



Recommendation ITU-R M.1652
(06/2003)

**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**

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

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RECOMMENDATION ITU-R M.1652*

Dynamic frequency selection (DFS)¹ in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band

(Questions ITU-R 212/8 and ITU-R 142/9)

(2003)

The ITU Radiocommunication Assembly,

considering

- a) that harmonized frequencies in the bands 5 150-5 350 MHz and 5 470-5 725 MHz for the mobile service would facilitate the introduction of wireless access systems (WAS) including radio local area networks (RLANs);
- b) that there is a need to protect the radars in the radiodetermination service operating in the bands 5 250-5 350 and 5 470-5 725 MHz;
- c) that in many administrations, the ground-based meteorological radars are extensively deployed and support critical weather services;
- d) that procedures and methodologies to analyse compatibility between radars and systems in other services are provided in Recommendation ITU-R M.1461;
- e) that representative technical and operational characteristics of radiolocation, radio-navigation and meteorological radars are provided in Recommendation ITU-R M.1638;
- f) that Recommendation ITU-R M.1313 provides typical technical characteristics of maritime radionavigation radars in, *inter alia*, the band 5 470-5 650 MHz;
- g) that WAS including RLANs as described in Recommendation ITU-R M.1450 are capable of operating both indoor and outdoor;
- h) Report ITU-R M.2034 which addresses the impact of certain detection requirements of the DFS on the performance of WAS,

recognizing

- a) that the band 5 250-5 350 MHz is allocated to the radiolocation service on a primary basis; that the band 5 250-5 350 MHz is also allocated to the Earth exploration-satellite service (EESS) (active) on a primary basis;
- b) that the band 5 470-5 650 MHz is allocated to the maritime radionavigation service on a primary basis;

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

¹ DFS is a general term used in this Recommendation to describe mitigation techniques that allow, amongst others, detection and avoidance of co-channel interference with respect to radar systems.

- c) that the band 5 350-5 650 MHz is allocated to the radiolocation service on a secondary basis;
- d) that ground-based radars used for meteorological purposes are authorized to operate in the band 5 600-5 650 MHz on a basis of equality with stations in the maritime radionavigation service (see No. 5.452 of the Radio Regulations (RR));
- e) that the band 5 650-5 725 MHz is allocated to the radiolocation service on a primary basis;
- f) that administrations may take account of detailed information on actual radar deployment when developing guidance for the use of DFS in WAS in consultation with potentially affected administrations,

noting

- a) that the high RF power level and the receiver sensitivity of radars in the radiodetermination service in conjunction with the expected high density of WAS including RLANs would, in general, not enable compatible operation of WAS including RLANs and radars on a co-channel basis in the absence of mitigation techniques;
- b) that WAS including RLANs could be deployed in these bands as licence-exempt devices, consequently making control of their deployment density more difficult;
- c) that there are various standards for RLAN specifications;
- d) that administrations may consider procedures to confirm the ability of interference avoidance mechanisms to function correctly in the presence of the radar systems deployed in this band,

recommends

- 1** that, in order to facilitate sharing with radars, mitigation techniques as described in Annex 1 be implemented by WAS, including RLANs in the bands used by radars at 5 GHz;
- 2** that the mitigation techniques comply with the detection, operational and response requirements as given in § 2 of Annex 1;
- 3** that the methodologies given in Annexes 4, 5, 6 and 7 can be used by administrations when conducting sharing studies between radars and WAS including RLANs.

NOTE 1 – The requirements stated in *recommends* 2 should be subject to further study on an urgent basis, based on practical experience.

Annex 1

The use of DFS in WAS including RLANs for the purpose of protecting the radiodetermination service in the 5 GHz band

1 Introduction

1.1 DFS

Resolution 736 (WRC-2000) calls, *inter alia*, for studies on the feasibility of sharing between the mobile service for WAS² and the radiodetermination service in the frequency bands 5 250-5 350 and 5 470-5 725 MHz. Link budget calculations have shown that interference mitigation techniques are required to enable sharing of WAS with other services such as radar systems. This Recommendation describes the interference mitigation technique(s) DFS³ as specified in the 5 GHz RLAN standards, with performance calculations based on typical implementations.

WAS and radars operating in the 5 GHz band will interfere when operating at the same frequencies and within range of each other.

