Radiocommunication Study Groups

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Annex 36 to Joint Task Group 4-5-6-7 Chairman's Report

PRELIMINARY DRAFT NEW REPORT ITU-R M.[5 350 MHz AERO]

Compatibility studies between radio local area network systems and aeronautical airborne radar systems in the 5 350-5 470 MHz frequency band

1 Introduction

[Joint Task Group 4-5-6-7] This Report considers [considered] compatibility between radio local area network (RLAN) systems and aeronautical airborne radar systems in the 5 350-5 470 MHz frequency band.

2 Conclusions

Studies were based upon various options of RLAN technical and deployment parameters. The study in Annex A found that without any RLAN mitigation measures, separation distances of 53 kilometres to greater than 420 kilometres (line-of-sight) would be required. The study in Annex B indicated that sharing is not feasible when RLAN mitigation techniques are limited to the following: dynamic frequency selection (DFS) (threshold of -64 dBm), predominately indoors (95%) and maximum e.i.r.p. of 200 mW. In addition, the efficiency of the DFS regarding the protection of frequency hopping radars needs to be further studied in order to determine if sharing is feasible.

Compatibility studies in the 5 725-5 850 MHz were not addressed in this report, as no RLAN parameters were agreed and available for study.

Annexes: A, B

ANNEX A

Studies in compatibility of RLAN with aeronautical radiodetermination radars in the frequency band 5 350-5 470 MHz

1 Introduction

[At the meetings of JTG 4-5-6-7] This frequency band was proposed for implementing radio local area network (RLAN) systems and studies in sharing between the RLAN systems and radiodetermination radars were commenced. Taking part in the studies the Russian Federation estimated protection distances required for ensuring interference-free operation of radiodetermination radars in the frequency band 5 350-5 470 MHz. Results of the estimations are presented below.

2 RLAN technical characteristics

Parameters of RLAN systems operating in the frequency band 5 350-5 470 MHz have not been adopted [by JTG 4-5-6-7] yet. Nevertheless [previous JTG 4-5-6-7 meeting discussed contributions which assumed] appropriate RLAN technical characteristics were assumed. Table 1 below presents assumed technical characteristics of RLAN systems as used for the sharing studies. [The assumptions correspond to RLAN technical characteristics described in Document 4-5-6-7/393, Annex 6, Attachments 9 and 10. *Note cannot be referred to in a DNR*]

TABLE 1

Assumed RLAN technical characteristics

Parameter	Value
e.i.r.p., mW	200; 25
Antenna type	omnidirectional
Frequency band, MHz	20; 160
Antenna height above the ground level, m	30
Wall propagation losses, dB	25
Deployment	Outdoor, indoor

3 Technical characteristics of radars operating in the band 5 350-5 470 MHz

The frequency band 5 350-5 470 MHz is used for operation of radiolocation, meteorological and aeronautical radionavigation radars. The radiolocation radars are designed for fulfilling multiple functions, such as:

- tracking the space launch vehicles and aircraft in the course of their development and operational tests;
- maritime and aerospace surveillance;
- environment monitoring (e.g. research of oceanic tides and such natural phenomena as hurricanes);
- Earth remote imaging, etc.

Aeronautical radionavigation radars are mainly used aboard aircraft for avoiding dangerous weather areas, for measuring wind parameters and for providing data to safety of life services (see RR No.**4.10**)

Meteorological radars are used for detecting dangerous weather phenomena such as tornado, thunderstorms and hurricanes. They are also useful for measuring amounts of rainfalls in certain areas to provide for hydrological forecasting of potential floods. Such data are important for warning the population on expected threats and hence they are part of safety of life services.

Technical characteristics of radiodetermination radars operating in the frequency band 5 250-5 850 MHz may be found in Recommendation ITU-R M.1638.

Technical characteristics of air-borne radars operating in the frequency band 5 350-5 470 MHz are shown in Table 2.

TABLE 2

Technical characteristics of airborne radars

Radar type	**Radar B**	**Radar D**	**Radar R**	**Radar S**
Purpose	**Meteorological**	**Aeronautical radionavigation**	**Earth remote sensing and imaging**	**Search and rescue**
3 dB IF receiver pass-band, MHz	0.6	1.0	147	1.0
Noise figure, dB	6	5	4.9	3.5
Antenna gain, dB	37.5	34	26	40
Noise temperature, К	865	627	606	359
Receiver thermal noise power, dBW	-141.4	-140.6	-119.1	-143.0
Protection criteria I/N, dB	- 6			
Acceptable interference power level, dBW	-147.1	-146.6	-126.1	-149.0

4 Sharing study methodology

The studies in compatibility of RLAN systems with air-borne radars estimated effective e.i.r.p. of RLAN transmitter using the following equation:

$$e.i.r.p._{eff} = e.i.r.p._{RLAN} + 10\lg(\Delta F_{RLS} / \Delta F_{RLAN}) \qquad (1)$$

Wall penetration losses were estimated using the following equation:

$$e.i.r.p._{eff} = e.i.r.p._{RLAN} + 10\lg(\Delta F_{RLS} / \Delta F_{RLAN}) - \sigma \text{, dBW;} \qquad (1a)$$

where:

σ - extra attenuation, dB.

Then the receiver thermal noise power was estimated for each of the radars concerned using the following equations:

$$T_N = 290 * \left(10^{\frac{NF}{10}} - 1\right) \text{ К,} \qquad (2)$$

$$N = 10 * \lg(k T_N \, \Delta F_{RLS}) \text{ dBW}, \tag{3}$$

where:

k – Boltzmann constant;

NF – radar receiver noise figure;

ΔF_{RLS} – radar receiver IF pass-band.

The maximum acceptable noise power at radar receiver front end was estimated using he following equation:

$$I_{acc} = N + I/N \text{, dBW.} \tag{4}$$

The estimation of interference caused to air-borne radars used a free space propagation model. In that case the separation distance R required for protecting the radiodetermination radar was estimated using the following equation:

$$R = 10^{\frac{e.i.r.p._{eff} + G_{RLS} + 20\lg(\lambda/4\pi) - I_{acc}}{20}}, \tag{5}$$

where:

G_{RLS} – radar antenna gain, dB;

λ – operational wavelength, m.

The compatibility of ground-based radars with RLAN was estimated using a method of minimum coupled losses (MCL). The required attenuation in a radio path was estimated such as:

$$L = e.i.r.p._{eff} + G_{RLS} - I_{acc} \text{, dB} \tag{6}$$

Then the separation distance *R* was estimated considering minimum required losses. The estimation used a propagation model described in Recommendation ITU-R P.452.

5 Estimation results for feasibility of sharing between RLAN and air-borne radiodetermination radars

Acceptable levels of interference power at airborne Radars B, D, R and S receiver front ends were estimated using equations (2) – (4). The estimates are shown in Table 3 and were used for the estimation of the required separation distances ensuring interference-free operation of airborne radars affected by emissions from a single RLAN outdoor transmitter.

Table 4 shows estimation results for separation distances required for the protection of airborne radars from a single RLAN outdoor transmitter.

TABLE 3

Minimum separation distances required for protection of airborne radars from a single RLAN outdoor transmitter

	Separation distance R, km			
	e.i.r.p.$_{eff}$=-7 dBW		***e.i.r.p.$_{eff}$=-16 dBW***	
ΔF$_{RLAN}$, MHz	20	160	20	160
Radar B	>R$_{LOS}$[*]	215	215	76
Radar D	>R$_{LOS}$	169	169	60
Radar R	71	27	27	24
Radar S	>R$_{LOS}$	>R$_{LOS}$	>R$_{LOS}$	157

[*] R$_{LOS}$ – line-of-sight distance equal to 420 km for a standard flight altitude of 12 000 m without taking refraction into consideration.

