing/ interference analyses

The study is organised as follows. Technical characteristics of IMT and radar systems used for simulations are provided in § 1. Section 2 gives an overview of AAS beamforming scenarios considered during the simulations discussed in later sections. Propagation and clutter models used for the simulations are described in § 3. Section 4 provides an overview of radar beam pointing directions used for analysing the compatibility between radars and IMT. Section 5 presents Monte Carlo based simulation methodology used for a comparative analysis of *I*/*N* at a selected shipborne radar receiver due to emissions from a three sector IMT BS over multiple beam steering scenarios. Section 6 analyses the aggregated interference from an AAS based IMT deployment with 25 urban macro BSs operating in a coastal area into various shipborne radar systems outlined in Recommendation ITU-R M.1465.

1 Characteristics of IMT and radar systems

1.1 Radar system characteristics

This study focuses on interference into ship based radar systems outlined in Recommendation ITU-R M.1465. Characteristics of these radar systems are shown in Table A1.54.

TABLE A1.54

Table of characteristics of radiolocation systems in the frequency range 3 100-3 700 MHz

Parameter	Units	Ship systems			
		A	B	C	D
Use		Surface and air search			
Modulation		P0N	Q7N	P0N/Q7N	Q7N
Tuning range	GHz	3.3-3.4	2.9-3.7	3.1-3.5	
Tx power into antenna (Peak)	kW	1 000	4 000-6 400	60-200	4-90
Pulse width	µs	0.25, 0.6	6.4-768	0.1-1000	0.1-100
Repetition rate	kHz	1.125	0.152-6.0	0.3-10	0.5-10
Compression ratio		Not applicable	64-512	Up to 20 000	Up to 400
Type of compression		Not applicable	CPFSK (1)	Not available	Not available
Duty cycle	%	0.28, 0.67	0.8-30.0	Max 20	Max 20
Antenna gain	dBi	32	42	Up to 40	Up to 40
Antenna type		PA (2)	PA		
Beamwidth (H,V)	degrees	1.75, 4.4, csc^2 to 30	1.7, 1.7	1.1-5, 1.1-5	1.5-6, 4-20
Vertical scan type		Not applicable	Random	Not applicable	Not applicable
Maximum vertical scan	degrees	Not applicable	90	90	90
Vertical scan rate	degrees/s	Not applicable	Instantaneous		
Horizontal scan type		Rotating	Random	Continuous 360 + Sector	Continuous 360 + Sector
Maximum horizontal scan	degrees	360	360		
Horizontal scan rate	degrees/s	24	Not applicable	30-360	50-180
Polarization		H	V	Not available	V
Rx sensitivity	dBm	−112	Not available	Not available	Not available
Rx noise figure	dB	4.8	5.0	1.5	1.5
Rx RF bandwidth (−3 dB)	MHz	Not available	400		
Rx IF bandwidth (−3 dB)	MHz	8	10	10-30	2-20
Deployment area		Worldwide	Worldwide	Worldwide	Worldwide

(1) CPFSK: Continuous-Phase FSK.

(2) PA: Phased Array.

1.2 Characteristics of IMT Systems

This study primarily considers characteristics of urban macro BSs that use AASs. General characteristics of such BSs are described in Table A1.55. For the purpose of comparison, studies described in § 5 consider a co-existence scenario between a non-AAS urban macro IMT-Advanced BS and a ship-based radar system. General characteristics of the IMT BSs that use non-AASs are outlined in Table A1.56. General characteristics of IMT User Equipment (UE)s are outlined in Table A1.57. Technical characteristics in Tables A1.56 and A1.57 are extracted from Recommendation ITU-R M.2292. It should be noted that simulation specific parameters are tabled within the sections relevant to specific simulations and could deviate from these general characteristics depending on the purpose of the simulations. Where deviations occur, parameters specified under the relevant sections for simulation studies are being used.

TABLE A1.55

Technical characteristics of IMT urban macro BSs that use AAS[8]

System Property	Value
Cell radius/Deployment density	0.15-0.6 km (typical figure to be used in sharing studies 0.3 km)
Antenna height	20 m
Sectorisation	3 sectors
Mechanical downtilt	10 degrees
Frequency reuse	1
Antenna pattern	According to ITU-R M.2101 (refer to § 1.3 for details)
Element gain (dBi)	8
Horizontal/vertical 3 dB beamwidth of single element (degree)	80° for H 65 for V
Horizontal/vertical front-to-back ratio (dB)	25 for both H/V
Antenna polarization	Linear ±45°
Antenna array configuration (Row × Column)	8 × 8 elements
Horizontal/Vertical radiating element spacing	0.6 of wavelength for H, 0.9 of wavelength for V
Indoor base station deployment	n.a.
Indoor base station penetration loss	n.a.
Below rooftop base station antenna deployment	50%
Array Ohmic loss (dB)	2
Conducted power (before Ohmic loss) per antenna element (5/10/20 MHz))	25/28/31dBm
Base station maximum coverage angle in the horizontal plane (degrees)	120

[8] Characteristics of IMT BSs that use AAS are taken from 5D/1120-E.

TABLE A1.56

Technical characteristics of IMT urban macro BSs that use non-AASSystem Property	**Value**
Cell radius/Deployment density	0.15-0.6 km (typical figure to be used in sharing studies 0.3 km)
Antenna height	20 m
Sectorisation	3 sectors
Downtilt	10 degrees
Frequency reuse	1
Antenna pattern	Recommendation ITU-R F.1336 (*recommends* 3.1) ka = 0.7 kp = 0.7 kh = 0.7 kv = 0.3 Horizontal 3 dB beamwidth: 65 degrees Vertical 3 dB beamwidth: determined from the horizontal beamwidth by equations in Recommendation ITU-R F.1336. Vertical beamwidths of actual antennas may also be used when available.
Antenna polarization	Linear/±45 degrees
Indoor base station deployment	n.a.
Indoor base station penetration loss	n.a.
Below rooftop base station antenna deployment	50%
Feeder loss	3 dB
Maximum base station output power (5/10/20 MHz)	43/46/46 dBm
Maximum base station antenna gain	18 dBi
Maximum base station output power/sector (e.i.r.p.)	58/61/61 dBm
Average base station activity	50%
Average base station power/sector taking into account activity factor	55/58/58 dBm

TABLE A1.57

Technical characteristics of IMT user terminals

System Property	**Value**
Indoor user terminal usage	70%
Building wall penetration loss	20 dB
User terminal density in active mode to be used in sharing studies	3/5 MHz/km^2

1.3 Antenna patterns for AAS

AAS antenna element patterns and composite array patterns are generated using relevant equations specified in Recommendation ITU-R M.2101. These are given in Table A1.58.

TABLE A1.58

AAS antenna pattern characteristics

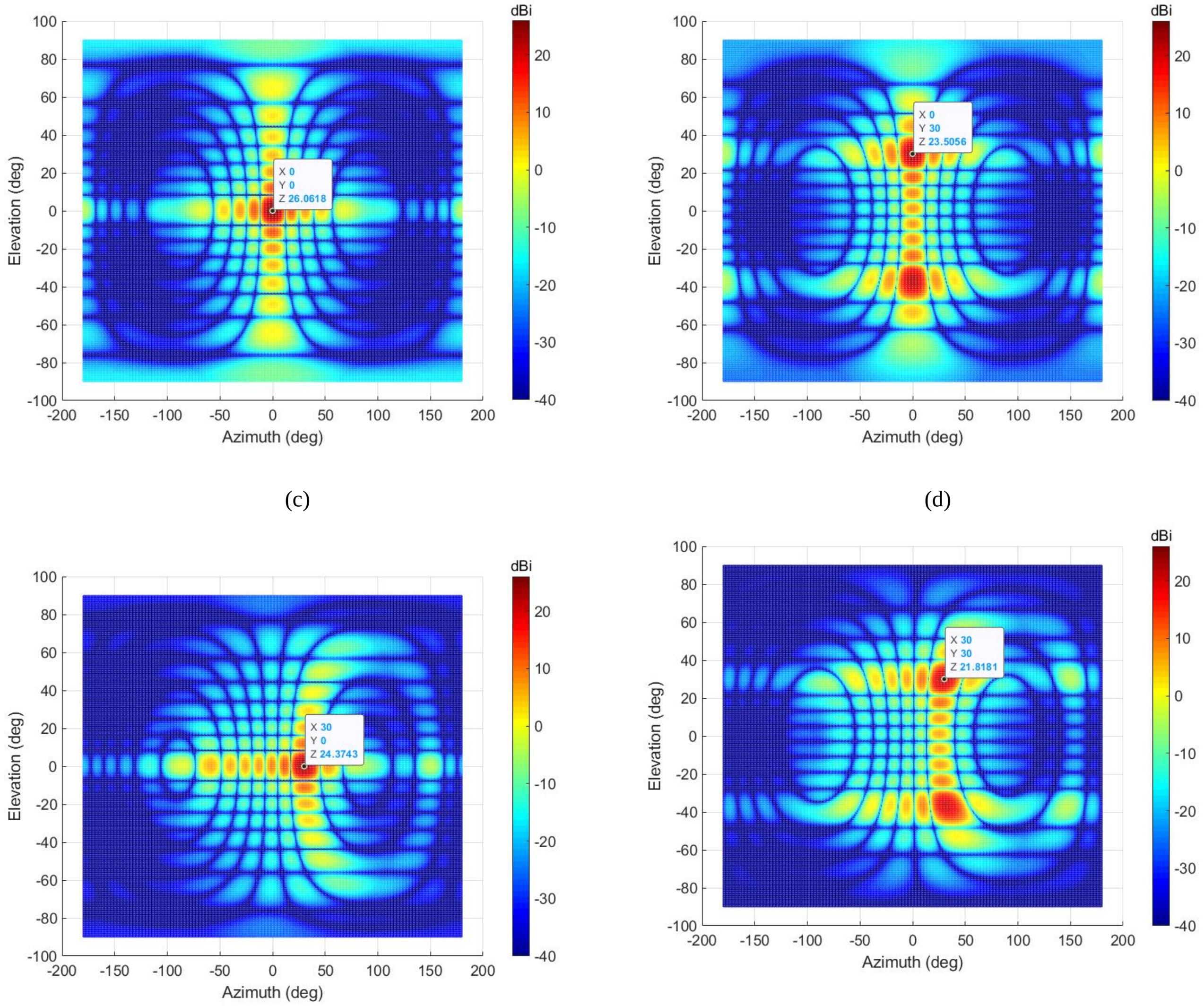
Single element horizontal radiation pattern	$A_{E,H}(\varphi) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^2, A_m\right] dB$ where: φ, defined between −180° and 180° is the azimuth angle 3 dB azimuth beamwidth φ_{3dB} = 80°, Front-to-back ratio A_m = 30 dB.
Single element vertical radiation pattern	$A_{E,V}(\theta) = -\min\left[12\left(\frac{\theta-90}{\theta_{3dB}}\right)^2, SLA_v\right]$ dB where: θ, defined between 0° and 180°, with 90° representing perpendicular angle to the array antenna aperture, is the elevation angle of the signal direction, 3 dB elevation beamwidth θ_{3dB} = 65°, Side-lobe ratio SLA_V = 30 dB.
Single element pattern	$A_E(\varphi,\theta) = G_{E,\max} - \min\{-\lfloor A_{E,H}(\varphi) + A_{E,v}(\theta)\rfloor, A_m\}$ where: Maximum single element gain $G_{E,max}$ = 8 dBi.
Composite array radiation pattern in dB $A_A(\theta,\varphi)$	For beam *i*: $A_{A,Beami}(\theta,\varphi) = A_E(\theta,\varphi) + 10\log_{10}\left(\left\lvert\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{i,n,m}\cdot v_{n,m}\right\rvert^2\right)$ the super position vector is given by: $v_{n,m} = \exp\left(\sqrt{-1}\cdot 2\pi\left((n-1)\cdot\frac{d_V}{\lambda}\cdot\cos(\theta) + (m-1)\cdot\frac{d_H}{\lambda}\cdot\sin(\theta)\cdot\sin(\varphi)\right)\right),$ $n = 1,2,\dots N_V; m = 1,2,\dots N_H;$ the weighting is given by: $w_{i,n,m} = \frac{1}{\sqrt{N_H N_v}} exp\left(\sqrt{-1}.2\pi\left((n-1).\frac{d_v}{\lambda}.\sin(\theta_{i,etilt}) - (m-1).\frac{d_H}{\lambda}.\cos(\theta_{i,etilt}).\sin(\varphi_{i,escan})\right)\right)$ where: N_V, N_H are the number of vertical and horizontal antenna elements, d_V, d_H are the vertical and horizontal antenna element spacing, $-\pi/2 \leq \theta_{i,etilt} \leq \pi/2$ is the downward beam steering tilt angle relative to boresight, $-\pi \leq \varphi_{i,escan} \leq \pi$ is the anti-clockwise horizontal beam steering scan angle relative to boresight.

Figure A1-33 depicts some example AAS beamforming patterns used during the simulations described in §§ 5, 6 and 7.

FIGURE A1-33

Beamformed AAS patterns (a) $\varphi_{i,escan}$= 0°, $\theta_{i,etilt}$ = 0°, (b) $\varphi_{i,escan}$= 0°, $\theta_{i,etilt}$ = 30°, (c) $\varphi_{i,escan}$= 30°, $\theta_{i,etilt}$ = 0°, (d) $\varphi_{i,escan}$= 30°, $\theta_{i,etilt}$ = 30°

(a) (b)



2 AAS Beamforming [9]

Beamforming capability in AASs can be used in multiple ways to direct radio frequency signals towards a receiver during transmit mode or improve gain towards a specific transmitter during receive mode. The most simplistic way of beamforming is to direct a single dedicated antenna beam towards a specific UE while steering the beam to track the UE location as shown in Fig. A1-34 (a). Transmit diversity can be achieved by sending the same data stream in multiple directions in order to jointly optimise the spatial and frequency domain. This is depicted in Fig. A1-34 (b). Spatial multiplexing techniques can be used to transmit multiple data streams to one or more UEs. The former represents a Single User-Multiple Input Multiple Output (SU-MIMO) beamforming scenario while the latter represents a Multi User- Multiple Input Multiple Output (MU-MIMO) beamforming scenario. These are shown in Figs A1-35 (c) and (d).

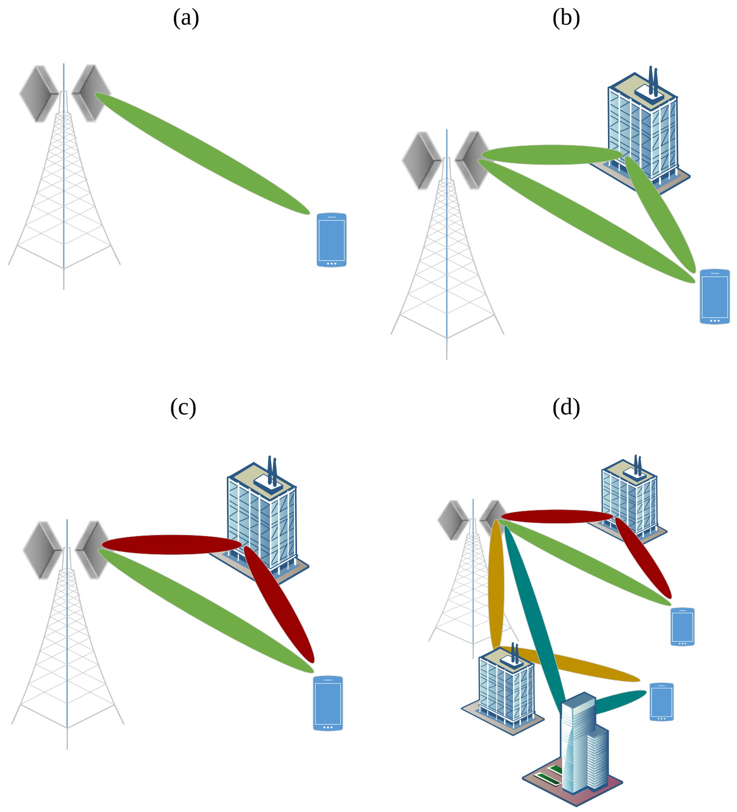
9 Beamforming characteristics for AAS are described under § 5.1 of 3GPP TR 37.840.

Multiple simultaneous data streams to an UE might use similar or different frequency and time based resource elements over multiple beams. When similar resource elements are being used, spatial isolation between beams and differences in channel properties over multiple propagation paths are used to achieve de-confliction between resource elements at reception.

Due to the multipath-rich nature of the propagation environment and expanse of BS sector coverage over multiple diffracting objects (e.g. buildings in an urban or sub-urban environment), transmit diversity and spatial multiplexing beamforming techniques are more effective compared to direct steering of a single beam towards an UE in sub-6 GHz frequencies[10]. A comparative *I*/*N* study for these multiple beamforming scenarios and a traditional fixed beam pointing scenario (for a non-AAS) is described in § 6.

FIGURE A1-34

AAS beamforming scenarios (different coloured beams showing different data streams) (a) dedicated single beam steered to track a single UE (b) transmit diversity – same data stream sent in different directions (c) SU-MIMO – several data streams transmitted in different directions simultaneously to a single UE (d) MU-MIMO-multiple data streams sent in different directions simultaneously to multiple UEs



3 Propagation environment

Recommendation ITU-R P.452 is used as the propagation model during simulations. Figure A1-35 shows the Recommendation ITU-R P.452 propagation loss variation with distance for parameter p = 1%, 10% and 20%. For all the simulations under this study, the propagation is considered to occur above sea waters where IMT BSs are located at the shoreline and a ship based radar located at various distances at sea. Table A1.59 provides parameters used to calculate propagation loss during simulations.

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[10] Ericsson white paper “Advanced antenna systems for 5G networks”.

TABLE A1.59

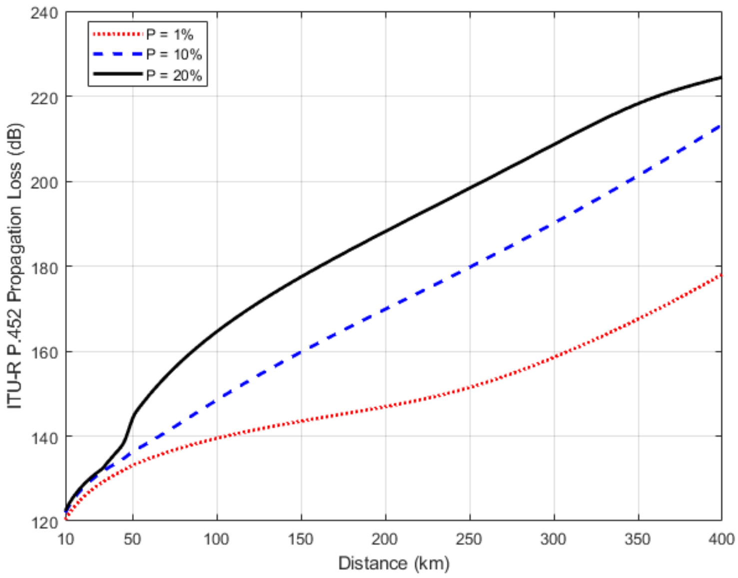
Parameters used to calculate ITU-R P.452 propagation loss

Symbol	Parameter	Value
	BS type	Macro Urban
	Location	Sydney, Australia
φt	BS Latitude (deg.)	−33.87126
ψt	BS Longitude (deg.)	151.25574
	Climate	Temperate
N_0	Sea-level surface refractivity (N-units)	337
deltaN	Average radio-refractive index lapse-rate (N-units/km),	46.2
dcr	Distance over land from BS antenna to the coastline (km)	0.3
f_r	Reference frequency	3 350 MHz

Figure A1-35 shows the variation of path loss with distance from the coastline. It should be noted that over short distances (for approximately up to 40 km from coast line) the difference in path loss for with parameter *p* = 1%, 10% and 20% are insignificant.

FIGURE A1-35

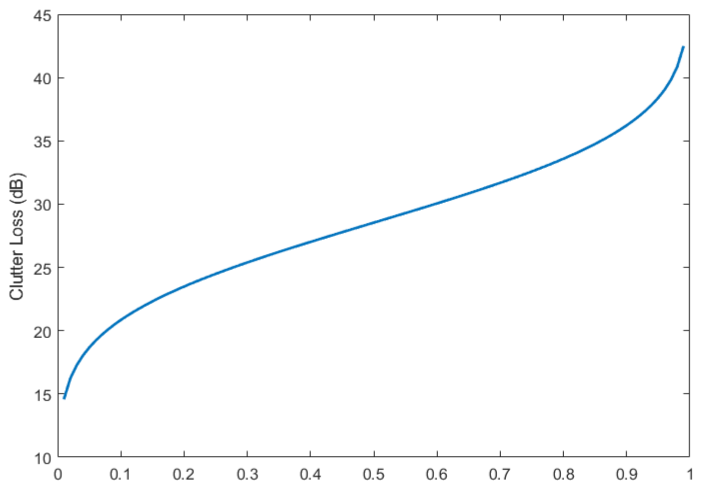
Path loss between IMT BS located on shore line and a ship based radar at sea



For aggregation studies, clutter loss is applied to 50% BSs with below rooftop antenna deployments as indicated in Table A1.55. During Monte Carlo simulations for aggregation studies, a statistical clutter value calculated according to Recommendation ITU-R P.2108 is applied at each case of iteration. Figure A1-36 shows the variation of ITU-R P.2108 clutter loss for 3350 MHz with percentage of locations considered in the model.

FIGURE A1-36

Variation of clutter loss for 3350 MHz with percentage of locations



4 Radar beam pointing for analysing the interference from coastal IMT deployments

In all the interference studies, it is assumed the radar antenna is pointing towards the IMT deployment. Radar elevation beam tilt is assumed to be 0^o. This is mainly due to the fact that the performance of a shipborne radar is generally measured for each azimuthal direction of its main beam. For a large IMT deployment along a coastal area, radar main beam coupling represents the prominent interference mode affecting the radar coverage towards the coast. This is shown in Fig. A1-37. Most radar modes lead to the same conclusion that the impact to the radar from multiple BSs lead to main beam coupling being the constant source of interference. In effect there are no radar maritime installations (ITU-R M.1465) that accept a sector of their azimuth to have desensitization. The following interference scenarios emphasise the inherent rationale for considering radar main beam coupling when evaluating the compatibility between radars and IMT.

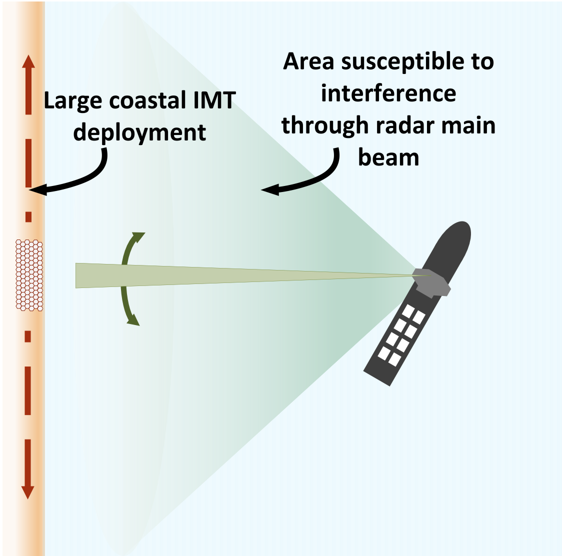
a. Rotating radars (e.g. Radar A): For a rotating radar, interference through radar main beam coupling from a large coastal IMT deployment will permanently affect a significant sector of the radar coverage area towards the coast (Figure 5). This remains constant irrespective of the ship's movement.

b. Radars in tracking or narrow sector scanning mode (e.g. Radar C and D): For these types of radars, interference through radar main beam coupling will permanently affect the tracking or sector scanning functions of the radar over the IMT deployment. Inability to track in the direction of the IMT deployment is detrimental to the radar performance overall.

c. Phased array radars in random search mode (e.g. Radar B): Even though the beam pointing of electronically scanned phased array radars are instantaneous, in search mode these types of radars fill the full 360^o search volume at a rapid rate (e.g. less than 1 second). In this case, the IMT deployment will be seen as a permanent source of interference within the radar coverage area. This is similar to rotating radars, where interference through radar main beam coupling from a large coastal IMT deployment will permanently affect a significant sector of the radar coverage area towards the coast.

FIGURE A1-37

Affected radar coverage due to a large IMT deployment towards the coast



5 Monte Carlo analysis of single entry *I*/*N* from a three sector BS into shipborne radar D

This section describes an approach taken to calculate interference from a single sector urban macro IMT BS into a shipborne radar. These scenarios are outlined in Table A1.60. Without loss of generality, shipborne Radar D is used as the victim radar. Figure A1-38 shows the antenna orientations for both radar and BS. It also shows an example interference coupling path between BS antenna and radar antenna when the BS antenna is deployed above the building rooftops.

For the purpose of calculations, it is assumed that the position of the ship with respect to the IMT BS is fixed at 22 km from the shoreline (at the limit of the territorial waters), and the radar antenna is pointing towards the BS. Radar elevation beam tilt is assumed to be 0°. Interference power into the radar receiver is calculated using the following equation:

$$I_{IMT} = P_{IMT} + G_{IMT} + G_{Radar} - L(f,d) - OTR \quad (1)$$

where:

- I_{IMT}: the received interference power level in the bandwidth of the radiolocation service radar (dBm)
- P_{IMT}: transmit power of IMT system (dBm)
- G_{IMT}: antenna gain of IMT system (dB)
- G_{Radar}: receive antenna gain of radiolocation service radar (dB)
- $L(f,d)$: the propagation loss (dB)
- OTR: On Tune Rejection as defined in Recommendation ITU-R SM.337.

Each Monte Carlo simulation uses 100’000 simulation seeds.

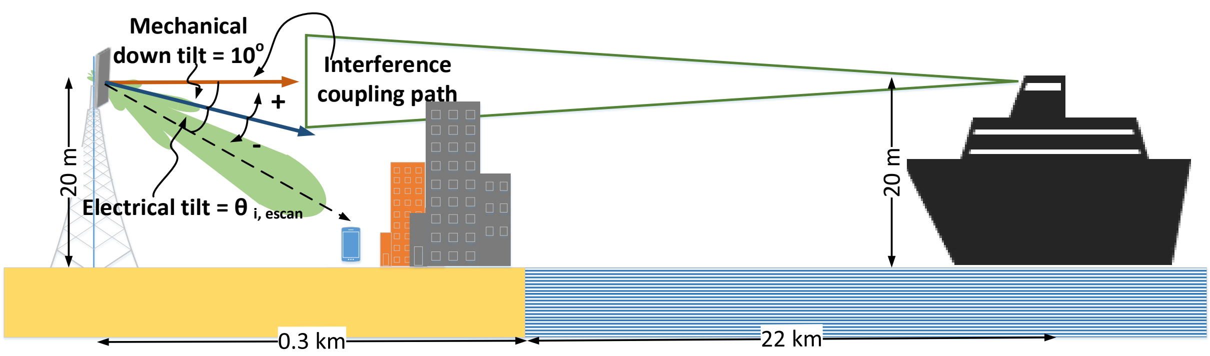
TABLE A1.60

Multiple beam forming scenarios

Scenario	Beam-forming Method	Number of UEs per sector	Total Number of UEs per BS	Total transmit power per sector after feeder/ ohmic losses	Transmit power per beam after feeder/ ohmic losses	Transmit bandwidth
A	Fixed pointing beam without beam steering (non-AAS)	N/A	N/A	43 dBm	43 dBm	20 MHz
B	Beam steered at the UE-single beam per UE (AAS)	1	3	43 dBm	43 dBm	20 MHz
C	Four beams per UE steered randomly in the direction of the UE resembling a MIMO scenario in a rich multipath environment (AAS)	1	3	43 dBm	36.98 dBm	20 MHz

FIGURE A1-38

Example antenna beam coupling between IMT station and radar



NOTE – Pictures are not to scale. For non-AAS case fixed down tilt = 10° and fixed azimuth direction towards the ship.

TABLE A1.61

Parameters used for calculation of *I*/*N* for single entry studies

Parameter	Value
Radar type	Radar D
Radar IF bandwidth	20 MHz
Radar antenna gain	40 dBi
Radar antenna azimuth beamwidth	6º
Radar antenna elevation beamwidth	20º
Radar antenna elevation beam tilt	0º
Radar beam back lobe gain	0 dBi
Radar antenna height	20 m
Radar antenna azimuth	Pointing at BS
Ship location	22 km from the shore line
BS type	Macro Urban
BS Latitude (deg.)	–33.87126
BS Longitude (deg.)	151.25574
Distance over land from BS antenna to the coastline (km)	0.3
AAS antenna pattern	Recommendation ITU-R M.2101 (Table 5 above)
Non-AAS antenna pattern	Recommendation ITU-R F.1336 (*recommends* 3.1)
BS antenna gain (AAS/ non-AAS)	Variable/ 18 dBi
BS antenna height	20 m
BS antenna mechanical down tilt	10º
BS antenna azimuth (AAS/ non-AAS)	Tracking UE/pointing at radar
Reference frequency	3 350 MHz
Occupied bandwidth	20 MHz
Propagation model	ITU-R P.452, *P* = 10%
Clutter loss	None
BS antenna deployment	Above rooftops
BS activity factor	50%
TDD factor (UL:DL)	20:80

Figure A1-39 depicts the sector orientations with respect to the radar. Scenario A represents a BS with conventional fixed pointing non-AAS. Technical parameters outlined in Table A1.56, Table A1.59 and Table A1.61 (non-AAS case) are used for calculating *I*/*N* at the radar receiver due to the emissions from the non-AAS BS. Scenario B represents a scenario where a dedicated single beam is steered to track a single UE (Fig. A1-34 (a)). Scenario C represents a spatial multiplexing or a transmit diversity beam steering scenario (Fig. A1-34 (b) to (d)) where four beams per UE are steered with beam pointing constraints shown in Fig. A1-40. During Monte Carlo simulations for Scenario C, a beam pointing direction is randomly chosen for each independent beam at each case of iteration from a uniformly distributed range of azimuth and elevation angels within the constraints shown in Fig. A1-40. Sector power is equally distributed among the beams for Scenario C following guidelines in Recommendation ITU-R M.2101. Figure A1-41 shows the *I*/*N* variations for Scenario A.

FIGURE A1-39

BS sector orientation used for simulations

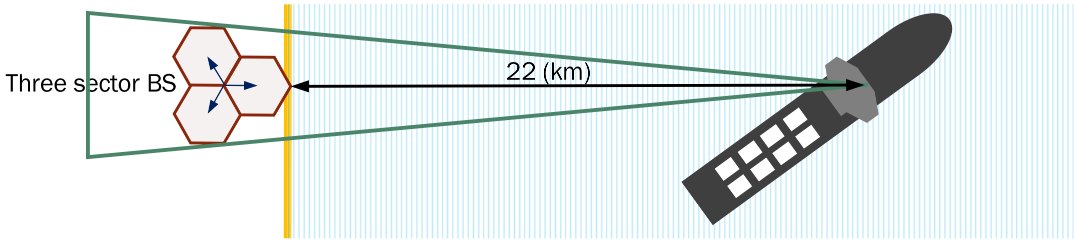


FIGURE A1-40

Beam steering limits for Scenario C (a) azimuth limits (b) elevation limits

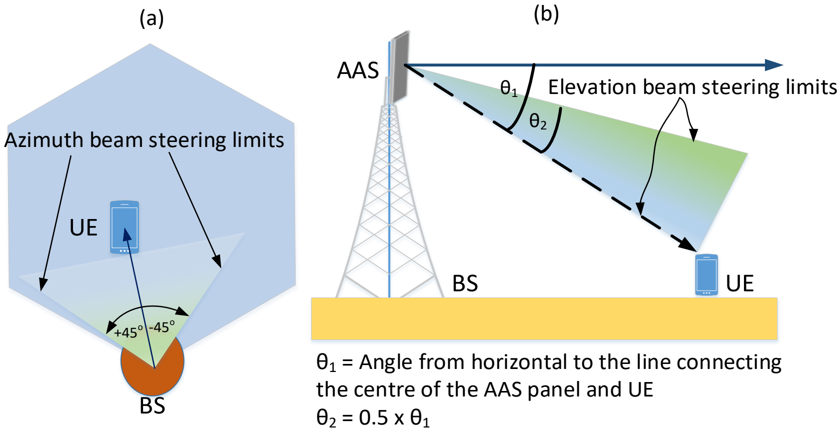
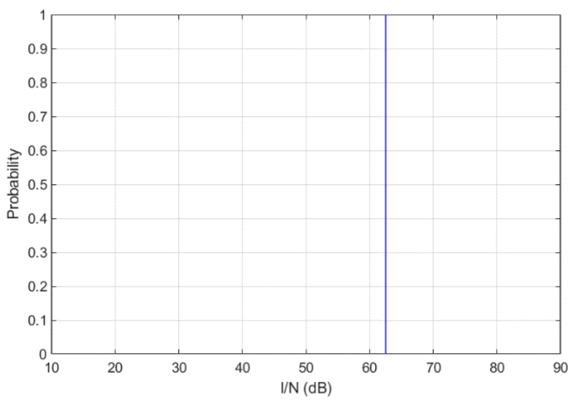


FIGURE A1-41

I/N at the receiver of Radar D for Scenario A

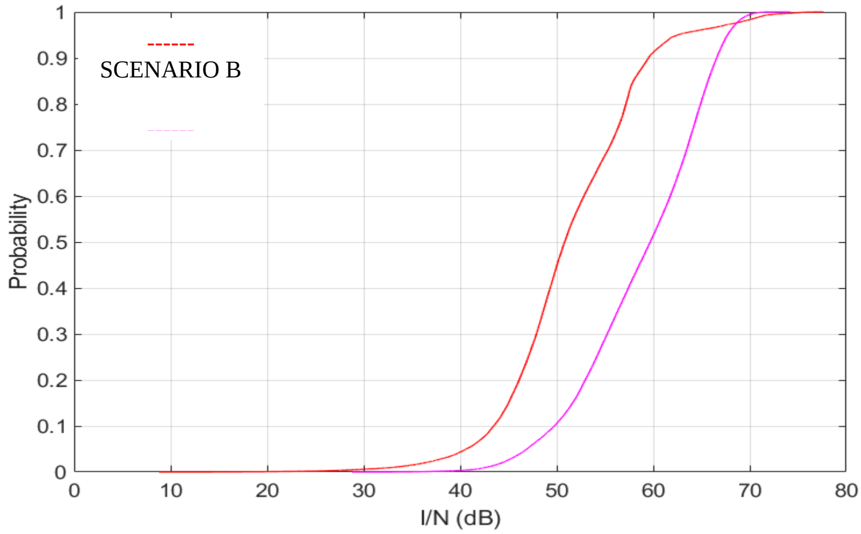


Curves in Fig. A1-42 represent Cumulative Distribution Functions (CDF) of *I*/*N* distributions for Scenario B and Scenario D. Monte Carlo simulation results show that the *I*/*N* values for 100% non-exceedance criteria (CDF probability = 1.0) received by the radar standing 22 km from shoreline are above 75 dB for both Scenarios B and C. This is significantly above the radar protection criteria of −6 dB.

If the 50% probability level of CDF is considered in order to compare impacts of various IMT BS beamforming methods (refer to Scenarios B, C in Table 7), Scenario B results in the lower *I*/*N* at the radar receiver compared to Scenario C. Scenario C records the highest *I*/*N* at 50% probability due to having the highest degree of freedom in terms of steering angles out of all the scenarios and using four steered beams per UE. As shown in Fig. A1-40 (b), AAS beams can be steered closer to the boresight of the radar antenna in elevation for Scenario C compared to Scenario B resulting in higher antenna coupling between IMT BS and the radar.

FIGURE A1-42

I/N at the receiver of Radar D for AAS Scenarios



5.1 Summary

In summary, it can be observed that for ship based Radar D standing 22 km from the shoreline at the edge of the territorial waters, based on 43 dBm transmit power per sector after feeder/ohmic losses within a 20 MHz bandwidth, as stated on Table A1.60, of an IMT urban macro BS standing at the shoreline are received 62-77 dB over the co-channel radar protection level of −6 dB depending on the IMT BS beamforming scenario. Note that the calculations assume temperate propagation conditions modelled using the ITU-R P.452 propagation model with $p = 10\%$. The results suggest that for the same effective sector transmit power affecting the victim receiver, the median *I*/*N* increases as the number of independently steerable beams within the sector increases. However, the two curves converge at around 99% CDF.

Beam steering scenario that represented spatial multiplexing and transmit diversity beam steering techniques recorded the highest median *I*/*N* out of all the AAS beamforming scenarios considered for this study. The results obtained above for the multi user MIMO environment considered certain beam forming scenario. However it is noted that AAS with massive MIMO in a multi-user environment may adopt various multi-beams techniques considering different deployment configurations and the results will vary accordingly.

6 Monte Carlo analysis of aggregated *I*/*N* from AAS-based IMT deployments

This section analyses aggregated interference from an AAS-based coastal urban macro IMT deployment with 25 BSs into various radar types in Table 1 using Monte Carlo simulations. In accordance with the guidelines in Recommendation ITU-R M.2101, a beam steering scenario similar to that of Fig. A1-34 (a), where a single beam is used to track a UE, is used during the aggregation studies. It should be noted that based on the single entry studies in § 5, this results in the best case median *I*/*N* at radar receivers out of all the AAS scenarios. An IMT bandwidth of 20 MHz is used for the simulations.

Section 6.1 analyses interference into various radar types stationed 22 km from the shoreline with radar antenna beams pointing towards the IMT deployment. Radar elevation beam tilt is assumed to be 0^o. Section 6.2 aims at calculating the protection distance between the IMT deployment and various radar types in order to meet the ITU-R recommended radar protection criteria of $I/N = -6$ dB. Each Monte Carlo simulation uses 100’000 simulation seeds.

6.1 Aggregated *I*/*N* for radars stationed 22 km from the coastline

This section analyses the aggregated *I*/*N* into various shipborne radar types in Table A1.54 from a coastal urban macro IMT deployment with 25 BSs that use AASs. Similar to § 5 and § 6, it is assumed that the position of the ship with respect to the IMT deployment is fixed at 22 km from the shoreline, and the radar antenna is pointing toward the IMT deployment. Radar elevation beam tilt is assumed to be 0^o. This is depicted in Fig. A1-43.

Radars C and D in Table A1.54 are further subdivided based on their beamwidth and IF bandwidth. OTR is calculated for radars with IF bandwidths less than 20 MHz using guidelines in Recommendation ITU-R SM.337. A rectangular spectrum mask with a relevant IF bandwidth is assumed for radar receivers for the purpose of calculating the OTR. Table A1.62 shows the notations used to identify these radars together with important radar related parameters used during the simulations.

Parameters related to IMT deployment shown in Table A1.63 are used during Monte Carlo simulations. According to the guidelines in Recommendation ITU-R M.2101, a wrap-around BS deployment methodology is used. CDF curves in Fig. A1.44 show the variation of aggregated *I*/*N* for various radar types.