DFS has then been envisaged to:

- ensure a spread of the loading across the available spectrum of the WAS under the field of view of a satellite to reduce the aggregate emission levels at the satellites of the FSS (feeder links) and EESS (active) from WAS; and
- avoid co-channel operation with other systems, notably radar systems.

Extension of the use of DFS as described herein allows WAS to avoid interfering with the radiodetermination service. The general principle applied is that WAS should detect interference and identify radar interferers and shall not use those frequencies used by the radar.

1.2 Objective of the use of DFS with respect to radars

The objective of using DFS in WAS is to provide adequate protection to radars in the 5 GHz band. This is achieved by avoiding the use of, or vacating, a channel identified as being occupied by radar equipment based on detection of radar signals.

For the purpose of this Annex, a discussion of radiodetermination systems in the 5 GHz range utilized in determining DFS characteristics can be found in Annex 3.

² Throughout this Recommendation the term “WAS” denotes “wireless access systems including RLANs”.

³ The DFS feature was specified in the 5 GHz RLAN standards initially in order to mitigate interference among uncoordinated RLAN clusters, and to provide optimized spectral efficiency for high-capacity, high bit-rate data transmission.

The implementation of radar detection mechanisms and procedures used by WAS are outside the scope of this Annex. The main reasons for this are that:

- WAS design affects implementation;
- practical experience may lead to innovative and more efficient means than can be formulated today;
- different manufacturers may make different implementation choices to achieve the lowest cost for a given level of performance; therefore only performance criteria rather than specifications for a particular mechanism should be given in regulatory documents.

2 DFS performance requirements

The DFS performance requirement is stated in terms of response to detection of an interference signal.

5 GHz WAS should meet the following detection and response requirements.

Procedures for compliance verification should be incorporated in relevant industry standards for RLANs.

2.1 Detection requirements

The DFS mechanism should be able to detect interference signals above a minimum DFS detection threshold of -62 dBm for devices with a maximum e.i.r.p. of < 200 mW and -64 dBm for devices with a maximum e.i.r.p. of 200 mW to 1 W⁴ averaged over 1 μ s.

This is defined as the received signal strength (RSS) (dBm), normalized to the output of a 0 dBi receive antenna, that is required to be detected within the WAS channel bandwidth.

2.2 Operational requirements

The WAS should be able to perform channel availability check: A check during which the WAS listens on a particular radio channel for 60 s to identify whether there is a radar operating on that radio channel.

The WAS should be able to perform in-service monitoring: Monitoring of the operating channel to check that a co-channel radar has not moved or started operation within range of the WAS. During in-service monitoring the radar detection function continuously searches for radar signals in-between normal WAS transmissions. This requires the use of quiet spaces between successive WAS transmissions (see Annex 4).

If the WAS has not previously been in operation or has not continuously monitored the channel with in-service monitoring, it should not start transmission in any channel before completion of a channel availability check.

⁴ In practice, it may not be necessary for each device to implement full DFS functionality, provided that such devices are only able to transmit under the control of a device that ensures that all DFS requirements are fulfilled.

2.3 Response requirements

A channel that has been flagged as containing a radar signal, either by a channel availability check or in-service monitoring, is subject to a 30 min period (non-occupancy period) where it cannot be used by the WAS device in order to protect scanning radars. The non-occupancy period should start at the time when the radar signal is detected.

Additionally, in the band 5 600-5 650 MHz, if a channel has been flagged as containing a radar, a 10 min continuous monitoring of the flagged channel is required prior to use of that channel. Otherwise, other appropriate methods such as channel exclusion would be required.

Channel move time is defined as the period of 10 s needed by a WAS to cease all transmissions on the operating channel upon detection of an interfering signal above the DFS detection threshold. Transmissions during this period will consist of normal traffic for typically less than 100 ms and a maximum of 200 ms after detection of the radar signal. In addition, intermittent management and control signals can be sent during the remaining time to facilitate vacating the operating channel. The aggregate time of the intermittent management and control signals are typically less than 20 ms.

2.4 Summary of the requirements

Table 1 provides a summary of the requirements described above. An example of the operating procedures is given in Annex 2.

TABLE 1

Parameter	Value
DFS detection threshold	–62 dBm for devices with a maximum e.i.r.p. of < 200 mW and –64 dBm for devices with a maximum e.i.r.p. of 200 mW to 1 W averaged over 1 μ s
Channel availability check time	60 s
Non-occupancy period	30 min
Channel move time	≤ 10 s

Annex 2

Radar detection and example of associated DFS procedures

An example of how a DFS mechanism could be described is given in this Annex.

