Radiocommunication Study Groups

Received: 12 September 2017

Document 5-1/139-E
13 September 2017
English only

France

COMPATIBILITY STUDY BETWEEN EESS (PASSIVE) AND MS IN THE FREQUENCY BAND 23.6-24 GHZ

1 Introduction

WRC-15 agenda item 1.13 deals with the consideration of identification including possible additional spectrum requirement for the mobile service (MS) and more specifically for International Mobile Telecommunication and other terrestrial mobile broadband application IMT systems in accordance with Resolution **238 (WRC-15)**.

This contribution addresses the possible new identification to 5G IMT systems in the 24.25-27.5 GHz and potential impact on the adjacent band 23.4-24 GHz allocated to passive services such as Earth exploration satellite and radio-astronomy services. Systems under these services are highly susceptible to interference from unwanted emissions of active services. It is therefore necessary to address the relevant protection of these services from mobile service unwanted emissions.

The methodology applied in this study consists in determining the values of unwanted emission of MS equipment that enables a total protection of Earth exploration satellite service (EESS).

2 Employed methodology

The methodology consists in determining the additional losses that the MS equipment has to add in order to protect passive services in adjacent band. The propagation loss required distance, at all azimuths under consideration, may be written in the following form:

$$AL = P_r - (P_t + G_r + G_t + A_g - Loss) \quad \text{(dB)} \qquad (1)$$

where:

P_t: maximum available transmitting unwanted power level (dBW) in the reference bandwidth at the end of the antenna of a transmitting terrestrial station (BS) or terminal (T) in the mobile service;

P_r: permissible interference power of an interfering emission (dBW) in the reference bandwidth at the end of the antenna of a receiving EESS;

AL: Additional losses to reach the protection criteria of passive EESS;

G_t: Average antenna gain (dBi) assumed for the terrestrial station (BS) or terminal in the mobile service in direction of the satellite;

G_r: the maximum gain (dBi) of the EESS;

A_g: Aggregated effect;

L_{oss}: Total losses due to propagation, clutter, body, ohmic (dB).

The propagation losses are calculated using free space (propagation model from Recommendation ITU-R P.525-2) and gas attenuation (propagation model from Recommendation ITU-R P.676).

3 Mobile service systems characteristics

The characteristics of MS systems in the 24.25-33-4 GHz range are defined in band and in adjacent band in Document 5D/TEMP/265. The following table (Table 1) summarize only the transmission characteristics in the case of base station (BS) and terminal user (TU) in the range 24.25-33.4 GHz for out-of-band emission. Table 2 provide the characteristic deployment of TU and BS in the case of outdoor scenario.

TABLE 1

Out of band characteristics for BS and UE in the range 24.25-33.4 GHz. Outdoor scenarios only

Parameter		BS		TU
Duplex Method		TDD		TDD
Channel bandwidth (MHz)		200 MHz		200 MHz
Power (dB)	P_{Tx} maximum	$P_{Tx} < 34.5$ dBm	$P_{Tx} \geq 34.5$ dBm	
	$0 \leq \Delta f < 20$ MHz(2)	–5 dBm/MHz	–5 dBm/MHz	–5 dBm/MHz
	20 MHz $\leq \Delta f < 400$ MHz(2)	Max(P_{Tx} – 47.5 dB, –20 dBm/MHz)	–13 dBm/MHz	–13 dBm/MHz
	$\Delta f > 400$ MHz (2)	Spurious domain limits	Spurious domain limits	Spurious domain limits
Spurious emissions(3)		–10 dBm/MHz		–10 dBm/MHz
Unwanted Emission within the band 23.6-24 GHz(1)		-21 dBW/200 MHz	-17 dBW / 200 MHz	-17 dBW /200 MHz

(1) The unwanted emission is calculated considering emission from the first MS adjacent channel of 200 MHz (24.25-24.45 GHz) and the measurement of the passive sensor in the 200 MHz in the upper part of the passive band (23.8-24 GHz).

(2) The value is given in terms of TRP.

(3) Value of spurious emission before antenna. Ohmic losses are considered further in the calculations.

TABLE 2

Deployment-related parameters for bands between 24.25-33.4 GHz. Outdoor scenarios only

	Suburban		**Outdoor Urban hotspot**
	Outdoor suburban open space hotspot[2]	**Outdoor Suburban hotspot**	
Base station characteristics/Cell structure			
Network topology and characteristics	0 or 1BS/km^2	10 BSs/km^2	30 BSs/km^2
Frequency reuse	1	1	1
Antenna height (radiation centre)	15 m (above ground level)	6 m (above ground level)	6 m (above ground level)
Downtilt	15 degrees	10 degrees	10 degrees
Antenna deployment	At the edge of the roof	Below roof top	Below roof top

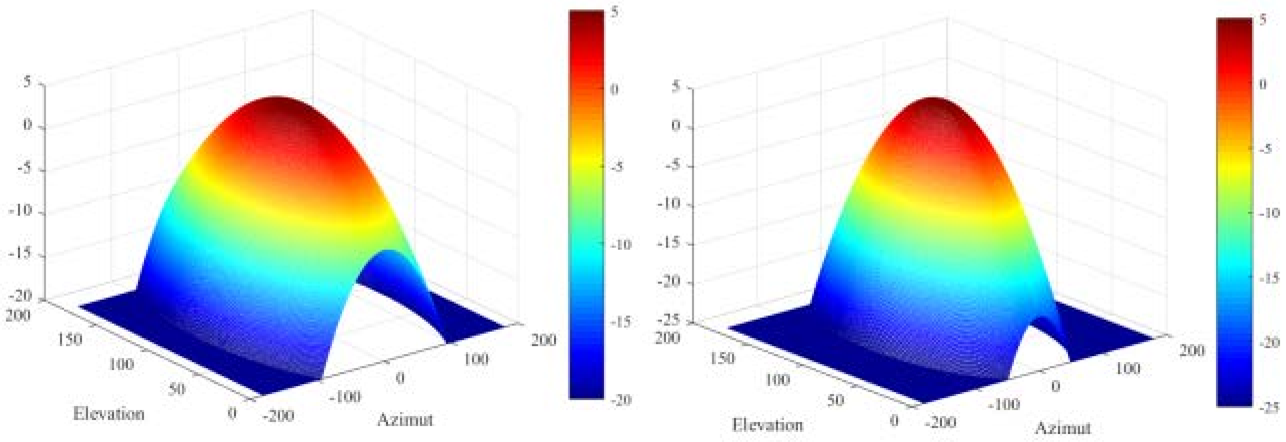
	Suburban		**Outdoor Urban hotspot**
	Outdoor suburban open space hotspot[2]	**Outdoor Suburban hotspot**	
Network loading factor (Average base station activity)	20%, 50%		20%, 50%
BS TDD activity factor	80%		80%
Antenna Characteristics			
Antenna pattern	Refer to Recommendation ITU-R M.2101		
Element gain (dBi)	5		5
Horizontal/vertical 3 dB beamwidth of single element (degree)	65º for both H/V		65º for both H/V
Horizontal/vertical front-to-back ratio (dB)	30 for both H/V		30 for both H/V
Antenna polarization	Linear ±45º		Linear ±45º
Antenna array configuration (Row × Column)	1 elements		1 elements
Array Ohmic loss (dB)	3		3
User terminal characteristics			
Indoor user terminal usage	5%		5%
User Equipment density for terminals that are transmitting simultaneously	30 UEs /km^2		100 UEs/km^2
Body loss resulting from proximity effects	4 dB		4 dB
UE TDD activity factor	20%		20%
Antenna characteristics			
Antenna pattern	Refer to Recommendation ITU-R M.2101		
Element gain (dBi)	5		5
Horizontal/vertical 3 dB beamwidth of single element (degree)	90º for both H/V		90º for both H/V
Horizontal/vertical front-to-back ratio (dB)	25 for both H/V		25 for both H/V
Antenna polarization	Linear ±45º		Linear ±45º
Antenna array configuration (Row × Column)	1 elements		1 elements
Horizontal/Vertical radiating element spacing	0.5 of wavelength for both H/V		0.5 of wavelength for both H/V
Array Ohmic loss (dB)	3		3
Conducted power (before Ohmic loss) per antenna element (dBm / 200 MHz)	10		10

As described in Recommendation ITU-R M 2101, an IMT system using an AAS will actively control all individual signals being fed to individual antenna elements in the antenna array in order to shape and direct the antenna emission diagram to a wanted shape, e.g. a narrow beam towards a user. In other words, it creates a correlated wanted emission from the antenna. The unwanted signal, caused by transmitter OOB modulation, intermodulation products and spurious emission components will not experience the same correlated situation from the antenna and will have a different emission pattern. A non-correlated AAS has an antenna emission pattern similar to a single antenna element.