FIGURE A1-43

BS sector orientation used for aggregated I/N simulations

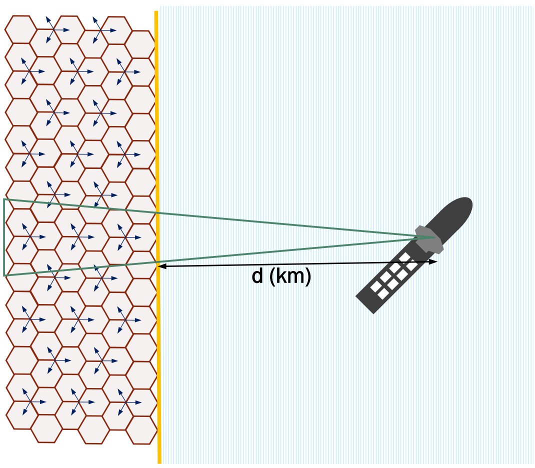


TABLE A1.62

Categorisation of radars based on beamwidth and IF bandwidth

Radar	Beamwidth (H,V)	IF bandwidth (MHz)	Antenna peak gain (dBi)	Noise Figure (dB)	Height above mean sea level (m)	OTR (dB)
A	1.75°, csc^2 beam in elevation from 4.4° to 30°	8	32	4.8	46	3.98
B	1.7°, 1.7°	10	42	5.0	20	3.01
C11	1.1°, 1.1°	10	40	1.5	20	3.01
C12	1.1°, 1.1°	30	40	1.5	20	0
C21	5°, 5°	10	40	1.5	20	3.01
C22	5°, 5°	30	40	1.5	20	0
D11	1.5°, 4°	2	40	1.5	20	10
D12	1.5°, 4°	20	40	1.5	20	0
D21	6°, 20°	2	40	1.5	20	10
D22	6°, 20°	20	40	1.5	20	0

TABLE A1.63

Simulation parameters related to IMT for aggregation studies

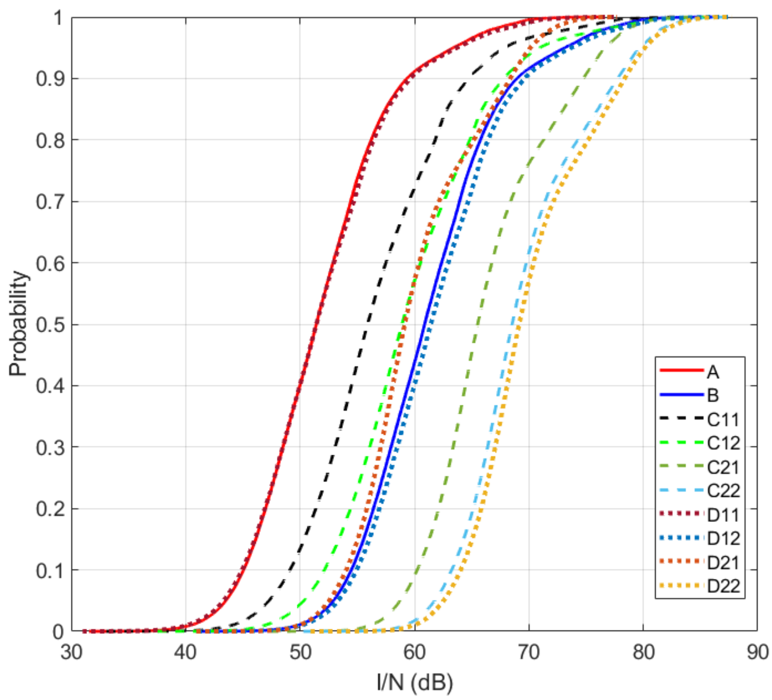
Parameter	Value
BS type	Macro Urban
BS (Front-Centre) Latitude (deg)	–33.87126
BS (Front-Centre) Longitude (deg)	151.25574
Distance over land from first layer of BS antennas to the coastline (km)	0.3
BS Antenna pattern	Recommendation ITU-R M.2101 (Table 5 above)
Antenna gain	Variable depending on steering angle
Array Ohmic loss (dB)	2
BS Antenna height above ground level (m)	20
BS Antenna mechanical down tilt	10°
BS Antenna electrical azimuth and elevation	Tracking UE
UE locations	Uniformly distributed within the sector
Indoor UE usage	70%
Height above terrain for indoor UEs (m)	Equally distributed among {1.5, 3.5, 5.5, 7.5, 9.5, 11.5, 13.5, 15.5, 17.5, 19.5} height levels
Height above terrain for outdoor UEs (m)	1.5
Below rooftop base station antenna deployment	50%
Reference frequency (MHz)	3 350
Occupied bandwidth (MHz)	20

TABLE A1.63 (*end*)

Parameter	Value
Conducted power (before Ohmic loss) per antenna element (dBm)	31
Propagation model	ITU-R P.452, P = 10%
Clutter loss for above rooftop antennas	None
Clutter loss for below rooftop antennas	Recommendation ITU-R P.2108
BS activity factor	50%
TDD factor (UL:DL)	20:80

FIGURE A1-44

Aggregated I/N variation at 22 km for various radar types



From the results, it can be see that *I*/*N* values for 99.999% non-exceedance criteria varies 76.25-87.48 dB depending on the radar type. It has to be noted that variations between interference for 100% and 99.999% are insignificant. This is significantly above the radar protection criteria of −6 dB.

6.2 Co-channel separation distances between coastal macro IMT deployments and ship based radars to meet the ITU-R M.1461 recommended radar protection criteria of *I*/*N* = −6 dB

This section uses the Monte Carlo methodology in order to calculate the protection distances between various radar types in Table A1.54 and a coastal urban macro IMT deployment with 25 BSs that use AAS in order to meet *I*/*N* radar protection criteria of −6 dB. Similar to § 5, it is assumed that radar antenna is pointing towards the IMT deployment with 0° elevation beamtilt as depicted in Fig. A1-45. Similar radar and IMT parameters to those in Tables A1.64 and A1.65 are used for simulations except the protection distances are calculated for ITU-R P.452 propagation model with p = 1%, 10% and 20% values. Table A1.64 shows protection distances for various radar types.

TABLE A1.64

Separation distances for the protection of radar

Radar	*P* = 1%	*P* = 10%	*P* = 20%
A	483	354	278
B	511	361	281
C11	494	361	307
C12	501	377	320
C21	535	404	329
C22	544	421	351
D11	477	355	240
D12	513	389	318
D21	513	376	295
D22	544	421	352

Based on these results, this study shows that significant mitigation techniques need to be employed for AAS based macro urban base stations in coastal zones for co-channel coexistence with ship borne radars.

6.3 Summary

In summary, it can be observed that for ship-based Radars A-D standing 22 km from the shoreline at the edge of the territorial waters, the emissions within a 20 MHz bandwidth from an AAS based urban macro IMT deployment with 25 BSs standing at the shoreline are received 82.42-93.68 dB over the co-channel protection criteria of –6 dB depending on the radar type for temperate propagation conditions using the ITU-R P.452 propagation model with p = 10%.

Protection distances to achieve the ITU-R M.1461 recommended radar protection criteria of $I/N = -6$ dB varies between 478-544 km, 355-422 km and 241-353 km depending on the radar type for ITU-R P.452 propagation model with p = 1%, 10% and 20% respectively.

Annex 2

Analysis of adjacent channel interference between IMT-advanced systems operating in the 3 300-3 400 MHz band and radar systems operating in the 3 100-3 300 MHz band

This Annex provides adjacent channel compatibility studies between IMT-Advanced systems in the frequency band 3 300-3 400 MHz and radar systems operating in 3 100-3 300 MHz, specifically scenarios where both systems operate close to each other in frequency. This is also meaningful for in-band coexistence between IMT and radar systems operating both in 3 300-3 400 MHz with a frequency offset.

This Annex presents separation distance results for the following scenarios:

– Interference from urban outdoor IMT micro base stations to ship-based radar;
– Interference from urban outdoor IMT macro base stations to ship-based radar;
– Interference from suburban outdoor IMT macro base stations to ship-based radar;
– Interference from urban outdoor IMT micro base stations to land-based radar;
– Interference from urban outdoor IMT macro base stations in to land-based radar;

considering many cases:

– 10 MHz and 20 MHz IMT base stations;
– single entry studies of interference from one IMT base station to one ship-based radar;
– aggregation studies of interference from IMT base stations deployment to a ship-based radar;
– propagation path fully over sea for scenario between a shipborne radar ar sea distance from base stations standing at the shoreline;
– mixed propagation path over sea, coastal and inland zones depending of scenarios with ship standing at the limit of territorial sea (22km) and base stations inside coastal or inland zones;
– propagations losses in tropical regions and those in equatorial regions.

The scenario of interference from IMT base stations operating multichannels over 3 300-3 400 MHz band (i.e. TDD mode with a bandwidth of 100MHz) has not been considered. An additional frequency channels aggregation factor would need to be taken into account in this case, leading to greater separation distances but the methodological approach would be the same. In addition, the document presents an assessment of the likelihood of interference from IMT terminals into radar systems, and from radar systems into IMT systems.

Study G

This Annex provides a study of adjacent band compatibility between IMT and radar systems. The following scenarios have been considered:

– Micro urban IMT BS interfering with shipborne radars;
– Macro urban IMT BS interfering with shipborne radars;

The impact of single entry and aggregate interference has been examined. In the analysis of single entry interference, under each scenario, the implications of path loss percentage time and clutter loss have been also investigated. In the case of aggregate interference analysis, a baseline analysis has been implemented for a set of assumptions. The implications of variations in assumed parameter values have been investigated as part of the sensitivity analysis.

In addition, the document presents a brief assessment of interference potential from IMT terminals into radar systems and from radar systems into IMT systems.

1 Technical characteristics of IMT and radar systems

1.1 IMT system parameters

Section 3.1 in the main body contains the list of parameters for IMT deployment. Main IMT BS modelling parameters are shown below for completeness.

TABLE A2.1

IMT BS main modelling parameters

Parameters	**Assumed Value**
Maximum transmit power	46 dBm / 20 MHz (Macro Urban) 24 dBm / 20 MHz (Micro Urban)
Maximum antenna gain	18 dBi (Macro Urban) 5 dBi (Micro Urban)
Antenna height (a.g.l.)	20 m (Macro Urban) 6 m (Micro Urban)
Unwanted emission mask	Category B Wide Area Mask (Macro Urban), ETSI TS 136 104 Local Area Mask (Micro Urban), ETSI TS 136 104

1.2 Shipborne radar parameters

Recommendation ITU-R M.1465 provides the characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 3 100-3 700 MHz.

Section 3.2 in the main body provides the key radar parameters to be used for these studies.

The key shipborne radar modelling parameters are summarised below for completeness.

TABLE A2.2

Shipborne Radar Modelling Parameters

Parameters	**Assumed Value**
Maximum antenna gain	42 dBi (Radar B) 40 dBi (Radar C, D and M)
Antenna height (a.g.l.)	20 m (Radar B, C, & D), 50 m (Radar M)
IF bandwidth	10 MHz (Radar B) 10-30 MHz (Radar C and M) 2-20 MHz (Radar D)
Noise figure	5 dB (Radar B) 1.5 dB (C, D and M))
Interference criterion	$I/N = -6$ dB
Selectivity fall-off	80 dB/decade

2 Propagation model and related parameters

The propagation model used to calculate the co-channel and adjacent band co-existence requirements is Recommendation ITU-R P.452-16.

The simple model described in § 3.2 of Recommendation ITU-R P.2108 has been incorporated into the modelling to consider the impact of clutter losses.

The implications of Equatorial and Tropical climatic zones have been taken into consideration.

3 Analysis approach

This section provides description of single entry and aggregate interference analysis methods adopted in this study.

3.1 Single entry interference analysis approach

The minimum required path loss to satisfy the interference criterion at the radar receiver is calculated for each scenario. The calculated path loss is then translated into separation distance using interference path propagation mechanisms described in Recommendation ITU-R P.452-16 for an assumed frequency separation between the edges of IMT BS transmitter and radar receiver channels (i.e. guard band).

Interference scenarios consider the implications of following deployment scenarios.

– Macro IMT BSs deployed in urban environment and micro IMT BSs deployed in urban environment;
– Four shipborne radar types assumed to be using various channel bandwidths;
– Clutter losses based on Recommendation ITU-R P.2108-0 model; and
– Tropical and equatorial climate zones.

3.2 Aggregate interference analysis approach

The following approach has been adopted to model the impact of interference aggregation from a population of IMT BSs deployed in a hypothetical town and assumed to be operating within the shipborne radar antenna main beam. The study considers that:

– From the radar receiver point of view, interference from a population of IMT BSs located at a distance in a hypothetical town within the main beam of the radar is assumed to be a point interference source.
– Antenna gain and path loss variations from individual IMT BSs that are modelled as an effective point interference source are assumed to be insignificant for the radar receiver located at the sea away from a hypothetical town where IMT BSs are deployed. Interference from sectors pointing towards the sea will dominate the aggregate interference.
– For an assumed distance between the radar and effective interference source, e.g. a territorial sea limit of 22 km, aggregate interference is calculated by taking account of clutter loss and aggregate IMT BS power towards the radar receiver.
– In order to obtain generic results without land effects, path losses are assumed to be associated with sea path propagation defined in Recommendation ITU-R P.452.
– The aggregate power towards the radar receiver is determined using the assumed density and activity factor of IMT BS transmitters.
– Aggregate interference is compared against the radar interference criterion and the analysis is repeated by varying the distance until the criterion is satisfied.

4 Off frequency rejection calculations

The key step of the adjacent band interference analysis is calculation of the effect of transmitter and receiver filtering. The calculation is based on a method where the transmitter emission mask and receiver selectivity mask are convolved to calculate Off Frequency Rejection (OFR) levels corresponding to different frequency offsets between the transmit and receive channel centre frequencies. Masks are shown in the following Figures.

FIGURE A2-1

IMT BS emission masks

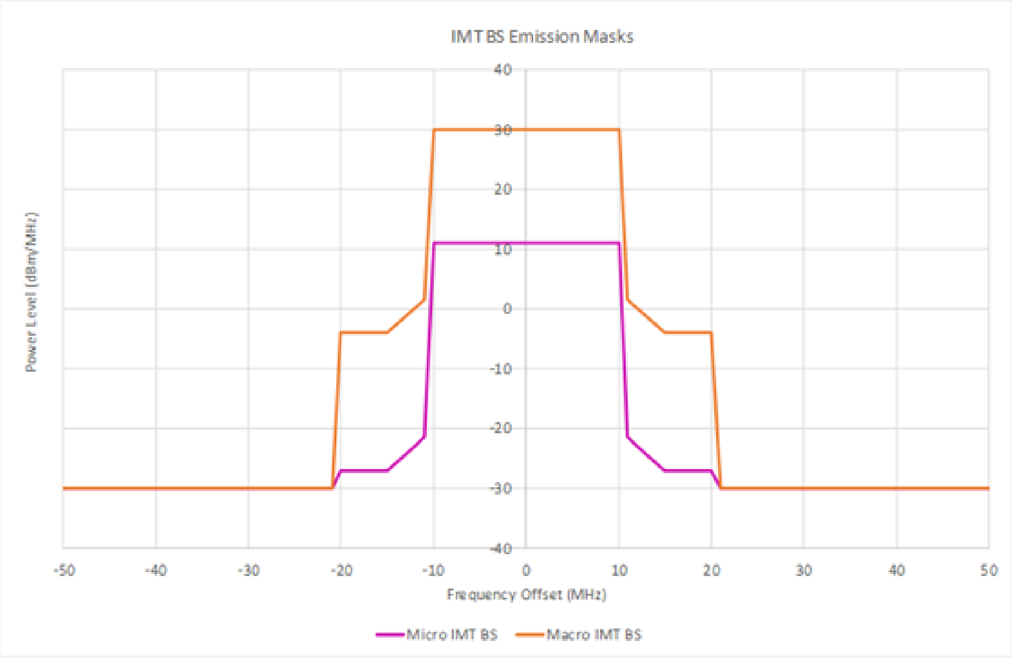
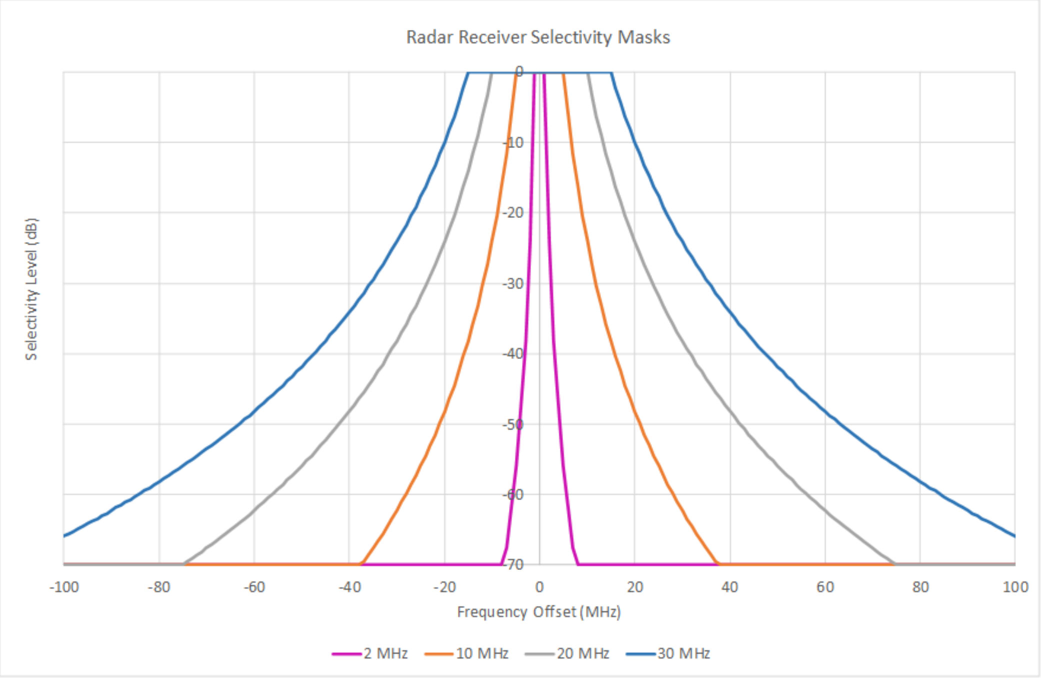


FIGURE A2-2

Radar receiver selectivity masks



The following Figures show calculated OFR plots for micro and macro IMT BS transmitters and radar receivers with 2, 10, 20 and 30 MHz bandwidth. OFR levels calculated for an assumed 10 MHz guard band between the edge of transmitter and receiver channels are also shown.

FIGURE A2-3

OFR plots for micro IMT BS transmitter (20 MHz) and radar receivers (2, 10, 20 and 30 MHz)

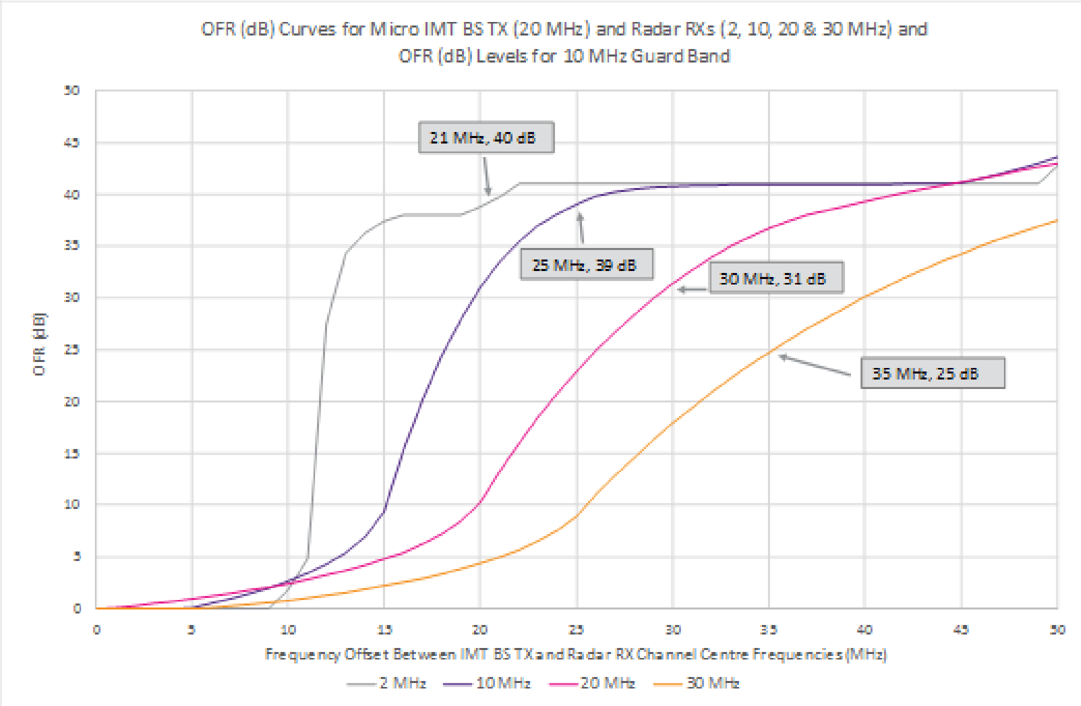
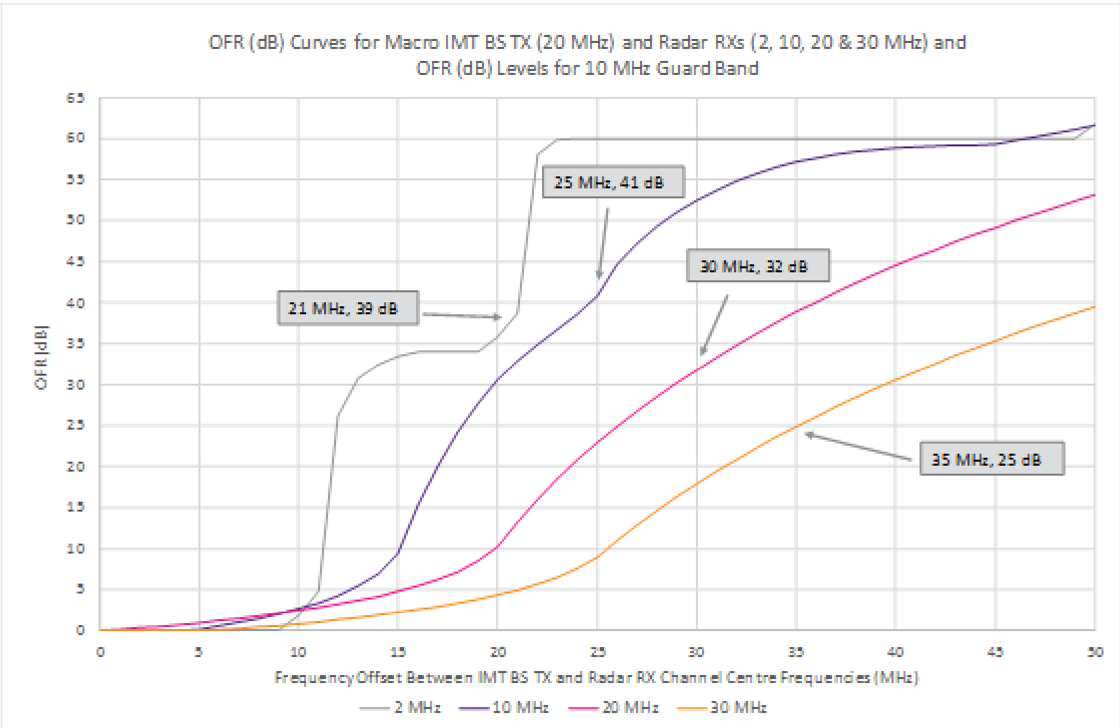


FIGURE A2-4

OFR plots for macro IMT BS transmitter (20 MHz) and radar receivers (2, 10, 20 and 30 MHz)



5 Adjacent band single entry interference analysis results

5.1 Micro urban

5.1.1 Baseline analysis

Table A2.3 provides single entry interference analysis results for the micro urban IMT BS transmitter when there is an assumed 10 MHz guard band between the edges of BS transmit channel and radar receive channels.

TABLE A2.3

Single Entry Interference from Micro Urban IMT BS

Parameter	Radar B	Radar C	Radar D	Radar M
Carrier Frequency (MHz)	3 300			
IMT BS Transmitter Bandwidth (MHz)	20			
IMT BS Transmitter Power (dBm)	24			
IMT BS Transmitter Max Antenna Gain (dBi)	5			
Guard Band (MHz)	10			
Radar Receiver Antenna Gain (dBi)	42	40	40	40
Radar Receiver Bandwidth (MHz)	10	10-30	2-20	10-30
Radar Receiver Noise Figure (dB)	5	1.5	1.5	1.5
Radar Receiver Interference Criterion (dBm) (1)	–105	(–108.5) – (–103.7)	(–115.5) – (–105.5)	(–108.5) – (–103.7)
OTR (dB)	3	3-0	10-0	3-0
OFR (dB)	39	39-25	40-31	39-25
Required Path Loss (dB) (2)	134	135.5-147.7	134.5-143.5	135.5-147.7
Protection Distance (km) (no clutter loss) (Path loss not exceeded for 10% of time)	41 (Equatorial) 41 (Tropical)	48-139 (Eq.) 44-85 (Tr.)	43-109 (Eq.) 42-70 (Tr.)	50-141 (Eq.) 50-87 (Tr.)
Protection Distance (km) (no clutter loss) (Path loss not exceeded for 20% of time)	39 (Equatorial) 27 (Tropical)	44-86 (Eq.) 30-46 (Tr.)	40-73 (Eq.) 28-42 (Tr.)	46-93 (Eq.) 36-58 (Tr.)

(1) kTBNF – 6 dB.

(2) Required path loss (dB) = IMT BS e.i.r.p. (dBm) + radar antenna gain (dBi) – OFR (dB) – OTR (dB) – radar interference criterion (dBm).

5.1.2 Analysis with clutter loss

The implications of clutter losses have been examined using 18, 28 and 38 dB loss values corresponding to clutter losses not exceeded for 5, 50 and 95% of IMT BS locations according to Recommendation ITU-R P.2108.

TABLE A2.4

Implications of clutter losses (micro urban)

Parameter	Radar B	Radar C	Radar D	Radar M
Required path loss from baseline analysis (dB)	134	135.5-147.7	134.5-143.5	135.5-147.7
	Path loss not exceeded for 10% of time			
Protection distance (km) (no clutter loss)	41 (Equatorial) 41 (Tropical)	48-139 (Eq.) 44-85 (Tr.)	43-109 (Eq.) 42-70 (Tr.)	50-141 (Eq.) 50-87 (Tr.)
Protection distance (km) (18 dB clutter loss)	5 (Equatorial) 5 (Tropical)	6-26 (Eq.) 6-26 (Tr.)	5-16 (Eq.) 5-16 (Tr.)	6-26 (Eq.) 6-26 (Tr.)
Protection distance (km) (28 dB clutter loss)	1 (Equatorial) 1 (Tropical)	2-8 (Eq.) 2-8 (Tr.)	2-5 (Eq.) 2-5 (Tr.)	2-8 (Eq.) 2-8 (Tr.)
Protection distance (km) (38 dB clutter loss)	1 (Equatorial) 1 (Tropical)	1-2 (Eq.) 1-2 (Tr.)	1-1 (Eq.) 1-1 (Tr.)	1-2 (Eq.) 1-2 (Tr.)
	Path loss not exceeded for 20% of time			
Protection distance (km) (no clutter loss)	39 (Equatorial) 27 (Tropical)	44-86 (Eq.) 30-46 (Tr.)	40-73 (Eq.) 28-42 (Tr.)	46-93 (Eq.) 36-58 (Tr.)
Protection distance (km) (18 dB clutter loss)	5 (Equatorial) 5 (Tropical)	6-24 (Eq.) 6-20 (Tr.)	5-15 (Eq.) 5-14 (Tr.)	6-24 (Eq.) 6-24 (Tr.)
Protection distance (km) (28 dB clutter loss)	1 (Equatorial) 1 (Tropical)	2-7 (Eq.) 2-7 (Tr.)	2-4 (Eq.) 2-4 (Tr.)	2-7 (Eq.) 2-7 (Tr.)
Protection distance (km) (38 dB clutter loss)	1 (Equatorial) 1 (Tropical)	1-2 (Eq.) 1-2 (Tr.)	1-1 (Eq.) 1-1 (Tr.)	1-2 (Eq.) 1-2 (Tr.)

As a next step, a scenario where a radar receiver is assumed to be at the territorial limit (22 km) has been investigated. The following table shows path loss and interference values (with no clutter loss) for each radar.

TABLE A2.5

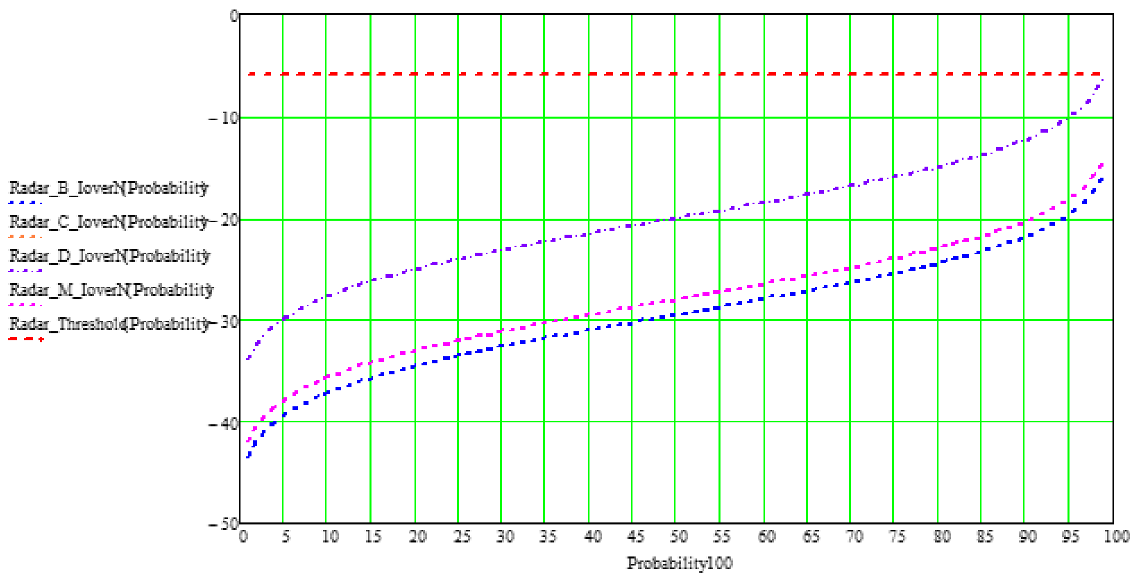
Radar Receiver at 22 km from the Shore (Micro Urban)

Parameter	Radar B	Radar C	Radar D	Radar M
Path loss (dB)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 131 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 131 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 131 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)
Representative Interference (dBm in radar bandwidth) (no clutter loss)	−100 (20%, Eq., 10 MHz radar bandwidth)	−102 (20%, Eq., 10 MHz radar bandwidth)	−91 (20%, Eq., 20 MHz radar bandwidth)	−102 (20%, Eq., 10 MHz radar bandwidth)
Radar Receiver Interference Criterion (dBm)	−105	−108.5	−105.5	−108.5

The impact of clutter losses has been examined using Recommendation ITU-R P.2108. Figure A2-5 shows the probability of *I*/*N* being less than a y-axis value. The results are also compared against the radar threshold of −6 dB.

FIGURE A2-5

***I/N* probability at 22 km from the shore (with clutter losses, micro urban, 20%, Eq.)**



Note that probabilities corresponding to Radar C and M are at the same level for a given *I*/*N* hence appear to be a single line.

5.2 Macro urban

5.2.1 Baseline analysis

Single entry interference analysis results for the macro urban IMT BS transmitter are presented in Table A2.6 for an assumed 10 MHz guard band between the edges of BS transmit channel and radar receive channels.

TABLE A2.6

Single entry interference from macro urban IMT BS

Parameter	Radar B	Radar C	Radar D	Radar M
Carrier Frequency (MHz)	3 300			
IMT BS Transmitter Bandwidth (MHz)	20			
IMT BS Transmitter Power (dBm) (including feeder losses)	43			
IMT BS Transmitter Antenna Gain (dBi) (10 degrees downtilted Rec. 1336 Antenna)	6			
Guard Band (MHz)	10			
Radar Receiver Antenna Gain (dBi)	42	40	40	40
Radar Receiver Bandwidth (MHz)	10	10-30	2-20	10-30
Radar Receiver Noise Figure (dB)	5	1.5	1.5	1.5
Radar Receiver Interference Criterion (dBm)	–105	(–108.5) – (–103.7)	(–115.5) – (–105.5)	(–108.5) – (–103.7)

TABLE A2.6 (*end*)

Parameter	Radar B	Radar C	Radar D	Radar M
OTR (dB)	3	3-0	10-0	3-0
OFR (dB)	41	41-25	39-32	41-25
Required path loss (dB)	152	153.5-167.7	155.5-162.5	153.5-167.7
Protection distance (km) (no clutter loss) (Path loss not exceeded for 10% of time)	179 (Equatorial) 113 (Tropical)	189-284 (Eq.) 120-196 (Tr.)	202-248 (Eq.) 129-165 (Tr.)	189-284 (Eq.) 120-194 (Tr.)
Protection distance (km) (no clutter loss) (Path loss not exceeded for 20% of time)	113 (Equatorial) 62 (Tropical)	119-180 (Eq.) 65-107 (Tr.)	126-155 (Eq.) 69-89 (Tr.)	125-187 (Eq.) 73-110 (Tr.)

5.2.2 Analysis with Clutter Loss

The effect of clutter losses is analysed in Table A2.7.

TABLE A2.7

Implications of clutter losses (macro urban)

Parameter	Radar B	Radar C	Radar D	Radar M
Required Path Loss from Baseline Analysis (dB)	152	153.5-167.7	155.5-162.5	153.5-167.7
	Path loss not exceeded for 10% of time			
Protection Distance (km) (no clutter loss)	179(Equatorial) 113 (Tropical)	189-284 (Eq.) 120-196 (Tr.)	202-248 (Eq.) 129-165 (Tr.)	189-284 (Eq.) 120-194 (Tr.)
Protection Distance (km) (18 dB clutter loss)	43 (Equatorial) 43 (Tropical)	50-164 (Eq.) 50-103 (Tr.)	62-123 (Eq.) 57-82 (Tr.)	50-164 (Eq.) 50-103 (Tr.)
Protection Distance (km) (28 dB clutter loss)	13 (Equatorial) 13 (Tropical)	16-79 (Eq.) 16-64 (Tr.)	20-45 (Eq.) 20-45 (Tr.)	16-79 (Eq.) 16-70 (Tr.)
Protection Distance (km) (38 dB clutter loss)	4 (Equatorial) 4 (Tropical)	5-26 (Eq.) 5-26 (Tr.)	6-14 (Eq.) 6-14 (Tr.)	5-26 (Eq.) 5-26 (Tr.)
	Path loss not exceeded for 20% of time			
Protection Distance (km) (no clutter loss)	113 (Equatorial) 62 (Tropical)	119-180 (Eq.) 65-107 (Tr.)	126-155 (Eq.) 69-89 (Tr.)	125-187 (Eq.) 73-110 (Tr.)
Protection Distance (km) (18 dB clutter loss)	39 (Equatorial) 32 (Tropical)	46-105 (Eq.) 35-58 (Tr.)	56-87 (Eq.) 39-53 (Tr.)	46-111 (Eq.) 41-70 (Tr.)
Protection Distance (km) (28 dB clutter loss)	12 (Equatorial) 12 (Tropical)	15-68 (Eq.) 15-44 (Tr.)	19-41 (Eq.) 19-33 (Tr.)	15-71 (Eq.) 15-51 (Tr.)
Protection Distance (km) (38 dB clutter loss)	4 (Equatorial) 4 (Tropical)	5-24 (Eq.) 5-24 (Tr.)	6-13 (Eq.) 6-13 (Tr.)	5-24 (Eq.) 5-24 (Tr.)

For a radar receiver at 22 km from the shore, it can be shown that the path loss and interference values (with no clutter loss) for each radar are as follows.

TABLE A2.8

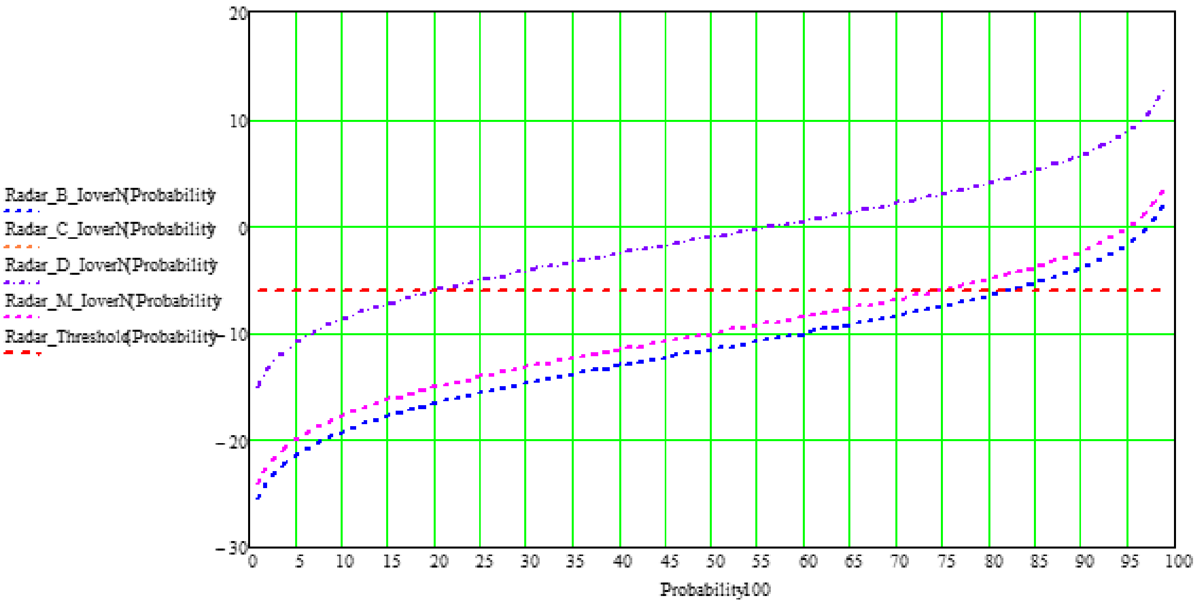
Radar receiver at 22 km from the shore (macro urban)

Parameter	Radar B	Radar C	Radar D	Radar M
Path loss (dB)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)	128 (10%, Eq.) 129 (20%, Eq.) 128 (10%, Tr.) 129 (20%, Tr.)
Representative Interference (dBm in radar bandwidth) (no clutter loss)	–82 (20%, Eq., 10 MHz radar bandwidth)	–84 (20%, Eq., 10 MHz radar bandwidth)	–72 (20%, Eq., 20 MHz radar bandwidth)	–84 (20%, Eq., 10 MHz radar bandwidth)
Radar receiver interference criterion (dBm)	–105	–108.5	–105.5	–108.5

Figure A2-6 shows the *I*/*N* probability when clutter losses are considered. The results are also compared against the radar *I*/*N* threshold.

FIGURE A2-6

***I*/*N* probability at 22 km from the shore (with clutter losses, macro urban, 20%, Eq.)**



Note that probabilities corresponding to Radar C and M are at the same level for a given *I*/*N* hence appear to be a single line.

6 Adjacent band aggregate interference analysis results

Analysis with a set of baseline assumptions together with the sensitivity analysis for assumed parameter values have been implemented.

6.1 Baseline analysis

6.1.1 Assumptions

Interference from IMT BS transmitters providing coverage within an area of a coastal town overlapping the radar receiver main beam is calculated. Considering the approximate size of Lagos and Cape Town, the coastal town is assumed to be 15 km radius. For an assumed radar distance to the shore and radar beamwidth, the town area overlapped by the main radar beam is calculated. The number of IMT BS transmitters covering the overlapped area is determined by assuming that the IMT cell radius is 2 km. Interference power towards the radar receiver is then calculated by aggregating IMT BS transmit powers.

The aggregate power is modified to take account of an assumed 50% BS transmitter activity (i.e. 3 dB reduction in aggregate power). The path loss is assumed to be sea path and approximated by the path loss between the radar and the centre of the town. It is assumed that the IMT BS sectors are pointing towards the radar receiver. It is also assumed that there is a 10 MHz guard band between the radar and IMT BS channels.