Analysis of Table 3 data shows that even in case of a single-source interference the required protection distance would significantly exceed the line-of-sight distance between an airborne radar receiver and an RLAN outdoor transmitter.

Table 4 shows estimation results for separation distances required for the protection of airborne radars from a single RLAN indoor transmitter.

TABLE 4

Minimum separation distances required for protection of air-borne radars from a single RLAN indoor transmitter

	Separation distance R, km			
	e.i.r.p.$_{eff}$=-7 dBW		***e.i.r.p.$_{eff}$=-16 dBW***	
ΔF$_{RLAN}$, MHz	20	160	20	160
Radar B	34	12	12	4
Radar D	27	10	10	3
Radar R	4	2	2	1
Radar S	71	25	25	9

Analysis of the obtained results shows that even with RLAN indoor transmitter and favourable conditions (i.e. attenuation due to building wall would be above 25 dB that is not true in the majority of cases) it would be able to cause unacceptable interference to the operation of airborne radars at distances exceeding several dozen kilometres.

It should be noted that the above estimates of the discussed separation distances were obtained assuming a single-source interference. When considering aggregate interference the separation distances shown in Tables 3 and 4 would be multifold exceeded. The increase in the separation distances would be a function of the deployment density related to RLAN transmitters and their operation modes.

For example, when only a hundred RLAN indoor transmitters operate within an urban ward area the distance required for ensuring the protection of an airborne radar at the altitude of 10 000 metres would exceed line-of-sight distance (>420 kilometres).

Based on the above a conclusion may be drawn that sharing between RLAN systems and airborne radiodetermination radars seems to be extremely difficult to implement.

6 Conclusions

The conducted compatibility studies show that to ensure protection of airborne radar receivers from emissions produced by both indoor and outdoor RLAN transmitters would require separation distances exceeding those of line-of-sight.

With due regard of levels of aviation activities and a variety of authorized international air routes a conclusion may be drawn that it would be impractical to provide for sharing between RLAN and airborne radars in the frequency band 5 350-5 470 MHz.

Based on the above it is proposed:

– to exclude the frequency band 5 350-5 470 MHz from consideration as a candidate band for deployment of the proposed RLAN systems.

ANNEX B

Compatibility studies between RLAN systems and aeronautical airborne radar systems in the 5 350-5 470 MHz frequency bands

1 Introduction

Radio local area networks sharing compatibility studies have been performed for the frequency range 5 350-5 470 MHz, which is comprised of two frequency bands: 5 350-5 460 MHz and 5 460-5 470 MHz. The 5 350-5 460 MHz band is allocated to the Earth exploration-satellite (active), radiolocation, aeronautical radionavigation, and space research (active) services. The 5 460-5 470 MHz frequency band is allocated to the Earth exploration-satellite (active), radiolocation, radionavigation, and space research (active) services.

This Report provides results of a study on the compatibility of RLAN systems operating in the 5 350-5 470 MHz frequency bands with incumbent primary airborne radiodetermination systems.

2 Background

This analysis uses the dynamic frequency selection (DFS) procedures and modelling to determine DFS suitability in the 5 350-5 470 MHz bands.

In particular, this study assessed whether DFS utilizing the current threshold (-64 dBm) was sufficient to protect airborne radiodetermination systems operating in the 5 350-5 470 MHz bands while not exceeding the airborne receiver protection threshold of I/N = -6 dB (as stated in Recommendation ITU-R M.1638).

3 Technical characteristics

3.1 Technical characteristics of airborne radiodetermination systems

The technical characteristics for the airborne radiodetermination systems considered in this analysis are shown in Table 1 (taken from Rec. ITU-R M.1638).

TABLE 1

Radar technical characteristics

Characteristics	**Radar 9 (S)**	**Radar 16 (D)**	**radar 17 (B)**
Function	Search	Aeronautical radionavigation	Multifunction
Tuning range (MHz)	5 250-5 725 (5400)	5 440	5 370
Transmitter peak power into antenna (kilowatts)	0.1 – 0.4 (0.1)	0.200	70
Modulation	unmodulated Pulse	N/Av	N/Av
Pulse Width (µs)	1	1-20	6.0
Pulse repetition rate (pps)	200-1 500	180-1 440	200
Antenna main beam gain (dBi)	30-40	34	37.5
Antenna gain pattern	M.1851 (COS)	M.1851 (COS)	M.1851 (COS)
Antenna elevation beamwidth (deg)	2-4 40 dBi gain (2) 30 dBi gain (4)	3.5	4.1
Antenna azimuthal beamwidth (deg)	2-4 40 dBi gain (2) 30 dBi gain (4)	3.5	1.1
Antenna motion (horizontal)	Continuous	Continuous	180° Sector
Horizontal scan rate (deg/s)	20	20	24
Antenna motion (vertical)	(Fixed at 5° below horizontal)	Sector (between -10° and +10° above horizontal)[1]	(Fixed at 5° below horizontal)
Vertical scan rate (deg/s)	N/A	45	N/A
Antenna polarization	N/Av	Horizontal	Horizontal
Antenna height (m)	9000	9000	9000
Receiver Intermediate Frequency 3 dB bandwidth (MHz)	1	1.0	0.6
Receiver noise figure (dB)	3.5	5	6
Noise Power (dBm)*	-110.5	-109.0	-110.2
Receiver Protection Threshold (dBm)* Based on an I/N =-6 dB	-116.5	-115.0	-116.2
N/A (not applicable) N/Av (not available)			

* The values contained in parenthesis are the ones used in this study

** These values are calculated based on the values in Recommendation ITU-R M.1638.

A 2 dB insertion loss for the receivers is included in the analysis.

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[1] Recommendation ITU-R M.1638 did not specify these limits so they were obtained from RTCA DO-173 “Minimum Operational Performance Standards for Airborne Weather and Ground Mapping Pulsed Radars”.

3.1.1 Description of Recommendation ITU-R M.1851 antenna pattern

Since Radar 17 uses a fan beam in which horizontal and vertical beamwidths are significantly different from each other, this study uses the cosine pattern of Recommendation ITU-R M.1851 for the antenna pattern because it is a function of beamwidth. In the analysis, the beamwidth used for the Recommendation ITU-R M.1851 pattern is calculated for each link as the half power beamwidth in the direction of the RLAN device. The following two tables are taken from Recommendation ITU-R M.1851 and describe the pattern used, which is plotted in Figure 1.

TABLE 2

Recommendation ITU-R M.1851 cosine directivity pattern

Relative shape of field distribution $f(x)$ where $-1 \leq x \leq 1$	Directivity pattern $F(\mu)$	θ_3 half power beam-width (degrees)	μ as a function of θ_3	First side-lobe level below main lobe peak (dB)	Proposed mask floor level (dB)
COS(π*x/2)	$\frac{\pi}{2}\left[\frac{\cos(\mu)}{\left(\frac{\pi}{2}\right)^2-\mu^2}\right]$	$68.8\left(\frac{\lambda}{l}\right)$	$\frac{\pi \cdot 68.8 \cdot \sin(\theta)}{\theta_3}$	−23	−50