1 Definitions

The following definitions are given for use within this Annex:

Available channel: A radio channel on which a channel availability check has not identified the presence of a radar.

Received radar signal: A signal as characterized below:

- an RSS equal to or greater than the DFS detection threshold level of T_{DFS} (dBm) within the WAS channel bandwidth;
- pulse repetition rates in the range 200-4 000 pulses/s;
- nominal pulse widths in the range 1-20 μ s.

Operating channel: Once a WAS starts to operate on an available channel then that channel becomes the operating channel.

2 Procedures

2.1 Finding an initial available channel

Before a WAS transmits, and if no available channel has yet been identified, it shall undertake a channel availability check on a radio channel before it is used for transmission. Consequently, when a network is installed and first powered on, channel availability check(s) should be undertaken, so as to identify at least one available channel. Having identified an available channel, the WAS can start operation on that channel; the checking of other radio channels to identify other available channels is optional.

2.2 Starting operation

Once a WAS starts to operate on an available channel then that channel becomes the operating channel.

2.3 Monitoring the operating channel

In-service monitoring is performed by the WAS to re-check the operating channel for co-channel radar signals that may have come within range of the WAS or started operation on the operating channel.

3 Implementation aspects

3.1 Radar signal detection

Radar signals may occur at any time and they may occur in the presence of co-channel WAS signals.

While finding an initial available channel, the WAS will not be operational and this will assure rapid and reliable detection of any radar signal with the possible exception of very slowly rotating radars. However, these will be detected by the in-service monitoring.

During in-service monitoring the radar detection function continuously searches for radar signal patterns – during or in between normal WAS transmissions. For weakly received radar signals, this may increase the time needed for radar signal detection. This is reflected in the requirements contained in Annex 1.

3.1.1 Detection of frequency hopping radars

Frequency hopping radars operate over a large frequency range, with a rapid change of the operating frequency.

The time required by a WAS for reliable detection varies with the pulse characteristics of the radar. In the case of frequency hopping radars, the time for which the radar occupies the WAS channel (dwell time) also influences the detection probability.

The results will be one of the following:

- if the dwell time is long enough, DFS detects the radar signal (see Annex 4) and WAS transmissions will cease on the current channel;
- if the dwell time is very short, the probability of detection of the radar by a WAS on the operating channel may be affected, depending on the number of pulses during the dwell time.

3.1.2 Threshold and antenna gain

The detection threshold is defined in terms of dBm normalized to the output of a 0 dBi receive antenna. If the WAS uses higher antenna gains, the T_{DFS} level should be increased, by adding the antenna gain.

3.1.3 Spurious emissions

Further study is required to determine the impact on the interaction between WAS and radars spurious emissions.

3.2 Channel move time

Upon detection of a signal above the detection threshold, the DFS procedures require the broadcasting of commands to cease all operational transmission and to effect a move to (one of) the available channels identified by the channel availability check. This broadcast will be repeated a number of times to assure reception by all member devices. Part of the WAS population may be in so-called “Sleep Mode” in which the devices re-awaken at intervals of typically hundreds of milliseconds but extremes of up to 60 s are possible. Disregarding the latter, the broadcast has to be repeated a number of times during the channel move time to ensure that, for all practical purposes, all of the WAS devices will have left the channel.

Annex 3

Use of characteristics of radiolocation, maritime radionavigation and meteorological radars

The technical characteristics of some meteorological, radiolocation and maritime radionavigation radars operating in the bands between 5 250-5 350 MHz and 5 470-5 725 MHz can be found in Recommendation ITU-R M.1638. This information is used for the determination of the technical requirements of the DFS mechanism to be implemented in the WAS, which is identified as necessary to enable the introduction of WAS in the mobile service (to be considered in accordance with Resolution 736 (WRC-2000)) in these frequency bands used by radars. Specifically radars A-S are considered in development of DFS characteristics.

Table 2 gives the allocations of sub-bands of the 5 GHz range to the radiodetermination service:

TABLE 2

Band (MHz)	Allocation
5 250-5 255	RADIOLOCATION
5 255-5 350	RADIOLOCATION
5 350-5 460	AERONAUTICAL RADIONAVIGATION (Note 2) Radiolocation (Note 3)
5 460-5 470	RADIONAVIGATION Radiolocation (Note 3)
5 470-5 650	MARITIME RADIONAVIGATION (Note 1) Radiolocation (Note 3)
5 650-5 725	RADIOLOCATION
5 725-5 850	RADIOLOCATION

NOTE 1 – In accordance with RR No. 5.452, between 5 600 and 5 650 MHz, ground-based radars for meteorological purposes are authorized to operate on a basis of equality with stations in the maritime radionavigation service.