The impact of clutter losses is considered by deriving the probability of aggregate interference being a less than a given value based on Recommendation ITU-R P.2108. For each IMT BS contributing to the aggregate interference power, it is assumed that the Recommendation ITU-R P.2108 clutter loss distribution applies, i.e. the probability of clutter loss being more than a given value is the same for each interfering IMT BS.

Table A2.9 shows the baseline analysis assumptions.

TABLE A2.9

Baseline analysis assumptions

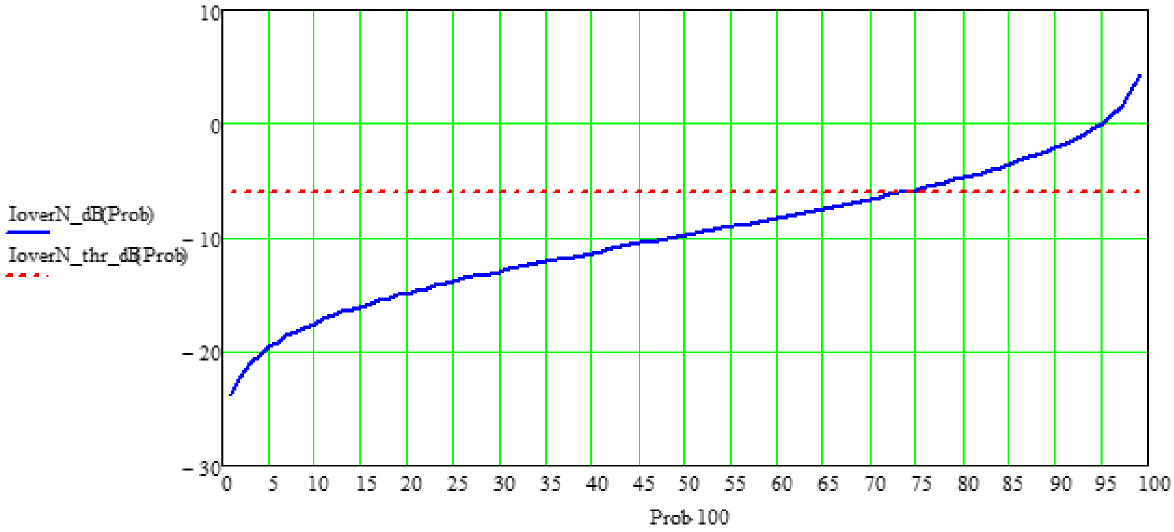
Parameter	Radar B	Radar C	Radar D	Radar M
Carrier frequency (MHz)	3 300			
IMT BS transmitter bandwidth (MHz)	20			
IMT BS transmitter power (dBm) (including feeder losses)	43			
IMT BS transmitter antenna gain (dBi) (6 degrees downtilted Rec.1336 Antenna)	10.5			
IMT BS transmitter activity factor (%)	50			
IMT cell radius (km)	2			
Percentage time for path loss (%)	20			
Guard band (MHz)	10			
Clutter loss	Rec. ITU-R P.2108			
Radar receiver antenna gain (dBi)	42	40	40	40
Radar antenna beamwidth (degree)	1.7	1.1	1.5	1
Radar receiver bandwidth (MHz)	10	10	20	10
Radar receiver noise figure (dB)	5	1.5	1.5	1.5
Radar receiver interference criterion (dBm)	−105	−108.5	−105.5	−108.5
OTR (dB)	3	3	0	3
OFR (dB)	41	41	32	41

6.1.2 22-km Scenario

The implications of aggregate interference have been analysed by assuming that the radar receiver is at 22 km from the shore in the equatorial region. In the case of radar B, for example, it can be shown that there are three IMT BSs covering the town area overlapped by the radar beam leading to an aggregation factor of 4.8 dB. The total interference at the radar receiver is −79 dBm/10 MHz with no clutter loss. This is approximately 26 dB above the interference criterion. On this basis, the following plot can be derived using Recommendation ITU-R P.2108 clutter loss model to show the probability of *I*/*N* being less than y-axis value. The plot also shows the *I*/*N* threshold −6 dB.

FIGURE A2-7

***I*/*N* probability at 22 km from the shore for aggregate interference into radar B**



As can be seen, the probability of satisfying *I*/*N* of −6 dB criterion is approximately 70%.

The analysis repeated for all radars and results are summarised below for the tropical and equatorial regions.

TABLE A2.10

22-km scenario analysis results

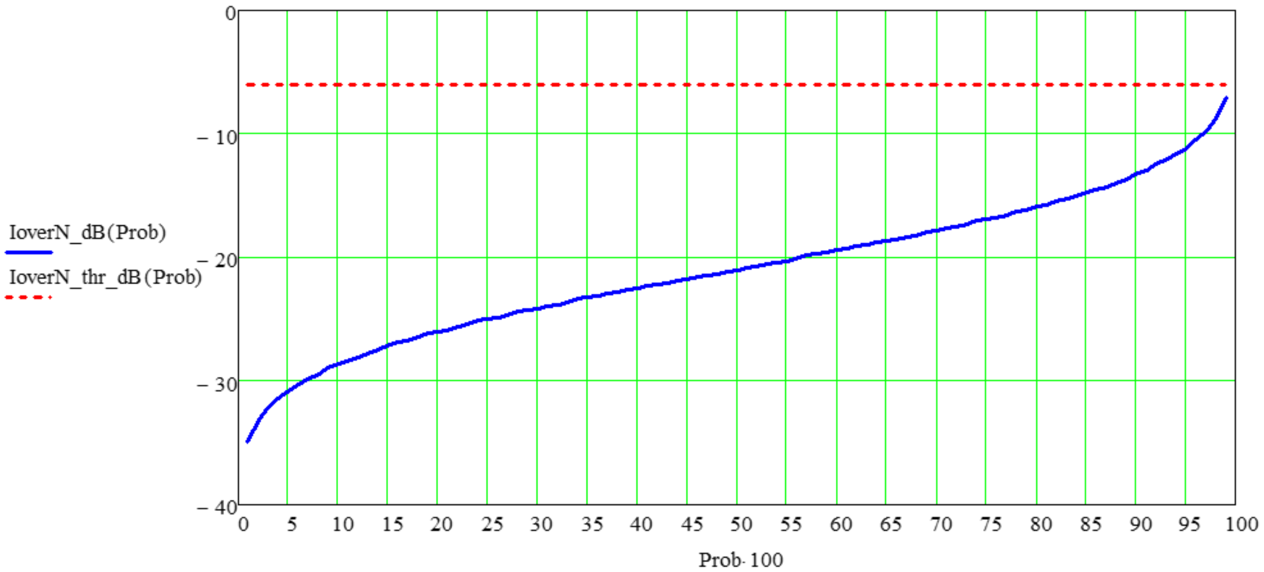
Parameter	Radar B	Radar C	Radar D	Radar M
No of IMT BSs within radar beamwidth	3	2	3	2
Aggregate interference at radar receiver with no clutter loss (dBm in radar bandwidth)	–80 (equatorial) –83 (topical.)	–84 (eq.) –86.5 (tr.)	–70 (eq.) –73 (tr.)	–84 (eq.) –84 (tr.)
Radar receiver interference criterion (dBm in radar bandwidth)	–105	–108.5	–105.5	–108.5
Excess compared to criterion (dB)	25 (equatorial) 22 (tropical)	24.5 (eq.) 22 (tr.)	35.5 (eq.) 32.5 (tr.)	24.5 (eq.) 24.5 (tr.)
Probability of satisfying *I*/*N* = −6 dB with clutter losses (%)	73 (equatorial) 85 (tropical)	75 (eq.) 87 (tr.)	15 (eq.) 25 (tr.)	75 (eq.) 75 (tr.)

6.1.3 Protection distances

Based on interference scenarios examined above, required protection distances from aggregate interference have been calculated by moving the radar further away from the shore and re-calculating the overlap area and number of IMT BS interferers. In the case of radar B, for example, when the distance from the shore is 94 km in the equatorial region there are 8 IMT BS transmitters within the radar beam and the *I*/*N* plot remains below the −6 dB criterion as shown below.

FIGURE A2-8

***I*/*N* probability at 91 km from the shore for aggregate interference into radar B**



The analysis has been repeated for all radars and the required protection distances are summarised in Table A2.11.

TABLE A2.11

Protection distance analysis results

Parameter	Radar B	Radar C	Radar D	Radar M
Protection distance from the shore (km)	91 (equatorial) 43 (topical)	91 (eq.) 42 (tr.)	137 (eq.) 61 (tr.)	94 (eq.) 53 (tr.)
No of IMT BSs within radar beamwidth	8 (equatorial) 5 (tropical)	5 (eq.) 3 (tr.)	10 (eq.) 5 (tr.)	5 (eq.) 3 (tr.)

6.2 Sensitivity analysis

Radar B has been assumed to be a representative radar for the adjacent band sensitivity analysis where the implications of variations in modelling parameters have been investigated.

6.2.1 IMT cell radius

The protection distances in the tropical region have been calculated for a range of assumed cell radius. Results are summarised in Table A2.12.

TABLE A2.12

Protection distances (Radar B, Tropical Region, IMT Cell Radius Sensitivity)

Parameter	0.3 km	0.6 km	1 km	2 km
Protection distance from the shore (km)	85	63	50	43
No of IMT BSs within radar beamwidth	315	62	19	5

6.2.2 Percentage Time

The calculation has been repeated for an assumed percentage time of 10%.

TABLE A2.13

Protection distances (radar B, tropical region, percentage time sensitivity)

Parameter	10%	20%
Protection Distance from the Shore (km)	87	43

6.2.3 IMT BS Activity Factor

Protection distances have been re-calculated for additional 20% and 80% activity factors.

TABLE A2.14

Protection distances (radar B, tropical region, IMT BS activity factor sensitivity)

Parameter	20%	50%	80%
Protection Distance from the Shore (km)	35	43	45

6.2.4 IMT BS Power

The impact of reduced transmit power has been examined for assumed 10 W and 5 W transmit power levels.

TABLE A2.15

Protection distances (Radar B, Tropical Region, IMT BS Transmit Power Sensitivity)

Parameter	5 W (37 dBm)	10 W (40 dBm)	20 W (43 dBm)
Protection distance from the shore (km)	31	38	43

6.2.5 Guard Band

The baseline modelling is based on 10 MHz guard band. The implications of increased guard band have been analysed and results are shown in Table A2.16.

TABLE A2.16

Protection Distances (Radar B, Tropical Region, guard band sensitivity)

Parameter	0 MHz (10 dB OFR)	10 MHz (40 dB OFR)	20 MHz (45 dB OFR)	40 MHz (55 dB OFR)
Protection distance from the shore (km)	162	43	17	3

6.2.6 IMT BS Bandwidth

Protection distances obtained for 10 and 20 MHz IMT BS bandwidths are shown in Table A2.17.

TABLE A2.17

Protection distances (Radar B, Tropical Region, bandwidth sensitivity)

Parameter	10 MHz	20 MHz
Protection distance from the shore (km)	45	43

6.2.7 Propagation loss

The implications of sea (which is used in the baseline modelling) and mixed land and sea paths have been examined for an assumed deployment in the equatorial region. It is assumed that the land portion of the interference path is spherical Earth.

TABLE A2.18

Protection Distances (Radar B, Equatorial Region, Propagation Path Sensitivity)

Parameter	Sea Path	Mixed Path
Protection Distance from the Shore (km)	91	67

Study H

1 Technical characteristics of IMT and Radar systems

1.1 IMT system parameters

Section 2 in the main body contains the list of parameters for IMT deployment, which are taken from Report ITU-R M.2292.

1.2 Radar parameters

Section 2 in the main body provides the key radar parameters to be used for these studies. Ship based Radar A cannot be considered in this study because this system operate above 3.5 GHz.

Table A2.19 gives the parameters used for shipborne radars in the 3 100-3 300 MHz band.

TABLE A2.19

Shipborne Radar considered parameters for adjacent bands compatibility study

Characteristics	Units	Radar B	Radar C	Radar D	Radar M
Antenna height above ground	m	20	20	20	50
Antenna gain	dBi	42	40	40	40
Feeder insertion loss	dB	0	0	0	0
Receiver IF 3 dB bandwidth	MHz	10	10-30	2-20	10-30
Receiver noise figure	dB	5	1.5	1.5	1.5
Receiver IF selectivity Fall-off	dB/decade	−80	−80	−80	−80
Horizontal beamwitdth	degree	1.7	1.1-5.0	1.5-6.0	1.0-5.0

In this study, indexes m and n of radars' names $R_{m,n}$ which are shown in some Tables or Figures indicate that the calculation used either minimum (m = 1) or maximum (m = 2) values for their receivers bandwidth, and either minimum (n = 1) or maximum (n = 2) values for their antenna beamwidth.

1.3 Frequency rejection

Figures A2-10 and A2-11 give plotted curves representing OFR values as a function of the frequency gap between different bandwidths of a transmitting IMT base station and a Radar receiver. The frequency gap is the frequency difference between −3 dB points respective to IMT transmission mask and radar reception IF filter. The frequency offset Δ*f* used in Recommendation ITU-R SM.337, defined between the IMT channel central frequency and radar band tuning frequency, could be calculated as the addition of the frequency gap and half bandwidths of each transmitter and receiver.

FIGURE A2-9

Emission masks of transmitters for IMT Macro base stations

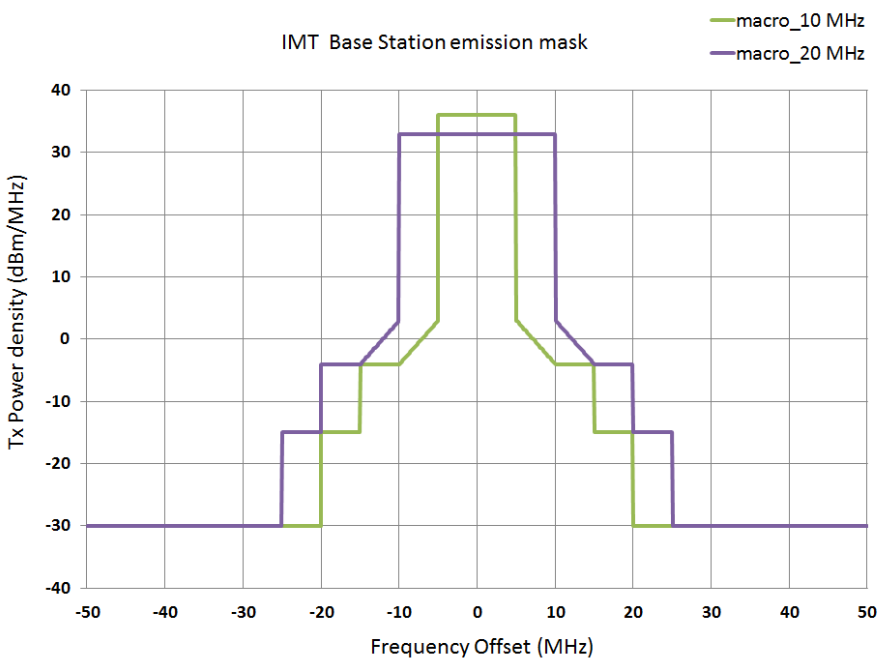


FIGURE A2-10

Emission masks of transmitters for IMT micro basestations

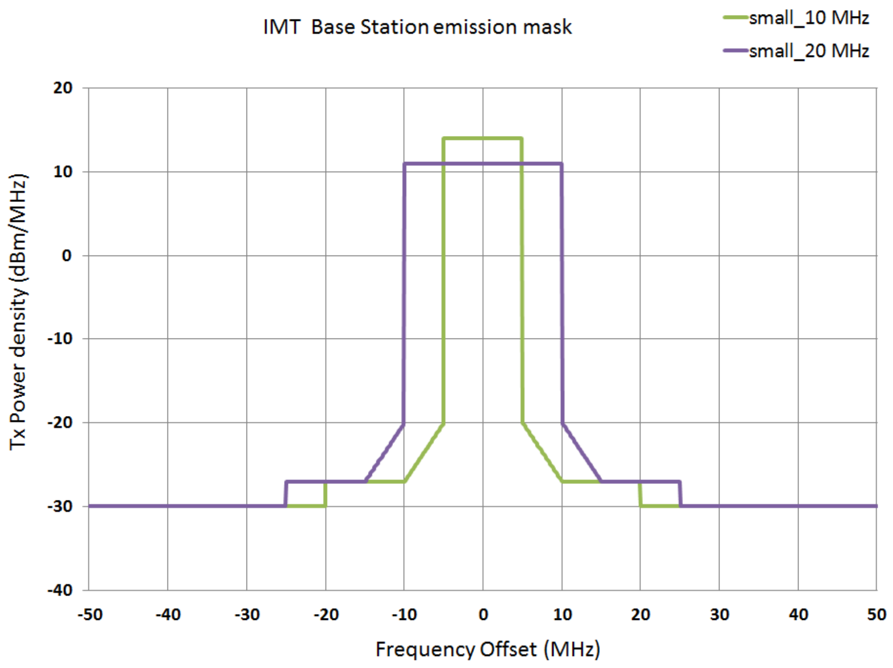


FIGURE A2-11

Frequency Offset and Gap between a radar receiver band and one IMT base station transmitter channel

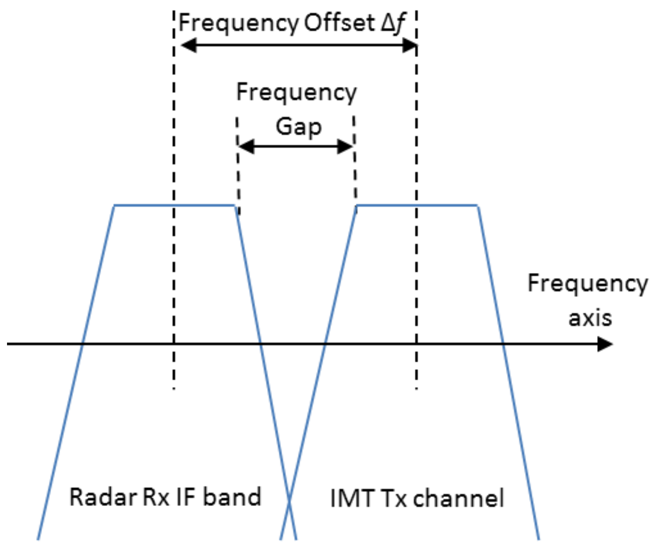
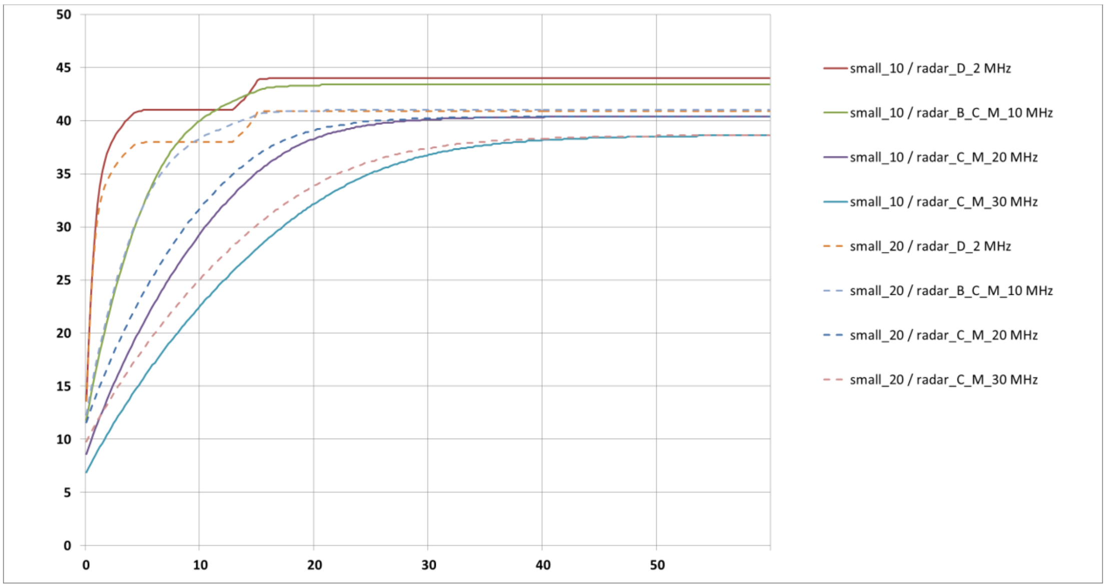


FIGURE A2-12

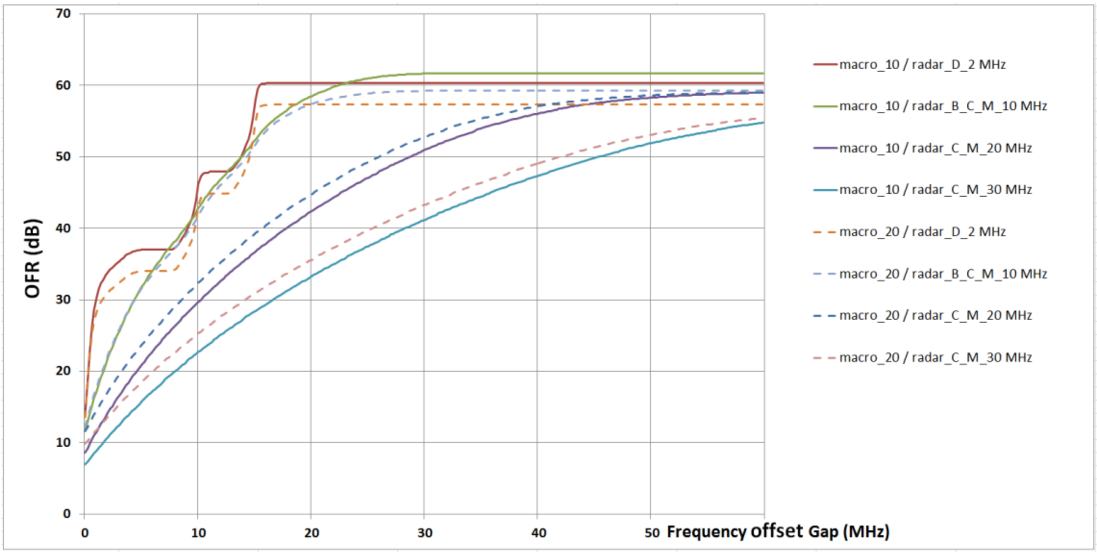
Off Tune Rejection (OFR) vs Frequency Gap, for radar receiver against an IMT micro base station transmitter operating one channel of 10 MHz or 20 MHz



It can be observed that considering a frequency gap of 10 MHz between IMT-Advanced micro base stations and shipborne radar systems, the FDR is less than 22.5 dB for small BS 10 MHz and less than 25.0 dB for small BS 20 MHz.

FIGURE A2-13

Off Tune Rejection (OFR) vs Frequency Gap, for radar receiver against an IMT macro base station transmitter operating one channel of 10 MHz or 20 MHz



It can be observed that considering a frequency gap of 10 MHz between IMT-Advanced macro base stations and shipborne radar systems, the FDR is less than 22.7 dB for macro BS 10 MHz and less than 25.3 dB for macro BS 20 MHz.

TABLE A2.20

Summary of values for OTR, and OFR for 10 MHz gap, for micro base stations

Base station type	Small 10 MHz				Small 20 MHz			
IMT Tx bandwidth (MHz)	10				20			
Radar type	D	B, C, D, M	C, D, M	C, M	D	B, C, D, M	C, D, M	C, M
Radar Rx bandwidth (MHz)	2	10	20	30	2	10	20	30
OTR (dB)	**7**	**0**	**0**	**0**	**10**	**3**	**0**	**0**
Frequency Offset Δ*f* for 10 MHz gap (MHz)	16	20	25	30	16	20	25	30
OFR for 10 MHz gap (dB)	**41.0**	**40.0**	**29.4**	**22.6**	**38.0**	**38.3**	**31.8**	**25.1**

Table A2.20 gives a summary of values of OTR and OFR for different type of radars and macro IMT base stations. Table A2.21 gives similar information for small base stations.

TABLE A2.21

Summary of values for OTR, and OFR for 10MHz gap, for macro base stations

Base station type	Macro 10 MHz				Macro 20 MHz			
IMT Tx bandwidth (MHz)	10				20			
Radar type	D	B, C, D, M	C, D, M	C, M	D	B, C, D, M	C, D, M	C, M
Radar Rx bandwidth (MHz)	2	10	20	30	2	10	20	30
OTR (dB)	**7**	**0**	**0**	**0**	**10**	**3**	**0**	**0**
Frequency Offset Δ*f* for 10 MHz gap (MHz)	16	20	25	30	16	20	25	30
OFR for 10 MHz gap (dB)	**46.2**	**42.8**	**29.7**	**22.7**	**43.1**	**41.8**	**32.4**	**25.3**

2 Coexistence and compatibility scenarios between IMT and radar

Recommendation ITU-R M.1465 provides indication of the typical uses of the airborne, land-based and ship-based radars operating in the frequency band 3 100-3 700 MHz. Based on the guidance of this recommendation, the following scenario of potential interference have been analysed:

2.1 Interference from IMT to ship based radar

The study considers a smooth earth between transmitter and receiver, and tropical and equatorial regions because propagations losses are significantly different.

– Interference from one micro IMT base station in urban MICRO-cell deployment to ship-based radars. In this case aggregated interference is evaluated under the assumption that radar main lobe can cover 0.3 km IMT cell radius range.

– Interference from one ell IMT 20 MHz micro base station in urban deployment to ship-based radars.

– Interference from one IMT 20 MHz macro base station in urban deployment to ship-based radars.

– Interference from one IMT 10 MHz macro base station in urban deployment to ship-based radars.
– Interference from aggregated 20 MHz IMT macro base stations in sub-urban or urban deployment to ship-based radars.

Interference from aggregated 10 MHz IMT macro base stations in sub-urban or urban deployments to ship-based radars. The scenario of interference from one or many aggregated IMT base stations operating few or fully multichannels over 3 300-3 400 MHz band has not yet be considered. An additional frequency channels aggregation factor will need to be taken into account in this case, leading to greater separation distances.

3 Interference criteria

In accordance to § 5 of main body of this Report.

4 Propagation models

In accordance to § 4 of main body of this report, the propagation model between IMT system and ship based radar is from Recommendation ITU-R P.452, and performed by an average year prediction with cases of parameter $p = 10\%$ and 20% (time percentage for which the calculated basic transmission loss is not exceeded). All the propagation factors in Recommendation ITU-R P.452, except clutter losses, are considered.

5 Study results

5.1 IMT outdoor micro base stations

The protection distance to avoid interference from an IMT system deployed in outdoor micro BS to ship based radars of type B, C, D and M is evaluated in this section for a frequency gap[11] of 10 MHz.

5.1.1 Single entry Interference from one IMT micro base-stations

Table A2.22 gives the required propagation loss to prevent interference from one IMT 20 MHz micro station toward a radar.

[11] The frequency gap is the frequency difference between –3 dB points respective to IMT transmission mask and radar reception IF filter.

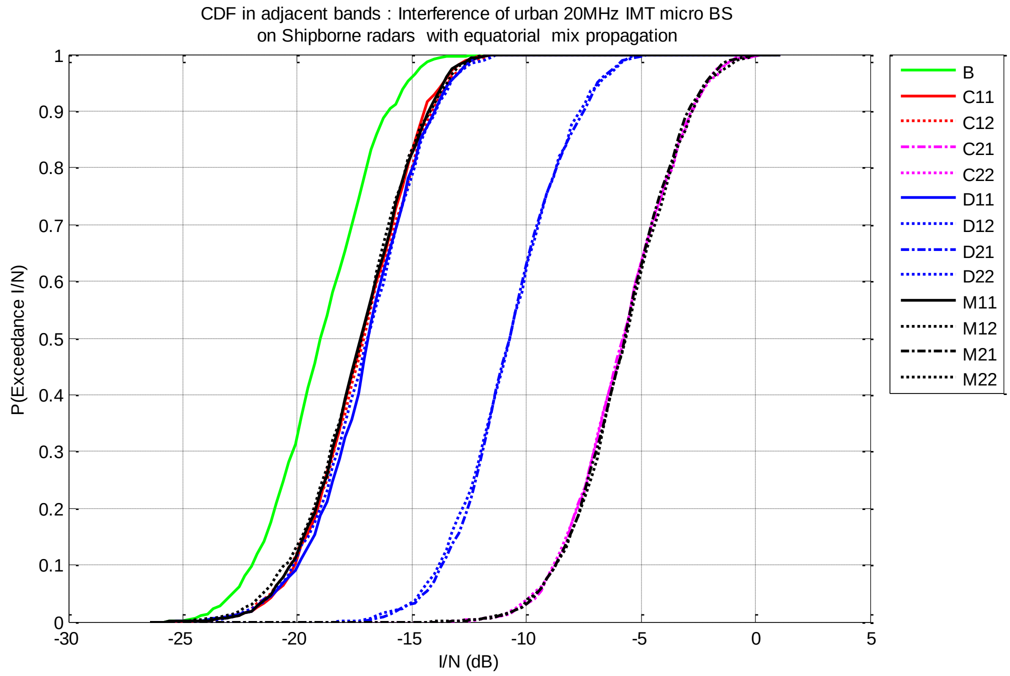
TABLE A2.22

Interference from one IMT outdoor 20 MHz micro base-station to ship-based radar stations with 10 MHz frequency gap

Parameters		Ship-based-B radar station	Ship-based-C radar station	Ship-based-D radar station	Ship-based-M radar station
Carrier frequency (GHz)		3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)		20	20	20	20
Maximum output power (dBm)		24	24	24	24
Antenna gain of outdoor micro IMT base-station (dBi)		5	5	5	5
Insertion loss of radar (dB)		0	0	0	0
Antenna gain radar (dBi)		42	40	40	40
Radar Noise figure (dB)		5.0	1.5	1.5	1.5
Number of IMT base-station		1	1	1	1
Average base station activity		100%	100%	100%	100%
Radar bandwidth (MHz)		10	10-30	2-20	10-30
OTR (dB)		3.0	3.0-0	10.0-0	3.0-0
Frequency gap (MHz)		10	10	10	10
OFR (dB)		38.3	38.3-25.1	38.0-31.8	38.3-25.1
Maximum Allowable interference power at radar receiver input (dBm)		−105	−108.5 / −103.7	−115.5	−108.5 /−103.7
Required propagation loss (dB) without clutter loss		134.7	136.2-147.6	136.5-142.7	136.2-147.6
Required propagation loss (dB) for BS locations with 18 dB clutter loss		116.7	118.2-129.6	118.2-124.7	118.2-129.6
Propagation model	**ITU-R P.452-16 (Case 1: *p* = 20%)**				
Protection distance (km) from BS locations without clutter loss, with a tropical sea pathloss,		28	29-44	29-36	29-44
Protection distance (km) from BS locations without clutter loss, with an equatorial sea pathloss		34	46-86	46-70	46-86
Protection distance (km) for tropical BS locations with 18dB clutter loss		5.1	6.2-19.6	6.2-13.1	6.2-19.6
Protection distance (km) for equatorial BS locations with 18dB clutter loss		5.2	6.1-23.7	6.1-13.3	6.1-23.7
Propagation model	**ITU-R P.452-16 (Case 2: *p* = 10%)**				
Protection distance (km) from tropical BS locations without clutter loss		38	44-84	44-68	44-84
Protection distance (km) from equatorial BS locations without clutter loss		42	52-138	52-102	52-138
Required propagation loss (dB) for BS locations with 18dB clutter loss		116.7	118.2-129.6	118.2-124.7	118.2-129.6
Protection distance (km) for tropical BS locations with 18dB clutter loss		5.3	6.4-25.6	6.4-14.2	6.4-25.6
Protection distance (km) for equatorial BS locations with 18dB clutter loss		5.3	6.4-25.6	6.4-14.2	6.4-25.6

With a statistical approach, Fig. A2-14 gives the cumulative distribution of the single entry interfering level received on radars standing 22 km from seashore using the propagation model with p = 20%, and obtained with a simulation taking into account the statistical law of clutter loss. The results show that the maximum single entry interference I/N is 6 dB above the radar protection criteria of $I/N = -6$ dB. The statistical result obtained at P (I/N) = 100% does not take into account 2% of base station's locations with clutter loss below 16 dB, including the worst case of 0dB clutter loss used for the MCL single entry calculation.

FIGURE A2-14



In summary, between one IMT 20 MHz urban micro base-station standing at shoreline without clutter loss and a ship-based Radar B/C/D/M, their bandwidths separated by a frequency gap of 10 MHz, the protection distance is 44 km or 86 km depending tropical or equatorial conditions using the propagation model with p = 20%, and 84-138 km for p = 10% respectively.

In this MCL study, considering low clutter losses or mask effect of buildings of 18 dB, considering their bandwidths separated by a frequency gap of 10 MHz, the radar protection distance from one micro base station is evaluated to 20-24 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%, and 26 km for p = 10% respectively

With a single entry statistical approach, taking into account the statistical law of clutter loss, the single entry interfering I/N is found 6 dB above the protection criteria of radars standing 22 km from seashore with a path loss using the propagation model with p = 20%.

5.1.2 Aggregation study of micro base-stations

The geometry of the scenario of this coexistence study using a frequency offset is similar to the co-channel coexistence study. Even, at the distance of a shipborne radar standing 22 km from the shoreline, between 10 to 80 active micro base stations needs to be aggregated, so the same methodology can be used. The large number of micro base stations in instantaneous visibility of the radar antenna when pointing in the direction of an IMT deployment area, have to be considered for doing an aggregated scenario.

This analysis is considered as static by assuming that the position of the ship with respect of the IMT-Advanced BSs on the ground is fixed and that the radar antenna is pointing toward the IMT deployment, The aggregation process is not done over the rotation of the radar antenna because the performance of shipborne radar is generally requested for each azimuthal direction of its main beam.

Monte-Carlo simulations are performed over the IMT mobile network and the radar within the area of simulation to calculate the aggregated interference with caused by the BSs in order to derive a reliable statistic, e.g. CDF of the experienced aggregated interference over noise level, i.e. I_{agg}/N.

The randomization process is done at each run of simulation on following parameters:

– Uniform repartition of position for each micro BS in its macro cell.

– Activity or not of the base station.

– Clutter value of the propagation path associated to each base-station.

Let us denote *j* the index of the random samplings of each micro base-station in the deployment.

The aggregated interference is then achieved in the following way:

$$Iagg = 10\log_{10}\left(\sum_{\substack{1\leq i\leq NbBSs,\\ 1\leq j\leq NbEvents}} 10^{\frac{P_{R,ij}}{10}}\right).$$

The simulation of the urban deployment considers and density of three micro BS per macro-cell.

Figures A2-15 and A2-16 depict the cdf of I_{agg}/N (i.e. $P(X \leq x_0)$ in ordinate while x-axis provides associated I/N values) for equatorial and tropical cases. Curves represent CDF for different radar types, with $R_{m,n}$ names' indexes indicating minimum and maximum values for their receivers bandwidths and antenna beamwidths.

FIGURE A2-15

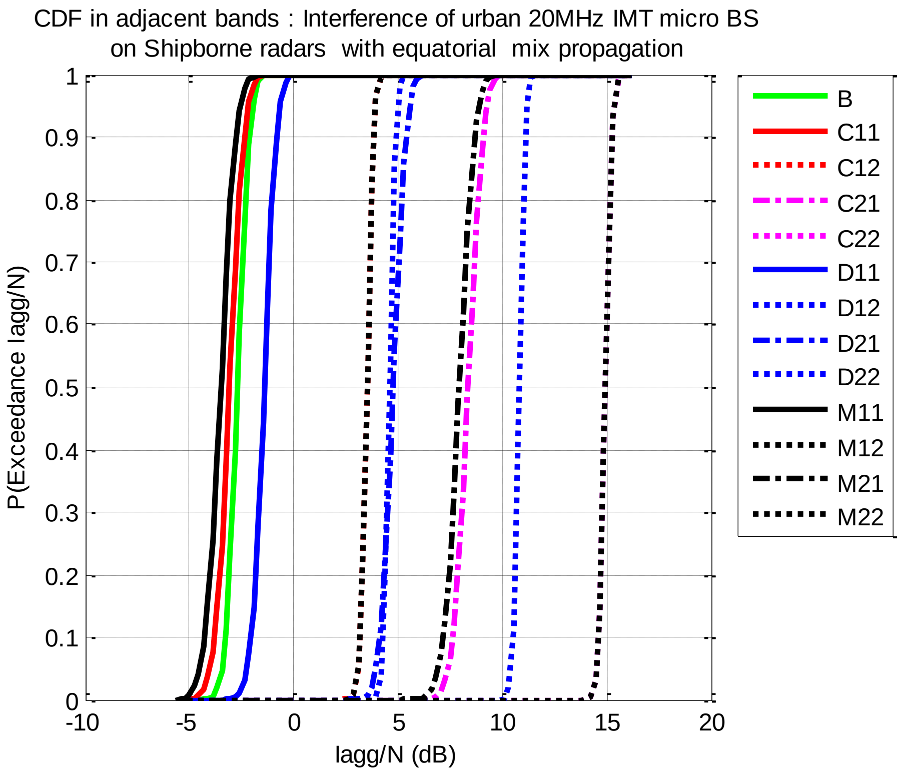
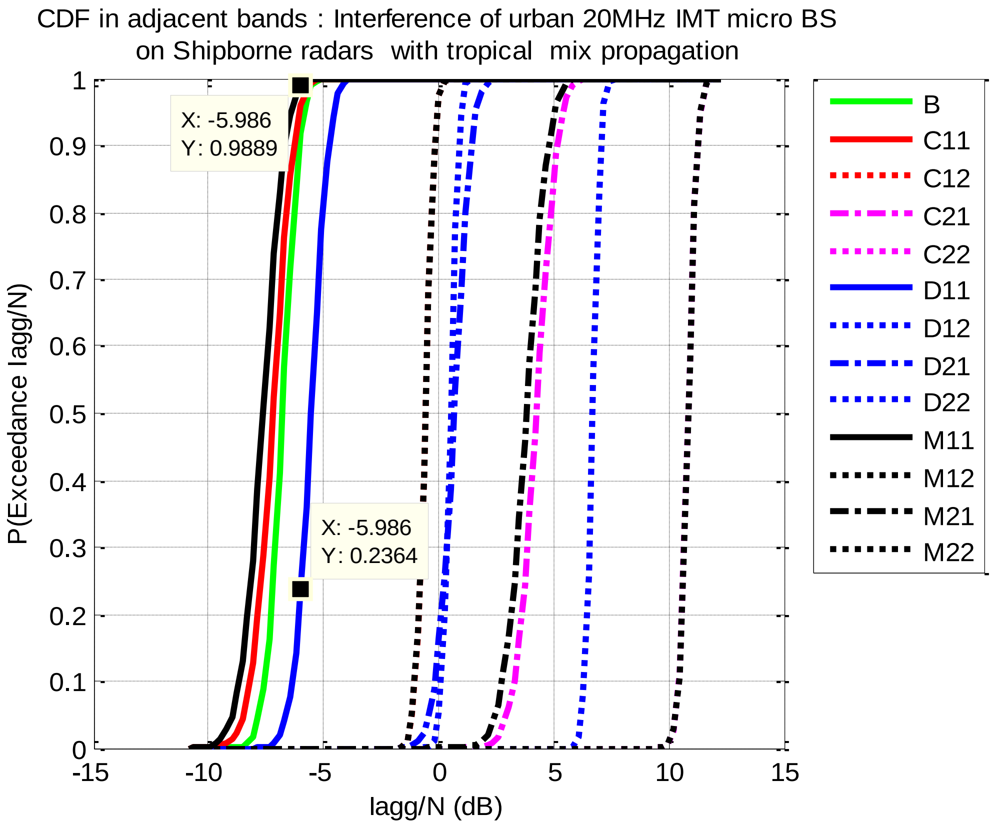


FIGURE A2-16



Monte Carlo simulation results show a value of the CDF at 100% which indicates that the aggregated interference ratio *I*/*N* received by the radar operating in adjacent band with a frequency gap of 10 MHz, is up to 12 dB or 17 dB depending tropical or equatorial propagation conditions using the propagation model with *p* = 20%, which is above the radar protection criteria of −6 dB.