TABLE 3

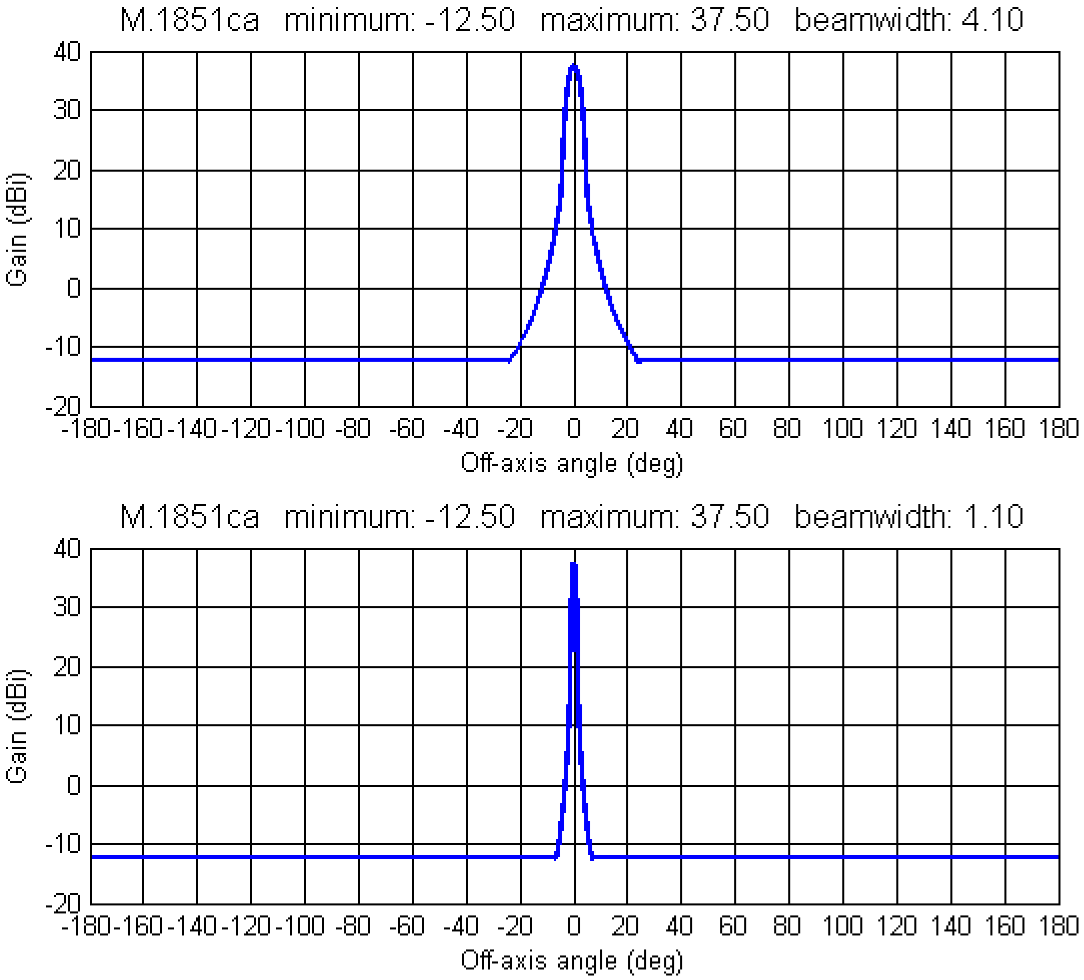
Recommendation ITU-R M.1851 cosine mask equation beyond pattern break point

Pattern type	Mask equation beyond pattern break point where mask departs from theoretical pattern (dB)	Peak pattern break point where mask departs from theoretical pattern (dB)	Average pattern break point where mask departs from theoretical pattern (dB)	Constant added to the peak pattern to convert it to average mask (dB)
COS	$-17.51 \cdot \ln\left(2.33 \cdot \frac{\lvert\theta\rvert}{\theta_3}\right)$	−14.4	−20.6	−4.32

3.1.2 Antenna patterns used in this study

FIGURE 1

Radar 17 elevation and azimuth “cuts” of the antenna beam



3.2 Mobile system parameters and deployment

The RLAN devices will be randomly distributed over three regions: urban, suburban, and rural. The three regions exist within concentric circles as shown in Figure 2.

FIGURE 2

RLAN Device Deployment Regions

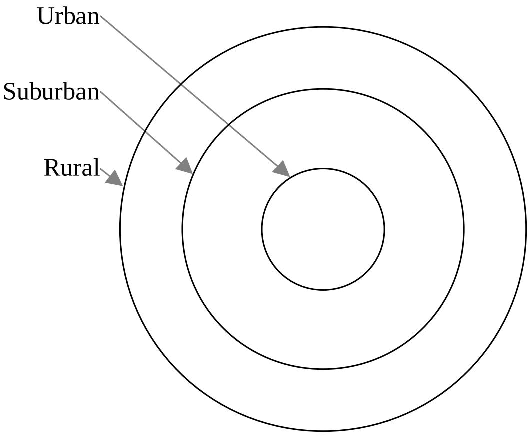


Table 4 provides the radius of each RLAN deployment zone.

TABLE 4

Deployment zones

RLAN deployment region	Radius from the centre (km)
Urban	0 to 5
Suburban	5 to 15
Rural	15 to 30

The population used for the baseline is 5.25 million people. Table 5 provides the population distribution within each zone in the RLAN device environment.

TABLE 5

Population zones

Total Population	Population split	Percent	Population in Zone
5 250 000	Urban	30%	1 575 000
	Suburban	50%	2 625 000
	Rural	20%	1 050 000

Number of on-tune, active RLAN devices

The following methodology was used to determine the number of on-tune active RLAN devices:

Step 1: Determine base population size by zone.

Step 2: Apply a Busy Hour factor to determine the base population by zone.

Step 3: Apply Market Factor (percent of users with devices) by zone.

Step 4: Apply System Factor (determine the number of cells by zone).

Step 5: Apply Activity Factor (percent of cells operating) by zone.

Step 6: Apply Bandwidth Factor (percent of devices on-tune based on bandwidth distribution model).

Using the six step methodology, the number of on-tune active RLAN devices per 20 MHz is forecasted in Table 6.

TABLE 6

RLAN on-tune, active devices

	Population	**Step 2 Busy Hour Factor**	**Busy Hour Population**	**Step 3 † Market**	**Step 4 † System**	**Step 5 † Activity**	**Step 6 * Bandwidth**
Urban	1 575 000	71%	1 118 250	894 600	62 622	15 656	
Suburban	2 625 000	64%	1 680 000	1 344 000	94 080	23 520	
Rural	1 050 000	47%	493 500	246 750	49 350	4 935	
Total						44 111	5 186 Per 20 MHz

The market, system, and activity factors used in the calculations are shown in Table 7.

TABLE 7

Market/System/Activity factors

†	Market	System	Activity
Urban	80%	7%	25%
Suburban	80%	7%	25%
Rural	50%	20%	10%

The distribution of channel bandwidths for the number active RLAN devices in a 20 MHz bandwidth is shown in Table 8.

TABLE 8

Distribution of RLAN channel bandwidths

Start Channel	*	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz**
5 150 MHz	Percent	10%	25%	50%	15%
End Channel	Devices	4411	11028	22056	6616
5 850 MHz	Channels	35	17	8	4
	On-tune	126	649	2757	1654

Technical parameters

The baseline will include RLAN devices employing omni-directional antennas. For each time step, the RLAN device power, operating bandwidth, and height will be randomly determined.

The RLAN device equivalent isotropically radiated power (e.i.r.p.) level distribution for the baseline is shown in Table 9.

TABLE 9

RLAN power distribution[2]

RLAN e.i.r.p. Level	**200 mW (Omni-Directional)**	**80 mW (Omni-Directional)**	**50 mW (Omni-Directional)**	**25 mW (Omni-Directional)**
RLAN device percentage (Indoor operation)	18%	26%	14%	37%
RLAN device percentage (Outdoor operation)	0.9%	1.3%	0.8%	2%

This study will consider a limit on the e.i.r.p. of 200 mW to determine sharing feasibility. If higher power levels are submitted, additional studies will be required.

The RLAN device transmitter bandwidth distribution for the baseline is shown in Table 10.

TABLE 10

Bandwidth distribution

RLAN transmitter bandwidth	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz**
RLAN device percentage	10 %	25 %	50 %	15 %

The RLAN antenna pattern in the azimuth orientations is omni-directional. The RLAN device elevation antenna pattern is described in Table 11. The angle θ is with respect to the horizontal. +θ is below the horizontal.