NOTE 2 – This Recommendation does not consider the aeronautical radionavigation radar since the 5 GHz band allocated to the aeronautical radionavigation service (ARNS) is the frequency band 5 350-5 460 MHz which is not envisaged for the introduction of WAS in the mobile service.

NOTE 3 – WRC-03 agenda item 1.5 addresses a possible upgrade of the status of the radiolocation service in the frequency range 5 350-5 650 MHz in accordance with Resolution 736 (WRC-2000).

Annex 4

Parameters and methodology to calculate the probability of detection of radiodetermination systems by WAS including RLAN devices using DFS in the 5 GHz band during in-service monitoring

The following methodology considers the probability that a WAS device operating in the 5 GHz band using DFS will successfully detect during in-service monitoring a 5 GHz radar operating in the radiodetermination service.

Step 1: Determine the amount of time that an individual device will be in the main beam of the radar antenna (i.e. 3 dB beamwidth/antenna scan rate). Table 3 identifies the radar parameters to be

used as a baseline in the study. Analysis time is the period during which the WAS is exposed to the main beam of the radar in one sweep based on the radar antenna pattern and scanned rate.

TABLE 3

Radar	C	K	P	S
3 dB beamwidth (degrees)	0.95	2.5	2.6	2
Scan rate (degrees/s)	36	Not applicable	72	20
Analysis time (ms)	26	100	36	100

Step 2: Radars C, K, P and S represent the more stringent cases and can be utilized to define sharing with all the radars shown in the radar characteristics document. Radar K does not utilize a 360° scan type of function.

Step 3: Based on a distribution of WAS devices using data rate and packet length distributions as shown in Table 4, create a waveform to represent WAS transmit time, and listening periods in length $(x) \cdot 9 + 50$ ms, where x is a random integer between 2 and 32 (i.e. 31 discrete possible durations, uniformly distributed).

TABLE 4

Weighting of RLAN transmit time

Packet size (bytes)	Weight	Data rate (Mbit/s)	Weight
64	0.6	6	0.1
538	0.2	12	0.1
1 500	0.2	18	0.1
		24	0.3
		36	0.3
		54	0.1

The WAS transmit waveform for each instance of a WAS packet transmission is created by randomly choosing a packet transmission, using weights shown in Table 4 for the packet size and transmission data rate, then calculating the transmission time as “Packet size”/(Data rate · 8). Each packet is followed by a quiet period that is required by the WAS network to facilitate sharing of the access medium (i.e. the WAS channel) by the multiple devices using the network. This quiet period is available for in-service monitoring. The quiet period is chosen as defined above. Another random chosen packet is then created in the same manner as the first, with another quiet period following. This is repeated until the waveform has the same duration as that of a WAS device in the main beam of the antenna, as calculated in Step 1.

Step 4: Create a waveform based on the pulse repetition rate (PRR) and pulse width of the radar being analysed. The values to be used for the baseline are shown in Table 5. The waveform should be of the same duration as calculated in Step 1.

TABLE 5
**Baseline radar values for determining
probability of detection**

Radar	C	K	P	S
Pulse width (μs)	0.95	1	20	1
PRR (pps)	200	3 000	500	200

Step 5: Determine if a detection event occurs by determining if radar pulses in the simulated radar waveform align with the listen periods in the simulated WAS network waveform.

Step 6: Repeat the simulation multiple times, recording the occurrence, or lack of occurrence of detection events, using this data to calculate the probability of detection (i.e. percentage of simulations during which the radar pulse is considered to be detected).

Step 7: Probability of detection in n rotations:

p : probability of detection in one rotation

p_n : probability of detection in n rotations

$$p_n = 1 - (1 - p)^n.$$

Annex 5

Interference assessment using link budget calculations involving a single WAS device and radiodetermination systems in the 5 GHz band

1 Background

This Annex addresses the case of interference from a single WAS. The values derived from the calculations in this Annex were used as starting values in the aggregate modelling (see Annex 6) for determination of a detection threshold.