In conclusion based on these results, and without additional mitigation techniques, it can be concluded that an urban micro BS IMT-Advanced deployment with a frequency gap of 10 MHz is not compatible with protection criteria of shipborne radar systems operating in adjacent band at 3.3 GHz or in adjacent channels within 3.3-3.4 GHz.

5.1.3 Summary of the frequency offset study of interference from Outdoor micro BS to shipborne radars

In summary, between one IMT 20 MHz urban micro base-station standing at shoreline and a ship-based Radar B/C/D/M, their bandwidths separated by a frequency gap of 10 MHz, the protection distance is 44 km or 86 km depending tropical or equatorial propagation conditions for using the propagation model with *p* = 20% and 84-138 km for *p* = 10% respectively.

With a statistical approach, the cumulative distribution with path loss using the propagation model with *p* = 20%, and obtained with a simulation taking into account the statistical law of clutter loss, the results show that the maximum single entry interference *I/N* ratio is +6 dB received on radars standing 22 km from seashore

Considering low clutter losses or mask effect of buildings of 18 dB, considering their bandwidths separated by a frequency gap of 10 MHz, the radar protection distance from one micro base station is evaluated to 20-24 km, depending tropical or equatorial propagation conditions using the propagation model with *p* = 20%, and 26 km for *p* = 10% respectively.

The interference study with aggregation of micro BS shows that a large number of base station needs to be considered. In the closest scenario of a shipborne radar standing 22 km from the shoreline, between 10 to 80 active micro BS are still to be considered. Monte Carlo simulation results shows that the aggregated interference ratio I/N received by the radar operating in adjacent band with a frequency gap of 10 MHz, is up to 12 dB or 17 dB (at 100% on the CDF) depending tropical or equatorial propagation conditions using the propagation model with p = 20%, which is above the radar protection criteria of −6 dB.

In conclusion based on these results, it can be concluded that additional mitigation techniques should be further studied for the deployment of urban IMT-Advanced micro BS to achieve the protection criteria of shipborne radar systems operating in adjacent band at 3.3 GHz or in adjacent channels within 3.3-3.4 GHz.

5.2 IMT base stations deployed in urban macro cells

The protection distance to avoid interference from an IMT system deployed in urban macro cells to ship based radars of type B, C, D and M is given in the Tables below for the adjacent channel.

5.2.1 Single entry Interference from one IMT station

5.2.1.1 Study case of a macro base station with a frequency gap of 10 MHz from radar operating band

In Table A2.23, the separation distance for allowable interference from one IMT 10 MHz macro base station interference is evaluated. Regarding the interfering transmitted power density, this case is more stringent than considering the IMT 20 MHz macro base station case.

TABLE A2.23

Interference from IMT outdoor urban macro 10 MHz base-station to ship-based radar stations

Parameters	Ship-based-B radar	Ship-based-C radar	Ship-based-D radar	Ship-based-M radar
Carrier frequency (GHz)	3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)	10	10	10	10
BS feeder loss (dB)	3	3	3	3
BS maximum output power (dBm)	46	46	46	46
Antenna gain of urban macro IMT base-station (dBi) (considering downtilt)	6	6	6	6
Insertion loss of radar (dB)	0	0	0	0
Antenna gain radar (dBi)	42	40	40	40
Radar noise figure (dB)	5.0	1.5	1.5	1.5
Number of IMT base-station	1	1	1	1
Average base station activity	100%	100%	100%	100%
Radar bandwidth (MHz)	10	10-30	2-20	10-30
OTR (dB)	0	0	7.0-0.0	0
Frequency gap (MHz)	10	10	10	10
OFR (dB)	42.8	42.8-22.7	46.2-29.7	42.8-22.7
Maximum allowable interference power at radar receiver input (dBm)	−105.0	−108.5 / −103.7	−115.5 / −105.5	−108.5 / −103.7
Required propagation loss (dB)	153.2	154.7-170.0	151.3-164.8	154.7-170.0
Propagation model	**Rec. ITU-R P.452-16 (Case 1: p = 20%)**			

TABLE A2.23 (*end*)

Parameters	Ship-based-B radar	Ship-based-C radar	Ship-based-D radar	Ship-based-M radar
Protection distance (km) at tropical sea	63	–66 – 114	–59 – 96	–66 – 114
Protection distance (km) at equatorial sea	116	–119 – 188	–110 – 163	–119 – 188
Loss for a 22 km sea path for macro BS height (dB) (equatorial and tropical)	129	129	129	129
Interference over coupling at 22 km on sea (dB)	24.2	25.7-41.0	22.3-35.8	25.7-41.0

In summary, it can be observed that for ship-based Radar B/C/D/M, considering a frequency gap of 10 MHz between –3 dB Base station's transmitter and radar's IF filter edges, considering no clutter loss, the protection distance between one IMT 10 MHz macro base-station located at the shoreline and a shipborne Radar is 114 or 188 km depending tropical or equatorial propagation conditions, using the propagation model with p = 20%.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, one IMT10MHz urban macro base-station standing at the shoreline, and their bandwidths separated by a frequency gap of 10 MHz, the IMT emissions of are received 41 dB over the protection level of the radar. At such low distance, considering 20 m heights for antennas of both systems, the propagation loss does not depend significantly of tropical or equatorial propagation conditions.

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, a pathloss over sea, coastal and land zones, and their bandwidths separated by a frequency gap of 10 MHz, without clutter loss, the protection distance of a radar from one IMT 10 MHz macro base station which is 62-110 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%and not taking into account any clutter loss or mask effect of buildings.

In this MCL study, considering low clutter losses or mask effect of buildings of 18 dB and bandwidths separated by a frequency gap of 10 MHz, the protection distance of a radar from one macro BS is 46-68 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%. For a median clutter loss of 28 dB, the protection distance of a radar from one macro base station is found to be 28-48 km depending tropical or equatorial propagation conditions using the propagation model with p = 20%. See Table A2.24.

Without any other mitigation technique, this study shows that the installation of macro base stations in coastal zones with a frequency gap of 10 MHz is not compatible with shipborne radars.

TABLE A2.24

Interference from one IMT outdoor macro 10 MHz base-station to a ship-based radar station standing at 22 km from shoreline, and with a frequency gap of 10 MHz – Propagation with path losses over sea, coastal and land zones of Rec. ITU-R P.452

Parameters	Ship-based-B radar	Ship-based-C radar	Ship-based-D radar	Ship-based-M radar
Single entry without clutter loss for one macro BS				
Required propagation loss without clutter (dB)	153.2	154.7-170.0	151.3-164.8	154.7-170.0
Protection distance (km) with a tropical pathloss	47	49-62	45-58	49-62
Protection distance (km) with an equatorial pathloss	70	74-110	66-96	74-110
Single entry with low clutter loss for one macro BS below rooftop				
Low clutter loss for a macro BS below rooftop (dB)	18	18	18	18
Required propagation loss with low clutter (dB)	135.2	136.7-152.0	133.3-146.8	136.7-152.0
Protection distance (km) with a tropical pathloss (p = 20%) and low clutter loss	31	33-46	29-41	33-46
Protection distance (km) with an equatorial pathloss (p = 20%) and low clutter loss	36	38-68	33-57	38-68
Single entry with median clutter loss for one macro BS below rooftop				
Median clutter loss for a macro BS below rooftop (dB)	28	28	28	28
Required propagation loss with median clutter (dB)	125.2	126.7-142.0	123.3-136.8	126.7-142.0
Protection distance (km) with a tropical pathloss (p = 20%) and median clutter loss	14	17-38	12-33	17-38
Protection distance (km) with an equatorial pathloss (p = 20%) and median clutter loss	14	16-48	12-38	16-48

5.2.1.2 Study case of a macro base station with a frequency gap of 30 MHz from radar operating band

Considering a frequency gap of 30 MHz between −3 dB base station’s transmitter and radar’s IF filter edges, of an IMT 10 MHz macro base station and a shipborne radar standing 22 km from the shoreline at limit of territorial waters, an additional rejection of interfering signals about 20 dB could be expected. Such mitigation technique could lead to request 50 MHz frequency offset between central frequencies of IMT interfering channel and victim radar receiver tuned band.

In that case, for the second scenario of a shipborne radar standing 22 km from the shoreline, the IMT emissions would be received 21 dB over the protection level of the radar (single entry MCL study using the propagation model with *p* = 20%).

Considering the case of macro urban base stations standing below rooftop masked with 18 dB low clutter losses, the IMT emissions from one BS located at shoreline would be received about 5 dB over the protection level of the radar standing 22 km at sea (single entry MCL study using the propagation model with *p* = 20%), The minimal protection distance for macro BS associated to low clutter losses is found of 32 km using the propagation model with *p* = 20%.

Considering the case of a macro urban base station standing below rooftop masked with median clutter losses of 28 dB, using the propagation model with *p* = 20%, the IMT emissions are received below the protection level of the radar standing at 22 km from the shoreline.

TABLE A2.25

Interference from one IMT outdoor macro 10 MHz base-station to a ship-based radar station with a frequency gap of 30 MHz

Parameters	Ship-based-B radar	Ship-based-C radar	Ship-based-D radar	Ship-based-M radar
IMT signal bandwidth (MHz)	10	10	10	10
Radar bandwidth (MHz)	10	10-30	2-20	10-30
OTR (dB)	0	0	7.0 – 0.0	0
Frequency gap (MHz)	30	30	30	30
OFR (dB)	62	62-41	60-51	62-41
Maximum Allowable interference power at radar receiver input (dBm)	–105.0	–108.5 / –103.7	–115.5 / –105.5	–108.5 / –103.7
Propagation model	Rec. ITU-R P.452 (Case 1 : *p* = 20%)			
Single entry without clutter loss				
Required propagation loss without clutter (dB)	134	135.5-151.7	137.5-143.5	135.5-151.7
Protection distance (km) with a tropical pathloss	32	34-60	38-44	34-60
Protection distance (km) with a equatorial pathloss	38	44-110	56-83	44-110
Loss for a 22 km sea path for macro BS height (dB) (equatorial and tropical)	129	129	129	129
Interference overcoupling at 22 km on sea (dB)	5	6.5-22.7	8.5-14.5	6.6-22.7
Single entry with 18 dB low clutter loss				
Low clutter loss for a macro BS below rooftop (dB)	18	18	18	18
Required propagation loss with low clutter (dB)	116	117.7-133.7	119.5-125.5	117.7-133.7

TABLE A2.25 (*end*)

Parameters	Ship-based-B radar	Ship-based-C radar	Ship-based-D radar	Ship-based-M radar
Protection distance (km) with a tropical pathloss and low clutter loss	4.8	5.8-30	7.2-15	5.4-30
Protection distance (km) with an equatorial pathloss and low clutter loss	4.8	5.8-32	7.2-14	5.8-32
Single entry with 28dB median clutter loss				
Median clutter loss for a macro BS below rooftop (dB)	28	28	28	28
Required propagation loss with median clutter (dB)	106	107.7-123.7	109.5-115.5	107.7-123.7
Protection distance (km) for tropical or equatorial BS locations with median clutter	1.5	1.8-12	2.2-4.5	1.8-12

5.2.2 Aggregation study

The Radar main lobe covers simultaneously many macro base-stations when pointing in the direction of an IMT deployment area

The typical value of deployment parameters used in this study are given in Table A2.26. The diameter of coastal IMT deployment area is based on realistic metrics like seaside cities of Lagos (Nigeria) and Capetown (South Africa).

TABLE A2.26

Parameters for macro BS aggregation study

Localisation	Scenario	Deployment area diameter ‘d’	Macro cell radius
Tropical	Sub-urban	20 km	0.6 km
Equatorial	Sub-urban	30 km	0.6 km
Tropical	Urban	5 km	0.3 km
Equatorial	Urban	8 km	0.3 km

The aggregated calculation takes into account the clutter or masking losses statistical distribution and the average activity of 50% for each macro base-station.

5.2.2.1 Scenario with shipborne radar at 22 km from seaside

This aggregation study considers a scenario of a shipborne radar standing on limit of territorial waters at a distance D_0 = 22 km from the shoreline, in front of an urban IMT 10MHz base stations deployment, with a pathloss over sea, coastal and land zones, and their bandwidths separated by a frequency gap of 10 MHz.

This analysis is considered as static by assuming that the position of the ship with respect of the IMT-Advanced BSs on the ground is fixed and that the radar antenna is pointing toward the IMT deployment, The aggregation process is not done over the rotation of the radar antenna because the performance of shipborne radar is generally requested for each azimuthal direction of its main beam.

Monte-Carlo simulations are performed over the IMT mobile network and the radar within the area of simulation to calculate the aggregated interference with caused by the BSs in order to derive a reliable statistic, e.g. CDF of the experienced aggregated interference over noise level, i.e. I_{agg}/N.

The randomization process is done at each run of simulation on following parameters:

– Uniform jitter on the position of the grid of BS macro site in transversal direction of the radar beam.

– Position below roof top macro BS (or not) in macro urban scenario.

– Activity or not of the base station.

– Clutter value of the propagation path associated to each base-station.

Let us denote *j* the index of the random samplings of macro base-stations) in the IMT deployment.

The aggregated interference is then achieved in the following way:

$$Iagg = 10\log_{10}\left(\sum_{\substack{1\le i\le NbBSs,\\ 1\le j\le NbEvents}} 10^{\frac{P_{R,ij}}{10}}\right).$$

Figures A2-17 and A2-18 depict the cdf of I_{agg}/N (i.e. $P(X \le x_0)$ in ordinate while x-axis provides associated I/N values) for equatorial and tropical cases. Curves represent CDF for different radar types, with $R_{m,n}$ names' indexes indicating minimum and maximum values for their receivers bandwidths and antenna beamwidths.

FIGURE A2-17

Analysis with a frequency gap of 10 MHz for ship based radar at 22 km (Tropical case)

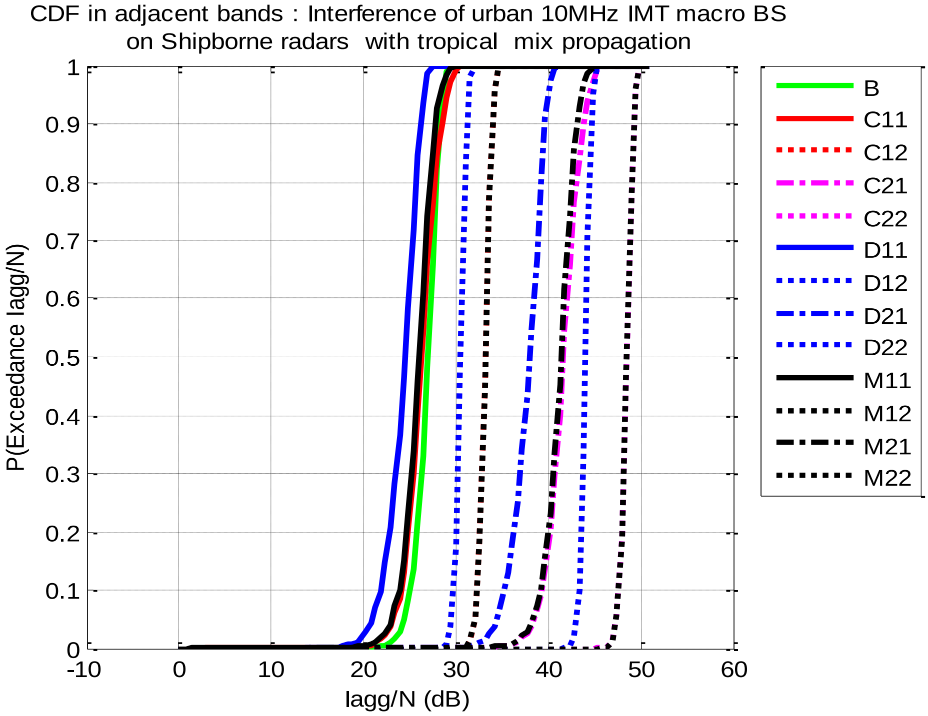
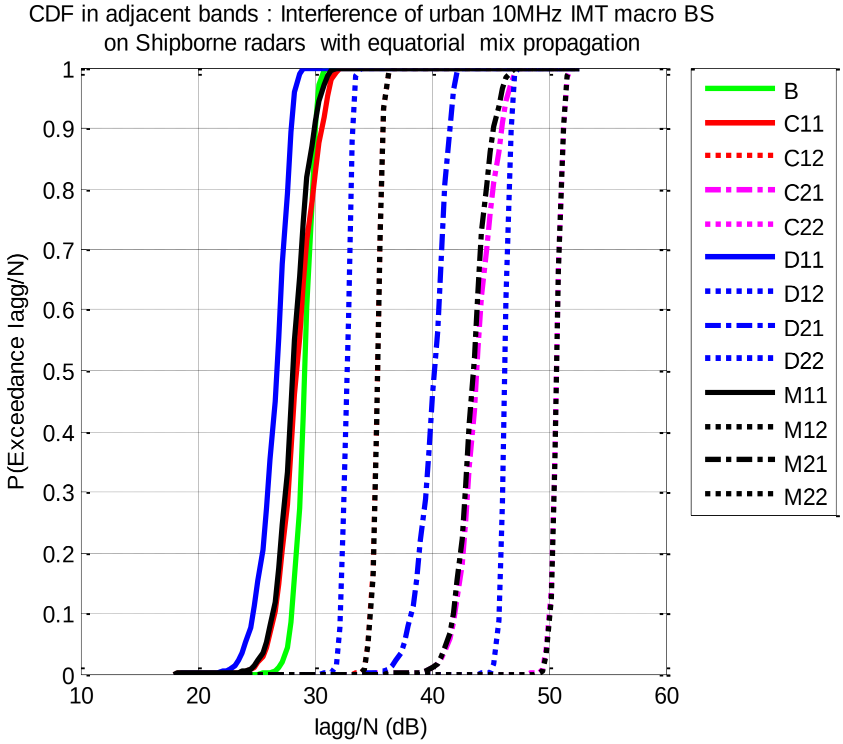


FIGURE A2-18

Analysis with a frequency gap of 10 MHz for ship based radar at 22 km (Equatorial case)



Monte Carlo simulation results show a value of the CDF at 100% which indicates that the aggregated interference ratio *I*/*N* received by radars operating in adjacent band with a frequency gap of 10 MHz, is up to 50 dB or 52 dB depending tropical or equatorial propagation conditions using the propagation model with p = 20%, which is far above the radar protection criteria of −6 dB.

In conclusion based on these results, and without additional mitigation techniques, it can be concluded that an urban macro BS IMT-Advanced deployment with a frequency gap of 10 MHz is not compatible with protection criteria of shipborne radar systems operating in adjacent band at 3.3 GHz or in adjacent channels within 3.3-3.4 GHz.

Study case of a macro BS with a frequency gap of 30 MHz from radar operating band

Figures A2-19 and A2-20 depict the CDF of I_{agg}/N (i.e. $P(X \leq x_0)$ in ordinate while x-axis provides associated *I*/*N* values) for equatorial and tropical cases with a frequency gap of 30 MHz.

FIGURE A2-19

Analysis with a frequency gap of 30 MHz for ship based radar at 22 km (Tropical case)

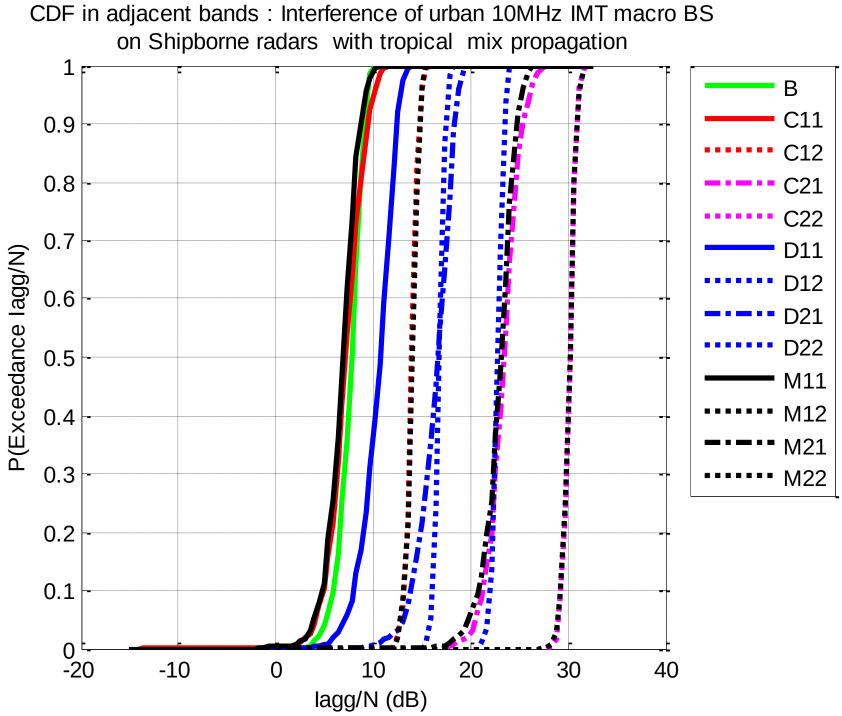
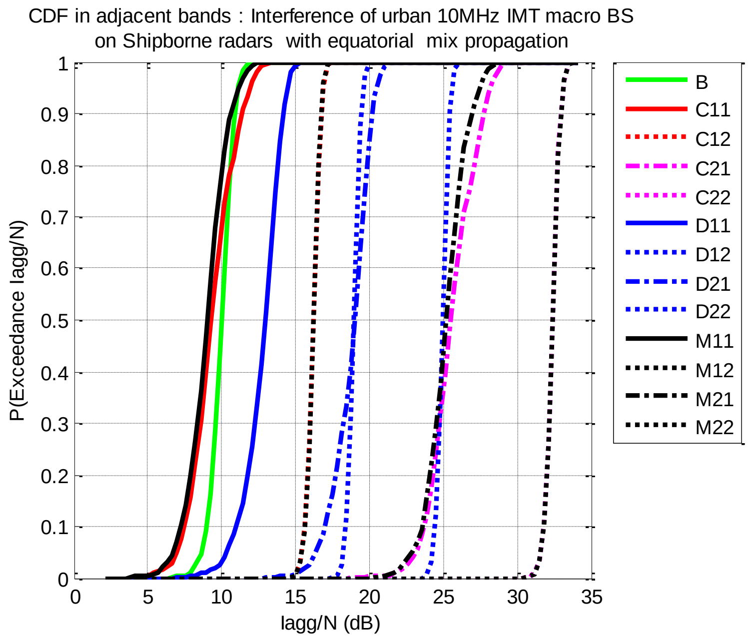


FIGURE A2-20

Analysis with a frequency gap of 30 MHz for ship based radar at 22 km (Equatorial case)



5.2.3 Summary of adjacent band interference from urban macro BS to shipborne radars

In summary, it can be observed that, for ship-based Radar B/C/D/M, considering no clutter loss, the protection distance between one IMT 10MHz macro base-station located at the shoreline and a shipborne Radar is 114 or 188 km for 10 MHz frequency gap between −3 dB edges of the IMT emission mask and radar IF bandwidth, depending of tropical or equatorial propagation conditions using the propagation model with p = 20%.

In a second scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, one IMT10MHz macro base-station standing at the shoreline, and their bandwidths separated by a frequency gap of 10 MHz, the IMT emissions of are received 41 dB over the protection level of the radar. At such low distance, considering 20 m heights for antennas of both systems, the propagation loss does not depend significantly of tropical or equatorial propagation conditions.

In a third scenario, considering a shipborne radar standing 22 km from the shoreline at limit of territorial waters, a pathloss over sea, coastal and land zones, and their bandwidths separated by a frequency gap of 10 MHz, the protection distance of a radar from one IMT 10 MHz macro base station is 62-110 km, depending tropical or equatorial propagation conditions for using the propagation model with p = 20%and not taking into account any clutter loss or mask effect of buildings. Considering low clutter losses or mask effect of buildings of 18 dB and a frequency gap of 10 MHz, the protection distance of a radar from one macro BS is found 46-68 km, depending tropical or equatorial propagation conditions using the propagation model with p = 20%. For a median clutter loss of 28dB, the protection distance of a radar from one macro base station is found to be 28-48 km depending tropical or equatorial propagation conditions using the propagation model with p = 20%.

Without any other mitigation technique, this MCL study shows that the installation of macro base stations in coastal zones with a frequency gap of 10 MHz is not compatible with shipborne radars.

Considering a frequency gap of 30 MHz, leading up to 50 MHz frequency offset between central frequencies of IMT interfering channel and victim radar receiver tuned band, an additional rejection of interfering signals about 20 dB could be expected. Nevertheless, for a shipborne radar standing 22 km from the shoreline, the IMT emissions would be received, using the propagation model with p = 20%,with 23 dB over the protection level of the radar. Considering 18dB low clutter losses for some BS located at shoreline, the IMT emissions would be received about 5 dB over the protection level of the radar standing 22 km at sea. The protection distance from macro BS associated to low clutter losses, is found of 32 km using the propagation model with p = 20%. Considering the case of an IMT 10 MHz macro urban base station standing below rooftop masked with median clutter losses of 28 dB, operating with a frequency gap of 30 MHz, using the propagation model with p = 20%, the IMT emissions would be received below the protection level of the radar standing at 22 km from the shoreline.

A forth scenario, considering urban deployment characteristics with density of 3 micro BS per macro cell, the results of a static analysis with Monte Carlo simulations show that the aggregated interference ratio I/N received by radars operating in adjacent band with a frequency gap of 10 MHz, is between +19 dB / +50 dB and +22 dB/+52 dB (based on 100% of CDF) depending tropical or equatorial propagation conditions using the propagation model with p = 20%, which is above the radar protection criteria of −6 dB.

5.3 IMT terminal interference to Radar system

According to Report ITU-R M.2292, the IMT terminal’s maximum transmit power is 23 dBm. However IMTs terminals have power control functionality and as a result the average transmit power is −9 dBm. In addition, the actual antenna gain is −4 dBi because of the body loss. Therefore, the IMT terminal e.i.r.p. is much lower than IMT base station and as a result the separation distance required to protect radars will be much shorter than the distance required to protect from IMT base stations.

5.4 Radar interference to IMT system

Report ITU-R M.2292 gives characteristics of IMT-Advanced (LTE) noting that:

– specification in 3GPP TS 36.104 states that the base station receiver can saturate at −43 dBm.

– according to specification 3GPP TS 36.104 the BS receiver blocking level (depending of channel's number) is approximately of −43 dBm for frequency gap < 20 MHz, −15 dBm for frequency gap >60 MHz, and −30 dBm between.

  – IMT-Advanced protection criteria of *I*/*N*= −6 dB.

TABLE A2.27

Interference into one IMT 10MHz macro base-station from one ship-based radar station standing at 22 km from shoreline and operating in adjacent band

	Ship-based B radar	**Ship-based C radar**	**Ship-based D radar**	**Ship-based M radar**
Carrier frequency (GHz)	3.3	3.3	3.3	3.3
Radar Transmitter bandwidth (−3 dB) (MHz)	4	25	15	25
Radar Transmitter output power (dBm)	98	83	79	90
Radar antenna gain (dBi)	42	40	40	40
Separation distance (km)	22	22	22	22
Propagation loss (dB) P.452-16, Equatorial, sea path, *p* = 20%)	129	129	129	129
IMT Urban Macro BS antenna gain (considering downtilt) (dBi)	6.0	6.0	6.0	6.0
IMT BS feeder loss (dB)	3	3	3	3
Frequency offset (MHz)	≥ 13 (spurious domain)	≥ 80 (spurious domain)	≥ 47 (spurious domain)	≥ 80 (spurious domain)
Attenuation of Radar emissions in the spurious domain (dB) (see ITU-R Rec. SM.329)	60	60	60	60
IMT BS Receiver bandwidth (MHz)	10	10	10	10
IMT BS Rx Noise Factor	5.0	5.0	5.0	5.0
Maximum allowable interference power at IMT BS receiver input (dBm)	–105	–105	–105	–105
IMT BS Receiver in band saturation (dBm)	–43	–43	–43	–43
IMT BS Receiver Blocking level (dBm) (for frequency gap < 20 MHz)	–43	–43	–43	–43
IMT BS Receiver Blocking level (dBm) (for frequency gap of 20-60 MHz)	–30	–30	–30	–30

TABLE A2.27 (*end*)

	Ship-based B radar	**Ship-based C radar**	**Ship-based D radar**	**Ship-based M radar**
IMT BS Receiver Blocking level (dBm) (for frequency gap > 60 MHz)	–15	–15	–15	–15
Interference power at BS receiver input (dBm)	**–46.0**	**–63.0**	**–67.0**	**–56.0**
Pulse width (μs)	6.4-51.2	0.1-1 000	0.1-100	0.1-1 000
Repetition rate (kHz)	0.152-6.0	0.3-10	0.5-10	0.3-10

It can be concluded that during transmitting mode of a shipborne radar standing 22 km from shoreline, with sufficient frequency offset for IMT Rx operating in radar's spurious domain, the RF pulses are not blocking the IMT receivers but strongly interfere.

Taking into account that radio interface characteristics of micro base stations and user equipments are in the same order of magnitude than macro BS, similar conclusion could apply.

The interference is too strong for even a short period of time, then the forward Error Correction (FEC) may not be effective. However, LTE also uses Hybrid-Automatic Repeat reQuest (HARQ) with Chase combining.

In this technique, if portions of one LTE frame are detected with errors that cannot be corrected by FEC, the frame is retransmitted and the received signals are weighted by their signal-to-noise ratio and soft combined until the frame is error free. This type of error correction is one of the most powerful mechanisms for retaining an acceptable throughput rate on a LTE network that is experiencing strong interference. Although a strong interferer could cause a high weighting for the packet in error that could cause further retransmission of the packets and lower the throughput, the IMT system can still work. The mechanism of HARQ can be found in Recommendation ITU-R M.2012, 3GPP TS 36211, 36213 and other related recommendations.

The long-period degradation of the IMT system and the HARQ mitigation technique performance, considering the short-period impulse feature of radar blocking signals, should be further evaluate.

Study I

1 Technical characteristics of IMT and land-based radar systems

1.1 IMT system parameters

Section 2 in main body contains the list of parameters for IMT deployment, which are taken from Report ITU-R M.2292.

1.2 Radar parameters

Section 2 in the main body provides the key radar parameters, and Table A2.28 gives parameters of land based radars to be used for these studies. For reducing the number of cases to study, the based radars to consider are types A to E, and a type M with IF bandwidth of 10 MHz.

The radar antenna height is 20 metres. The radar receiver IF selectivity fall-off is −80 dB/decade.

TABLE A2.28

Land based Radar considered parameters for the compatibility study

Characteristics	Radar								
	A	**B**	**C**	**D**	**E**	**I**	**K**	**L**	**M**
Antenna height above ground (m)	20	20	20	20	20	20	20	20	20
Antenna gain (dBi)	39	40	31	40	22	33.5	40	43	40
Receiver IF 3 dB bandwidth (MHz)	380	0.67	2	30	5-10	1.5, 3.5	NA	NA	10-30
Receiver noise figure (dB)	3.1	4.0	1.5	4	3	2	NA	NA	1.5
Receiver IF selectivity Fall-off (dB/decade)	−80	−80	−80	−80	−80	−80	−80	−80	−80

1.3 Frequency rejection

Figures A2-23 and A2-24 shows off-tune Frequency rejection curves as a function of the frequency gap, for small and macro base stations.

The frequency gap is the frequency difference between −3 dB points respective to IMT transmission mask and radar reception IF filter. The frequency offset Δ*f* used in Recommendation ITU-R SM.337, defined between the IMT channel central frequency and radar band tuning frequency, could be calculated as the addition of the frequency gap and half bandwidths of each transmitter and receiver.

FIGURE A2-21

Emission masks of transmitters for IMT Macro base stations

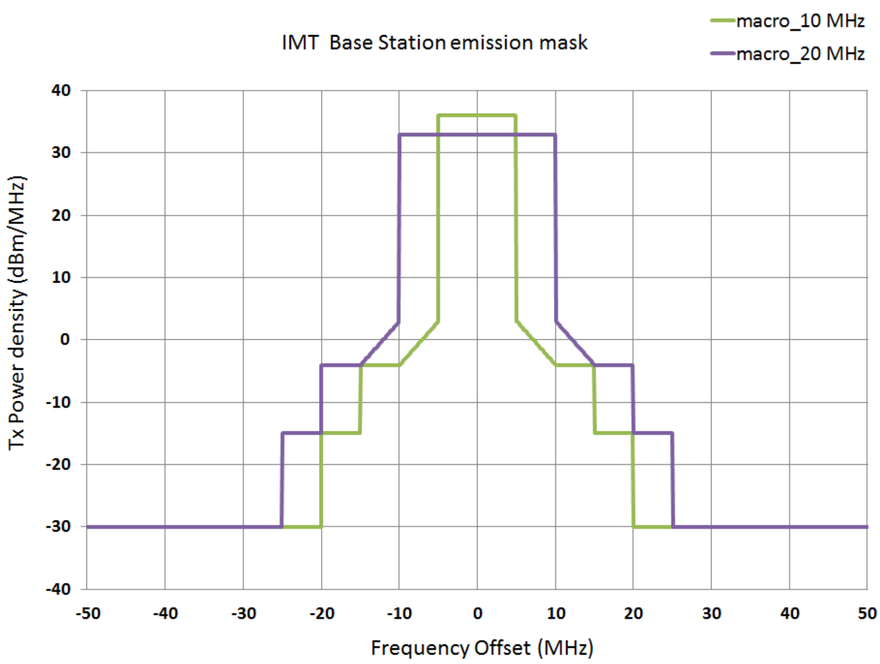


FIGURE A2-22

Emission masks of transmitters for IMT micro base stations

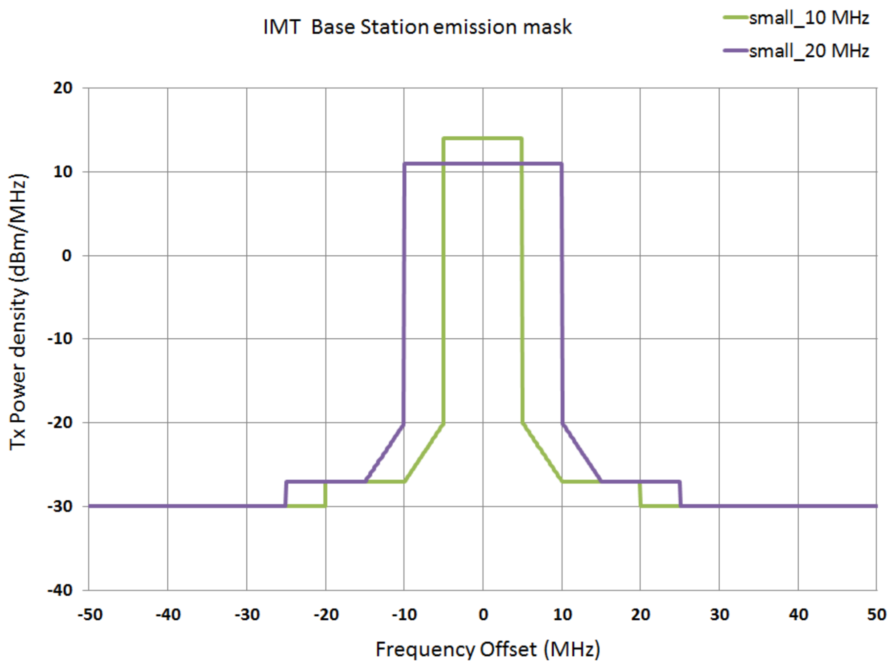


FIGURE A2-23

Frequency Offset and Gap between a radar receiver band and one IMT base station transmitter channel

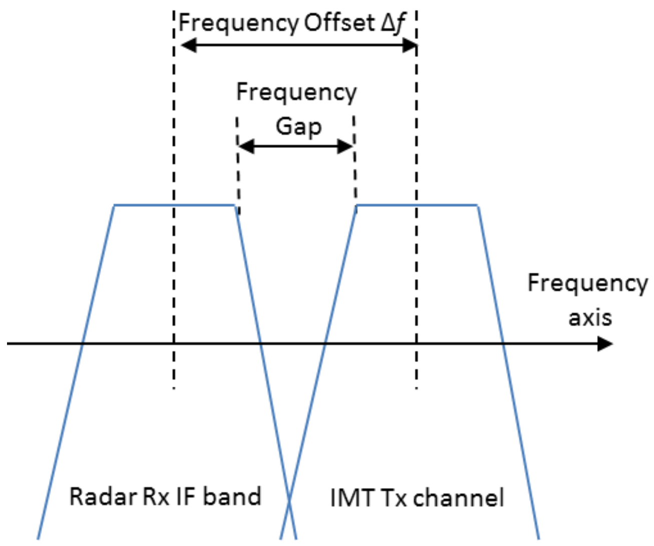


FIGURE A2-24

Off Tune Rejection (OFR) vs Frequency Gap, for radar receiver against an IMT micro base station transmitter operating one channel of 20 MHz

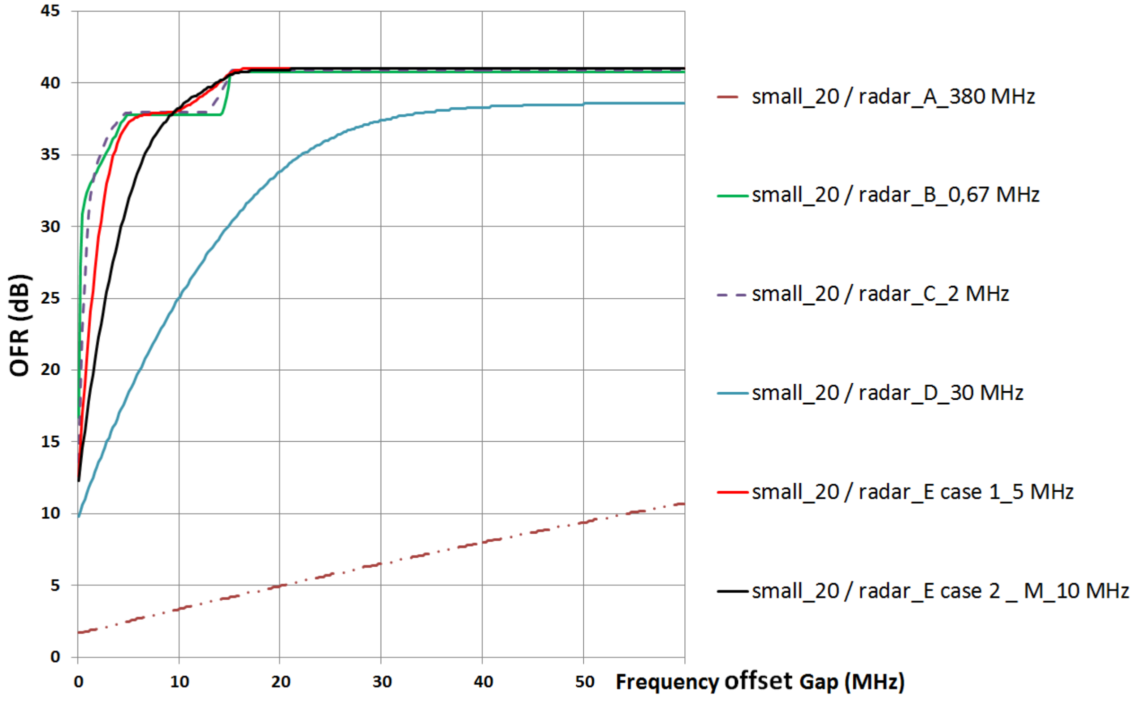
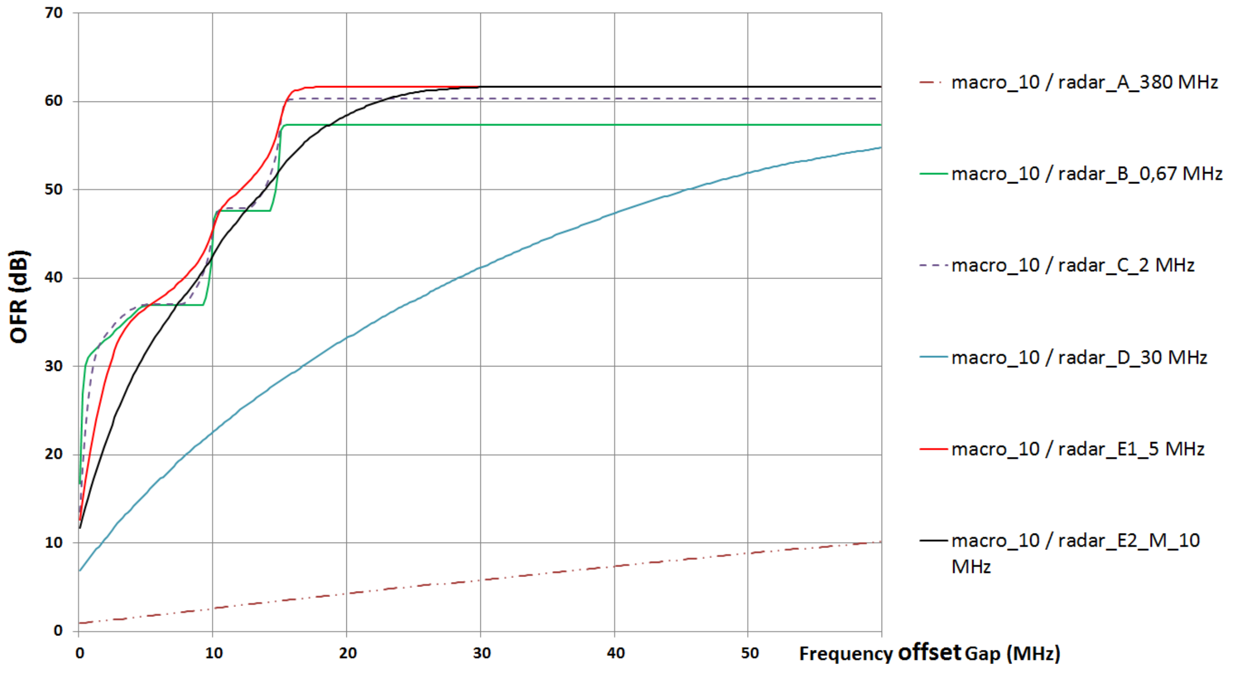


FIGURE A2-25

Off Tune Rejection (OFR) vs Frequency Gap, for radar receivers against IMT macro base station transmitter operating one channel of 10 MHz



Tables A2.29 and A2.30 give a summary of OTR and OFR values respectively for small and macro IMT base stations and for the different type of land based radars.