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[2] The e.i.r.p. levels and percentages are derived from: 1) predictions of shipped devices for various devices classes; 2) expected e.i.r.p. of the device classes; 3) matching the percentages from the sum of the rows in device distribution and 4) traffic mix in a Basic Service Set between Access Point and client.

TABLE 11

RLAN device elevation antenna pattern

Elevation angle θ (Degrees)	Gain (dBi)
45 < θ ≤ 90	-4
35 < θ ≤ 45	0
0 < θ ≤ 35	3
–15 < θ ≤ 0	-1
–30 < θ ≤ –15	-4
–60 < θ ≤ –30	-9
–90 < θ ≤ –60	-8

Table 12 provides the distribution of RLAN device antenna heights for each RLAN deployment zone.

TABLE 12

Distribution of RLAN device antenna heights

RLAN deployment zone	Antenna height (meters)
Urban	1.5 to 28.5 (3 meter increments)
Suburban	1.5, 4.5
Rural	1.5, 4.5

For omni-directional RLANs the antenna heights are randomly selected using a uniform probability distribution from the set of floor heights at 3 meter steps specified in Table 13 for the urban, suburban and rural zones.

The analysis examines sharing with a scenario comprised of 95 percent of the RLAN devices operating indoors and 5 percent operating outdoors.

4 Radar deployments

The analysis considers airborne radars.

4.1 Airborne radars

In the simulation, the airborne radar starts 450 kilometres from the RLAN distribution centre and flies through the centre to 100 kilometres beyond the centre. Simulations begin with the radar antenna azimuth set to 0. If there is vertical motion of the antenna, the antenna elevation is also set to 0 at the start of the simulation.

5 Analysis

5.1 Assumptions:

a) **RLAN totals, densities and distribution**: The RLAN characteristics used in this study are the latest available or projected characteristics. For example, this study uses a total RLAN population of 44 111.

b) **Propagation modelling**: The propagation model used is Recommendation ITU-R P.528 with a percentage of time of 50. This analysis also includes an additional reduction for indoor RLANs due to building loss. This additional loss is a Gaussian random variable with mean 17 dB and standard deviation 7 dB. Any values that would fall below 0 dB are set to 0 dB. See equation 5.

c) **Clutter loss:** This study also includes the clutter loss of Recommendation ITU-R P.452-15 equations 57 and 57a to account for the effects of ground cover in cases where the obstacles could typically intercede on the interfering signal path. For emitters in the rural area the “High crop fields” clutter category of Table 4 of that Recommendation is utilized. For the suburban area, “Suburban”, is utilized and for the urban area, “Urban”. These clutter losses are shown in Table 13, and they are applied only in cases where the elevation angle from the RLAN to the radar is less than the associated maximum elevation angle specified in Table 14. The latter maximum elevation angles were computed using the clutter heights and distances specified in Table 4 of Rec. ITU-R P.452, and negative elevation angles were truncated at 0° because they will not occur in this analysis. No clutter loss is assumed when the elevation angle of the interfering signal path exceeds the applicable maximum elevation angle shown in Table 14.

TABLE 13

Clutter losses values used in study

Ht (m)	Clutter Loss (dB)		
	High crop fields	**Suburban**	**Urban**
1.5	17.3	19.6	19.7
4.5	0[3]	16.0	19.6
7.5	These cases do not occur given the assumed heights of RLAN devices (see Table)		18.8
10.5			15.1
13.5			6.8
16.5			1.3
19.5			0
22.5			0
25.5			0[3]
28.5			0

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[3] Any values that would fall below 0 dB are set to 0 dB.

TABLE 14

Elevation angles below which clutter losses could typically occur

Ht (m)	**Maximum Elevation Angle (degrees)**		
	High crop fields	**Suburban**	**Urban**
1.5	1.4	16.7	42.8
4.5	0.0	10.2	37.8
7.5	These cases do not occur given the assumed heights of RLAN devices (see Table)		32.0
10.5			25.4
13.5			18.0
16.5			9.9
19.5			1.4
22.5			0.0
25.5			0.0
28.5			0.0

d) **RLAN channel bandwidths:** This study uses RLAN channel bandwidths of 20, 40, 80 and 160 MHz.

e) **RLAN DFS detection threshold and bandwidths:** This study uses a DFS detection threshold of -64 dBm and DFS detection bandwidth of 20 MHz.

f) **Probability of Coincidence (POC):** The value used for the POC to detect the airborne system pulse width is 1(i.e. 100%).

5.2 Methodology

5.2.1 DFS detection model description

Dynamic Frequency Selection (DFS) is a mechanism that dynamically detects signals from other systems and avoids co-channel operation with these systems. When the DFS detection threshold is exceeded for a particular RLAN, the model generates a uniform random number between 0 and 1 and compares it to the probability of a radar pulse overlapping with an RLAN burst rest “listening” period, which in this model is referred to as the probability of coincidence (POC). The DFS detection occurs when coincidence has been declared and when the received power from the radar in the RLAN detector exceeds the detection threshold. The POC is based on the packet length and the timing of the RLAN transmissions. Recommendation ITU-R M.1652 describes the parameters and methodology for calculating the POC for the DFS RLAN devices.[4] However, for the purpose of this analysis, a POC of 1 (100%) was used.

This received signal level from the radar at the input of the RLAN receiver is evaluated by using Equation 1.

$$I^{RLAN} = P_{RADAR} + G_{RADAR} + G_{RLAN} - L_{Radar} - L_P - L_C - L_A - FDR \tag{1}$$

Where:

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[4] Recommendation ITU-R M.1652, *Dynamic Frequency Selection (DFS) in Wireless Access Systems Including radio local area networks for the Purpose of Protecting the Radiodetermination Service in the 5 GHz Band* (2003), at Annex 4.

I^{RLAN} = Received interference power at the output of the RLAN antenna (dBm);

P_{RADAR} = Peak power of the radar (dBm);

G_{RADAR} = Antenna gain of the radar in direction of the RLAN (dBi);

G_{RLAN} = Antenna gain of the RLAN in direction of the radar (dBi);

L_{RADAR} = Radar transmit insertion loss (dB);

L_P = Propagation loss (dB);

L_C = Clutter loss due to ground cover (dB);

L_A = Additional building loss (dB);

FDR = Frequency dependent rejection (dB).

If the receiver sampling rate is sufficiently high to capture the peak radar pulse power, the FDR in Equation 1 is zero; otherwise the FDR used is the following:

$$FDR = \max\left(0, 20\log_{10}\left(\frac{B_{tx}}{B_{rx}}\right)\right) \tag{2}$$

Where:

B_{tx} = Bandwidth of the radar transmitter;

B_{rx} = Bandwidth of the RLAN DFS receiver.

5.2.2 Analysis model description

Equation 1 is calculated for each RLAN in the distribution. The value obtained is then compared to the DFS detection threshold under investigation. Any RLAN for which the threshold has been exceeded will begin to move to another channel, and thus is not considered (for the remainder of the simulation) in the calculation of interference to the radar, as given by Equation 3.

$$I^{RADAR} = P_{RLAN} + G_{RLAN} + G_{RADAR} - L_{RADAR} - L_P - L_C - L_A - FDR \tag{3}$$

Where:

I^{RADAR} = Received interference power at the input of the radar receiver (dBm);

P_{RLAN} = Power of the RLAN (dBm);

G_{RLAN} = Antenna gain of the RLAN in the direction of the radar (dBi);

G_{RADAR} = Antenna gain of the radar in the direction of the RLAN (dBi);

L_{RADAR} = radar receiver insertion loss (dB);

L_P = Radiowave propagation loss (dB);

L_C= Clutter loss due to ground cover (dB);

L_A= Additional building loss losses (dB);

FDR = Frequency dependent rejection (dB).