So, in an adjacent frequency band situation with IMT as the interfering system, **the antenna pattern for the unwanted emission can be assumed to have a similar antenna pattern as a single antenna element** (see Figure 1). The antenna pattern used in simulation between MS and EESS is based on the pattern from one element.

FIGURE 1

Cartesian Representation of AAS antenna gain for BS (left) and UT (right) in unwanted domain



4 EESS Systems Characteristics

Recommendation ITU-R RS.2017 provides the protection criteria for EESS (passive) systems in band 23.6-24 GHz as given in Table 3 below.

TABLE 3

Protection criteria of passive sensor in the band 23.6-24 GHz

Frequency band (GHz)	Total bandwidth (MHz)	Reference bandwidth (MHz)	Maximum interference level (dBW)	Percentage of area or time permissible interference level may be exceeded(1)
23.6-24	400	200	-166	0.01

(1) For a 0.01% level, the measurement area is a square on the Earth of 2 000 000 km.

Recommendation ITU-R RS.1861 provides characteristics of EESS (passive) sensors operating in the band 23.6-24 GHz. In this band, 8 sensors operate. Their characteristics relevant to the present analysis are summarized in Table 4.

TABLE 4

Characteristic of passive sensor in the band 23.6-24 GHz

	Sensor F1	Sensor F2	Sensor F3	Sensor F4	Sensor F5	Sensor F6	Sensor F7	Sensor F8
Sensor type	Conical scan			Mechanical nadir scan		Conical scan	Push-broom	Conical scan
Altitude	817 km	705 km	828 km	833 km 822 km*	824 km	835 km	850 km	699.6 km
Inclination	20°	98.2°	98.7°	98.6° 98.7°*	98.7°	98.85°	98°	98.186°
Maximum beam gain	40 dBi	46.7 dBi	52 dBi	34.4 dBi	30.4 dBi	43 dBi	45 dBi	48.5 dBi

	Sensor F1	Sensor F2	Sensor F3	Sensor F4	Sensor F5	Sensor F6	Sensor F7	Sensor F8
Instantaneous field of view	63 km × 38 km	32 km × 18 km	18 km × 12 km	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*	Nadir FOV: 74.8 km Outer FOV: 323.1 × 141.8 km	36 km × 86 km	16 km × 2 282 km	26 km × 15 km
Footprint size	1880	452	169	1847 / 9298	4395 / 35983	2431	201 / 28 676	306
Off-nadir pointing angle	44.5°	47.5°	46.6°	±48.33° cross-track	±52.725° cross-track	55.4°	0° to ±50°	47.5°
Incidence angle at Earth	52.3°	55°	55.2°	0° (nadir) 57.5°*	0° (nadir) 64°	68.6°	0° (nadir) 60.3°	55°
Channel bandwidth	400 MHz	400 MHz centred at 23.8 GHz		270 MHz centred at 23.8 GHz		400 MHz centred at 23.8 GHz	N/A	400 MHz centred at 23.8 GHz

FIGURE 2

Footprint representation for mechanical scan Sensor F5. Footprints are represented every second. Red circle: Position of satellite every second

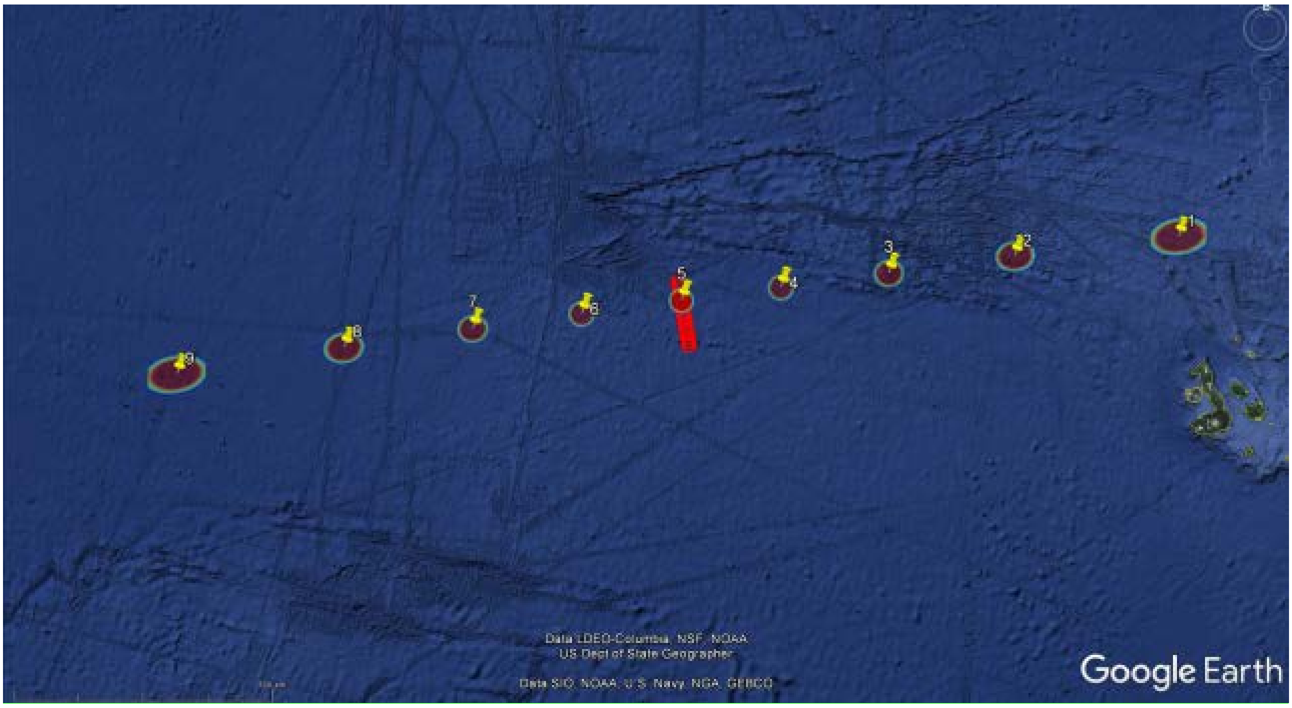
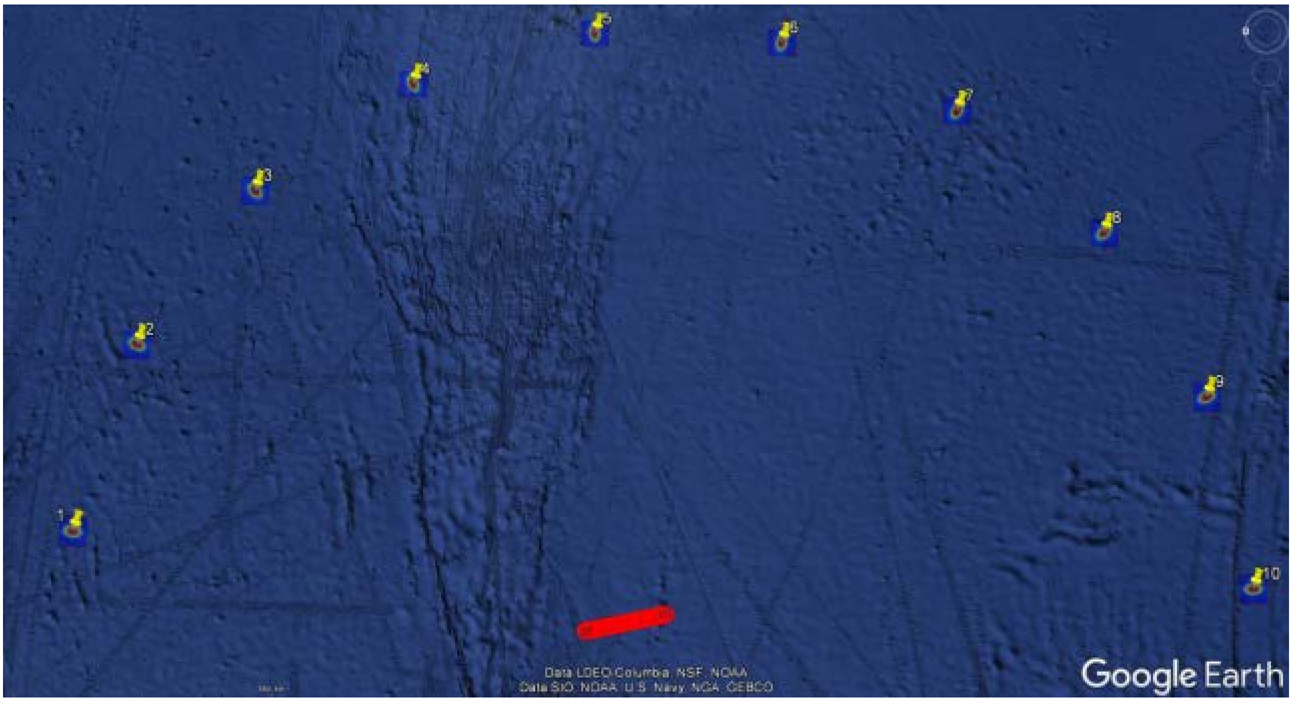