2 Methodology

The calculations presented in this Annex are based on link budget analysis. The threshold is determined from a link budget analysis, assuming that this threshold must be reached when the radar can be interfered with by emissions of a single WAS device (i.e. when the WAS signal at the radar receiver exceeds the radar tolerable interference level). This is based on the assumption of a symmetrical propagation path between the path and the radar.

This method based on link budget is considered appropriate to study static cases which involve one WAS and one radar. It is based on Recommendations ITU-R SM.337 and ITU-R M.1461 and applied in the specific case of DFS.

3 Calculation based on link budget with radars from Recommendation ITU-R M.1638

The determination of the maximum tolerable interference level from emissions of a single WAS device at the radar receiver is based on Recommendation ITU-R M.1461, where it is said that this level should be lower than $N + (I/N)$ where N is the radar receiver inherent noise level and I/N the interference to noise ratio (taken as -6 dB as given in Recommendations ITU-R M.1461 and ITU-R M.1638).

A calculation table is given in Appendix 1 to this Annex. From that Table, if we ignore radar J, under these conditions, the necessary detection threshold is equal to -52 dBm to protect radars from a single WAS.

4 Calculation based on link budget for some new radars

In addition to the radars described in Recommendation ITU-R M.1638, two new ground radars have been recently deployed by some administrations in Region 1. Some parameters have been made available to perform link budget calculations. These are given in Appendix 2 to this Annex.

From the calculations, it appears that the necessary detection threshold is equal to -62 dBm to ensure non-interference to the considered radars from a single 1 W WAS device.

5 Possibility of a variable detection threshold

In this Annex, the calculations assume a single outdoor WAS with 1 W e.i.r.p., which constitutes a worst-case single interferer analysis. It has been expressed that 1 W e.i.r.p. WAS will not represent the majority of the deployed WAS.

Consequently, the idea of a variable detection threshold value which will vary with the WAS e.i.r.p. level may be introduced. According to the methodology used in this Annex, the detection threshold is proportional to the WAS e.i.r.p.

According to the methodology used in this Annex for scenarios related to a single WAS device, the detection threshold is proportional to the WAS e.i.r.p.

Under these conditions, for example, if a 1 W WAS must detect radar above $-N$ dBm, for a 200 mW WAS, the corresponding threshold can be set up at $-(N - 7)$ dBm.

6 Influence of the WAS architecture on the detection threshold

In the case of a centralized WAS architecture, it may be expected that the DFS will be controlled by one specific device within a network or a cell. There might be circumstances where significant propagation path loss differences occur between a radar and the devices within a network or a cell and the assumption of a symmetrical propagation path between the radar and the detection device is not valid.

Measures should be considered by administrations to ensure that each WAS device within a single network will not interfere with radars.

Appendix 1 to Annex 5

Calculation of detection threshold based on link budget for the radars of Recommendation ITU-R M.1638

	Characteristics	A	C	E	F	G	H 1	H 2	H	H	J	K	L	M	N	O	P	Q
RADAR	Function	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Meteo	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Surface and air search	Surface and air search
	Platform type	Ground/ship	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ground	Ship	Ship
	Tx power into antenna peak (kW)	250	250	250	250	250	250	250	250	250	2.25	250	2 800	1 200	1 000	165	360	285
	Receiver IF _{3 dB} bandwidth (MHz)	0.5	20	0.91	0.6	0.5	0.7	4	0.1	3	10	1	4.8	4	8	8	1.5	10
	Antenna polarization	V	H	H	H	H	H	H	H	H	H	V/left-hand circular	V/left-hand circular	V/left-hand circular	V/left-hand circular	V/left-hand circular	H	H
	Antenna main beam gain (dBi)	39	44	50	40	40	50	50	50	50	35	38.3	54	47	45.9	42	28	30
	Antenna height (m)	30	10	30	30	30	30	30	30	30	10							
	e.i.r.p. radar (dBm)	123.0	128.0	134.0	124.0	124.0	134.0	134.0	134.0	134.0	98.5	122.3	148.5	137.8	135.9	124.2	113.6	114.5
	Receiver noise figure (dB)	7	4	2.3	3	3	3.5	3.5	1.5	1.5	3	6	5	5	11	5	5	10
	$N = k T B F$ (dBm)	-110.0	-97.0	-112.1	-113.2	-114.0	-112.0	-104.5	-122.5	-107.7	-101.0	-108.0	-102.2	-103.0	-93.9	-99.9	-107.2	-94.0
	$N - 6$ dB	-116.0	-103.0	-118.1	-119.2	-120.0	-118.0	-110.5	-128.5	-113.7	-107.0	-114.0	-108.2	-109.0	-99.9	-105.9	-113.2	-100.0
WAS	e.i.r.p. (dBm) outdoor	30																
	TPC (dB)	0																
	Bandwidth (MHz)	18																
	Antenna gain (omni) (dBi)	0																