Using Equation 3, the values are calculated for each RLAN being considered in the simulation that has not detected energy from the radar in excess of the DFS detection threshold. These values are then used in the calculation of the aggregate interference to the radar by the RLANs using Equation 4.

$$I^{AGG} = 10\log[\sum_{j=1}^{N} I_j^{Radar}] + 30 \tag{4}$$

Where:

I^{AGG} = Aggregate interference to the radar from the RLAN devices (dBm);
N = Number of RLANs remaining in the simulation;
I^{RADAR} = Interference into the radar from an individual RLAN device (watts).

It is necessary to convert the interference power calculated in Equation 2 from dBm to watts before calculating the aggregate interference seen by the radar using Equation 3.

The propagation model used in the analysis was Recommendation ITU-R P.528.

In addition to the propagation loss, this analysis includes an additional reduction due to building losses. This loss is represented by a Gaussian random variable with mean 17 dB and standard deviation 7 dB. After these values are generated any values below 0 dB are set to 0 dB.

```
building_att_dB= Max(0,17+7*randn)
```
(5)

Note: The Matlab function `randn(n)` returns a pseudorandom value drawn from the standard normal distribution.

This loss would apply to the 95% of RLAN devices operating indoors. No building losses would be included for the 5% devices operating outdoors.

In this analysis, the RLAN transmitters will be operating co-frequency with the radar receivers and the FDR is computed using Equation 6.

$$FDR = \max\left(0, 10\log_{10}\left(\frac{B_{tx}}{B_{rx}}\right)\right) \tag{6}$$

Where:

B_{tx} = Bandwidth of the RLAN transmitter;

B_{rx} = Bandwidth of the radar receiver.

6 Results

6.1 Radar 9 analysis results

Figure 3 shows the results for Radar 9 operating in a 1 MHz bandwidth. The first graph shows the number of RLANs that are turned off as a result of DFS detection process during the simulation. The second and third graphs show the aggregate received power from the RLANs at the output of the radar receiver as a function of simulation time and distance. The red line is the receiver protection threshold. The fourth graph is a function of distance showing the maximum received power level at the output of any of the RLAN receivers that are not turned off. The red line is the DFS detection threshold (-64 dBm). The maximum aggregate interference power at the input of the radar receiver is 15.8 dB above the airborne receiver protection threshold and it happened after the radar had moved 341.4 kilometres from the start. The analysis results for each radar system are presented as a series of these four graphs. The following table explains the title in each figure.

TABLE 15

Summary of Parameters

el:-5	The antenna elevation angle was 5° below the horizontal at the end of the simulation.
Dir:0	There were no RLANs with directional antennas
Omni:5186	There were 5 186 RLANs with omni-directional antennas
DFS(off):-64	DFS turned any RLAN off (that exceeded a detection threshold of -64 dBm) for the remainder of the simulation.
poc:1	The probability of coincidence was 1 (i.e. 100%).
distctr@450	The radar started 450 km away from the RLAN distribution centre
P528	The propagation model used was Recommendation ITU-R P.528
#e:118	The number of interference events was 118
le:1.5	The longest event was 1.5 seconds
RLAN transmit bandwidths were 20, 40, 80, and 160 MHz occurring in exactly the percentages of total RLANs listed, respectively	
The detection bandwidth was 20 MHz for 100% of the RLANs.	
Max overage:15.8323 dB@341.4492 km	The maximum over threshold was +15.8323, which occurred when the radar was at 341.4492 km in the 3rd graph.
outdoor:0.04994	Exactly 4.994% of the RLANs were outdoor

Figure 4 is provided to verify that random distributions in the study are as expected. It shows normalized histograms of additional loss due to building attenuation, and emitter maximum e.i.r.p. and antenna heights used. The additional loss shows more than 5% of emitters at 0 dB because it includes not only the 5% of devices which are outdoors but also the indoor devices which fell below 0 dB when the Gaussian random variable was cast.