TABLE A2.29

Summary of values for OTR, and OFR for 10 MHz gap, for a micro 20 MHz IMT transmitter and land based radars

Base station type		Small 20 MHz					
IMT Tx Bandwidth	MHz	20					
Radar type		A	B	C	D	E case 1	E case 2, M case 1
Radar Rx bandwidth	MHz	380	0.67	2	30	5	10
OTR	**dB**	**0**	**11.7**	**7.0**	**0.0**	**3.0**	**0.0**
Frequency Offset Δ*f* for 10 MHz gap	MHz	210	20.3	21	35	22.5	25
OFR for 10 MHz gap	**dB**	**3.4**	**37.8**	**38.0**	**25.1**	**38.1**	**38.3**

TABLE A2.30

Summary of values for OTR, and OFR for 10 MHz gap, for 10 MHz macro transmitter and land based radars

Base station type		Macro 10 MHz					
IMT Tx Bandwidth	MHz	10					
Radar type		A	B	C	D	E case 1	E case 2, M case 1
Radar Rx bandwidth	MHz	380	0.67	2	30	5	10
OTR	**dB**	**0**	**11.7**	**7.0**	**0.0**	**3.0**	**0.0**
Frequency Offset Δf for 10MHz gap	MHz	210	20.3	21	35	22.5	25
OFR for 10 MHz gap	**dB**	**2.6**	**46.7**	**46.2**	**22.7**	**45.9**	**42.8**

2 Coexistence and compatibility scenarios between IMT and Radar

Recommendation ITU-R M.1465 provides indication of the typical uses of the airborne, land-based and ship-based radars operating in the frequency band 3 100-3 700 MHz. Based on the guidance of this recommendation, the following scenario of potential interference have been analysed:

2.1 Interference from IMT to land based radar

The study considers:

– a smooth earth between transmitter and receiver, with a path terrain profile at 0 metre above sea level at all points,

– a full inland propagation path,

– Scenarios considering equatorial regions because propagations losses are significantly less than tropical region.

As shown in Fig. A2-26, following scenarios are evaluated:

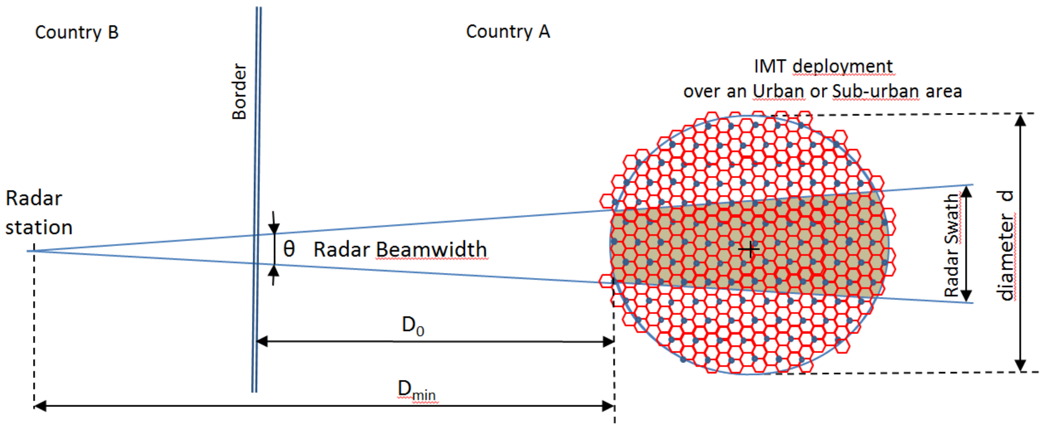
– Single entry study of interference from one IMT 20MHz micro base station in an urban deployment to land-based radars standing in a foreign country.

– Single entry study of interference from one IMT 10 MHz macro base station in an urban deployment to land-based radars standing in a foreign country.

– Interference from aggregated 10 MHz IMT base stations in urban macro BS deployment to radars.

FIGURE A2-26

IMT base-stations from a country A deployment, and in visibility of a Radar station located in a country B



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The scenario of interference from a mix of urban and suburban macro BS in instantaneous visibility of the radar antenna beam is not considered in this study, neither a mix of 10 MHz and 20 MHz base stations.

The scenario of interference from one or many aggregated IMT base stations operating few or fully multichannels over 3 300-3 400 MHz band has not yet be considered. An additional frequency channels aggregation factor will need to be taken into account in this case, leading to greater separation distances.

3 Interference criteria

In accordance to §5 of the main body.

4 Propagation models

The propagation model between IMT system and land based radar is from Recommendation ITU-R P.452, and performed by an average year prediction with cases of parameter p =10% and 20% (time percentage for which the calculated basic transmission loss is not exceeded). All the propagation factors in Recommendation ITU-R P.452, except clutter losses, are considered.

The calculation of pathlosses, fully in land, takes into account the ITU-R P.452 radio climatic zone A2. As recommended in Recommendation ITU-R P.452, the in-land zone is 50 km away from coastal salt waters.

Table A2.31 gives parameters used to calculate propagation losses.

TABLE A2.31

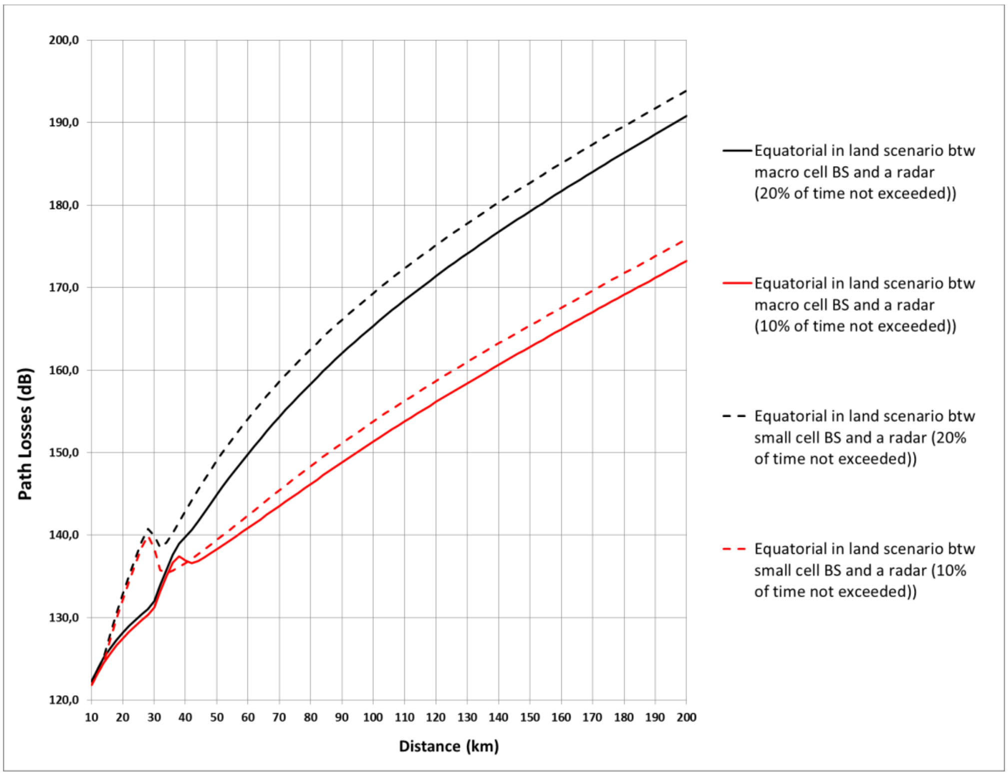
Parameters used propagation losses calculated with Rec. ITU-R P.452

	Geographic situation	**Equatorial**	**Equatorial**
	Base station type	**Macro**	**Micro**
φt	Latitude Transmitter (degree)	3° 52’	3° 52’
ψt	Longitude Transmitter (degree)	11° 31’	11° 31’
φr	Latitude Receiver (degree)	2° 05’	2° 05’
ψr	Longitude Receiver (degree)	11° 29’	11° 29’
htg	Transmitter Height (metres)	20	6
hrg	Receiver Height (metres)	20	20
Gt	Transmitter Antenna gain (dB)	6-10	5
Gr	Transmitter Antenna gain (dB)	22-40	22-40
N0	Sea-level surface refractivity (N-units)	375	375
deltaN	Average radio-refractive index lapse-rate (N-units/km),	50	50

Figure A2-27 shows annual average pathlosses calculated completely in land, and during 10% and 20% of time for which the transmission loss is not exceeded. The curves indicate the minimum path losses respectively using the propagation model with p = 10% and p = 20%. It should be noticed the sensitivity of this parameter showing variation around 20 dB on pathloss at large distances over horizon between the two cases of percentage of time. For short distance below 30 km, losses are not very sensitive to time percentage.

FIGURE A2-27

Path losses between an IMT base station and a land-based radar (ITU-R P.452-16 with $p = 10\%$ and $p = 20\%$)



Clutter models

In accordance to § 4 in main body, the clutter loss value is defined to zero for MCL single entry calculation. Informative analysis with clutter losses of 18 and 28 dB is also done. For aggregation studies, the impact of buildings on separation distance or margin will be approximated by using the statistical distribution defined in § 4 of main body.

5 Study results

5.1 IMT micro base stations deployed in outdoor

The protection distance to avoid interference in adjacent scenario from an IMT system deployed in outdoor micro BS to land based radars is evaluated in this section.

5.1.1 Single entry Interference from one IMT micro base-station

Table A2.32 gives the required propagation loss and protection distance of a radar from one 20 MHz micro base station.

TABLE A2.32

Interference from one IMT outdoor 20 MHz micro base-station to land based radar stations

Parameters	Radar A	Radar B	Radar C	Radar D	Radar E	Radar M
Carrier frequency (GHz)	3.3	3.3	3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)	20	20	20	20	20	20
Maximum output power (dBm)	24	24	24	24	24	24
Antenna gain of outdoor IMT micro base-station (dBi)	5	5	5	5	5	5
Antenna gain radar (dBi)	39	40	31	40	22	40
Radar Rx noise figure	3.1	4.0	1.5	4.0	3.0	1,5
Radar IF bandwidth (MHz)	380	0.67	2	30	5-10	10
On Tune Rejection (dB)[12]	0	14.7	10.0	0	6.0-3.0	3.0
Frequency gap (MHz)	10	10	10	10	10	10
OFR (dB)	3.4	37.8	38.0	25.1	38.1	38.3
Maximum allowable interference power at radar receiver input (dBm)	−91.1	−117.7	−115.5	−101.2	−110.0 / −107.0	−108.5
Propagation model	ITU-R P.452-16 (Case 1: *p* = 20%)					
Single entry without clutter loss for one micro BS						
Required propagation loss (dB) without clutter	155.7	134.2	127.5	145.1	116.9 / 116.7	136.2
Protection distance (km) with equatorial land pathlosses for *p* = 20%	63	21	16	44	5.2	23
Single entry with low clutter loss for one micro BS						
Low clutter loss for micro BS (dB)	18	18	18	18	18	18
Required propagation loss (dB)	137.7	116.2	109.5	127.1	98.9 / 98.7	118.2
Protection distance (km) with an equatorial pathloss and low clutter loss	27	4.8	2.2	15	0.7	6.2

[12] Recommendation ITU-R SM.337 defines the On Tune Rejection (OTR) as the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of a transmitted signal exceeding the receiver bandwidth.

TABLE A2.32 (*end*)

Parameters	Radar A	Radar B	Radar C	Radar D	Radar E	Radar M
Single entry with median clutter loss for one micro BS						
Median clutter loss for micro BS (dB)	28	28	28	28	28	28
Required propagation loss with median clutter (dB)	127.7	106.2	99.5	117.1	88.8	108.2
Protection distance (km) with an equatorial pathloss and median clutter loss	16	1.5	0.7	5.4	< 0.5	1.9

In summary, it can be observed that the protection distance between one IMT 20 MHz outdoor micro base-station and a land based Radar, operating with their bandwidths separated by a frequency gap of 10 MHz, without clutter loss, is 63 km depending equatorial propagation conditions over the land using the propagation model with p = 20%.

In this MCL study, taking into account low clutter losses or mask effect of buildings of 18 dB, the protection distance of a radar from one micro BS, operating with 10 MHz frequency gap, is reduce to 27 km. With a median clutter loss of 28 dB, the protection distance of a radar from one IMT 20 MHz micro base station, operating with 10 MHz frequency gap, is found to be lower 16 km

5.1.2 Aggregation study of micro base stations

This analysis is considered as static by assuming that the position of the land based radar with respect of the IMT-Advanced BS is fixed. And that the radar antenna is pointing toward the IMT deployment, the aggregation process is not done over the rotation of the radar antenna because the performance of shipborne radar is generally requested for each azimuthal direction of its main beam. Monte-Carlo simulations are performed over the IMT mobile network and the radar within the area of simulation to calculate the aggregated interference with caused by the BSs in order to derive a reliable statistic, e.g. CDF of the experienced aggregated interference over noise level, i.e. I_{agg}/N.

The randomization process is done at each run of simulation on following parameters:

– Uniform repartition of position for each micro BS in its macro cell.

– Activity or not of the base station.

– Clutter value of the propagation path associated to each base-station.

Let us denote j the index of the random samplings of each micro base-station in the deployment.

The aggregated interference is then achieved in the following way:

$$Iagg = 10\log_{10}\left(\sum_{\substack{1\le i\le NbBSs,\\ 1\le j\le NbEvents}} 10^{\frac{P_{R,ij}}{10}}\right).$$

The simulation of the urban deployment considers and density of three micro BS per macro-cell. The scenario does not take into account any suburban ring of BS between urban and radar receiver.

Figures A2-28 and A2-29 depict the CDF of I_{agg}/N (i.e. $P(X \le x_0)$ in ordinate while x-axis provides associated I/N values) for equatorial case. Curves represent CDF for different radar types, with Rm names' indexes indicating minimum and maximum values for the receivers' bandwidths. Only one case of antenna beamwidth per radar type is considered in this study.

Two cases of separation distance, 22 km and 55 km, are analysed.

FIGURE A2-28

Separation distance of 55 km

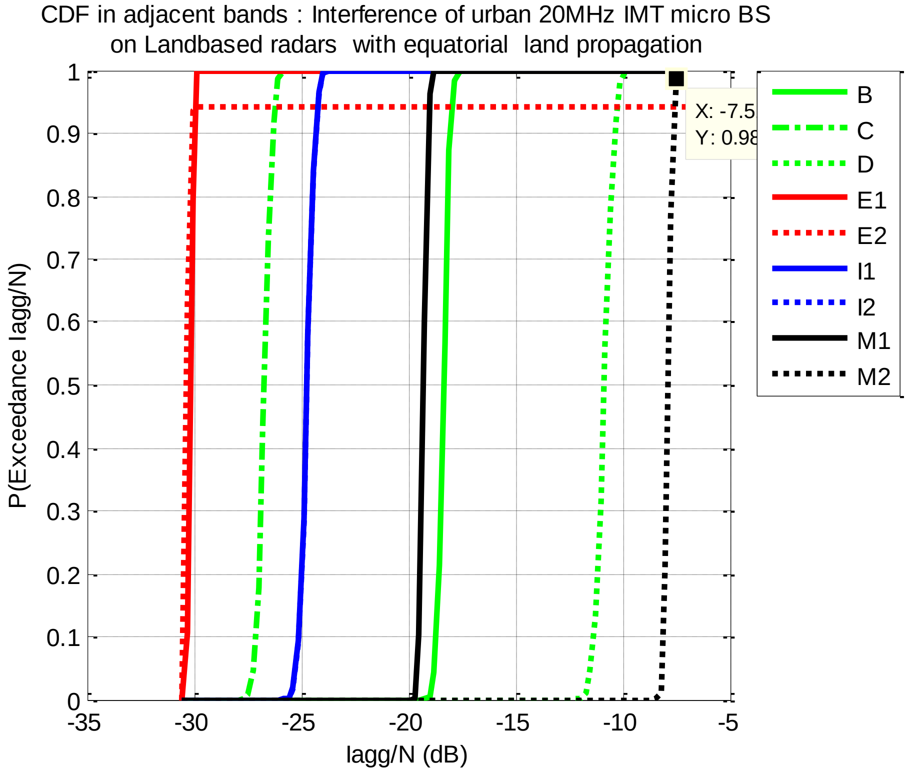
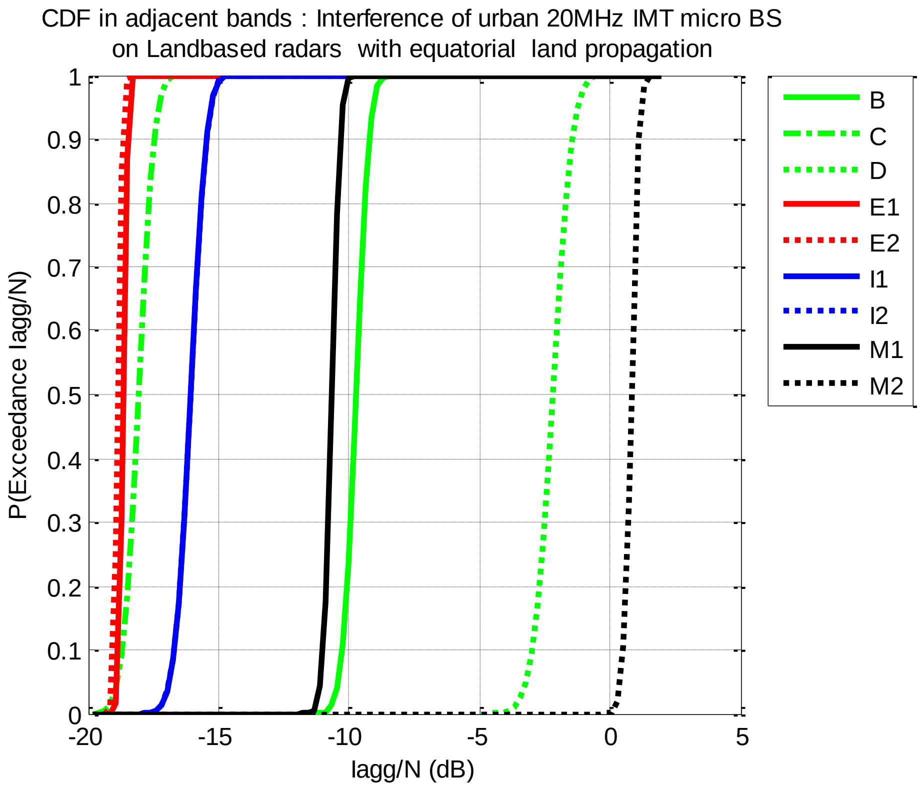


FIGURE A2-29

Separation distance of 22 km



Considering urban deployment characteristics with density of 3 micro BS per macro cell, the results of a static analysis with Monte Carlo simulation show that the aggregated interference ratio *I*/*N* received by radars operating at 22 km in adjacent band with a frequency gap of 10 MHz, is in range of −20 dB to +2 dB (at 100% on the CDF) in equatorial propagation conditions using the propagation model with p = 20%, which is for some radar cases above the radar protection criteria of −6 dB. With a separation distance of about 55 km, and similar other simulation parameters, it is found that all the simulated radar types are not victims of harmful interference with propagation conditions using the propagation model with p = 20%.

5.2 IMT macro base stations

This section studies the protection distance to avoid harmful interference from an IMT system deployed in urban macro BS to land based radars operating with their bandwidths separated by a frequency gap of 10 MHz.

5.2.1 Single entry interference from one urban IMT 10 MHz macro base-station

Table A2.33 evaluates the separation distance from only one urban IMT 10 MHz macro base-station to a land based radar operating with 10 MHz frequency gap.

TABLE A2.33

Single entry analysis from one IMT 10 MHz macro base-station to a land based radar

Parameters	**Radar A**	**Radar B**	**Radar C**	**Radar D**	**Radar E**	**Radar M**
Carrier frequency (GHz)	3.3	3.3	3.3	3.3	3.3	3.3
IMT signal bandwidth (MHz)	10	10	10	10	10	10
Maximum output power (dBm)	46	46	46	46	46	46
Antenna gain of macro IMT base-station (dBi)	6	6	6	6	6	6
Antenna gain radar (dBi)	39	40	31	40	22	40
Noise figure	3.1	4.0	1.5	4.0	3.0	1.5
Radar bandwidth (MHz)	380	0.67	2	30	5-10	10
On Tune Rejection (dB)[13]	0	11.7	7.0	0	3.0-0.0	0
Frequency gap (MHz)	10	10	10	10	10	10
OFR (dB)	2.6	46.7	46.2	22.7	45.9-42.8	42.8
Maximum Allowable interference power at radar receiver input (dBm)	−91.1	−117.7	−115.5	−101.2	−110.0 / −107.0	−108.5
Propagation model	**ITU-R P.452-16 (Case 1: *p* = 20%)**					

[13] Recommendation ITU-R SM.337 defines the On Tune Rejection (OTR) as the rejection provided by a receiver selectivity characteristic to a co-tuned transmitter as a result of a transmitted signal exceeding the receiver bandwidth.

TABLE A2.33 (*end*)

Parameters	Radar A	Radar B	Radar C	Radar D	Radar E	Radar M
Single entry without clutter loss						
Required propagation loss (dB) without clutter	176.5	148.3	142.3	167.5	132.1 / 125.2	154.7
Protection distance (km) with equatorial land pathlosses for p = 20%	139	57	45	107	30 / 14	71
Single entry with low clutter loss						
Low clutter loss (dB)	18	18	18	18	18	18
Required propagation loss (dB)	158.5	130.3	124.3	149.5	114.1 / 107.2	136.7
Protection distance (km) with an equatorial pathloss (p = 20%) and low clutter loss	80	26	13	60	3.8	35
Single entry with median clutter loss						
Median clutter loss (dB)	28	28	28	28	28	28
Required propagation loss with median clutter (dB)	148.5	120.3	114.3	139.5	104.1 / 97.2	126.7
Protection distance (km) with an equatorial pathloss (p = 20%) and median clutter loss	56	7.9	3.9	40	1.2	16

In summary, it can be observed that the protection distance between one IMT 10 MHz urban macro base-station and a land based Radar, their bandwidths separated by a frequency gap of 10 MHz, and without clutter loss, is 139 km depending equatorial propagation conditions over the land for using the propagation model with p = 20%.

In this MCL study, taking into account low clutter losses or mask effect of buildings of 18 dB, the protection distance of a radar from one urban macro base station is 80 km. With a median clutter loss of 28 dB, the protection distance of a radar from one macro base station is found to be 56 km.

Study J

The aim of this study is analysing the interference received by a radar operating fully in the spurious emissions domain of IMT base-stations, like a radar operating in the adjacent band below 3 300 MHz with short separation distance of few kilometres between the two systems

This is the case in many places where rivers are used as border between two countries, with a large town on one bank of the river and an airfield equipped with an air surveillance radar on the other bank. A typical example is the N’Djamena international airport, Tchad, in front of Kousseri town, Cameroun, on the other bank of the Chari river.

Considering the spurious emission requirement of −30 dBm/MHz as mentioned in Report ITU-R M.2292 noting 3GPP 36.104 v.11.2.0, Table 6.6.4.1.2.1-1, the required separation distance of 31 km between one IMT-Advanced base station and a radar is not compatible to such scenario (see § 5.1).

This study shows that level of IMT spurious emission requirement of about −60 dBm/MHz could be necessary to mitigate harmful interference on land radar with a separation distance of 1 km.

1 Technical characteristics of IMT and land-based radar systems

1.1 IMT system parameters

Section 2 in main body contains the list of parameters for IMT deployment, which are taken from Report ITU-R M.2292.

1.2 Radar parameters

Section 2 in the main body provides the characteristics of and protection criteria for radars operating in the radio determination service in the frequency band 3 100-3 700 MHz.

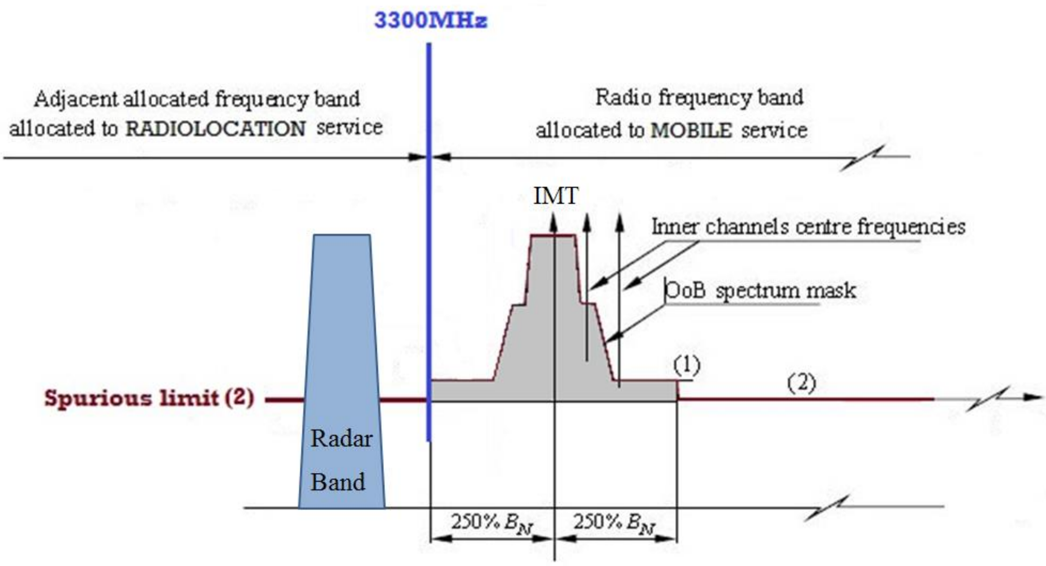
Section 2 in the main body provides the key parameters of terrestrial radar models B, C and I used in this study.

2 Coexistence and compatibility scenarios between IMT and Radar

The study focuses on IMT spurious emissions desensitizing a radar operating in the adjacent band below 3300 MHz as described in Fig. A2-30.

FIGURE A2-30

IMT base-station spurious emission desensitizing a radar in adjacent band



1: Out-of-Band domain
2: Spurious domain

3 Interference criteria

In accordance to main body § 5.

4 Propagation models

The propagation model between IMT system and ship based radar is from Recommendation ITU-R P.452 and performed by an average year prediction with parameter $p = 20\%$ (time percentage for which the calculated basic transmission loss is not exceeded). It can be noticed that at short distance below roughly 30 km, the propagation losses are not very sensitive to time percentage (see § 4 in Study C Annex 2). All the propagation factors in Recommendation ITU-R P.452 are considered.

The scenario considers no clutter loss.

TABLE A2.34

Parameters used propagation losses calculated with Rec. ITU-R P.452

	Base station type	**Macro**	**Micro**
φt	Latitude Transmitter (degree)	12° 07’ N	12° 07’ N
ψt	Longitude Transmitter (degree)	15° 03’ E	15° 03’ E
φr	Latitude Receiver (degree)	12° 07’ N	12° 07’ N
ψr	Longitude Receiver (degree)	15° 03’ E	15° 03’ E
htg	Transmitter Height (metres)	20	6
hrg	Receiver Height (metres)	20	20
Gt	Transmitter Antenna gain (dB)	6-10	5
Gr	Transmitter Antenna gain (dB)	33-40	33-40
N0	Sea-level surface refractivity (N-units)	330	330
deltaN	Average radio-refractive index lapse-rate (N-units/km)	50	50

5 Study results

5.1 Single entry interference from IMT spurious emissions

5.1.1 IMT micro base-station

Table A2.35 gives the required propagation loss and protection distance of a radar from spurious emissions from one IMT outdoor micro base station.

TABLE A2.35

Interference from spurious emissions of one IMT outdoor micro base-station

Parameters	Radar B	Radar C	Radar I
Spurious emission (dBm/MHz)	−30	−30	−30
IMT Feeder loss (dB)	0	0	0
Antenna gain of outdoor IMT micro base-station (dBi)	5	5	5
Antenna gain radar (dBi)	40	31	33.5
Radar Rx Noise figure	4.0	1.5	2.0
Radar IF bandwidth (MHz)	0.67	2.0	3.5
Maximum Allowable interference power at radar receiver input (dBm)	−116.0	−118.5	−118.0
Required propagation loss (dB)	131.0	124.5	126.5
Propagation model	Recommendation ITU-R P.452 (case 1: *p* = 20%)		
Protection distance (km)	**18.5**	**13.0**	**15.0**

In summary, it can be observed that the protection distance between one IMT outdoor micro base-station and a land based Radar, operating in adjacent bands, without clutter loss, is 18.5 km due to the spurious emissions of the IMT micro base stations.

5.1.2 Urban IMT macro base-station

Table A2.36 gives the required propagation loss and protection distance of a radar from spurious emissions from one urban IMT macro base station.

TABLE A2.36

Interference from spurious emissions of one urban IMT macro base-station

Parameters	Radar B	Radar C	Radar I
Spurious emission (dBm/MHz)	−30	−30	−30
IMT Feeder loss (dB)	3	3	3
Antenna gain of urban IMT macro base-station (dBi)	6	6	6
Antenna gain radar (dBi)	40	31	33.5
Radar Rx Noise figure	4.0	1.5	2.0
Radar IF bandwidth (MHz)	0.67	2.0	3.5
Maximum Allowable interference power at radar receiver input (dBm)	−116.0	−118.5	−118.0
Required propagation loss (dB)	129.0	122.5	124.5
Propagation model	Recommendation ITU-R P.452 (case 1: *p* = 20%)		
Protection distance (km)	**22.0**	**10.2**	**13.0**

In summary, it can be observed that the protection distance between one IMT urban macro base-station and a land based Radar, operating in adjacent bands, without clutter loss, is 22.0 km due to the spurious emissions of the IMT urban macro base stations.

5.1.3 Sub-Urban IMT macro base-station

Table A2.37 gives the required propagation loss and protection distance of a radar from spurious emissions from one sub-urban IMT macro base station.

TABLE A2.37

Interference from spurious emissions of one sub-urban IMT macro base-station

Parameters	Radar B	Radar C	Radar I
Spurious emission (dBm/MHz)	−30	−30	−30
IMT Feeder loss (dB)	3	3	3
Antenna gain of urban IMT macro base-station (dBi)	10	10	10
Antenna gain radar (dBi)	40	31	33.5
Radar Rx Noise figure	4.0	1.5	2.0
Radar IF bandwidth (MHz)	0.67	2.0	3.5
Maximum allowable interference power at radar receiver input (dBm)	−116.0	−118.5	−118.0
Required propagation loss (dB)	133.0	126.5	128.5
Propagation model	Rec. ITU-R P.452 (case 1: *p* = 20%)		
Protection distance (km)	**31.0**	**16.5**	**20.8**

In summary, it can be observed that the protection distance between one sub-urban IMT macro base-station and a land based Radar, operating in adjacent bands, without clutter loss, is 31 km due to the spurious emissions of the sub-urban IMT macro base-stations.

5.2 Single entry interference mitigation on IMT spurious emissions level

5.2.1 IMT micro base-station

Table A2.38 gives the required spurious emissions level from one IMT outdoor micro base station to protect a radar at short distance.

TABLE A2.38

Interference from spurious emissions of one IMT outdoor micro base-station

Parameters	Radar B	Radar C	Radar I
IMT Feeder loss (dB)	0	0	0
Antenna gain of outdoor IMT micro base-station (dBi)	5	5	5
Antenna gain radar (dBi)	40	31	33.5
Radar Rx Noise figure	4.0	1.5	2.0
Radar IF bandwidth (MHz)	0.67	2.0	3.5
Maximum allowable interference power at radar receiver input (dBm)	−116.0	−118.5	−118.0
Propagation model	Rec. ITU-R P.452 (case 1: p = 20%)		
Protection distance (km)	1.0	1.0	1.0
Required propagation loss (dB)	102,8	102,8	102,8
Maximum spurious emission level (dBm/MHz)	**−58.2**	**−51.7**	**−53.7**

In summary, a maximum spurious emissions level of −58.2 dBm/MHz is required at the IMT micro base-station’s transmitter output.

5.2.2 Urban IMT macro base-station

Table A2.39 gives the required propagation loss and protection distance of a radar from spurious emissions from one urban IMT macro base station.

TABLE A2.39

Interference from spurious emissions of one urban IMT macro base-station

Parameters	Radar B	Radar C	Radar I
IMT Feeder loss (dB)	3	3	3
Antenna gain of urban IMT macro base-station (dBi)	6	6	6
Antenna gain radar (dBi)	40	31	33.5
Radar Rx noise figure	4.0	1.5	2.0
Radar IF bandwidth (MHz)	0.67	2.0	3.5
Maximum allowable interference power at radar receiver input (dBm)	−116.0	−118.5	−118.0
Propagation model	Rec. ITU-R P.452 (case 1: p = 20%)		
Protection distance (km)	1.0	1.0	1.0
Required propagation loss (dB)	102.8	102.8	102.8
Maximum Spurious emission level (dBm/MHz)	**−56.2**	**−49.7**	**−51.7**

In summary, a maximum spurious emissions level of −56.2 dBm/MHz is required at the urban IMT macro base-station’s transmitter output.

5.2.3 Sub-Urban IMT macro base-station

Table A2.40 gives the required propagation loss and protection distance of a radar from spurious emissions from one sub-urban IMT macro base station.

TABLE A2.40

Interference from spurious emissions of one sub-urban IMT macro base-station

Parameters	Radar B	Radar C	Radar I
IMT Feeder loss (dB)	3	3	3
Antenna gain of urban IMT macro base-station (dBi)	10	10	10
Antenna gain radar (dBi)	40	31	33.5
Radar Rx noise figure	4.0	1.5	2.0
Radar IF bandwidth (MHz)	0.67	2.0	3.5
Maximum allowable interference power at radar receiver input (dBm)	−116.0	−118.5	−118.0
Required propagation loss (dB)	133.0	126.5	128.5
Propagation model	Rec. ITU-R P.452 (case 1: p = 20%)		
Protection distance (km)	1.0	1.0	1.0
Required propagation loss (dB)	102.8	102,8	102,8
Required Spurious emission (dBm/MHz)	**−60.2**	**−53.7**	**−55.7**

In summary, a maximum spurious emissions level of −60.2 dBm/MHz is required at the sub-urban IMT macro base station’s transmitter output.

5.2.4 Conclusion

In conclusion for a single entry scenario, with a realistic separation distance of 1 km, the spurious level of IMT-Advanced macro base stations should be below −60 dBm/MHz to be compatible of urban, and suburban deployments.

In conclusion for a single entry scenario, with a realistic separation distance of 1 km, the spurious level of IMT-Advanced micro base stations should be below −58 dBm/MHz to be compatible of a worse case installation without clutter loss in an urban deployment.

More stringent requirements on spurious levels of BS should be necessary to take into account the aggregated effect of many IMT base stations.

Study K

1 Scenarios for coexistence study

Coastal area scenarios are considered. Ship-based radiolocation radars B and C defined in Recommendation ITU-R M.1465 receive interference from single entry IMT-Advanced BS operating in co-channel or adjacent channel. IMT-Advanced BS is assumed to locate at shoreline in Incheon, Korea. The worst case is studied where the peak antenna gain of radar are taken, and peak gain with a loss due to antenna tilting is considered for computing the antenna gain of BS.

2 System characteristics

2.1 Characteristics for IMT BS with adaptive antenna system

Table A2.41 summarises the relevant base station characteristics from Report ITU-R M.2292.

TABLE A2.41

Characteristics of IMT-Advanced System in 3 300-3 400 MHz frequency band (Table 1 of Att. 4.13 to Document 5D/875)

Parameter	Macro suburban	Macro urban	Micro urban
Carrier frequency (GHz)	3.3	3.3	3.3
Signal bandwidth (MHz)	10	10	10
Maximum output power (dBm/10 MHz)	46	46	24
BS antenna height (m)	25	20	6
Downtilting (degrees)	6	10	0
Antenna gain with downtilting (dBi)	10.4	5.8	5
Feeder loss (dB)	3	3	0
EIRP/10 MHz (dBm)	53.4	48.8	29
Below rooftop base station antenna deployment (%)	0	50	100

2.2 Characteristics of the Radiolocation systems

Recommendation ITU-R M.1465 provides characteristics of radiolocation radars operating in the frequency range 3 100-3 700 MHz. Part of parameters for sharing study are summarized in Table A2.42. The antenna height is 20 metres. Rx IF bandwidth of 10 or 30 MHz for Radar C are applied because the 10 MHz operation causes the worst case of co-channel study while the 30 MHz does that of adjacent channel study.

TABLE A2.42

Characteristics of Radar in 3 300-3 400 MHz frequency band (Rec. ITU-R M.1465-2)

Parameter	Units	Ship-Based Radar B	Ship-Based Radar C	
Antenna gain	dBi	42	Up to 40	
Antenna height	m	20	20	
Rx noise figure	dB	5.0	1.5	
Rx IF bandwidth (−3 dB)	MHz	10	10	30
Allowable interference power	dBm/10 MHz	−105	−108.5	−103.7

3 Propagation models

The propagation model between IMT system and ship based radar is from Recommendation ITU-R P.452-16. All the propagation factors in Recommendation ITU-R P.452 are considered. The 20%, 10%, and 1% time percentages are used, but cannot be considered as a worst case because some missions of radar systems could be more demanding.