10 log (Brad/BWAS)	-15.6	0.5	-13.0	-14.8	-15.6	-14.1	-6.5	-22.6	-7.8	-2.6	-12.6	-5.7	-6.5	-3.5	-3.5	-10.8	-2.6
	185.0	177.0	198.1	189.2	190.0	198.0	190.5	208.5	193.7	172.0	182.3	192.2	186.0	175.8	177.9	171.2	160.0
Link budget for WAS signal received at radar receiver $N - 6$ dB	169.4	177.0	185.1	174.4	174.4	183.9	183.9	185.9	185.9	169.4	169.7	186.4	179.4	172.3	174.4	160.4	157.4
Necessary detection threshold	-46.4	-49.0	-51.1	-50.4	-50.4	-49.9	-49.9	-51.9	-51.9	-70.9	-47.4	-38.0	-41.6	-36.4	-50.2	-46.9	-42.9

Appendix 2 to Annex 5

Calculation of detection threshold based on link budget for new radar deployed by some administrations in Region 1

RADAR	Function	Air search
	Platform type	Ground/vehicle
	Tx power into antenna peak (kW)	15
	Receiver IF _{3 dB} bandwidth (MHz)	4
	Antenna polarization	V
	Antenna main beam gain (dBi)	35
	Antenna height (m)	10
	e.i.r.p. (dBm)	106.8
	Receiver noise figure (dB)	5
	$N = k T B F$ (dBm)	-103
	$N - 6$ dB	-109
WAS	e.i.r.p. (dBm) outdoor	30
	TPC (dB)	0
	Bandwidth (MHz)	18
	Antenna gain (omni) (dBi)	0

10 log (Brad/BWAS)	-6.5
Propagation loss for WAS signal received at the radar receiver $N - 6$ dB (dB)	175.0
	168.4
Necessary detection threshold (dBm)	-61.7

It is noted that this Table assumes a single 1 W e.i.r.p. WAS, which may be the highest power value in a statistical distribution of the e.i.r.p. in a deployment of WAS (e.g. as described in Table 7 of Annex 6). For example, consideration of a lower e.i.r.p. (< 100 mW) will lead to a corresponding increase by 10 dB of T_{DFS} .

Annex 6

Parameters and methodology for conducting aggregate interference studies involving WAS including RLANs and radiodetermination systems in the 5 GHz band

The following considerations should be utilized to define the baseline scenario for studies to be conducted in determining DFS parameters:

- Recommendation ITU-R M.1461 was utilized in interference calculations.
- The radar antenna pattern contained in Appendix 1 to this Annex was utilized.
- The WAS antenna pattern contained in Appendix 2 to this Annex was utilized.
- The probability of detection (see Annex 4) was utilized in the sharing studies to determine the aggregate interference into radars. This probability was set for each step interval.
- A step interval of 1° was utilized.
- Three concentric rings were utilized to define the WAS deployment as shown in Table 6. Uniform distribution of devices in each zone should be utilized throughout each volumetric zone including height.

TABLE 6
WAS user distribution

	Urban zone	Suburban zone	Rural zone
Radius from the centre (km)	0-4	4-12	12-25
WAS user (%)	60	30	10
Building height (m)	30	6	6

- A total of 2753 WAS devices operating on a co-channel basis with a radiodetermination system at a given moment was utilized.
- WAS power distribution in Table 7 was utilized.