FIGURE 3

Radar 9 results, 40 dBi, 9 km

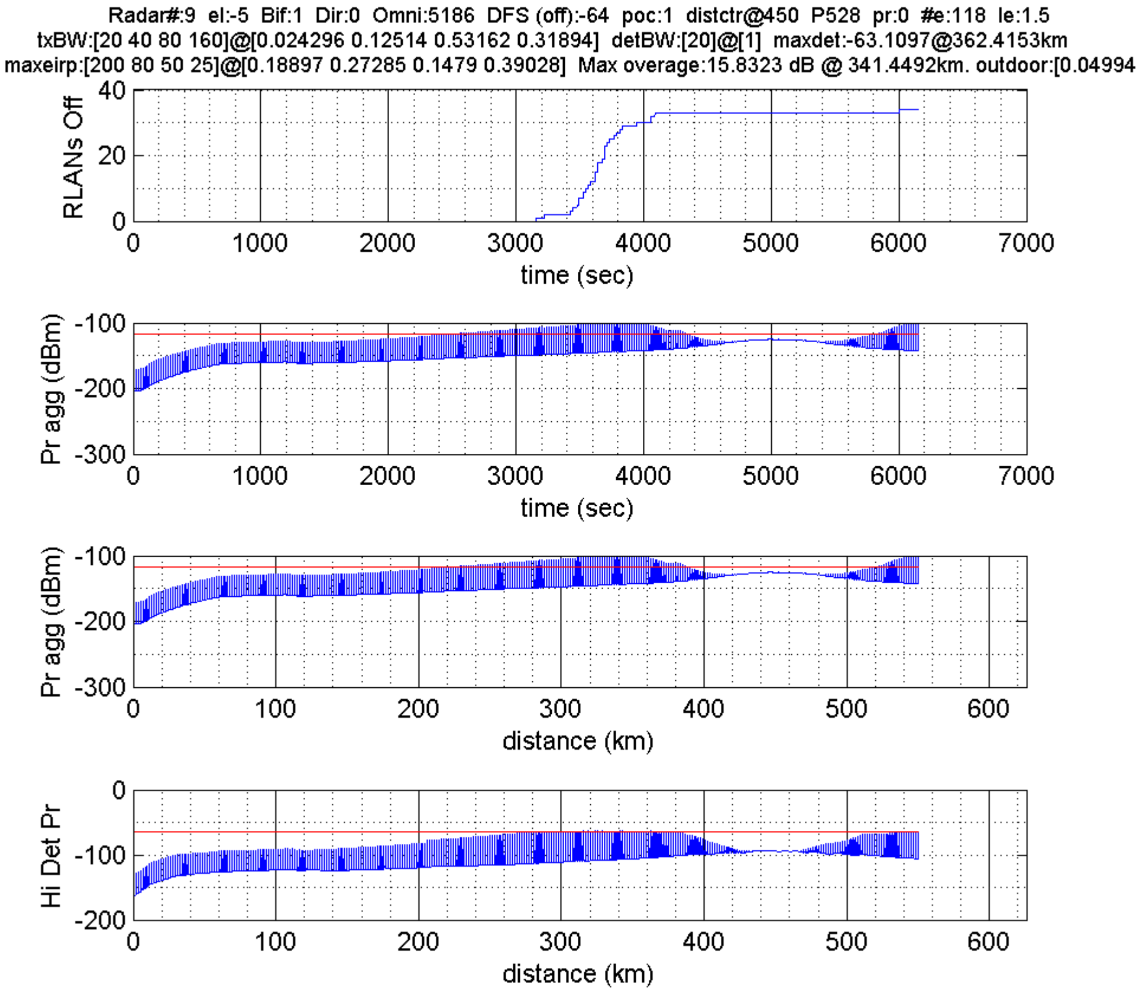


FIGURE 4

Additional Losses

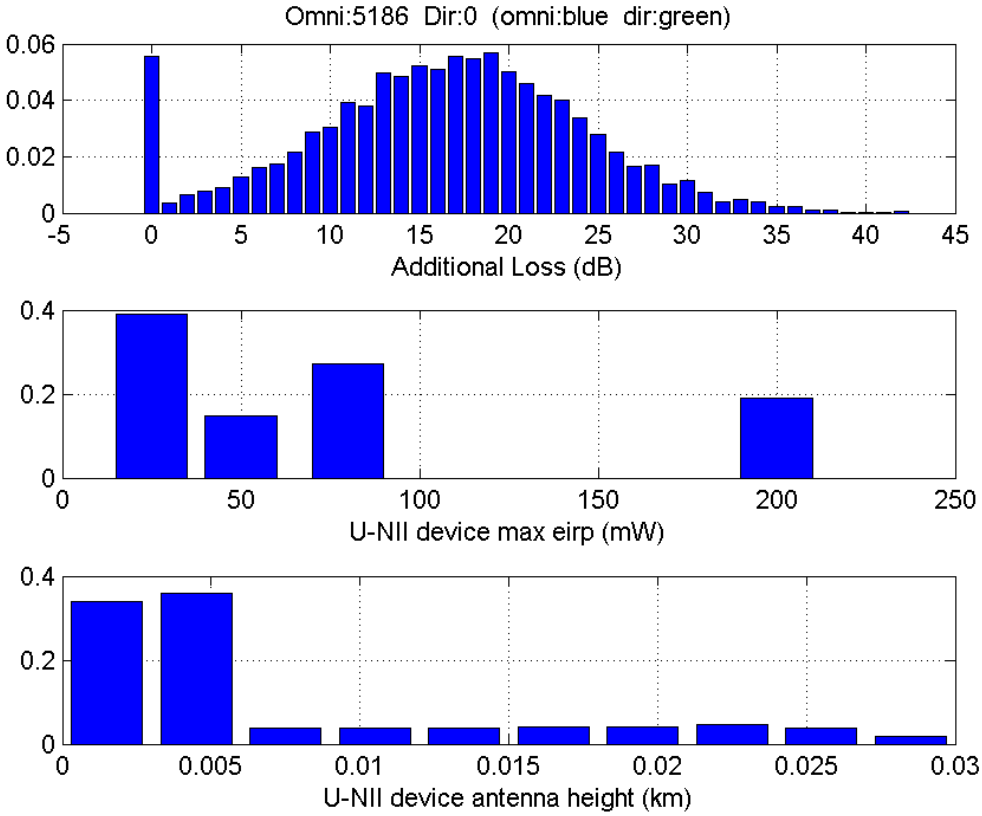


FIGURE 5

Radar 9 results, 30 dBi, 9 km

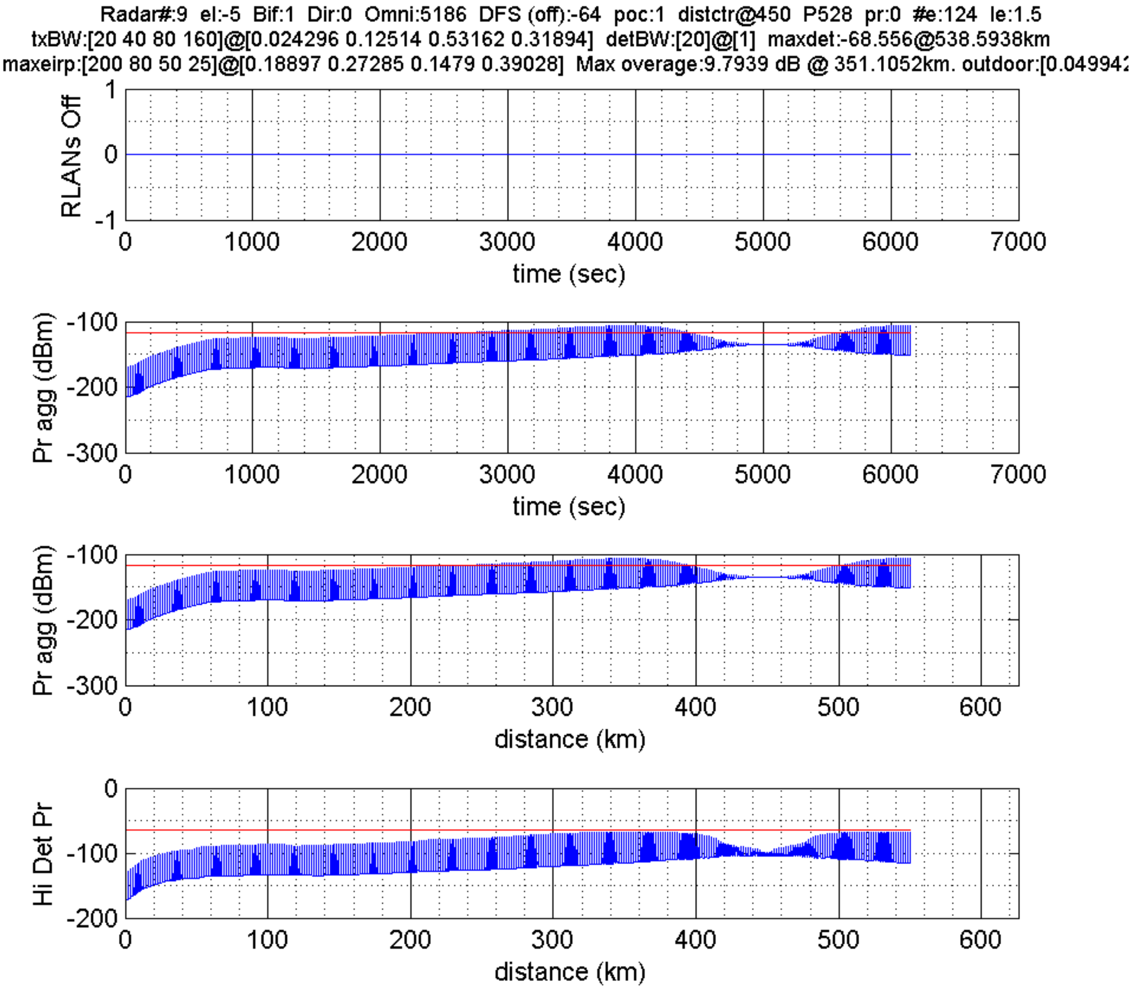
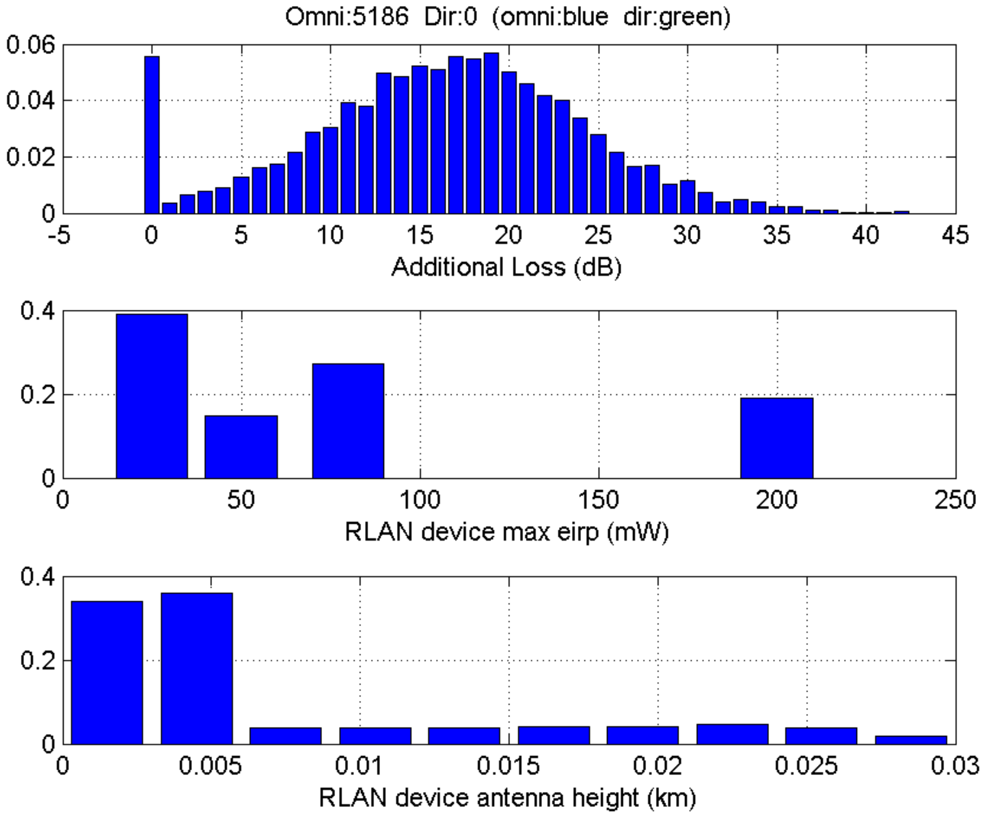