The clutter loss model used in this report combines for each IMT deployment, a percentage of above rooftop base stations without clutter loss and a percentage of below rooftop base stations with clutter loss values defined in § 3.2 of the Recommendation ITU-R P.2108 by a statistical model for end correction of terrestrial to terrestrial long-path propagation.

TABLE A2.43

Parameters used propagation losses calculated with Rec. ITU-R P.452

Symbol	Parameter	Value
φt	Latitude Transmitter (degree)	37.45
ψt	Longitude Transmitter (degree)	37.45
φr	Latitude Receiver (degree)	126.59
ψr	Longitude Receiver (degree)	126.59
htg	Transmitter Height (metres)	25(suburban macro), 20 (urban macro), 6 (urban micro)
hrg	Receiver Height (metres)	20
hgt	Transmitting ground height above mean sea level (metres)	0, 50
hgr	Receiving ground height above mean sea level (metres)	0
Gt	Transmitter antenna gain (dB)	18(suburban macro), 18(urban macro), 5(urban micro)
Gr	Transmitter antenna gain (dB)	40 (radar B), 42 (radar C)
N0	Sea-level surface refractivity (N-units)	330
ΔN	Average radio-refractive index lapse-rate (N-units/km)	45

4 Interference criteria

Signals received by radars from other systems could generate different types of degradation of performances. Desensitisation is generally due to low level of interfering signals, and saturation or blocking of receivers could be observed for larger interfering signals.

Recommendation ITU-R M.1465 provides the radar interference criteria in the radiolocation service given as $I/N \leq -6$ dB, where I is the interference power for radar and N is the receiver noise power.

5 Methodology for interference calculation from IMT to Radar

5.1 Methodology for single entry studies in co-channel

Assuming one IMT BS or user equipment interferes a radiolocation service radar in co-channel or adjacent channel, the received interference power level at the radiolocation service radar is given by

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

where:

I_{IMT}: the received interference power level in the bandwidth of the radiolocation service radar (dBm)

P_{IMT}: transmission power 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 propagation loss (dB)

OTR: On tune rejection as defined in Recommendation ITU-R SM.337.

5.2 Methodology for single entry studies in adjacent-channel

Assuming one IMT BS or user equipment interferes a radiolocation service radar in co-channel or adjacent channel, the received interference power level at the radiolocation service radar is given by

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

where:

I_{IMT}: the received interference power level in the bandwidth of the radiolocation service radar (dBm)

P_{IMT}: transmission power of IMT system (dBm)

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

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

$L(f,d)$: propagation loss (dB)

FDR : Frequency dependent rejection (dB) as defined in Recommendation ITU-R SM.337

Δf : Frequency offset (Hz) as defined in Recommendation ITU-R SM.337.

6 Results of coexistence studies

6.1 Adjacent-channel studies between single IMT base station and radar

The Minimum Coupling Loss method is applied to estimate potential interference power from in single entry. The 30 MHz guard band (referred to as frequency gap in Att. 4.13 to Doc. 5D/875) is applied to macro BS only.

TABLE A2.44

Summary of values for OTR and OFR for 10MHz guard band, for macro base stations (Tables A2-B2, A2-B3, A2-B8 of Att. 4.13 to Doc. 5D/875)

Base station type		**Macro**		**Micro**	
IMT Tx Bandwidth	MHz	10		10	
Radar type		B, C	C	B, C	C
Radar Rx bandwidth	MHz	10	30	10	30
OTR	dB	0	0	0	0
OFR for 10 MHz guard band	dB	42.8	22.7	40	22.6
OFR for 30 MHz guard band	dB	62	41		

TABLE A2.45

Minimum propagation loss required to protect required to protect ship-based radars B and C from IMT BS interference

Guard band (MHz)	**BS type**	**Minimum propagation loss (dB)**		
		Radar B 10 MHz	**Radar C 10 MHz**	**Radar C 30 MHz**
10	Macro Suburban	157.6	159.1	174.4
	Macro Urban	153	154.5	169.8
	Micro Urban	136	137.5	150.1
30	Macro Suburban	138.4	139.9	156.1
	Macro Urban	133.8	135.3	151.5
	Micro Urban			

TABLE A2.46

Minimum separation distance required to protect ship-based radars from IMT BS interference, no clutter loss

Guard band (MHz)	BS ground height above sea level (m)	Percentage of time (%)	Minimum separation distance (km)		
			Radar B 10 MHz	Radar C 10 MHz	Radar C 30 MHz
Macro Suburban					
10	0	1	333	347	495
		10	133	141	231
		20	71	75	129
	50	1	292	306	452
		10	124	131	216
		20	75	76	124
30	0	1	91	106	318
		10	56	62	126
		20	39	40	67
	50	1	89	103	278
		10	60	62	117
		20	51	54	73
Macro Urban					
10	0	1	284	300	448
		10	110	116	198
		20	58	61	107
	50	1	249	263	408
		10	103	110	187
		20	68	70	106
30	0	1	55	65	268
		10	39	44	103
		20	31	33	55
	50	1	56	64	234
		10	43	50	98
		20	39	43	67
Micro Urban					
10	0	1	69	80	246
		10	41	46	88
		20	28	29	44
	50	1	70	81	229
		10	51	53	94
		20	43	46	61

Presented below are the amount of additional reduction in interference power required to protect the ship-based radars B and C locating 1 or 22 km far from shoreline. The additional reduction could be achieved with higher clutter loss, lower e.i.r.p. of IMT BS, and/or building entry loss due to indoor deployment of IMT BS.

Percentage of time has little effect on the amount of additional reduction since propagation losses at distances below 25 km are almost same as shown in Fig. A1-1. BS ground height also hardly affect the amount of additional reduction.

TABLE A2.47

The amount of additional reduction in interference power required to protect ship-based radar B from IMT BS interference

<table>
<tr><th rowspan="3">Clutter loss (dB)</th><th rowspan="3">BS ground height above sea level (m)</th><th rowspan="3">Percentage of time (%)</th><th colspan="4">Additional reduction in interference power (dB)</th></tr>
<tr><th colspan="2">10 MHz Guard Band</th><th colspan="2">30 MHz Guard Band</th></tr>
<tr><th>1 km far from shoreline</th><th>22 km far from shoreline</th><th>1 km far from shoreline</th><th>22 km far from shoreline</th></tr>
<tr><td colspan="7">Macro Suburban</td></tr>
<tr><td rowspan="6">0</td><td rowspan="3">0</td><td>1</td><td rowspan="6">55</td><td>32</td><td rowspan="6">36</td><td>13</td></tr>
<tr><td>10</td><td>30</td><td>11</td></tr>
<tr><td>20</td><td>29</td><td>10</td></tr>
<tr><td rowspan="3">50</td><td>1</td><td>32</td><td>13</td></tr>
<tr><td>10</td><td>29</td><td>11</td></tr>
<tr><td>20</td><td>29</td><td>10</td></tr>
<tr><td colspan="7">Macro Urban</td></tr>
<tr><td rowspan="6">0</td><td rowspan="3">0</td><td>1</td><td rowspan="6">51</td><td>28</td><td rowspan="6">32</td><td>8</td></tr>
<tr><td>10</td><td>25</td><td>6</td></tr>
<tr><td>20</td><td>25</td><td>5</td></tr>
<tr><td rowspan="3">50</td><td>1</td><td>28</td><td>8</td></tr>
<tr><td>10</td><td>25</td><td>6</td></tr>
<tr><td>20</td><td>25</td><td>5</td></tr>
<tr><td rowspan="6">18</td><td rowspan="3">0</td><td>1</td><td rowspan="6">33</td><td>10</td><td rowspan="6">14</td><td rowspan="6">0</td></tr>
<tr><td>10</td><td>7</td></tr>
<tr><td>20</td><td>7</td></tr>
<tr><td rowspan="3">50</td><td>1</td><td>10</td></tr>
<tr><td>10</td><td>7</td></tr>
<tr><td>20</td><td>7</td></tr>
<tr><td rowspan="6">28</td><td rowspan="3">0</td><td>1</td><td rowspan="6">23</td><td rowspan="6">0</td><td rowspan="6">4</td><td rowspan="6">0</td></tr>
<tr><td>10</td></tr>
<tr><td>20</td></tr>
<tr><td rowspan="3">50</td><td>1</td></tr>
<tr><td>10</td></tr>
<tr><td>20</td></tr>
</table>

TABLE A2.47 (*end*)

Clutter loss (dB)	BS ground height above sea level (m)	Percentage of time (%)	Additional reduction in interference power (dB)			
			10 MHz Guard Band		30 MHz Guard Band	
			1 km far from shoreline	22 km far from shoreline	1 km far from shoreline	22 km far from shoreline
Micro Urban						
0	0	1	34	11		
		10		8		
		20		5		
	50	1		10		
		10		8		
		20		8		
18	0	1	16	0		
		10				
		20				
	50	1				
		10				
		20				
28	0	1	6	0		
		10				
		20				
	50	1				
		10				
		20				

TABLE A2.48

The amount of additional reduction in interference power required to protect ship-based radar C (10 MHz) from IMT BS interference in macro suburban

Clutter loss (dB)	BS ground height above sea level (m)	Percentage of time (%)	Additional reduction in interference power (dB)			
			10 MHz Guard Band		30 MHz Guard Band	
			1 km far from shoreline	22 km far from shoreline	1 km far from shoreline	22 km far from shoreline
Macro Suburban						
0	0	1	57	34	38	15
0	0	10	57	32	38	13
0	0	20	57	31	38	12
0	50	1	57	34	38	15
0	50	10	57	32	38	13
0	50	20	57	31	38	12
Macro Urban						
0	0	1	53	30	34	10
0	0	10	53	27	34	8
0	0	20	53	27	34	7
0	50	1	53	30	34	10
0	50	10	53	27	34	8
0	50	20	53	27	34	7
18	0	1	35	12	16	0
18	0	10	35	9	16	0
18	0	20	35	9	16	0
18	50	1	35	12	16	0
18	50	10	35	9	16	0
18	50	20	35	9	16	0
28	0	1	25	2	6	0
28	0	10	25	0	6	0
28	0	20	25	0	6	0
28	50	1	25	2	6	0
28	50	10	25	0	6	0
28	50	20	25	0	6	0

TABLE A2.48 (*end*)

<table>
<tr><th rowspan="3">Clutter loss (dB)</th><th rowspan="3">BS ground height above sea level (m)</th><th rowspan="3">Percentage of time (%)</th><th colspan="4">Additional reduction in interference power (dB)</th></tr>
<tr><th colspan="2">10 MHz Guard Band</th><th colspan="2">30 MHz Guard Band</th></tr>
<tr><th>1 km far from shoreline</th><th>22 km far from shoreline</th><th>1 km far from shoreline</th><th>22 km far from shoreline</th></tr>
<tr><td colspan="7">Micro Urban</td></tr>
<tr><td rowspan="6">0</td><td rowspan="3">0</td><td>1</td><td rowspan="6">36</td><td>13</td><td rowspan="18" colspan="2"></td></tr>
<tr><td>10</td><td>10</td></tr>
<tr><td>20</td><td>7</td></tr>
<tr><td rowspan="3">50</td><td>1</td><td>12</td></tr>
<tr><td>10</td><td>10</td></tr>
<tr><td>20</td><td>10</td></tr>
<tr><td rowspan="6">18</td><td rowspan="3">0</td><td>1</td><td rowspan="6">18</td><td rowspan="6">0</td></tr>
<tr><td>10</td></tr>
<tr><td>20</td></tr>
<tr><td rowspan="3">50</td><td>1</td></tr>
<tr><td>10</td></tr>
<tr><td>20</td></tr>
<tr><td rowspan="6">28</td><td rowspan="3">0</td><td>1</td><td rowspan="6">8</td><td rowspan="6">0</td></tr>
<tr><td>10</td></tr>
<tr><td>20</td></tr>
<tr><td rowspan="3">50</td><td>1</td></tr>
<tr><td>10</td></tr>
<tr><td>20</td></tr>
</table>

TABLE A2.49

The amount of additional reduction in interference power required to protect ship-based radar C (30 MHz) from IMT BS interference in macro suburban

Clutter loss (dB)	**BS ground height above sea level (m)**	**Percentage of time (%)**	**Additional reduction in interference power (dB)**			
			10 MHz Guard Band		**30 MHz Guard Band**	
			1 km far from shoreline	**22 km far from shoreline**	**1 km far from shoreline**	**22 km far from shoreline**
Macro Suburban						
0	0	1	72	49	55	31
		10		47		29
		20		46		□□
	50	1		49		31
		10		46		29
		20		46		□□
Macro Urban						
0	0	1	68	45	50	26
		10		42		24
		20		42		23
	50	1		45		26
		10		42		24
		20		42		23
18	0	1	50	27	32	8
		10		24		6
		20		24		5
	50	1		27		8
		10		24		6
		20		24		5
28	0	1	40	17	22	0
		10		14		0
		20		14		0
	50	1		17		0
		10		14		0
		20		14		0

TABLE A2.49 (*end*)

Clutter loss (dB)	BS ground height above sea level (m)	Percentage of time (%)	Additional reduction in interference power (dB)			
			10 MHz Guard Band		30 MHz Guard Band	
			1 km far from shoreline	22 km far from shoreline	1 km far from shoreline	22 km far from shoreline
Micro Urban						
0	0	1	50.8	28		
		10		25		
		20		22		
	50	1		27		
		10		25		
		20		25		
18	0	1	32.8	10		
		10		7		
		20		4		
	50	1		9		
		10		7		
		20		7		
28	0	1	22.8	0		
		10		0		
		20		0		
	50	1		0		
		10		0		
		20		0		

6.2 Studies between IMT terminals and radars

According to Att. 4.13 to Document 5D/875, the separation distance required to protect radars would be much shorter than the distance required to protect from IMT base stations.

7 Summary and concluding remarks

All numerical results are analysed for BS locating at shoreline and ship-based radars in adjacent channel.

The results presented in this Report show clearly that mitigation techniques and measures are necessary for the coexistence of future deployment of IMT-Advanced systems with incumbent radar systems in these bands.

7.2 Adjacent channel studies

7.2.1 10 MHz guard band

Interference powers at victim radars locating 1 km far from shoreline exceed the protection criteria for all cases. They need to be further reduced by at least 55 dB for suburban macro and 51 dB for urban macro and 34 dB for urban micro, on the assumption of zero clutter loss.

It is required to protect radars 22 km far from shoreline for the following environment.

– Between radar B and macro urban BS with 28 dB clutter loss.

– Between radar B and micro urban BS with 18 or 28 dB clutter loss.

– Between radar C (10 MHz bandwidth) and macro urban BS with 28 dB clutter loss.

– Between radar C (10 MHz bandwidth) and micro urban BS with 18 or 28 dB clutter loss.

– Between radar C (30 MHz bandwidth) and micro urban BS with 28 dB clutter loss.

TABLE A2.50

The amount of additional reduction in interference power required to protect ship-based radars B and C from IMT BS (10 MHz) interference for 10 MHz guard band

Clutter loss (dB)	BS ground height above sea level (m)	Percentage of time (%)	Required additional reduction in interference power (dB)					
			Radar B 10 MHz		Radar C 10 MHz		Radar C 30 MHz	
			1 km from shoreline	22 km from shoreline	1 km from shoreline	22 km from shoreline	1 km from shoreline	22 km from shoreline
Macro Suburban								
0	0-50	1-20	55	29-32	57	31-34	72	46-49
Macro Urban								
0	0-50	1-20	51	25-28	53	27-30	68	42-45
18	0-50	1-20	33	7-10	35	9-12	50	24-27
28	0-50	1-20	23	0	25	0-2	40	14-17
Micro Urban								
0	0-50	1-20	34	5-11	36	7-13	51	25-28
18	0-50	1-20	16	0	18	0	33	7-10
28	0-50	1-20	6	0	8	0	23	0

7.2.2 30 MHz guard band

The 30 MHz guard band is applied to macro BS only.

Interference powers at victim radars locating 1 km far from shoreline exceed the protection criteria for all cases. They need to be further reduced by at least 36 dB for suburban macro and 32 dB for urban macro, on the assumption of zero clutter loss.

It is required to protect radars 22 km far from shoreline for the following environment.

– Between radar B and macro urban BS with 18 or 28 dB clutter loss.

– Between radar C (10 MHz bandwidth) and macro urban BS with 18 or 28 dB clutter loss.

– Between radar C (30 MHz bandwidth) and macro urban BS with 28 dB clutter loss.

TABLE A2.51

The amount of additional reduction in interference power required to protect ship-based radars B and C from IMT BS (10 MHz) interference for 30 MHz guard band

Clutter loss (dB)	BS ground height above sea level (m)	Percentage of time (%)	Required additional reduction in interference power (dB)					
			Radar B 10 MHz		Radar C 10 MHz		Radar C 30 MHz	
			1 km far from shoreline	22 km far from shoreline	1 km far from shoreline	22 km far from shoreline	1 km far from shoreline	22 km far from shoreline
Macro Suburban								
0	0-50	1-20	36	10-13	38	12-15	55	28-31
Macro Urban								
0	0-50	1-20	32	5-8	34	7-10	50	23-26
18	0-50	1-20	14	0	16	0	32	5-8
28	0-50	1-20	4	0	6	0	22	0

Study L

This section provides a study of compatibility between IMT and radar systems in the frequency band 3 300-3 400 MHz. The study examines the impact of an IMT network of macro urban BS equipped with Advanced Antenna System into land based radars type B, D and I operating in an adjacent channel. The study shows the out of block emissions levels required at the BSs in order to achieve a given probability of exceeding the *I*/*N* threshold at the radar receiver.

1 Technical characteristics of IMT and radar systems

TABLE A2.52

IMT base station deployment

Parameters	Assumed Value
Base station coordinates (x_{BS}, y_{BS})	**Hexagonal deployment of macro-cells** N_{BS} base stations are distributed on a hexagonal grid with a given ISD, and where each base station is located a distance d from the radar receiver where $d_{min} \leq d \leq d_{max}$, d_{min} = 3 000 metres, d_{max} = 5 000 metres. Macro-cell ISD: Urban: 1.5 × 300 = 450 metres. See **ITU-R M.2292**.
Base station antenna height (above ground) z_{BS}	Macro-cells: Urban: 20 metres. See **ITU-R M.2292**.

TABLE A2.52 (*end*)

Parameters	Assumed Value
Sectorization	Each macro base station would have three independent sectors (120° each). See **3GPP TR 37.840**. The orientation of the sectors need not change from one Monte Carlo trial to the next.
TDD factor	TDD factor can be accounted for in the Monte Carlo trials by multiplying all radiated powers by the *same single* binary random variable x (0 or 1), where $\Pr\{x = 1\}$ = ratio of DL transmissions to total frame duration. A DL ratio of 0.8 will be assumed. Use of a *single* value is based on the assumption of synchronised UL/DL phases in a network. This value is based on the proposed value in **ITU-R TG5/1 document 36**.
Network loading	A network loading factor of 0.5 is assumed. See **ITU-R M.2292**.

TABLE A2.53

IMT-2020 AAS base station antenna element and array parameters

Parameters	Assumed Value
Antenna element directional pattern $a_{E\,\mathrm{dB}}(\theta,\varphi)$	According to 3GPP TR 37.840 (section 5.4.4.2**)**: $a_{E\,\mathrm{dB}}(\theta,\varphi) = -\min\{-[A_{E,V\,\mathrm{dB}}(\theta) + A_{E,H\,\mathrm{dB}}(\varphi)],\ A_{m\,\mathrm{dB}}\}$, $A_{E,H\,\mathrm{dB}}(\varphi) = -\min\left\{12\left(\frac{\varphi}{\varphi_{3\mathrm{dB}}}\right)^2, A_{m\,\mathrm{dB}}\right\}$, $A_{E,V\,\mathrm{dB}}(\theta) = -\min\left\{12\left(\frac{\theta-90°}{\theta_{3\mathrm{dB}}}\right)^2, SLA_{V\,\mathrm{dB}}\right\}$, where: 3 dB elevation beamwidth θ_{3dB} = 65°, 3 dB azimuth beamwidth φ_{3dB} = 80°, Front-to-back ratio A_m = 30 dB, Side-lobe ratio SLA_V = 30 dB. NOTE 1 – $a_E(\theta,\varphi) \leq 1$. NOTE 2 – Each antenna element is larger in size in the vertical direction, and so $\theta_{3dB} < \varphi_{3dB}$. See **3GPP TR 37.840**.
Antenna element gain $G_{E\,\mathrm{dB}}$	8 dB
Number of base station beamforming elements (N_V, N_H)	8.8
Element spacing	0.9λ vertical separation. 0.6λ horizontal separation. NOTE – Larger vertical spacing provides narrower array beamwidth in elevation. See **3GPP TR 37.840** (Table 5.4.4.2.1-1).
Mechanical downtilt	Macro-cell: 10° NOTE – For macro-cell, see **ITU-R M.2292** for 20 metres height and 300 m sector radius.

TABLE A2.54

IMT-2020 base station antenna element and array parameters (2)

Parameters	Assumed Value
Array beamforming directional pattern $a_A(\theta,\varphi)$	According to **3GPP TR 37.840** (**section** 5.4.4.2): $$a_A(\theta,\varphi) = 1 + \rho\left[\left\|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{m,n}v_{m,n}\right\|^2 - 1\right]$$ where: $$v_{m,n} = \exp\left[j\frac{2\pi}{\lambda}\{(m-1)d_H\sin(\varphi)\sin(\theta) + (n-1)d_V\cos(\theta)\}\right],$$ $$w_{m,n} = \frac{1}{\sqrt{N_H N_V}}\exp\left[-j\frac{2\pi}{\lambda}\{(m-1)d_H\sin(\varphi_{SCAN})\cos(\theta_{TILT}) - (n-1)d_V\sin(\theta_{TILT})\}\right],$$ and: ρ is the signal correlation across the antenna elements, N_V, N_H are the number of vertical and horizontal antenna elements, d_V, d_H are the vertical and horizontal antenna element spacings, $-\pi/2 \le \theta_{TILT} \le \pi/2$ is the downward beam steering tilt angle relative to boresight, and $-\pi \le \varphi_{SCAN} \le \pi$ is the anti-clockwise horizontal beam steering scan angle relative to boresight. NOTE – $0 \le a_A(\theta,\varphi) \le N$. At each Monte Carlo trial, in each sector a single beam is steered in azimuth and elevation toward a UE which is dropped randomly within the sector.
Correlation	ρ = 0 and 1 (as a sensitivity analysis)
Indoor user terminal usage	In the macro-cell urban scenario, 70% of UEs will be considered indoor (see ITU-R M.2292), with a height above ground that is uniformly distributed with values of 1.5 + {0, 3, 6, 9, 12, 15} metres. Outdoor UEs in all cases are assumed to be at a height of 1.5 m above the ground.

TABLE A2.55

IMT-Advanced base station antenna pattern (non-AAS)

Parameters	Assumed Value
Maximum antenna gain dBi (3-sector sites assumed for macro)	18 dBi
Antenna type	3 sectors
Antenna pattern	ITU-R F.1336 – 4 (average side lobe)
3 dB antenna beamwidth in elevation	Calculated by using 1336-4 formula and 65 degrees azimuth.)
3 dB antenna beamwidth in azimuth (from M.2292)	65°
Polarization	± 45° cross-polarized

TABLE A2.56

Radar receiver parameters (land based Radar types B, D and I)

Parameters	Assumed Value
Radar receiver coordinates (x_{RAD}, y_{RAD})	(0, 0) NOTE – Radar receiver is positioned at the origin and is surrounded by mobile network base stations.
Radar receiver antenna height above ground z_{BS}	30 metres NOTE – The height for terrestrial radar can vary from 4 to 30 metres.
Radar receiver maximum gain	Radar B/D: 40 dBi Radar I: 33.5 dBi
Antenna side lobe (SL) levels (1st SLs and remote SLs)	Radar B/D: there is no reference in M.1464, but for Radar J or M, the max antenna gain is up to 40 dBi, the 1st SLs and remote SLs information can be a reference > 32 typical < –10, in this study 32 and –10 is considered Radar I: 26 35
Beamwidth (H,V) degrees	Radar B: 1.05, 2.2 Radar D: 1-4.5 degree (consider the same Beamwidth as Radar B for the same max antenna gain) Radar I: 1.5,4.8
Mechanical up-tilt	0° NOTE – No up-tilt is used in the absence of other information.
Mechanical azimuth scan	At every Monte Carlo trial, the radar antenna points to a random azimuth direction that is uniformly distributed between 0 and 360°.
Noise figure	Radar B/D: 4 dB Radar I: 2 dB
Target experienced interference I/N	–6 dB.
Probability of interference exceeding the target level	1%...10%

2 Propagation model

TABLE A2.57

Frequency	3300 MHz
Median path loss and clutter	Macro-cell: P.452 P = 20%, P.2109 clutter loss Clutter losses apply only to 50% of the BSs (those located below rooftops) and do not apply to the 50% of BSs that are located above rooftop. For the BSs below rooftops, a random clutter value taken from P.2109 applies
Building penetration loss	15 dB (Traditional building penetration loss defined in Recommendation ITU-R P.2109.The model is based on the measurement data collated in Report ITU-R P.2346 in the range 80 MHz to 73 GHz.). In the cases where the served UE is indoor and located in the path from the BS to the radar, the building penetration loss has been added to the pathloss between the BS and the Radar.
Polarisation loss	3dB

3 Modelling approach

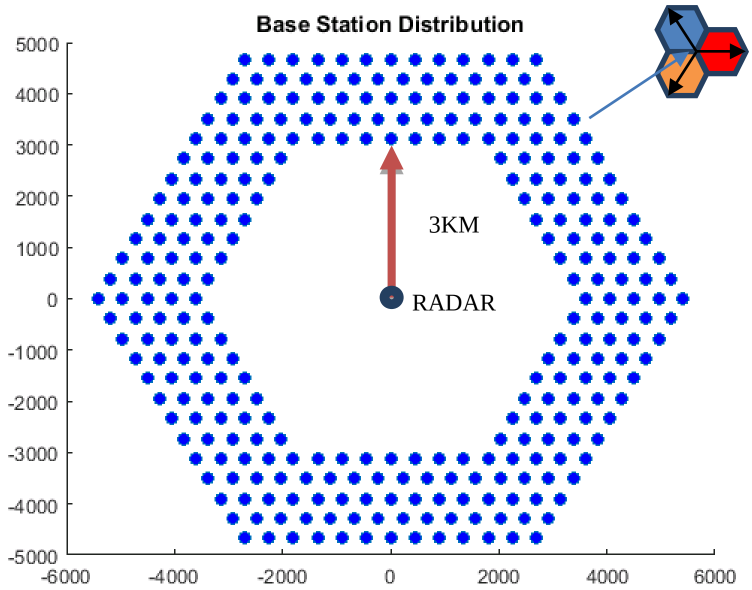
Figure A2-31 illustrates the modelling of IMT macro base stations. Here, a radar receiver is surrounded by multiple rings of tri-sector IMT base stations in a hexagonal arrangement. Under the “3km separation distance” case the minimum and maximum separations between the radar and IMT base stations are 3 000 and 5 000 metres, respectively. This implies a total of five rings and 300 macro-sites, with an inter-site distance of 450 metres for urban macro scenario.

Modelling of UE distribution was following the description of ITU-R M.2292, which is a three-hexagonal-sector with 450 metres ISD.

This study considers macro base station deployments because they (rather can micro cell deployments) represent the more critical case in terms of the likelihood of harmful interference to radar.

FIGURE A2-31

A radar receiver is surrounded by 5 rings of 300 tri-sectored MFCN macro base stations



The IMT base stations are assumed to operate with a TDD DL:UL ratio of 8:2, a network loading of 50%, and with antennas located 20 metres above the ground with a mechanical downtilt of 10°.This is the typical deployment configuration for IMT deployed in urban scenario. The antenna element radiation pattern is based on Recommendation ITU-R M.2101, with vertical and horizontal 3 dB beamwidths of 65° and 80°, respectively, a front-to-back ratio of 30 dB, and a gain of 8 dBi.

The radar receiver antenna is modelled as located 30 metres above the ground with a mechanical downtilt of 0°. Land based Radar B/D and I are evaluated in this study.

Interference to the radar receiver is calculated as the aggregate of the out-of-block emissions of all IMT base stations, using the ITU-R P.452 propagation model. ITU-R P.2108 clutter loss is assumed for the geometry considered.

Figure A2-32 illustrates the way in which angular discrimination is modelled at the IMT base stations and radar receiver:

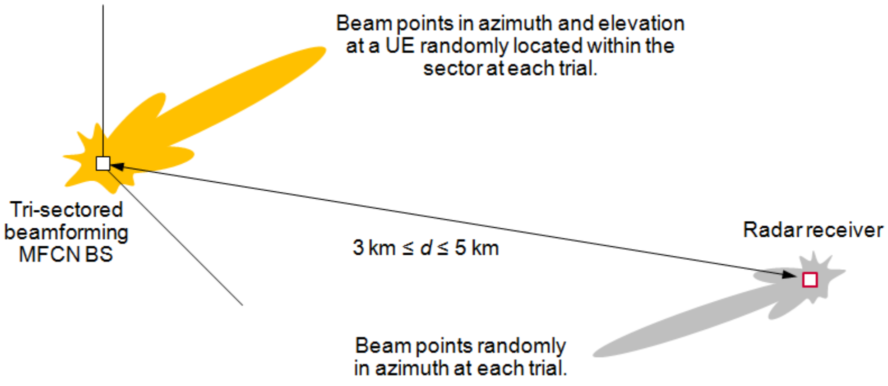
– At each Monte Carlo trial, the radar receiver is assumed to point its beam towards a random direction in azimuth (uniformly distributed between 0° and 360°).

– At each Monte Carlo trial, each IMT base station sector is assumed to radiate towards a user equipment (UE) which is located within the area of the sector. Indoor UEs ratio is based on ITU-R M.2292. Outdoors UEs are assumed to be 1.5 metres above ground.

The intention in the above modelling approach is to adequately capture the benefits of angular discrimination at the transmitters and receiver. It should be noted that the extent to which the out-block transmissions of an IMT base station undergo beamforming depends on the level of the correlation of the signals across the transmitting antenna elements.

FIGURE A2-32

Modelling of angular discrimination



In practice, it is difficult to know the precise value of the correlation ρ for the out-of-block signal. This is because unwanted emissions are generated by a mix of noise sources and non-linearities which can be common or distinct among the multiple transmitter chains. This study assumes no correlation ($\rho = 0$) as the baseline as suggested by Recommendation ITU-R M.2101, and full correlation as the sensitivity analysis.

4 Simulation results

4.1 AAS systems

This section contains simulation results for scenarios with IMT-2020 systems using AAS. There are results for the combination of the following parameter values:

This section contains simulation results for the scenarios resulting from the combination of the following parameter values:

– Three radar types: Land Radar types B, D and I
– Separation distance between the radar the innermost ring of IMT cells: 3 km and 10 km.
– Correlation between the emissions of the antenna elements (ρ): 0 and 1
– Building penetration loss:
  - indoor UEs located in the path from the BS to the radar with a 15dB building penetration loss (according to Recommendation ITU-R P.2109);
  - indoor UEs without building penetration loss.

The results are presented in terms of the required TRP OOBE for different percentages of likelihood that the aggregated interference (*I*/*N*) is below −6 dB.

TABLE A2.58

OOBE TRP Requirement for Radar B/D with 3 km separation distance

	OOBE requirement (dBm/MHz TRP)			
Likelihood that *I*/*N*< –6 dB	**Non correlated scenario**		**Correlated scenario**	
	70% indoor with building penetration loss	**70% indoor without building penetration loss**	**70% indoor with building penetration loss**	**70% indoor without building penetration loss**
99%	**−41.1**	**−44.2**	**−42.8**	**−50.6**
98%	−40.3	−43.9	−42.8	−46.2
97%	−40.2	−43.9	−42.7	−44.8
96%	−38.8	−43.9	−37.4	−43.8
95%	**−38.5**	**−41.6**	**−35.3**	**−43.8**
94%	−37.5	−41.6	−34.9	−43.1
93%	−37.5	−41.6	−34.9	−43.1
92%	−37.4	−41.6	−34.2	−42.8
91%	−37.2	−41.1	−33.9	−40.2
90%	**−35.1**	**−40.3**	**−32.7**	**−39.5**

TABLE A2.59

OOBE TRP Requirement for Radar I with 3 km separation distance

	OOBE requirement (dBm/MHz TRP)			
Likelihood that *I*/*N* < –6 dB	**Non correlated scenario**		**Correlated scenario**	
	70% indoor with building penetration loss	**70% indoor without building penetration loss**	**70% indoor with building penetration loss**	**70% indoor without building penetration loss**
99%	**−35.3**	**−37.8**	**−36.3**	**−44.2**
98%	−34.9	−37.5	−36.3	−40.9
97%	−33.9	−37.5	−36.3	−39.5
96%	−33.8	−37.5	−36.2	−38.4
95%	**−33.8**	**−37.5**	**−35.6**	**−37.9**
94%	−33.8	−36.7	−35.6	−37.9
93%	−33.8	−36.3	−35.6	−37.1
92%	−32.8	−36.3	−32.6	−36.9
91%	−32.3	−36.3	−29.2	−36.8
90%	**−31.7**	**−35.3**	**−28.8**	**−36.8**

TABLE A2.60

OOBE TRP Requirement for Radar B/D with 10 km separation distance

	OOBE requirement (dBm/MHz TRP)			
Likelihood that *I*/*N* < –6 dB	**Non correlated scenario**		**Correlated scenario**	
	70% indoor with building penetration loss	**70% indoor without building penetration loss**	**70% indoor with building penetration loss**	**70% indoor without building penetration loss**
99%	**−34.7**	**−36.8**	**−36.2**	**−47.2**
98%	−34.7	−36.8	−32.3	−46.8
97%	−34.6	−36.4	−31.9	−44.6
96%	−34.6	−36.2	−31.7	−44.6
95%	**−33.6**	**−36.2**	**−31.7**	**−43.6**
94%	−33.2	−36.2	−30.7	−41.0
93%	−33.1	−35.5	−29.8	−40.6
92%	−32.9	−35.1	−29.6	−39.2
91%	−32.5	−34.6	−29.1	−38.3
90%	**−32.2**	**−34.6**	**−28.9**	**−38.3**

TABLE A2.61

OOBE TRP Requirement for Radar I with 10 km separation distance

	OOBE requirement (dBm/MHz TRP)			
Likelihood that *I*/*N*< –6 dB	**Non correlated scenario**		**Correlated scenario**	
	70% indoor with building penetration loss	**70% indoor without building penetration loss**	**70% indoor with building penetration loss**	**70% indoor without building penetration loss**
99%	**−28.3**	**−31.1**	**−29.7**	**−42.9**
98%	−28.3	−30.6	−28.1	−42.9
97%	−28.3	−30.5	−28.1	−40.8
96%	−28.3	−30.5	−27.1	−40.4
95%	**−28.3**	**−30.5**	**−26.0**	**−38.2**
94%	−27.2	−30.3	−25.6	−38.2
93%	−27.0	−30.3	−25.4	−37.2
92%	−26.9	−30.2	−25.4	−34.6
91%	−26.6	−30.0	−23.7	−34.3
90%	**−26.1**	**−29.9**	**−23.4**	**−33.2**

4.2 Non-AAS systems

This section contains simulation results for scenarios with IMT-advanced systems using non-AAS. There are results for the combination of the following parameter values:

– Three radar types: Land Radar types B, D & I

– Separation distance between the radar the innermost ring of IMT cells: 3 km and 10 km.

– Building penetration loss:
  - indoor UEs located in the path from the BS to the radar with a 15 dB building penetration loss (according to Recommendation ITU-R P.2109);
  - indoor UEs without building penetration loss.

The results are presented in terms of the required TRP OOBE for different percentages of likelihood that the aggregated interference (*I*/*N*) is below −6 dB.

TABLE A2.62

OOBE TRP Requirement for Radar B/D with 3 km separation distance

Likelihood that *I*/*N*< –6 dB	OOBE requirement (dBm/MHz TRP)	
	70% indoor with building penetration loss	70% indoor without building penetration loss
99%	**−42.4**	**−45.3**
98%	−42.1	−45.2
97%	−41.9	−44.4
96%	−41.1	−44.3
95%	**−39.8**	**−44.3**
94%	−38.6	−43.3
93%	−37.7	−43.3
92%	−37.5	−42.4
91%	−36.8	−42.3
90%	**−36.6**	**−42.0**

TABLE A2.63

OOBE TRP Requirement for Radar I with 3 km separation distance

Likelihood that *I*/*N* < –6 dB	OOBE requirement (dBm/MHz TRP)	
	70% indoor with building penetration loss	70% indoor without building penetration loss
99%	**−35.9**	**−38.9**
98%	−35.7	−38.8
97%	−35.5	−38.0
96%	−34.7	−38.0
95%	**−33.8**	**−38.0**
94%	−32.3	−37.1
93%	−31.6	−36.9
92%	−31.5	−36.9
91%	−31.2	−36.9
90%	**−30.3**	**−36.2**

TABLE A2.64

OOBE TRP Requirement for Radar B/D with 10 km separation distance

	OOBE requirement (dBm/MHz TRP)	
Likelihood that *I*/*N* < –6 dB		
	70% indoor with building penetration loss	**70% indoor without building penetration loss**
99%	**−36.2**	**−40.3**
98%	−35.4	−39.7
97%	−33.5	−38.7
96%	−33.5	−38.7
95%	**−33.4**	**−38.7**
94%	−33.4	−37.6
93%	−33.0	−37.6
92%	−33.0	−37.6
91%	−32.8	−37.4
90%	**−32.5**	**−37.4**

TABLE A2.65

OOBE TRP Requirement for Radar I with 10 km separation distance:

	OOBE requirement (dBm/MHz TRP)	
Likelihood that *I*/*N* < –6 dB		
	70% indoor with building penetration loss	**70% indoor without building penetration loss**
99%	−30.9	−34.5
98%	−29.7	−34.5
97%	−29.6	−34.5
96%	−28.7	−33.9
95%	−27.3	−33.2
94%	−27.2	−33.2
93%	−27.1	−33.2
92%	−26.9	−32.0
91%	−26.9	−31.9
90%	−26.8	−31.3

Study M

1 Introduction

This study provides calculation and simulation results of the potential interference from IMT systems with non-AAS and AAS antennas operating in 3 300-3 400 MHz band to radar systems operating in 3 100-3 300 MHz. Adjacent-band interference are considered for both IMT non-AAS BS and AAS BS.

Based on the interference analysis results, possible interference mitigation techniques are proposed for in-band and adjacent band scenarios.

2 Adjacent band sharing and compatibility study

2.1 Co-existence scenarios and assumptions

The co-existence scenarios and assumptions for the co-existence between IMT and Radars are described in Attachment M.1.

2.2 Study results for the co-existence between IMT non-AAS and radars at 3 300 MHz

For the co-existence between IMT non-AAS and radars at 3 300 MHz, only the study results for single entry case are obtained with MCL calculation method. The MCL calculations are described in Attachment M.2 results are summarised in Table A2.66.

The results presented in Table A2.66 are calculated with the following assumptions:

1 IMT non AAS antenna with an 18 dBi gain and 3 dB feeder loss.

2 A discrimination of polarization equal to 3 dB.

3 At a separation distance of 1 km.

Free Space propagation model without clutter loss.