FIGURE 3

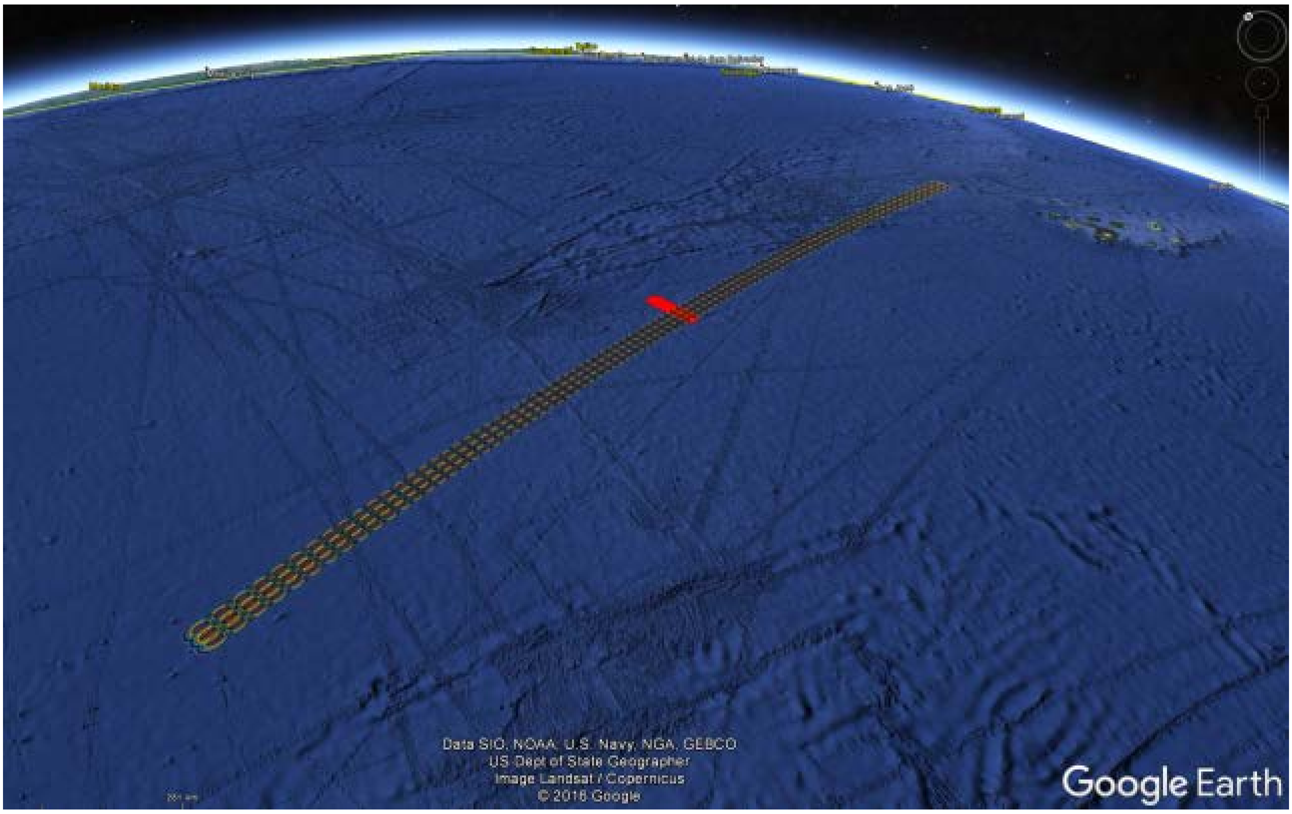
Footprint representation for conical Sensor F3. Footprints are represented every 100 ms.
Red circle: Position of satellite every second



Concerning, the percentage given in Table 3, 0.01 % of an area of 2 000 000 km^2, means that at maximum a surface of 200 km^2 could accept an exceedance of the interference level. In addition, Table 4 provides the IFOV (Instantaneous Field Of View) and corresponding footprint size over which the detector is really sensitive to radiation. Most of this IFOV (except F3) are larger than 200 km^2. Figures 2, 3 and 4 present the footprint representation on ground for Sensor F5, F3 and F7. For conical scan sensor, the incidence angle at Earth is constant, whereas for mechanical nadir scan, it changes constantly between angle ranges defined in Table 4 and for push-broom, 90 different beams are covering the angle ranges defined in Table 4.

FIGURE 4

Footprint representation for Push Broom Sensor F7 every 2 seconds. Red circle: Position of satellite every second



5 Average gain of MS in main beam of EESS

In order to develop the average gain toward the main beam of satellite passive sensor, a dynamic simulation was performed. This simulation took into account each satellite orbital characteristic and the each particular off-nadir pointing angle. Due to the low inclination angle of the satellite with sensor F1 (20°), the mobile systems (BS and UT) were placed on earth closed to the equator in the city of Bamako, pointing respectively in the North direction and to the zenith (the UT is considered to be used parallel to the ground). Base station is considered placed on a wall perpendicular to the ground and pointing on the horizon with a mechanic tilt of minus ten degrees. Different azimuths of pointing are considered from North to South and From South to North. A user terminal is considered placed in a user hand, moving from zenith (perpendicular to ground – 90°) to horizon (parallel to ground – 0°). As considered during the previous meeting of TG 5/1 and due to the potential consideration of antenna panels at UT front side (display side) and other in the back side. The antenna pattern in the adjacent frequency band situation has therefore to be considered randomly in elevation in the range –90 to 90° and in azimuth in the range –60° to +60° in the direction of the BS. The probability density function (PDF) of the BS gain towards the main beam of the satellite was built considering only the satellite position for which the main beam of the satellite sensor is in direction of the mobile systems. In order to develop the average gain for each case, a weighted sum of each PDF (in linear) was performed.