TABLE 7
WAS power distribution

Power level	1 W	200 mW	100 mW	50 mW
WAS users (%)	5	25	40	30

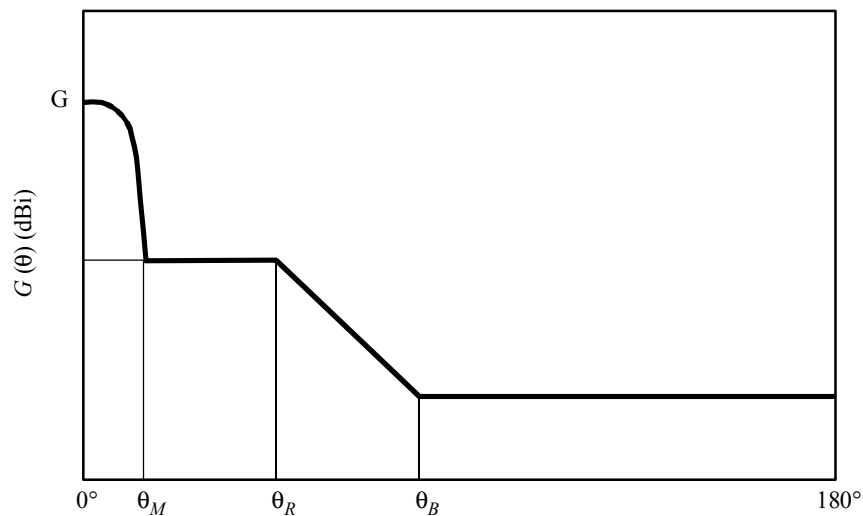
- Tracking radars were modelled starting with random placement and a random start angle and then moving directly overhead to the opposite horizon.
- Maritime radars were modelled starting at the horizon of the rural area and tracked into the centre of the urban zone.

- Airborne radars were modelled starting at the horizon of the rural area and tracked over the centre of the urban zone.
- The studies focused on the following radars:
C, I, K, P and S as defined in Recommendation ITU-R M.1638.
- For ground-based radars a random propagation factor was utilized in determining the propagation path loss to each WAS device. A value from 20 to 35 $\log D$ was used. In addition a random building/terrain propagation attenuation was used. A value from 0 to 20 dB was used. A uniform distribution was applied in determining these values.
- For airborne radars, free space loss +17 dB was used.
- For maritime radars, free space loss +0 to 20 dB was used.
- A smooth Earth line-of-sight calculation was utilized. Any WAS devices beyond the line-of-sight were discounted.

Appendix 1 to Annex 6

There are no existing radar antenna reference patterns currently in ITU, therefore the following is provided as a baseline. A statistical gain antenna model is used to determine the radar antenna gain in the azimuth and elevation orientations. The model gives the antenna gain as a function of off-axis angle (θ) for a given main beam antenna gain (G). The model includes separate algorithms for very high-gain, high-gain, and medium-gain antennas, corresponding to antennas with gains greater than 48 dBi, gains between 22 and 48 dBi, and gains between 10 and 22 dBi, respectively. Figure 1 illustrates the general form of the antenna gain distribution. The equations for the angles θ_M (first side-lobe shelf), θ_R (near side-lobe region), and θ_B (far side-lobe region) are given in Table 8. The antenna gains as a function of off-axis angle, are given in Table 9 for very high-gain antennas, in Table 10 for high-gain antennas, and in Table 11 for medium-gain antennas. The angle θ is in degrees and all gain values are given in terms of decibels relative to an isotropic antenna (dBi).

FIGURE 1



1652-01

TABLE 8
Angle definitions

Very high-gain ($G > 48$ dBi)	High-gain ($22 < G < 48$ dBi)	Medium-gain ($10 < G < 22$ dBi)
$\theta_M = 50 (0.25 G + 7)^{0.5} / 10^{G/20}$ $\theta_R = 27.466 10^{-0.3G/10}$ $\theta_B = 48$	$\theta_M = 50 (0.25 G + 7)^{0.5} / 10^{G/20}$ $\theta_R = 250 / 10^{G/20}$ $\theta_B = 48$	$\theta_M = 50 (0.25 G + 7)^{0.5} / 10^{G/20}$ $\theta_R = 250 / 10^{G/20}$ $\theta_B = 131.8257 10^{-G/50}$

TABLE 9
Equations for very high-gain antennas ($G > 48$ dBi)

Angular interval (degrees)	Gain (dBi)
0 to θ_M	$G - 4 \times 10^{-4} (10^{G/10}) \theta^2$
θ_M to θ_R	$0.75 G - 7$
θ_R to θ_B	$29 - 25 \log (\theta)$
θ_B to 180	-13

TABLE 10
Equations for high-gain antennas ($22 < G < 48$ dBi)

Angular interval (degrees)	Gain (dBi)
0 to θ_M	$G - 4 \times 10^{-4} (10^{G/10}) \theta^2$
θ_M to θ_R	$0.75 G - 7$
θ_R to θ_B	$53 - (G/2) - 25 \log (\theta)$
θ_B to 180	$11 - G/2$