TABLE A2.66

Calculated unwanted emission levels for IMT non-AAS BS for the protection radars operation below 3 300 MHz

Radar type	Radar I	Radar L-D
Maximum e.i.r.p. below 3 300 MHz	−45.6 dBm/MHz	−50.1 dBm/MHz
Maximum unwanted emission levels below 3 300 MHz at IMT BS Tx output	−51.6 dBm/MHz	−56.1 dBm/MHz

The results given in Table A2.66 represent a co-existence case in an open rural area at 1 km separation distance between IMT BS non-AAS antenna and Radars type I and type L-D.

2.3 Study results for the co-existence between IMT AAS and radars at 3 300 MHz

The calculations between IMT AAS and radars are described in Attachment M.3.

2.3.1 Results for single entry scenario

The results for single entry scenario calculated with MCL method are given in Tables 2 and 3.

TABLE A2.67

The required unwanted emission levels (TRP in dBm/MHz)

Necessary unwanted emission Levels (TRP in dBm/MHz)					Necessary unwanted emissions e.i.r.p. (dBm/MHz)
	Worst case main beam to main beam	**BS tilt −10° (antenna discrimination 9 dB)**	**BS tilt −40° (antenna discrimination 21 dB)**	**BS tilt −70° (antenna discrimination 35 dB)**	
	Land based radar I (Rec. ITU-R M.1464) H: 10 m				
0° (3 km)	−59.2	−50.2	−38.2	−24.2	−36.2
0° (1 km)	−68.7	−59.7	−47.7	−33.7	−45.7
	Land based radar L-D (Rec. ITU-R M.1465-3) H: 10 m				
0 ° (3 km)	−63.7	−54.7	−42.7	−28.7	−40.7
0° (1 km)	−73.2	−64.2	−52.2	−38.7	−50.2

NOTE 1 – The given unwanted e.i.r.p. is provided as an example. It is the minimum level (more stringent) calculated depending of various parameters (as an example, the value −45.7 dBm/MHz e.i.r.p. is the minimum value obtained using the various TRP values (depending on the tilt) + the antenna gain corresponding to the tilt (−38.2 dBm + 23 dBi −21 dBc = −36.2 dBm/MHz). The −21 dBc is obtained using the antenna diagram.

NOTE 2 – The BS tilt cases −10°, −40°, −70° are used to give some examples among a multitude of possible cases.

The required unwanted emission levels (TRP in dBm/MHz) for IMT AAS BS at 10° downtilt for protecting land radars at 1 km and 3 km separation distances are summarized in Table A2.68.

TABLE A2.68

Required unwanted emission levels (TRP in dBm/MHz) under assumption of 10° downtilt

		BS unwanted emission limit (single entry scenario)	
	Land based radar	**TRP (dBm/MHz**	**e.i.r.p. (dBm/MHz)**
At 1 km	I	−59.7	−45.7
	L-D	−64.2	−50.2
At 3 km	I	−50.2	−36.2
	L-D	−54.7	−40.7

2.3.2 Monte-Carlo simulation results for multiple entry case

Monte-Carlo simulations taking into account the aggregated effect are given in Table A2.69.

Based on assumptions and parameters described in Annex 1, a simulation software has been developed (Python language). This simulation makes several thousands of draws using a variation of the considered parameters:

– Uniform distribution of the UE around the BS (that corresponds approximately to BS tilt values from −10° to −75°)

– Distribution of the distances between radars and base stations (from 1 or 3 km to 12 km)

– Clutter: assumption 1 without clutter, assumption 2 clutter on 50% of cases (Draw to define the value of the clutter).

The TRP value is obtained when 99% of the calculated cases in the simulation ensure that the radar protection criterion is met. Examples of simulation results are given in Attachment M.3.

TABLE A2.69

Simulation results for the scenario of radar in the vicinity of a town

Radar	Antenna beamwidth	Propagation	Necessary TRP limit dBm/MHz	
	ϴ		1-12 km	3-12 km
I	1,5°	Free space +clutter	−51.7	−44.2
		Free space	*−53.2*	*−45.5*
L-D	1°	Free space +clutter	−55.2	−47.7
		Free space	***−56.8***	*−49*
	1,5°	Free space +clutter	−56.2	−48.6
		Free space	*−57.7*	*−50*
	4°	Free space +clutter	−**58.3**	−50.9
		Free space	*−59.7*	*−52.5*

Results (in terms of TRP levels) varies from −44.2 to −58.3 dBm/MHz. These results are dependent of numerous factors, like:

– minimum distance taking into account between radar and base station (1 or 3 km),
– BS activity factor (or network load),
– clutter loss (Recommendation ITU-R P.2108),
– diagram of AAS base station antenna,
– radar position (in the vicinity of a town).

Furthermore, antenna tilt is assumed to be always lower than −10° (included).

2.4 Summary and conclusions

The required unwanted emission levels for the protection of radiolocation radars type I and type L-D are summarised in Table A2.70 for IMT non-AAS BS and in Table A2.71 for IMT AAS BS.

TABLE A2.70

Required unwanted emission levels for IMT non-AAS BS for protecting radars below 3 300 MHz (MCL calculation)

Radar type	Separation distance	unwanted emission level (e.i.r.p. in dBm/MHz)	Max unwanted emission level below 3300 MHz at IMT BS (Tx output power dBm/MHz)
Radar I	1 km	−45.6 dBm/MHz	−51.6 dBm/MHz
Radar L-D	1 km	−50.1 dBm/MHz	−56.1 dBm/MHz

TABLE A2.71

Required unwanted emission levels for IMT AAS BS for protecting radars below 3 300 MHz (Monte-Carlo simulations)

Radar type	**unwanted emission level (TRP in dBm/MHz)**
Radar I	−52 dBm/MHz
Radar L-D	−58 dBm/MHz

3 Possible interference mitigation techniques

3.1 Possible interference mitigation techniques for in-band co-existence

The possible interference mitigation techniques for protecting radiolocation radars in in-band co-existence cases are summarised in Table A2.72.

TABLE A2.72

Possible interference mitigation techniques for in-band co-existence

Case	Mitigation technique	Remark
Limited number of fix radar	Coordination with appropriate separation distance to ensure the interference level at radar receiver does not exceed the protection ratio $I/N = -6$ dB	The required separation distance depend environment, IMT BS antenna height, transmit power, etc.
Transportable radar	The co-existence becomes difficult in the same geographical area, two possible solutions: 1) Stop emissions of IMT sites in the same geographical area during the operation period of the radars or 2) Tune the radars operating below 3 300 MHz	When radar operation frequency is tuned below 3 300 MHz, interference mitigation measures for adjacent band co-existence apply

3.2 Possible interference mitigation techniques for adjacent-band co-existence

The possible interference mitigation techniques for protecting radiolocation radars in adjacent-band co-existence cases (i.e. radar operations limited to below 3 300 MHz) are summarised in Table A2.73.

TABLE A2.73

Possible interference mitigation techniques for adjacent-band co-existence

Limited number of fix radars	1) Coordination with appropriate separation distance to ensure the interference level at radar receiver does not exceed the protection ratio *I*/*N* = –6 dB IMT non AAS: separation distance from 23 to 35 km (based on spurious level) IMT AAS: estimated separation distance should be approximately the same order or 2) Additional filters at IMT BS to reduce the unwanted emission levels	The required separation distance depend environment, IMT BS antenna height, transmit power, etc. The required unwanted emission levels for protecting radars are given in Table A2.70 for IMT non-AAS BS and in Table A2.71 for IMT AAS BS. In order to reach the required unwanted emission limits below 3 300 MHz, a guard band may be needed in order to implement the necessary filter at IMT BS transmitter side.
Unknown radar numbers and locations	Additional filters at IMT BS to reduce the unwanted emission levels	The required unwanted emission levels for protecting radars are given in Table A2.70 for IMT non-AAS BS and in Table A2.71 for IMT AAS BS. In order to reach the required unwanted emission limits below 3 300 MHz, a guard band may be needed in order to implement the necessary filter at IMT BS transmitter side.

Attachment M.1

System parameters, co-existence scenarios, Interference calculation/ simulation methodology

1.1 Radars characteristics (3 100-3 400 MHz)

Characteristics of radars used in this study are described in the following Recommendations:

– Land based radar I: Recommendation ITU-R M.1464-2

– Land based radar L-D and radar S-D: Recommendation ITU-R M.1465-3

The characteristics of radar type I, L-D, S-D, are summarized in Table A2.74.

TABLE A2.74

Radar system parameters

Recommendation ITU-R	ITU-R M.1464	ITU-R M.1465-3	
Parameter	**Radar I**	**Radar L-D**	**Radar S-D**
Use	Land based system	Land based system	Ship system
Tuning range	2 700-3 400	2 800-3 400	/
Tx bandwidth	2.5	7-40	3-15
Rx bandwitdh	2.5	30	2-20
Rx noise figure	2	4	1,5
Sensitivity	–104/–123	–115	/
Antenna gain	33.5	40	Up to 40
Beamwidth (H,V)	1.5°	1°-4.5°	1.5°-6°, 4°-20°
N = *kTBF*	−108 dBm/2.5 MHz	−95.2 dBm/30 MHz	−109.5 dBm/2 MHz −99.5 dBm/20 MHz
kTBF (in 1 MHz)	*−112 dBm/MHz*	*−110 dBm/MHz*	*−112.5 dBm/MHz*
I/N	−6 dB	−6 dB	−6 dB
Desensitization	−118 dBm/MHz	−116 dBm/MHz	−118.5 dBm/MHz

1.2 IMT BS characteristics (3 300-3 400 MHz)

IMT system characteristics are summarized in Table A2.75.

TABLE A2.75

IMT system characteristics

BS macro	Antenna gain	Feeder loss	Tilt	Antenna height (urban/sub)
IMT non AAS	18 dB	3 dB	10°/6°	20 m/25 m
IMT AAS	23 dB	0 dB	10°/6°	20 m/25 m

The unwanted emissions for IMT 5, 10, 15, and 20 MHz channel bandwidths are given in Table A2.76.

TABLE A2.76

Unwanted emissions for 5, 10, 15 and 20 MHz channel bandwidths

Reference: Recommendation ITU-R M.2070-1			Referred to 1 MHz
OOB Macro BS	3GPP 36.104 v.11.2.0, Table 6.6.4.1.2.1-1	−15 dBm /MHz	−15 dBm/MHz
OOB Micro BS	3GPP 36.104 v.11.2.0, Table 6.6.4.1.2.1-1	−37 dBm /100 kHz	−27 dBm/MHz
Reference: Rec. ITU-R SM.329 (category B)			
SPURIOUS			−30 dBm /MHz

IMT system parameters and network layout assumptions are given in Table A2.77.

TABLE A2.77

IMT system parameters and network layout assumptions

	Macro suburban	**Macro urban**	**Small cell outdoor/ Micro urban**	**Small cell indoor/ Indoor urban**
Cell radius/Deployment density	0.3-2 km (typical 0.6 km)	0.15-0.6 km (typical 0.3 km)	1-3 per urban macro cell <1 per suburban macro site	Depending on indoor coverage/capacity demand
Antenna height	25 m	20 m	6 m	3 m
Sectorization	3 sectors	3 sectors	Single sector	Single sector
Downtilt	6 degrees	10 degrees	n.a.	n.a.
Antenna pattern	Rec. ITU-R F.1336		Rec. ITU-R F.1336 omni	
Antenna polarization	Linear/± 45 °	Linear/±45°	Linear	Linear
Below rooftop BS antenna deployment	0%	50%	100%	n.a.
Feeder loss	3 dB	3 dB	n.a	n.a
Maximum BS output power (5/10/20 MHz)	43/46/46 dBm	43/46/46 dBm	24 dBm	24 dBm
Maximum BS antenna gain	18 dBi	18 dBi	5 dBi	0 dBi
Maxi BS output power/sector e.i.r.p.	58/61/61 dBm	58/61/61 dBm	29 dBm	24 dBm
Average base station activity	50%	50%	50%	50%
Average BS power/sector taking into account activity factor	55/58/58 dBm	55/58/58 dBm	26 dBm	dBm
Antenna polarization	Linear/±45°	Linear/±45°	Linear	Linear

1.3 Interference calculation/simulation methodology

Methodology used in this contribution refers to the procedure of Recommendation ITU-R M.1461 – Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services. Three interference mechanisms can occur on radar reception:

– Front-end saturation (or overload, or blocking): not studied in this Report

– Intermodulation: not studied in this Report

– Desensitization (degradation of sensitivity).

To avoid radar desensitization, signal received at the radar receiver input must be lower than the signal level at which the radar receiver performance starts to degrade.

$$I_D = I/N + N \text{ (dBm)}$$

where:

N : receiver inherent noise level

I/N : interference-to-noise ratio at the detector input (IF output) necessary to maintain acceptable performance criteria (dB) and N is the receiver inherent noise level (dBm).

Calculation is based on the following equation:

$$I = P_T + G_T + G_R - L_T - L_R - L_P - \Delta, \text{ or } \; L_P = P_T + G_T - L_T + G_R - L_R - I - \Delta$$

where:

I: peak power of the undesired signal at the radar receiver input (dBm)

P_T: peak power of the BS transmitter under analysis (dBm)

G_T: antenna gain of the undesired system in the direction of the radar under analysis (dBi)

G_R: antenna gain of the radar station in the direction of the system under analysis (see Note 3) (dBi)

L_T: insertion loss in the transmitter (dB)

L_R: insertion loss in the radar receiver (dB)

L_P: propagation path loss between transmitting and receiving antennas (dB)

and:

$$\Delta = FDRIF + DPol + \Delta\, Ant$$

$FDRIF$: frequency-dependent rejection produced by the receiver IF selectivity curve on an unwanted transmitter emission spectra (dB)

$DPol$: polarization discrimination

$\Delta\, Ant$: angular discrimination (tilt).

NOTE:

1 – Polarization discrimination: see assumptions.

2 – Desensitization

2-1 – It is considered a co-channel scenario, therefore there is no rejection due to a frequency gap (FDR is equal to 0 dB in that case).

2-2 – It is taken into account the difference between radar receiver bandwidth and transmitter bandwidth, using the same unit (dBm/MHz).

3 – Insertion loss in the radar receiver (L_R) is equal to 0.

The following assumptions are used in the calculations:

H 1: calculations are realized at a frequency equal to 3 300 MHz

H 2: propagation model: separation distances are calculated with free space, and Recommendation ITU-R P.452, Recommendation ITU-R P.528, cf. Annex II

H 3: discrimination of polarization can take different values between 0 and 3 dB according to the different antenna configurations between the two systems (IMT Linear / ±45°, radar linear or circular):

"main beam to main beam" configuration

"first and second lobe to main beam" configuration

Main lobe to side lobe, side lobe to back lobe…etc.

To simplify calculations a value of 3 dB is used in all cases.

H 4 : radar protection criteria

Desensitization ($I_D = I/N + N$)

An I/N of −6 dB is used in this contribution according to ITU-R M.1461 (in general cases, a signal from another service resulting in an I/N below −6 dB is acceptable by the radar users)

Desensitization level of considered radar are calculated in Attachment M.1.

Radar I (M.1464), $I_D = -118$ dBm/MHz

Radar L-D (M.1465-3), $I_D = -115{,}8$ dBm/MHz

Radar S-D (M.1465-3), $I_D = -118{,}5$ dBm/MHz

H 5: IMT Antenna gain in the direction of radar antenna

These co-existence scenarios have to be studied in the following configuration:

BS antenna main-beam to radar antenna main beam (worst case).

BS antenna side lobe (taking into account angular discrimination) to radar antenna main beam.

Macro base station antenna: considering that the line of sight between land based/maritime radars and base stations is in the horizontal plane (elevation angle 0°), and taking into account the down tilt angle of the radiating pattern, the gain of urban macro BS antennas is calculated for each configuration (tilt from −10° to −75°).

1) MCL calculation for single entry case

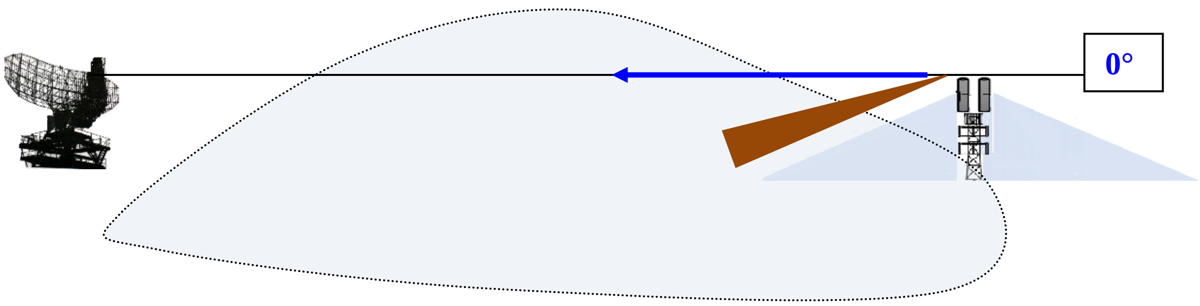
Necessary BS level to avoid radar desensitization is defined with the following equation.

$$I_D = P_T + G_T - L_T + G_R - L_P - \Delta, \ \ (or\ \ L_P = P_T + G_T - L_T + G_R - I_D - \Delta)$$

1) MCL calculation for single entry case

Necessary BS level to avoid radar desensitization is defined with the following equation.

$$I_D = P_T + G_T - L_T + G_R - L_P - \Delta, \ \ (or\ \ L_P = P_T + G_T - L_T + G_R - I_D - \Delta)$$



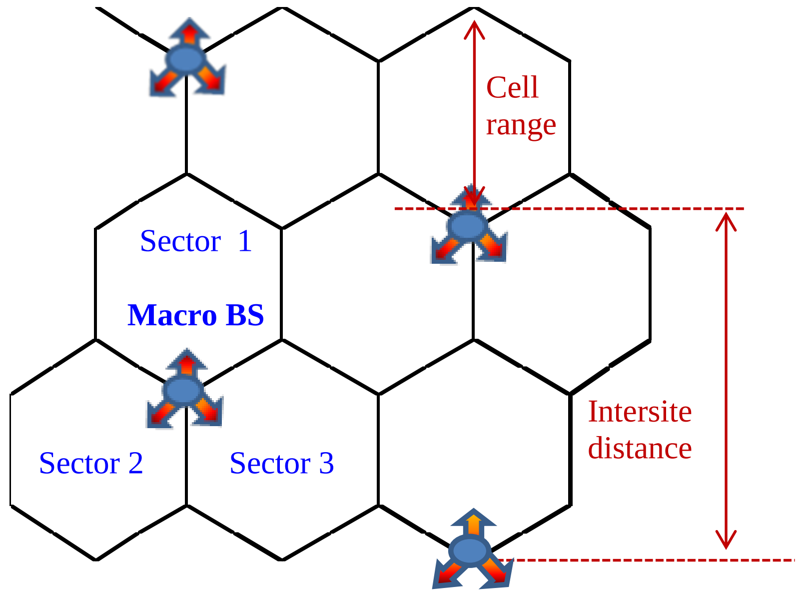
Tilt radar – 5 to 5 °	BS tilt **–10°**
H 10 m	H 20 m/25 m
	BS Antenna gain towards radar antenna is equal to the gain **at 0°**

2) Monte-Carlo simulation for multiple entry case

1 Overview on the scenario of coexistence between IMT and radar systems

a. Deployment of the IMT mobile network

IMT mobile network is considered over a city distributed in urban and suburban areas. The hexagonal cell structure of the Macro BSs is recalled in the below picture.

<table>
<tr><th>IMT Base station in network (macro BS only)</th><th></th></tr>
<tr><td>
</td><td>Reference: Doc. 3GPP TR25.816

Inter site distance
Urban: 450 m
Suburban: 900 m

Urban cell range: 300 m
Suburban cell range: 600 m

: macro BS (3 sectors)

: transmitter</td></tr>
</table>

For the sake of simplicity, suburban/urban areas over the town are modelled as concentric circular areas within the BS density is supposed to be uniform as described in the following Table.

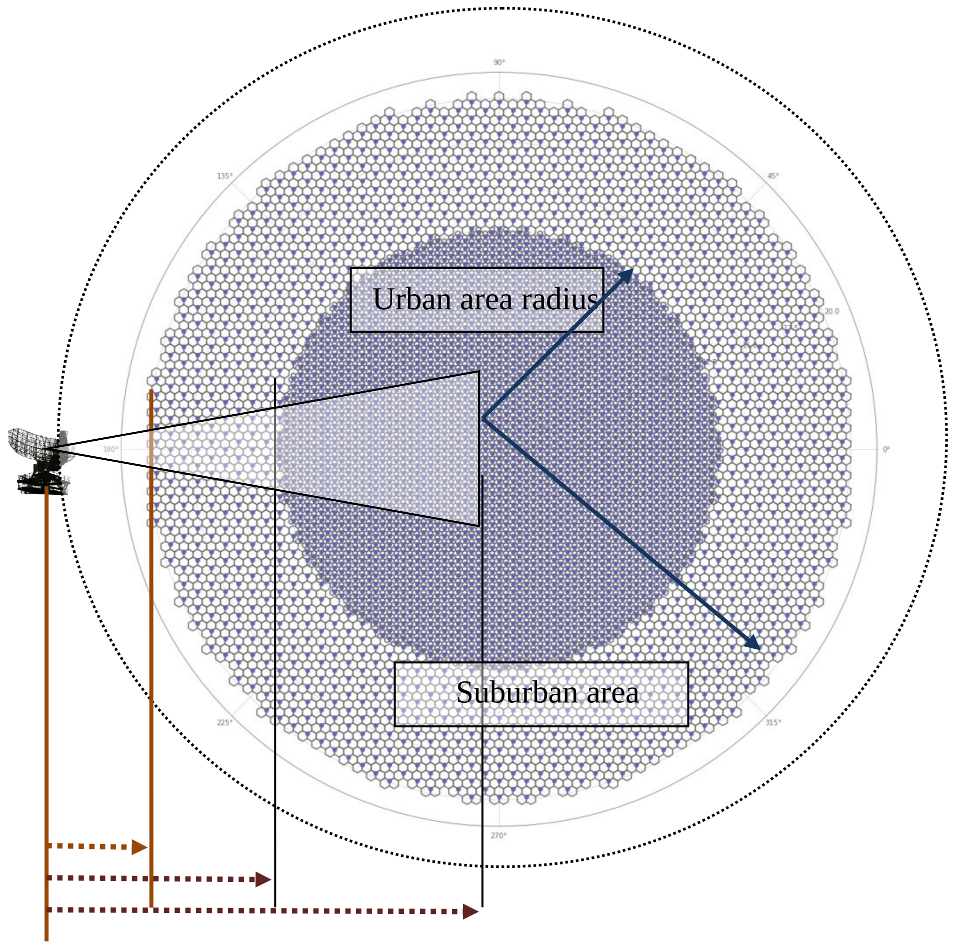
IMT BASE STATION		
BS inter site distance:	0.9 km (sub urban)	0.45km (urban)
	BS Density **1.4 BS/km²**	**5.7 BS/km²**
	SubUrban/urban site (3 sectors): 0.70 km²	0.17 km²
Number of active BSs/km²	**0.7**	

b. Deployment of the radar in the city

The radar system is assumed to be located at the edge of the city but its antenna is radially pointing towards the town.

Environment	**Distance (BS, Radar)**	**Discrimination angle between horizon and direction BS to radar antennas**
Urban	8..13 km	0.05..0.03°
suburban	1..8 km	0.6..0.1°

For the sake of simplicity, this angle is fixed to 0° for all subcases.

	Urban area: radius 5 km, suburban area: radius 12 km					
Radar in the vicinity of the town						
3 assumptions		**D1**	**D2**	**D3**		
Assumption 1		1 km	8 km	13 km		
Assumption 2		3 km	10 km	15 km		

2 Analysis of the interference from Base Stations in adjacent band

a) Modelling of the e.i.r.p. of multiple sources of interference

– BSs simultaneously transmitting load and traffic factors

In practice, all BSs within the network do not simultaneously transmit that's why it is important to define the network load (Average base station activity) as to be 0.5. This means that half of the BSs are simultaneously radiating with full conducted power, but not necessarily the same all the time. Consequently, it is important to determine at each trial which BSs are active to know the orientation of the antenna panel when determining the direction (towards the victim) of the e.i.r.p. assessment.

Moreover a TDD factor needs also to be considered in regard to the traffic asymmetry of a terrestrial mobile network. This factor can be accounted for in the Monte Carlo trials by multiplying all radiated powers by the same single binary random variable x (0 or 1), where Pr{x = 1} = ratio of DL transmissions to total frame duration. A DL ratio of 0.8 will be assumed.

– Statistics of the BS antenna beam-steering within the cell

For each IMT BS sector, a single beam of the antenna with a mechanical tilt is steered in phi-scan and electrical tilt toward a UE which is dropped randomly within the sector (uniform distribution of UE on the cell area). UEs are assumed to be only outdoor, and 1.5 metres above ground.

– Calculation of the antenna gain of the BSs within the IMT network in the direction of radar receiver

Use of the 3GPP LTE-Advanced AAS model (correlation coefficient = 1 'antenna pattern beam formed').

Antenna array 8 × 8	Unit	Value
Maximum composite antenna gain	dBi	26
Maximum element gain	dBi	8
Radiating single element H/V 3 dB beamwidth	°	80/65
Front-to-back ratio and Sidelobe ratio	dB	30 for both
Horizontal and Vertical element spacing	N/A	0.6λ for horizontal 0.9λ for vertical

b) Propagation of the radiated unwanted emissions from BSs

– Description of the physical phenomena involved in the propagation

As indicated previously, at each trial the active BSs may change (which makes the distance (active BS, radar) vary at each event) which requires modelling the BS index as a random variable, e.g. discrete uniform. Moreover, as a generic analysis on the aggregate interference caused by BSs, the path profile between the Radar and each BS is assumed to be not specific, i.e. with a flat terrain with buildings (featuring urban and suburban areas). Considered phenomena involved in the losses of the Link Budget between the radar and the BSs for distance lower than the horizon distance are:

– the free space loss,

– losses due to clutter in the vicinity of the BSs area (suburban & urban) which are modelled in a statistical way. It has to be noted that not all BSs are subject to clutter loss depending on the nature of the area where the BS is located

  • no clutter is assumed for suburban area because each BS antenna is set above the roof.

  • half of BSs are not subject to clutter for urban environment (as indicated in Report ITU-R M.2292).

– Models used to describe these phenomena

Recommendation ITU-R P.2108-0 is selected to describe the clutter loss in the vicinity of the BS. Two key parameters of this Recommendation are the percentage of locations and the distance between the interferer and the receiver. In Monte-Carlo simulations, the percentage of locations is assumed to vary within all actives BSs at each trial, that's why a uniform random value within the range 1.99%) is generated for each active BS at each event. In addition, the distance between the radar and the BS also varies for each trial because the active BSs change at each event (leading to clutter loss values in the range 15.43 dB in 3.3 GHz).

Recommendation ITU-R P.525 is used to describe the free space loss.

c) Cumulative effect of the BS unwanted emissions levels at the radar receiver

– Direction of interest concerning the radiated interference

Although the antenna of the radar rotates within the horizon plane, the study focuses on the impact of the BSs for a given orientation of the antenna, when the radar receiver is pointing its beam towards the centre of the town.

– Choice of the metric featuring the aggregate interference

The calculation of the aggregate interference at the receiver level can be computed over 300000 trials using Monte Carlo methods. Cumulative density function (cdf) of the aggregate received interference level (as a random variable[14]) is computed from these trials and a 99th percentile of the cdf is selected to be compared to the maximum acceptable interference level I_{max}.

Any exceedance of the maximum acceptable level I_{max} (by Δ = 99th percentile(cdf)- I_{max} >0) is balanced by reducing the conducted power/Total Radiated Power (TRP) of the BS by Δ dB.

Attachment M.2

Calculation and simulations of potential interference from IMT BS non-AAS to Radars at 3 300 MHz

For non-AAS antenna (antenna with an 18 dBi gain and 3 dB feeder loss), and in a single entry scenario, Table A2.78 summarizes necessary unwanted emissions e.i.r.p. level to ensure radar protection:

TABLE A2.78

Unwanted emission levels for IMT non-AAS BS below 3 300 MHz

	Radar I	**Radar L-D**
Maximum e.i.r.p.	−45.6 dBm/MHz	−50.1 dBm/MHz
Maximum unwanted emission levels below 3 300 MHz at IMT BS Tx output	−51.6 dBm/MHz	−56.1 dBm/MHz

Level calculated with a separation distance of 1 km, without clutter, and with a discrimination of polarization equal to 3 dB.

[14] This random variable results from the generation of multiple random variables such as: UE statistic distribution (for AAS electronic beam orientation), clutter loss and location/orientation of active BS antenna sector.

Result for radar L-D

Tx spurious	-65,1	dBm/MHz	-65,1	-65,1
Feeder loss	3	dB		
Antenna Gain (6 10 18)	18,00	dBi		
[Antenna gain - feeder loss]	15,00	dB		
Spurious EIRP		dBm/MHz	-50,1	-50,1
Frequency (GHz)	3300,00	MHz		
Reception part: Radar			UIT-R M1464	UIT-R M1465
Noise temperature	290	°K	radar I	radar L-D
characteristics			Land based system	
Tx power into antenna peak		kW		1000
Receiver IF3dB bandwidth MHz		MHz	2,5	30
Antenna mainbeam gain		dBi	33,5	40
Radar feeder loss		dB	0	0
E.i.r.p radar		dBm		137,8
Receiver noise figure		dB	2	4
N=FkTB		dBm	-108,0	-95,2
Protection criteria: I/N		dB	-6	-6,0
N per MHz		dBm/MHz	-112,0dBm/MHz	-110,0dBm/MHz
Imax		dBm/MHz	-118,0	-116,0
Link Budget BS -- radar				
polarisation discrimination	3,00	dB		
Allowable Interfering power level 'I' on the antenna port		dBm/MHz	-151,5	-156,0
Required Attenuation (dB)		dB	98,4	102,9
Separation distance BS->Radar		km	0,6	1,0
Propagation part at 1km	102,9	dB	102,9	102,9
polarisation discrimination	3	dB	3,0	3,0
Clutter loss	0	dB	0,0	0,0
signal received on radar		dBm/MHz	-122,5dBm/MHz	-116,0dBm/MHz
Margin or exceeding		dB	-4,5	0,0
Propagation part at 3km	112,3	dB	112,3	112,3
polarisation discrimination	3	dB	3,0	3,0
Clutter loss	0	dB	0,0	0,0
signal received on radar		dBm/MHz	-131,9dBm/MHz	-125,4dBm/MHz
Margin or exceeding		dB	-13,9	-9,4

Result for radar I

Tx spurious	-60,6	dBm/MHz	-60,6	-60,6
Feeder loss	3	dB		
Antenna Gain (6 10 18)	18,00	dBi		
[Antenna gain - feeder loss]	15,00	dB		
Spurious EIRP		dBm/MHz	-45,6	-45,6
Frequency (GHz)	3300,00	MHz		
Reception part: Radar			UIT-R M1464	UIT-R M1465
Noise temperature	290	°K	radar I	radar L-D
characteristics			Land based system	
Tx power into antenna peak		kW		1000
Receiver IF3dB bandwidth MHz		MHz	2,5	30
Antenna mainbeam gain		dBi	33,5	40
Radar feeder loss		dB	0	0
E.i.r.p radar		dBm		137,8
Receiver noise figure		dB	2	4
N=FkTB		dBm	-108,0	-95,2
Protection criteria: I/N		dB	-6	-6,0
N per MHz		dBm/MHz	-112,0dBm/MHz	-110,0dBm/MHz
Imax		dBm/MHz	-118,0	-116,0
Link Budget BS -- radar				
polarisation discrimination	3,00	dB		
Allowable Interfering power level 'I' on the antenna port		dBm/MHz	-151,5	-156,0
Required Attenuation (dB)		dB	102,9	107,4
Separation distance BS->Radar		km	1,0	1,7
Propagation part at 1km	102,9	dB	102,9	102,9
polarisation discrimination	3	dB	3,0	3,0
Clutter loss	0	dB	0,0	0,0
signal received on radar		dBm/MHz	-118,0dBm/MHz	-111,5dBm/MHz
Margin or exceeding		dB	0,0	4,5
Propagation part at 3km	112,3	dB	112,3	112,3
polarisation discrimination	3	dB	3,0	3,0
Clutter loss	0	dB	0,0	0,0
signal received on radar		dBm/MHz	-127,4dBm/MHz	-120,9dBm/MHz
Margin or exceeding		dB	-9,4	-4,9

Attachment M.3

Calculation and simulations of potential interference from IMT with AAS to Radars at 3 300 MHz

3.1 Configuration, methodology and assumptions

The configuration, methodology and assumptions used for calculation and simulations of interference from IMT with AAS to Radars at 3 300 MHz are described in Attachment m.1

3.2 Results for the single entry scenario

Necessary unwanted emissions LEVEL (TRP in dBm/MHz)					*Necessary unwant emissions e.i.r.p. (dBm/MHz)*
	Worst case main beam to main beam	BS tilt −10° (antenna discrimination 9 dB)	BS tilt −40° (antenna discrimination 21 dB)	BS tilt −70° (antenna discrimination 35 dB)	
	Land based radar I (Rec. ITU-R M.1464) H: 10 m				
0 ° (3 km)	*−59.2*	−50.2	−38.2	−24.2	*−36.2*
0° (1 km)	*−68.7*	−59.7	−47.7	−33.7	*−45.7*
	Land based radar L-D (Rec. ITU-R M.1465-3) H: 10 m				
0° (3 km)	*−63.7*	−54.7	−42.7	−28.7	*−40.7*
0° (1 km)	*−73.2*	−64.2	−52.2	−38.7	*−50.2*

NOTE 1 – The given unwanted emissions e.i.r.p. is provided as an example. It is the minimum level (more stringent) calculated depending of various parameters (as an example, the value −45.7 dBm/MHz e.i.r.p. is the minimum value obtained using the various TRP values (depending on the tilt) + the antenna gain corresponding to the tilt (−38.2 dBm + 23 dBi −21 dBc = −36.2 dBm/MHz). The −21 dBc is obtained using the antenna diagram.

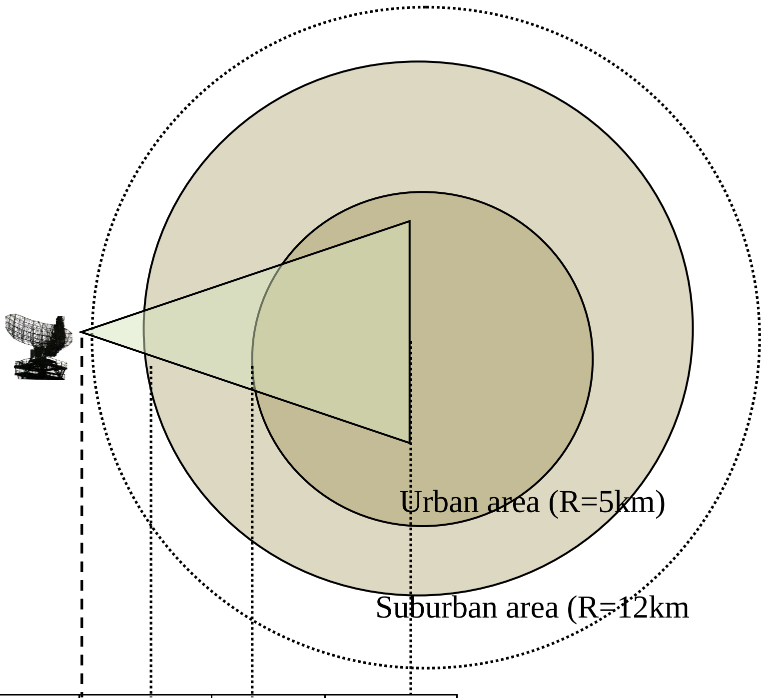
NOTE 2 – The BS tilt cases −10°, −40°, −70° are used to give some examples among a multitude of possible cases.

Assuming that BS antenna tilt is −10° and for a single entry scenario, spurious (TRP) should be lower than the following values:

		BS power limit (single entry scenario)	
	Land based radar	**TRP**	***e.i.r.p.***
At 1 km	I	−59.7 dBm/MHz	*−45.7 dBm/MHz*
	L-D	−64.2 dBm/MHz	*−50.2 dBm/MHz*
At 3 km	I	−50.2 dBm/MHz	*−36.2 dBm/MHz*
	L-D	−54.7 dBm/MHz	*−40.7 dBm/MHz*

3.3 Results for the aggregated effect scenario

This scenario (radar in the vicinity of the town) is considered with the following configuration and parameters.



	D1	D2	D3
Assumption 1	1 km	8 km	13 km
Assumption 2	3 km	10 km	13 km

Based on hypothesis and parameters described in Attachment M.1, a simulation software has been developed (Python language). This simulation makes several thousand of draws using a variation of the considered parameters:

– Uniform distribution of the UE around the BS (that corresponds approximately to BS tilt values from −10° to −75°)

– Distribution of the distances between radars and base stations (from 1 or 3 km to 12 km)

– Clutter: assumption 1 without clutter, assumption 2 clutter on 50% of cases (Draw to define the value of the clutter).

The TRP value is obtained when 99% of the calculated cases in the simulation ensure that the radar protection criterion is met.

Simulation results for the scenario of radar in the vicinity of a town

Radar		**Propagation**	**Necessary TRP power limit below 3 300MHz**	
	ϴ		1-13 km	3-15 km
I	1,5°	Free space +clutter	−51.1 dBm	−49.3 dBm
L-D	1°	Free space +clutter	−55.2 dBm	53.3 dBm
	1,5°	Free space +clutter	−55.5 dBm	−53.7 dBm
	4°	Free space +clutter	**−57.8 dBm**	−55.8 dBm
S-D	*1,5°*	Free space +clutter	*−57.4*	*−55.7*

Results (in terms of TRP levels) varies from −44.2 to −58.3 dBm. These results are dependent of numerous factors, like:

– minimum distance taking into account between radar and base station (1 or 3 km),
– BS activity factor (or network load),
– clutter loss (Recommendation ITU-R P.2108),
– diagram of AAS base station antenna,
– radar position (in the vicinity of a town).

Furthermore, antenna tilt is assumed to be always lower than –10° (included).

3.4 Comparison between single entry scenario and aggregated effect scenario

In the Table below:

– The TRP levels for the "single entry scenario" are obtained in the case of a −10° tilted base station.
– The TRP levels for "aggregated effect scenario" are obtained with a statistical simulation (*300 000 draws, distances between BS and radars, BS antenna tilts, a limited of active base stations simultaneously*) gives a substantially stronger level.

			TRP power limit, for BS, below 3 300MHz	
Radar	ϴ	Min d radar/BS	**"Single entry"** *BS tilt –10°*	**"Aggregated effect"** *BS tilt –10° to –90°*
I M.1464	1,5°	1 km	−59.7 dBm/MHz	−51.1 dBm/MHz
		3 km	−50.2 dBm/MHz	−49.3 dBm/MHz
L-D M.1465-3				
	1,5°	1 km	−64.2 dBm/MHz	−55.5 dBm/MHz
		3 km	−54.7 dBm/MHz	−53.7 dBm/MHz
	4°	1 km		−57.8 dBm/MHz
		3 km		−55.8 dBm/MHz
S-D M.1465-3	1,5°	1km		−57.4
		3km		−55.7

The difference between "single entry case" and "aggregated effect scenario" can be explained because:

– The "single entry case" (maximum antenna gain and minimum distance) is statistically possible but unlikely (could be non-existing) even with 300 000 draws (and would be certainly not retained as part of the 1% cases not retained (the TRP level is given for the 99%).

– The cumulative effect of the base stations is almost negligible (only 0.5 to 4.8 BS taken into account in each draw, see Table 5).