FIGURE 5

Satellite positions for which the main beam of sensor 1, 2 and 6 are in the direction of the BS (respectively in green, orange and blue)

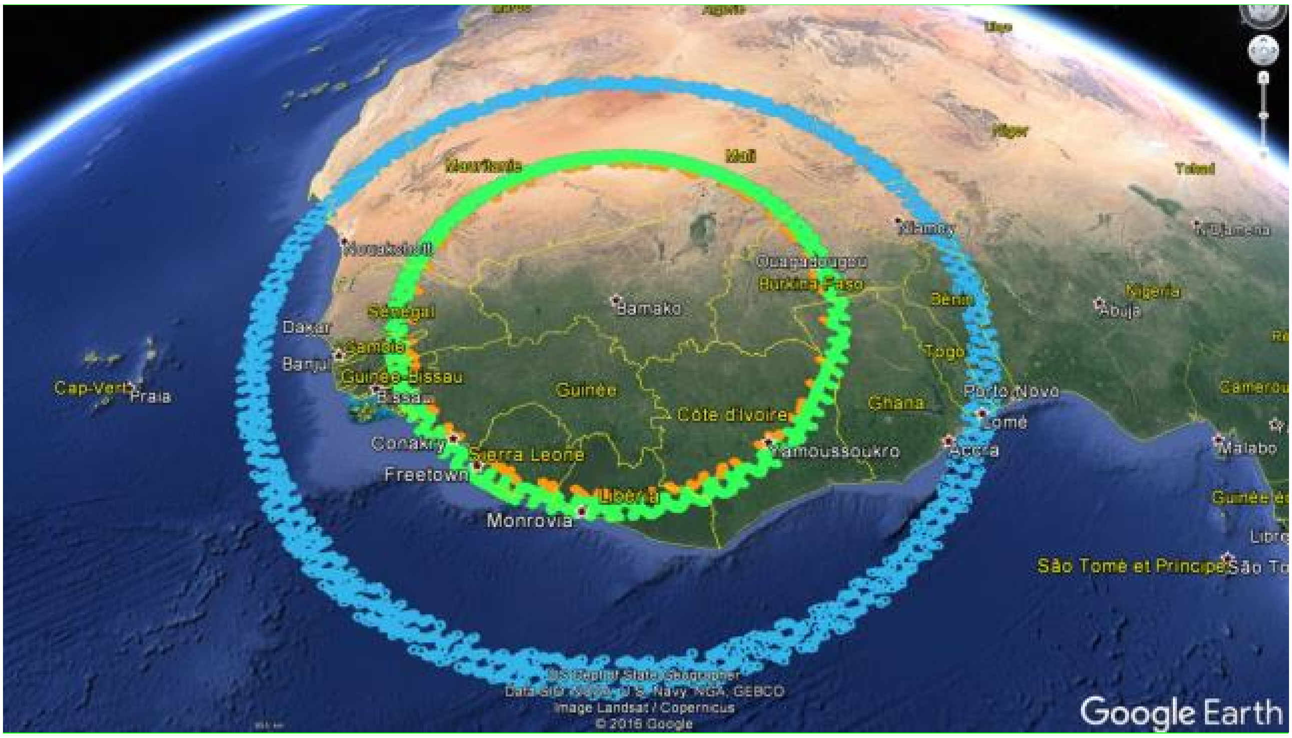


FIGURE 6

Position for which the main beam of the sensor 4 is in the direction of the BS (purple)