FIGURE 6

Random variables associated with RLAN emitters for Radar 9



6.2 Radar 16 Analysis Results

FIGURE 7

Radar 16 results, 9 km

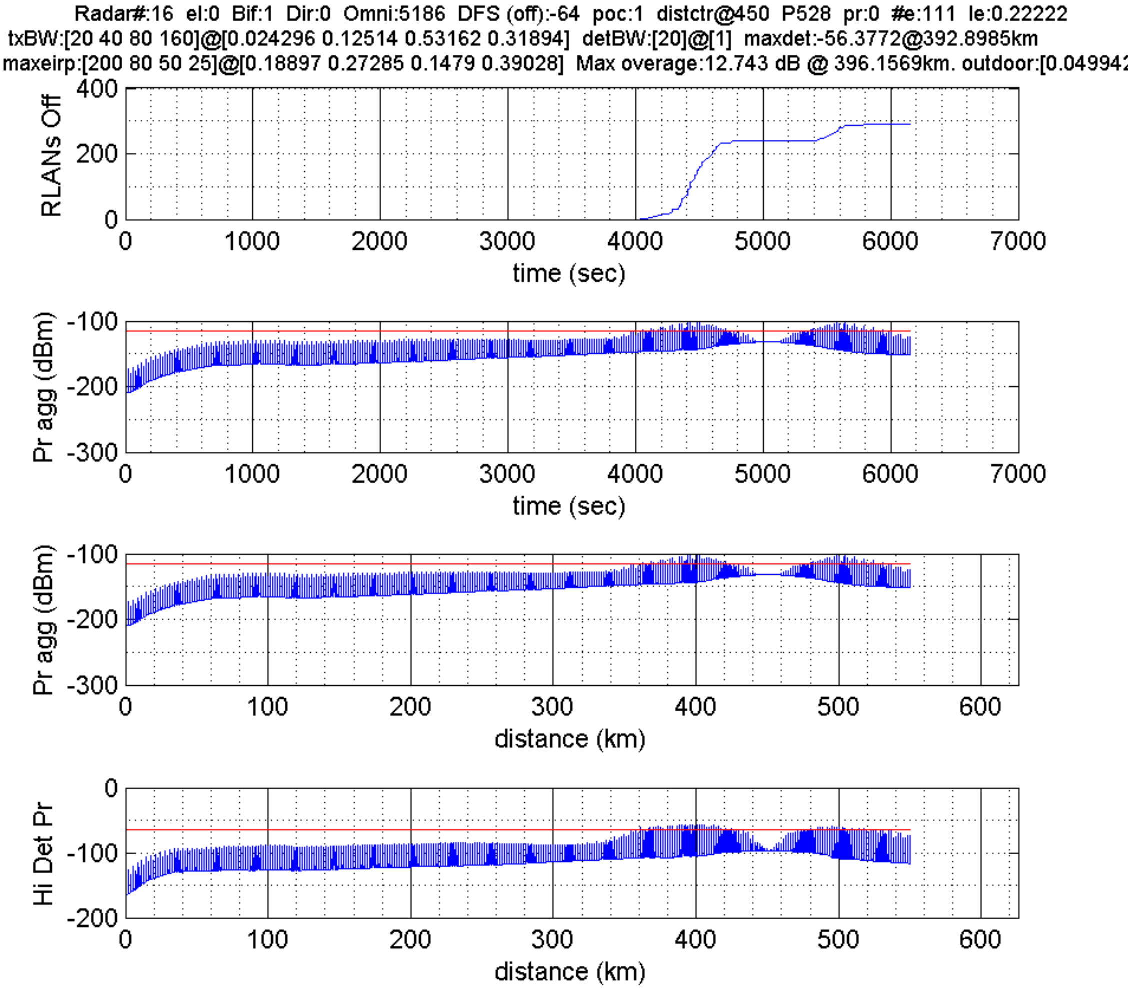
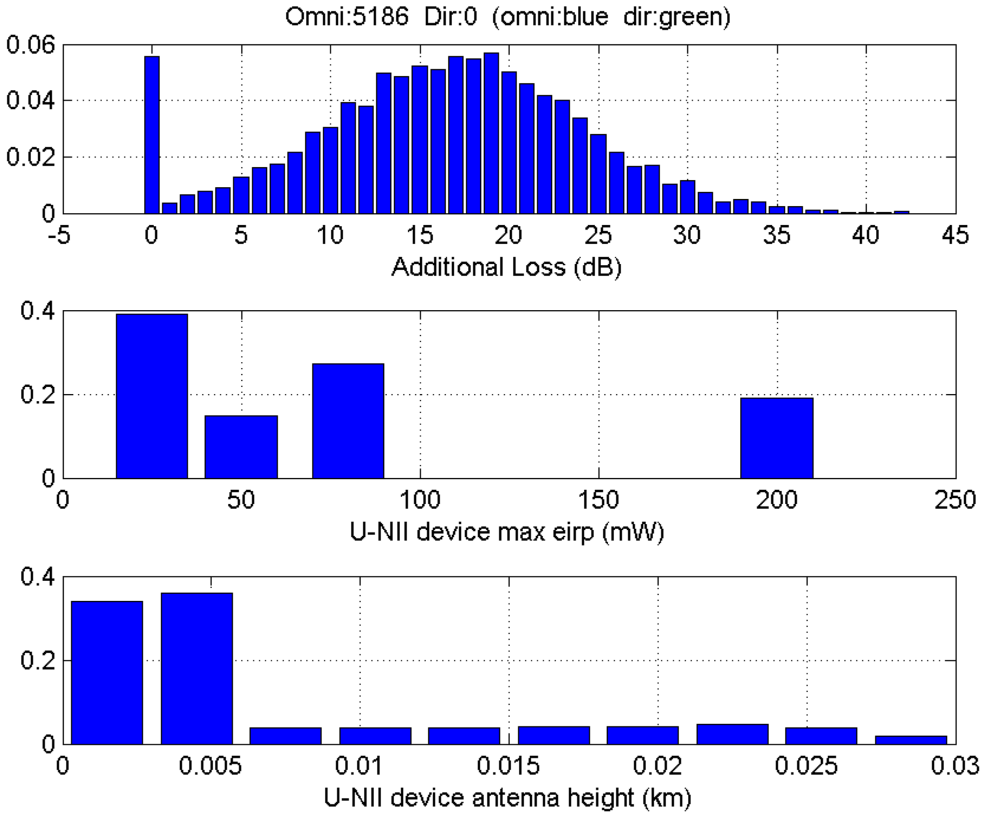