TABLE 11
Equations for medium-gain antennas ($10 < G < 22$ dBi)

Angular interval (degrees)	Gain (dBi)
0 to θ_M	$G - 4 \times 10^{-4} (10^{G/10}) \theta^2$
θ_M to θ_R	$0.75 G - 7$
θ_R to θ_B	$53 - (G/2) - 25 \log (\theta)$
θ_B to 180	0

Appendix 2 to Annex 6

WAS antenna patterns

The WAS antenna pattern in the azimuth orientations is omnidirectional. The WAS antenna pattern in elevation orientations was determined by examination of WAS antenna patterns. The pattern used is described in Table 12. Note that use of directional WAS antennas, given the same e.i.r.p., may result in less interference to the radiodetermination receiver, but could result in significantly higher interference levels to the WAS receiver if main beam-to-main beam coupling were to occur.

TABLE 12

WAS elevation antenna pattern

Elevation angle, φ (degrees)	Gain (dBi)
$45 < \varphi \leq 90$	−4
$35 < \varphi \leq 45$	−3
$0 < \varphi \leq 35$	0
$-15 < \varphi \leq 0$	−1
$-30 < \varphi \leq -15$	−4
$-60 < \varphi \leq -30$	−6
$-90 < \varphi \leq -60$	−5

In order for most devices to radiate with 1 W e.i.r.p. an antenna gain of 6 dBi will typically be required. For this pattern the following description is given in accordance with Recommendation ITU-R F.1336:

$$G(\theta) = \max[G_1(\theta), G_2(\theta)]$$

$$G_1(\theta) = G_0 - 12 \left(\frac{\theta}{\theta_3} \right)^2$$

$$G_2(\theta) = G_0 - 12 + 10 \log \left[\left(\max \left\{ \frac{|\theta|}{\theta_3}, 1 \right\} \right)^{-1.5} + k \right]$$

$$\theta_3 = 107.6 \times 10^{-0.1G_0}$$

where:

$G(\theta)$: antenna gain (dBi)

θ : elevation angle (degrees)

$k = 0.5$

$G_0 = 6$ dBi.

Annex 7

Interference assessment results analysis and recommendation on DFS threshold values

A summary of the results of simulations using the methodologies detailed in Annexes 5 and 6, for simulating respectively static interference from one WAS device and aggregate interference from a deployment of WAS into a victim radar receiver, is presented for the relevant 5 GHz radars.

Table 13 shows the values derived from the calculations in Annex 5 for the case of interference from a single WAS.

TABLE 13
Values derived from the calculations in Annex 5

Radar per Annex 5	Link budget analysis per Annex 5	–62 dBm for 1 W device
		–55 dBm for 0.2 W device
		–52 dBm for 0.1 W device

Table 14 shows a summary of required protection threshold levels resulting from the aggregate interference modelling calculations.

TABLE 14
Required protection threshold levels

Radar type	Simulation scenario	DFS threshold for protection (T_{DFS}) (Note 1)
Rotating radars A, C, E, F, G, H, I, J. Radars P and Q	Standard per Annex 6	–52 dBm and operational considerations utilized by radar systems
Radar I	Annex 6 but radar antenna height between 500 and 1 000 m	–62 dBm
Radar S	Standard per Annex 6	See Note 2
Radar K	Standard per Annex 6	–67 dBm
	Annex 6 but half population density	–64 dBm
	Annex 6 but all devices 50 mW	–62 dBm

NOTE 1 – Assuming a receive antenna gain normalized to 0 dBi for WAS.

NOTE 2 – The sharing situation between this radar and WAS is extremely difficult. Initial calculations based on the baseline results show that a required DFS detection threshold of values below the operating noise floor of WAS devices would be required. Based on discussions, it was found that these systems were limited to military aircraft only. It was agreed to not consider this case when developing a detection threshold requirement.

Notes on parameters and methodologies used

The impact of the parameters and methodology variations can be summarized as follows:

- a) A reduction in active device density by half results in a 3 dB increase in T_{DFS} . Similarly, doubling the active device density results in a 3 dB decrease in T_{DFS} .
 - b) The transmit power of a single interferer in the link budget calculation has a direct dB for dB impact on the required protection threshold. In the aggregate analysis, the impact depends on the distribution of power levels used in the simulation.
 - c) In most cases the interaction of variables in the aggregate modelling is not intuitive and therefore simple conclusions cannot be drawn from changes in a single variable.
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