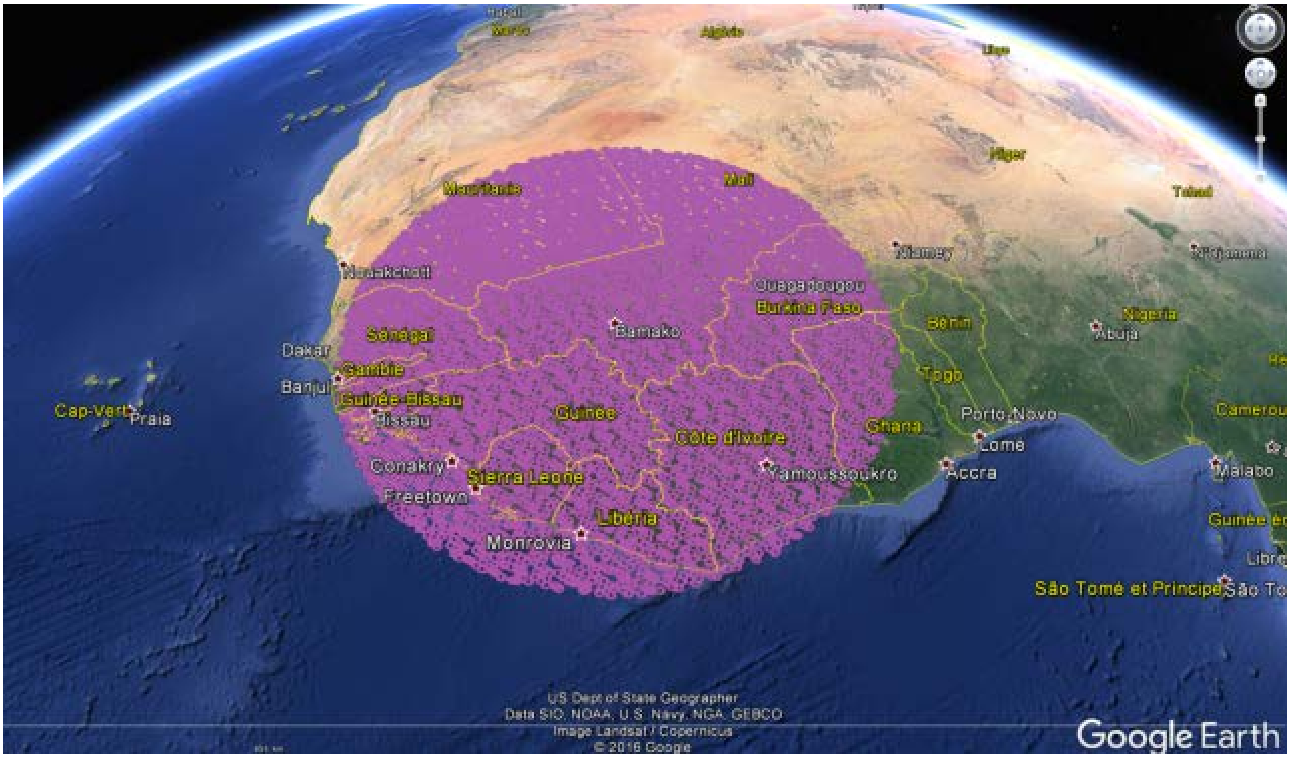


FIGURE 7

PDF of the BS antenna gain towards the satellite main beam for each sensor

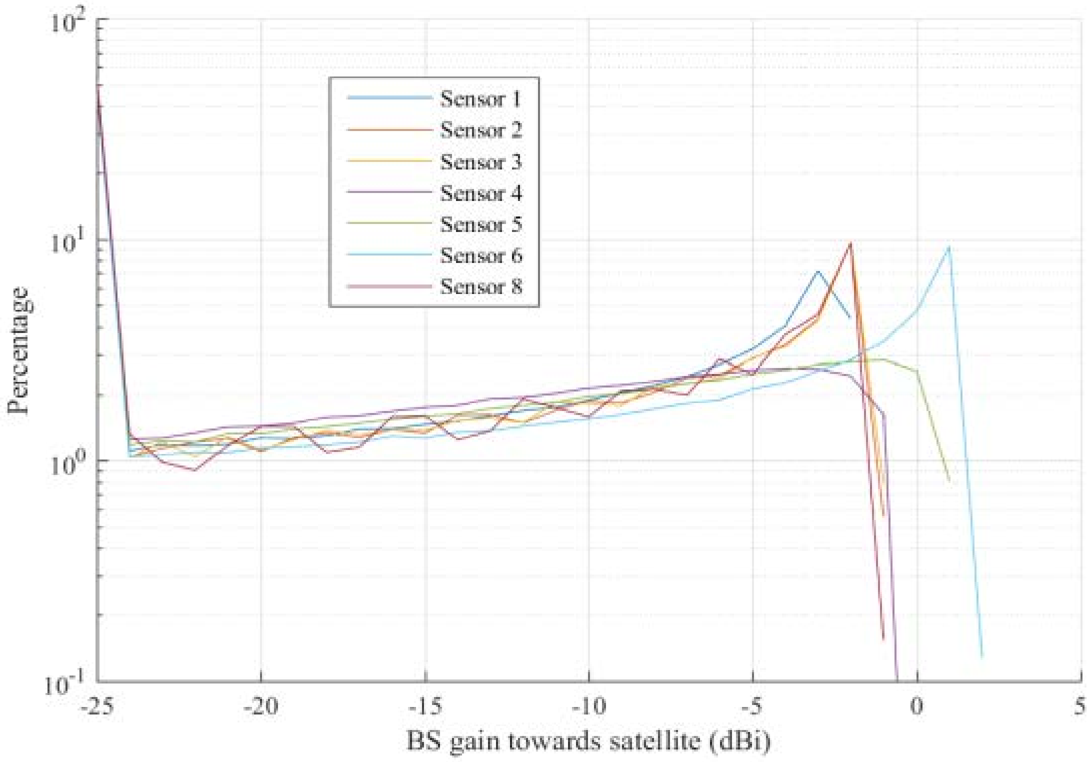
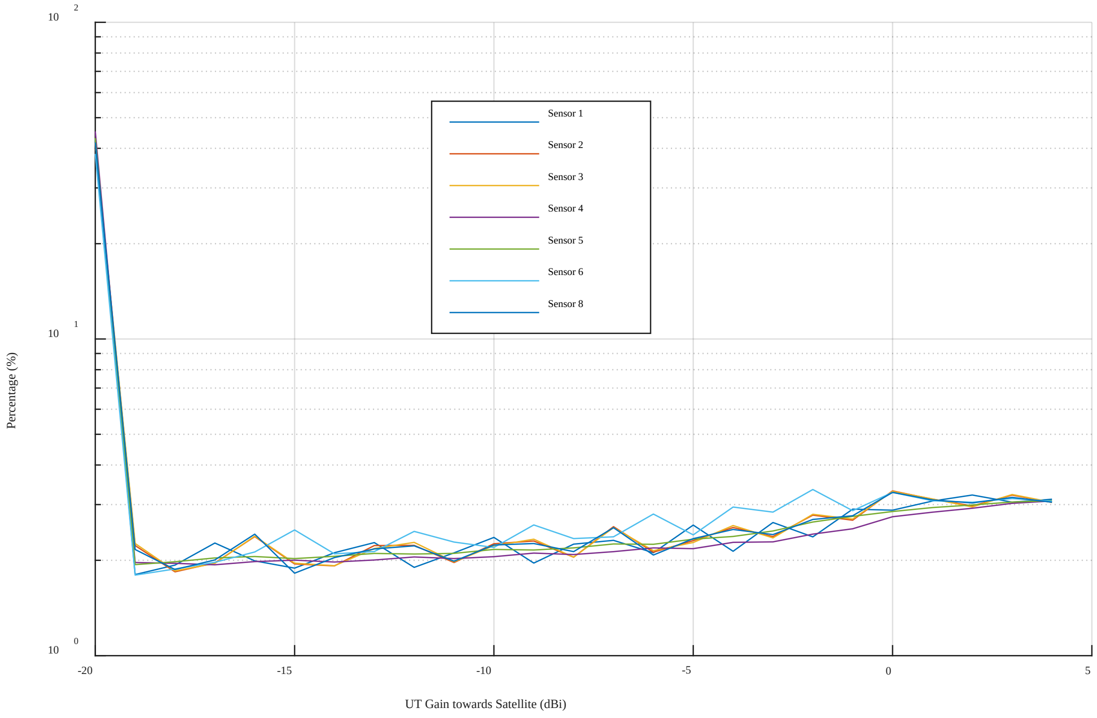


FIGURE 8

PDF of the UT antenna gain towards the satellite main beam for each sensor



Figures 5 and 6 present respectively simulation examples for conical, mechanical and Push Broom scan sensor:

- For conical scan sensor, the incidence angle at Earth is constant, so all position could be represented by a circle centred on the BS position.
- For mechanical nadir scan, the footprint move from one side to another side, so it changes constantly between ranges defined in Table 4, so all possible satellite position could be represented by a disk centred on the BS position.
- The representation of area for Push Broom sensor is similar to mechanical and could be represented by a surface centred on the BS

Figure 7 and Figure 8 give the PDFs for each case of sensors in the case respectively of BS and MS. The weighed sums of PDF (mean values of gain) are summarized in Table 5.

TABLE 5

Evaluation of average gain towards the satellite

	Sensor F1	**Sensor F2**	**Sensor F3**	**Sensor F4**		**Sensor F5**		**Sensor F6**	**Sensor F7**		**Sensor F8**
Incidence angle at Earth	52.3°	55°	55.2°	57.5°	0° (nadir)	63.9°	0° (nadir)	68.6°	60.3°	0° (nadir)	55°
Elevation from Earth	37.7°	35°	34.8°	32.4°	90°	26.01°	90°	21.4°	29.7°	90°	35°
Gain from UT toward sensor	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6
Gain from BS toward sensor	-9.3	-8.7	-8.7	-10.5	-25	-8.8	-25	-5.8	-8.8	-25	-8.8

5 Mean attenuation of UT unwanted emission due to power control

The statistic of the UE antenna beam pointing can be inherited from the BS, recalling that UE terminal points to the BS location in order to maximize the throughput of the link. However, the orientation of the device is of interest since this latter is influenced by the user behaviour (in addition to the beam steering) as depicted in the TG 5/1 Chairman's Report that the UE antenna panel positioning ("mechanical azimuth" and "mechanical tilt") "*has therefore to be considered randomly in elevation in the range -90 to 90° and in azimuth in the range -60° to +60° in the direction of the BS.*"

Another key parameter in the computation of the power radiated by UEs deals with the power control performed during the BS-UE radio link. The algorithm driving UE conducted power is taken from the Recommendation ITU-R M.2101 (Section 4.2)

It has to be noted that *PL* parameter in the algorithm between UE and BS as defined in this Recommendation also covers other losses, i.e. body loss and (BS and UE) ohmic losses, if any but also the UE and BS antenna gains[1] (respectively towards BS and UE). *PL* parameter can be understood as a coupling loss component. The input parameters required to derive the UE output power are extracted from Document 5-1/36 are provided in Table 2.

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[1] Calculated with the normalization factor.

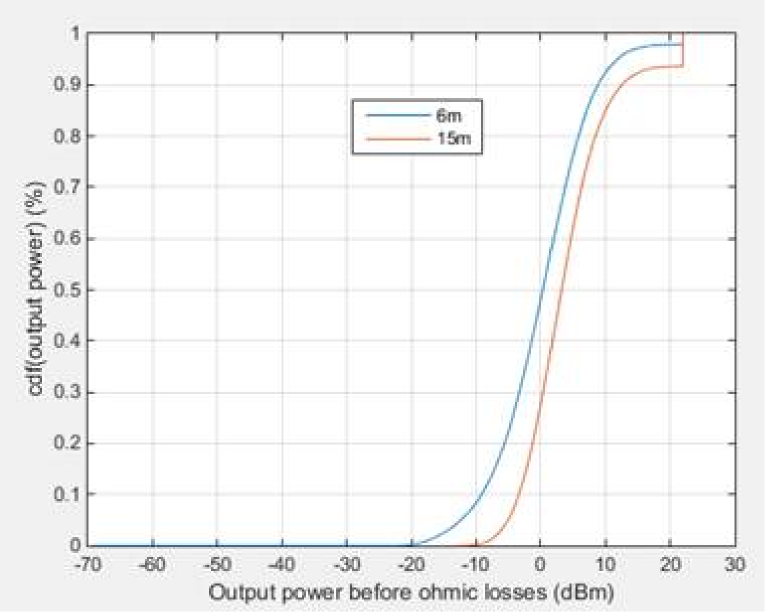
TABLE 6

UE Power control algorithm input parameters

Maximum user terminal output power P_{CMax}	dBm	22
Transmit power target value per $P0_{PUSCH}$	dBm/180 kHz	-95
Pathloss compensation factor α	N/A	1
UE Body Loss	dB	4

FIGURE 9

Simulation of distribution of power



Based on these parameters and the BS antenna beam pointing statistics, the distribution of the UE output power when connected to BS antenna at height=6 m and 15 m was simulated and is depicted in Figure 9. The curves show that a low percentage of UEs (about 5%) is subject to transmit with maximum power P_{CMax}. Finally the weighted sums of these distributions show that the mean conducted power (before ohmic losses) is equal to:

1 +7.8 dBm for a terminal connected to a BS at 6 m.

2 +11.5 dBm for a terminal connected to a BS at 15 m

Considering the assumption that the decrease of unwanted emission (out-of-band and spurious) power follows the decrease of in-band power, the mean attenuation due to power control in adjacent band could be summarized respectively as 14.2 dB (rounded to 14 dB in Table 9) and 10.5 dB for antenna connected with BS at 6 or 15 m.