FIGURE 8

Random variables associated with RLAN emitters for Radar 16



6.3 Radar 17 Analysis Results

FIGURE 9

Radar 17 results, 9 km

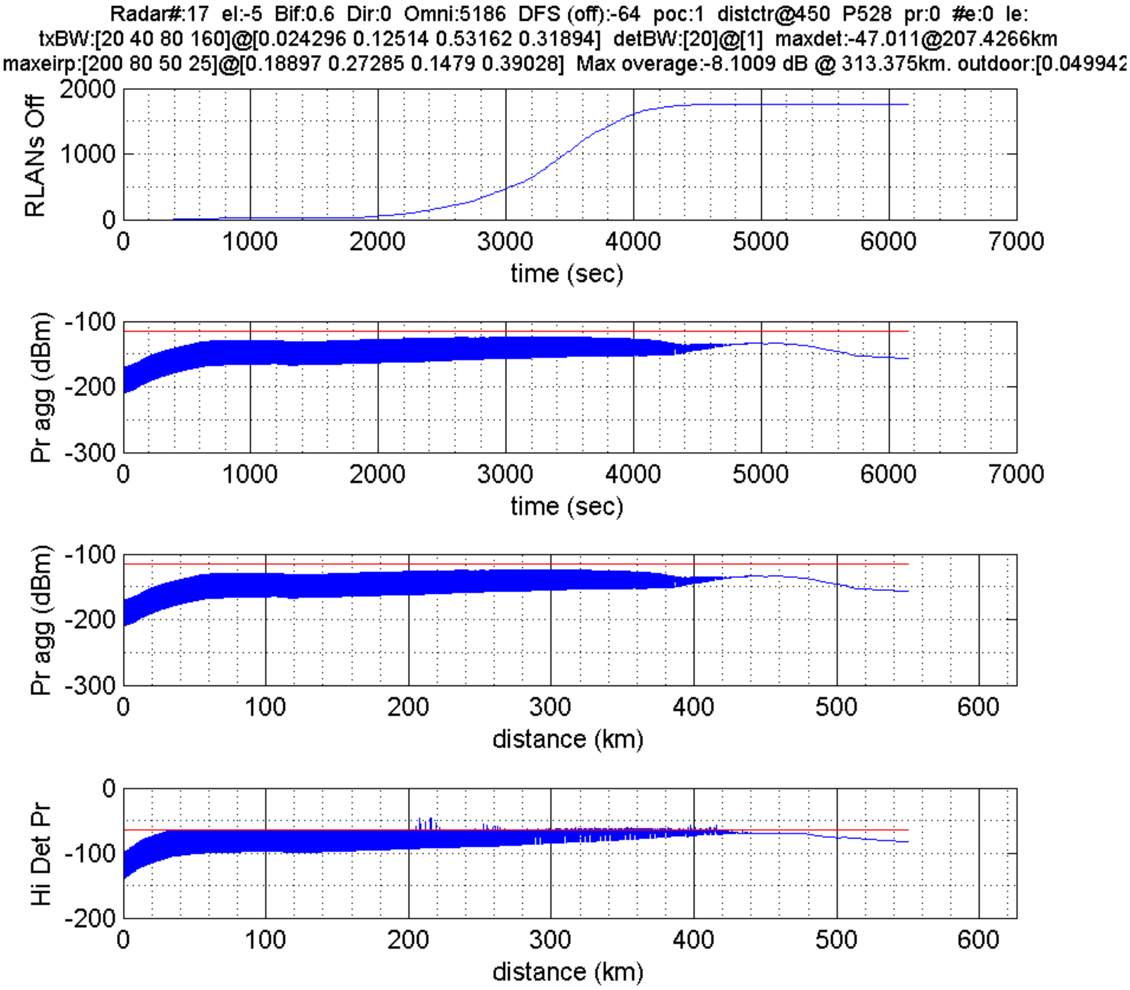
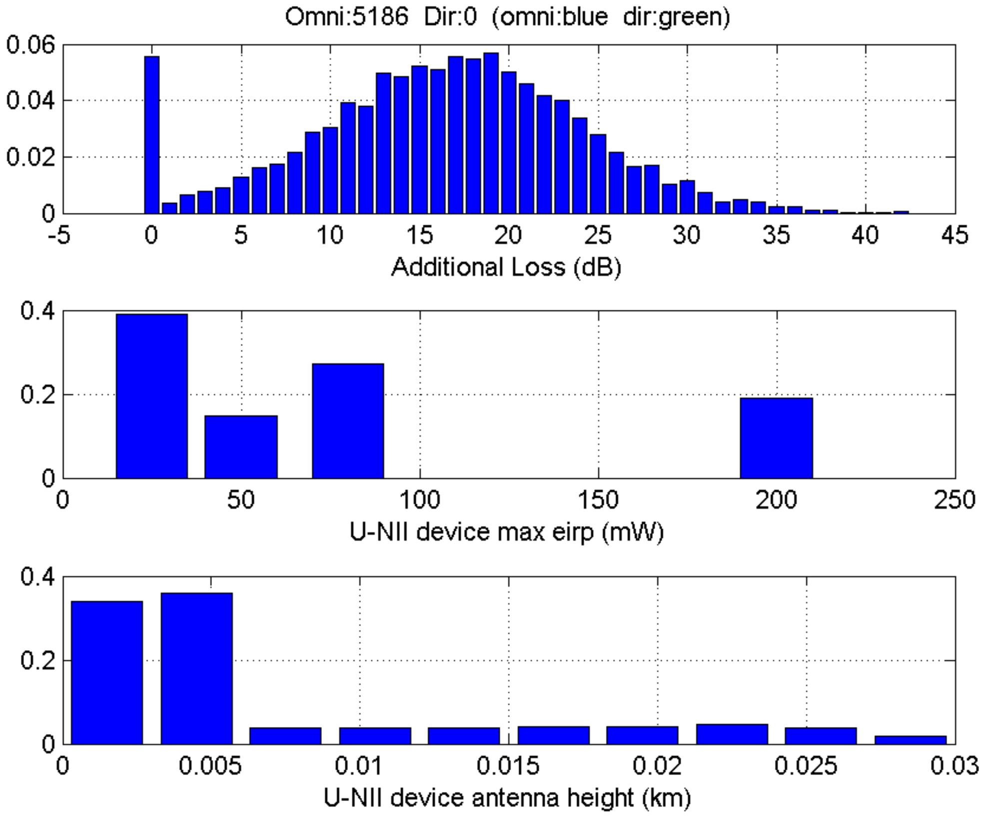


FIGURE 10

Random variables associated with RLAN emitters for Radar 17



Conclusions

The results of this study are summarized in Table 16. Based on the technical and deployment characteristics and assumptions considered in this study, the aggregate interference from the RLAN emitters will exceed the airborne receiver protection threshold for Radar 9 by up to 15.8 dB, and will exceed the protection threshold for Radar 16 by up to 12.7 dB. RLAN emitters do not exceed the protection threshold for Radar 17.

The mitigation techniques assumed in this study are DFS (threshold of 64 dBm), predominately indoors (95%) and low power (maximum e.i.r.p. of 200 mW). Sharing between RLANs and airborne radiodetermination systems in the 5 350-5 470 MHz frequency bands is not feasible when mitigation is limited to these techniques.

If different transmit powers or detection levels are applied, or if additional mitigation techniques are developed, the results may be different. Additional studies would be required to evaluate any other mitigation measures to determine their efficacy for RLAN sharing with airborne radiodetermination systems.

TABLE 16

Summary of results

Radar Identifier	Maximum over protection threshold (dB)
Radar 9, 40 dBi, 9 km	+15.8
Radar 9, 30 dBi, 9 km	+9.8
Radar 16, 9 km	+12.7
Radar 17, 9 km	-8.1

Note: The values of 40 dBi or 30 dBi refer to the radar antenna main beam gain, and the value of 9 kilometres refers to the radar altitude.