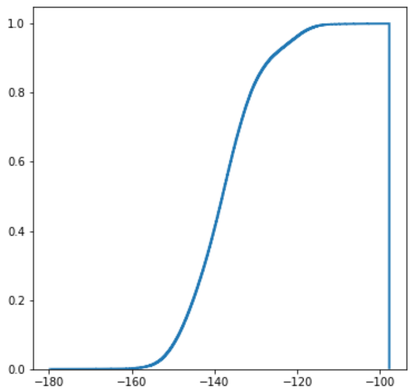
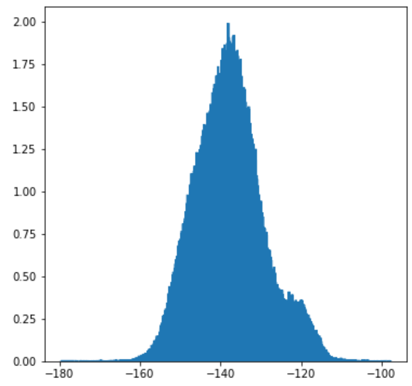
Table A2.79 summarizes results obtained for radar I, radar L-D and radar S-D, in the case of a separation distance of 1 km (i.e. considering there is no BS between radar and 1 km, BS are randomly placed between 1 km and 13 km), and in the case where clutter is used.

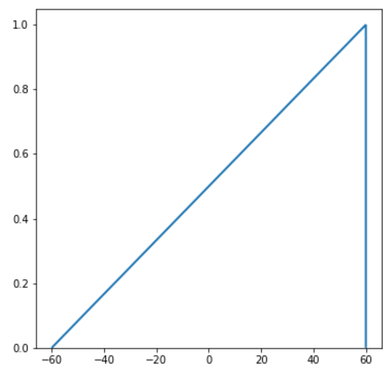
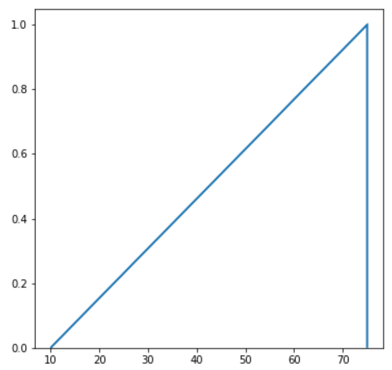
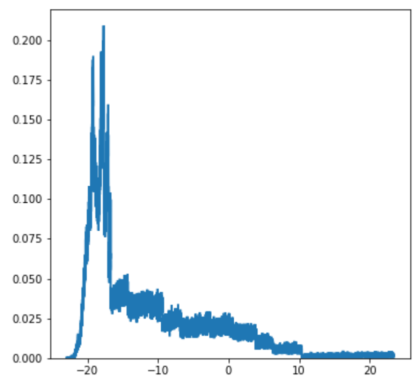
TABLE A2.79

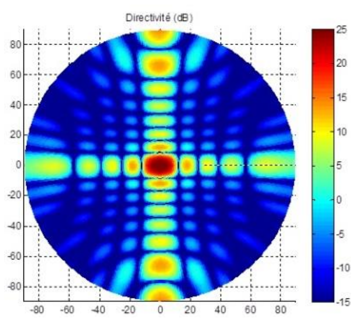
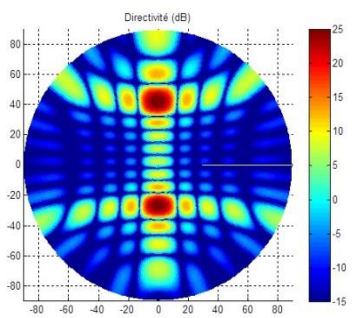
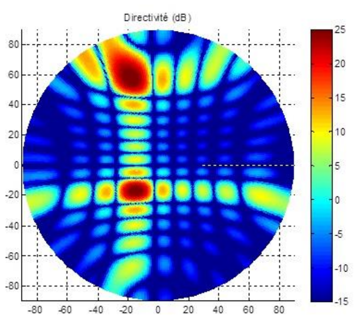
		"Min" TRP power limit below 3 300MHz
radar	**Ө**	**"Aggregated effect" scenario**
I, M.1464	1,5°	−52 dBm/MHz
L-D, M.1465-3	1°	−55 dBm/MHz
	1,5°	−55.5 dBm/MHz
	4°	−57.8 dBm/MHz
S-D, M.1465-3	**1,5°**	**−57.4 dBm/MHz**

NOTE – The separation distance of 1 km has to be considered as a realistic value for real operational deployment scenario for tactical radars. This includes peace time deployments in or in the close vicinity of urban areas where these types of radars are used to protect major events (e.g. Summits, major sport events …).

3.5 Examples of interim results

Results	Cumulative	Histogram
Example of result for radar L-D (Θ = 1,5°) Free space + clutter Distances: 1/8/13 km		

Distribution of BS antenna azimuth angle (between –60 to 60°)	Distribution of BS antenna elevation angle (between –10 to –75°)	Distribution of calculated values of antenna gain in the direction of radar
		

AAS 8x8 [0,6λ (H) and 0,9 λ (V)] examples of directivity		
Elevation 0° azimut 0°	**Elevation –30° azimut 0°**	**Elevation –20° azimut –20°**
		

Nb of active BS in the radar antenna beamwidth		Assumption 1	Assumption 2
	Distances D1 D2 D3	1 km 8 km 13 km	3 km 10 km 15 km
1,5°	active BS (suburban)	0,5	0,7
	active BS (urban)	3,1	3,7
4°	active BS (suburban)	1,2	1,8
	active BS (urban)	8,4	10

Study N

The study examines the impact of an IMT network of macro urban BS equipped with Advanced Antenna System into land based radars type B, D and I operating in an adjacent channel. The study shows the levels of unwanted emissions required at the BSs in order to achieve the protection criteria at the radar receiver.

The reference scenario is to calculate the aggregated interferences I/N level received by a rotating radar operating in adjacent band. The radar is located in the centre and at 3 km distance from a circular deployment of five rings of macro urban IMT 20 MHz base stations. The AAS BS which are active, and in DL mode, are pointing their antenna main lobe toward an outdoor UE located uniformly in the BS cell. The Report ITU-R M.2292 IMT deployment, Recommendations ITU-R P.2109 clutter loss and ITU-R P.452 p = 20% propagation loss assumptions are taken into account.

In this adjacent band study, no value of the frequency gap or frequency offset is provided for the calculations of the FDR. It is understood that the calculations are based on ratio of IMT unwanted emissions spectrum power density and radar receivers' bandwidth.

Use of 10 000 randomized runs for the Monte Carlo simulations.

The results of three parametric studies are also provided.

– A first parametric study on the number of rings (5 to 30) in the BS deployment modelling.
– A second parametric study on the AAS correlation factor uncertainties in the estimation of unwanted emissions aggregated interference from IMT AAS, depending on the assumption done on the correlation factor between ρ = 0 (no correlation, no beamforming angular discrimination) and ρ=1 (correlation, beamforming angular discrimination).
– A third parametric study on the impact of the statistical distribution of the AAS tilt, using only the outdoor UE uniform distribution or taking into account indoor UE as described in Report ITU-R M.2292.

1 Technical characteristics of IMT and radar systems

TABLE A2.80

IMT base station deployment

Parameters	Assumed Value
Base station coordinates (x_{BS}, y_{BS})	**Hexagonal deployment of macro-cells** N_{BS} base stations are distributed on a hexagonal grid with a given ISD, and where each base station is located a distance d from the radar receiver where $d_{min} \leq d \leq d_{max}$, Reference study : d_{min} = 3000 metres, d_{max} = 5000 metres. Parametric study : d_{min} = 3000 metres, d_{max} = 4000…18000 metres. Macro-cell ISD: Urban: 1.5 × 300 = 450 metres. See **ITU-R M.2292**.
Base station antenna height (above ground) z_{BS}	Macro-cells: Urban: 20 metres. See **ITU-R M.2292**.

TABLE A2.80 (*end*)

Parameters	Assumed Value
Channel bandwidth	20 MHz. NOTE – For information only. Not relevant to calculations.
Sectorization	Each macro base station would have three independent sectors (120° each). See **3GPP TR 37.840**. The orientation of the sectors need not change from one Monte Carlo trial to the next.
TDD factor	TDD factor can be accounted for in the Monte Carlo trials by multiplying all radiated powers by the *same single* binary random variable *x* (0 or 1), where Pr{*x* = 1} = ratio of DL transmissions to total frame duration. A DL ratio of 0.8 will be assumed. Use of a *single* value is based on the assumption of synchronised UL/DL phases in a network. This value is based on the proposed value in **ITU-R TG5/1 document 36**.
Network loading	A network loading factor of 0.5 is assumed. See **ITU-R M.2292**.

TABLE A2.81

IMT base station antenna element and array parameters

Parameters	Assumed Value
Antenna element directional pattern $a_{E\ \mathrm{dB}}\ (\theta,\varphi)$	According to **3GPP TR 37.840 (section** 5.4.4.2**)**: $a_{E\ \mathrm{dB}}\ (\theta,\varphi) = -\min\{-[A_{E,V\ \mathrm{dB}}(\theta) + A_{E,H\ \mathrm{dB}}(\varphi)],\ A_{m\ \mathrm{dB}}\}$, $A_{E,H\ \mathrm{dB}}(\varphi) = -\min\left\{12\left(\frac{\varphi}{\varphi_{3\mathrm{dB}}}\right)^2, A_{m\ \mathrm{dB}}\right\}$, $A_{E,V\ \mathrm{dB}}(\theta) = -\min\left\{12\left(\frac{\theta-90°}{\theta_{3\mathrm{dB}}}\right)^2, SLA_{V\ \mathrm{dB}}\right\}$, where: 3 dB elevation beamwidth θ_{3dB} = 65°, 3 dB azimuth beamwidth φ_{3dB} = 80°, Front-to-back ratio A_m = 30 dB, Side-lobe ratio SLA_V = 30 dB. NOTE 1 – $a_E(\theta,\varphi) \leq 1$. NOTE 2 – Each antenna element is larger in size in the vertical direction, and so $\theta_{3dB} < \varphi_{3dB}$. See **3GPP TR 37.840**.
Antenna element gain $G_{E\ \mathrm{dB}}$	8 dB
Number of base station beamforming elements (N_V, N_H)	8.8
Element spacing	0.9λ vertical separation. 0.6λ horizontal separation. NOTE – Larger vertical spacing provides narrower array beamwidth in elevation. See **3GPP TR 37.840 (**Table 5.4.4.2.1-1).
Mechanical downtilt	Macro-cell: 10° NOTE – For macro-cell, see **ITU-R M.2292** for 20 metres height and 300 m sector radius.

TABLE A2.82

IMT base station antenna element and array parameters (2)

Parameters	Assumed Value
Array beamforming directional pattern $a_A(\theta,\varphi)$	According to **3GPP TR 37.840** (**section** 5.4.4.2): $$a_A(\theta,\varphi) = 1 + \rho\left[\left\|\sum_{m=1}^{N_H}\sum_{n=1}^{N_V} w_{m,n} v_{m,n}\right\|^2 - 1\right]$$ where: $$v_{m,n} = \exp\left[j\frac{2\pi}{\lambda}\{(m-1)d_H\sin(\varphi)\sin(\theta) + (n-1)d_V\cos(\theta)\}\right],$$ $$w_{m,n} = \frac{1}{\sqrt{N_H N_V}}\exp\left[-j\frac{2\pi}{\lambda}\{(m-1)d_H\sin(\varphi_{SCAN})\cos(\theta_{TILT}) - (n-1)d_V\sin(\theta_{TILT})\}\right],$$ and: ρ is the signal correlation across the antenna elements, N_V, N_H are the number of vertical and horizontal antenna elements, d_V, d_H are the vertical and horizontal antenna element spacings, $-\pi/2 \leq \theta_{TILT} \leq \pi/2$ is the downward beam steering tilt angle relative to boresight, and $-\pi \leq \varphi_{SCAN} \leq \pi$ is the anti-clockwise horizontal beam steering scan angle relative to boresight. NOTE – $0 \leq a_A(\theta,\varphi) \leq N$.
Correlation	Reference study : ρ = 0 Parametric study : ρ = 0 or ρ = 1
Array beamforming directional (power) gain $g(\theta,\varphi)$	Power $P(\theta,\varphi)$ radiated by antenna array system in direction (θ,φ) is $P(\theta,\varphi) = P_{TX}\, g(\theta,\varphi)$ where P_{TX} is the conducted power, and: $$g(\theta,\varphi) = G\, a(\theta,\varphi) = G\, a_E(\theta,\varphi)\, a_A(\theta,\varphi)$$ where: $$G = \frac{1}{L}\left(\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} a(\theta,\varphi)\sin(\theta)\, d\theta d\varphi\right)^{-1}$$ is the normalization factor and L is the antenna loss.
Antenna loss L	L = 0 dB. NOTE – Loss is not relevant, since the objective is to derive radiated power.
Beamforming	At each Monte Carlo trial, in each sector a single beam is steered in azimuth and elevation toward a UE which is dropped randomly within the sector. In the macro-cell urban scenario, Reference study: 100% of Outdoor UE Parametric study: – Case 1: 100% of Outdoor UE – Case 2: 70% of UEs will be considered indoor (see **ITU-R M.2292**), with a height above ground that is uniformly distributed with values of 1.5 + {0, 3, 6, 9, 12, 15} metres. Outdoor UEs in all cases are assumed to be at a height of 1.5 m above the ground.

TABLE A2.83

Radar receiver parameters (land based Radar types B, D and I)

Parameters	Assumed Value
Radar receiver coordinates (x_{RAD}, y_{RAD})	(0, 0) NOTE – Radar receiver is positioned at the origin and is surrounded by mobile network base stations.
Radar receiver antenna height above ground z_{BS}	30 metres
Radar receiver maximum gain	Radar B: 40 dBi Radar D: 40 dBi Radar I: 33.5 dBi
Antenna side lobe (SL) levels below main lobe (1st SLs and remote SLs)	Assumption for Radar B / D / I: −40dB
Beamwidth (H,V) degrees	Radar B: 1.05, 2.2 Radar D: 1- 4.5 Radar I: 1.5, 4.8
Mechanical up-tilt	0° NOTE – No up-tilt is used in the absence of other information.
Mechanical azimuth scan	At every Monte Carlo trial, the radar antenna points to a random azimuth direction that is uniformly distributed between 0 and 360°.
Radar IF 3dB bandwidth	Radar B: 0.67 MHz Radar D: 30 MHz Radar I: 2.5 MHz
Noise figure	Radar B: 4 dB Radar D: 4 dB Radar I: 2 dB
Protection criteria	−6 dB.
Probability of interference exceeding the protection criteria	1%

2 Propagation model

Frequency	3 300 MHz
Median path loss and clutter	Macro-cell: P.452 P = 20%, P.2109 clutter loss Clutter losses apply only to 50% of the BSs (those located below rooftops) and do not apply to the 50% of BSs that are located above rooftop. For the BSs below rooftops, a random clutter value taken from P.2109 applies
Polarisation loss	0 dB

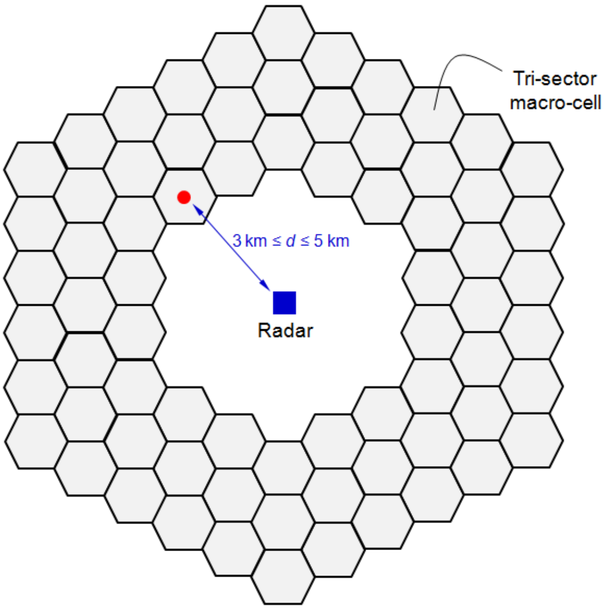
3 Modelling approach

Figure A2-33 illustrates the modelling of IMT macro base stations. Here, a radar receiver is surrounded by multiple rings of tri-sector IMT base stations in a hexagonal arrangement. The minimum and maximum separations between the radar and IMT base stations are 3 000 and 5 000 metres, respectively. This implies a total of five rings and 272 macro-sites, with an inter-site distance, e.g. 450 metres for urban macro scenario.

This study considers macro base station deployments because they (rather can micro cell deployments) represent the more critical case in terms of the likelihood of harmful interference to radar.

FIGURE A2-33

A radar receiver is surrounded by five rings of 272 tri-sectored AAS macro base stations (only three rings are shown)



The IMT base stations are assumed to operate with a TDD DL:UL ratio of 8:2, a network loading of 50%, and with antennas located 20 metres above the ground with a mechanical downtilt of 10°.This is the typical deployment configuration for IMT deployed in urban scenario. The AAS antenna radiation pattern is based on Recommendation ITU-R M.2101, with technical characteristics of Tables A2.80 and A2.81.

The radar receiver antenna is modelled as located 30 metres above the ground with a mechanical downtilt of 0°. Land based Radar B/D and I are evaluated in this study.

Interference to the radar receiver is calculated as the aggregate of the out-of-block emissions of all IMT base stations, using the Recommendation ITU-R P.452 propagation model. Recommendation ITU-R P.2108 clutter loss is assumed for the geometry considered.

Figure A2-34 illustrates the way in which angular discrimination is modelled at the IMT base stations and radar receiver:

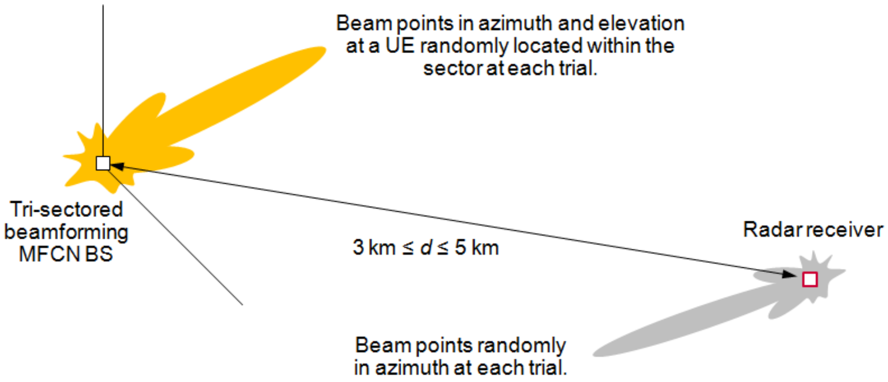
– At each Monte Carlo trial, the radar receiver is assumed to point its beam towards a random direction in azimuth (uniformly distributed between 0° and 360°).

– At each Monte Carlo trial, each IMT base station sector is assumed to radiate towards a user equipment (UE) which is located within the area of the sector.

The intention in the above modelling approach is to adequately capture the benefits of angular discrimination at the transmitters and receiver. It should be noted that the extent to which the out-block transmissions of an IMT base station undergo beamforming depends on the level of the correlation of the said signals across the transmitting antenna elements.

FIGURE A2-34

Modelling of angular discrimination.



In practice, it is difficult to know the precise value of the correlation ρ for the out-of-block signal. This is because unwanted emissions are generated by a mix of noise sources and non-linearities which can be common or distinct among the multiple transmitter chains.

4 Simulations results

4.1 Simulations of reference

Based on the assumptions, results computed for aggregated macro BSs into land based radars B, D and I operating in an adjacent band, are provided hereafter. The TRP level of unwanted emissions at the BSs is tuned for each simulation case in order to achieve the protection criteria $I/N = -6$ dB at the radar receiver for 99th percentile of the aggregated I/N CDF. Simulations results with CDF curves and TRP values are shown in Figs A2-35 to A2-36. This study assumes no correlation ($\rho = 0$).

FIGURE A2-35

Aggregated *I*/*N* Radar B

Unwanted emissions TRP = −50.6dBm/MHz

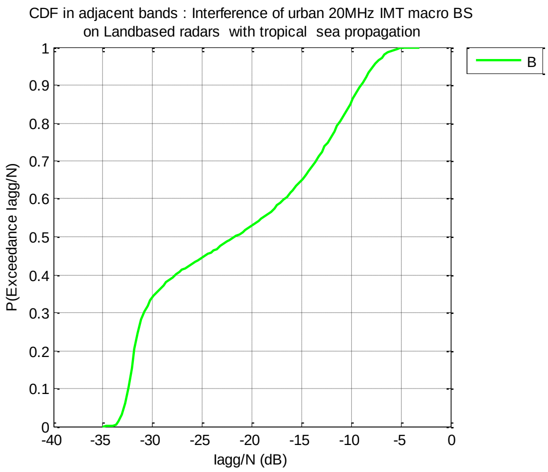


FIGURE A2-36

Aggregated *I*/*N* Radar D

Unwanted emissions TRP = −49.5 dBm/MHz

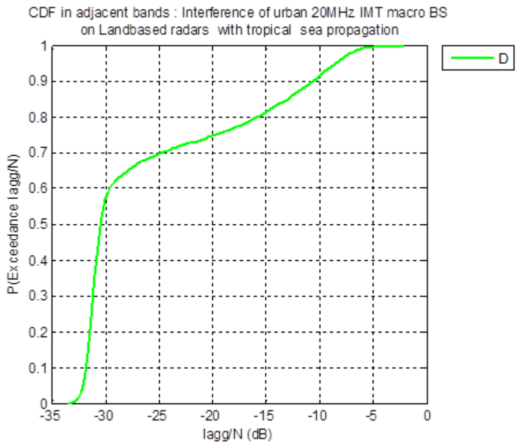
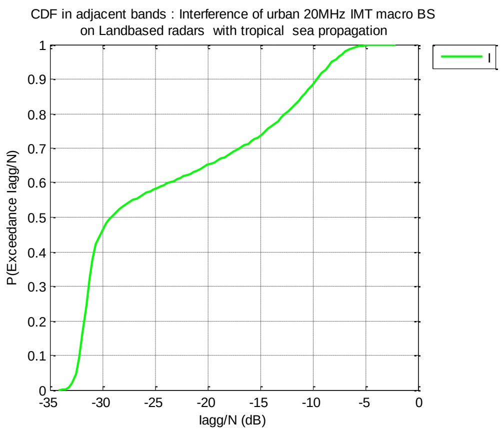


FIGURE A2-37

Aggregated *I*/*N* Radar I

Unwanted emissions TRP = −45.5 dBm/MHz



The results of these simulations shows that under the assumptions done the maximum permitted unwanted emissions at the BSs are calculated in the range −45.5 / −50.6 dBm/MHz.

These results are taken as the baseline for the parametric studies in §§ 4.2 to 4.6 below.

4.2 Parametric study on the number of IMT BS rings in simulations

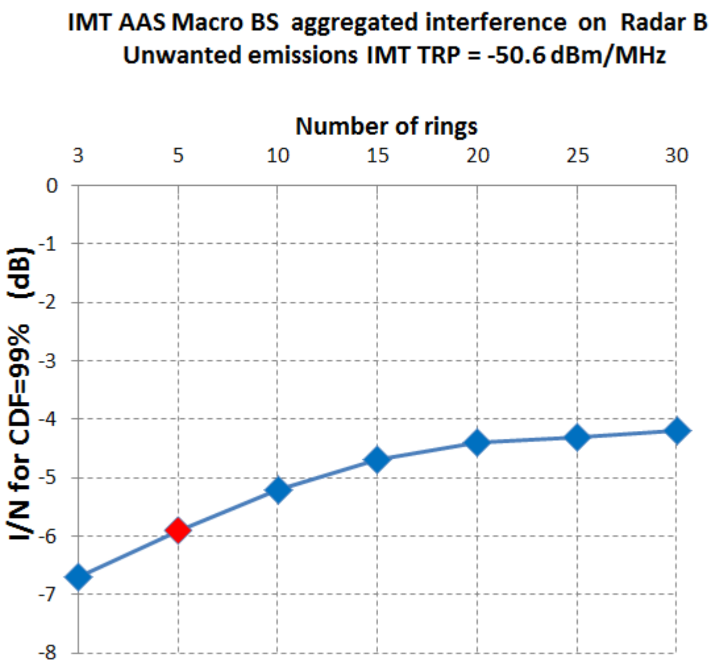
This parametric study aims to verify if the modelling assumption of five rings of tri-sector IMT base stations in a hexagonal arrangement is sensitive.

With five rings the minimum and maximum separations between the radar and surrounding IMT base stations are 3 000 and 5 000 metres, respectively.

The simulations are done on the radar B and IMT uncorrelated AAS case, with an unwanted emission TRP of −50.6 dB/MHz. This level is used as a reference point for having $I/N = -6$ dB with five rings (see red marker in Fig. A2-38). Then the simulations are done for 3, 5, 10, 15, 20, 25, 30 rings, and resulted values of *I*/*N* for 99th percentile of CDF are plotted in Fig. A2-38. It is observed that *I*/*N* increases of +2 dB between 5 rings and 30 rings of IMT deployment cases.

FIGURE A2-38

Aggregated *I*/*N* to number of rings



In conclusion, using a BS deployment model with five rings surrounding a radar could lead to underestimate up to 2 dB aggregated interferences received by the radar receiver. In particular, for modelling an IMT deployment of 18 rings at 3 km from a radar type B (similar to an urban IMT deployment diameter of 8 km) would lead to a maximum permitted unwanted emissions TRP of −52 dBm/MHz.

4.3 Parametric study on impact of AAS correlation coefficient

Depending of the frequency offset from the transmitting IMT channel, relatively to the technology and design of the AAS equipment, constructive or destructive RF combinations could integrate the unwanted emissions of each radiating element, producing daisy lobes in the AAS radiation pattern. Considering large scale manufacturing processes with high reproducibility at electronic component and printed board levels, a general trend is to observe more and more correlation phenomena between transmitting channels of array antennas. Without measurement on AAS equipment, the choice of one single value for the correlation factor at all frequencies in the OOB and Spurious domains is not obvious.

This parametric study aims to estimate the impact of the AAS correlation factor on the maximum permitted unwanted emission levels at the BSs. Figures A2-39, A2-41, A2-43 and A2-40, A2-42, A2-44 show respectively results obtained for uncorrelated and correlated AAS. Other assumptions are those used in § 2.

FIGURE A2-39

AAS UNCORRELATED

Radar B – Unwanted emissions
TRP = −50.6 dBm/MHz

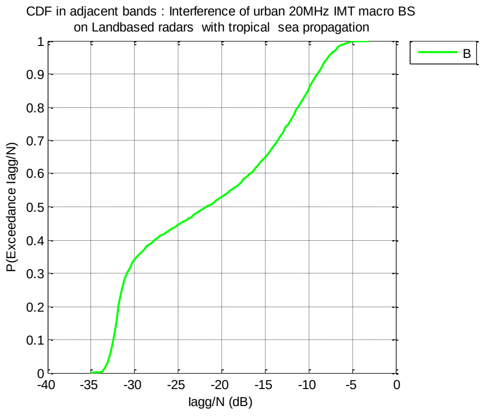


FIGURE A2-40

AAS CORRELATED

Radar B – Unwanted emissions
TRP = −57.0 dBm/MHz

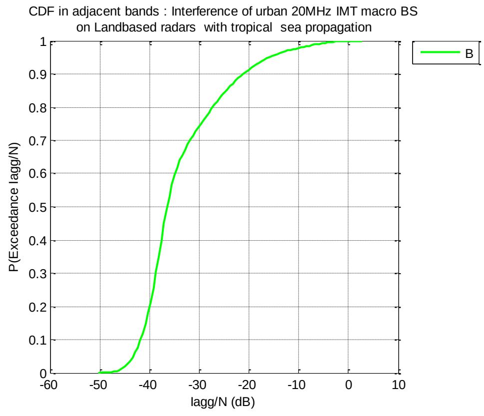


FIGURE A2-41

AAS UNCORRELATED

Radar D – Unwanted emissions
TRP = −49.5 dBm/MHz

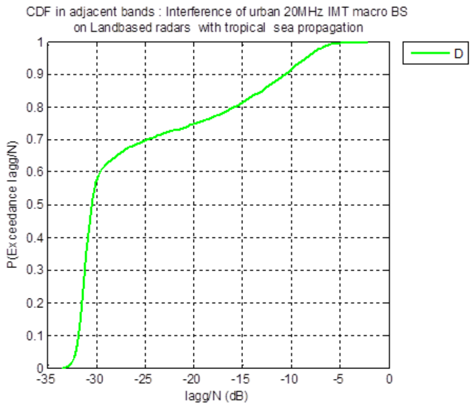


FIGURE A2-42

AAS CORRELATED

Radar D – Unwanted emissions
TRP = −53.0 dBm/MHz

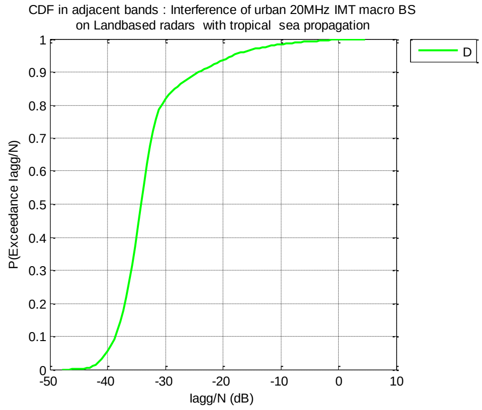


FIGURE A2-43

AAS UNCORRELATED

Radar I – Unwanted emissions
TRP = −45.5 dBm/MHz

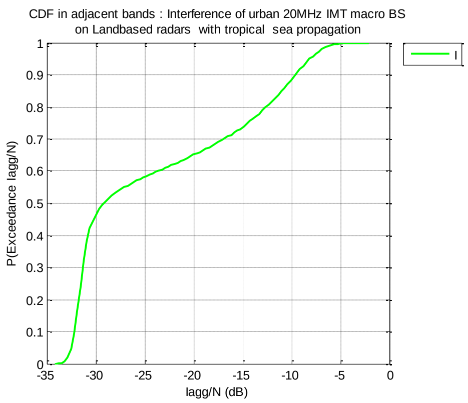


FIGURE A2-44

AAS CORRELATED

Radar I – Unwanted emissions
TRP = −50.2 dBm/MHz

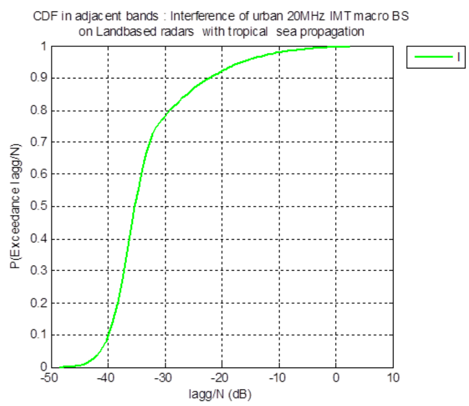


Table A2.84 summarizes the results.

TABLE A2.84

AAS correlation synthesis

Necessary unwanted emission TRP	**Radar B**	**Radar D**	**Radar I**
AAS uncorrelated	−50.6 dBm/MHz	−49.5 dBm/MHz	−45.5 dBm/MHz
AAS correlated	−57.0 dBm/MHz	−53.0 dBm/MHz	−50.2 dBm/MHz
Variation	6.4 dB	3.5 dB	4.7 dB

The results obtained in this study show 3.5 dB to 6.4 dB of uncertainties in the estimation of unwanted emissions interference from IMT AAS depending the assumption done on the correlation factor between $\rho = 0$ (no correlation, no beamforming angular discrimination) and $\rho = 1$ (correlation, beamforming angular discrimination).

4.4 Parametric study on the impact of AAS electronic tilt statistical law

This parametric study aims to estimate the impact of the statistical distribution of the AAS electronic tilt on the estimation of permitted unwanted emissions interference from IMT AAS base stations.

A first modelling scenario is to consider that BS AAS are pointing only toward only outdoor UE and these UE are uniformly distributed in the IMT cell. This case is used in reference simulation shown in § 1 and § 2. Results of simulations are shown in Figs A2-43 and A2-44 respectively for uncorrelated and correlated AAS BS.

A second modelling scenario is to consider the Report ITU-R M.2292 with base station pointing toward 30% of outdoor UE and toward 70% of indoor UE. These indoor UE are with a height above ground that is uniformly distributed with values of 0, 3, 6, 9, 12, 15 metres.

A third modelling scenario is to consider an uniform distribution of tilt angle for AAS base station, which is an easier way to approach the second modelling scenario. Results of simulations are shown in Figs A2-45 and A2-46 respectively for uncorrelated and correlated AAS BS.

It can be noticed in case of uncorrelated AAS BS, the distribution law has no sensitive impact on the permitted unwanted emission. This is due to the fact that uncorrelated AAS BS has no spatial discrimination.

It can be noticed in case of correlated AAS BS, using the assumption of uniform distribution of outdoor UE on the IMT underestimate the aggregated interference received from the IMT BS deployment. Comparing results of Fig. A2-46 with Fig. A2-44, we can conclude that the permitted unwanted emissions should be reduced of 3 dB.

FIGURE A2-45

Uniform distribution of Outdoor UE

AAS uncorrelated

Radar B – Unwanted emissions TRP = −50.6 dBm/MHz

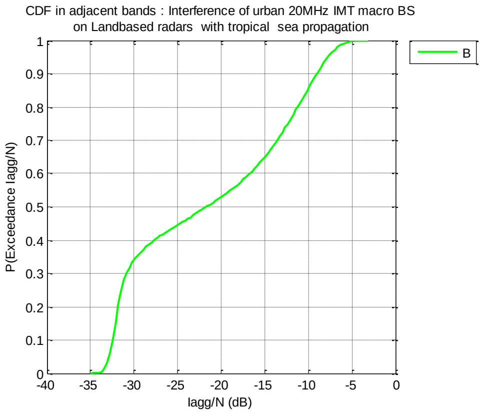


FIGURE A2-46

Uniform distribution of Outdoor UE

AAS correlated

Radar B – Unwanted emissions TRP = −57.0 dBm/MHz

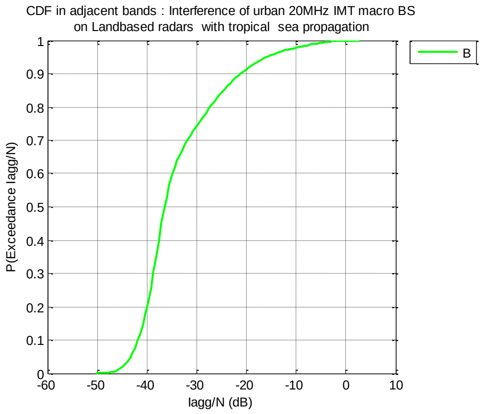


FIGURE A2-47

Uniform tilt angle

AAS uncorrelated

Radar B – Unwanted emissions TRP = −50.6 dBm/MHz

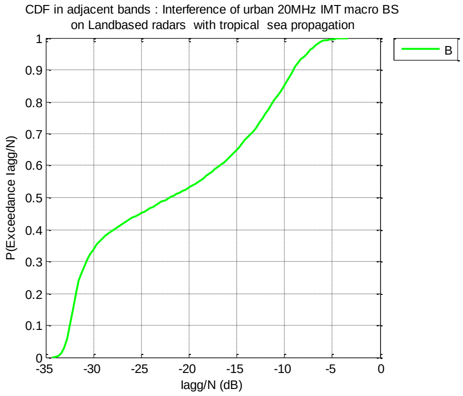
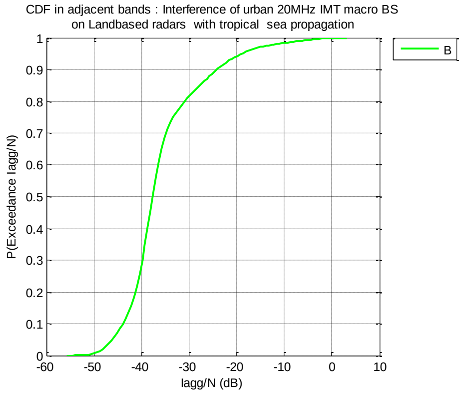


FIGURE A2-48

Uniform tilt angle

AAS correlated

Radar B – Unwanted emissions TRP = −60.2 dBm/MHz



4.5 Study case of IMT AAS deployment modelled with 20 rings

Taking into account assumptions and amendments done in §§ 1, 2, 3 and 4, Figs A2-49 and A2-50 provide results of simulations performed for an IMT deployment of 20 rings of respectively uncorrelated (ρ = 0) or correlated (ρ = 1) AAS macro based stations and radar B. The permitted unwanted emissions TRP is found in the range −58.6 / −52.3 dBm/MHz.

FIGURE A2-49

AAS UNCORRELATED

Radar B – Unwanted emissions
TRP = −52.3 dBm/MHz

IMT Deployment simulated with 20 rings

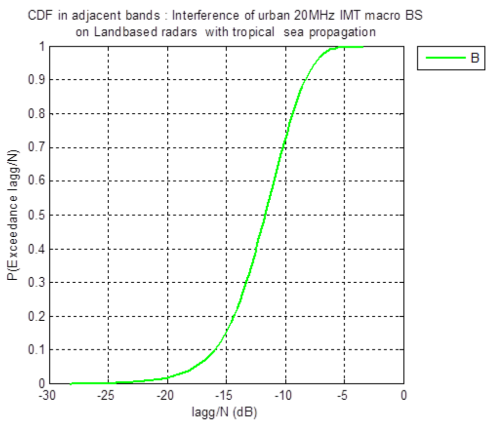
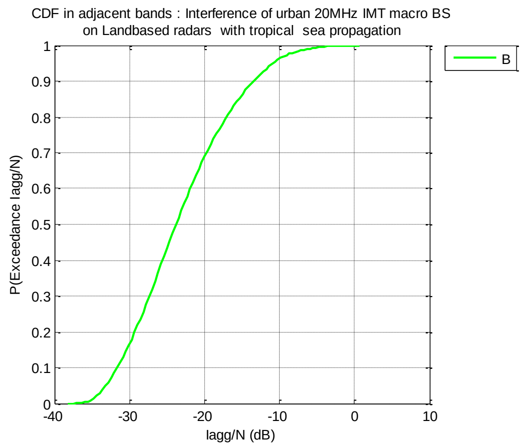


FIGURE A2-50

AAS CORRELATED

Radar B – Unwanted emissions
TRP = −58.6 dBm/MHz

IMT Deployment simulated with 20 rings



5 Summary of results

The results of simulations shows that under the assumptions done the maximum permitted unwanted emissions at the BSs are calculated in the range −45.5 /−50.6 dBm/MHz, but should be amended by the results of three parametric studies.

A first parametric study on the number of rings in the BS deployment modelling shows a sensitivity to estimate the aggregated interferences received by the radar receiver. An assumption of five rings underestimates up to 2 dB the level of IMT AAS uncorrelated interference. In particular, for modelling an IMT deployment of 18 rings at 3 km from a radar type B (similar to an urban IMT deployment diameter of 8 km) would lead to a maximum permitted unwanted emissions TRP of −52 dBm/MHz.

A second parametric study on the AAS correlation factor shows uncertainties in the estimation of unwanted emissions aggregated interference from IMT AAS. Depending the assumption done on the correlation factor between ρ = 0 (no correlation, no beamforming angular discrimination) and ρ = 1 (correlation, beamforming angular discrimination), estimation could have 6 dB variation.

A third parametric study on the impact of the statistical distribution of the AAS tilt, shows that using only the outdoor UE uniform distribution underestimates of 3 dB the aggregated interference received by the radar, compared to using an uniform electronic tilt law as an approximation of using a complete modelling of outdoor and indoor UE as described in Report ITU-R M.2292.

Finally, it is found that permitted unwanted emissions are in range TRP −58.6 /−52.3 dBm/MHz for an IMT deployment of 20 rings of urban AAS macro based stations, respectively correlated (ρ = 1) and uncorrelated (ρ = 0), at 3 km from a radar B, with an uniform distribution of outdoor UE.

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