It should be noted that these figures are representatives of a certain UE deployment within the IMT cell leading to a level of more than 95% of LoS and do not take into account that interference from indoor UE, likely to transmit at higher power, will be reduced by the building entry loss. Other scenarios presenting to lower figures of LoS cases may impact the value of the UE average power control attenuation, hence the interference level on EESS (passive) sensors. These possible cases have not been studied in the present document.

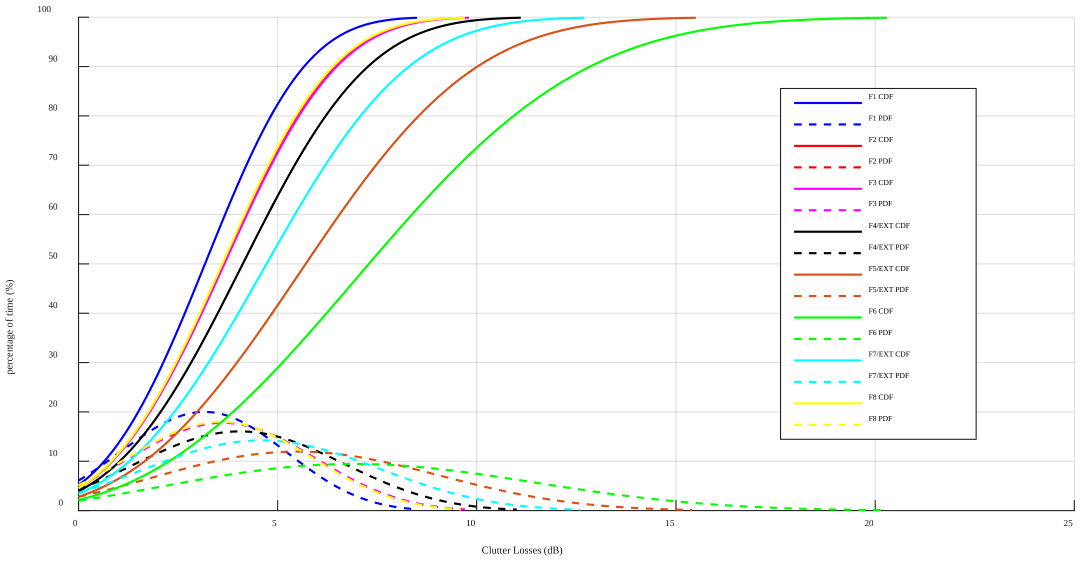
6 Clutter losses

Recommendation ITU-R P.2108 proposes to derive the clutter losses between a satellite/aircraft and a terrestrial system. Section 3.3 provides equations to calculate the statistical distribution of clutter loss where one end of the interference path is within man-made clutter, and the other is a satellite, aeroplane, or other platform above the surface of the Earth.

Table 5 in the previous section provides the elevation of the satellite sensor from the Earth. It is possible to note that elevations for the various EESS (passive) sensors are within the range 21.4° to 90°. The following Figure 10 provides the cumulative distribution function (CDF) and the probability distribution function (PDF) for different case of elevation from ground at a frequency of 23.8 GHz. The mean losses value per sensor are described in the final calculation table (Table 8).

FIGURE 10

Clutter losses for different elevation between MS and satellite. Elevation is taken from ground



7 Generic city for mobile equipment deployment (Ra, Rb) (Option 1)

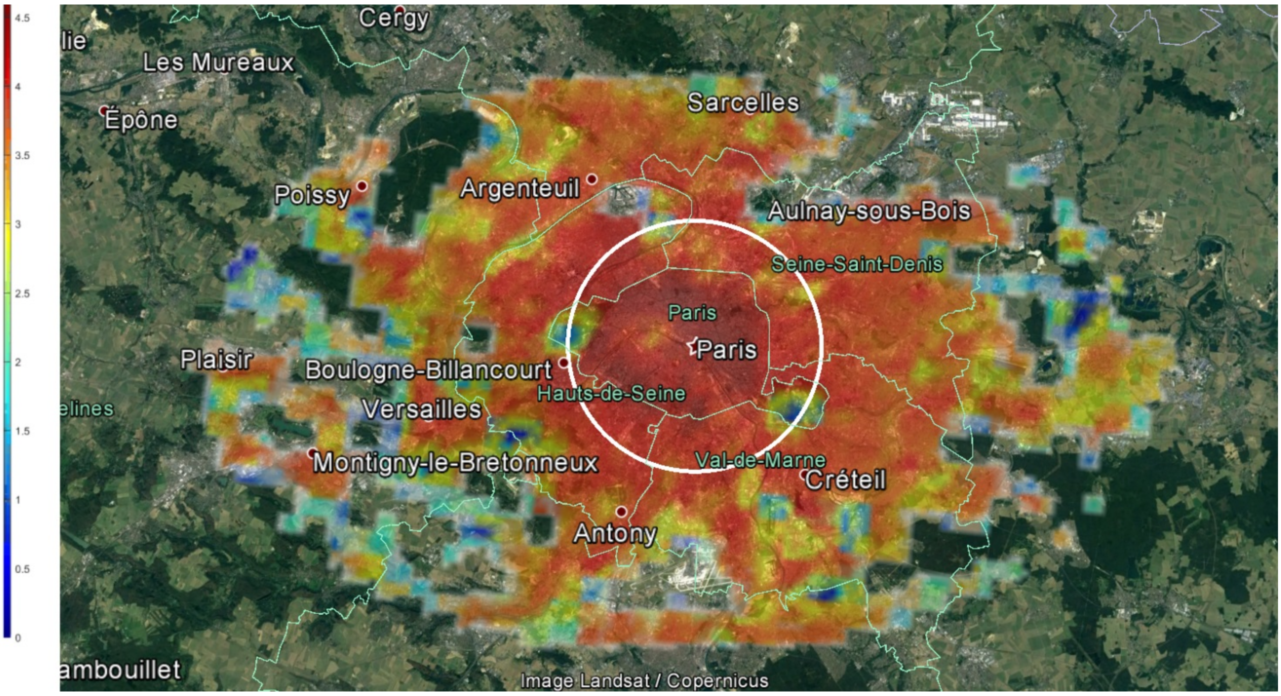
The percentage given in Table 3 (i.e. 0.01 % of an area of 2 000 000km) means that a surface of 200 km^2 could accept an exceedance of the interference level. To give an idea, 2 000 000 km² could be summarized as the surface of West Europe (from France to Hungary in longitude). Several cities in this area are much greater than 200 km².

Moreover, all footprints (except one) are much greater than 200 km² and 5 of them are greater than 1 000 km². The idea is to consider a generic city enables to represent calculation for protection of most sensors.

A generic city was built on the example of Paris and its neighbourhood. The total dense urban area covers approximatively 8 km of radius (surface of approximatively 200 km² - white circle in Figure 9). If the footprint surface is greater than 200 km², the rest of the surface in the footprint is considered as a mix of urban and suburban region, taking into account the value of Ra for each region and a value of Rb equal to 5%. Figure 11 provides an example of methodology considering sensor F1 footprint, the calculation for each sensor footprint could be found in the final calculation table (Table 8)

FIGURE 11

Representation of generic city (Paris). First circle = Dense urban area (16 km of diameter). Population density (per km²) in the F1 footprint (in logarithm)



8 Population density (Option 2)

This section proposes to develop a methodology to spatially distribute the BS in function of population density, in order to ensure a realistic deployment of 5G networks. The first assumption is linked to the number of total BS on the French territory, considering 30 BS/km² and 100 UT/km², the values of Ra and Rb equal to respectively 7% and 5% and an area of 643 801 km², the number of BS and UT could be synthetized as respectively 67 600 and 225 330 deployed on French territory. Considering approximatively 66.81 millions of inhabitant, the density of BS per inhabitant (inh) could be calculated as **0.001 BS /inh and 0.003 UT/inh**. These values are inserted in the population density grid (per km²) in order to derive the number of BS per location

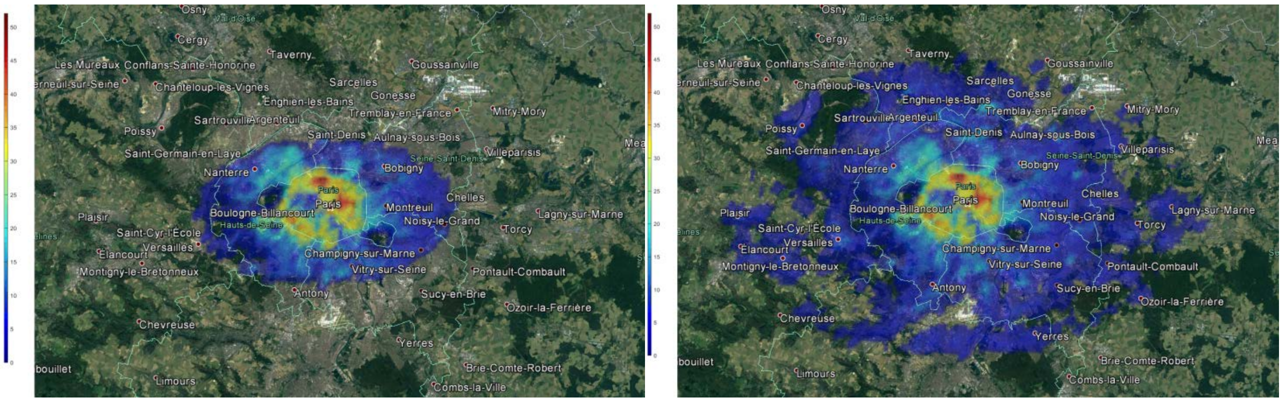
TABLE 7

Number of BS in each EESS (passive) footprint. For Mechanical scan sensors (S4 and S5), two calculations are presented: for the outer IFOV and for IFOV in Nadir

	F1	**F2**	**F3**	**F4**		**F5**		**F6**	**F7**	**F8**
Instantaneous field of view	63 km × 38 km	32 km × 18 km	18 km × 12 km	Nadir FOV: 48.5 km Outer FOV: 149.1 × 79.4 km 147 × 79 km*		Nadir FOV: 74.8 km Outer FOV: 323.1 × 141.8 km		36 km × 86 km	16 km × 2 282 km	26 km × 15 km
Footprint size (km²)	1 880	452	169	1 847	9 298	4 395	35 983	2 431	201 / 28 676	306
Number of BS	8 875	5 388	3 163	9 065	11 217	10 563	12 915	9 132	3 515	4 385

FIGURE 12

Representation of the number of BS in Paris in footprint (S1on the right and S2 on the left)



9 Compatibility studies

Based on parameter defined in all previous section, the Table 6 provides the compatibility studies for each sensor. The worst case of compatibility is linked to sensors F3 and F7. As seen in Section 6, the generic city considered under Option 1 is composed of an area of dense urban of 79 km² and a suburban area of approximatively 1 177 km² (the total area is 1 256 km²). All footprints are greater than 79 km² but certain footprints are smaller than 1 256 km². For these ones, the calculation considers that the footprint is centred on the urban dense area and present the rest of its surface on the suburban area. In these cases, the MS equipment deployment in the footprint is restricted to the footprint size.

On the parameter provided by WP 5D, the real deployment is linked to two different factors Ra and Rb. In this study, the satellite footprint is considered pointing on the city, so the parameter (Rb) linked to the ratio between the built areas and the total area of region in study is clearly equal to 100%. Ra is defined as ratio of hotspot areas to areas of cities/built areas/districts. WP 5D propose to consider 7% in urban and 3% in suburban area. The Table 6 provides the calculation considering for the deployment proposed by WP 5D.

The loading factor for area inferior to 50 km² is considered equal to 50%. All footprint areas are superior to 50 km², so the loading network is taken equal to 20%.

TABLE 8

Final calculation for EESS protection.

Sensor geometric characteristics											
Type of sensor	conical	conical	conical	Mechanical (cross-track)		Mechanical (cross-track)		conical	Push-broom		conical
Orbit altitude (km)	817	705	828	833		824		835	850		699.6
Nadir angle (°)	44.5	47.5	46.6	±48.33	0.0	±52.725	0.0	55.4	±50	0.0	47.5
Elev at ground Ɵ (°)	37.7	35.0	34.8	32.4	90.0	26.01	90.0	21.4	29.7	90.0	35.1
Slant path distance (km)	1 228	1 124	1 309	1 378	833	1 563	824	1 767	1 482	850	1 114
Footprint size (km²)	1 880	452	169	9 298	1 847	35 983	4 395	2 430	201	201	306
Antenna gain (dBi)	40	46.7	52	34.4	34.4	30.4	30.4	43	45	45	48.5
Protection criteria (dBW/200 MHz)	-166	-166	-166	-166	-166	-166	-166	-166	-166	-166	-166
Apportionment (dB)	3	3	3	3	3	3	3	3	3	3	3

Propagation Losses											
Free space losses (dB)	181.72	180.95	182.27	182.72	178.34	183.81	178.25	184.88	183.35	178.52	180.87
Atmospheric losses (dB)	0.69	0.73	0.74	0.78	0.42	0.95	0.42	1.15	0.85	0.42	0.73
Clutter losses (dB) (5)	2.75	3.12	3.15	3.51	0	4.66	0	5.75	3.97	0	3.1
Polarisation losses (dB)	3	3	3	3	3	3	3	3	3	3	3
Total Losses (dB)	188.16	187.8	189.16	190.01	181.76	192.42	181.67	194.78	191.17	181.94	187.7
OPTION 1											
Urban BS Characteristics (P_{Tx} < 34.5 dBm)											
Unwanted emission (dBW/200 MHz)	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21
Urban deployment (BS/km^2)	30	30	30	30	30	30	30	30	30	30	30
Urban area (km²)	200	200	200	200	200	200	200	200	200	200	200
Ra (%) urban	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%
Number of BS (1)	420	420	420	420	420	420	420	420	420	420	420
Suburban Deployment (BS/km2)	10	10	10	10	10	10	10	10	10	10	10
remaining area (km²)	1 680	252	-31	9 098	1647	35 783	4 195	2 230	1	1	106
Ra (%) suburban	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Rb (%)	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Number of BS (1) in remaining area	202	30	0	1092	198	4294	503	268	0	0	13
Total number of BS	622	450	420	1512	618	4714	923	688	420	420	433
Loading factor (%)	20	20	20	20	20	20	20	20	20	20	20
Aggregation of sources (dB)	20.9	19.5	19.2	24.8	20.9	29.7	22.7	21.4	19.2	19.2	19.4
Antenna gain (dBi) (2)	-9.3	-8.7	-8.7	-10.5	-25	-8.8	-25	-5.8	-8.8	-25	-8.8
Additional power (TRP)	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Ohmic losses (dB)	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Aggregated emitted e.i.r.p (dBW/200 MHz)	-7.6	-8.4	-8.7	-4.9	-23.3	1.7	-21.5	-3.6	-8.8	-25	-8.6
Received power by sensor receiver from BS only (P_{Tx} < 34.5 dBm)											
Interference power (dBW/200 MHz)	-155.8	-149.5	-145.9	-160.5	-170.66	-160.3	-172.8	-155.4	-155	-161.9	-147.8
Exceedance power (dB)	13.24	19.5	23.14	8.49	-1.66	8.68	-3.77	13.62	14.03	7.06	21.2
Received power by sensor receiver from BS only (P_{Tx} >34.5 dBm) (3)											
Interference power (dBW/200 MHz)	-151.8	-145.5	-141.9	-156.5	-166.66	-156.3	-168.8	-151.4	-151	-157.9	-143.8
Exceedance power (dB)	17.24	23.5	27.14	12.49	2.34	12.68	0.23	17.62	18.03	11.06	25.2
Urban UT characteristics											
Unwanted emission (dBW/200 MHz)	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17
Mean power control attenuation (dB)	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14
Urban deployment (UT/km^2)	100	100	100	100	100	100	100	100	100	100	100
Urban area (km²)	200	200	200	200	200	200	200	200	200	200	200
Ra (%)	7	7	7	7	7	7	7	7	7	7	7

Number of UT [(1)]	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
Suburban deployment (UT/km²)	30	30	30	30	30	30	30	30	30	30	30
Suburban area (km²)	1680	252	0	9098	1647	35783	4195	2230	1	1	106
Ra (%)	3	3	3	3	3	3	3	3	3	3	3
Rb (%)	5	5	5	5	5	5	5	5	5	5	5
Number of UT [(1)]	664	100	0	3594	651	14134	1657	881	0	0	42
Total number of UT	2064	1500	1400	4994	2051	15534	3057	2281	1400	1400	1442
Aggregation of sources (dB)	33.1	31.8	31.5	37	33.1	41.9	34.9	33.6	31.5	31.5	31.6
Antenna gain (dBi) [(2)]	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6
Additional power (TRP)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Ohmic losses (dB)	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Body loss (dB)	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Aggregated emitted e.i.r.p. (dBW/200 MHz)	-6.1	-7.4	-7.7	-2.2	-6.1	2.7	-4.3	-5.6	-7.7	-7.7	-7.6
Received power by sensor receiver from UT only											
Interference power (dBW/200 MHz)	-154.3	-148.5	-144.9	-157.8	-153.46	-159.3	-155.6	-157.4	-153.9	-144.6	-146.8
Exceedance power (dB)	14.74	20.5	24.14	11.19	15.54	9.68	13.43	11.62	15.13	24.36	22.2
Total received power by sensor from UT and BS (respectively 20% and 80% per cell)											
Interference power (dBW/200 MHz)	-155.4	-149.3	-145.6	-159.8	-160.1	-160.1	-162.2	-155.7	-154.7	-151.3	-147.6
Exceedance power (dB)	13.6	19.7	23.4	9.2	8.9	8.9	6.8	13.3	14.3	17.7	21.4
OPTION 2											
Urban BS characteristics ($P_{Tx} < 34.5$ dBm)											
Unwanted emission (dBW/200 MHz)	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21	-21
Footprint dimension (km²)	1880	452	169	9298	1847	35983	4395	2431	201	201	306
Number of BS [(1)]	8875	5388	3163	11217	9065	12915	10563	9132	3515	3515	4385
Loading factor (%)	20	20	20	20	20	20	20	20	20	20	20
Aggregation of sources (dB)	32.5	30.3	28	33.5	32.6	34.1	33.2	32.6	28.5	28.5	29.4
Antenna gain (dBi) [(2)]	-9.3	-8.7	-8.7	-10.5	-25	-8.8	-25	-5.8	-8.8	-25	-8.8
Additional power (TRP)	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Ohmic losses (dB)	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Aggregated emitted e.i.r.p (dBW/200 MHz)	4	2.4	0.1	3.8	-11.6	6.1	-11	7.6	0.5	-15.7	1.4
Received power by sensor receiver from BS only ($P_{Tx} < 34.5$ dBm)											
Interference power (dBW/200 MHz)	-144.2	-138.7	-137.1	-151.8	-158.96	-155.9	-162.3	-144.2	-145.7	-152.6	-137.8
Exceedance power (dB)	24.84	30.3	31.94	17.19	10.04	13.08	6.73	24.82	23.33	16.36	31.2
Received power by sensor receiver from BS only ($P_{Tx} > 34.5$ dBm)											
Interference power (dBW/200 MHz)	-140.2	-134.7	-133.1	-147.8	-154.96	-151.9	-158.3	-140.2	-141.7	-148.6	-133.8
Exceedance power (dB)	28.84	34.3	35.94	21.19	14.04	17.08	10.73	28.82	27.33	20.36	35.2

Urban UT characteristics											
Unwanted emission (dBW/200 MHz)	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17	-17
Mean power control attenuation (dB)	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14	-14
Footprint dimension (km²)	1880	452	169	9298	1847	35983	4395	2431	201	201	306
Number of UT [1]	26625	16164	9489	33651	27195	38745	31689	27396	10545	10545	13155
Aggregation of sources (dB)	44.3	42.1	39.8	45.3	44.3	45.9	45	44.4	40.2	40.2	41.2
Antenna gain (dBi) [2]	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6	-3.6
Additional power (TRP)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Ohmic losses (dB)	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
Body loss (dB)	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Aggregated emitted e.i.r.p. (dBW/200 MHz)	5.1	2.9	0.6	6.1	5.1	6.7	5.8	5.2	1	1	2
Received power by sensor receiver from UT only											
Interference power (dBW/200 MHz)	-143.1	-138.2	-136.6	-149.5	-142.26	-155.3	-145.5	-146.6	-145.2	-135.9	-137.2
Inteference power from cell (dBW/200 MHz)	25.94	30.8	32.44	19.49	26.74	13.68	23.53	22.42	23.83	33.06	31.8
Total received power by sensor from UT and BS (respectively 20% and 80% per cell)											
Interference power (dBW/200 MHz)	-143.9	-138.6	-137	-151.2	-148.9	-155.8	-152.1	-144.6	-145.6	-142.6	-137.7
Exceedance power (dB)	25.1	30.4	32	17.8	20.1	13.2	16.9	24.4	23.4	26.4	31.3

[1] The dense urban area is considered as a circle with a radius of 16 km. The rest of the area in the footprint is a combination between suburban and urban area.

[2] See Table 5

[3] To obtain the value for BS only (P_{Tx} > 34.5 dBm), a simple translation of 4 dB is applied on the result for (P_{Tx}< 34.5 dBm), see last row of Table 1.

[4] Average of clutter losses for all positions (in linear).

[5] Clutter losses are used both for UT and BS.

On this basis, the unwanted emission levels of IMT 5G stations need to be decreased by the amount of exceedance power (or negative margins), i.e. 23.4 dB for option 1 and 32 dB for Option 2, hence leading to the following levels:

- Under Option 1:
  - For BS: maximum unwanted emission level of (-24 -23.4) = -47.4 dBW/200 MHz.
  - For UT: maximum unwanted emission level of (-20 -23.4) = -43.4 dBW/200 MHz.
- Under Option 2:
  - For BS: maximum unwanted emission level of (-24 -32 = -56 dBW/200 MHz.
  - For UT: maximum unwanted emission level of (-20 -32) = -52 dBW/200 MHz.

Such a direct translation of the BS and UT unwanted emissions correspond to an solution for which the interference “allocation” is apportioned at equal level between BS and UT (i.e. a 50%/50% apportionment).

Alternatively, if it appears that the unwanted emissions decrease would be more difficult to apply for either BS or UT, depending on design constraints, other apportionment of the interference “allocation” could be envisaged.

Table 9 below provides maximum BS and UT unwanted emissions levels that would result from 2 different apportionment schemes, i.e. 20% BS / 80% UT and 20% BS / 80% UT.

TABLE 9

Possible Apportionment

		Option 1		**Option 2**	
		BS	**UT**	**BS**	**UT**
Case 1	Apportionment (%)	20%	80%	20%	80%
	level (dBW/200 MHz)	-45.37	-47.39	-53.97	-55.99
Case3	Apportionment (%)	80%	20%	80%	20%
	level (dBW/200 MHz)	-51.39	-41.37	-59.99	-49.97

8 Conclusion and discussions

The present analysis has been made under the following assumptions:

1 The unwanted emission at the antenna input (TRP reduced by 3 dB)

2 All the potential losses on the path between mobile equipment and satellite (free space, gas and clutter)

3 The average gain form mobile equipment towards satellites considering ohmic losses.

4 The dimension of satellite footprints and particularly the ratio of the footprint surface on the generic city when the footprint is smaller than the city surface.

5 Option 1: A generic city of radius equal to 8 km with approximatively 16% of urban dense area, together with the deployment parameter provided by WP 5D for outdoor 5G systems (with parameter Ra=7% in urban dense area and 3% in suburban area)

6 Option 2: the global density of equipment per inhabitant and the population density.

7 Only the emission from the first mobile adjacent channel of 200 MHz (24-25-24.45 GHz).

For both options studied, the analysis shows that protection of EESS (passive) sensors in the band 23.6-24 GHz will require a drastic reduction of the 5G IMT systems unwanted emissions.

The analysis also shows that the impact of the BS and UT distributions over the area of studies has an important impact on the results, with a difference of 7.6 dB between Option 1 (generic city scenario with Ra/Rb) and Option 2 (population distribution based scenario).
